WIRELESS SENSOR NETWORK BASED SMART HOME FOR ELDER CARE

A thesis presented in partial fulfilment of the requirement for the degree of

DOCTOR OF PHILOSOPHY
In
Electronics Engineering

At

School of Engineering and Advanced Technology,

Massey University,

Manawatu Campus,

New Zealand

ANUROOP GADDAM

2011

Abstract

The proportion of elderly people in any population is growing rapidly creating the need to increase geriatric care and this trend isn't going to change in the near future. In New Zealand, the median age of the population is projected to rise from 36.6 in 2010 to 43.1 in 2050. This will put tremendous strain on national resources and the cost of elder care is only going to escalate. More and more elderly people are choosing to stay alone, independently, rather than in a retirement village or old people's home. Such people, often frail and infirm, do however require constant monitoring so that medical help can be provided immediately in times of dire needs.

Considerable research efforts have been focused towards in-home monitoring of elderly people, often using wireless personal area networks. As wireless sensing technology continues to evolve, it is playing an important role in improving the quality of life for elderly people and their families. Wireless sensors based smart home monitoring system provides a safe, sound and secure living environment for the elderly people. A wireless sensors based smart home consists of number of wireless sensors that provide information. The information from the sensors can be used for monitoring elderly people by detecting their abnormal patterns in their daily activities and picking up any unforeseen abnormal condition when occurs.

The thesis is focused on research and developmental issues of an intelligent wireless sensors based smart home and determination of person's daily activities based on the usage of different appliances. The daily pattern can then be compared to determine the early signs of behavioural pattern change of elderly, which can potentially allow for early medical intervention. While several sensors are readily available off the shelf, making them "intelligent" in the context of a specific application (such as monitoring of the elderly) is always a challenging task. We have developed a framework, dealing with the design intricacies and implementation issues of novel sensors, targeted to achieve a Digital Home specifically for the elderly. This smart home monitoring may circumvent institutionalizing the older persons and can help them live at home in safety and independence.

The design methodology is on the impediments in designing, implementing and testing a wireless sensor network based smart home for monitoring the elderly and to propose an optimal solution to circumvent the impediments. The smart home is based on a few smart and intelligent sensors, which are developed, fabricated and configured around a wireless ad-hoc network. The system will generate early warning message to care giver, when an unforeseen abnormal condition occurs. It will also, analyse gathered data to determine resident behaviour using optimal number of intelligent sensors. In general terms intelligent sensors, i.e., sensing devices having intelligent aspects, can be considered as an extension of conventional sensors with advanced learning and adaptation capabilities.

The developed monitoring system is used to recognize activities of daily living and life style of elderly person living alone. Even though the monitoring system uses a limited number of sensors, it determines the daily behaviour of the person. The system was installed in residential environments with ease. Moreover, the proposed sensing system presents an alternative to sensors that are perceived by most people as invasive such as cameras and microphones, making the sensors are almost invisible to the user thereby increasing the acceptance level to use the system in a household environment.

The results obtained from this research demonstrate the feasibility to build a system based on wireless sensors, to identify, and possible to distinguish between normal and abnormal situation of an elderly person living alone in a home.

Acknowledgments

Words can never describe my sense of gratitude for my supervisor Professor Subhas Mukhopadhyay. This work would not have been possible without his kind support, expert guidance, the trenchant critiques, and most of all the remarkable patience. I cannot thank him enough for giving me the opportunity to work on this project and providing me the enthusiasm and inspiration.

My sincere thanks to my co-supervisor Dr Xiang Gui, for his guidance and support throughout the academic program.

I sincerely thank Dr Gourab Sen Gupta, my co-supervisor for the earlier part of my PhD study for providing me valuable technical advice and numerous suggestions.

I thank Graduate Research School for awarding me the Doctoral Scholarship and supporting me financially. In my later work, I am particularly indebted to Mr. Suryadevara Nagendra Kumar for his support and help for developing the software. I would like to acknowledge the efforts of Mr Ken Mercer, Mr Colin Plaw, Mr Bruce Collins and Mr Anthony Wade.

Lastly, I would like to thank my family for all their love and encouragement. And most of all for my loving, supportive, encouraging, wife Lydia, whose faithful support during the final stages of this Ph.D., is so appreciated. Thank you.

List of Publications

Journal publications: 2

[J.1] S. C. Mukhopadhyay, Anuroop Gaddam and Gourab S. Gupta, "Wireless Sensors for Home Monitoring - A Review, Recent Patents on Electrical Engineering", January 2008, Volume: 1, Number: 1, pp. 32-39.

[J.2] A. Gaddam, S. C. Mukhopadhyay and G. Sen Gupta, "Elderly Care Based on Cognitive Sensor Network", IEEE Sensors Journal, March 2011, Volume: 11 Issue: 3, pp. 574 - 581.

Chapter in Books: 2

[BC.1] A. Gaddam, S.C.Mukhopadhyay and G. Sen Gupta, "Development of a Smart Home for Elder-People Based on Wireless Sensors", Lecture Notes in Electrical Engineering, Smart Sensors and Sensing Technology, ISSN 1876-1100, ISBN 978-3-540-79589-6 Springer-Verlag, July 2008, pp. 361-380.

[BC.2] A. Gaddam, S.C.Mukhopadhyay and G. Sen Gupta, "Sensors for Smart Homes", Human behavior recognition technologies: Intelligent applications for monitoring and security, yet to be published by IGI Global publications.

Publications in Conference Proceedings: 9

[C.1] A. Gaddam, S.C.Mukhopadhyay, G. Sen Gupta, "Wireless Sensors networks Based Monitoring: Review, Challenges and Implementation Issues", Proceedings of the 3rd International Conference on Sensing Technology, Library of Congress 2008, November 30 to December 3, 2008, pp. 533-538.

[C.2] A. Gaddam, S. C. Mukhopadhyay and G. Sen Gupta, "Wireless Sensors Based Smart Home to care Elder People", Proceedings of 2008 Digital signal Processing Creative Design Contest, , Southern Technological University, Tainan, Taiwan, November 29, 2008, pp. 21-28.

[C.3] S.C.Mukhopadhyay, A. Gaddam and G. Sen Gupta, "A safe, sound and Secured Living Environment for Elder People: Wireless Sensors based Digital Home", Proceedings of 2008 IEEE TENCON, Hyderabad, India, October 18-21, 2008, (6 pages).

[C.4]. G. Sen Gupta, A. Gaddam and S.C. Mukhopadhyay, “Implementation of Wireless Sensors Based Home Monitoring System”, Proceedings of the 2008 IEEE Sensors conference, Lecce, Italy, October 26-28, 2008, pp. 1332-1335.

[C.5]. A. Gaddam, S.C. Mukhopadhyay and G. Sen Gupta, “Necessity of a Bed Sensor in a Smart Digital Home to Care for Elder-people”, Proceedings of the 2008 IEEE Sensors conference, Lecce, Italy, October 26-28, 2008, pp. 1340-1343.

[C.6] A. Gaddam, S.C.Mukhopadhyay and G. Sen Gupta, “Integrating a Bed Sensor in a Smart Home Monitoring System”, Proceedings of IEEE International Instrumentation and Measurement Technology Conference, Victoria, Canada, May 12-15, 2008, pp. 518-521.

[C.7] A.Gaddam, K. Kaur, S.C.Mukhopadhyay, G. Sen Gupta, “Selection and Optimization of Wireless Sensors in a Smart Digital Home for the Elderly”, Proceedings of 2009 IEEE SENORS Conference, Christchurch, New Zealand, October 25-28, 2009, pp. 1382-1386.

[C.8] A. Gaddam, S.C.Mukhopadhyay and G. Sen Gupta, “Smart Home using Optimised Number of Sensors for Elderly Care”, Proceedings of IEEE Applied EletroMagnetic Conference (AEMC) 2009, Kolkata, India, , Library of Congress: 2009905498, December 14-16, 2009 (4 pages).

[C.9] A. Gaddam, K. Kaur, G. Sen Gupta and S. C. Mukhopadhyay, “Determination of Sleep Quality of Inhabitant in a Smart Home using an Intelligent Bed Sensing System”, Proceedings of 2010 IEEE I2MTC Conference, Austin, Texas, USA, May 4-6, 2010, pp. 1607-1611.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1. Background

The population throughout the world is growing. It is considered as a human success story, through triumph of public medical and health advancements. But this ageing process also puts a lot of challenges regarding national development, issues concerning heath of the elderly individual, the sustainability of families, and the ability of health care system to provide for ageing populations [1]. The terms “Elderly”, “Older population” and “Senior citizens” are generalized to refer to people aged 60 years or older. People aged 80 years or older is referred as the oldest of old. Between 2000 and 2050, the share of the population aged 60 and over is projected to increase in every country in the world; the same is true for the 80+ population [2]. The number of people over the age of 60 is expected to reach 1 billion by 2020 and almost 2 billion by 2050 (representing 22 percent of the world’s population). The proportion of individuals aged 80 or over (the so-called “oldest old”) is projected to rise from 1 percent to 4 percent of the global population by 2050 [3]. Practically in all regions of the world the older population is growing in an unprecedented rate than the normal population and also the difference in the growth rates is ever increasing. In the current situation, ageing is not just limited to an individual or community, but as a world.

1.2. Ageing Population: Statistics and Growth rate

The term population ageing is defined as the percentage of population aged 65 or older to the given population. The world’s elderly population has been growing at an accelerated pace and projections suggest that the annual net gain will continue to exceed 10 million over the next decade—more than 850,000 each month. Today, one in every nine persons in the world is 60 years or older.

In 2009, an estimated 737 million persons were aged 60 years or over and constituted the "older population" of the world, nearly two thirds of whom lived in developing countries [4]. Their number is projected to increase to 2 billion in 2050, by which time older persons will outnumber children (persons aged 0 to 14 years). Today, more than half of the older population lives in Asia (54 per cent) and a fifth lives in Europe (21 per cent) [5]. The projections suggest that elderly population around the world will outnumber the children under age 5 for the first time in the history in the coming 20 years [6]. Also the oldest old that is people aged 80 and above is rising as shown in Table 1.1.

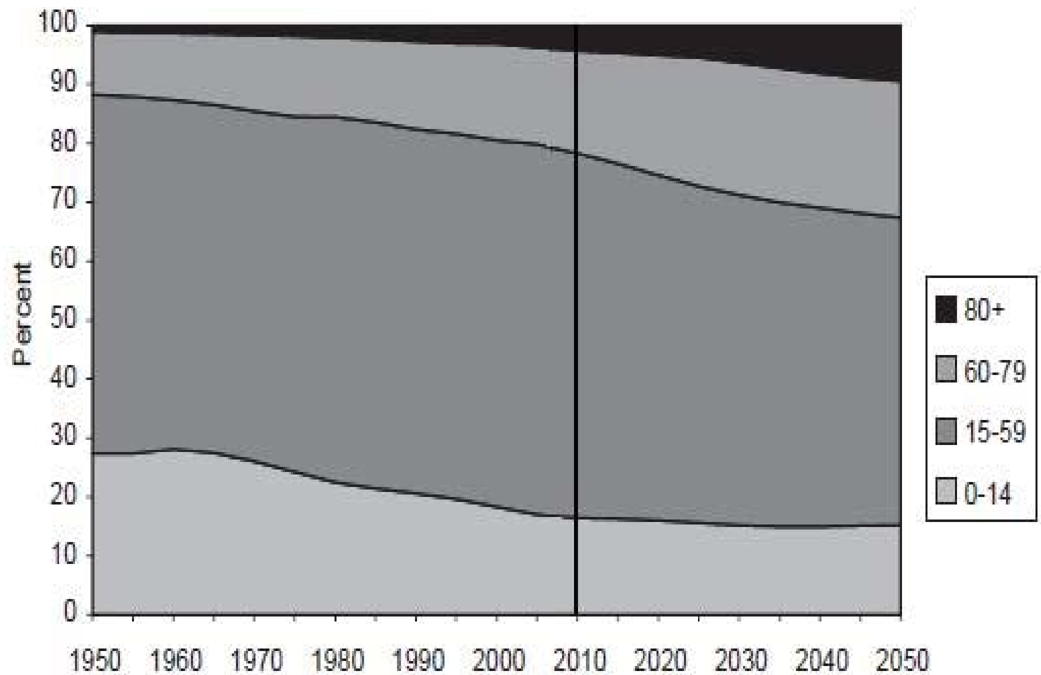
Table 1.1: Percentage of population in older ages by region, 2008, 2020, and 2040

Region	65 years and over	75 years and over	80 years and over
Northern Africa			
2008	4.9	1.6	0.7
2020	6.7	2.2	1.1
2040	12.8	5.0	2.5
Sub-Saharan Africa			
2008	3.0	0.9	0.3
2020	3.3	1.0	0.4
2040	4.2	1.4	0.6
Asia (excluding Near East)			
2008	6.8	2.4	1.1
2020	9.3	3.3	1.7
2040	16.2	6.8	3.7
Near East			
2008	4.6	1.7	0.8
2020	5.7	2.0	1.1
2040	9.9	3.8	2.0
Eastern Europe			
2008	14.5	6.0	3.0
2020	17.3	6.9	4.3
2040	24.4	12.6	7.8
Western Europe			
2008	17.8	8.5	4.9
2020	20.9	10.1	6.2
2040	28.1	15.0	9.3
Latin America/Caribbean			
2008	6.5	2.5	1.2
2020	8.8	3.3	1.8
2040	15.3	6.6	3.7
Northern America			
2008	12.8	6.2	3.8
2020	16.5	6.9	4.0
2040	20.8	11.6	7.3
Oceania			
2008	10.8	4.9	2.9
2020	13.7	5.7	3.3
2040	18.5	9.1	5.5

Source: U.S. Census Bureau, International Data Base (www.census.gov/ipc/www/idbnew.html, accessed Jun. 12, 2011).

1.3. Increasing Life Expectancy

The demographic projections of population ageing indicate that the world is experiencing a historically unprecedented phenomenon. During the recent years the number of persons aged 60 or over has increased from 200 million in 1950 to around 670 million. The ageing people accounts for a substantial proportion of the total world population. Many countries are forecast to see a higher share of people aged 60+ in the coming years. Even in the developed world much of the population already has large number of aged people. People aged 60 and over consist of twenty percent of the total population in developed countries today, and this will rise to over 30 percent in the next four decades as shown in Figure 1.1. In the developing world, less than 10 percent of the population is over the age of 60 years. By 2050, however, the proportion is expected to more than double, and the 60+ age group will comprise 20 percent of India's population and 30 percent of China's by the middle of this century—a total of over 760 million people [7].



Source: UN, World Population Prospects 2010

Figure 1.1: Developed countries, population share by age group [8]

Over the past century, the life expectancy of human has increased and has become almost doubled. The maximum life span—the longest number of years a human being has lived—has increased spectacularly as well. There is little disagreement over these facts [7]. The growth of the world population can be seen in the Figure 1.2, as is shown below.

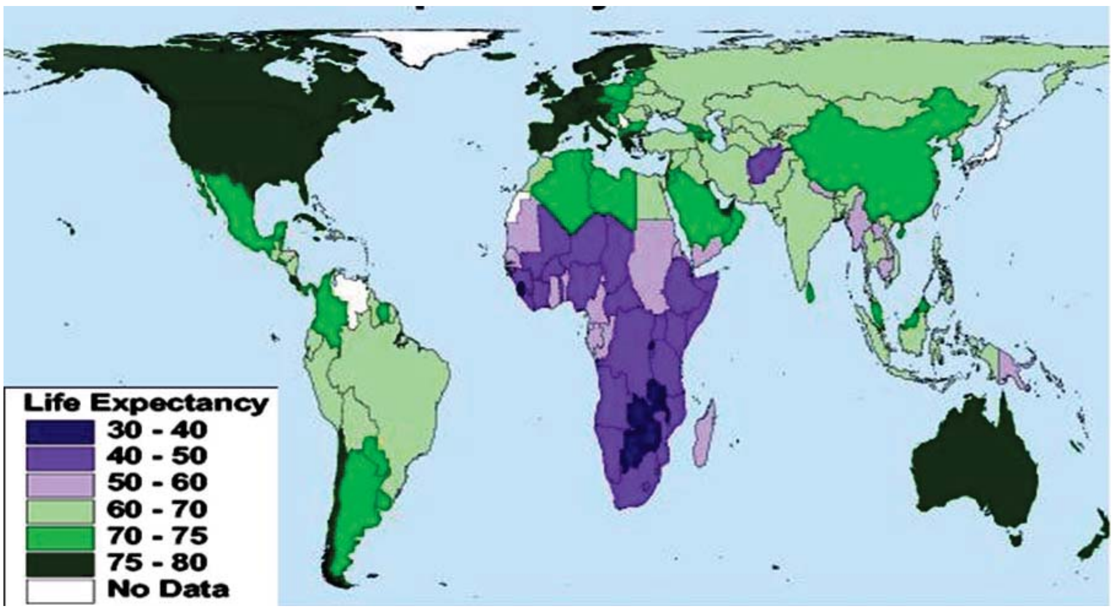


Figure 1.2: Life Expectancy around the world [8]

1.4. Socio-Economic and Health Related Determinants Influenced By Elderly Population Growth

Diverse studies have identified a number of socio-economic factors that affect health and longevity. Elderly people who are living alone will get affected by their life satisfaction, health, and chances of institutionalization. Availability of kin, personal wealth, health, and individual preferences are key determinants of older persons living arrangements. Also in many places the cultural norms and money are equally important in deciding whether an older person lives alone or with family members. A Majority of older people, especially older women in developed countries often live alone, while living with kin is still the norm in the developing world.

According to the Australian Institute of Health and Welfare in 2008, elderly women and the "oldest old" are likely to be overrepresented among long-term care residents. These long-term care facilities usually include nursing homes, assisted living/residential care facilities, and sometimes hospice centres. There is an increased demand in institutional residence, as it predominantly becoming a lone option for older people in developed countries who have difficulties with activities of daily living or who require specialized medical services. These facilities come with a price and not all elderly people can afford. This can cause an immense stress on the scarce resources of a country to care for the elderly. According to current estimates, health care in many countries including US, EU and much of Asia is now a significant part of the economy. It is estimated that the predicted health cost in US alone will be 2.9 trillion dollars in 2015, which is approximately 17.8% of the GDP [5].

Coupled with this, the present workforce shortage poses difficulty with the cost of elderly care, since 55-60% of the costs incurred during health care is mainly the high labour costs. Therefore the importance of enabling the elderly to live in their own home as long as possible is crucial. However, if they prefer to live alone they do require constant monitoring so that medical help can be provided immediately in times of dire needs.

1.5. Elderly Population in New Zealand

Population in New Zealand is ageing too. There is a documented proof that the share of elderly population is increasing in comparison with the entire New Zealand population. It can be noticed that the process of ageing is not new or unique to New Zealand as shown in Figure 1.3. In fact when compared to other developed nations around the world the population here started to grow over the past century. According to [9] between 1901 and 1951, the number of New Zealanders aged 65 years and over increased almost six-fold, from 31,000 to 177,000. Over the next 48 years, it grew by another 151 percent to reach 446,000 in 1999. The number of people aged 65 and over is projected to increase from half a million in 2005 to 1.33 million in 2051. It has been predicted that the largest increase in the 65 and over group will occur in the

2020's and 2030's. In New Zealand, a gradual transition of this age structure started in the 1800's and continuing into the 2000's.

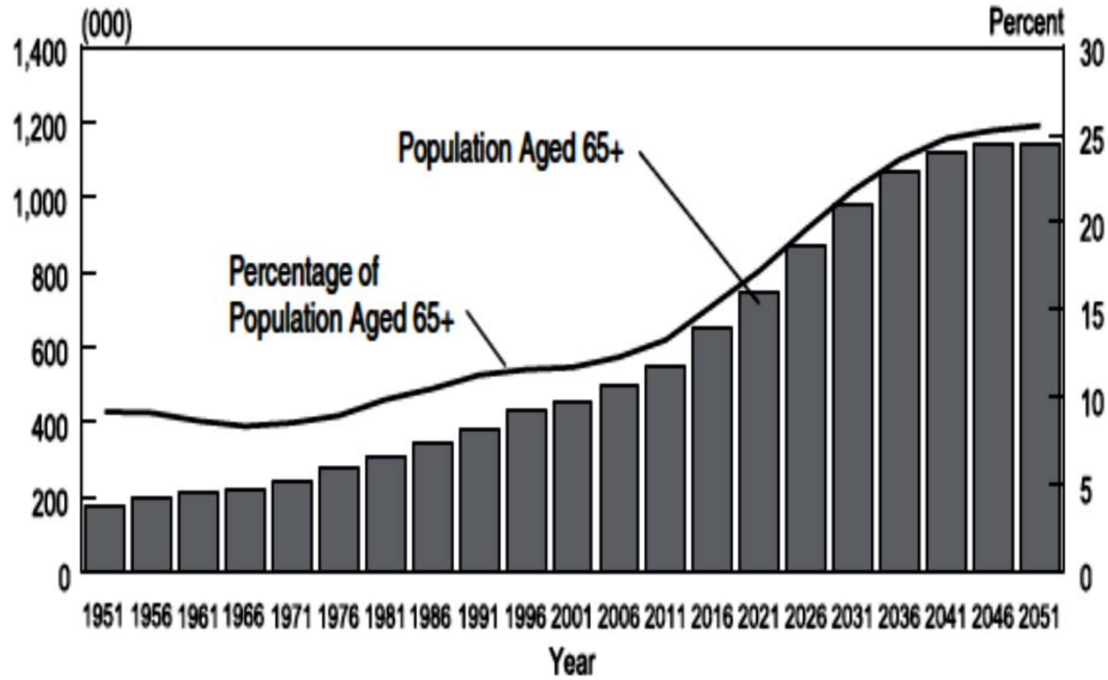


Figure 1.3: Elderly Population in New Zealand, 1951 – 2050[9]

Even the oldest of the old population group is projected to rise. According to [10] in 2005 , 10 percent of the total population was aged 68+ and the oldest 10 percent of the total population will be 74+ in 2026 and 81+ in 2051. According to New Zealand population statistics, the median age (half the population is younger, and half older, than this age) increased from 26 years in 1971 to 36 years in 2005. According to projection series 5, half the population will be 40+ in 2020,and half the population will be 45+ in 2045. The relative share of the population aged 65+ has increased slowly from 8 percent in the 1960s to 12 percent in 2005. This share is projected to increase significantly in the coming decades.

These trends of population ageing can have an obvious implication in New Zealand. Since older people need more health services there will be an increase in the level of resources devoted to health care. Therefore the importance of enabling the elderly to live in their own home as long as possible is crucial. At the same time the old people living in their home should be safe and sound.

1.6. Need for Early Detection of Ageing Changes

The increase ageing of population in the world is associated with the increase of suffering with many disabilities. So there is a need for an in-home pervasive network which assists and helps the residents by controlling home appliances, medical data look back and also communicating in case of an emergency. Too often are headlines such as these seen in the paper: "Elderly man lay dead for days", and "Woman found starved in flat". It is shocking to know that no one was looking after these people and imagine they must have an uncaring family. At the same time however, as a society we value our rights to live independently and keep control of our own lives. Many dread the thought of being forced to live with their adult children, or in a rest home or other sheltered living arrangement yet at the same time they know there is a high risk of death because of a collapse, a fall, or stroke. There are many people in our community who because of age or some infirmity, or perhaps because their memory and judgment can no longer be totally relied upon, are having pressure put on them by loving relatives to leave their home and give up their precious independence.

Any abnormal events which can occur to an old person in a home often leads to more serious illnesses or even death. But in a case of reduced mobility or other factors which leads to this kind of situation should also be considered for effective monitoring, which will make a significant impact on the health of the elderly people. Surely, with the technology of today, there is a better way for these people to resolve this problem. This technological assistance or monitoring of a person in the home is achieved using few but effective wireless sensors, which are centralized in structure and distributed around the house. The smart home concept is a promising way to improve the living standards of elderly by improving the home care for the elderly. The smart home monitoring can circumvent institutionalizing the older persons and can help them live at home in safety and provide independence. The smart homes target to improve comfort, quality of life, safety, monitoring, monitoring mobility and physiological parameters. Modern sensor not only assists and monitors people with reduced physical functions but helps to resolve the social isolation they face. They are capable of providing assistance without limiting or disturbing the resident's daily routine, giving him or her greater comfort, pleasure, and well-being. A number of smart homes have now been developed around the world by many institutes and researchers. The smart home is based on smart and intelligent sensors, which are developed, fabricated and configured around a wireless network. It is expected that these smart homes can reduce escalating medical costs.

1.7. Review of Current Market Situations

A huge amount of work and technical literature is available now. A detailed literature has been surveyed and has been reported in Chapter 2. In this section a few systems are discussed to present different approaches adopted by different groups. In Patent US06796799, the system uses a detective approach to determining uncharacteristic behaviour of a monitored subject. Figure 1.4 illustrates the system with sensors. This system would provide an excellent method of determining whether the monitored subject is presenting normal behaviour or not. However there are potential drawbacks to this kind of system:

1. Extremely costly to purchase the system, due to costs of sensors such as cameras and toilet flushing sensors.
2. Again, extreme costs to install the system as each sensor utilises a different physical property and requires individualised installation.
3. Finally, the system provides such an insight into the subject's life that they could easily feel over-monitored and uncomfortable.

The real question with this system is where you draw the line, what level of monitoring will a subject be comfortable with and can they afford this kind of monitoring?

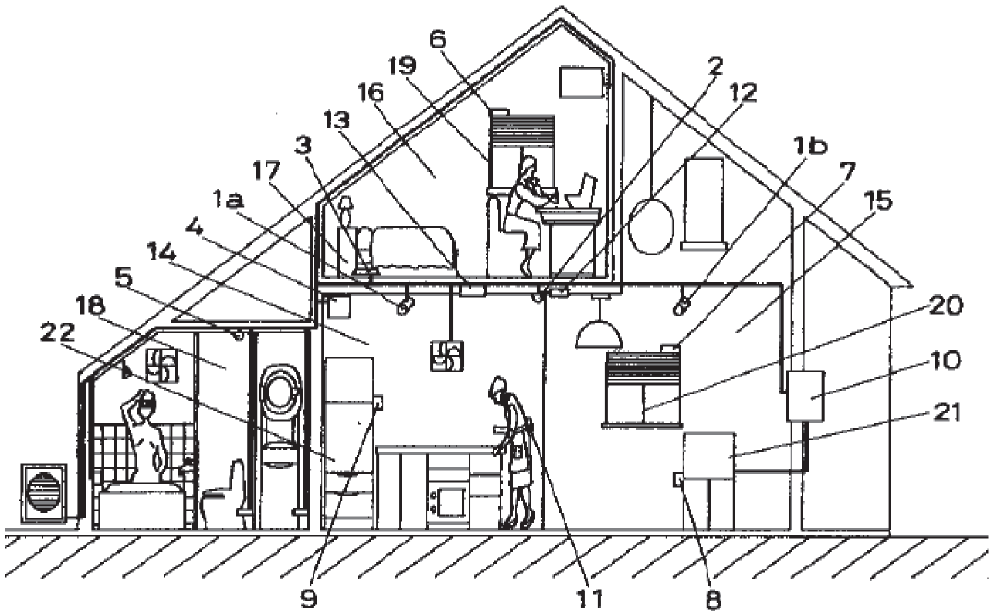


Figure 1.4: System Block Diagram available at US Patent US06796799 [11]

In [11] a real life test bed called the "Ubiquitous Home" was discussed. It was developed by Information and Communication technology (ICT) housing test facility. The main objective of this facility is to create new home services, with the help of linking devices, sensors and appliances across data networks. In this Ubiquitous home, daily human behaviour over a long term can be measured. The experimenters can collect real life data as if living in their own houses, instead of a laboratory. Unlike other test beds developed by various institutions or research facility, the ubiquitous home, has an added sensor ubiquity in it, facilitated by installing many cameras and microphones in each room, and various sensors are installed to monitor locations in every space of the home. Furthermore, robots are introduced in the test bed for home services.

The Ubiquitous Home is an apartment comprised of a living room, dining room/kitchen study, bedroom, washroom, and bathroom. In addition to the apartment, a Japanese-style room is provided as a living space for extended family members, such as a grandmother and/or grandfather. Between the apartment and the Japanese-style room, is a computer room called the Network Operating Centre (NOC). Apart from cameras and microphones installed in the Ubiquitous Home, it is also equipped with various sensors to monitor human activities, like floor pressure sensors installed throughout the flooring, used to track residents' movement or detect furniture positions. Infrared sensors installed above the entrance to each room, at foot positions in the kitchen and along the corridor are used to detect residents' movement. Underside of the bedroom floor, all four corners have four accelerometers or vibration sensors attached, for detection of human behaviour. Radio Frequency Identification(RFID) system is used in this test bed, a series of active/passive scanners are located in the ceiling of each room, to detect persons tagged with RFID passes through the entrance of a room. For the audio-visual contents to the residents, Plasma panel or LCD's and speakers are installed thorough out the Ubiquitous Home. The researchers of this project are planning for moving to Ubiquitous Home to the Universal city, which will be built on the similar framework as Ubiquitous Homes.

Even though the system was able to understand the human behaviour by using various appliances and sensors, the overall cost of the system will be expensive and cannot be affordable by all. Since the Ubiquitous Home uses highly networked, sensor embedded systems and devices like cameras and microphones, causing the residents not consciously aware off, thus losing their privacy. But as the title of the paper says "Beyond Smart Home", the author can justify using this kind of technologies in a residential place.

In [12] a customised monitoring, early detection of deteriorating health conditions such as shuffling gait, restless sleep, rapid change in activity level, or an unusual change in typical routine of a person can be possible. Various researchers developed smart homes, to enhance the resident's safety and to monitor health conditions by using various sensors and other supporting technologies. The main aim of this paper is to present an evaluation framework, which has been developed and tested with an actual smart home project for a formative and participatory evaluation of a smart home application. It was implemented in a real world setting rather than a laboratory or demonstration site. Therefore, the test site for this experimentation is an independent retirement facility in Columbia, Missouri called "Tiger Place". By supporting residents to maintain their health status and activity levels for longer periods of time by providing on-going assessment and early detection of a specific illness. The system has a capability of sensing alert conditions such as falls and changes in the daily activities, thus detecting and indicate the abnormal activity. This intelligent monitoring system – Tiger Place distinguishes a typical pattern for an individual from what would be an abnormal pattern for a specific individual. The In-Home monitoring system (IMS) consists of a set of wireless infrared proximity sensors to detect motion, as well as pressure switch pads (sensor mats) that can be used to infer specific activities based on the position of the mat. The system also includes a stove temperature sensor, switches on cabinet doors and a bed sensor capable of detecting presence, respiration (normal/ abnormal), pulse (low, normal or high) and movement in the bed.

The Data Manager collects data from the sensors, date-time stamps the data and logs it into a file that is sent to a secure server as binary streams stripped of identifiers. The system exploits low-cost X10 technologies coupled with specialised filtering and analysis. With the help of these, raw vibration signals which is fed to the gait monitor, which will analyse the extracted data to provide basic gait characteristics. A series of video sensor network is embedded into the IMS to collect more detailed information that is not available by the other sensors. To make the system adaptable, fuzzy rules are used to train it, when there is ample amount of data is present in a database of the system. The system follows guidelines to cover four areas: system interface, training, user support, content and security.

At Tiger Place [12], residents operation of the system, ease of use, adjusting to changing needs maintenance, impact of the information on lifestyle, psychological factors, including confidence in using the interface, reliability of the system, trust in its accuracy and performance are addressed by the focus group and interviews by the representatives. The smart home concept at Tiger Place is meant to increase the security, functionality and quality of life of an elderly individual. The involvement of study groups and interviewers at initials days of installation of the system is a good idea, to ensure to identify whether the installed technology becoming obtrusive during daily activities in the home. Since the system is targeted to mass of elderly people instead of an individual or a small group, several ethical issues and challenges had to be addressed, such as the possibility of removing choice and control from individuals, and making them dependent more on automation and reducing the social interactions.

Future more, the case of transferring of personal information that is stored in the database of the system, to the third parties is always risky. And the whole point of "Being at one's own home" is lost.

1.8. Our Approach and Solution

Recent advances in sensor technology, communication systems, and information technologies have created ample opportunities to develop novel tools enabling remote monitoring in-case of emergency conditions, and to care the elderly. In-home monitoring has the added benefit of evaluating individualized health status and reporting it to care providers, and caregivers alike; allowing timelier and individually targeted preventive interventions [13]. The smart homes equipped with the wireless sensor networks will benefit both health care providers and their patients. By monitoring the patient continuously and reporting any abnormal situation, the system frees human labour and thus reducing labour costs and increasing efficiency by notifying doctors or health care provider quickly. The data collected from various sensors over the network in a smart home can be stored and integrated into comprehensive health record. Other issues like quality of life for elder people, such as privacy, independence, dignity and convenience are supported and enhanced by the ability to provide services in the patient's own home. It is a known fact that the use and the way of implementation of wireless sensor networks drastically change from one application to other application; the need for in-depth study on performance parameters is vital. While several sensors are readily available off the shelf, making them "intelligent" in the context of a specific application (such as monitoring of the elderly) is always a challenging task. For example, an intelligent wireless sensor system will not only detect the usage pattern of the daily appliances, it will have capabilities to collate the data and analyse them. Depending on the data analysis it can detect any abnormality.

To achieve this I have developed and implemented a SMART component-based system by integrating various sensors and communicating via standard radio frequency protocols. The system depends on a set of selected number of wireless sensors and controller which relies on inputs from sensors. This system will consist of a proof-of-concept that what I have developed is feasible, reliable, practical and scalable.

1.9. Original Contribution of the Thesis

The original contribution of the thesis can be summarised as:

1. A home monitoring system based on smart wireless sensors network has been designed and developed. The system aims to provide a safe, sound and secured living environment to elderly people, especially the old people living alone at home. There are wireless sensor network based systems available to monitor either a large area or a retirement village type environment. Also the system using camera or vision based sensors to monitor home activities are available. But to the best of our knowledge there is no system available to monitor the activities of the elderly person living at a small two bed-room house. I have aim to develop a smart home monitoring system which will be low-cost and will be affordable to lower income people or people living on retirement benefit.
2. The initial design of the system was based on radio frequency wireless communication. In the later version the system has been developed using ZigBee.
3. The developed system uses the signals of sensors for tracking different appliances to determine the behaviour of the elderly. The measured behaviour can be compared with the stored behaviour to determine any abnormality in their behaviour.
4. Using current transformer smart electrical appliance monitoring unit has been developed. The developed unit determines the use, intensity and duration of use of the appliances. The data is then transmitted to the central controller using ZigBee based wireless protocol.
5. Using flexi force sensor a smart bed monitoring unit has been designed and developed. The system can determine the occupancy of the person on bed.

With an extensive version of the system (with four sensors under four legs) the bed monitoring unit can be used as a stand-alone unit to analyse the sleeping pattern of the person. Using the same principle the system is used to determine the occupancy of the person in sofa, toilet and chair, which are used by the person in his/her day-to-day life.

6. Using a flow-sensor a water use monitoring unit has been designed and developed. The unit can provide information on the use of water at home.
7. An emergency panic button has been included in the system. The panic button can be used for asking emergency help an also to deactivate a false alarm.
8. An intelligent process has been developed to collect and analyse the uses of appliances. The analysis can determine the behaviour of the person.

1.10. Organization of the Thesis

The thesis is divided into seven chapters. Chapter 1 discusses on the introduction of this research followed by the background for this research, significance of this research, the approach taken and original contribution.

Chapter 2 describes about the literature review done for the previous work that had been done in the area of smart home sensors. This includes the review and suggestion that gave ideas in conducting this research.

Chapter 3 discusses the approach and methods used for developing our first wireless sensors network based home monitoring system. Experiments in terms of suitability, performance and reliability of sensor chosen to build the monitoring system are discussed in this chapter.

In Chapter 4, our second ZigBee based home monitoring system prototype is discussed. This chapter debates our need for using widely used standardized wireless communication protocol. Experiments to determine the efficiency of wireless communication and the performance of the ZigBee based sensors are discussed in detail.

Chapter 5 describes the wireless sensors setup, communication and an intelligent process for person's activity behaviour detection. In this chapter the set up and configurations required to analyse the activity of a person are discussed.

Chapter 6 describes how the developed intelligent software detects the activity and wellness of the person. Discussion on the real time implementation and experimental results are done within this chapter.

Chapter 7 presents a summary of the results of the experiments, my conclusions and suggestions for future work.

1.11. Conclusion

An insight of elderly population growth across the world is discussed in this chapter. According to the statistics there is increasing number of elderly people around the world. Since elderly people are more prone to accidents if they prefer to live alone in their own home, a need of technological assistance and monitoring is paramount.

By integrating sensors in the house hold of an elderly person they can be monitored constantly. The smart home monitoring using wireless sensors concept is a promising way to improve the living standards of elderly by improving the home care for the elderly.

Chapter 2

Literature Review

2.1. Introduction

A smart sensor system with an intelligent, pervasive information and communications technology led the user to experience a rich variety of heterogeneous services. The smart home has the potential to be a cost-effective alternative, capable of providing quality health care and monitoring households. Most of the projects discussed here have used wide varieties of approaches in using the sensors to build a smart home. Some of the key design challenges to develop, implement a smart home monitoring system have been discussed in this chapter. The sensors, along with their intelligent technological features, allow design of smart home for elderly people to live autonomously in a comfortable and secured environment. Still today, there is not a single acceptable definition for smart homes. But smart home monitoring can be viewed as a system in a house with integrated technologies and services that supports those with cognitive disabilities by monitoring their activities, allowing simplified access to devices within the home, and social alarm systems that link the home to remote locations for the availability of immediate help or care.

Apparently, today's generation of smart homes has evolved more into intelligent, but relatively simple monitoring and controlling systems. The smart home has now been developed to be able to monitor elderly subjects with various disabilities. In each case the smart home consists of various appliances and devices which are commonly used by the resident on a daily basis. These appliances and devices have been fitted with sensors, actuators, and/or biomedical monitors to detect the activities of daily life of the resident. In some cases the entire house is monitored using audio-visual technologies.

This chapter discusses the review of research in the field of the smart home monitoring. It addresses the various issues involved in developing the methodologies and methods in this field. More specifically reviews on smart homes monitoring were grouped into three categories,

1. Smart homes using Audio – Visual based systems.
2. Wearable sensors.
3. Sensors for tracking and monitoring various appliances in a home.

2.2. Smart homes using Audio – Visual based systems

A variety of smart camera architectures has been designed in academia and industry for automation applications, assisted living systems and also surveillance. Assisted living systems can be categorised into manual and automated ones.

Yilmaz et al. give an extensive survey on object tracking [14]. An IEEE Signal Processing Special Issue on surveillance [15] surveys the current status of automated surveillance systems. Siebel et al. especially deal with the problem of multi-camera tracking and person handover within the ADVISOR surveillance system [16]. Hampur et al. describe IBM's S3 comprehensive multi-scale tracking system, which is also detailed in [17] and includes distance estimation using stereo vision. Reference [18] also provides a broad overview on this subject. At the University of California, San Diego, Trivedi et al. presented distributed interactive video arrays for situation awareness [19]. This work encompasses a comprehensive system for traffic and incident monitoring that has been installed around San Diego, and this system can be used in a house-hold for monitoring people. Shah et al. presented Knight, an automated real-world surveillance system [20] running on a centralized server. Collins et al. in collaboration with DARPA show the implementation of a system for autonomous video surveillance in [21]. A broader overview about human activity recognition is given in [22] by Ribeiro et al. All these systems share the fact that they are host centralized, which requires the transmission of video feeds, costs bandwidth, and leave the door wide open for misuse and privacy hacks. Quaritsch et al. presented a multi-camera tracking method in image domain on distributed, embedded smart cameras with a fully decentralized handover procedure between adjacent cameras [23].

Few visual systems addressing privacy issues have been discussed in this section: Schiff et al. implements a very interesting approach, the respectful camera [24], where the problem of automatically obscuring faces in real time to assist in visual privacy enforcement is considered. To this end, persons are required to wear coloured hats or vests. This approach primarily targets surveillance applications where the raw video stream is necessary, e.g., if an alarm is detected. Also at a workshop on computer vision and pattern recognition, privacy research in vision has been started to scramble videos as shown by Dufaux and Ebrahimi [25] or de-identificate faces as presented by Gross et al. [26]. A layered approach where privacy levels are coupled to users' access control rights is presented by Senior et al. [27]. Cucchiara et al. at the University of Modena also cover face obscuration [28] within their comprehensive video surveillance approach.

A visual surveillance by stationary cameras instead provides contactless observation without the need to equip the elderly belongs to the former class [29]. Important to note is the work by Aghajan et al., especially [30, 31] where a distributed accident management system for assisted living is presented that combines a wireless sensor solution worn by each person with a visual surveillance system. Privacy is addressed by not recording the camera feed if no accident is detected. Cucchiara et al. [32], Hauptmann et al. [33], and Williams et al. [34] present their approaches for assisted living and visual falling person detection.

Toreyin et al. in [35] combine visual cues with audio cues to increase robustness. What all smart cameras share is the combination of a sensor, an embedded processing unit, and a connection, which is nowadays often a network unit. The processing means can be roughly classified in digital signal processors (DSPs), general-purpose processors, field-programmable gate arrays (FPGAs), and a combination thereof. Wolf et al. identified smart camera design as a leading-edge application for embedded systems research [36]. Reference [37] provides a comprehensive overview of current research in the field of embedded vision systems. Rinner et al. [38] designed an innovative smart camera for distributed embedded surveillance together with ARC. It consists of a network processor and a variable number of DSPs. Chalimbaud and Berry presented a smart camera based on FPGAs [39]. Kleihorst et al. presented a smart camera mote with a Xetal-II high-performance yet low power single-instruction multiple-data processor [40]. Hengstler et al. presented MeshEye [41], an embedded, low-resolution stereo vision system on ARM7TDMI RISC microcontroller basis. IP based cameras are emerging where the primary goal is to transmit live video streams to the network by self-contained camera units with (often wireless) Ethernet connection and embedded processing that deals with the image acquisition, compression (MJPEG or MPEG4), a Web server, and the TCP/IP stack, and offer a plug and play solution. Further processing is typically restricted to, e.g., user-definable motion detection. All the underlying computation resources are normally hidden from the user.

Various approaches have been proposed for monitoring with the use of vision systems [42], [43], infrared (IR) cameras [44], multiple binary state sensors [45], passive infrared (PIR) sensors [46, 47] and ultrasonic and microwave detectors [48, 49]. Use of omnidirectional vision sensor for detecting fall and object tracking in a house-hold is described in [50]. Vision systems equipped with omnidirectional sensors can also be used for mobile robot localization and navigation in a smart home [51].

Although each approach has strengths, it also has weaknesses. For instance, camera imaging systems, including IR cameras, can arguably intrude on privacy and have high refusal rates in home monitoring and low acceptability by elderly, multiple sensor systems are cumbersome and costly to install and often misguide the monitoring system [52].

2.3. Elder Care Based on Wearable Sensors

For health care monitoring the use of wireless wearable sensor is getting popular. These wireless sensor networks provide continuous monitoring regardless of a caregiver's location and activity [53]. The Body Sensor Network (BSN) consists of collection of mobile sensor nodes which are worn on the elder's body. These mobile sensors are usually equipped with temperature sensors, pulse sensor, accelerometer and even ECG, EMG, EEG etc. Different sensors can be used for people with different disabilities.

For example CustoMed [54], discusses about implementation of a personal sensor network for health care monitoring using smart sensor nodes and a control node based on Bluetooth piconet. Some of the implementation issues like self-organization capability, data centric approach and flexibility are discussed in good detail. This system is proposed to be used in many applications including portable health monitors like ECG, intelligent control of medication delivery and also for battlefield soldier monitoring. Wireless body area sensor networks are increasingly used in medicine to improve quality and efficiency in health care processes [55, 56]. In [57], a remote health care system based on wireless sensor network is designed and implementation of a two-tiered sensor network based on embedded Web Server was discussed. The proposed system can be placed in a hospital or at patient's house. The sensor nodes collect some of the physiological indexes of the patients and also monitor the running state of the medical devices to transmit the data to the sink node or the local computer. The wireless sensor network then sends the data to a remote central server as shown in Figure 2.1.

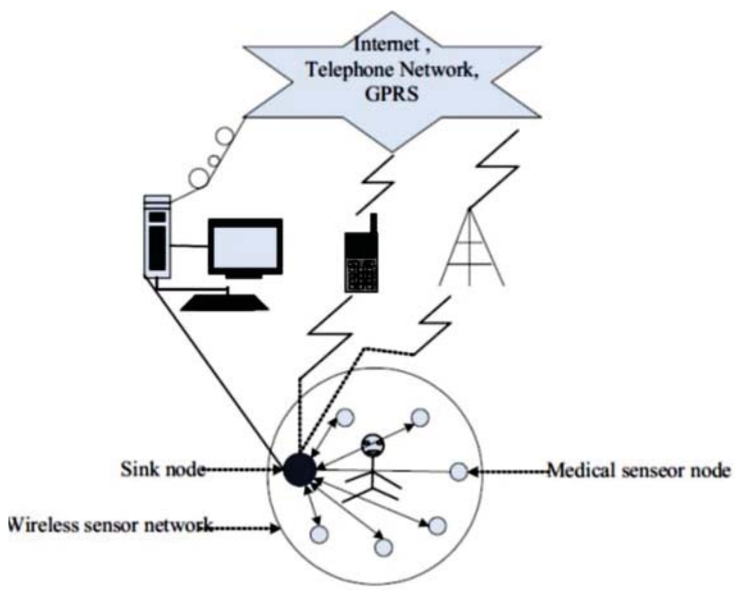


Figure 2.1: Structure of the health care system based on wearable sensors [57]

Body area network (SG-BAN), a new study group, established by IEEE 802.15 working group, to develop short range wireless communication technology in and around human body. [58] introduced the IEEE SG-BAN and also investigated the performance of 802.15.4b and 802.15.4a for wearable healthcare applications in the heterogeneous networks environment. Topics including how and where to implement BAN, scalability issues, asymmetric clear channel assessment (CCA) abilities among different types of wireless technology are explained in detail. This paper [57] gave guidelines for using wireless technologies for medical device communications in various healthcare services.

The use of ZigBee communication technology based on wireless standard 802.15.4 in medical care and monitoring is getting popular in the recent times. It is an extension of the WPAN. Omeni O.C. et at., proposed a new energy-efficient MAC protocol [58], designed for wireless body area network (WBAN) to provide services on universal health care application.

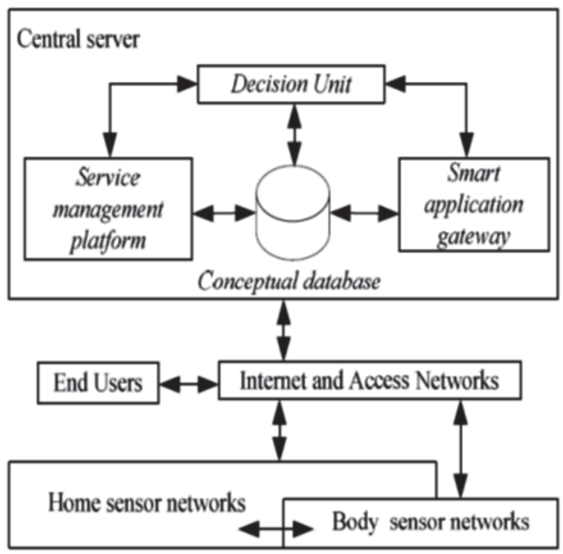


Figure 2.3: Body Area Network Architecture of health-care system [62]

Cavallo F [59] introduced an intelligent rehabilitation system based on the ZigBee network. This system improves the independent living of the elderly and people with disabilities. The system consists of various sensors, a coordinator, a promote node to identify and manage the patient's ability, when confronting urgent requests by sending warning message to the medical staff. The ZigBee system proposed by Jung et al. [60], discusses about a dynamic medical management system, the data from the sensor device is sent to mobile system via wireless personal area networks, in order to gather the biological or environmental information. A system proposed by Sugano Masashi in [61] is capable of capturing diabetes pathology and recording information, such as weight, blood pressure and other data of a person. This system does not need special computer settings to get the necessary information, which can be a great advantage for elder users. Moreover the system is capable of quickly setting up its ZigBee-based home network using sensor information network services.

[62] proposed a project to integrate the technologies of wireless sensor networks and public communication networks to construct an efficient healthcare system for elderly at home without interfering their daily activities. This system shown in figure 2.3 consists of four main functionalities like indoor monitoring, outdoor monitoring, activity and health state decision, emergency decision and alarm. The system automatically measure and collect body and home parameters and send the data to the central server over different public networks, wired or wireless.

This system is able to provide an interconnection platform, and a service management platform to support distant healthcare for elderly. In [63] Sugano et al, proposed a concept of an online medical diagnosis system for ubiquitous health care using a wireless ECG sensor as shown in Figure 2.4.

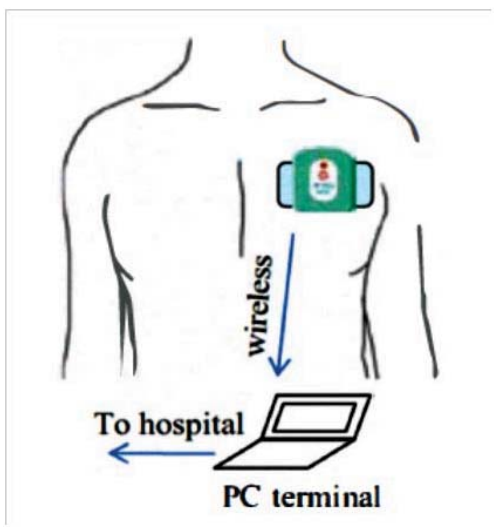


Figure 2.4: Monitoring physiological parameters by a wireless wearable sensor

Also a scope to improve the data transmission capability by the wireless ECG by sensor using multiple receivers for a single wireless sensor was discussed in [64], developing a wireless BAN (body area network) using a machine measuring the human acceleration and electrocardiogram readings.

More Research is being done on wearable technologies, which are able to collect, process, store, and transmit (and receive) information about the wearer's body vital signs, wirelessly to (and from) any remote location. These portable, versatile medical devices can be moved in a homecare setting [65]. Also in [66] a discussion on the applications and impact of this kind of technology in the continuum of life for independent living for senior citizens was done. The field of smart textile-based wearable biomedical systems (ST-WBSs) started generating a lot of interest in the academic research areas. The key components in a ST-WBS include sensors to capture/measure vital body parameters, thus providing a pervasive healthcare [67, 68].

Even though the wearable technology provides safety, help and transforms the healthcare by enhancing the quality of life for senior citizens there are many drawbacks associated with it. These kinds of sensor are needed to be in contact with the body of the individual at all times, which can cause discomfort. Because of this discomfort many users do not feel like wearing them, which can hinder the reliability of the system. Since this kind of wireless devices are close to the body they may interfere with other devices like pace maker etc. [69].

2.4. Sensors for tracking and monitoring various appliances in a home

In this section research works on finding the residents behaviour by monitoring the appliance usage is discussed. The sensors installed in a smart home will monitor the usage of the appliances and devices of the person in their daily life. The behaviour pattern is identified in correlation with the usage of the appliances. By using sensors to monitor the usage of appliances and devices in a house-hold, an estimate of the resident's life pattern can/may be established. The real-world situations can be sketched by the data collection, the abstraction of the data collected.

This kind of approach keeps residents' privacy without intrusion of the house, in comparison to systems like the audio-video based health care system. Smart homes that have now been developed are able to monitor elderly subjects with motor, visual, auditory or cognitive disabilities. In each case the smart house consisting of varied types of appliances and devices which are commonly used by the resident on daily basis. These appliances and devices have been fitted with sensors, actuators to detect the activities of daily life of the resident(s). It is feasible to detect certain real-world situation [70, 71] through capture sensors data. Some of the sensors which are most predominantly used in building a smart home are discussed below.

2.4.1. Pressure Sensor:

In many smart home applications piezoelectric pressure sensors are generally employed. This kind of sensor uses the piezoelectric effect to measure pressure, acceleration, strain or force by converting them to an electrical signal. Kaddoura et al. [72] has described such a system where a pressure sensor is centrally placed underneath each square foot block of the floor and is able to detect a foot step on any part of that block. The Gator Tech Smart House has a residential-grade raised floor consisting of floor tiles measuring one square foot each, [73], a sensor that covers the whole floor area would be able to locate and track the position of multiple users in a smart home. The pressure sensors have a wide range of applications for smart home monitoring. The pressure sensors can be used for bed monitoring. Pressure sensors are placed on a regular grid under each bed sheet. Each sensor indicates a value that corresponds to the amount of pressure being exerted on it.

One such device manufactured by the Tactex Controls Inc, Bed Occupancy Sensor (BOSTM) which can be installed under the bed mattress to monitor the patient's condition at rest [74]. These pressure mats can detect the changes in bed entry and exit patterns, thus identifying the changes in the physiological condition of the occupant on the bed. The sensor monitors occupants' sleep patterns and keep track of sleepless nights. The pressure sensors can be used on grab bars in the home especially in bathrooms. This grab bars can identify and monitor the entry and exit from the shower and bathtub, as well as transfers on and off the toilet.

2.4.2. Motion / Proximity Sensor:

Proximity Infrared (PIR) sensors can be installed strategically in a home environment to detect the movement of the person within the home. This helps to find out the activity of a person. These Sensors track the presence and motion of the resident throughout the living space by infrared motion sensors which are installed in each room. This type of sensor can also be used as a fall detection device [75]. The values can be continuously checked via an analogue to digital converter (ADC); it then packetizes the values and sends for processing. The system with this kind of sensor can detect any abnormality in the living pattern of the resident, if a person extensively stays in one room may indicate a problem with the resident's mobility or if he/she is wandering or sporadic changes in the direction of motion may indicate signs of mental anxiety or confusion. In [76, 77] mentioned the use of IR sensors along with magnetic switches for statistical detection of abnormal inactivity or household appliance use. One of many disadvantages of Motion / Proximity Sensor's is their limited reliability. These sensors can be deceived by warm objects and motionless individuals. Also the acceptance level of smart homes based on this technology is not much.

2.4.3. Temperature Sensors:

Temperature sensor can be used in a smart home to monitor house-hold temperature changes. These sensors can provide information regarding stove or oven status, as well as faucet water temperature [78]. When installed on the appliances like fridges the usage of the fridge can be known.

2.4.4. RFID Sensors:

Radio Frequency Identification sensors have proved useful for detecting a variety of fine-grained activities. Patterson et al. report accuracies of around 80% for recognition of 12 activities in a kitchen instrumented with 60 RFID tags [79]. A common problem of elderly people and patients with early stages of Alzheimer's or dementia is forgetfulness where they have placed commonly used objects. RFID tags can be placed on commonly misplaced objects to retrieve them at home [80]. Tags do not require a power source of their own, but they get the energy they require from a nearby reader which they then use to transmit their designation to the reader.

RFID enabled sensors can be installed at the door entrance/hall way to detect and monitor the person, which room he/she is in. The main objective of this sensor is to detect if a person with early stages of Alzheimer's disease goes out of his/her house. RFID sensing system consist of a series of active/passive scanners that are located in the ceiling of each room, to detect persons tagged with RFID passes through the entrance of a room to determine who it is that is in the area [81]. The main disadvantage of RFID sensors is the number of sensors that are needed to be installed in a home and also there is a need for the inhabitant to carry a RFID reader at all times. This may cause inconvenience to the user and also makes it impractical in 24/7 monitoring.

2.4.5. Switch Sensors:

Magnetic switches can be used on doors throughout the home, kitchen appliances, such as the oven, refrigerator, or dishwasher, which monitors whether the appliance is 'open' or 'closed'. This is useful in monitoring the entry and exit from the various rooms of the home. The MIT Place Lab [82] is a residential condominium, which has been designed to be an observational facility for the scientific study of people in home environments using over 300 switch sensors which are installed in nearly every part of the home ranging from switch sensors on lights, cupboards, electrical appliances faucet, and mail boxes. The switches can be placed all around the knobs of different appliances, in order to detect the state of each of them. The data from all of these sensors is sent to a central processing and storage device wirelessly to detect the activities of daily living in the facility and to monitor the activity of the resident.

2.4.6. Vibration Sensors:

Accelerometers can be placed in a smart home for detecting vibrations, when a person moves around the house [83]. These can be installed on everyday objects like chairs, sofas, bed etc. to monitor the resident's movements. Impacts with the sitting furniture could represent a lack of muscular strength or control over time. Impacts with the floor, however, could represent the occupant losing their balance and falling, which may require immediate attention. With proper installation the vibration sensors can detect the fall/slips of the elderly person at the smart home in an efficient way.

2.4.7. Water flow monitoring Sensors:

Most common consumable that a household uses is water. Monitoring the water flow into the house will give a general overview of when water is being used in the home. Without water people cannot survive. Water is used for drinking and washing. People also use water to have a shower or bath. It is used in a toilet system and also used to clean clothes and dishes. This covers a large variety of systems in a home. The water use in the household can be monitored with the use of water monitoring sensor [84].

2.4.8. Current Sensors:

Detection the usage of electrical devices for general equipment (such as the kettle and toaster) acts as a medium between the power socket and the equipment to be monitored. The level of monitoring can range heavily depending on each case; some people may object to a high level of monitoring and are happy with one or two simple rules such as the kettle. C. Kiluk [85] has reported a method of an alarm system which is intended for monitoring of apartments for elderly and/or handicapped person in his invention. The energy consumption of the apartment is measured and recorded over a period in a computer. The actual energy consumption of the apartment is compared with the expected energy consumption which is recorded in the computer to generate different degree of alarm level.

Housing Learning & Improvement network published [86] a smart home definition offered by Interetec, which states that a smart home is a dwelling incorporating a communications network that connects the key electrical appliances and services, and allows them to be remotely controlled, monitored or accessed using current sensors.

2.5. Sensor systems installed in new home environment

Early work done related to smart environments was concentrated on new home environment that could improve the experience of inhabitants. Applications like localization, people tracking and activity recognition are some of the early approaches. These formed the foundations of the intelligent environment. In [87, 88] have used ultrasonic location tracking sensors to build smart floor for accurate location calculation of the resident in a smart home. Kidd et al. [89] used ultrasonic sensors along with RF technology, floor sensors to identify Patterns of the resident in a smart home. Tamura et al. [90] employed various sensors and magnetic switches for health Monitoring and to detect bed temperature, behaviour of the resident in a smart home. Some the facilities like Senior Care, Tiger Place, and Elite Care have used technologies to help take care of their elderly residents [91, 92, 93].

Researchers at the University of Florida have instrumented a house with ultrasound localization and displays with the goal of providing timely and relevant information to residents [94]. A person tracking in a scientific environment was achieved using variety of sensors, including RFID badges and infrared or ultrasound sensors [95, 96, 97, 98]. Researchers used an array of motion detectors and contact switches at the Medical Automation Research Centre (MARC) at the University of Virginia to detect activities of daily living of the inhabitant [99]. MIT have worked on developing smart architectural surfaces like smart kitchen gadgets like sensors attached to spoons, tables, dishwashers, food containers, water sink, and many more[100].

At Georgia Institute of Technology [101], a smart home used sensors to determine the location information of the resident, places sensor to aid his/her memory and also control of devices using gesture. They have painted a digital family portrait which could communicate the general well-being of a person to family members.

IPSI Research Institute, Germany has developed an integrated home automation system which can integrate consumer electronics, mobile communications, and personal computing for monitoring home environment [102]. University of Illinois has created active spaces for ubiquitous computing, the system can sense inhabitant actions and assist them with different tasks. The University of Florida developed a smart environment by deploying a large array of smart devices and sensors to create a complete smart home, called the Gator Tech Smart House [73]. In this smart home the goal of creating assistance with the help of sensors and telematics was achieved. In

[103] employed neural networks and sensors to control/monitor heating, lighting, ventilation, water temperature, and the desires of the inhabitant were well formulated using these techniques.

Using fuzzy logic based expert system [104] called "iDorm" a research facility monitors the inhabitant interactions with devices in a house-hold. It predicts inhabitant needs and also consumption of energy is controlled. MavHome (Managing an Adaptive Versatile Home) project [105], located at the University of Arlington at Texas, used sensors and device controllers is able to monitor the elderly and provide comfort. This system uses tools like artificial intelligence, data mining, and prediction for automated decision making. The repetitive tasks performed by inhabitants on daily basis were identified and stored in the system. This data is used to predict the inhabitant's next action in order to automate such selected repetitive tasks.

2.6. Sensor systems installed in an existing home environment

Lot of research is being done on non-invasive wireless sensors used in existing home environment to transform it into a smart home. There is a paramount of need in this kind of monitoring systems. Especially, in case of elderly monitoring where many elderly people want their existing home to be transformed into a smart home [106]. In [106], presents a life pattern sensor for behaviour monitoring for a health care system as shown in Figure 2.5.

Figure 2.5: Wireless sensor systems installed in an existing home environment [107]

This sensing system has a variety of important applications, including energy monitoring, home automation, and health care.

In [107] the system detects activity level of the elderly using home automation sensors. The system is equipped with sensors to monitor and detect any abnormal state of the elderly, by monitoring house-hold items like such bed and chair sensors, a mini PC connected to a TV, medical sensors. The system is designed specifically for elderly patients, who wish to spend their time in their own home. The system has a potential to increase independence and quality of life for seniors who prefer to live in their own home. The system analyses the activity patterns of an elder person and the central computer detects unusual behaviour, using an intelligent method like Fuzzy Logic. The application stored in the web server analyses the data and medical record from home automation sensor and medical devices, by using intelligent methods like fuzzy logic or other more complex cognitive systems, to find the potential health problem. The system is able to trigger an alarm if it detects a problem that may result in an automated data transmission to a doctor.

2.7. Conclusion

An in-depth review of various types of smart home monitoring systems and the sensors that can be used has been discussed in this chapter. Also various issues, methodologies and methods involved in developing a smart home based monitoring system have been discussed. From the literature survey it can be noted that there is tremendous need to develop wireless sensors based monitoring systems specific to needs of the end user. By using and developing this kind of technologies the living environment of the end user can be transformed into a smart home environment.

Chapter 3

Wireless Sensors Network Based Home Monitoring: Our first prototype

3.1. Introduction

During recent years different kinds of home monitoring/smart home systems have been developed by many organisations and institutions, considering the fact that there is an increasing tendency in the numbers of elderly people. Most of elderly are suffering with chronic illnesses and disabilities, the majority of them are women, living alone, many with cognitive impairment, in the oldest-old age group. It has been realised that there is a need for technology which can significantly offset the decline in health and self-care abilities and enable elderly people with or without disabilities to continue to live alone in a home. The whole purpose of the design of smart home or digital home is to provide a safe, sound and secured living environment to the elderly people who are living alone at home.

By taking the advantages of the advancement of the semiconductor technology, sensors and sensing systems, embedded processors and communication devices, a lot of design and development of smart home technology prototype devices and systems have been developed.

These devices which are developed to enhance independency are classified into four types according to the type of technology used to develop them, namely;

1. ***Adaptive Technology***: The technology which is used to develop devices is adaptive i.e. the system or device can be modified with ease according to the needs of the individual, so that the device or system performs its task more efficiently and easily, without any complexities.

2. ***Assistive Technology***: By implementing this kind of technology in to the devices or system which are meant for home monitoring, can allow an individual to perform a task they would otherwise be unable to do so. The devices or systems which are built on this technology can increase the ease and safety with which the task can be performed.

3. ***Inclusive Designs***: These types of devices or systems are designed on the principle that they can be used by wide a range of people as possible.

4. ***Medical Technologies***: As the name suggest this kind of devices or systems are developed to monitoring a health care environment for prevention, diagnosis, monitoring, treatment or alleviation of illness or injury.

3.2. Wireless Sensors Network for In-Home Healthcare: Potential and Challenges

With the advancements in the sensors, embedded systems and networking technologies, it has opened up new opportunities in many fields especially in health care. Since the population of the world is ageing, the suffering of the elderly people with many old-age diseases will also increase. So there is a need for an in-home pervasive network which assists and helps the residents by controlling home appliances, medical data look back and also communicating in case of an emergency.

To implement this sensor networks for in home health care there is need to consider the following potentials and challenges;

1. ***Interoperability and Interference***: Since many sensors nodes are present in an in-home wireless sensor network, there a need to limit or avoid interference between increasing crowded biomedical sensors and various RF devices. The home care network must provide middle ware interoperability between disparate devices, and support unique relationship among various devices such as implants' and their outside controllers. In home operation have more interference due to wall and other obstructions. So there is a need to reduce or eliminate unwanted emissions and glitch.

2. ***Real time data acquisition and processing:*** There is a critical need for efficient communication and processing of the data over the sensor network. Some techniques which come handy for this kind of situation are event ordering, time stamping, synchronisation, and quick response in emergency situations.

3. ***Reliability and robustness:*** Since the sensor network is not meant for frequent maintenance and not situated in a controlled environment, these devices and other sensors must be operated with good reliability, so as to provide reliable data for medical treatment and diagnosis.

4. ***Data Management:*** There is a need for embedded real time database which stores data of interest and allows the care giver or the providers to query.

5. ***Data privacy and security:*** There an at most need to protect the privacy of the person who is being monitored using wireless sensors in a network. The data collected through the network may be sensitive if it is misused. Data is only accessible during an emergency situation, but the accesses should have non-reputable "trial", so abuses can be detected.

6. ***Comfort and unobtrusive operation:*** The sensors which are designed for this task should be almost invisible and should have stealthiest if needed.

By implementing these in-home health care using wireless sensor networks, enable to extend healthcare from the traditional clinic or hospital setting to the patients' own home and also avoids prohibitive costs. In a smart home a person can avoid visit to doctors at regular intervals, self-reporting experienced symptoms, problems and conditions. The wireless sensor network may collect all the data according to the physician's specification thus reducing burden of the patient or an old person and provide a continuous record to assist diagnosis.

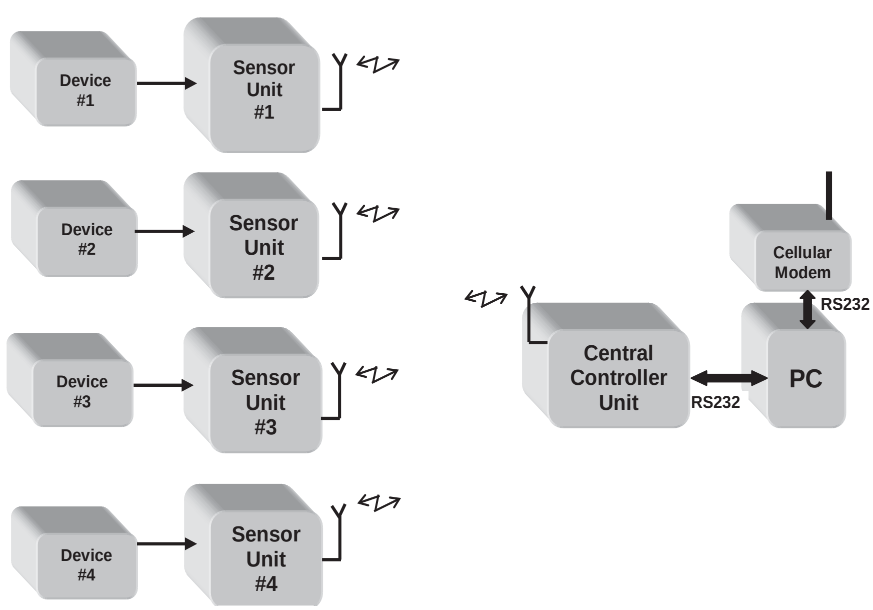
The smart homes equipped with the wireless sensor networks will benefit both health care providers and their patients. By monitoring the patient continuously and reporting any abnormal situation, the system frees human labour and thus reducing labour costs and increasing efficiency by notifying doctors or health care provider quickly. Many wearable sensors devices can sense even small changes in vital signals that we might overlook. The data collected from various sensors over the network in a smart home can be stored and integrated into comprehensive health record. Other issues like quality of life for elder people, such as privacy, independence, dignity and convenience are supported and enhanced by the ability to provide services in the patient own home.

3.3. Building the prototype – Progress

In the first attempt a wireless monitoring system called "Selective Activity Monitoring (SAM) system" has been developed based on three sensors; the sensors detect use or No-use of electricity while the target appliances are connected to mains supply. But it has been realised soon that there is a requirement of a few more sensors to making a smart home monitoring system more effective and efficiently. The development and prototyping of the system for home monitoring system has been discussed in this section.

3.3.1. System Architecture

Figure 3.1 shows the functional block diagram of the wireless sensors network based smart home. The whole idea of the system is as follows: The system will consist of many wireless sensors, each sensor will detect the status of the appliances whether they are used or not. The appliances are used by the elderly person for the day-to-day activities. The monitoring of the appliances will provide the person's daily activities. The daily actual monitored activities are then compared with the person's daily routine activities. The routine activities of the person are stored in the system. Based on the comparison the system will be able to tell whether the person is leading a normal life or there is any kind of abnormality. In the event of any abnormality, the system will inform to the appropriate person for necessary help.



Each appliance that needs to be monitored is connected to a sensor unit (SU). The SU detects activity or usage of the appliances. The SUs and the central controller unit (CCU) are equipped with RF (radio frequency) transceivers for two-way communication. The CCU polls the SUs at regular intervals and gathers the status of the appliances. The RF communication between the SUs and CCU is at 418 MHz frequency. The maximum data transfer rate is 40 kbps. The CCU is connected to a personal computer (PC) using RS232 serial communication protocol. Message service (SMS) facility of the cellular telephone network, to the mobile phone of a family member or a care giver who can then take appropriate action to contact the person and provide help if necessary.

3.3.2. Hardware design

The hardware components of the system are the Sensor Units (SU), the Central Controller unit (CCU), a PC and a cellular modem. In this section the details of the design of the custom built SUs and CCU are discussed. The PC and the cellular modems are standard off the shelf devices.

3.3.2.1. Electrical Appliance Monitoring Unit

The electrical appliances are the most common devices used by elderly or any person at home. There are many electrical appliances used at home such as electric lamps, television, refrigerator, microwave oven, toaster, hot-water kettle, electric heater, music system, and so on. If all electric appliances are analysed, it is seen that some devices such as electric lamps may not be accessible for an old-home. Since the objective of the developed system is to help elderly people living alone, in most of the cases the houses will be an already-build house. So those appliances are considered which are connected to electric supply separately. Moreover, some appliances such as refrigerator which are connected to electrical system and used continuously in an automatic manner will not provide any information on the behaviour of the elderly.

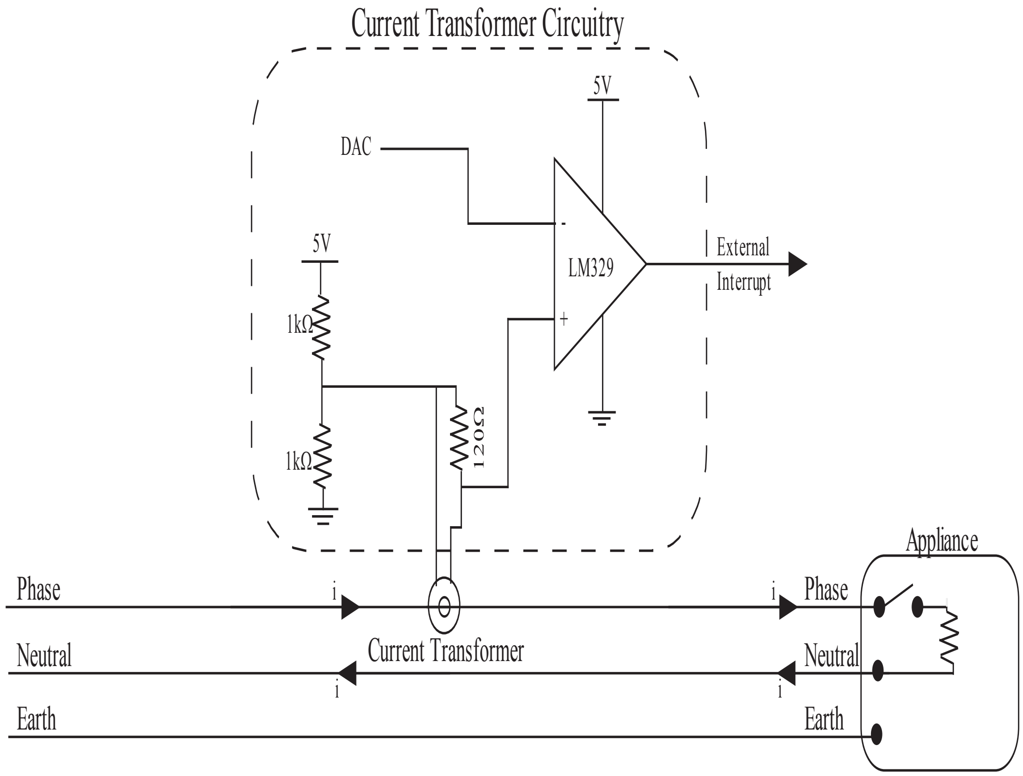


Figure 3.2: Current transformer connections and circuitry

A current transformer (CT) is used to detect the current flow in the phase line of the AC mains connected to an appliance. The necessary circuit and connection diagram of the current transformer for the detection of the status of the electrical appliance is shown in figure 3.2. When an appliance is turned on, the current drawn by the appliance passes through the primary coil of the CT. This produces a proportional current in the secondary coil of the CT, which, flowing through a 120 Ω resistor, generates an AC voltage of 50 Hz frequency across it. This voltage is compared with a reference voltage to detect the status of the appliance.

The peak voltage across the 120 Ω resistor is 2 V for a load current of 10 A, which is the maximum for our design. If the maximum current of the appliance is more than 10 A, a necessary change of the number of turns in the CT is required. The comparator is run off a single +5V supply. To prevent presentation of negative voltage at the input of the comparator, the voltage across the 120 Ω resistor is shifted up by 2.5 V using the voltage divider circuit as shown in figure 3.2. This voltage is compared with the programmable voltage of the Digital-to-Analogue converter (DAC) output of the microcontroller. The LM329 op-amp based comparator generates a transition at its output each time the CT output crosses the DAC threshold. In summary, when an appliance is turned on, the circuit generates a series of pulses, at a frequency of 50Hz, at its out. These pulses, used as external interrupts to the microcontroller, are counted by the program running on the microcontroller.

The sensitivity of the Sensor Unit, i.e. the minimum current which it should detect, can be altered by changing the DAC output which is used as a reference.

The task of the load detection software is to continuously evaluate whether the load is active or not. It does this by counting the number of pulses received from the CT circuitry on the external interrupt pin of the microcontroller over a predetermined period of time.

A timer has been configured to generate an interrupt every 500 ms. If 10 external interrupts occur within this period, the appliance is deemed to be active. Although ideally I would expect 25 pulses over half a second, this was sometimes not the case. The most obvious example of this is a regulated heater, which controls the temperature by switching the load on and off. If this happens within the 500 ms monitoring window, the number of pulses counted is less than 25. The flow chart of the algorithm for load detection is shown in figure 3.3.

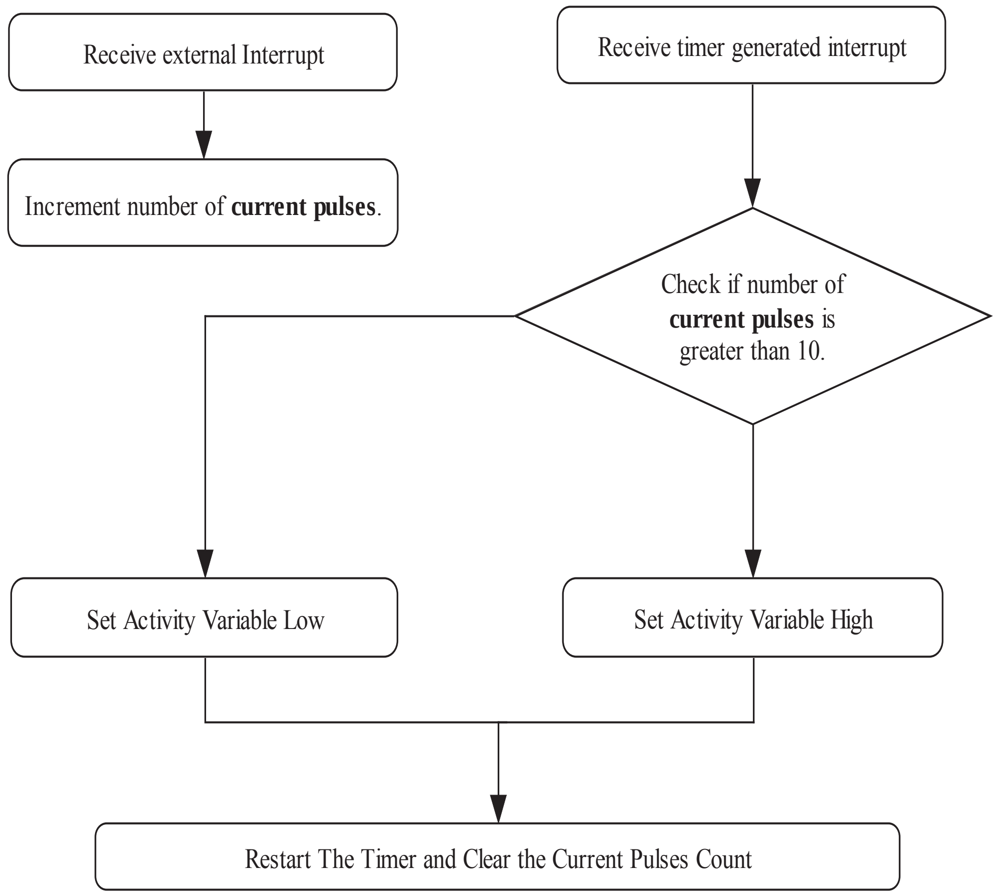


Figure 3.3: Algorithm for Current Detection

The microcontroller used is the SiLab C8051F020 mixed signal microcontroller. The microcontroller development board was used to build the prototype as it provided ready connection terminals for analogue and digital I/O.

Figure 3.4 shows the basic components of the electrical appliance monitoring unit along with the picture of the fabricated system. There are 3 Light Emitting Diodes (LED) – one to indicate that power to the SU is powered on, another to show that the RF communication with the SU is currently in progress and the third to indicate that the appliance connected to the SU is active, i.e. turned on.

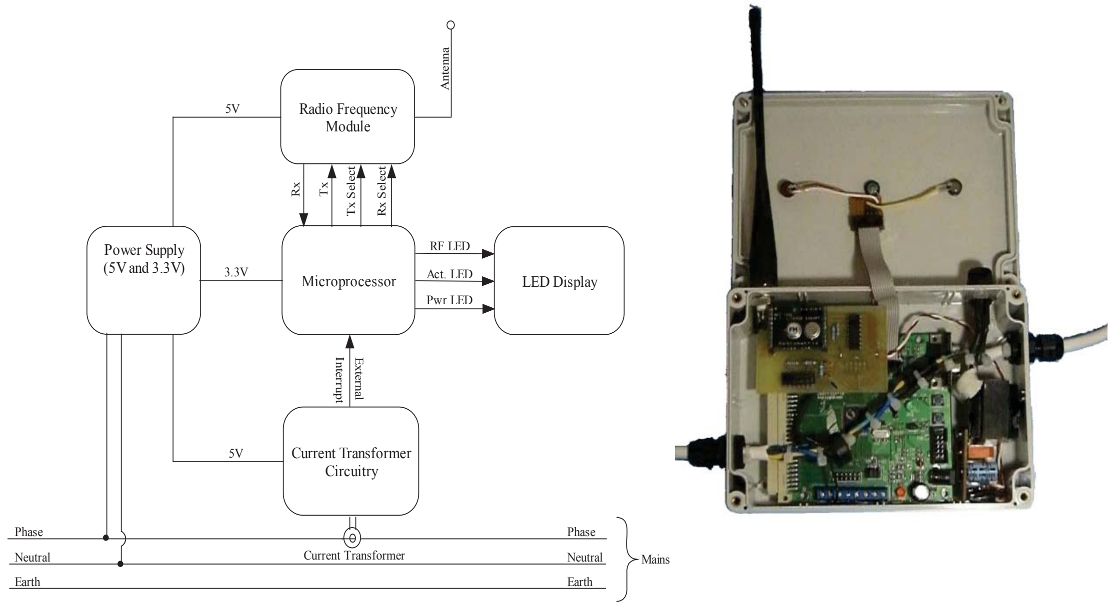


Figure 3.4: Core components of the electrical appliance monitoring unit

3.3.2.2. Bed Monitoring Unit

One of the important appliances used by an elderly person at home is the bed. The bed is used at the night for sleeping as well as can be used during the day time for taking rest. An elderly person spends almost 10 hours or more everyday on bed. So the monitoring the bed is very important to know the well-being of the person. The main purpose of this kind of sensor unit, is to monitor the bed usage of an old person or a patient who is living all alone in a house and need immediate medical attention in case of an emergency.

Let us consider two kinds of situations, which a person can experience when living alone, suppose a person who has a habit of waking up every morning at a particular time slot, but on a particular day, tends to be lying on the bed till late in the morning. Or, suppose a person who has a habit of going to use the bed at a particular time slot every night, but on a particular night if he/she is not on the bed even after the given time slot. This situation may indicate that the person might have had a health issue or fell down somewhere in the house which made him/her unable to reach for medical assistance.

In the absence of helpers at night for a person living alone it is required for a preventive measure to avoid sudden accidents in the home environment. A person can stay in physiologically stable condition on a bed. The main aim of this kind of sensor system is to monitor the occupancy of the bed by the person and if necessary, sleeping pattern of the person. Who is living all alone in a house and needs immediate medical attention in case of an emergency or an abnormal situation raised. This kind of intelligent sensor can perform various data collection and processing functions, including data interpretation, storing data on a database. While several sensors are readily available off the shelf, making them “intelligent” in the context of a specific application (such as monitoring of the elderly) is always a challenging task. In case of an intelligent bed-sensor, it not only detects the usage pattern of the bed but also has capabilities to collate the data and flag out abnormalities.

By monitoring some of these physiological quantities and creating a database of collected data over several months or years could be helpful for many purposes such as retrospective studies of the patients or a data base for public health studies.

Bed monitoring unit monitors the abnormalities in the person’s daily sleep window period and may act as a lifesaver. A prototype of bed monitoring device has been developed, which has demonstrated its feasibility for mentoring the activity of a subject in bed. Being different from the previous developed methods, this device monitors the subject 24-hours 365 days with a low cost, less complexity and good accuracy

The Bed Monitoring unit system consists of four sensor units with a driving circuit and a microcontroller. The Tekscan make flexiforce sensor has been used for the bed monitoring unit [108]. FlexiForce® sensor was chosen because of its flexibility, cost-effectiveness, and ease of integration. FlexiForce force sensors are ultra-thin (0.008"), flexible, non-obtrusive printed circuits.

The construction of FlexiForce sensor allows for easy manoeuvring and an exclusive fit, even during the most delicate of procedures. The FlexiForce sensors as shown in figure 3.5 use a resistive-based technology. By application of an external force to the “active sensing area” of the sensor results in a change in the resistance of the sensing element which is inverse proportion to the force applied on the sensor. These sensors are constructed of two layers of substrate composed of polyester film. On each layer, silver is applied for electrical contact which is then followed by a layer of pressure sensitive ink. Adhesive is then used to laminate the two layers of substrate together to form the sensor. The silver circle on top of the pressure-sensitive ink defines the "active sensing area." Silver extends from the sensing area to the connectors at the other end of the sensor forming the conductive leads. FlexiForce sensors are strategically placed underneath the bed legs to determine if a force is being exerted on the bed (confirming whether someone is lying on it). The voltage output varies linearly with the exerted force. The pressure sensor can measure up to 444 N of force (100 lbs.). To differentiate between inanimate objects and human beings, we need to calibrate the sensor unit so that the force applied by each extremity should produce a significant voltage output. The pressure sensor basically acts like a means to detect force, as some body lies on the bed, this will be accomplished by setting up a force-to-voltage circuit. In addition, the sensors will need to be conditioned. Once this is accomplished, the sensor's output is repeatable within 2.5%.

Figure3.5: FlexiForce® sensor [108]

Some of the physical parameters of flexi force sensor are:

- The operating range of temperature is from -9°C to 60°C,
- Repeatability is +/- 2.5% of full scale (conditioned sensor when 80% force applied),
- Linearity is < $\pm$ 5%,
- Hysteresis is <4.5% of full scale

According to the Tekscan's user manual, to calibrate, apply a known force to the sensor, and equate the sensor resistance output to this force. Repeat this step with a number of known forces that approximate the load range to be used in testing. A Force versus Conductance (1/R) plot can be drawn as shown in the figures 3.6 and 3.7 respectively. A linear interpolation can then be done between zero load and the known calibration loads, to determine the actual force range that matches the sensor output range.

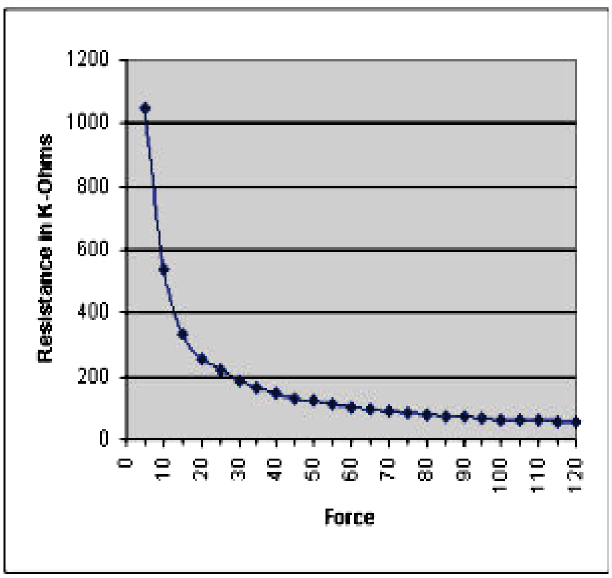


Figure 3.6: Resistance Curve

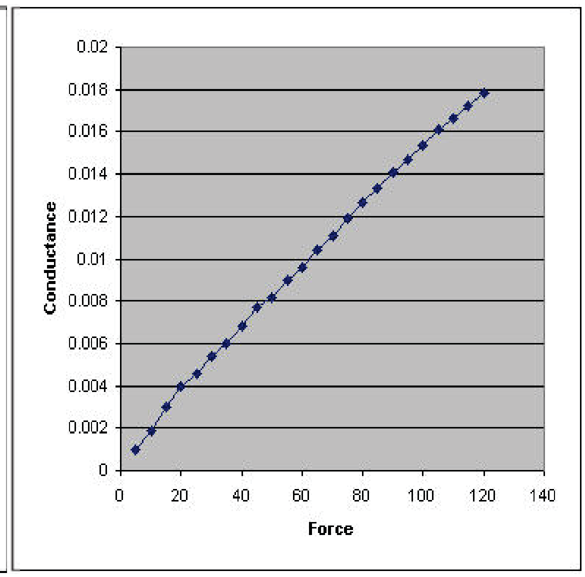


Figure 3.7: Conductance Curve

The recommended driving circuit is shown in figure 3.8, it is driven by a -5 V DC excitation voltage. This circuit uses an inverting operational amplifier arrangement to produce an analogue output based on the sensor resistance and a fixed reference resistance (RF). The output of the inverting amplifier is connected to an analogue-to-digital converter provide in the microcontroller. The ADC is used to change this voltage to a digital output. In this circuit, the sensitivity of the sensor could be adjusted by changing the reference resistance (RF) and/or drive voltage (VT), a lower reference resistance and/or drive voltage will make the sensor less sensitive, and increase its active force range. In the circuit shown, the dynamic force range of the sensor can be adjusted by changing the reference resistor (R_F) or by changing the Drive Voltage (V_O).

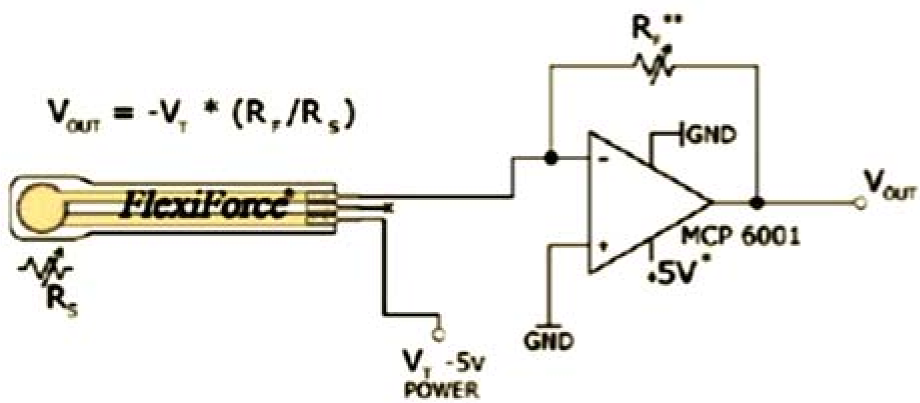


Figure 3.8: Electronic circuit of the part of the Bed Monitoring Unit

Figure 3.9 shows the actual circuit with four force sensors, the outputs of the inverting amplifier S1, S2, S3, and S4 are connected to the four channels of analogue to digital converter. Since Silabs 8051F020 is used in this project, the analogue reference voltage of ADC converter is 2.4 V. Therefore the maximum output response of the sensor is made to be below / equal to 2.4V. This is done by adjusting the R_F potentiometer. Since the driving circuit need two supply voltages +5V to power up the inverting amplifier and -5V to drive the sensors. LM7805, a 3-terminal positive voltage regulator is used to produce a constant +5V supply. MAX828 chip is used to produce -5V. The MAX828 are ultra-small monolithic, CMOS charge-pump inverters. It is used to generate a -5V supply from a +5V logic supply to power analogue circuitry. This IC comes in a 5-pin SOT23-5 package and can deliver 25mA with a voltage drop of 500mV. Since MAX828 is a Switched-Capacitor Voltage Inverters it caused a 12 KHz noise at the output. This noise can considerably affect the output of the sensor, resulting in unstable output. To eliminate this noise a simple low-pass filter is employed at the output terminal of each sensor. Using 0-25 lbs. Flexiforce sensor, the force to voltage characteristics are noted and is shown in the figure 3.10,

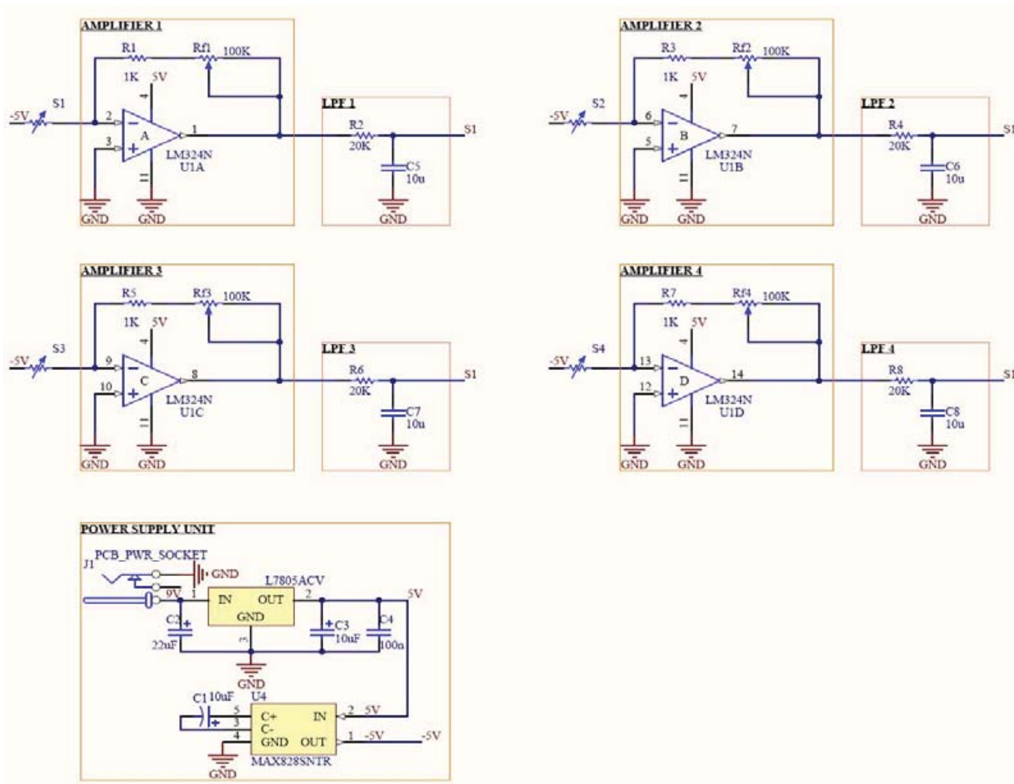


Figure 3.9: Electronic circuit for the four sensors

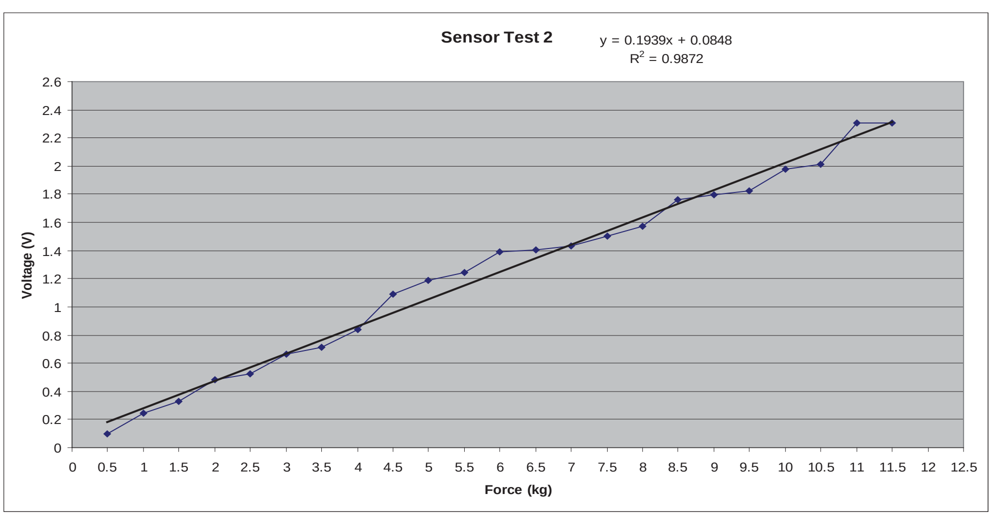


Figure 3.10: Force to Voltage characteristics

The sensing part of the sensor is sandwiched (taped) between two small metal discs (having the diameter almost the same as active sensing area of the sensor) for equal weight distribution. The experiment was started off with 500 g of weight. Reading was taken with increment of 500 g weight until 11.5 Kg's. Three consecutive reading were taken for every additional weight added to the sensor to check its repeatability. After 11.5 Kg's the response of the sensor was saturated.

In our experimentation I used a table to test our sensors. The table used was an evenly balanced table with equal amount of force being exerted on each of the legs. The four sensors were connected to the bottom of the four legs of the table as shown in figure 3.11.

Figure 3.11: Experimental Setup with four force sensors

The sensors were sandwiched between flat metal plates with almost the same diameter as the sensing part of the sensor. These plates were used to ensure that equal amount of force was distributed to every point in the sensing head of the sensor. It was also made sure that the table is being tested on an even floor so that equal amount of force is applied on each of the legs.

The potentiometers (R_F) on the driving circuit were also adjusted to show the same output value for all the sensors in idle condition. This was also useful as the force was applied on the sensors, as all the values increased with the same rate and showed the same value when weight was applied at the centre point of the table.

The sensors were connected to the driving circuit which gives the analogue output voltage as the force is applied on a sensor. The analogue input was then sent to the microcontroller in which the ADC converts it to a digital output and displays it on the LCD as shown in figure 3.12.

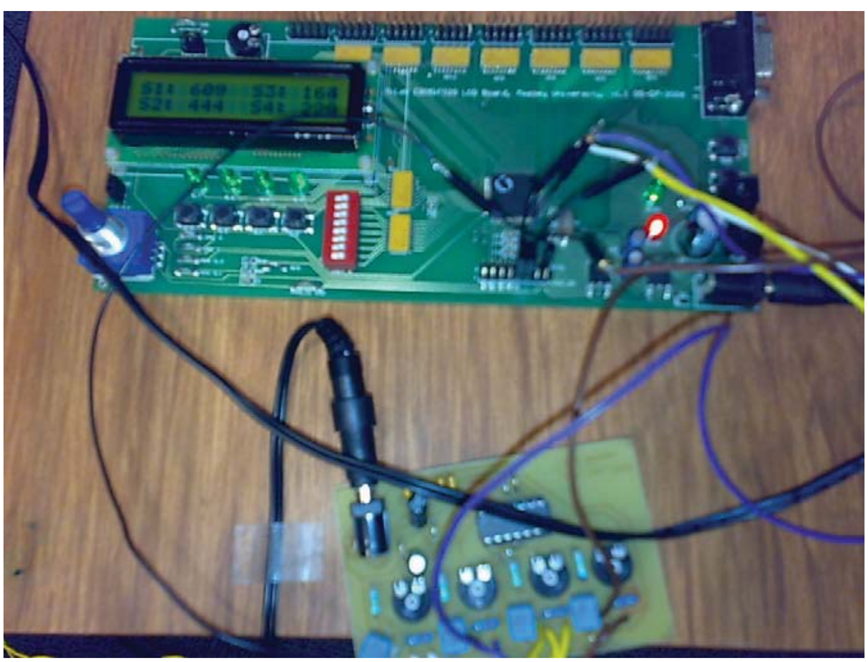


Figure 3.12: Sensor response displayed on LCD in grams

In the laboratory setup, further each of these zones was further divided into cells along horizontal X-axis and vertical Y-axis as shown in figure 3.11. The cells were 10 X 14 that is 10 cells along the X-axis and 14 cells along the Y-axis as shown in figure 3.13. The table was calibrated in this way to get the exact reaction of the sensors and to see how force being applied in each of the cells affected the output. The force verses voltage results were taken by placing equal amount of weight in each of the cells and recording the output from the microcontroller. These results determined the reaction of the sensors when applied with force.

A fixed amount of weight (6 kg) was used to test the sensors. I have used a thin solid cylindrical base at the bottom of the weight to make sure that the whole force was acting directly on the particular cell on the table.

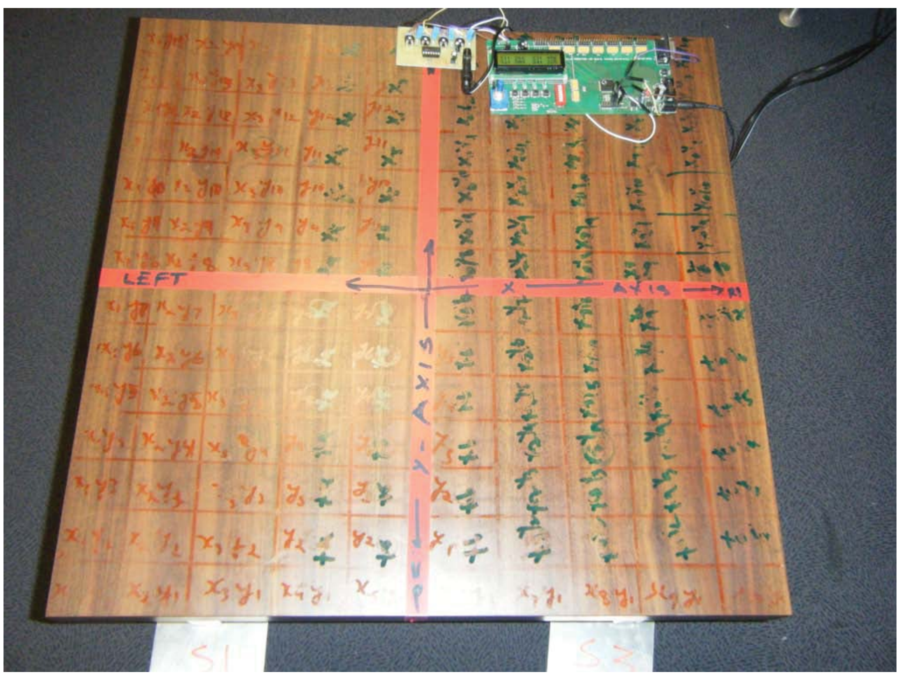


Figure 3.13: Cells along the X and Y axes

After the set-up was complete for the experiments the results are taken. The fixed weight of 6 kg was used to apply force at each of the cells and take the corresponding output from the microcontroller.

The following surface plots show the result of our experiments done on the table. The plots were plotted as the reaction force output which results as the 6 kg weight is applied on each of the cell. The plots show exactly where the maximum force is being applied. The force is plotted on the vertical Z-axis and the horizontal Y and X-axes represent the cell where the force is being applied. The surface colour distribution represents the amount of weight that is being applied on the sensors.

From this first plot, shown in figure 3.14, the response of sensor 1 can be seen. The highest value for this sensor is 884 which is equal to 8.84 kg's. This value is at the cell X_1Y_1 which is the position right above the leg of the table where sensor 1 is attached. The minimum value for this sensor is at cell $X_{10}Y_{14}$ which is above the leg where sensor 4 is attached. This result is true with actual fact that the sensor will show the highest value when the weight is directly above it and show the minimum value when the weight is at the farthest point from the sensor.

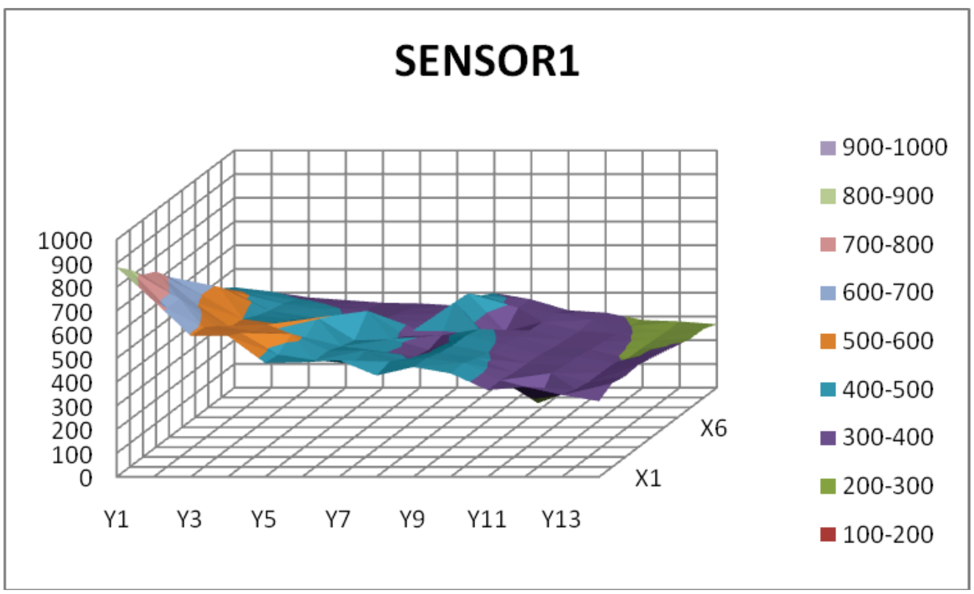


Figure 3.14: Response of Sensor 1

The following plot, shown in figure 3.15, is the result for Sensor 2. From this plot it can be noticed that the highest value is around 700, which is at the cell X_1Y_{14} which is located right above the leg where sensor 2 is connected. The minimum value is 225 at cell $X_{10}Y_1$ which is the farthest part from sensor 2.

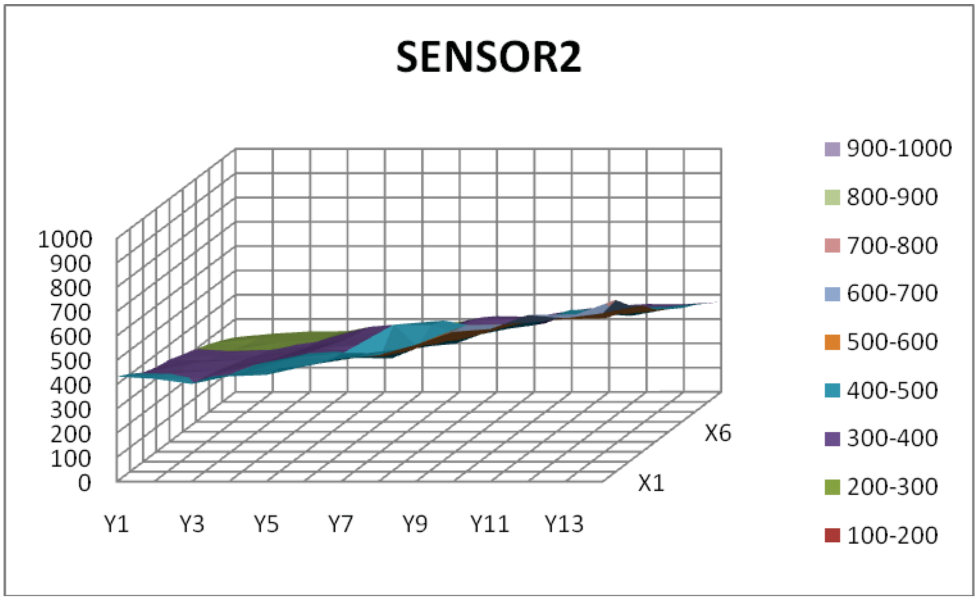


Figure 3.15: Response of Sensor 2

Similarly it can be seen from the surface plot for sensor 3, shown in figure 3.16 that the maximum value is at cell $X_{10}Y_1$ which is 845. This cell is located on top of the leg of the table where sensor 3 is placed. The minimum value for this sensor will be at the cell located above the sensor 2.

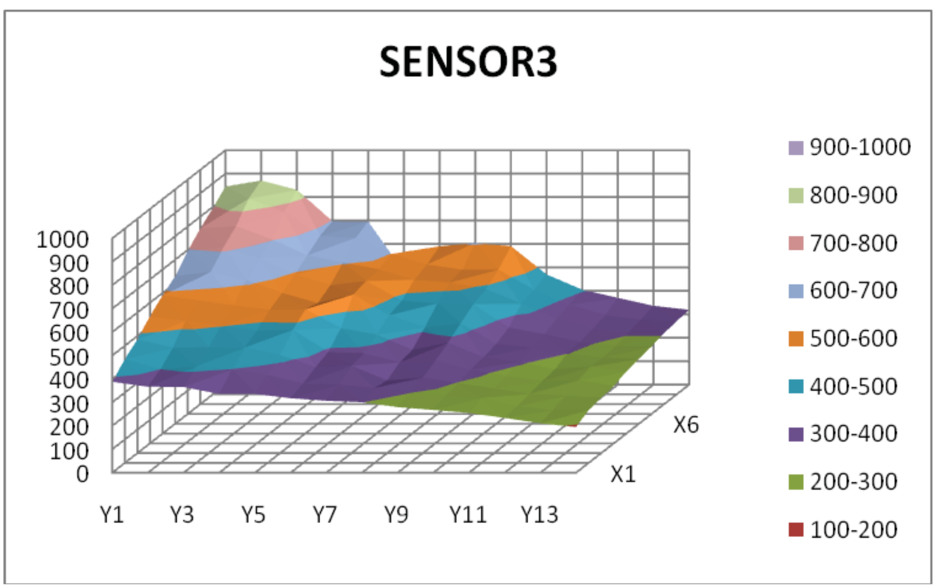


Figure 3.16: Response of Sensor 3

Sensor 4, shown in figure 3.17, also shows similar response with the highest value 888 being at the cell $X_{10}Y_{14}$ which is above the leg connected to sensor4. The minimum value for this sensor is at the cell located above the sensor 1.

The figure 3.18 shows the combined results of all the four sensor outputs. It can be seen from the U-shaped curve that more force is being applied to the corners. These are the four corners of the table under which the sensors are placed. This is true with the fact that sensors will experience the maximum force when the weight is placed directly on top of the sensor.

The table was calibrated and divided into four zones known as Zone 1, Zone 2, Zone 3 and Zone 4 as shown in figure 3.19.

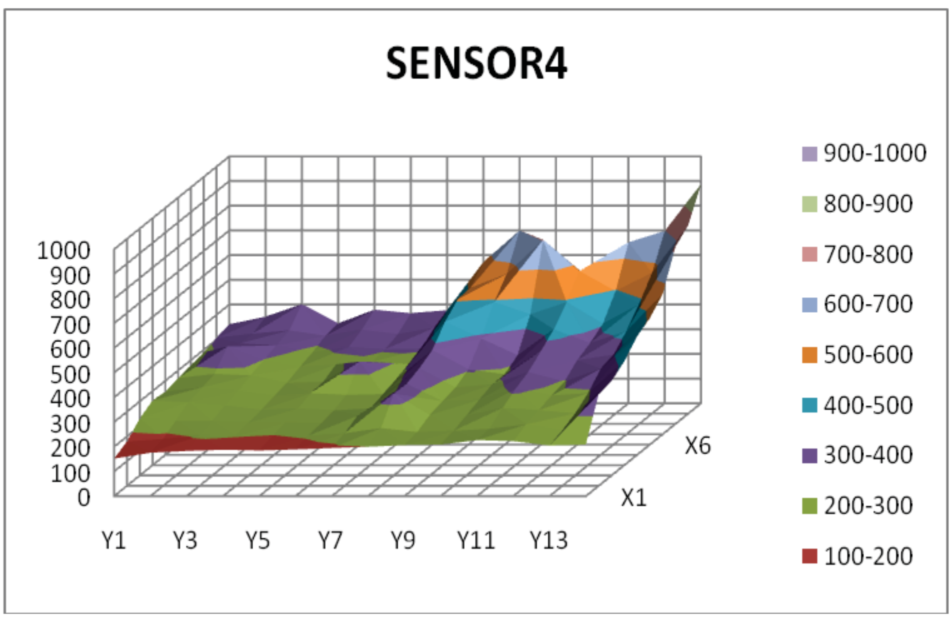


Figure 3.17: Response of Sensor 4

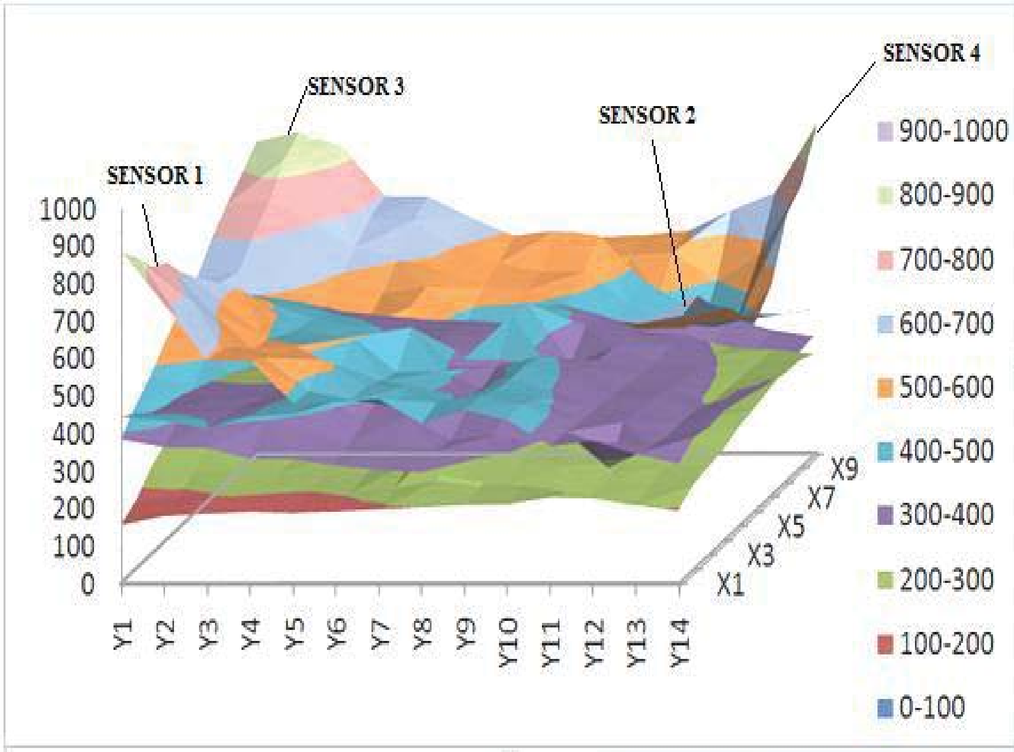


Figure 3.18: Combined results of all the four sensor outputs

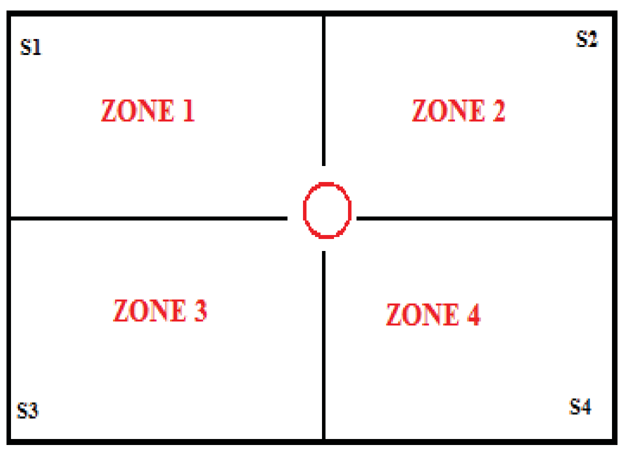


Figure 3.19: Zone Allocation

Ideally if the weight is in the centre point of the table, the response of sensors,

$S1 = S2 = S3 = S4 = S_{AVG}$; where $S_{AVG} = 1/4(S1+S2+S3+S4)$.

In real time situation this may not be possible as there is an error of the sensor's response.

To detect the position of the weight with respect to the zone on the table, the microcontroller program is made to continuously monitor the ADC inputs from the four sensors. And the weight position is calculated by the following equations:

If (S1+S2) > (S3+S4), then the weight is positioned at upper half (UH),

If (S3 +S4) > (S1+S2), then the weight is positioned at lower half (LoH),

If (S1+S3) > (S2+S4), then the weight is positioned at left half (LeH),

If (S2+S4) > (S1+S3), then the weight is positioned at right half (RH).

Based on the above observation, it can be concluded that

ZONE 1: If UH and LeH both are true,

ZONE 2: If UH and RH both are true,

ZONE 3: If LeH and LoH both are true,

ZONE 4: If LoH and RH both are true.

The Table 3.1 shows the experimental observation.

Table 3.1: Experimental observation of locating the weight

Position	**Sensors 1**	**Sensors 2**	**Sensor 3**	**Sensor 4**	**Observation**
ZONE 1	890	441	498	370	ZONE 1
ZONE 2	470	791	385	485	ZONE 2
ZONE 3	480	405	815	460	ZONE 3
ZONE 4	**385**	**452**	**472**	**857**	**ZONE 4**

Once the above observations are done further investigations are carried out to calculate/estimate, at which location the weight is predominant. The weight is positioned at various points along the line joining the middle point and the edge of the location of sensors 1. The maximum value of the sensor 1 signal corresponding to the location of the weight on top of leg 1 is assumed as 1000. By using the following interpolation technique the position of the weight is calculated and is shown in Table 3.2.

$$p = \frac{S1 - S_{avg}}{S1_{\max} - S_{avg}} d \qquad \text{------ (3.1)}$$

$S1_{max}$: Maximum signal of the sensor 1 corresponding to the weight located on leg-1
S_{avg}: Average signal of the sensors
S1: Signal of sensor 1
d: Distance between the centres of the table to the edge corresponding to the sensor 1

Table 3.2: Location of the weight

Actual position of the weight from the centre (cm)	Calculated position (cm)	Error (%)
0	4	-
10	9	10
20	17	15
30	27	10
40	39	2.5
50	49	2

From the Table 3.2 it is seen that the system can be used to estimate the location of the weight. The error can be reduced further if the signals of the other sensors are also used in the interpolation technique.

Under No-load condition the output from the voltage comparator stays at high state at +5V. But when a load is applied, a change in the resistance in the FlexiForce sensor causes the voltage to reduce dramatically to an order of millivolts, experimental results shows that the voltage drops from +5V to +0.1178V.

So when the load is applied on the sensor the output from the voltage comparator goes to a low state. This output signal is then fed as an interrupt to a micro controller through the port pin available on the Silabs® C8051F020 microcontroller development board.

The microcontroller polls for the interrupt signal, which is generated when there is a transitions from low state signal to high state signal and vice versa. Thus making the bed sensor is to monitor bed activity continuously.

In this process of monitoring, there arises the case of temporary loading/unloading of the sensor unit. This may occur when somebody uses the bed, which is being monitored, for a certain period. This causes the sensor unit to send unnecessary data points to the controlling unit, causing a huge amount of data build up in its data base. This can worsen the SAM system decision making capabilities by reducing its sensitivity. To avoid this, a rigid rule set need to be set in the supervisory program which runs on the PC, to which the whole unit is connected.

Thus by monitoring the person's daily activity, data is collated by Personal Computer which saves all data for processing as well as future use. The habits or the life-style of the person under care is stored in the system.

The collected data points are compared with the stored data points and depending on the situation the actions are defined as unusual or abnormal. If the system detects any unusual activity a warning or alarm message is issued to the care-giver or concern person.

The Bed monitoring sensor system consists of a RF module for wireless communication with the SAM Controller, and a 10 pin port for communication with the microcontroller and a Force sensor driving circuit. The necessary electronic circuit is shown in figure 3.20.

For the Bed Monitoring the sensor unit consists of a Radiometrix BiM-418-40chip for RF communication, a force sensor FlexiForce Sensor fitted to a driving circuit and a Silab C8051F020 Microcontroller development board.

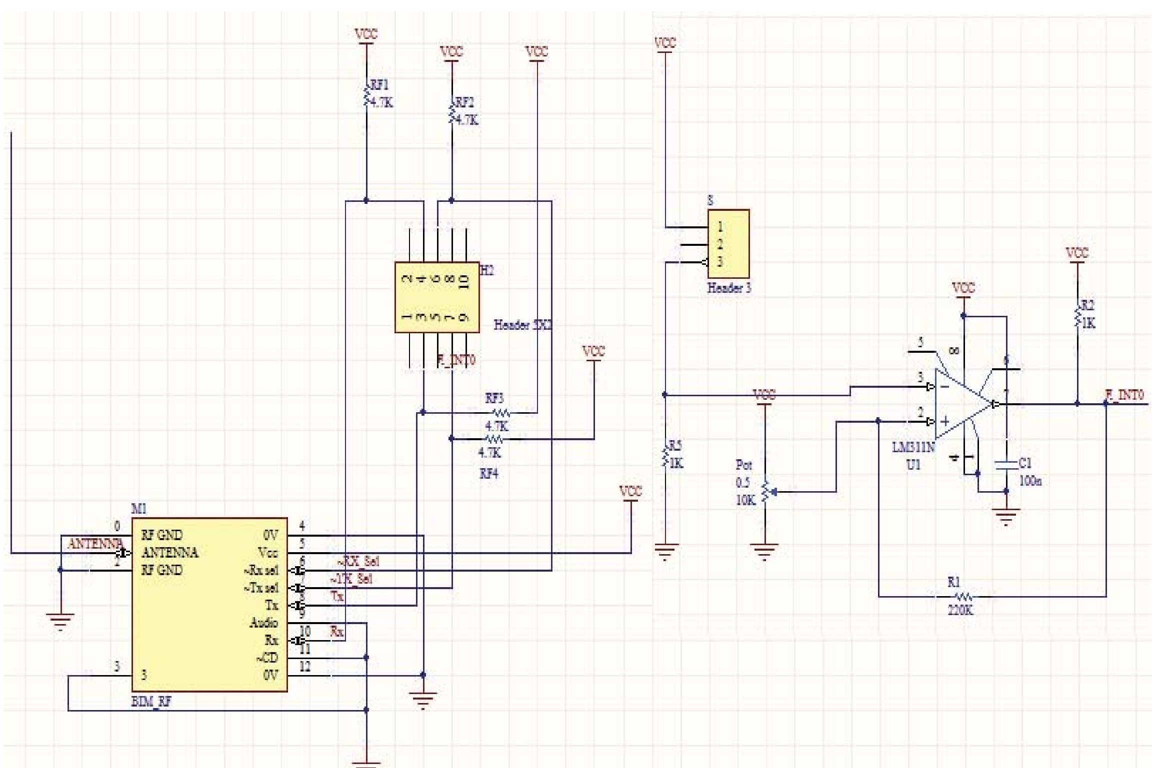


Figure 3.20: Schematic of Bed Monitoring the sensor unit

The Bed Monitoring Wireless Device communicates wirelessly with a controller unit. This controller unit is connected to a Personal Computer loaded with a supervisory program through RS232 interface. The functional flow chart of the SAM device is shown in the figure 8. The PC at any particular time requests the controller unit for the status of a particular sensor. The controller unit request the sensor unit wirelessly trough RF communication for a status report. Once the sensor unit receives the request from the controller it responds by sending the activity data point to the controller unit via RF communication. Then the controller which is connected to the PC sends the status of the sensor. The software rule set which are created in the PC program decide where to send or not to send an alert text messages to a concern personnel with the help of the GSM Modem which is connected to the PC. Figure 3.21 shows the picture of the fabricated bed monitoring unit.

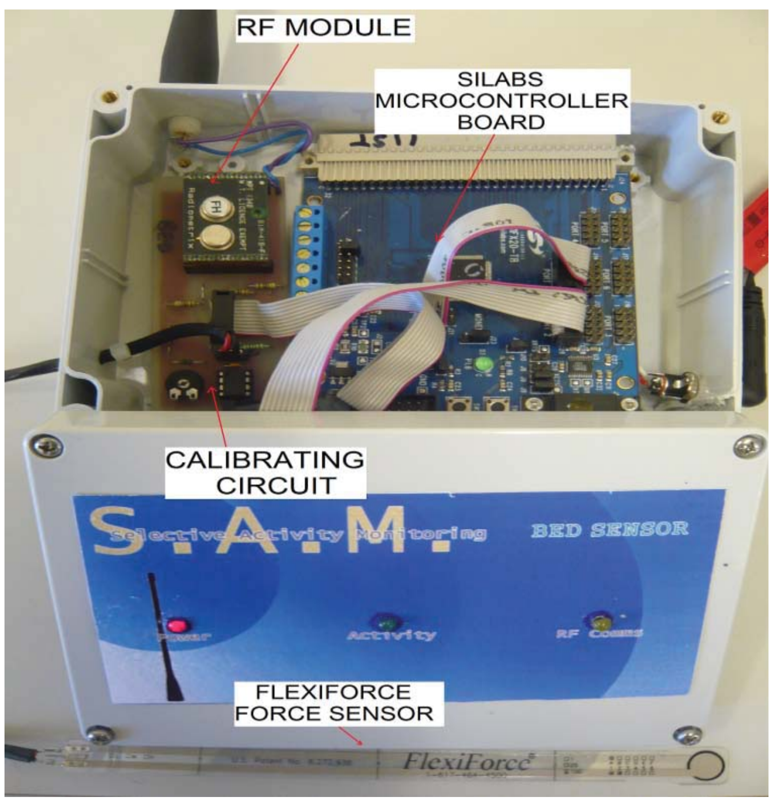


Figure 3.21: Fabricated prototype of Bed Monitoring Unit

.

3.3.2.3. Water-use Monitoring Unit

After electricity the next most common consumable that a household needs is water. Monitoring the water use in the house will give a general overview of when water is being used in the home. All homes have the need for water. People use water to drink, wash, gardening, shower or bath. It is used in a toilet system and also used to clean clothes and dishes. This covers a large variety of systems in a home. Although not all of these systems are needed to be monitored. For example a dish washer and washing machine both are turned on and walk away appliances, therefore it doesn't actually give a good indication of whether or not the person is ok or not and they can be monitored with the current sensor without modification.

Moreover, the dish washer and washing machines are not used on a regular basis. The shower is the main system of note in the household monitoring as it can't be monitored with the current system and therefore a water-use monitoring unit is the best way to monitor its use. A shower or bath is also of concern for a user as a slip in the shower can end very badly. The shower can have the sensor installed after the shower mixer. If the shower is on for a longer than average period then the system will flag something could be wrong. As the system will still be running, it is vital that the situation is dealt with more priority than an electrical device as it is less likely that a person will forget to turn the shower off.

For the prototype system an inline Flow transducer was used as shown in figure 3.24. This Flow sensor worked outputting a square wave as is shown in figure 3.23 that increased or decreased in frequency as the flow rate increased and decreased. The sensor can be positioned in many positions in the home. It could go after the hot water cylinder but this will also give an idea of when appliances like dishwashers and washing machines are being used (if they exist and, in the case of the washing machine, use a hot/warm wash).

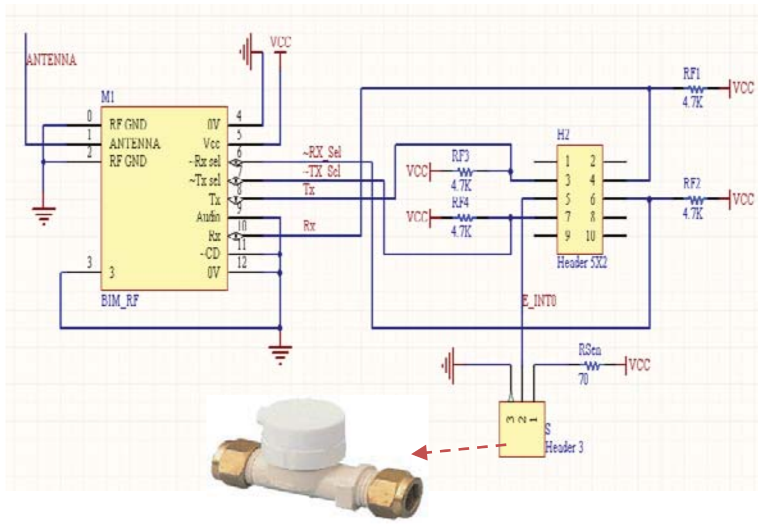


Figure 3.22: Core components of Water-use Monitoring Unit

The sensor itself is then connected to the microcontroller as is shown in figure 3.22. Due to the sensors current requirement of 30 mA being a bit high in ambient light the sensor resistor was adjusted to bring the current down. Due to resistance values available 21 mA was used as the input current which worked well. This was selected as a resistor was soldered into the sensor itself as the microcontroller boards used for the system have an output voltage of 3.3 V so this resistor gave 18 mA which worked well. But as the system was going to be used on the same port as the wireless module it meant it could use the 5 V supply from the wireless which therefore required an extra resistor on the power line.

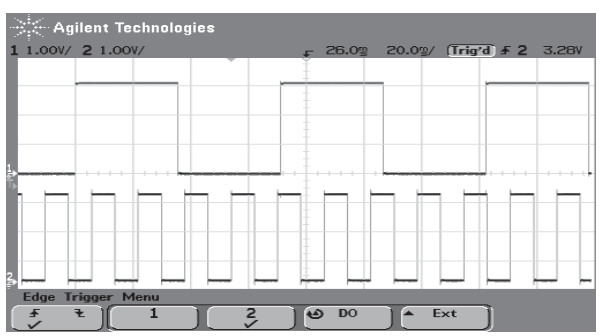


Figure 3.23: Square pulse output of the flow sensor

So the flow sensor is connected to the same port, on the microcontroller, as it uses the external interrupt which runs on the same port as the UART which is used for communication between the microcontroller and the wireless module. The microcontroller has an external interrupt that was setup to be triggered when it saw an edge pulse on the port that it monitored. This then provides the microcontroller with information that it can use to determine if the flow sensor has water flowing through it or not. The Water-use Monitoring unit communicates wirelessly with a controller unit.

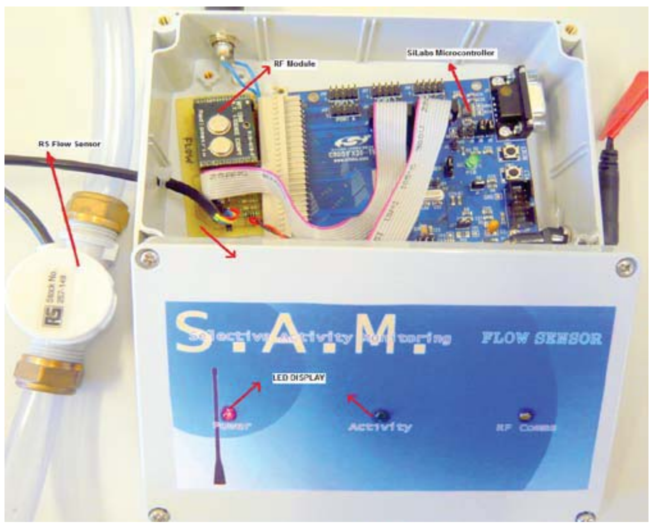


Figure 3.24: Fabricated prototype of water-use monitoring Unit

This controller unit is connected to a Personal Computer loaded with a supervisory program through an RS232 interface. The PC at any particular time requests the controller unit for the status of the sensor unit. The external interrupt will wait for an edge pulse on the port pin allocated to it. When this occur the external interrupt's interrupt service routine will be executed. For this task it will just increment a number called number of pulses.

The task will also require the use of timer 3. The reason for this is that the microcontroller does not get an incorrect reading. If the number of pulses was just read and not reset it could say it was on all the time or it may say it's off when it is on although unlikely.

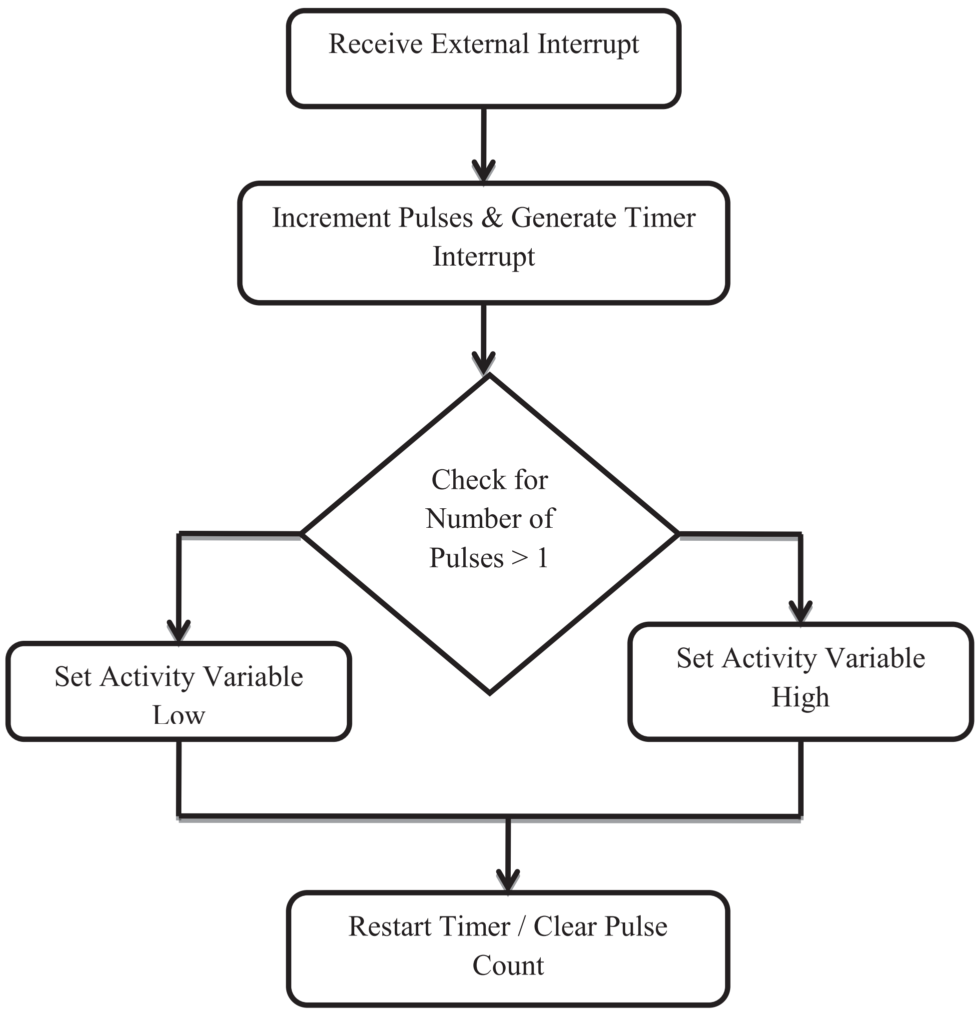


Figure 3.25: Algorithm for water-use monitoring

Timer 3's job is to therefore check the number of pulses in a set time and set the active variable high or low accordingly, as is shown in the flowchart in figure 3.25.

The idea here would be to make sure the Timer was checking the number of pulses before it could overflow and reset. This would be assumed to be at the sensors maximum frequency as well. At the same time, it is better to ensure the sensor is on at the time and therefore the number of pulses needs to be given a chance to increment itself a little bit. This would be when the sensor is at its lowest realistic frequency.

3.3.2.4. Emergency Button

In case of emergency or an urgent assistance, there is an option for the users to use the emergency button or panic button. It is integrated in to SAM system. The panic button has the highest priority than the other sensor units. Once the emergency button is set by the user, the controller receives the request, and overrides all other request from other sensor units. It immediately sends message (SMS) to the relative, care-giver or the emergency services for immediate help.

3.3.2.5. Central Control Unit (CCU)

The S.A.M. Central Controller Unit acts like a base station for the S.A.M. Unit. For the prototype design of the sensor units and controller unit, silicon lab C8051F020 Development board has been used. The block diagram representation of the CCU unit is shown in figure 3.26.

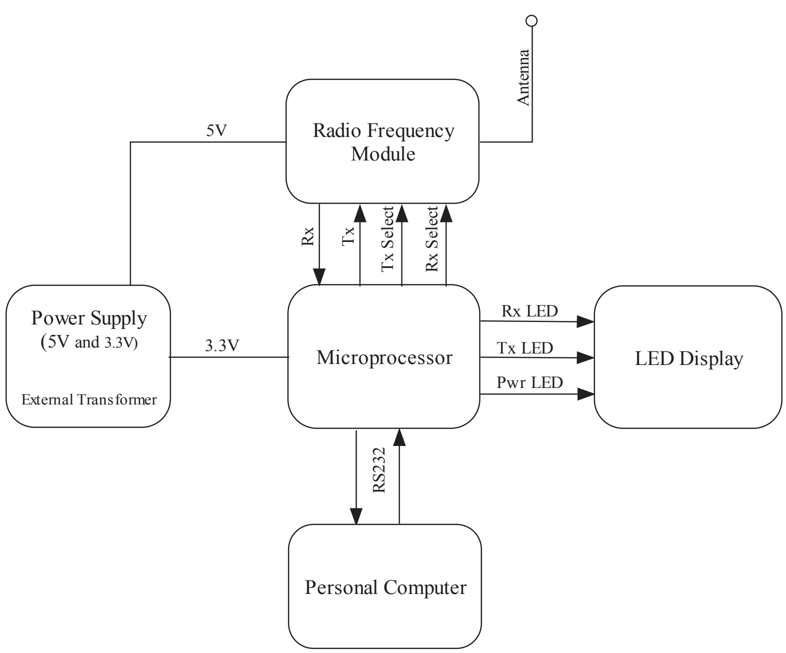


Figure 3.26: Block diagram representation of the Central Control Unit

It is equipped with the Silabs C8051F020 microcontroller, with the help of the supervisory program, it controls the transmission signals like Rx, Tx, Rx Select, Tx Select, thus enabling the RF module which is connected to it. The microcontroller is connected to the PC on the RS232 serial communication port which is set to operate at 115200 bauds. Since the CCU employs the polling technique, and requests the status of the SU in a particular time slot, the problem of data flooding can be avoided. Figure 3.27 shows the picture of the fabricated CCU unit.

Figure 3.27: Picture of the fabricated unit of the Central Control Unit

3.3.2.6. The Cellular Modem

The Wavecom Wismo cellular modem used within the S.A.M. It is a GSM cellular modem, which means in runs the same protocol as Vodafone New Zealand, simply by inserting a Vodafone New Zealand SIM card enabling to connect into the New Zealand network thus enables the SAM to send SMS to any cell phone around the world. The cellular modem comes with its own power supply and only has one connection to the personal computer which is completely independent of the SAM controller's connection. The cellular modem receives commands from the Personal computer through a RS232 interface. Figure 3.28 shows the cellular modem used in the system.

Figure 3.28: Wismo cellular modem

3.3.2.7. Radio Trans-Receiving Module

A Radiometrix BiM-418-40 chip is used for RF communication, which is interfaced / connected to the Silab C8051F020 Microcontroller development board. The Radiometrix BiM-418-40 is a Miniature PCB Mounting module which operated at UHF 418Mhz and capable of half duplex data transmission at speeds up to 40 Kbit/s over distances of 30 metres "in-building" and 120 metres open ground. The TxSelect and RxSelect signals from the micro-controller configure the transmit or receive mode of the RF transceiver. The Rx and Tx are the receive and transmit data lines respectively. In our design, the data transfer rate is set to 38400 bauds.

3.4. Software Interface

In this section I will discuss about software interface and various implementing issues.

3.4.1. Radio Frequency Communication protocol

As all the sensor units communicate with the central controller unit on the same frequency, it is important that a protocol be established to avoid data collisions. Data collisions occur when multiple devices try to communicate simultaneously on the same channel. The basic principle behind the protocol used in the SAM system is that sensors will respond only when told to do so. This means the controller is the only device that can transmit on the radio channel, unprompted. The controller is in fact the master which decides which SU should transmit. Figure 3.29 explains the sequence of actions that take place when the SU and CCU communicate with each other.

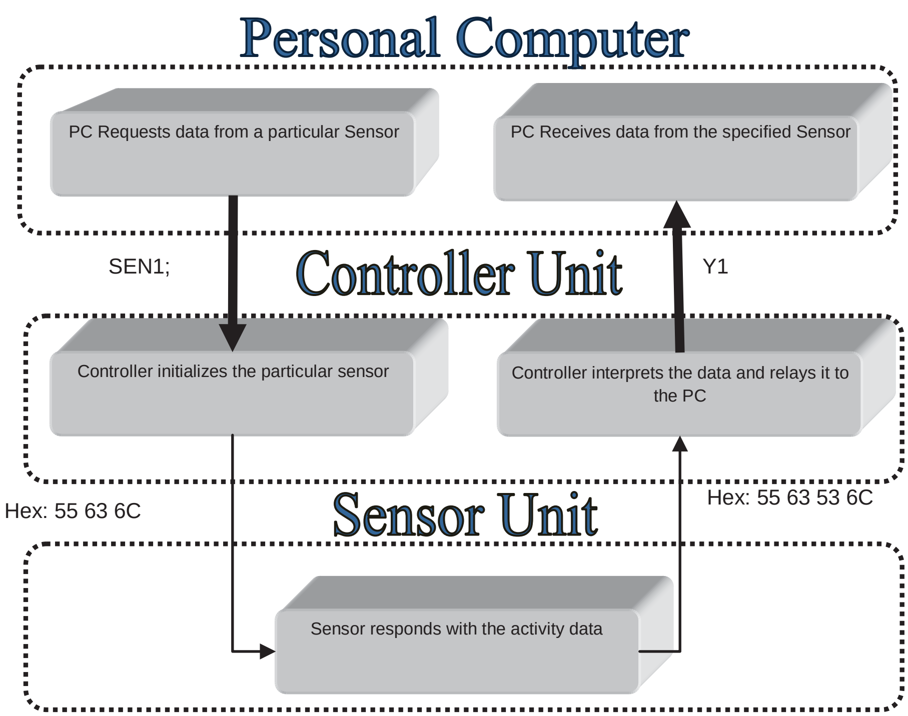


Figure 3.29: RF communication protocol

The personal computer determines which sensor it requires data from, in this case it requires data from sensor one. It therefore sends the command "SEN1;" serially over the RS232 interface to the controller. The controller receives this command and converts it to an appropriate hexadecimal / binary packet for radio transmission. The packet is received by all the SUs but only the specified sensor unit will respond. This ensures that only one SU 'talks' at any time. The packet sent back by the SU contains the status byte indicating whether the appliance is active or inactive. The controller receives this response and transmits it to the personal computer, via the RS232 link.

The computer then confirms that the correct sensor has responded and continues with the monitoring process, querying the next SU.

There are two packet formats within the SAM system, the first is transmitted by the controller and the second is a response to the former from the sensor.

The first packet format is the "wake up" packet. This wake up packet is transmitted by the controller to initiate communications with a specific sensor.

The format of the wake up packet is illustrated in the figure 3.30. The total packet contains three bytes of information, relating to 24 bits.

Start Byte	ID Byte	End Byte

Figure 3.30: The Wake-up Packet

There is one key advantage to transmitting a packet opposed to only the identification byte. The packet drastically reduces the likelihood of detecting a false activation signal, while also increasing the likelihood of detecting a transmitted activation signal. The inclusion of the identification byte ensures only the specified sensor responds, as only the specified sensor will have the same identification byte.

The second packet with the system is the response packet. The format of the second packet is illustrated in the figure 3.31. This packet is transmitted by the sensors in response to the controller's packet being received. This packet contains an extra byte of information corresponding to a total of 32 bits.

Start Byte	ID Byte	Activity Byte	End Byte

Figure 3.31: The Response Packet

The response byte is identical to the wake up byte with the exception of the additional activity byte. The activity byte is the whole point of the communication protocol. This information relates to the activity of the load and is vital to the complete systems operation. The identification byte is retained in the response packet to allow the computer to double check the response has come from the correct sensor.

The most important feature of the bytes present within SAM packets is that they are all bit balanced. All bytes contain just as many binary 1s as they do binary 0s, this ensures the complete packet is in fact a bit balanced packet. Ensuring a bit balanced communication protocol greatly increases the performance of the radio frequency link.

The table 3.1 below outlines the hexadecimal and hence, bit balanced binary bytes assigned within the system. While only four identification bytes have been added, there is room to incorporate more, allowing the integration of additional sensors in the future.

Table 3.3: Radio Communication - Hex Values

Description	Hex Value	Binary Value
Start Byte	0x55	01010101
End Byte	0x6C	01101100
ID Byte: 1	0x63	01100011
ID Byte: 2	0x33	00110011
ID Byte: 3	0x36	00110110
ID Byte: 4	0x3A	00111010
Activity Byte: Active	0x53	01010011
Activity Byte: Inactive	0x69	01101001

3.4.2. Interface and control software

The interface and control software has been written in Visual Basic and runs on the PC. It allows the user to configure the sensor units; now up to 6 six sensors may be selected and associated with different appliances. The complete fabricate system is shown in figure 3.32.

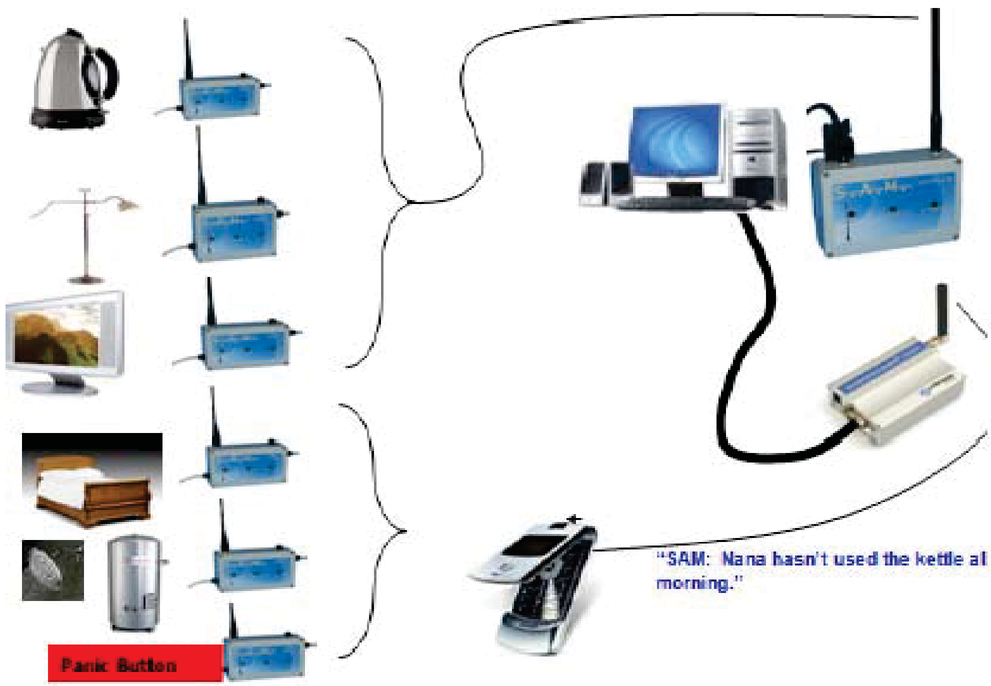


Figure 3.32: The picture of the fabricated S.A.M.

The Graphical User Interface (GUI) to accomplish this is shown in figure 3.33. Once the sensors have been set up, the monitoring can start. Figure 3.34 shows the monitoring screen.

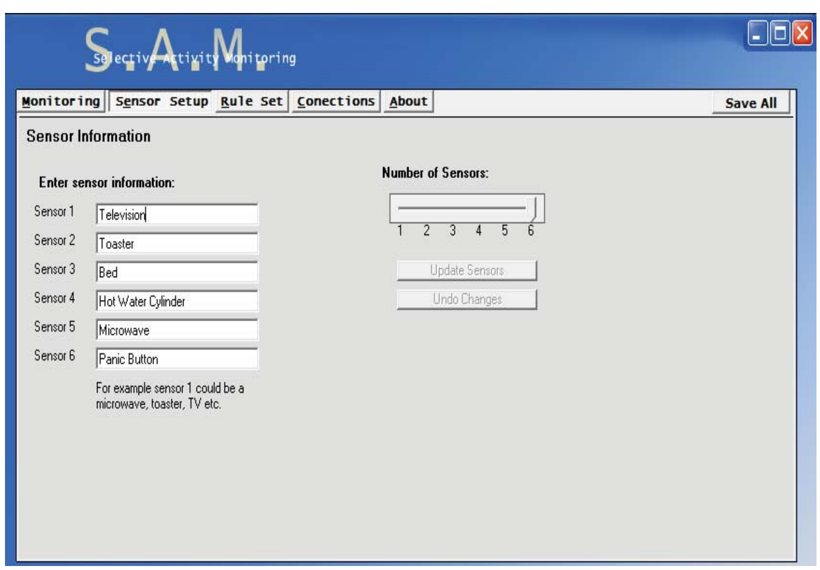


Figure 3.33: GUI for Senor Setup

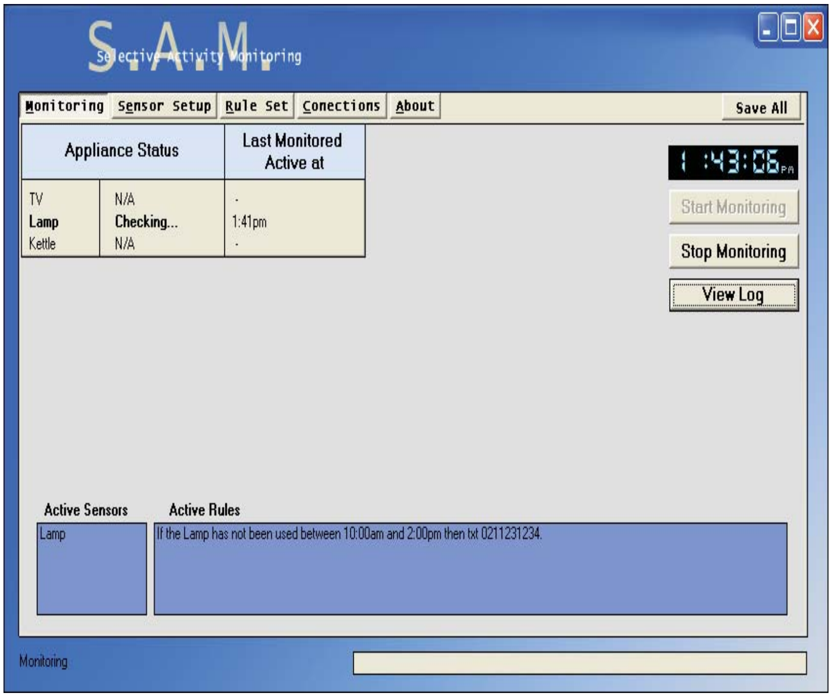


Figure 3.34: Monitoring the appliances

Once the sensors have been configured, the rule creation can begin. There are two methods of creating a rule. The user can use an elaborate rule creation wizard and be guided through the rule creation process with examples at each step. Or, the user can bring up an immediate window which allows for a much faster rule creation process. The rule creation wizard would be the recommended method initially, until the user has come to terms with the software. The GUI of the rule creation wizard is shown in figure 3.35.

The user can select a rule to either be a rule type one or rule type two. A rule type one checks whether an appliance is activated within a given time period. For example, has the television been used between 6pm and 8pm? A rule type two checks whether an appliance is still active after a predetermined time. For example, has the television been left active after 11pm? The rules are based around a 24-hour cycle. The user can turn a rule off on particular days of the week.

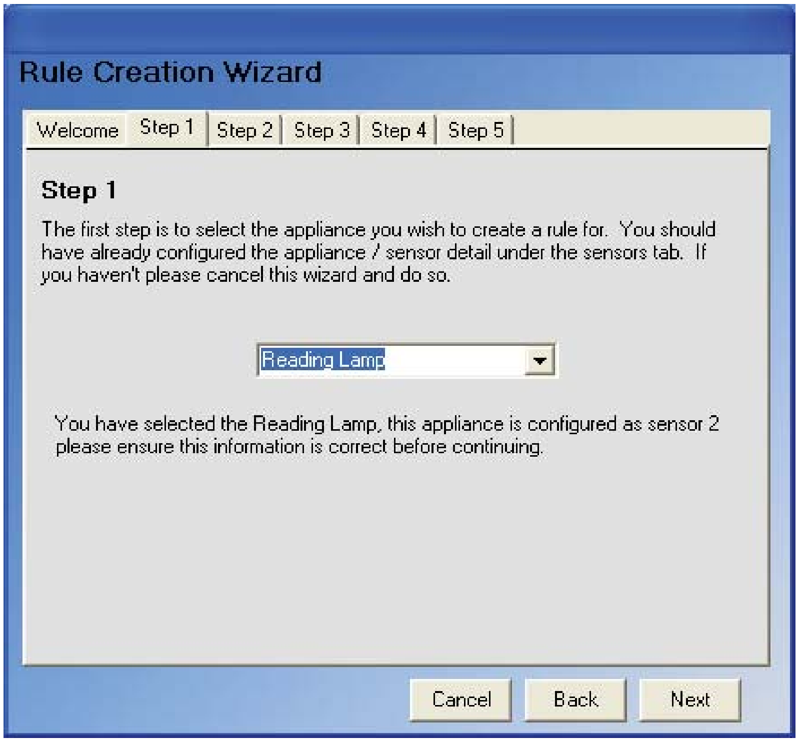


Figure 3.35: Rule creation wizard

3.5. Experimental Results

The system was fabricated and successfully tested with six sensor units and one central controller unit in a home as shown in figure 3.34. This wireless sensor system consists of three sensors for detecting use of electrical appliances, one sensor for bed use, one sensor for water use and a panic button for emergency need. The selected sensors were installed to monitor television, reading lamp, toaster, microwave oven, bed, among other locations as shown in figure 3.36.

The sensor unit was successfully tested for various conditions, and load. A Wavecom Wismo cellular modem was used for sending text messages to a mobile phone.

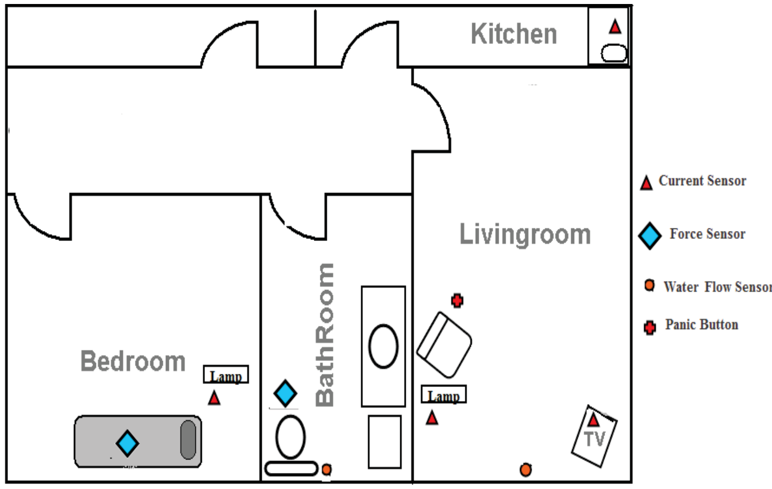


Figure 3.36: Placement and testing the S.A.M. unit in a home

During this experimental stage, the reliability and efficiency of the sensors are tested for various conditions, and loads. By considering various factors like reflections due to walls, noise caused by household appliance the sensor node RF communication reliability was also tested and the results obtained are satisfactory. Figure 3.37 shows the communication success rate as a function of distance in the trial home environment. It is seen after 17 meters the communication rate starts dropping which is not a problem in the home environment.

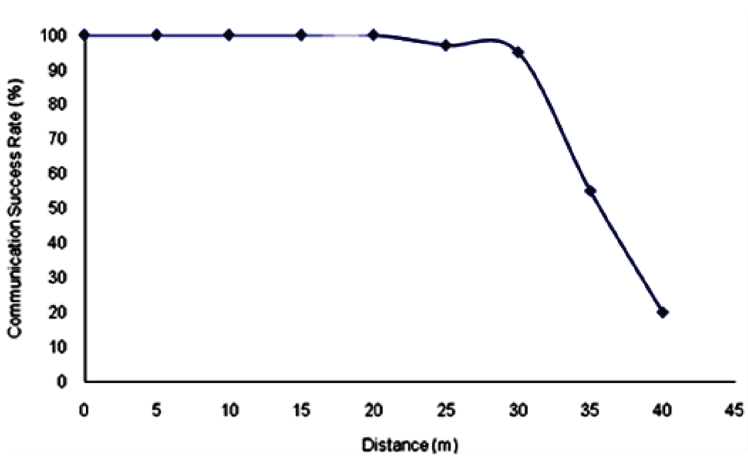


Figure 3.37: Communication success rate as a function of distance in home environment

As part of the system testing, a data logger was developed and integrated into the SAM control software. It logs every activity, which can be viewed later. Figure 3.38 shows the activity log viewer.

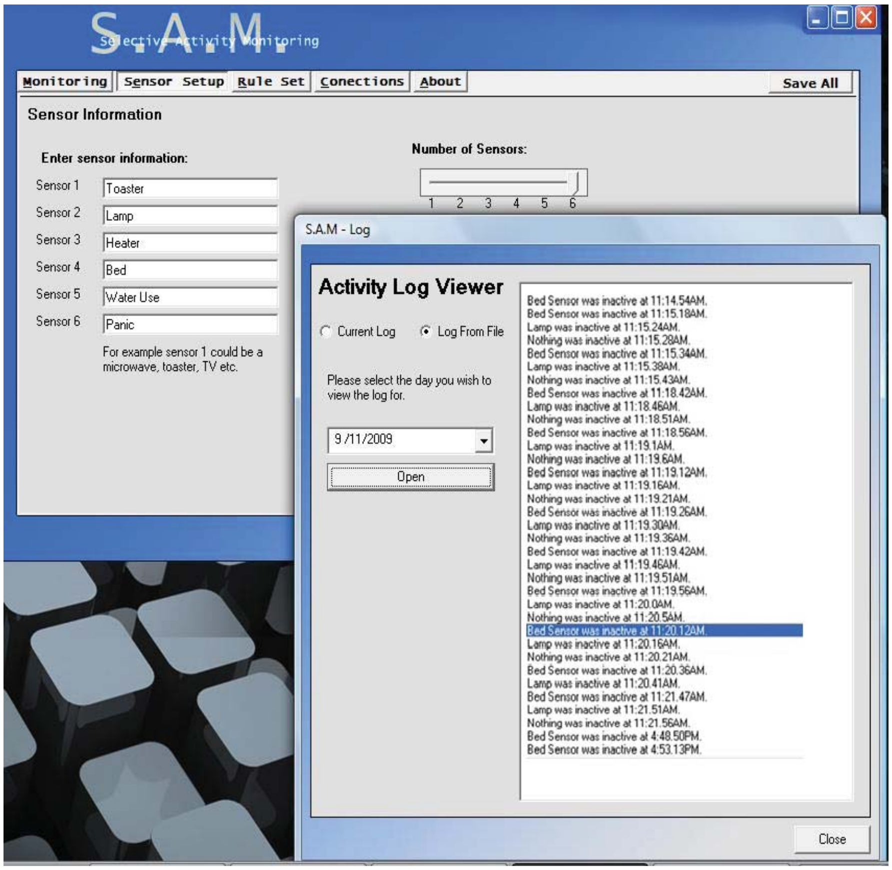


Figure 3.38: Data logger window

From the collected data it is possible to know activity of the appliances. Figure 3.39 shows the daily activity pattern of the few appliances monitored by the S.A.M. unit.

This pattern helps us to identify the lifestyle of the person effectively and set the rules in system effectively. Since the sensors are almost invisible to the user and no cameras are used, the acceptance level to use the system in a house hold environment is good and privacy of the resident will not be hindered.

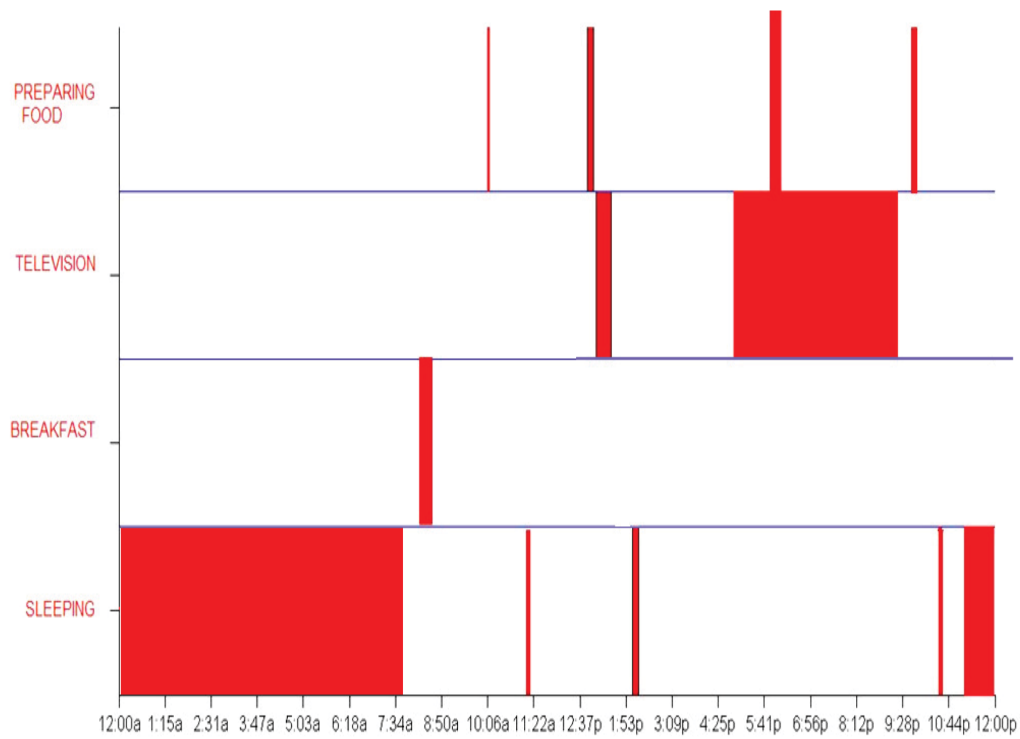


Figure 3.39: Daily Activity pattern

3.6. Conclusions

In this chapter the details of the design and implementation of the first prototype of the wireless sensor network based home monitoring system. The system has been used at a trial home which is a part of retirement village. The developed work has been reported in a local newspaper (Manawatu Standard on 08/07/2008) as well as in the national television.

Though there are a lot of improvements are needed to make it a low-cost commercially available system to be used by the elderly people, the outcome of the first prototype is successful and pleasing.

The next chapter will describe the improvement works carried out to make it a more complete system.

Chapter 4

ZigBee Based Home Monitoring System: Our Second Prototype

4.1. Introduction

The first prototype was developed using RF communication at 418 MHz. After developing the first prototype it has been realised that the system needs some modifications. The first requirement was to go for a widely used wireless communication protocol. While the first prototype was demonstrated and was awarded the first prize in an international contest, it was difficult to explain why I did not use IEEE protocol for the wireless communication. So I have decided to replace the communication part used in our first prototype by ZigBee based wireless protocol. Wireless sensor networks application for home monitoring has many technologies like Infrared, Bluetooth and ZigBee, etc. Because the angle limit problem of the infrared transmission, and the infrared have not be used for Physiological signal transmission. Although Bluetooth is better than ZigBee for transmission rate, ZigBee has lower power consumption and higher range [109]. Most of the wireless technologies are very difficult to adapt to the feature of low cost, low energy of wireless sensor network. A comparative representation of some of the technologies is in table 4.1.

Considering the home monitoring environment and the popularity of ZigBee in recent reported development, ZigBee has been adopted in our second prototype. The sensor units and the central controller unit or a base station is equipped with RF (radio frequency) transceivers for two-way communication.

Table 4.1: Comparison of some of the technologies for Wireless Sensor Network

	Infrared	**Bluetooth**	**ZigBee**	**GPRS**	**RF 418 MHz**
Range	10 cm - 1.5 m	10m - 100 m	10 m – 60 m	GSM system covered area	Up to 60 m
Data Rate	Up to 4 Mbps	1 Mbps(Ver. 1) - 3 Mbps(Ver. 2)	10 Kbps - 250 Kbps	Up to 114 Kbps	10 Kbps
LOS	Required	Not Required	Not Required	Not Required	Not Required
Area	Local Area	Local Area	Local Area	Wide Area	Local Area
Point-to-Point	Point-to-Point	Point-to-Multi-point	Point-to-Multi-point / Mesh	Point-to-Multi-point	Point-to-Multi-point
Power	Low	Relatively high	Low	Low	Relatively high
License	Not Needed	Not Needed	Not Needed	Needs operator SIM card	Not Needed

The first version of prototype system was equipped with Radiometrix BiM-418-40 chip is used for RF communication, which is interfaced / connected to the Silab's C8051F020 Microcontroller development board. The Radiometrix BiM-418-40 is a miniature PCB mounting module which operated at UHF 418MHz and capable of half duplex data transmission at speeds up to 40 Kbit/s over distances of 30 metres "in-building" and 120 metres open ground[102]. The TxSelect and RxSelect signals from the micro-controller configure the transmit or receive mode of the RF transceiver. The Rx and Tx are the receive and transmit data lines respectively. In our design, the data transfer rate is set to 38400 bauds. One problem of this system that the BiM-418-40 needed a 5 V supply compared to 3.3 V for the microcontroller.

The second version of the system was fabricated using Linx TRM-418-LT RF chip, which operates at UHF 418 MHz's. This low power consuming RF chip requires 3.3 V to power up. It is capable of half duplex data transmission at speeds up to 40 Kbit/s over distances of 30 metres "in-building". As all the sensor units communicate with the base station on the same frequency, it is important that a protocol be established to avoid data collisions. Data collisions occur when multiple devices try to communicate simultaneously on the same channel. So a protocol was designed as that the sensors will respond only when told to do so. This means the base station is the only device that can transmit on the radio channel, unprompted.

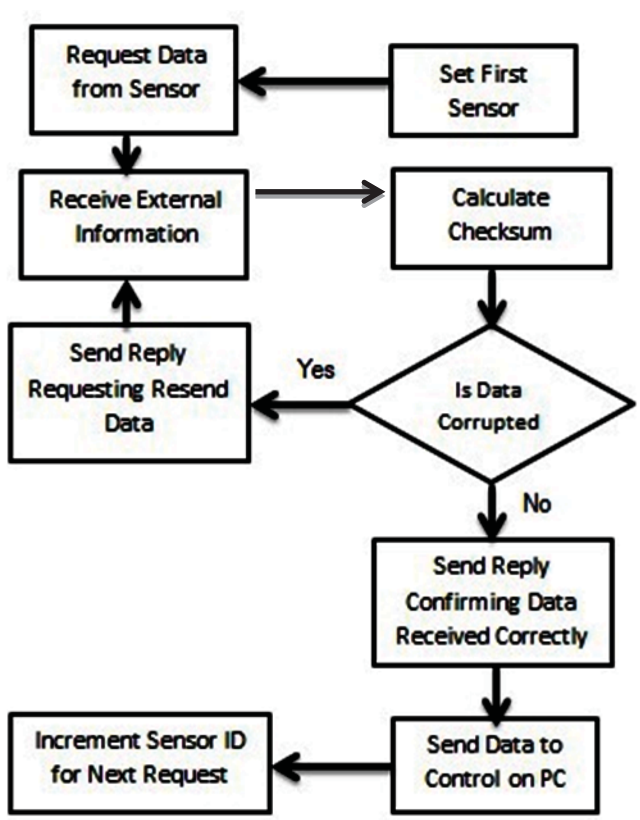


Figure 4.1: RF Protocol for the base station

The base station is in fact the master which decides which sensor unit should transmit. To make the communication between the sensors and the controller more rigid, error checking was implemented to check the validity of the transmitted data. The data will be sent to the base station when a request for data from the specific sensor's received. The software protocol for the base station is shown in figure 4.1. This module has got decoding the checksum and checking the validity of the data received, replying to the sensor that sent the data so that it knows if the data has to be resent. The algorithm is completely customizable and it can be configured depending on the situation.

Disadvantages of RF communication at 418 MHz:

1. RF communication is simple and doesn't support advanced features like multi-point connections, security, and alternate configurations.
2. There is no standardized protocol
3. Potential conflicts with other wireless network devices
4. Encoding should be done in software
5. More prone to data-loss and interference
6. Since 418 MHz is free band in New Zealand, it is more crowded with other transmissions.
7. Requires additional hardware for multiplexing Tx and Rx channels

4.2. ZigBee Based Sensor Network:

ZigBee is one of the most popular RF technology used in wireless sensor networks around the world. Currently, ZigBee technologies are widely used in home automation, home monitoring, traffic management/ control, military applications, structural monitoring, environmental monitoring, disaster monitoring and other fields. ZigBee sensors have attracted a huge research interest in recent times due to their features such as user-friendly, low power consumption, high security, localization at high level accuracy. Hence, ZigBee is usually preferred for 24 hours monitoring RF communication systems, making it an ideal technology used in wireless sensors. In addition the network-setup is easy and fast, so that an extension of new sensors is possible without problems.

4.3. Overview of ZigBee and IEEE 802.15.4:

The packet data transmission in ZigBee protocol relies on IEEE 802.15.4 Physical (PHY) and MAC layers. Like wireless local area networks MAC layer uses Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA). Using PAN (Personal Area Network) ID an ad-hoc network will be created at run time. Based on the network initialization parameters, the nodes in a network either join to a specific PAN, or join to any PAN within range. The primary ZigBee node that initiates PAN formation and self-organizes around a Coordinator. The sensor nodes or End-Devices collect the sensor values and forward them to the PAN. The End-Devices can connect directly to the Coordinator or through a Router. The nodes try to connect to the coordinator when they are powered ON. End-Devices can be configured to sleep for most of their duty cycle, waking only to read a sensor and forward the data to the coordinator. This technique can reduce power consumption.

But in case of Coordinators and Routers, they should be always active, as they are required to forward or collect data at any given time. End- Devices originate data from their local sensors. A ZigBee Network incorporates a hierarchical structure with roles defined in firmware that interacts with the ZigBee protocol stack. The Coordinator advertises the number of the PAN it is creating by broadcasting a Beacon. Other router and endpoint devices then issue an Associate request to join the PAN, which is acknowledged by the Coordinator.

The ZigBee Network (NWK) layer then assigns IEEE Short Addresses to the devices to use as members of the PAN. From then on, all devices use the Short Address assigned to them to communicate with other nodes. All nodes provide a basic heartbeat throughout the network, which is used to detect when a node is orphaned. An end-device that loses its connection to the PAN transitions to Orphan state. An orphaned node issues a Re-join request, which is acknowledged by the Router. This is the mechanism used for node failover – re-join the PAN within a couple of heartbeats of link failure. Ad-hoc On-demand Distance Vector (AODV) routing algorithm is used by ZigBee. This routing algorithm records the logical distance to the next router for path optimization. Each router maintains its list of local neighbours in a routing table. As nodes associate with, or drop out from contact with a given router, this routing table is updated. Routes are established using route discovery in which the originating device broadcasts a Route Request and the destination devices send back the Route Reply. Figure 4.2 shows the complex ZigBee Protocol Stack, which consists of the Application (APL) Layer on top of the Application Support Layer (APS), and the Network (NWK) Layer, which provides routing and network management [110].

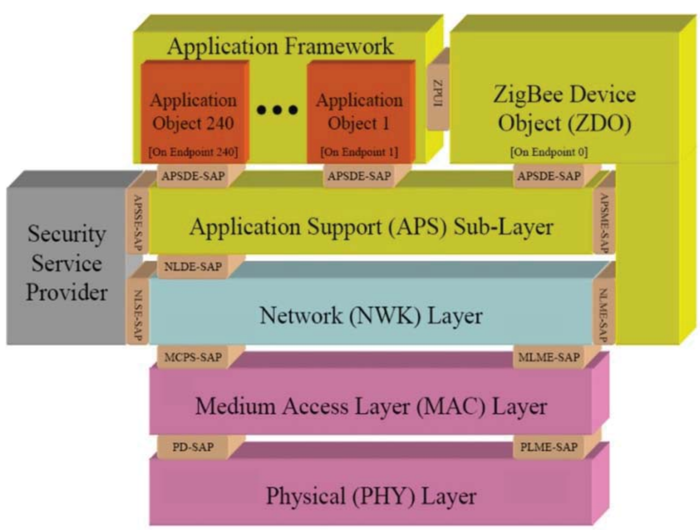


Figure 4.2: ZigBee Protocol Stack [110]

These layers sit on top of the IEEE 803.15.4 MAC and PHY layers, completing the full stack. The ZigBee APL Layer contains the Application Framework, which contains the specific application code defining the role and function of each node within the PAN. Application Objects interact with End-Points (specific software entity used primarily to bind an application to a specific ZB device) within the APL, and interact with the ZB Protocol Stack through the ZigBee Device Object (ZDO) Layer [111].

The ZigBee Alliance [111], an industry working group standardized application on top of the IEEE 802.15.4 wireless standard [106]. The alliance works closely with the IEEE to ensure an integrated, complete, and interoperable network for the market. A result of active standard development in Alliance is new standard ratification in 2004 and new versions in 2006. Newer versions like ZigBee PRO incorporate more security features like key management, authentication and encryption. For identifying and avoiding RF interference, channel managements are an addition feature in this newer version of ZigBee. Using interfacing software the ZigBee devices are assigned in PAN ID to which each device associates by default. The ZigBee protocol is evolving rapidly, as are many of the alternative protocols, in response to market needs and technological advances.

4.4. ZigBee Topology

The ZigBee can be configured in four basic topologies. They are Peer to peer, Star, Mesh, Cluster tree.

The topology is selected based on the network problem and network scheme. Each topology has its own advantages and disadvantages [119].

4.5. ZigBee Structure

ZigBee got three important functional modules

1. PAN Coordinator

2. Full Functional Devices (FDD) – can able to communicate with any other Reduced Function Devices (RFD) or FFD. FFD can be made network coordinator and actively contribute to message passing from source to sink node.
3. Reduced Function Devices (RFD) - RDF can be able to communicate only with FFD. For this reason RDF consumes low power and is simple to implement.

4.6. ZigBee Based Sensors Network for Home Monitoring:

The ZigBee based sensors provide a possibility to build an easy to configure Network, with a high data rate up to 230400 Baud/s. They come in a preconfigured mode and establish the communication automatically. In addition they are powered by 2.7 to 3.3V and can be connected to the C8051F020 without any additional power-supply circuit.

4.6.1. Electrical Connections

The current sensor system has been developed around a Silabs C8051F020 microcontroller [115]. The microcontroller has been used so that it will have some processing capability. In future the microcontroller based sensing system can be used in stand-alone mode. So in the current setup the ZigBee has been used only as a wireless communication protocol.

To connect the XBee module to the Microcontroller only four wires are necessary. The Power-Supply (3.3V), Ground and TX and RX of the Microcontroller are connected to VCC, GND, DIN and DOUT of the XBee module as shown in figure 4.3.

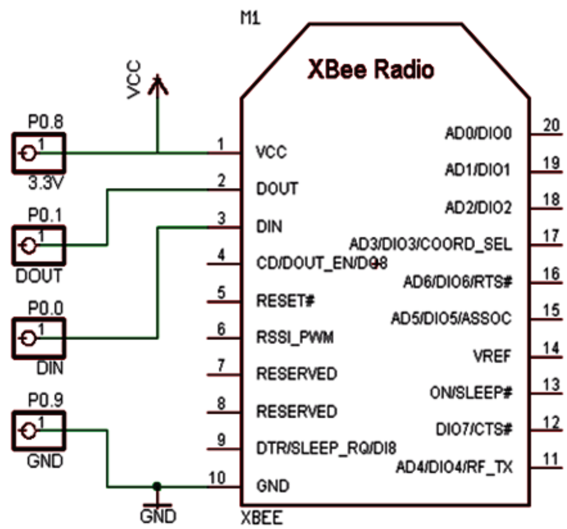


Figure 4.3: Electrical connection of XBee Module with Microcontroller

4.6.2. Configuration and Setup

To configure the XBee Modules, the provided software X-CTU provided by Digi ® [116] is used. This program is designed to interact with the firmware files on the XBee modules and provides a simple to use graphical user interface. Figure 4.4 shows the main tabs of X-CTU window and each tab is detailed below.

1. **PC Settings:** Allows to select the desired COM port and configure that port for required settings
2. **Range Test:** Allows to perform a range test between two XBee modules
3. **Terminal:** Allows access to the computer's COM port with a terminal emulation program. This tab also allows the ability to access the XBee module's firmware using AT commands.

4. **Modem Configuration**: allows the ability to program the XBee module's firmware settings. It also enables to update latest firmware versions available.

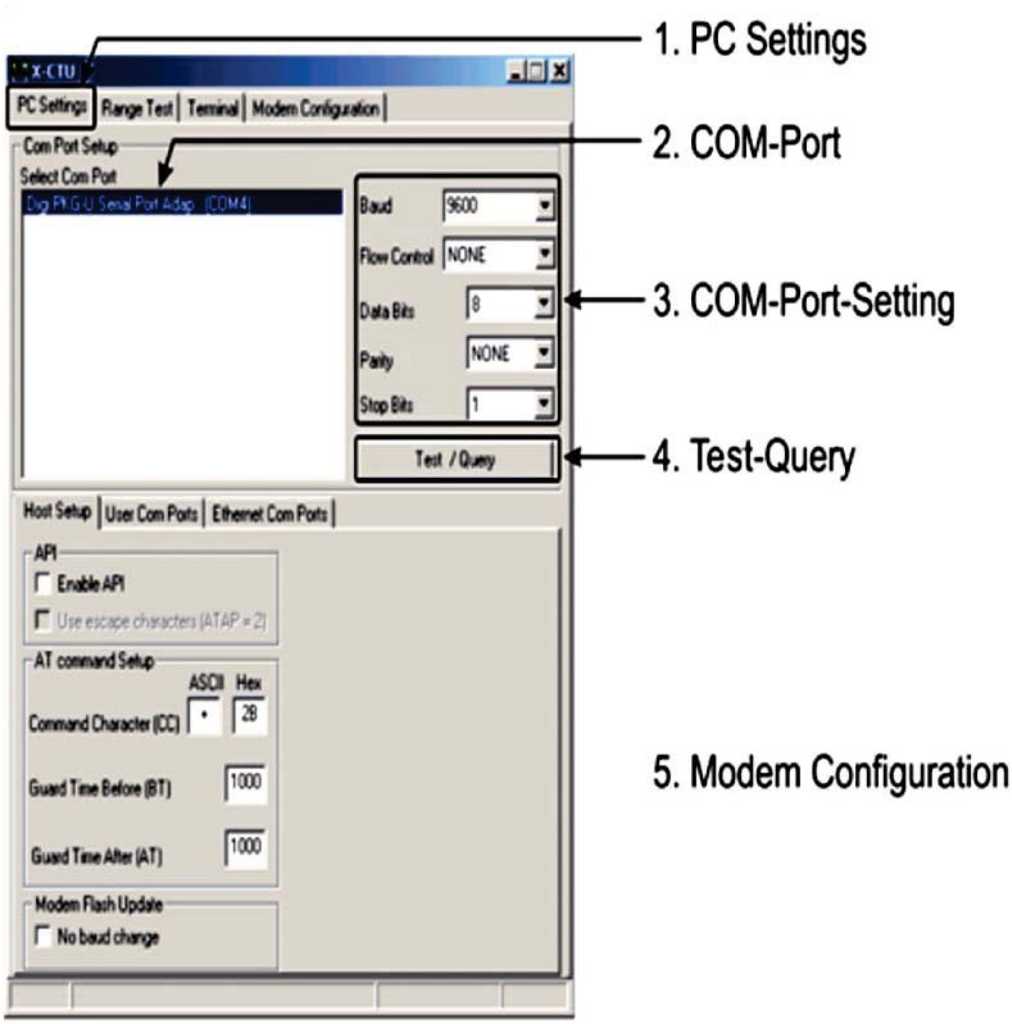


Figure 4.4: XBee configuration with X-CTU

To set up a network the following conditions have to be fulfilled:

- Each network needs one Coordinator and several End-Devices
- All modules have to have the same firmware and PAN-ID

The Test/Query button is used to test the selected COM port and PC settings. If the settings and COM port are correct, a response similar to the one depicted in figure 4.5 will be displayed.

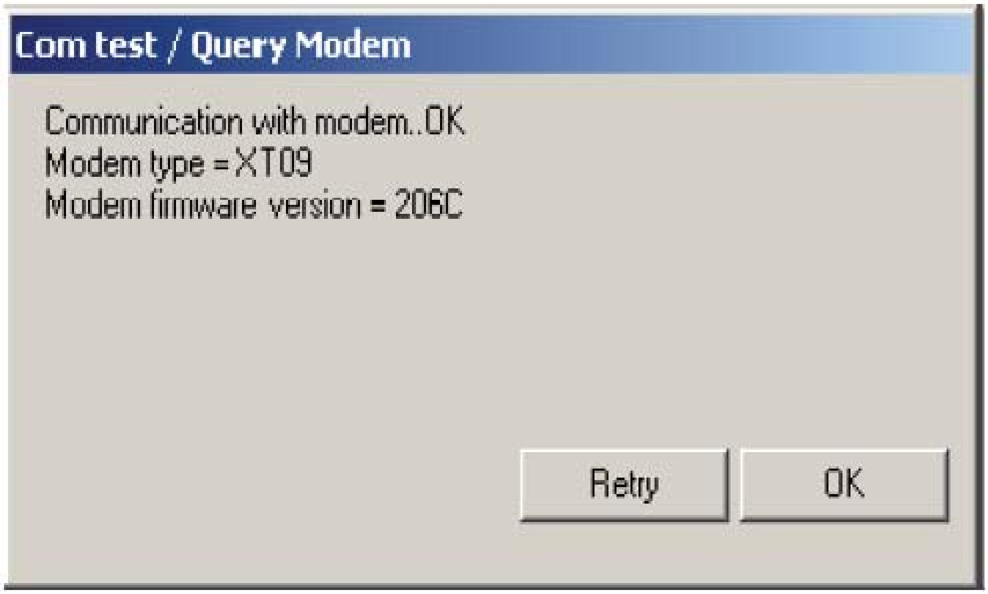


Figure 4.5: Test/Query Response

4.6.2.1. Modem Configuration:

The modem configuration tab has four basic functions,

1. Provide a graphical user interface with the XBee module's firmware
2. Read and write firmware to the XBee module's microcontroller
3. Download updated firmware files from either the web or from a compressed file
4. Saving or loading modem profile

4.6.2.2. Reading XBee module's firmware

To read XBee module's firmware, the following steps to be followed,

1. Connect the XBee module to the interface board and connect this assembly or a packed radio (PKG) to the Pc's corresponding port (IE: USB, RS232, Ethernet etc.).
2. Set the PC settings tab to the XBee module's default settings.

3. On the modem configuration tab, select “Read” from the modem parameters and firmware section as shown in figure 4.6.

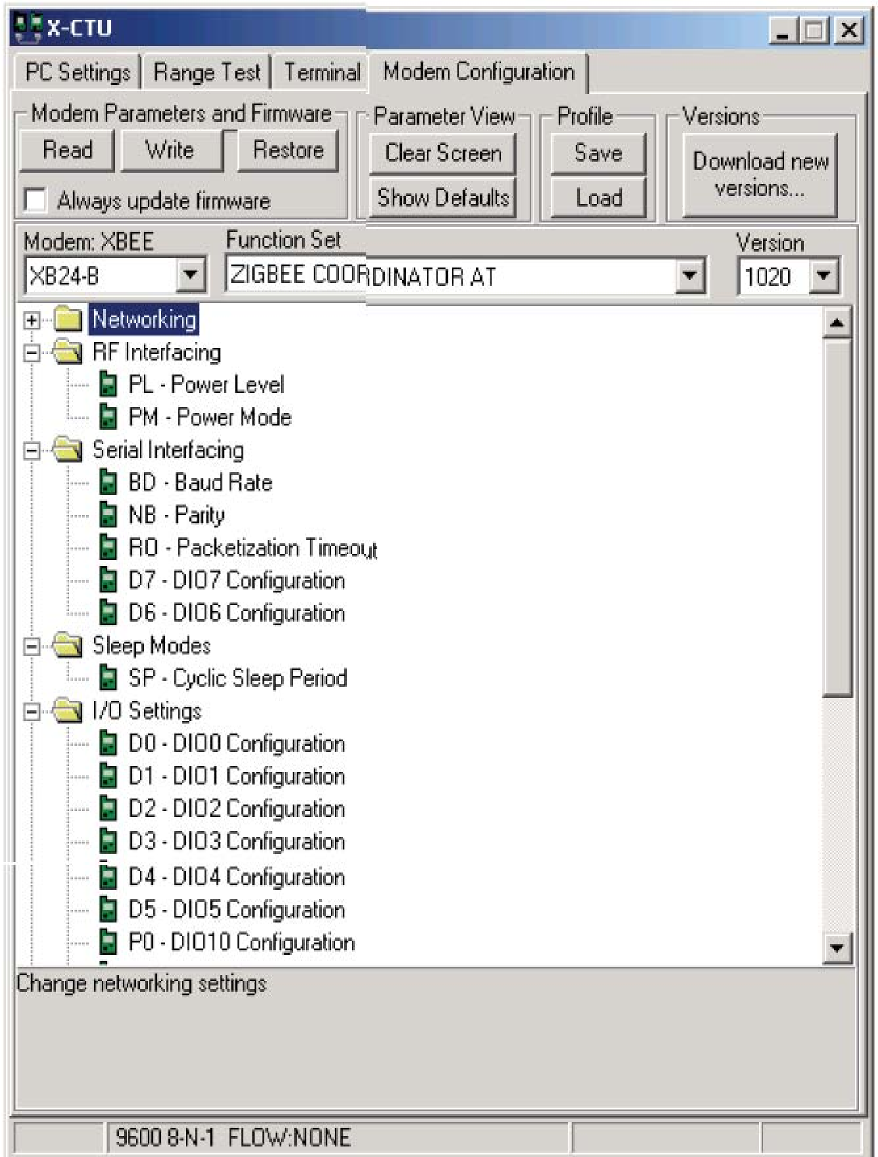


Figure 4.6: XBee Modem configuration

If everything is setup correctly, the coordinator establishes a connection to the End-Devices automatically. The Coordinator sends Broadcast Commands, and the End-Devices can send to Coordinator only. Although a Mesh-Network is possible, where the End-Devices act like a Router and forward data from devices which are out of the range from the Coordinator.

The transmission of the XBee Modules doesn't provide a checksum or any other possibility to verify the correctness of the received data. To avoid corrupted data and to see which station was sending the data an own communication protocol is needed. The send string from the sensor contains 6 to 16 characters. The first three characters indicate the name of the sensor, then the remaining characters are the sensor data separated by "- "identifier. "#" indicates the end of data packet.

4.6.3. Performance Tests on ZigBee Modules

The final version of the wireless sensing system was fabricated using ZigBee based RF communication. **XBee Pro Series 1** RF module, which works in point to point fashion, was considered for experimentation. The XBee chips transmit 2.4 GHz signals with a baud rate of 115200 maximum. Both the coordinator and a receiver node are interface to a C8051F020 microcontroller. And the coordinator is connected to the PC via microcontroller. The PC is on a software program which is able to track the sending and receiving of data. This software logs the received data and analyses the lost packets, delay packets, and the corrupted packets of data. In this experiment 100 bytes of data were sent one at a time. After sending each byte I gave 5000ms to the receiving ZigBee to reply back. If the receiving ZigBee does not reply back within that time that byte is counted as "not-received". If the receiving ZigBee sends a wrong byte then that byte is counted as "not-received". If the receiving ZigBee sends the correct byte that byte is treated as "valid". I kept the count of how many "valid" bytes after sending the 100th byte. The experimental setup is shown in figure 4.7.

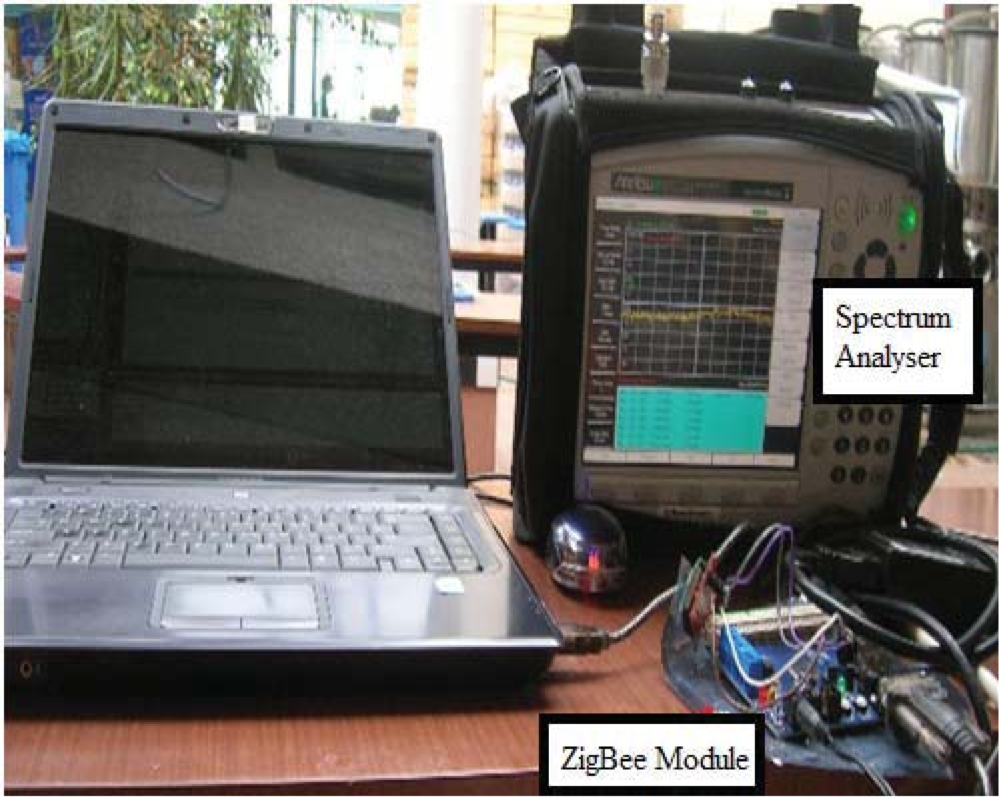


Figure 4.7: XBee communication reliability test setup

A spectrum analyser was used to check the received signal strength. The longest distance I could find was 35 meters. At that distance, the reliability of the communication was near perfect. So we tried placing microwave oven near one of the XBee. It looks like the reliability of the XBee series 1 reduces drastically when there are 2.4 GHz background noises. The possible explanation for the trend I noticed in this experiment is that, due to the presence of the obstacles in the path, when the distance gets longer the amount of obstacles in the path increases too. So as the distance gets longer the XBee signals have higher chance of colliding different objects and get reflected and lose its energy. So as the distance gets longer the reliability drops as shown in Table 4.2. The other thing that was noticed is the Wi-Fi noise comes as a burst and during that burst the entire communication of the XBee's becomes unreliable.

The calculation of the communication reliability is done using the formula in equation (4.1).

$$Reliability = \frac{No.\ of\ data\ bits\ recived}{No.\ of\ data\ bits\ sent} \quad .....(4.1)$$

Table 4.2: Communication Success Rate - Indoor-(No clear line of sight)

Distance	Reliability
2	100
4	100
6.5	99.67
8	99.67
10	99.33
12	99.33
14	99.33
16	98.33
18	96.33
20	96
22	95
24	80.25
26	91.67

From the table 4.2, it can be noticed that at the distance of 24m the reliability showed an uncharacteristically lower value. The reason being, one of the XBee receiver is placed near a Wi-Fi hot spot which has interfered with the XBee communication signal. The figure 4.8 is the graph plotted based on the values in table 4.2.

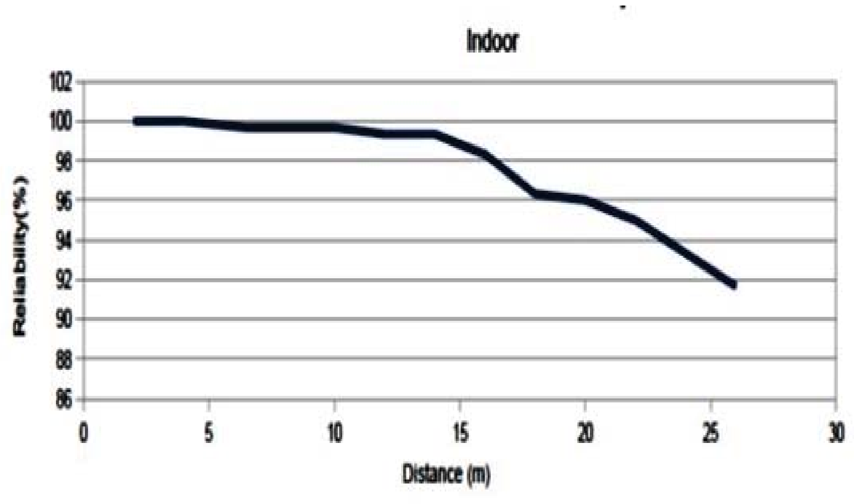


Figure 4.8: XBee – Distance Vs. Reliability

When there are obstacles present in the path of the XBee modules the reliability drops when the distance gets longer. At short distances (up to 10m) the rate of change of reliability is very small and the reliability is 100%. At longer distances the rate of the reliability drops is very high. It almost looks like an exponential growth for the rate of the reliability drop at longer distances. Based on the valves cumulative reliability difference is calculated in table 4.3 and a graph is plotted (figure 4.9).

Table 4.3: Reliability Drop vs. Distance

Distance (m)	Cumulative Difference
2	0
4	0
6.5	0.33
8	0.33
10	0.33
12	0.67
14	0.67
16	1.67
18	3.67
20	4
22	5
26	8.33

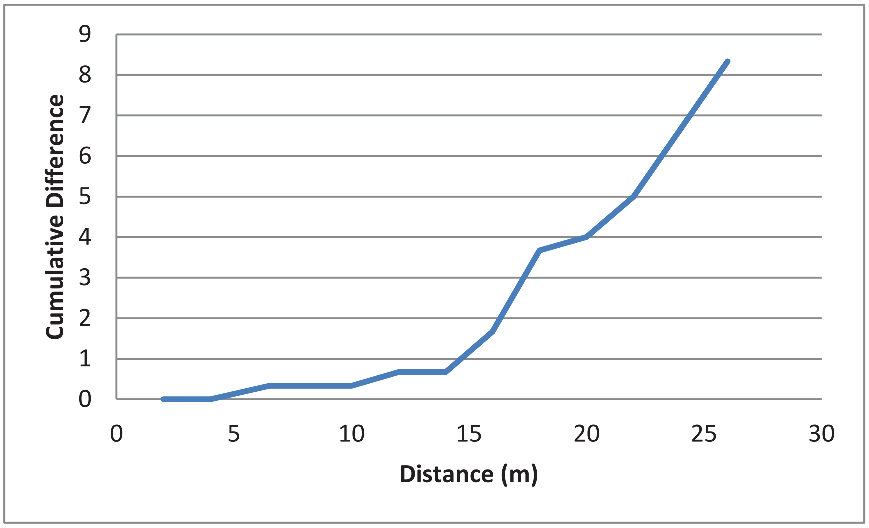


Figure 4.9: Reliability vs. Distance of XBee

In another experiment this reliability test was done in direct line-of-sight and there were not any considerable obstacles present in the path. The longest distance I could find was 35 meters. Even at that distance, the reliability of the communication was near perfect. So I tried placing microwave oven near one of the XBee module.

- Reliability at 30m when microwave interference is not present 100%
- Reliability at 30m when microwave interference is present 66.15%

When it is clear line of sight and no real background noises are present, the reliability of 100% up to 30 meters. It looks like the reliability of the XBee modules (series 1) reduces drastically when there are 2.4 GHz background noises present and when there are obstacles presents. The possible explanation for the trend that came across in the prior experiment is that, due to the presence of the obstacles in the path, when the distance gets longer the amount of obstacles in the path increases too. So as the distance gets longer the XBee signals have higher chance of colliding different objects and get reflected and lose its energy. So as the distance gets longer the reliability drops. The other thing that was noticed is that Wi-Fi noise comes as a burst and during that burst the entire communication of the XBee becomes non-existent. In this experiment, it is observed that if there is no obstacles present, XBee signal strength can carry even up to 30m with near perfect reliability. Based on this experiment and also from literature survey [111, 112], the channels of the XBee are changed, a considerable improvement in the reliability in communication was noticed. Obtained results from this experiment enabled us to determine precision of the distance and communication reliability evaluation in sensors communication.

Finally implementing XBee Pro Series 2 RF chips, which communicate in mesh network, was considered. An improvement in the reliability of the communication was noticed with these modules.

4.6.4. ZigBee Based Bed Monitoring Wireless Sensor

The developed bed monitoring system has been modified and interfaced with ZigBee. The bed monitoring system was tested using a bed and real life scenario as shown in Figure 4.10. The sensors used in this experiment were the 100 lbs. (45.5 kg) sensors.

Figure: 4.10: The placement of a sensor under a leg

The Flexi-Force sensors were strategically placed under the legs of the bed to determine if a force is being exerted on the bed i.e. someone is on the bed. In this experiment the sensors were calibrated to make sure that the force being exerted on the bed was from a human body rather than some inanimate object. The schematic representation of the four sensors placed under the bed is in shown figure 4.11 below. S1, S2, S3 and S4 represent the four sensors Sensor 1, Sensor 2, Sensor 3 and Sensor 4 respectively.

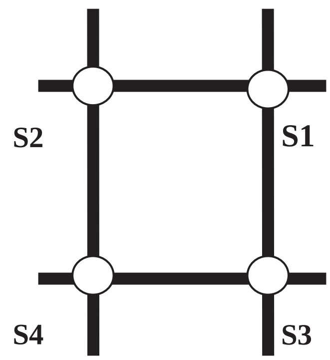


Figure: 4.11: The position of four sensors under the four legs of a bed

The experiments to test the bed sensor system were conducted with three inhabitants, one elderly person of 74 years of age and around 42 kg of weight as is shown in figure 4.12, one 5 year old child with 20 kg of weight as is shown in figure 4.13 and one adult with 68.5 kg of weight.

Figure 4.12: An elderly person lying on bed is being monitored

Figure 4.13: A child lying on bed is being monitored

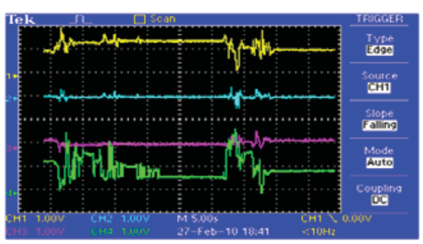
The results that were concluded from the experiment are shown in table 4.4. It is seen from these results that under normal situation all the four sensors read very similar weights. The sensors only measure the weight of the bed in this situation, so each sensor shows roughly one-fourth of the weight of the bed.

When a person lies on the bed the sensors read different readings depending on the amount of weight shared by that particular leg of the bed. The total weight measured by the four sensors is roughly equal to the weight of the bed and the weight of the person. From table 4.4 it can be easily said whether the bed is occupied by an elderly or a child from weight consideration. The position of the head whether the head is at (S1, S2) side or (S3, S4) side can easily be said by checking the difference of the sensors signals. The pair of sensors with the head side on them would show higher reading as compared to the other sensors.

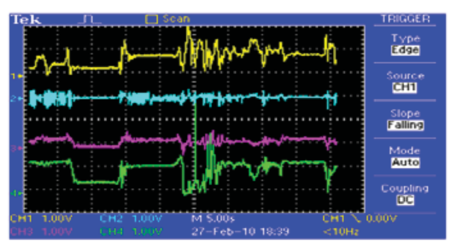
Table 4.4: Experimental results with inhabitant lying on bed

Test condition	Reading S1 (kg)	Reading S2 (kg)	Reading S3 (kg)	Reading S4 (kg)	Total weight (kg)
Only Bed	10.3	10.4	10.3	10.5	41.2
Elderly in the middle	18.4	15.2	23.6	26.9	84.1
Elderly on one side	19.3	16.5	26.2	22.2	84.2
Elderly on another side	14.0	21.3	18.5	30.5	84.3
Child in the middle	13.5	14.3	16.9	17.0	61.7
Child on one side	14.6	10.5	21.6	15.1	61.8
Child on another side	12.2	13.4	13.7	22.4	61.7
Adult in the middle	18.7	20.8	36.7	33.8	110
Adult on one side	25.2	14.2	45.5	25.3	110.2
Adult on another side	13.7	22.5	25.8	48.1	110.1
Adult lying diagonally (S4-S1)	17.2	20.5	28.2	44.3	110.2
Adult lying diagonally (S3-S2)	21.5	17.4	44.8	26.5	110.2

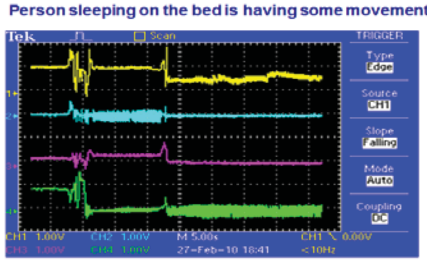
The transient response of the sensor was studied in order to understand performance of the sensor in real time. Figure 4.14 shows the transient response of the Bed Sensor.



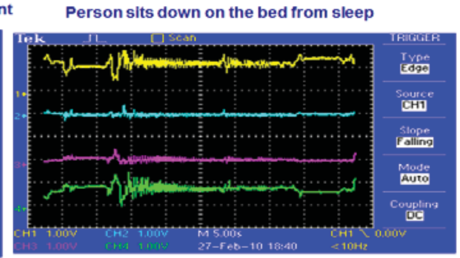
Person sleeping on the bed is having some movement



Person sits down on the bed from sleep



Person gets down from the bed from sleep



Person has some shivering feeling while sleeping on the bed

Figure 4.14: Transient response of the sensor

The output signals from the four sensors are interfaced to four different channels of the 12-bit ADC of the Silabs microcontroller C8051F020. The output signals from the microcontroller are used to determine all the information related to person's posture, quality of sleep and so on. The signals are measured and sent to the XBee coordinator for another level of processing.

4.6.5. ZigBee based Electrical Appliance Monitoring Unit

The developed electrical appliance monitoring unit has been modified to monitor more than one appliance to reduce the sensor-count. The electrical appliance monitoring unit is fabricated to accommodate three different electrical appliances on a single power inlet, having the intelligence to detect which particular device is ON and for how long it is used. The block diagram representation of interfacing of current sensor circuit is shown in figure 4.15.

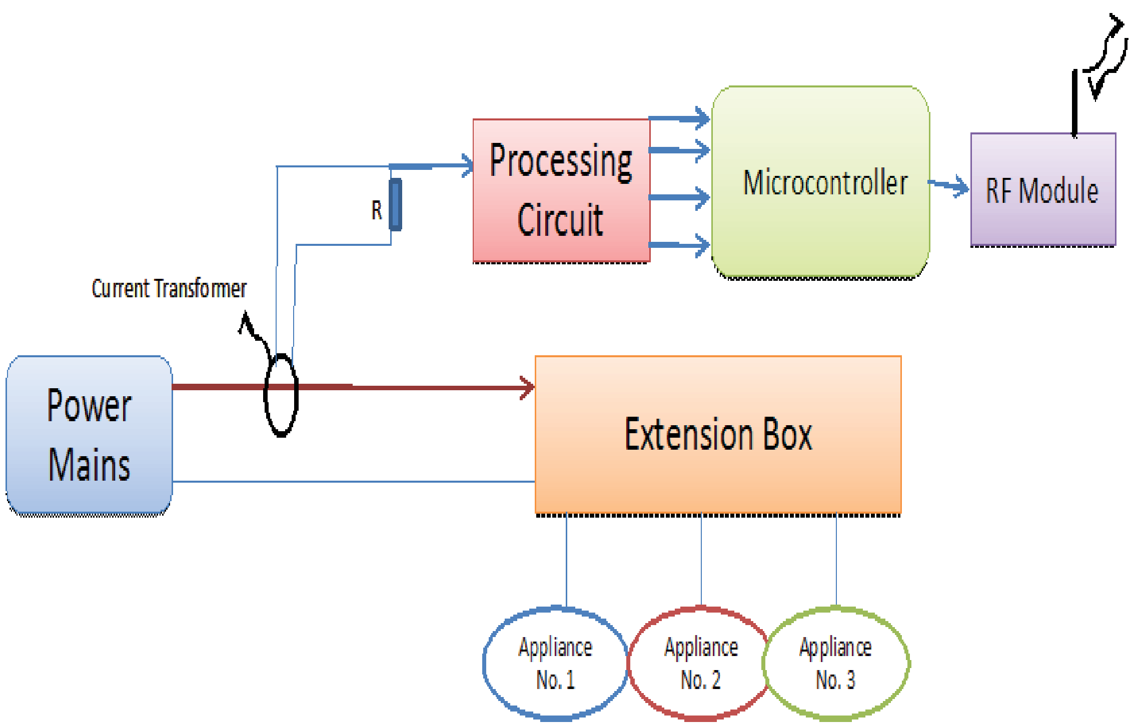


Figure 4.15: Block diagram representation of interfacing of current sensor

This sensor can be connected to general electrical appliances such as the kettle and toaster. It acts as a medium between the power socket and the equipment to be monitored, installation is as simple as it involves plugging in an extension cord and connected various electrical appliances to it. Since each electrical appliance has a different power rating the input current of each appliance is different as shown in the table 4.5.

The current flow in the phase line of the AC mains is detected by the current transformer and a voltage signal is produced. This voltage signal from the current transformer is then passed to a precision amplifier for amplifying to a required level. The connected load can be calculated as shown in table 4.5.

A comparator circuit generates a transition at its output when a particular/ combination of appliance/s turned ON. The generated transitions are fed to the port pins of the microcontroller and the status of devices is checked.

Table 4.5: Experimental values of load current and output voltage for different appliances

Appliance	Sensor Output (mV)	Current Intake (A)	Calculated Load (W)
Microwave Oven	19.7	5.75	1380
Kettle	28.996	8.74	2097.6
Bed Lamp	1.08	0.23	55.2
Electrical Heater	27.86	8.32	1996.8
Toaster	26.45	7.32	1683.6

The current transformer and the associated circuitry are shown in figure 4.16. These signals are used as external interrupts to the microcontroller, are counted by the program running on the microcontroller. It is possible to know the type of load as well as duration by changing the reference voltage, by changing the value of resistors in the potential divider. The pin transitions corresponding to the load are shown in figure 4.17. When a 1000W load is turned on, the port pin 1.0 of the microcontroller goes high.

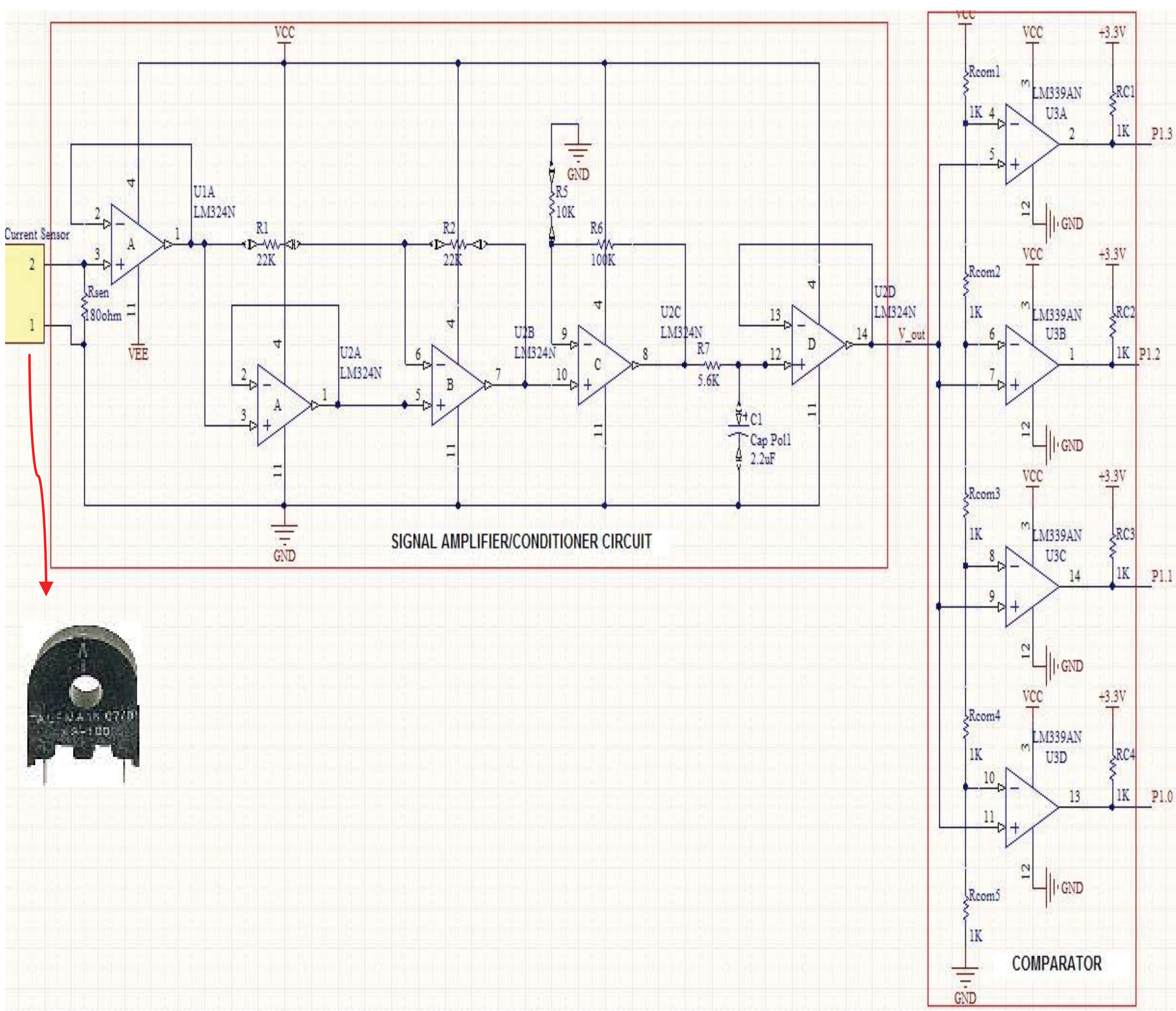


Figure 4.16: Current flow monitoring and interfacing circuit

The program inside the microcontroller decides which appliance is turned on and for how long. If there one or more number of appliances are turned on, the more number of port pins goes high. The intelligent program inside the microcontroller then decides which appliances are turned on, based on the combination of the port pin transitions.

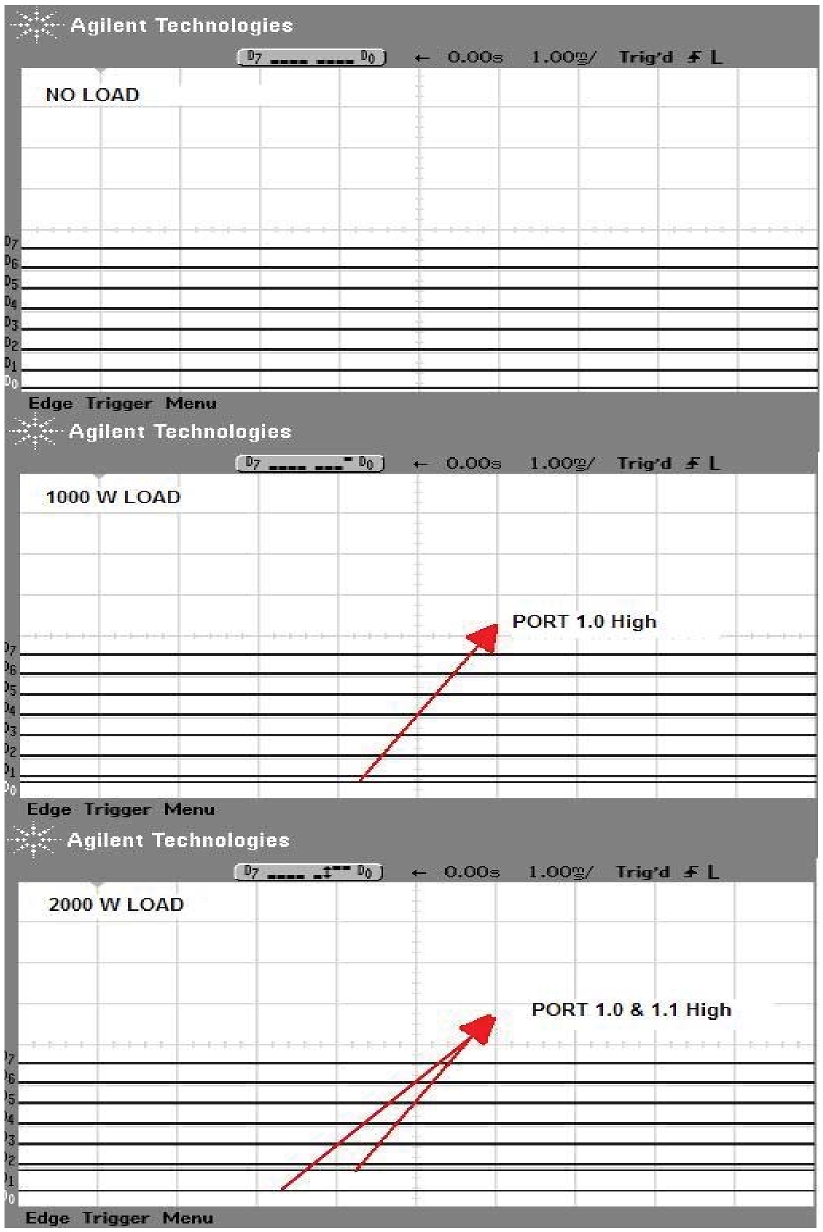


Figure 4.17: Pin transitions corresponding to the load

The intelligent load detection software which runs inside the microcontroller will be analysing these pin transition continuously and evaluate which appliance/s is turned

ON/OFF and for how long. The software inside the microcontroller can be configurable with many intelligent features as shown in figure 4.18.

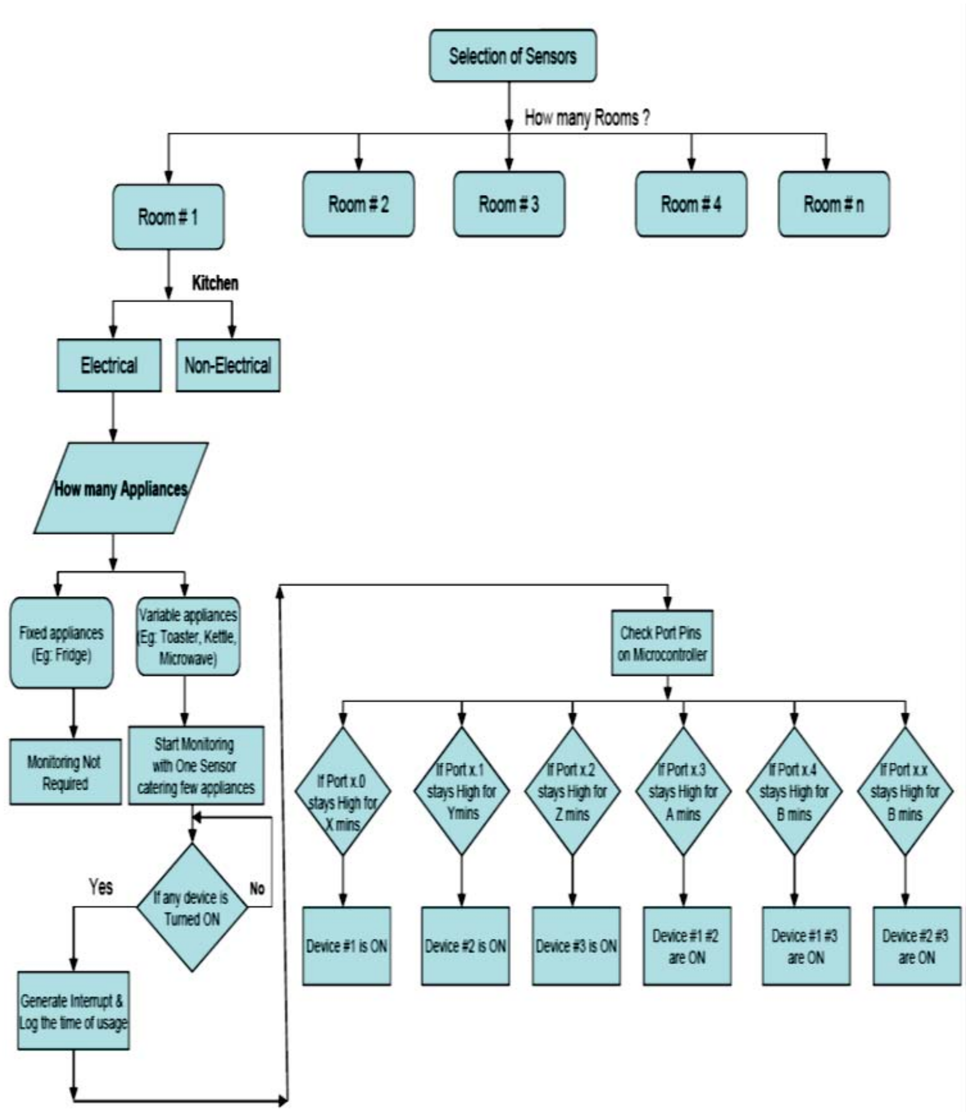


Figure 4.18: Decision making flowchart of current sensor

4.6.6. ZigBee Based Temperature and Humidity Monitoring Unit

The temperature monitoring unit monitors the changes in ambient temperature in a home. It can identify any abnormal temperature changes, for example a sharp rise in temperature in a home during cooking time may indicate a fire danger. Also this unit can be used to monitor and report the elderly resident if the room temperature dropped from ambient temperature, especially in winters. The temperature in this unit is measured by an integrated circuit, the DS600 temperature sensor produced by MAXIM - Dallas Semiconductor. The circuit of temperature sensor DS600 is shown in figure 4.19.

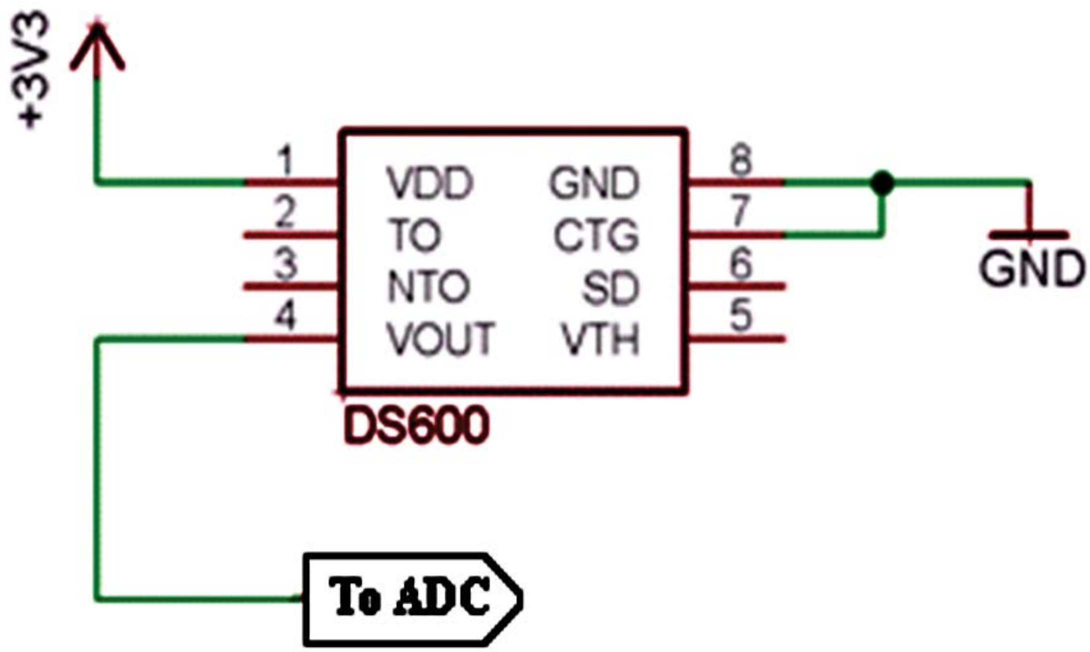


Figure 4.19: Circuit of temperature sensor DS600

The Sensor gives an analogue output depending on the measured temperature. This voltage has to be measured by the microcontroller using a 12bit Analogue-to-Digital converter (ADC). DS600 has an accuracy of ±0.5°C and a linear output with 6.45mV/°C and an offset of 509mV as shown in figure 4.20.

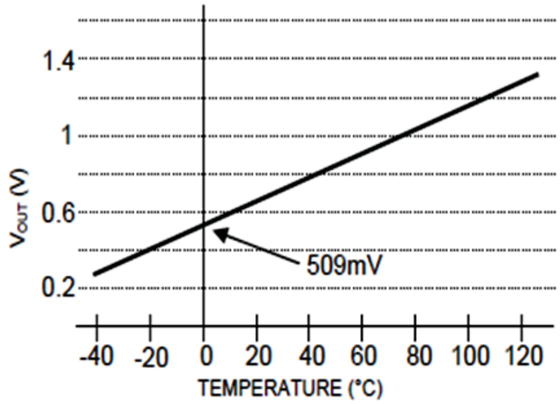


Figure 4.20: DS600 Output characteristic

The Output of the ADC has to be converted to get the temperature value. The ADC-value is first compared with the Reference Voltage of 2.4V in equation 4.2 and then with the characteristic of the DS600 to get the value for the Temperature (T) using the formula in equation 4.3.

….. (4.2)

…………….. (4.3)

The captured temperature change in a home can be seen in Figure 4.21.

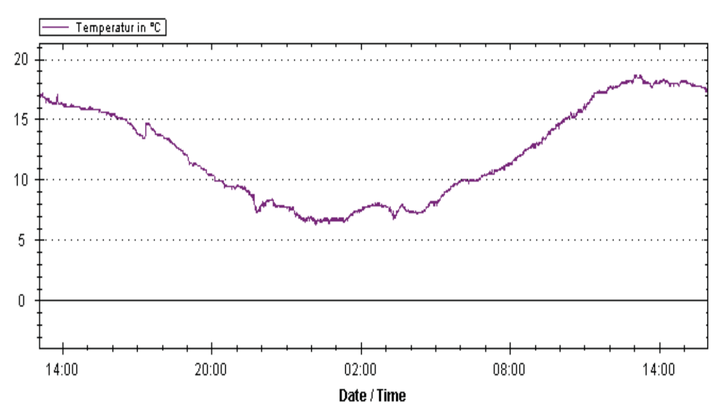


Figure 4.21: Daily temperature in °C change captured by DS600

Like temperature the humidity changes in a home when somebody is taking shower, cooking. By measuring the changes in the humidity in home, the activities of the daily living of a person can be identified more efficiently. I have used an integrated circuit, the HIH-4010 produced by Honeywell International Inc. Like the temperature sensor, the Humidity sensor gives an analogue output, which is measured by the 12Bit ADC of the C8051F020. The circuit of Humidity measuring sensor is shown in figure 4.22.

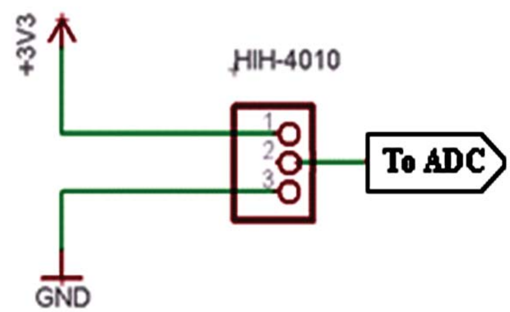


Figure 4.22: Humidity measuring circuit

The Humidity sensor has and accuracy of ±3.4% relative Humidity. To get the Humidity from the analogue input the formulas in the equations (4.4) and (4.5) are needed.

….. (4.4)

….. (4.5)

The calculated Humidity (H) needs to be temperature compensate equation (4.6).

….. (4.6)

Where, temperature (T) is from the DS600 sensor.

The daily trend of the humidity change in a home can be seen in Figure 4.23.

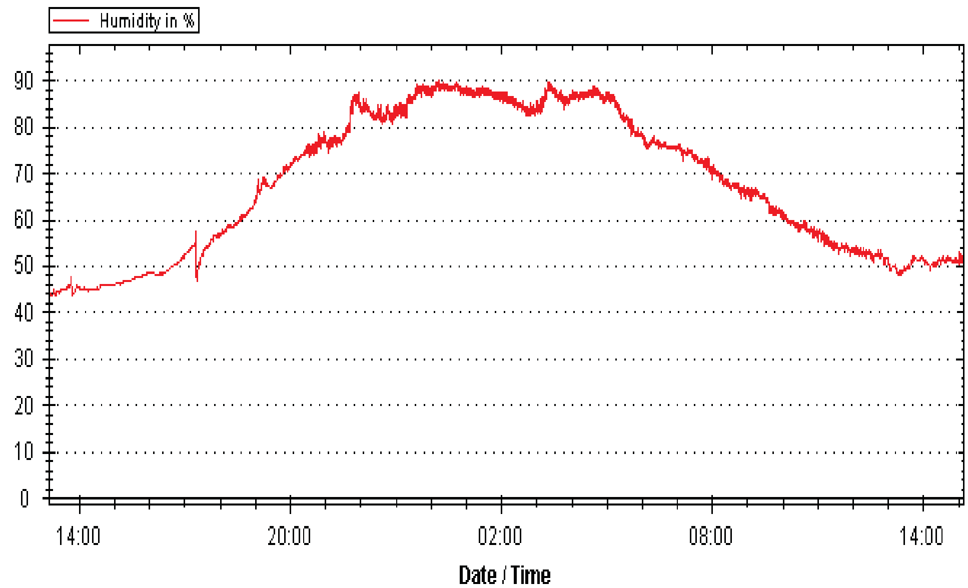


Figure 4.23: Daily Humidity change captured with HIH-4010

The temperature and humidity monitoring unit is then interfaced with an XBee module to send the capture values. The functional block diagram of the XBee based temperature and humidity monitoring unit is shown in figure 4.24.

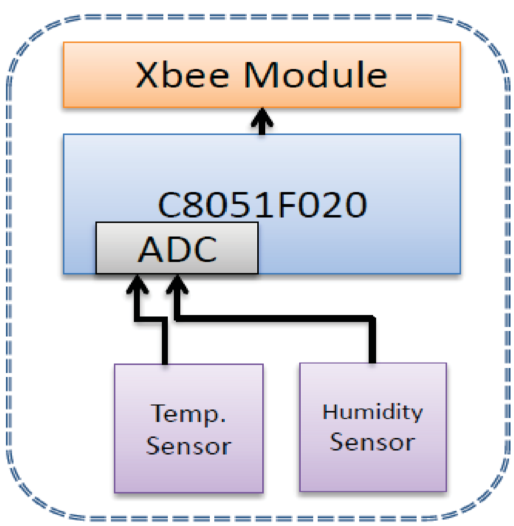


Figure 4.24: Functional block diagram of the XBee based temperature and humidity monitoring unit

4.6.7. ZigBee Based Panic Button

A Panic button was included in the system, with a highest priority. If the elderly subject needs urgent help from outside in case of emergency, he or she can activate it but touch of a button. The panic button can be place around the house where there is an ease of access to the elderly resident. In the earlier prototype monitoring system, the option for panic button was floppy. But the ZigBee based panic button has additional feature, it can also be used to reset any false alarm which is generated by the monitoring system. When a signal is received from an activated panic button, the system will supersede all other data coming from other sensor and gives it a high primacy. An alarm message will be sent immediately to a care giver in case of emergency.

4.6.8. ZigBee Based Contact Sensor

This wireless contact sensor is fitted to cupboards, fridge/freezer doors, drawers, doors, windows to monitors their usage. Monitoring the opening – closing of the doors, windows etc. by an elderly resident inside a home make the system more efficient in identifying the activities of the person. It is a two-part design comprising a compact spiral wounded metallic wire taped to the either sides of the door, as shown in figure 4.25.

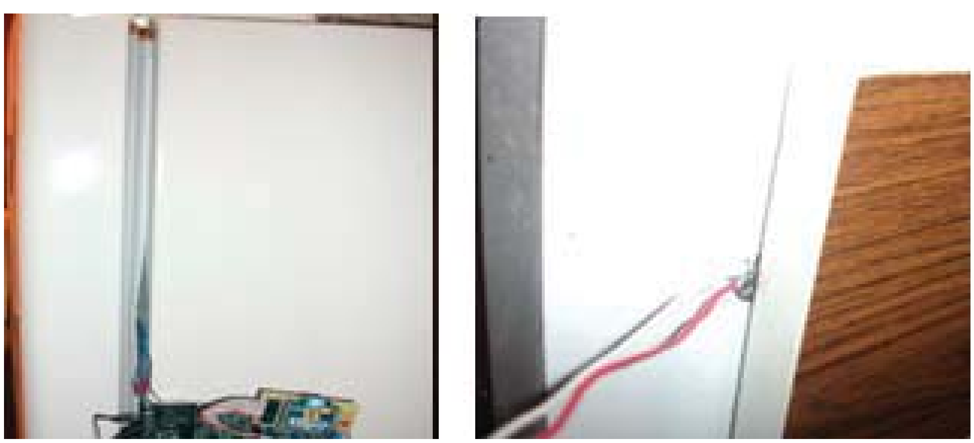


Figure 4.26 ZigBee Based Contact Sensor

These wires are connected to the port pins of the microcontroller to identify the status. This unit reports status opening and closing events as they occur.

4.6.9. Cellular Modem

The cellular modem used within the developed system is a Wavecom Wismo. It is a GSM cellular modem enables to connect into the GSM network and send text message to a caregiver/family/friend in case of emergency. The cellular modem receives commands from PC serially through USB connection as illustrated in figure 4.27.

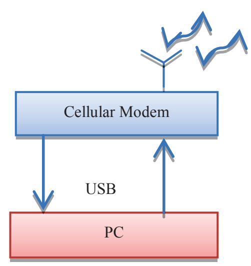


Figure 4.27: Functional Diagram of Cellular Modem

To send a text message the command required to be sent to modem from developed software program running on PC is:

AT+CMGS= "Phone number"

This command initiates the send message routine and takes a cell phone number as a parameter. The following line (CGMS) then contains the message to be sent.

4.7. Conclusion

A relative study and the reasons for choosing ZigBee based communication for the smart monitoring system have been discussed in this chapter. By reviewing and understanding the ZigBee architecture and implementation methods, this wireless communication technology has been implemented in smart home monitoring system.

The existing electrical appliance monitoring unit, bed monitoring unit, panic button has been upgraded to use ZigBee based communication.

From this upgrade the complexity of embedded software and the need for additional hardware components has been reduced drastically. By eliminating the redundant components, the cost and the size of the smart monitoring unit had been reduced. Also a temperature-humidity sensor unit and contact sensor has been supplemented to the existing system to detect the inhabitants patter more efficiently.

Chapter 5

Wireless Communication and Intelligent Process for Activity Behaviour Detection

5.1. Introduction

Activity detection in wireless sensor networks based smart home is an important challenge for tasks such as monitoring house-hold appliances in a home. In elderly monitoring where robust and reliable monitoring is vital, it is essential to detect unusual activity in an accurate and timely manner.

But in practice, however, wireless sensor network have limited resources, bandwidth, memory, and computational capabilities [120]. These inherent limitations of sensor nodes can make the network less reliable and sometimes fails to identify the abnormality. So it is important to identify the suitable communication and data processing methods for a reliable and secure functioning of the monitoring system. In this chapter, an overview of our system's ability to detect resident behaviour using some of the methods and the implementation of wireless sensors communication is discussed. The distribution of observed measurements in a smart home monitoring using wireless sensors is highly application-dependent.

So our developed system have to consider the application requirements and deal with issues such as how often the nodes should communicate, where/how to store the received data and effective ways of processing the data to achieve a consensus decision regarding the detected abnormality while minimizing faults in the system.

5.2. Communication of Sensors

The design of our wireless sensor network is done by ZigBee radio frequency (RF) transceivers, sensors, microcontrollers and power sources. The sensors operate within the Industrial Scientific and Medical (ISM) band of 2.4 GHz, which provides license free operations, huge spectrum allocation and worldwide compatibility.

5.2.1. ZigBee Networking Concepts

In ZigBee network usually consists of a coordinator, routers and several end devices. In our home monitoring system the nodes are configured as "End Nodes". Since the range of ZigBee RF modules is 55-60 meters, the need of routers is not need in a home based monitoring system. Below is the main characteristics and configuration of each device type,

5.2.1.1. Coordinator

The coordinator is used to start the ZigBee network. This module which is connected to the PC send the data collected from the end nodes to the computer tough serial communication. During network initialisation phase, the coordinator looks for the available radio channels and selects the channel with least activity.

Choosing the least activity channel reduces the level of interference, by excluding the channels used by other RF sources like Wi-Fi. Our experiments show that the coordinator takes approximately 8-9 seconds to scan all the available channels. The scan times of coordinator is shown in Table 5.1.

Table 5.1: Channels scan times of coordinator

No. of Attempts	Time taken to select the channel (Seconds)
1	10.2
2	8.3
3	8.9
4	7.8
5	10.6
6	11.1
7	9.2

The coordinator is configured by giving a unique PAN ID (Personal Area Network Identifier). Also the other ZigBee end nodes are assigned with a fixed 64 bit MAC address. Also a 16 bit shot address is given to the end nodes, which will be fixed for the network's life time. During network initialisation, the coordinator allocates itself a short address 0x0000. The network address of the PAN coordinator is always 0.

Once the coordinator finished its initialisation phase it enters "coordinator mode", during this phase it awaits requests from ZigBee devices to join the network. The main characteristics of the ZigBee coordinator are,

1. Selecting a suitable channel with a PAN ID (64 and 16 bit) to start the network.
2. Requesting end devices to join the network.
3. Assisting in routing and transferring data.
4. Cannot sleep and must be mains powered.

5.2.1.2. End Device

A ZigBee end node is integrated with the sensor hardware. The physical parameters captured by the sensing module are fed to the end node. As the sensor modules are powered on, the ZigBee end nodes enters initialisation stage. In this stage the end node scans for available channels to identify the network it wishes to join. Sometimes there may be multiple networks in the same channel, but are normally distinguished by their PAN ID. The node selects which network to join based on the PAN ID. The end node transmits a request to the network coordinator to join the network. Once the coordinator receives the request it then decides whether the requesting device is permitted to connect to the home network. The ZigBee standard based networks prevent unauthorised devices joining the network by providing a short user defined period where device may join. The permitted end nodes are recorded in the device database and stored on the coordinator. Some of the main characteristics of the end nodes are,

1. Must join a ZigBee PAN before it can either transmit or receive data.
2. Should not allow unauthorized nodes to join the network.
3. Always transmit and receive data through its parent i.e. coordinator and cannot route data.

5.2.1.3. PAN ID

The ZigBee network is identified by a unique PAN identifier or PAN ID. This ID is shared among all devices on the same personal area network. Usually the end node devices are preconfigured with a unique PAN ID. In our monitoring system the network coordinators are configured to select 16-bit PAN ID and the end nodes have 64-bit PAN ID and will join a network with any 16-bit PAN ID as long as the 64-bit PAN ID is valid.

The ZigBee modules on the same network share both 64-bit and 16-bit PAN ID, there is need of having a unique PAN ID's to operate within range of each other. All transmissions in the ZigBee network have 16-bit PAN ID defined by the 802.15.4 standard as a MAC layer addressing. This limited addressing space (65535 ID's) may cause multiple ZigBee networks within the same range using the same PAN ID. This problem is resolved by defining a 64-bit PAN ID. This 64-bit PAN ID is regarded as a true unique identifier. It is used when devices join a network and is a factor to resolve 16-bit PAN ID conflict resolution.

5.2.2. Network Topology

The ZigBee nodes in network can be arranged using three different network topologies: star, tree and mesh. In our system I have implemented the star topology. Limited number of sensor nodes and the home based monitoring is the reasons I have choose the star network topology. The ZigBee network contains one coordinator, no routers and a limited number of end node devices. Each end device is within radio range of the coordinator. Each end node connects directly to the coordinator – all inter-node communications are passed through the coordinator. Data that is exchanged between end node devices must pass through the Coordinator in this topology as shown in figure 5.1.

By using AT command one can determined the number of end devices that can join a device. This same command was used in determining network topologies. By giving Node Discover (ND) AT command I was able to find all end nodes found in the network. This information is used to determine the networks topology.

1. PARENT_NETWORK ADDRESS (2 Bytes)
2. DEVICE_TYPE<CR> (1 Byte: 0-Coordinator, 2-End Device)

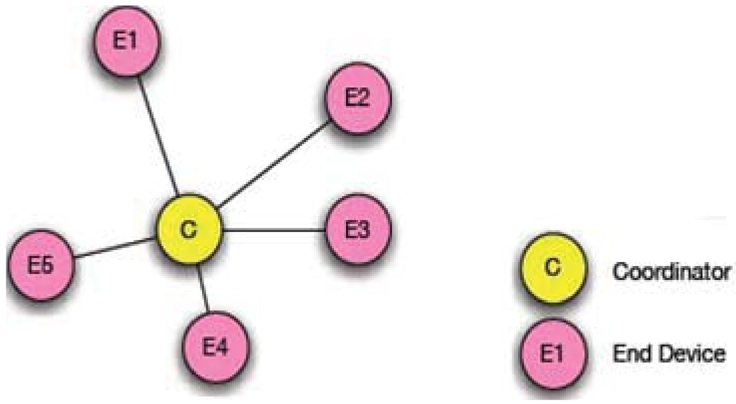


Figure 5.1: ZigBee Star Topology

The main advantages of a star networking is that it is the simplest of all other topologies, if one end node is broken it will not have any effect on the rest of the network, and it is easy to add or remove the end nodes. In this simple topology the data packet needs only to go through at most two hops to reach their destination i.e. the coordinator.

There is a disadvantage of star topology, all the data from the end nodes should pass to the coordinator as there is no alternative path. It may cause the coordinator to overload. But this topology limitation will not affect our system because there are very limited numbers of end nodes in our system.

5.3. Software Architecture

Wireless sensor network integrated with ZigBee modules capturing the sensor data based on the usage of house hold appliances and stores data in the computer system for further data processing as shown in Figure 5.2. A coordinator collects data from the device end smart sensors and forward to the computer system for data processing. Figure 5.3 shows the way the system collects and pre-process the data from the sensor.

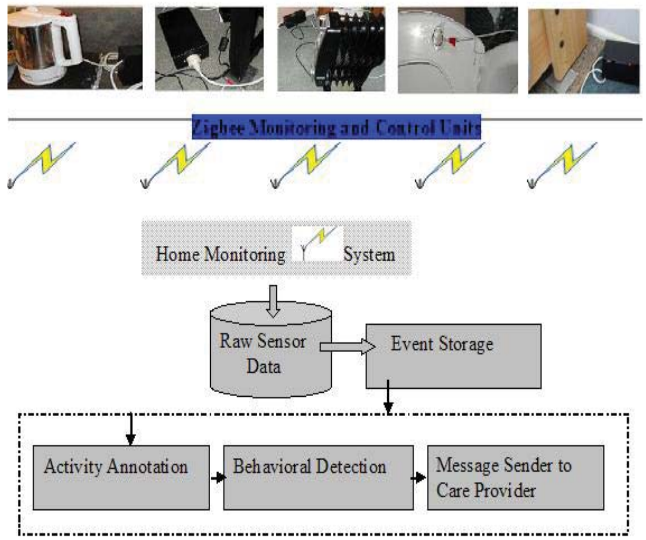


Figure 5.2: Architecture of the developed system with sensors and functional description of activity recognition.

Collected sensor data is of low level information containing few parameters like status of the sensor as active or inactive and identity of the sensor. To sense the activity behaviour of elder in real time, the next level software module will analyse the collected data by following an intelligent mechanism at various level of data abstraction based on time and sequence behaviour of sensor usage. Issues like, storage requirements for continuous flow of data streams and processing of data to generate patterns/abnormal events in real time were effectively dealt in the current system for execution of the system in real time.

The developed software system consists of various modules which can simultaneously do the following processing,

1. Data Acquisition
2. Event based storage
3. Recognising activity behaviour
4. Raise of Level – 1 and Level – 2 Activity warnings

5. Wellness determination based on daily activity and generation of Level – 3 activity warning

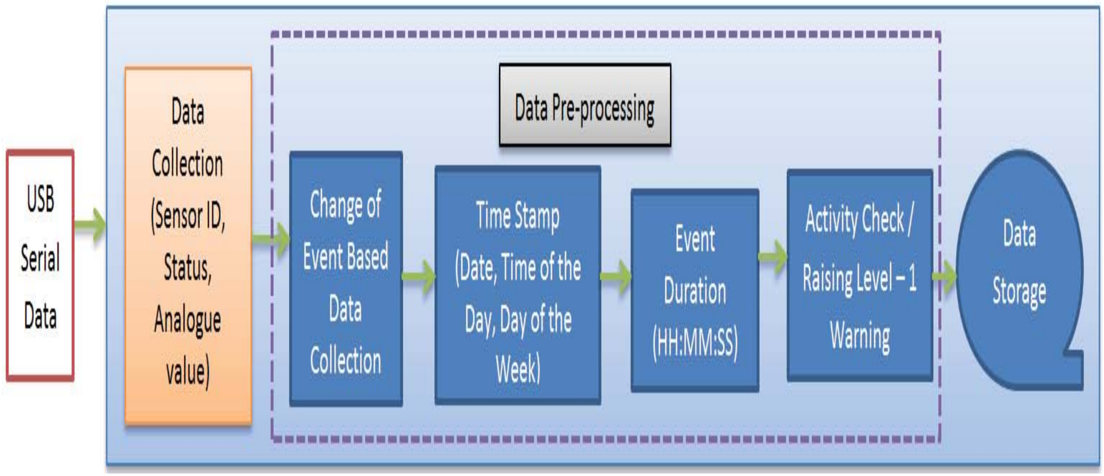


Figure 5.3: Sensor Data Collection

5.3.1. Data Acquisition

The idea of is to recognise the essential activities of daily living behaviour of the elderly living alone by using few sensors. For this, Wireless Sensor Network consisting of different types of sensors like Electrical, Force, Contact sensors with ZigBee module are installed in Elderly home.

Electrical appliance monitoring sensor unit are connected to appliances like Microwave Oven, Water Kettle, Toaster, Room heater, Television and dishwasher as they are regularly used by the inhabitant. Force sensors are attached to Bed, Couch, Toilet and Dining chair to monitor their usage. Fabricated contact sensors are fixed to the Fridge and Grooming cabinet to detect the open and close door operations for recognizing the usage of these appliances. The output of electrical appliance monitoring sensor unit is either ON or OFF based on the use of connected electrical appliance. Normally, one electric sensor is required to sense each electrical appliance. In order to have minimum sensors to monitor more electrical appliances and reduce cost, the electrical appliance monitoring unit is fabricated to support two electrical appliances on a single power inlet, having intelligence to detect which particular device is on. I have tested by connecting water kettle and toaster to be monitored by single sensor thereby reducing number of sensors and cost for monitoring elderly behaviour. Also, Emergency help and Deactivate operations are made-up with ZigBee module to facilitate the respective operations during the real-time activity monitoring of the inhabitant.

5.3.2. Event Based Storage of Data

Since there is continuous flow of data streams I have stored the sensor data in the processing system only when there is change in the sensor events-Event based monitoring i.e. when status (active or inactive) of sensor is changed. This is most efficient technique, as it reduces the size of storage to large extent and more flexible for processing of data in real time. Figure 5.4 shows a comparative storage difference between continuous monitoring and event based monitoring.

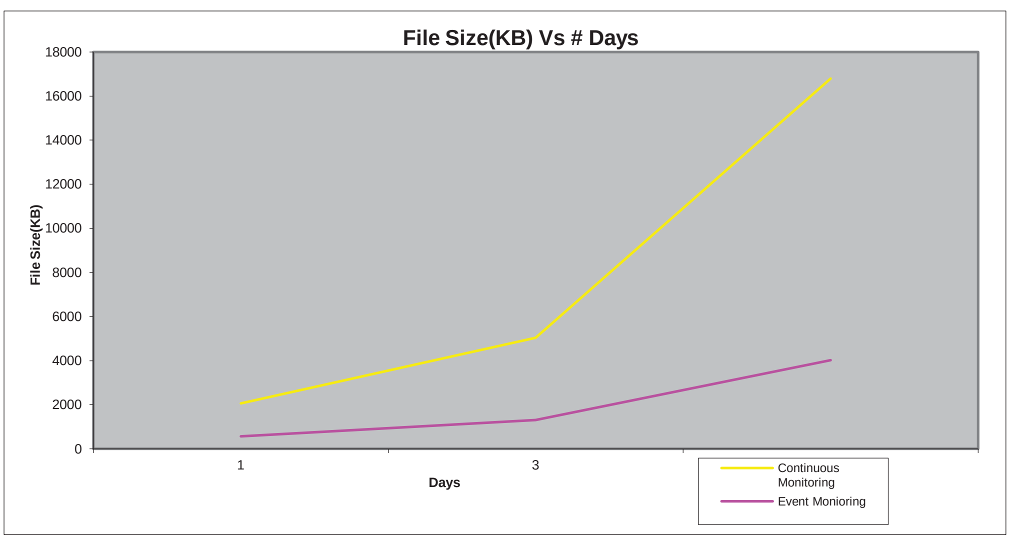


Figure 5.4: Comparative storage difference between continuous monitoring and event based monitoring

Developed data acquisition module in figure 5.5, receive the sensor's ID, active or inactive status and also analogue values.

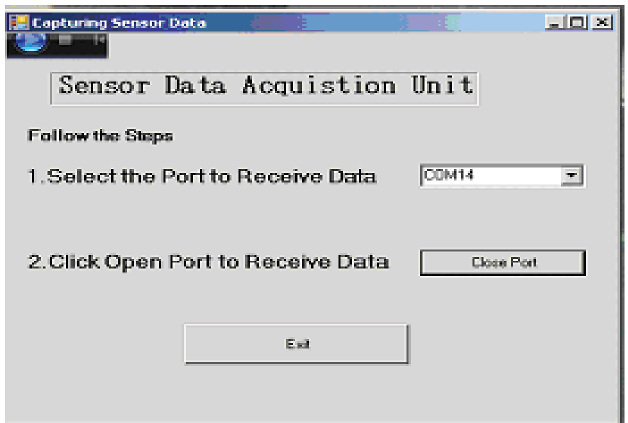


Figure 5.5: Developed sensor data acquisition software

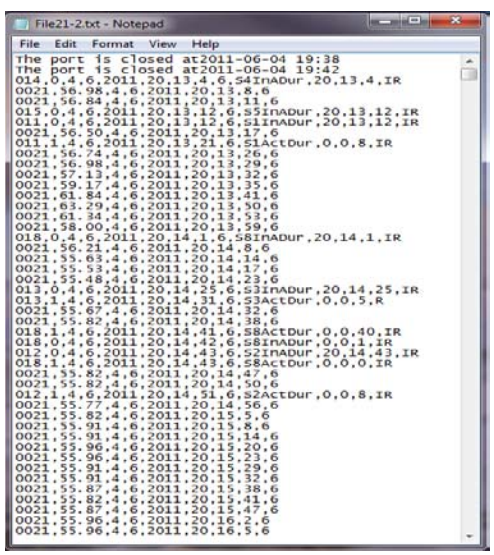
5.3.3. Time Stamping

Captured data is dynamically changing and demanding fast real time response time for detecting the activity of the elderly person. For analysing the data properly an efficient process of storage mechanism of sensor data onto the computer system is developed and executed. This follows that, when there are changes in status of sensor, data is recorded along with their time instance.

5.3.4. Activity Check, Level 1 Warning and Data Storage

Activity recognition and determining behaviour as regular or irregular are two important functions to be done in timely manner by the system. To label an activity as regular or irregular, there is a need to understand the daily activity of person living in a house-hold. In order to get an insight and to understand the person's daily activity I have interviewed elderly people, who are 65 and over. A questionnaire is given to the person to fill. The questions in it include the activities a person usually done at a particular time of the day and the appliances he will be using. The activities include sleeping, toileting, self-grooming, cooking breakfast, cooking lunch, etc. A sample questionnaire is shown in appendix 1.

From these interviews I did gained a good insight of the person's activities and the type of appliances he/she might be using. Based on the answers from the questionnaire, the daily appliance usage of the person is then projected. After this I have started monitoring the status of the appliances which the person will be using at a particular time of the day. If an appliance has not been used as mentioned by the user according to the questionnaire then a Level 1(either R or IR) warning is issued. It is achieved by cross checking the data from the sensor (time of the day / activity duration) with the Ground truth i.e. the answers from the questionnaire. The data segment from the sensor is labelled as regular activity (R) or irregular activity (IR). This data is then stored on the PC for further processing. Each individual stored data segment consists of sensor ID, activity status or ADC value, date (DD, MM, YY), time (HH:MM:SS), activity duration, level 1 warning. The storage file with the pre-processed data is shown in figure 5.6.


File21-2.txt - Notepad

File Edit Format View Help

```
The port is closed at2011-06-04 19:38
The port is closed at2011-06-04 19:42
014,0,4,6,2011,20,13,4,6,S4InADur,20,13,4,IR
0021,56.98,4,6,2011,20,13,8,6
0021,56.84,4,6,2011,20,13,11,6
015,0,4,6,2011,20,13,12,6,S5InADur,20,13,12,IR
011,0,4,6,2011,20,13,12,6,S1InADur,20,13,12,IR
0021,56.50,4,6,2011,20,13,17,6
011,1,4,6,2011,20,13,21,6,S1ActDur,0,0,8,IR
0021,56.74,4,6,2011,20,13,26,6
0021,56.98,4,6,2011,20,13,29,6
0021,57.13,4,6,2011,20,13,32,6
0021,59.17,4,6,2011,20,13,35,6
0021,61.84,4,6,2011,20,13,41,6
0021,63.29,4,6,2011,20,13,50,6
0021,61.34,4,6,2011,20,13,53,6
0021,58.00,4,6,2011,20,13,59,6
018,0,4,6,2011,20,14,1,6,S8InADur,20,14,1,IR
0021,56.21,4,6,2011,20,14,8,6
0021,55.63,4,6,2011,20,14,14,6
0021,55.53,4,6,2011,20,14,17,6
0021,55.48,4,6,2011,20,14,23,6
013,0,4,6,2011,20,14,25,6,S3InADur,20,14,25,IR
013,1,4,6,2011,20,14,31,6,S3ActDur,0,0,5,R
0021,55.67,4,6,2011,20,14,32,6
0021,55.82,4,6,2011,20,14,38,6
018,1,4,6,2011,20,14,41,6,S8ActDur,0,0,40,IR
018,0,4,6,2011,20,14,42,6,S8InADur,0,0,1,IR
012,0,4,6,2011,20,14,43,6,S2InADur,20,14,43,IR
018,1,4,6,2011,20,14,43,6,S8ActDur,0,0,0,IR
0021,55.82,4,6,2011,20,14,47,6
0021,55.82,4,6,2011,20,14,50,6
012,1,4,6,2011,20,14,51,6,S2ActDur,0,0,8,IR
0021,55.77,4,6,2011,20,14,56,6
0021,55.82,4,6,2011,20,15,5,6
0021,55.91,4,6,2011,20,15,8,6
0021,55.91,4,6,2011,20,15,14,6
0021,55.96,4,6,2011,20,15,20,6
0021,55.96,4,6,2011,20,15,23,6
0021,55.91,4,6,2011,20,15,29,6
0021,55.91,4,6,2011,20,15,32,6
0021,55.87,4,6,2011,20,15,38,6
0021,55.82,4,6,2011,20,15,41,6
0021,55.87,4,6,2011,20,15,47,6
0021,55.96,4,6,2011,20,16,2,6
0021,55.96,4,6,2011,20,16,5,6
```

Figure 5.6: Data file storing the appliance usage events

Figure 5.7 shows the uses of an electrical appliance, namely the hot-water kettle in the morning duration for 3 consecutive days. The first day was Sunday, the 2nd day was Monday but was a national holiday and the 3rd day was Tuesday. It is seen that the usage is slightly different from each other. So knowledge of the usage of the appliances is very important for determining the irregular behaviour of the person.

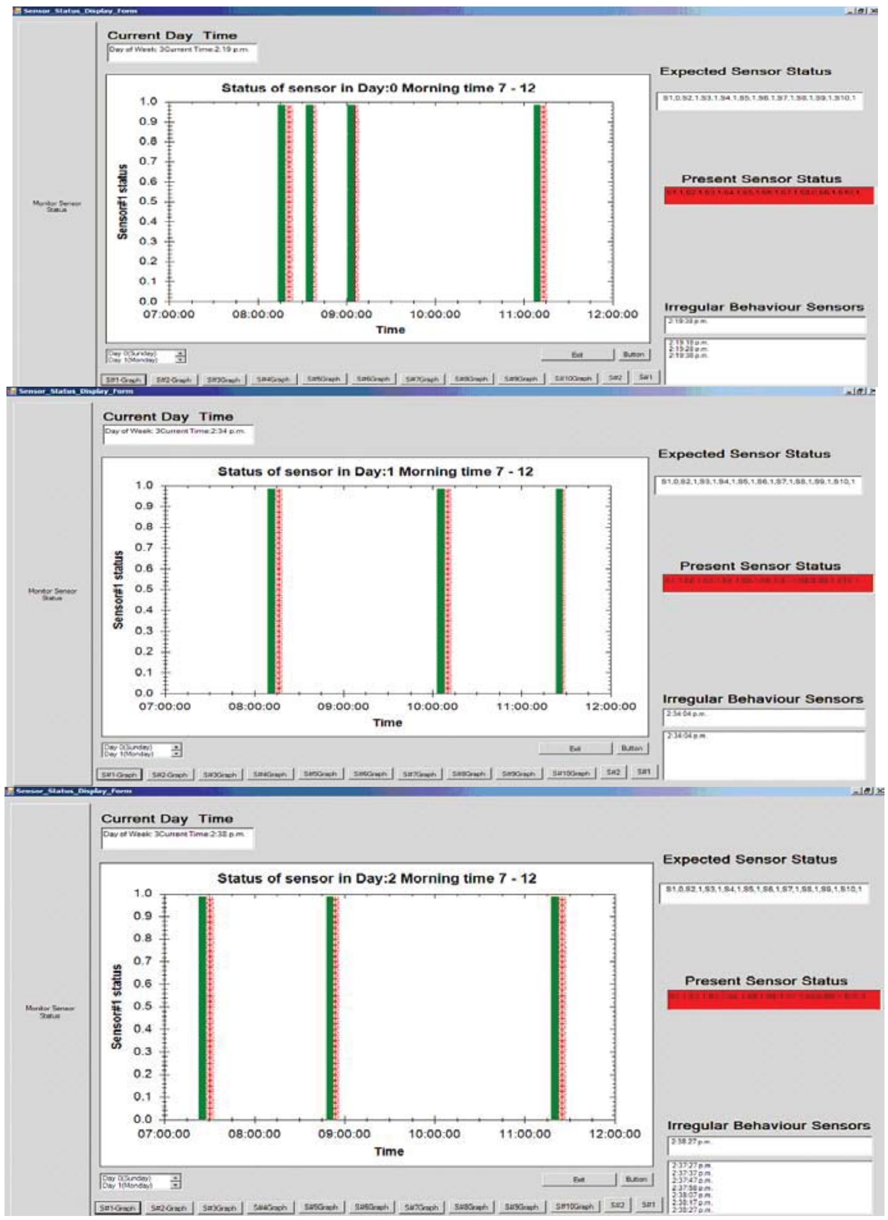


Figure 5.7: The usage pattern of an electrical appliance during morning time for 3 consecutive days

5.4. Data Processing and Activity Annotation

Data processing is done with the help of file handling mechanism to generate the pattern of sensors usage activity. Multi-level check is performed in order to determine the usages of the appliances are proper at respective time instance or not in real time. During the initial check, the activity of sensor during particular time duration is flagged with regular or irregular status.

If an irregular flagged sequence is generated then the pattern of the sensors activity is then compared with the classified model of the regular or irregular pattern of the sensors. The classified model is generated based training set given to the system from the collected data for a period of twenty one days at an elder home.

5.4.1. Activity Annotation and Level 2 Warning

Activity labelling for the activities of daily living of the elderly during real-time monitoring of appliances use is directly done with the help of 'sensor events'. Activities like Sleeping, Preparing Breakfast/Lunch/Dinner, Dining, Toileting and self-grooming were recognized based on the pre-processed data from the sensors. Table 5.2 depict the activity labelling in real-time.

Activities like watching television, preparing tea are done with the help of respective sequence patterns of sensor ids which are active. Activity annotation involves automatically discovering inhabitant behaviour over time. Data was not segmented into separate sequences for each activity rather it was processed as continuous stream. Here the sizes of time slots are neither too large nor too small, as they provide sufficient data for doing analysis at later step.

Table 5.2: Activity Annotation and Labelling

Sensor-id/ Status	Connected to Appliance	Type of Sensor	Time of Usage	Annotated Activity	Run Time Data
18(Active)	Bed	Pressure Sensor	09:00pmto 06:00am	**Sleeping(SL)**	2011-6-9 21:02:10 18 ON SL begin 2011-6-10 05:50:10 18 OFF SL end
11/12/13 (active)	Microwave Oven/ Water Kettle/ Toaster	Electrical sensor	6:00amto 10:00am	**Breakfast(BF)**	2011-6-5 06:16:42 11 ON BF begin 2011-6-5 06:21:35 11 OFF BF end
11/12/13 (active)	Microwave Oven/ Water Kettle/ Toaster	Electrical sensor	11:01amto 02:00pm	**Lunch(LN)**	2011-6-6 12:11:27 13 ON LN begin 2011-6-6 12:12:18 13 OFF LN end
11/12/13 (active)	Microwave Oven/ Water Kettle/Toaster	Electrical sensor	07:00pmto 10:00pm	**Dinner(DN)**	2011-6-4 20:59:26 11 ON DN begin 2011-6-4 20:59:32 11 OFF DN end
17(active)	Dining Chair	Pressure sensor	Anytime	**Dine(DI)**	2011-6-11 14:43:02 17 ON DI begin 2011-6-11 14:43:05 17 OFF DI end
10(active)	Toilet	Pressure sensor	Anytime	**Toileting(TO)**	2011-6-7 02:15:30 10 ON TO begin 2011-6-7 02:16:07 10 OFF TO end
19(active)	Couch	Pressure sensor	Anytime	**Relax(RE)**	2011-6-8 05:20:45 19 ON RE begin 2011-6-8 05:35:30 19 OFF RE end
26(Active)	Grooming Cabinet	Contact	Anytime	**Self Grooming(SG)**	2011-6-8 09:20:10 26 ON SG begin 2011-6-8 09:22:40 26 OFF SG end
14(Active)	TV	Electrical sensor	14->19 or 19->14	**Watching TV(WTV)**	2011-6-6 17:20:35 14 ON TV begin 2011-6-6 17:20:45 19 ON WTV begin 2011-6-6 18:05:39 19 OFF WTV end 2011-6-6 18:06:05 14 OFF TV end
25(Active)	Fridge	Contact	25->12 or 12->25	**Preparing Tea(PT)**	2011-6-9 10:15:20 25 ON FR begin 2011-6-9 10:15:50 12 ON PT begin 2011-6-9 10:15:45 25 OFF FR end 2011-6-9 10:16:50 12 OFF PT end

Even if the sensors are active for multiple times during a particular time slot, activity labelling is done according to the definition. I experimented with models that used time slot of sizes 1hr, 3hr, 4hr, 6hr.Table:1 show Number of times Sensor_id:11 and 12 active during 6:00am to 10:00am. Hence, Activity recognition in terms of 3hr and 4hr time slot sizes are giving more modelling accuracy for further data processing.

If there are multiple times the sensor_id 11, 12 or 13 are active during four hour or three hour time slots the event is annotated with defined activity as breakfast, lunch and dinner respectively. Obviously an event doesn’t happen at same time every day, but it is usually similar i.e. breakfast between 6:00am to 10am. So sensors in the kitchen between 6:00am to 10:00am use labelling as breakfast. Figure 5.7 shows the sequence of activity at house.

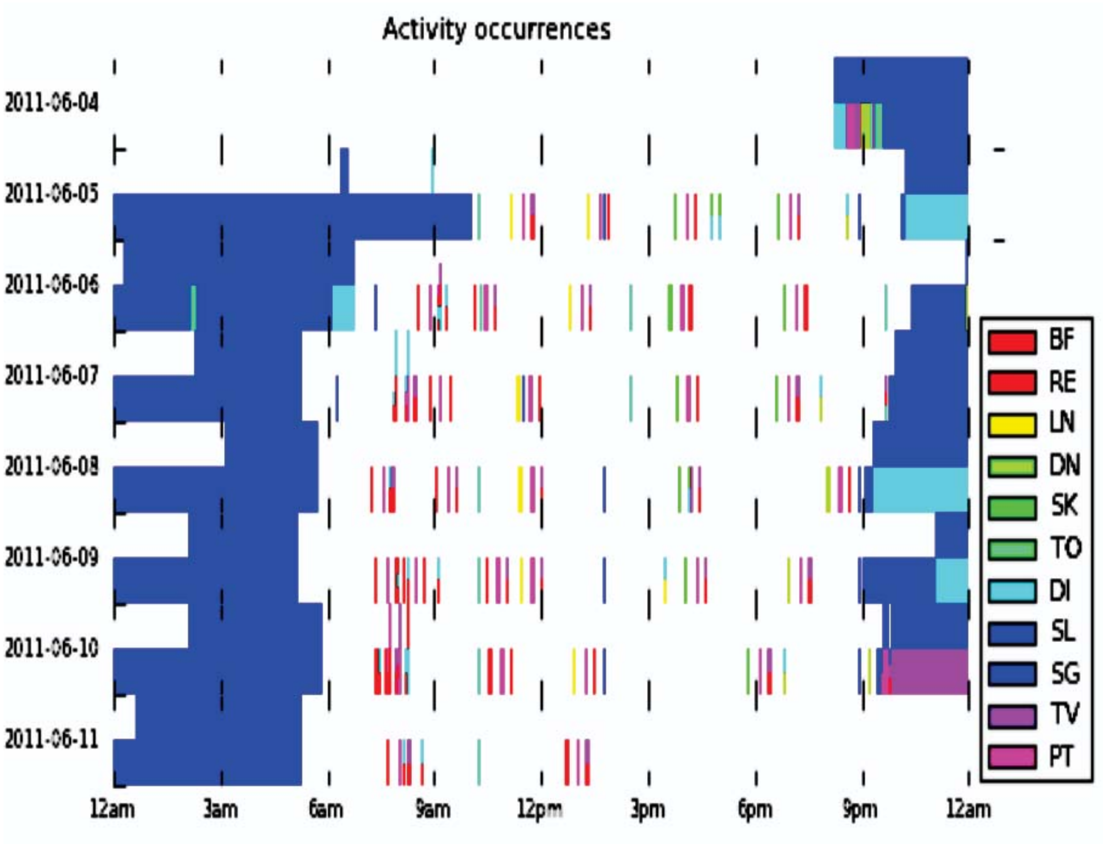


Figure 5.8: Pictorial representation of activity occurrence-based on data obtained from a running system. (Refer Table: 5.2 for acronyms in legend.)

Based on the activity annotation, the time the activity occurs is verified by cross checking with the stored historical activity data or a trained model. If there is a mismatch of time the activity occurs, then a Level 2 warning is generated by the system.

In order to verify the recognition of the activities based on features selected, sensor_id and time of day are optimal, I have used two machine learning methods:

i) **LogitBoost:** To get better correctness of any given learning method LogitBoost may be used. The purpose of boosting is to have a highly intense classifier by merging less intense classifier. This method is less sensitive to noisy data and minimizes expectation of loss function and robust to regression model to optimize likelihood.

ii) **Naïve Bayes:** Probabilistic classifier based on applying Bayes' theorem with strong (naive) independence assumptions. This method can be applied to small and independent data sets. After the model is built, they can provide fast responses to queries.

Experiments on the collected sensor data from the real environment are done. The testing tool I used is Weka [121] provides an implementation of machine learning algorithms that can be easily apply to our own dataset. Using Weka, I have assessed the classification performance of our two selected machine learning algorithms using 10-fold cross validation. Activity recognition process was able to perform annotation in real time to 79.84 percent correct.

```
Tester:     weka.experiment. PairedCorrectedTTester
Analysing:  Percent_correct
Datasets:   1
Resultsets: 2
Confidence: 0.05 (two tailed)
Dataset                   (1) meta.Log | (2) bayes
------------------------------------------------------------
SensorData               (10)   79.84 |   78.40
------------------------------------------------------------
Tester:     weka.experiment.PairedCorrectedTTester
Analysing:  SF_entropy_gain
Datasets:   1
Resultsets: 2
Confidence: 0.05 (two tailed)
Dataset                   (1) meta.Logi | (2) bayes.
----------------------------------------------------------------
SensorData              (10)   333.31 |   327.38
```

5.4.2. Activity Detection

The core part of the system, which is complex of the real-time system is forecasting of the inhabitant activity behaviour. Inhabitant activity behaviour is meticulously learned (lifelong) by the system based on the day-to-day activities and performs aptly in real-time situation avoiding disastrous situation at early stage of execution.

Abnormality recognition model for the present real-time system is capable of reasoning accurately based on the environmental event history and performing suitably to the dynamic situation.

Abnormality recognition model for the developed system consists of multi-level checks performed at various steps of real time execution. Importance of multi-level check is to reduce unnecessary alarms (warning messages) while system is in use.

Check #1: is done during the data acquisition step. If the event data match with the predefined irregular event conditions of the system, then the event is flagged with "IR" status otherwise event is flagged with "R" status and updated accordingly in the knowledge base.

Predefined Irregular event conditions can be customizable depending on the inhabitant behaviour. In our testing case, based on the questionnaire filled by the inhabitant prior to the system installation, irregular event conditions are identified and were inserted at appropriate steps of data acquisition. These, "IR" and "R" status events will enable in modelling the abnormal activity.

"IR" flagged events can change their flag status to "R" so that in future the same type of event doesn't result to Irregular status. This updating is done by the inhabitant, pressing the abnormal reset button when there is an alarm (message).

Based on inhabitant questionnaire about usage of household appliances I have customized predefined irregular events and included in the program. When there is a raise in irregular events the output of check #1 step during real-time system execution is,

```
016,0,4,6,2011,20,36,5,6,S6InADur,0,4,38,R
0021, 57.18,4,6,2011,20,36,10,6
018,1,4,6,2011,20,36,10,6,S8ActDur,0,2,7,IR
016,1,4,6,2011,20,36,11,6,S6ActDur,0,0,5,R
018,0,4,6,2011,20,36,11,6,S8InADur,0,0,1,IR
0021, 57.18,4,6,2011,20,36,16,6
016,0,4,6,2011,20,36,17,6,S6InADur,0,0,5,R
0021, 57.38,4,6,2011,20,36,19,6
018,1,4,6,2011,20,36,19,6,S8ActDur,0,0,8,IR
```

Status IR events can be changed to R events with the intervention of inhabitant, by pressing alarm reset button.

Check #2: is performed after the events are triggered with R or IR flag status and while sensor-id is ON and a particular activity is in begin state.

The function of this level check is to discover event activity occurring such as:

If the active sensor duration of the present event is greater than existing event duration in the knowledge base then alarm message is generated

Pseudo Code for check#2 operation:

```
If (((SensorActive.Minute) + MaxofsensorAct) = ((Now. Minute)) and
Sensosractflag = "0") Then
    Sensoractflag = "1"
    Message("From Sensor S011")
 End If
```

Here, time the sensor is active value is obtained simultaneously from the file when the system is running and respective sensor is active

To deactivate the alarm message, inhabitant can press the reset button so that the event can be considered as regular event.

5.4.3. Wellness determination of Inhabitant

I have introduced two wellness functions to determine the wellness of the inhabitant person under the monitoring environment. The first function is to determine the non-usage or inactive duration of the appliances. The second function is to determine the over-usage of household appliances.

The two functions are β1 and β2, used to determine the wellness of inhabitant based on the usage of house hold appliances.

5.4.3.1. Wellness function β1

The wellness function, designated as 'β_1' is defined as

$$\beta_1 = 1 - \frac{t}{T} \qquad \text{..... (5.1)}$$

Where,

β1 =Wellness function of the inhabitant based on Inactive measurement of appliances

t = Time of Inactive duration of all appliances (i.e.) duration time none are used

T= Maximum inactive duration during which appliances are used.

If β1 is equal to 1.0 indicates the inhabitant is under healthy situation. If β1 is less than 1.0 and goes below 0.5 the situation indicates some abnormal situation.

5.4.3.2. Wellness function β_2

The wellness function, designated as 'β_2' is defined as

$$\beta_2 = 1 + \left(1 - \frac{Ta}{Tn}\right) \qquad \text{..... (5.2)}$$

Where,

β_2 = Wellness function of the inhabitant based on excess usage measurement of appliance.

T_a = Actual usage duration of any appliance.

T_n = Maximum usage during of use time of appliance.

Under normal condition, $T_a < T_n$ (i.e.) No Abnormality

Only if $T_a > T_n$ then β2 is calculated using the eq. (5.2). The value of β_2 close to 0.8 to 1 may be considered as normal situation. If β_2 goes less than 0.5 indicates excess usage of the appliance and may lead to an abnormal condition.

"β_1" and "β_2" functions can tell us, how well the inhabitant activity is being performed. Wellness functions were helpful in deducing no appliance and excess used by the inhabitant at their houses. Real time implementation and experimental results based on this approach are discussed in detail in chapter 6.

5.5. Optimizing the number of sensors

Based on frequency of the usage of the house-hold appliances at various locations of the elderly house, I was able to determine the importance of the sensor required to be positioned at various points of the house. From Figure 5.9 and 5.10, it can be inferred that number of recorded sensor events at different subject houses varies and are helpful in the calculation of the activity recognition for day to day activities.

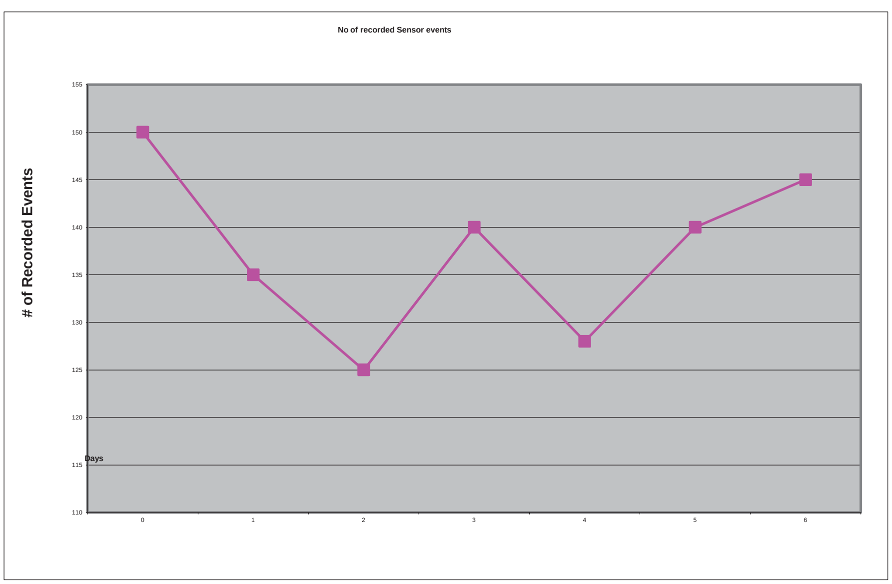
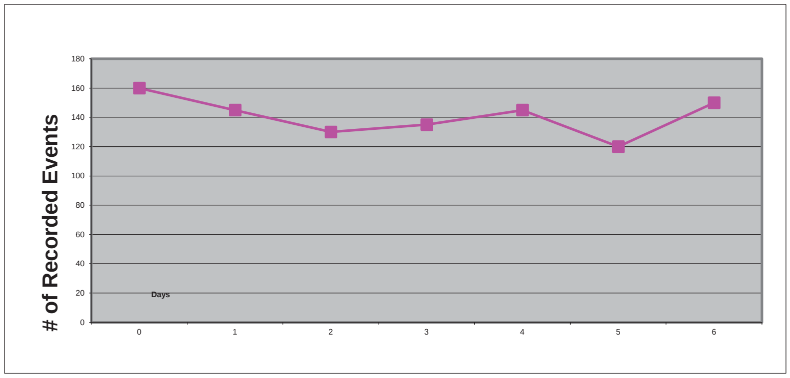


Figure 5.9: Subject 1-Total number of recorded sensor event over time (time unit=days)



Subject #2

Figure 5.10: Subject 2-Total number of recorded sensor event over time (time unit=days)

Frequency (η) of a particular sensor type in a location is determined by eq. (5.3).

$$\eta_T^c{}_{(loc)} = 1 / \sum_{s \in S_c^l}^{|s_c^l|} f_T(s) \qquad \text{….. (5.3)}$$

Where, loc=specific location,

c=sensor type,

S_c=Set of Sensors of a particular type c,

$f_T(S)$ = frequency of sensors over a time period T.

Table 5.3: Frequency of sensor unit usage for determining an optimal number of sensors required for activity recognition.

Room Type	Sensor Type	Connected to Device	η	
			Trial	Test
Living	Force, Electrical	Couch, Chair, TV, Heater	0.03, 0.05, 0.05,0.1	0.03, 0.04, 0.03,0.1
Kitchen	Electrical	Microwave, Toaster, Kettle	0.05, 0.05, 0.02	0.04, 0.06, 0.00
Bed	Force	Bed	0.29	0.37
Bath	Force	Toilet	0.35	0.33
Storage	Contact	Cupboard	0.01	0.00

From Table 5.3, it can be determined that the usage of contact sensor for the storage room is inadequate and can be ignored for determining the elderly activity recognition.

5.6. Alarm Generations

Alarms (warning sounds) are produced by the system based on the unusual activity behaviour in terms of appliance usage duration in real time. The alarm generation rules are,

```
Duration_Appliance (A) > Max_Duration_Trial_Appliance (A) And
Duration_Appliance_DayofWeek (A) > Duration_Trial_DayofWeek (A) or
NumberofTimes_Active_DayofWeek_Appliance (A) >
NumberofTimes_Active_DayofWeek_Trial_Appliance (A)
```

Elderly person pressed sensor_id "000" to deactivate the alarm and consider the excess duration of the appliances as normal duration.

If the alarm is not deactivated by the elderly person then a message is sent to the care provider.

5.7. Conclusion

Setting up, configuring the smart home monitoring system and implementing the developed intelligent software program has been discussed in this chapter. The developed intelligent software program displayed efficiency in interpreting and detecting person's activity behaviour.

The intelligent software is able to monitor the usage of different household appliances using wireless sensors and recognize the activity pattern in real time. This made the system to identify essential activities of an elderly person, such as preparing breakfast/lunch/dinner, showering, rest room use, dinning, sleeping and self-grooming in real time. Alarms or warning sounds are generated by the system in an event of unusual activity behaviour in terms of appliance usage duration in real time.

Chapter 6

Experimental Results of the Developed Intelligent Software

6.1. Introduction

In order to determine the activity of the elderly person, the software components of the wireless sensor system need to be evaluated. This chapter presents experiments performed that evaluate the ability of developed application software and the reliability of the system's hardware.

The developed intelligent ZigBee based home monitoring had been put on test to detect activity of an elderly person by monitoring the basic appliances used for the day-to-day life. Several levels of alarm conditions have been incorporated based on the inference rules generated from the knowledge base. Apart from inference rule checks, the knowledge base is customized in relation to the need of the activity of a particular individual. The developed intelligent program is able to read continuous data from the coordinator and efficiently stores it on the system for further data processing in real time. The data processing involves steps for multi-level check on the knowledge base for predicting the change in the normal activity pattern of the system and generates alarm in case of any abnormality detected.

The fabricated sensor modules along with ZigBee components are configured to have effective communication with ZigBee coordinator for recording sensor values in system for processing of data. Received sensor data is recorded in different files of the software system and simultaneously do file processing for determining wellness function values, generated warnings and send text message in case of emergency.

During our trials the system would be running for about couple of weeks continuously. The data which is gathered during the first week is used as a reference for activity patter of the inhabitant. This data is used to train up the system. The monitoring system estimates the inhabitant's life pattern after detecting the usage of the appliance. Based on the data gather during the first week a correlation of the appliances usage times and the inhabitant's life pattern is estimated.

6.2. System Installation

In order to successfully deploy sensors around the home, a series of hardware and software installations and configurations were required. The sequence of steps that were taken is described below:

Step 1: Programing the sensors unit to send unique ID for each type of sensor

The sensor units are programed to send unique identifier for each type of sensor. This enables the software program to identify the type sensor it is communicating with. The Table 6.1 below shows the ID's the sensor sensors send to the coordinator.

Table 6.1: Sensor ID and Types of Sensors

Sensor ID	Type of Sensor
011, 012, 013, 014, 015, 016	Electrical Appliance Monitoring Sensors
017. 018, 019, 010	Force Sensors
021, 022	Contact Sensor
031	Temperature & Humidity Sensor
000, 999	Reset/Panic Button

In case of electrical appliance monitoring sensor events, when the appliance is used the sensor system output will be “0” – indicates active status and for inactive status it indicates “1”.

In case of force sensor events to monitor bed, couch, toilet, dining chair the sensor system will transmit ADC value along with the sensor ID’s. Data acquisition unit will process the obtained ADC values to determine the status of the device connected to the force sensor. The program will consider the starting ADC value as the base value and if the corresponding force sensor connected device is used by the elderly, then a new ADC value is transmitted. This new ADC value is compared with the base ADC value to determine the status of the device. If the new ADC value is varied largely then the program will consider as “active” status. If the new ADC value is almost near to the base value then the program will consider as “inactive” status.

For contact sensor events, the contact sensor system connected to devices like fridge door, grooming/drawer cabinet will transmit “0” if there is no connection between the doors, otherwise “1” will be transmitted.

Step 2: Installation of the software package onto the computer

The setup of the data acquisition system involves the installation of the developed intelligent software. Program for Data Acquisition in real-time are written using Microsoft Visual Studio.

Step 3: Connecting the ZigBee Coordinator and GSM modem to PC

Once the intelligent software is installed and running, the ZigBee coordinator and the GSM modem are connected to the PC’s USB ports. The corresponding port numbers are then selected on the software program. ZigBee module acting as coordinator is associated with WSN to collect and monitor the inhabitant behaviour.

Step 4: Set up of wireless sensor nodes

Six electrical sensors, four force sensors, two contact switch sensor, one combined temperature/humidity monitoring sensor, one panic alarm/reset button are installed in home to monitor inhabitant behaviour. The electrical appliances such as hot water kettle, microwave oven, toaster, television, room heater and washing machine are monitored using electrical sensor. The forces sensor based units are used to monitor bed, toilet, sofa, and chair which are used by the elderly person. Fabricated contact sensors are fixed to the fridge and grooming cabinet to detect the open and close door operations for recognizing the usage of these appliances. Other than those sensors, a panic button for emergency help and a temperature cum humidity sensor has been used in the system. Figure 6.1 shows the few installed ZigBee based wireless sensors, which are used to track the appliances used by the person for day-to-day activities.

Figure 6.1: Sensors monitoring some of appliances used for the day-to-day life

Step 5: Execution of the intelligent program

Once all the system's hardware is connected, the serial port is opened on the software program. The program initially records and displays the number of sensors in the network as shown in figure 6.2. This feature enables us to verify whether all the sensor nodes are communication with coordinator and working properly. Any sensor node failure can be detected and rectified at this stage.

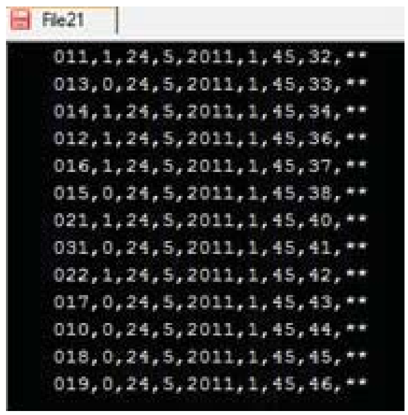


Figure 6.2: Program displaying the number of sensors connected

6.3. System Trials and Evaluation

I have installed and trialled the system for about couple of weeks in four different homes with elderly inhabitants living alone.

6.3.1. Trial 1

The system was installed in a single bed room house, whose inhabitant is a 68 years old person.

6.3.1.1. Sensor Installation

The appliances that are monitored using the wireless sensors in this home are microwave oven, toaster, water kettle, audio device, room heater, television, dining chair, bed, couch, and toilet.

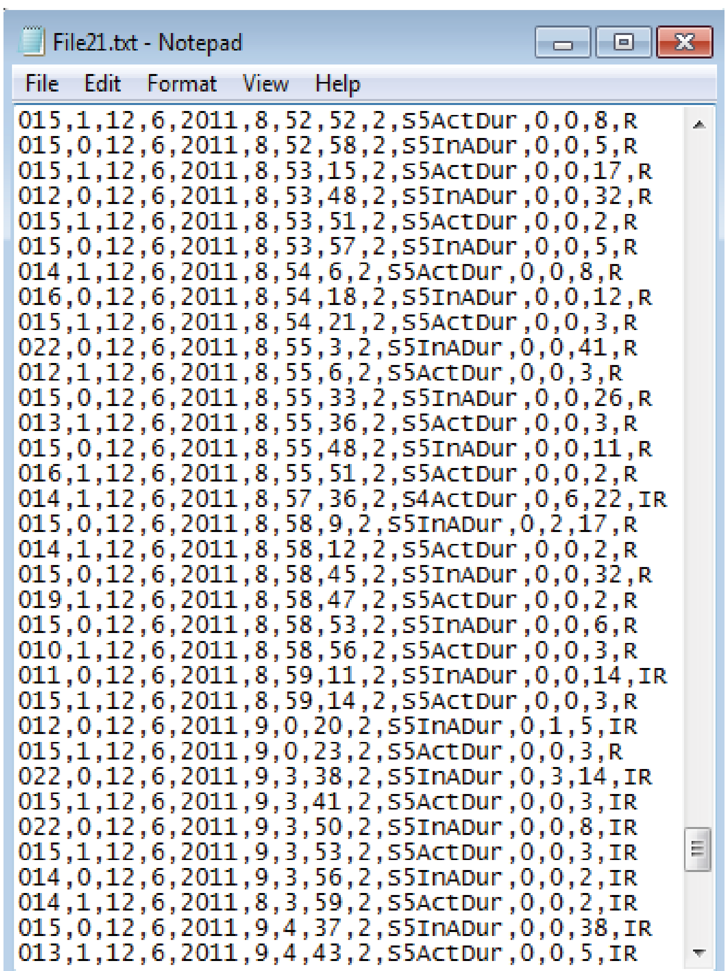
6.3.1.2. Real time sensors data

The following figure 6.3 shows the collection of sensor data at subject-1 house. The sensor event structure is comma (,) separated values as shown in figure xx,

Sensor ID	Status	Date	Month	Year	Hours	Minutes	Seconds	Day of the week	Sensor active/ inactive label	Sensor active/inactive duration (hours)	Sensor active/inactive duration (minutes)	Sensor active/inactive duration (seconds)	Regular/Irregular flag

Figure 6.3: Sensor event structure

The real time sensor data storage file is shown in figure 6.4.



```
File21.txt - Notepad
File  Edit  Format  View  Help
015,1,12,6,2011,8,52,52,2,S5ActDur,0,0,8,R
015,0,12,6,2011,8,52,58,2,S5InADur,0,0,5,R
015,1,12,6,2011,8,53,15,2,S5ActDur,0,0,17,R
012,0,12,6,2011,8,53,48,2,S5InADur,0,0,32,R
015,1,12,6,2011,8,53,51,2,S5ActDur,0,0,2,R
015,0,12,6,2011,8,53,57,2,S5InADur,0,0,5,R
014,1,12,6,2011,8,54,6,2,S5ActDur,0,0,8,R
016,0,12,6,2011,8,54,18,2,S5InADur,0,0,12,R
015,1,12,6,2011,8,54,21,2,S5ActDur,0,0,3,R
022,0,12,6,2011,8,55,3,2,S5InADur,0,0,41,R
012,1,12,6,2011,8,55,6,2,S5ActDur,0,0,3,R
015,0,12,6,2011,8,55,33,2,S5InADur,0,0,26,R
013,1,12,6,2011,8,55,36,2,S5ActDur,0,0,3,R
015,0,12,6,2011,8,55,48,2,S5InADur,0,0,11,R
016,1,12,6,2011,8,55,51,2,S5ActDur,0,0,2,R
014,1,12,6,2011,8,57,36,2,S4ActDur,0,6,22,IR
015,0,12,6,2011,8,58,9,2,S5InADur,0,2,17,R
014,1,12,6,2011,8,58,12,2,S5ActDur,0,0,2,R
015,0,12,6,2011,8,58,45,2,S5InADur,0,0,32,R
019,1,12,6,2011,8,58,47,2,S5ActDur,0,0,2,R
015,0,12,6,2011,8,58,53,2,S5InADur,0,0,6,R
010,1,12,6,2011,8,58,56,2,S5ActDur,0,0,3,R
011,0,12,6,2011,8,59,11,2,S5InADur,0,0,14,IR
015,1,12,6,2011,8,59,14,2,S5ActDur,0,0,3,R
012,0,12,6,2011,9,0,20,2,S5InADur,0,1,5,IR
015,1,12,6,2011,9,0,23,2,S5ActDur,0,0,3,R
022,0,12,6,2011,9,3,38,2,S5InADur,0,3,14,IR
015,1,12,6,2011,9,3,41,2,S5ActDur,0,0,3,IR
022,0,12,6,2011,9,3,50,2,S5InADur,0,0,8,IR
015,1,12,6,2011,9,3,53,2,S5ActDur,0,0,3,IR
014,0,12,6,2011,9,3,56,2,S5InADur,0,0,2,IR
014,1,12,6,2011,8,3,59,2,S5ActDur,0,0,2,IR
015,0,12,6,2011,9,4,37,2,S5InADur,0,0,38,IR
013,1,12,6,2011,9,4,43,2,S5ActDur,0,0,5,IR
```

Figure 6.4: Subject-1 Real-time sensor data

6.3.1.3. Activity Pattern

Sensor activity status is recorded simultaneously in the storage system. Figure 6.5 depicts the activity status of the sensors for a day at the subject-1 house. The active status of the respective sensor against the time of usage in terms of hourly notation is plotted and stored in the file of the storage system for further data processing. Based on the sensor usage times the activity pattern of the subject 1 is estimated.

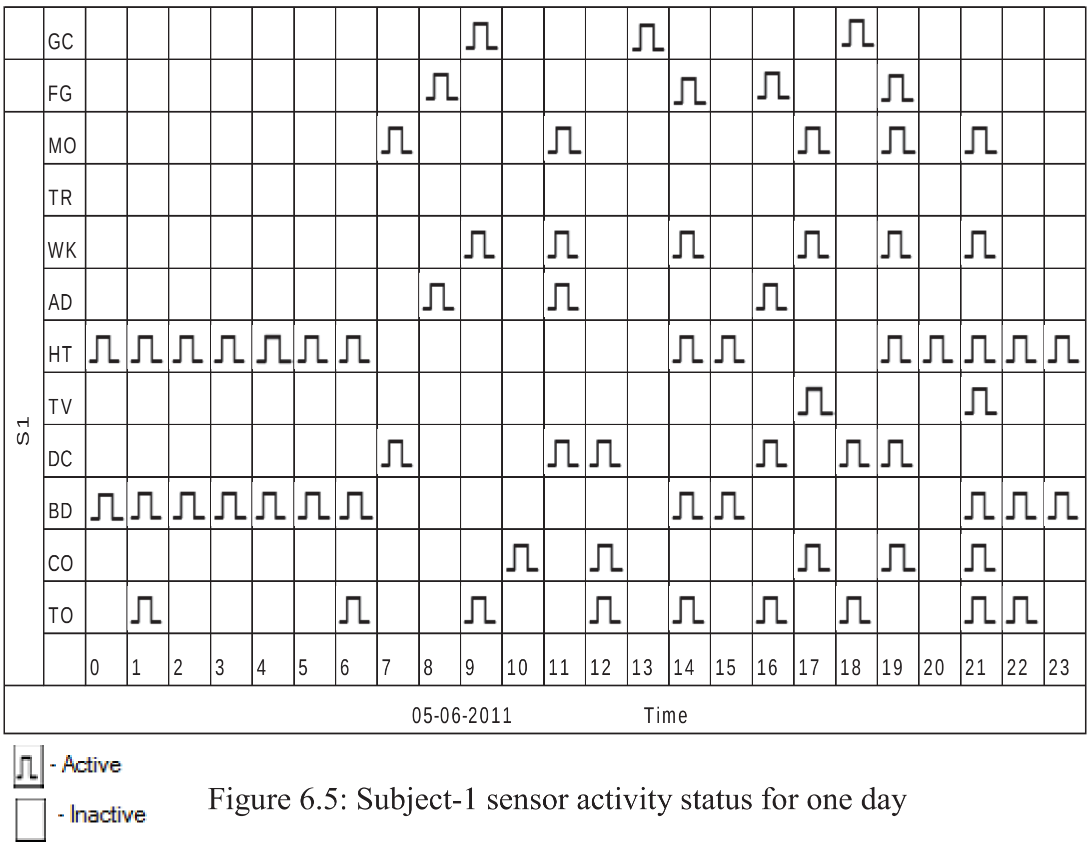


Figure 6.5: Subject-1 sensor activity status for one day

Sensor_id notations are as follows:

MO – Microwave Oven	BD – Bed
TR – Toaster	CO – Couch
WK – Water Kettle	TO – Toilet
AD – Audio device	RH – Room Heater
TV – Television	NA – No Appliance used
GC – Grooming Cabinet	FG – Fridge door
BH – Bed room heater	

6.3.1.4. Active duration of the appliances

Figure 6.6 shows the results of the percentage usage duration of the appliance operations in one day of weekdays.

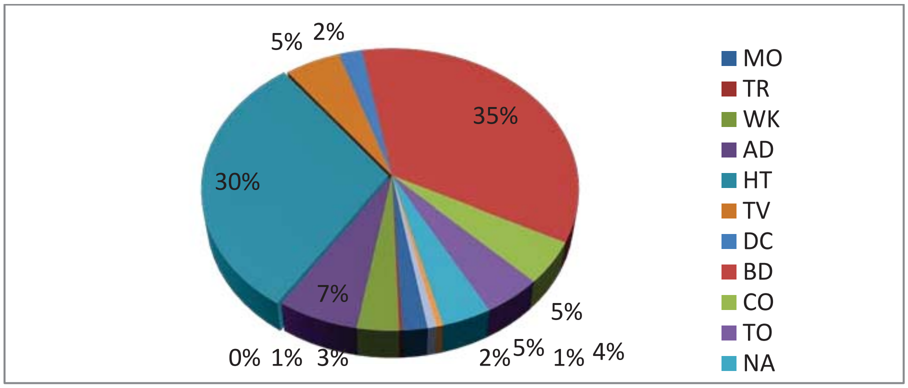


Figure 6.6: Percentage use of different appliances at subject-1 house in one day of weekdays

6.3.1.5. Wellness Determination of Subject-1

The "β_1 and β_2" functions can tell us, how well the inhabitant activity is being performed. The wellness function of the inhabitant based on Inactive measurement (β_1) of appliances is shown in table 6.2.

Table 6.2: Wellness function β_1 measurement for subject-1

Date	Time No Appliance used	Max Time No Appliance used during trial run	β_1
17/07/2011	0:20:15	2:20:15	0.85561
18/07/2011	0:30:52	1:23:16	0.6293
19/07/2011	0:21:15	1:32:15	0.76965
20/07/2011	0:31:45	2:05:15	0.74651
21/07/2011	0:18:25	2:22:39	0.8709
22/07/2011	0:40:12	1:41:15	0.60296
23/07/2011	0:23:56	1:14:58	0.68075

Active duration of every sensor is recorded during one week of trial run and is given in table 6.3.

Table 6.3: Maximum active duration of the appliances during one week trial run

Date/Appliance	Active Duration(hh: mm: ss)											
	Bed	Toilet	Chair	TV	Couch	Microwave	Heater	Water Kettle	Audio Device	Toaster	Fridge	Grooming Cabinet
05/06/2011(Sun)	10:06:00	0:22:20	0:15:45	1:26:50	0:47:45	0:32:25	8:15:16	0:54:12	1:45:56	0:00:00	0:04:56	0:03:25
06/06/2011(Mon)	9:50:10	0:18:35	0:25:35	1:45:20	2:45:50	0:28:42	10:10:19	0:45:16	0:32:56	0:04:12	0:05:10	0:02:10
07/06/2011(Tue)	8:20:10	0:16:45	0:35:28	1:15:10	1:30:10	0:22:15	8:56:22	0:49:20	0:48:46	0:04:13	0:08:19	0:01:58
08/06/2011(Wed)	9:45:50	0:17:55	0:30:20	0:45:50	1:55:20	0:31:19	8:22:56	0:52:12	0:56:59	0:00:00	0:04:28	0:02:05
09/06/2011(Thu)	9:35:25	0:13:20	0:38:45	2:55:30	1:20:10	0:26:33	8:38:45	0:55:32	0:46:12	0:00:00	0:05:40	0:01:16
10/06/2011(Fri)	10:15:25	0:19:45	0:28:35	1:40:20	2:30:45	0:35:16	8:58:10	0:48:19	0:35:19	0:08:56	0:06:10	0:01:08
11/06/2011(Sat)	9:55:15	0:12:55	0:24:30	1:50:10	1:10:35	0:29:58	8:46:49	0:39:15	1:12:02	0:00:00	0:04:58	0:01:41
Maximum	10:15:25	0:22:20	0:38:28	2:55:30	2:45:50	0:29:58	10:10:19	0:54:12	1:45:56	0:08:56	0:08:19	0:03:35

The maximum duration of each appliance which is required for calculating β_2 is derived from this data. During the testing phase β_2 are calculated using the eq. (5.2) and are shown in table 6.4.

Table 6.4: Subject-1 active duration of the appliances during one week testing phase

Date/Appliance	Active Duration(hh: mm: ss)											
	Bed, β_2	Toilet, β_2	Chair, β_2	Couch, β_2	TV β_2	Microwave β_2	Heater β_2	Water Kettle β_2	Audio Device β_2	Toaster β_2	Fridge β_2	Grooming Cabinet β_2
12/06/2011-Sun	9:45:22,	0:18:45,	0:14:35,	0:45:35,	1:55:12	0:18:15	8:15:21	0:22:15	2:10:22	0:05:12	0:07:22	0:02:15
	1.048829	1.160448	1.620884	1.725126	1.34358974	1.39098999	1.18837216	1.589483395	0.769351794	1.41791045	1.11423	1.37209302
13/06/2011-Mon	8:14:28,	0:22:15,	0:17:25,	2:10:40,	1:16:25	0:21:15	9:12:10	0:31:45	2:42:56	0:08:12	0:08:01	0:03:21
	1.196534	0.981343	1.542894	1.21206	1.5645774	1.29087875	1.09527841	1.414206642	**0.461925739**	1.08208955	1.03607	1.06511628
14/06/2011-Tue	9:30:57,	0:16:05,	0:10:30,	1:55:15,	1:56:36	0:25:01	8:25:45	0:26:48	1:56:56	0:08:05	0:06:12	0:03:58
	1.072255	1.25	1.72487	1.305025	1.33561254	1.16518354	1.17133182	1.505535055	0.896161108	1.09514925	1.25451	0.89302326
15/06/2011-Wed	8:50:45,	0:17:10,	0:18:25,	2:45:30,	2:16:29	0:16:26	8:36:12	0:48:12	2:22:17	0:06:58	0:06:56	0:04:22
	1.137576	1.205224	1.516898	1.00201	1.22231719	1.4516129	1.15420956	1.110701107	0.65685966	1.22014925	1.16633	0.78139535
16/06/2011-Thu	9:10:30,	0:19:15,	0:19:55,	2:15:20,	2:36:12	0:22:59	9:45:10	0:44:56	2:16:48	0:07:12	0:07:10	0:03:15
	1.105484	1.115672	1.490901	1.18392	1.10997151	1.23303671	1.04120812	1.17097171	0.708621775	1.19402985	1.13828	1.09302326
17/06/2011-Fri	9:40:20,	0:14:55,	0:15:45,	0:55:40,	2:48:12	0:28:11	8:58:12	0:31:12	2:44:47	0:08:10	0:03:12	0:02:58
	1.057007	1.339552	1.594887	1.664322	1.04159544	1.05951057	1.1181627	1.424354244	**0.444461926**	1.0858209	1.61523	1.17209302
18/06/2011-Sat	10:45:52,	0:18:35,	0:25:20,	0:35:40,	2:10:12	0:23:56	8:19:12	0:24:25	2:05:10	0:06:56	0:04:15	0:03:49
	0.950521	1.160448	1.334922	1.784925	1.25811966	1.20133482	1.18206396	1.549507995	0.81843927	1.2238806	1.48898	0.93488372

β_2 values during one week testing phase at subject-I is shown in Figure 6.7

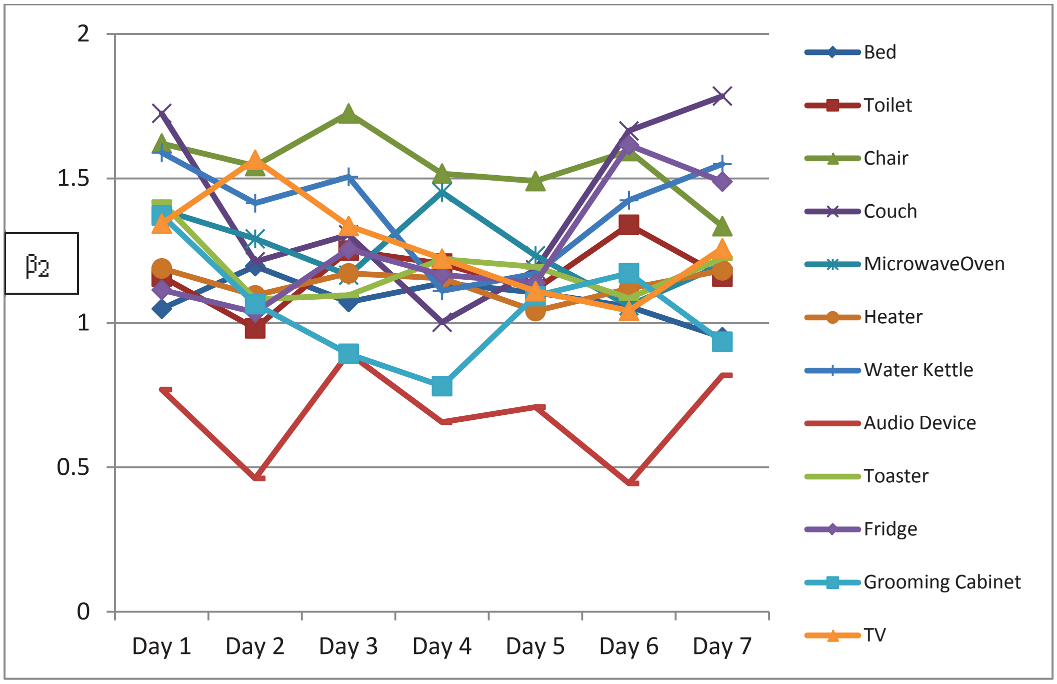


Figure 6.7: β_2 values during one week test run of the system

6.3.1.6. Observations

It can be observed from the table 6.4 there are instances (values denoted in bold) of excess usage of the appliances by the inhabitants during one week of testing phase. The Subject-1 has two instances of over usage of audio device. Firstly it was on 13/06/2011 for time duration two hours, forty two minutes and fifty six seconds which exceeds the maximum utilization duration during trial run (01:45:56). An alarm was generated and subsequently deactivated by the user. As it is a false alarm considered by the user the over usage duration of the corresponding appliance is considered as maximum utilization duration of the device by the inhabitant and the intelligent program has updated its knowledge base as normal active duration. Also, it was observed that the subsequent utilization of the audio device (i.e.) on 17/06/2011, alarm was not generated up-to two hours forty two minutes and fifty six seconds but when it crossed this limit an alarm was raised and the user has deactivated the alarm using panic/reset button. Developed program was able to consider the excess usage duration of appliances as normal usage duration if the user has deactivated the alarm.

6.3.2. Trial 2

The system was installed in a single bed room house, whose inhabitant is a 66 years old person.

6.3.2.1. Sensor Installation

The appliances that are monitored using the wireless sensors in this home are microwave oven, toaster, water kettle, room heater, bed room heater, television, dining chair, bed, couch, fridge door, and toilet.

6.3.2.2. Activity Pattern

Based on the sensor usage times the activity pattern of the subject 2 is estimated in day of the week. Figure 6.8 depict the real time active status of the sensors at the subject-2's house.

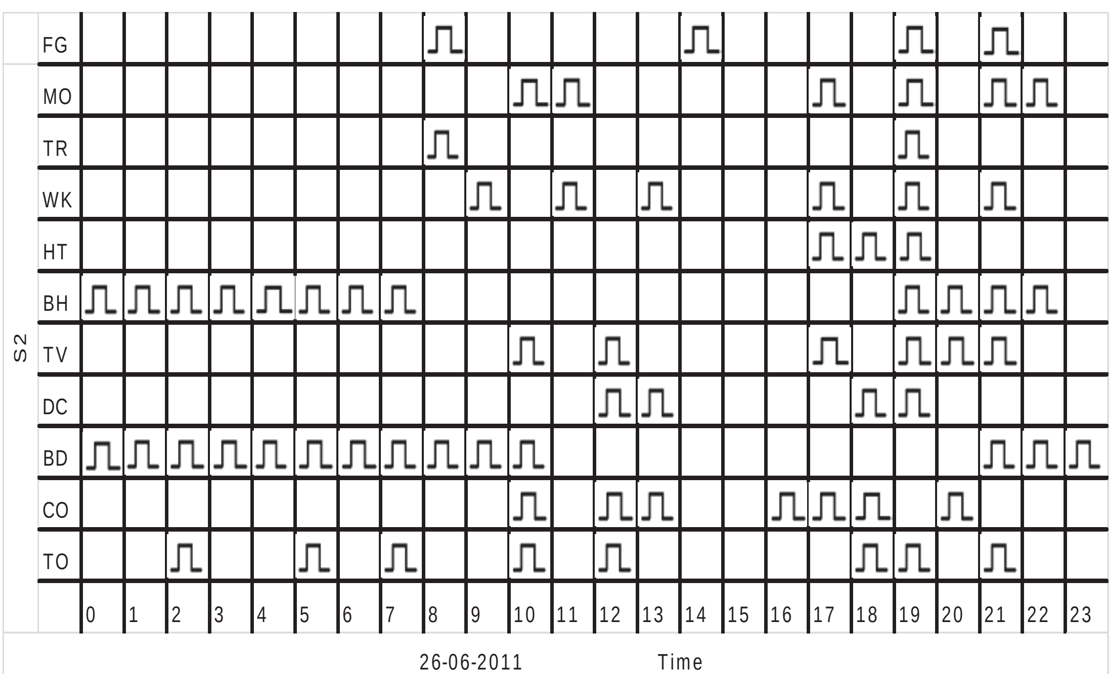


Figure 6.8: Subject-2 real-time sensor activity status

6.3.2.3. Active duration of the appliances

Figure 6.9 shows the results of the percentage usage duration of the appliance operations in one day of weekdays.

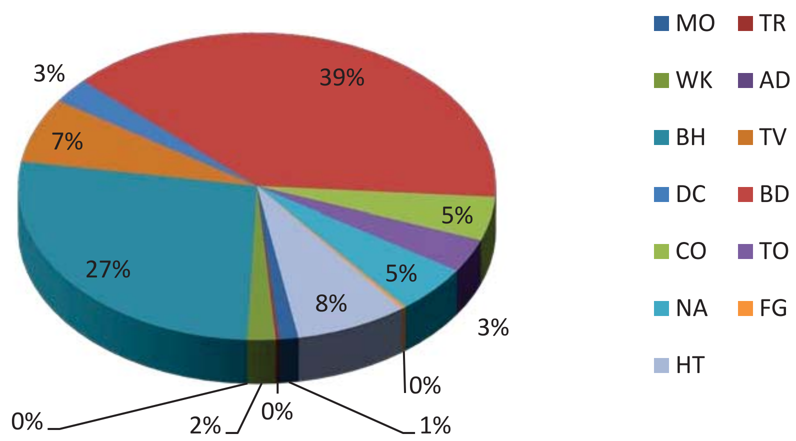


Figure 6.9: Percentage use of different appliances at subject-2 house

6.3.2.4. Wellness Determination of the Subject-2

The wellness function of the inhabitant based on Inactive measurement (β_1) of appliances is shown in table 6.5.

Table 6.5: Wellness function β_1 measurement for subject-2

Date	**Time No Appliance used**	**Max Time No Appliance used during trial run**	**β1**
26/06/2011(Sun)	0:35:45	1:10:15	**0.491103**
27/06/2011(Mon)	0:12:10	0:55:10	0.7794562
28/06/2011(Tue)	0:05:23	0:52:41	0.8978171
29/06/2011(Wed)	0:04:56	1:02:14	0.9207284
30/06/2011(Thu)	0:02:45	1:10:56	0.9612312
01/07/2011(Fri)	0:03:49	0:47:12	0.9191384
02/07/2011(Sat)	0:04:10	1:25:10	0.9510763

Active duration of every sensor is recorded during one week of trial run and is shown in table 6.6.

Table 6.6: Maximum active duration of the appliances during one week trial run

Date/Appliance	Active Duration(hh: mm: ss)										
	Bed	Toilet	Chair	TV	Couch	Microwave Oven	Bedroom Heater	Water Kettle	Room Heater	Toaster	Fridge
26/06/2011(Sun)	10:35:22	0:18:46	0:14:55	0:57:25	0:37:45	0:20:15	10:15:21	0:21:15	5:21:15	0:03:21	0:04:21
27/06/2011(Mon)	9:45:30	0:16:55	0:18:35	0:35:20	0:55:50	0:31:20	9:58:45	0:20:56	4:48:21	0:03:25	0:02:22
28/06/2011(Tue)	8:50:50	0:12:35	0:16:25	1:25:10	1:40:30	0:18:21	10:21:15	0:04:21	4:22:45	0:03:20	0:04:46
29/06/2011(Wed)	9:35:31	0:11:25	0:12:40	1:48:50	1:55:20	0:21:15	10:52:46	0:31:01	4:56:22	0:00:00	0:02:58
30/06/2011(Thu)	8:45:55	0:13:53	0:18:05	0:45:20	0:50:40	0:05:21	8:56:12	0:08:42	2:54:01	0:03:21	0:02:01
01/07/2011(Fri)	9:58:10	0:14:37	0:17:42	1:15:40	0:40:15	0:11:02	9:25:12	0:24:56	3:25:48	0:12:10	0:04:58
02/07/2011(Sat)	10:15:45	0:15:19	0:15:25	2:30:10	1:50:25	0:21:15	9:54:26	0:16:21	4:28:47	0:00:00	0:02:12
Maximum	10:35:22	0:18:46	0:18:35	2:30:10	1:55:20	0:31:20	10:52:46	0:31:01	5:21:15	0:12:10	0:04:58

The maximum duration of each appliance which is required for calculating β_2 is derived from this data. During the testing phase β_2 are calculated using the eq. (5.2) and are shown in table 6.7.

Table 6.7: Maximum active duration & β_2 values during a week of testing phase

Date/Appliance	Active Duration(hh: mm: ss)										
	Bed, β_2	Toilet β_2	Chair β_2	Couch β_2	TV β_2	Microwave Oven β_2	Bedroom Heater β_2	Water Kettle β_2	Room Heater β_2	Toaster β_2	Fridge β_2
03/07/2011	10:15:10	0:16:10	0:20:15	0:45:50	0:36:12	0:16:22	8:21:15	0:21:15	4:58:12	0:00:00	0:03:25
(Sun)	1.031793	1.138544	0.910314	1.602601	1.75893452	1.4776596	1.23211459	1.3148845	1.071751	2	1.3120805
04/07/2011	8:10:15	0:14:15	0:14:35	1:10:15	1:05:12	0:21:36	9:45:10	0:16:58	4:31:22	0:03:35	0:03:24
(Mon)	1.228398	1.245115	1.233184	1.390896	1.56581576	1.3106383	1.10355921	1.4529823	1.1552789	1.7054795	1.3154362
05/07/2011	9:15:10	0:12:25	0:16:18	0:55:10	0:22:12	0:04:58	7:15:22	0:22:46	5:31:59	0:00:00	0:02:45
(Tue)	1.126226	1.351687	1.125561	1.521676	1.85216426	1.8414894	1.33304397	1.265986	0.9665888	2	1.4463087
06/07/2011	8:55:30	0:09:45	0:28:20	0:35:15	0:23:45	0:20:58	8:26:45	0:26:22	4:22:47	0:03:36	0:03:25
(Wed)	1.15718	1.511545	**0.479821**	1.694364	1.8418424	1.3308511	1.22368891	1.1499194	1.1819974	1.7041096	1.3120805
07/07/2011	9:35:35	0:13:30	0:12:15	1:45:10	1:35:12	0:25:58	7:56:10	0:08:52	4:56:12	0:03:30	0:04:45
(Thu)	1.094093	1.298401	1.340807	1.608382	1.36603774	1.1712766	1.27054078	1.7141322	1.0779767	1.7123288	1.0436242
08/07/2011	9:20:45	0:12:15	0:35:45	0:58:20	0:45:12	0:14:58	8:19:19	0:13:29	5:01:12	0:00:00	0:03:53
(Fri)	1.117439	1.351687	**0.103139**	1.49422	1.69900111	1.5223404	1.23507634	1.5652875	1.0624125	2	1.2181208
09/07/2011	9:55:20	0:15:35	0:19:30	1:05:15	0:56:12	0:21:01	8:06:59	0:24:45	5:12:10	0:06:12	0:04:47
(Sat)	1.063008	1.191829	0.964126	1.434249	1.62574917	1.3292553	1.25397028	1.2020419	1.028275	1.490411	1.0369128

The graph with the calculated β_2 values during one week testing phase is shown in figure 6.10.

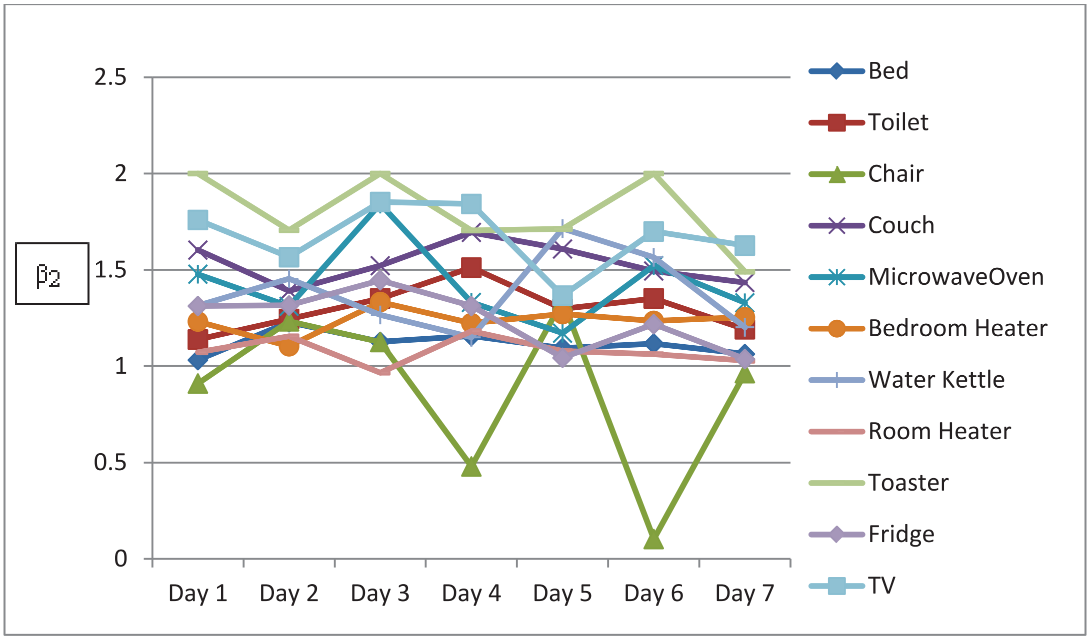


Figure 6.10: β_2 values during one week test run of the system

6.3.2.5. Observations

It can be observed from the table 6.5 (values denoted in bold), there one instance where β_1 was below 0.5, this made the system to generate an alarm. Also there are two instances (values denoted in bold), where Subject 2 has over usage of chair. This time an alarm was generated and a text message was sent.

6.3.3. Trial 3

The system was installed in a single bed room house, whose inhabitant is a 72 years old female living alone.

6.3.3.1. Sensor Installation

The appliances that are monitored using the wireless sensors in this home are microwave oven, toaster, water kettle, bed room heater, room heater, television, dining chair, bed, couch, drawer cabinet and toilet.

6.3.3.2. Activity Pattern

Based on the sensor usage times the activity pattern of the subject 3 is estimated in day of the week. Figure 6.11 depict the real time active status of the sensors at the subject house.

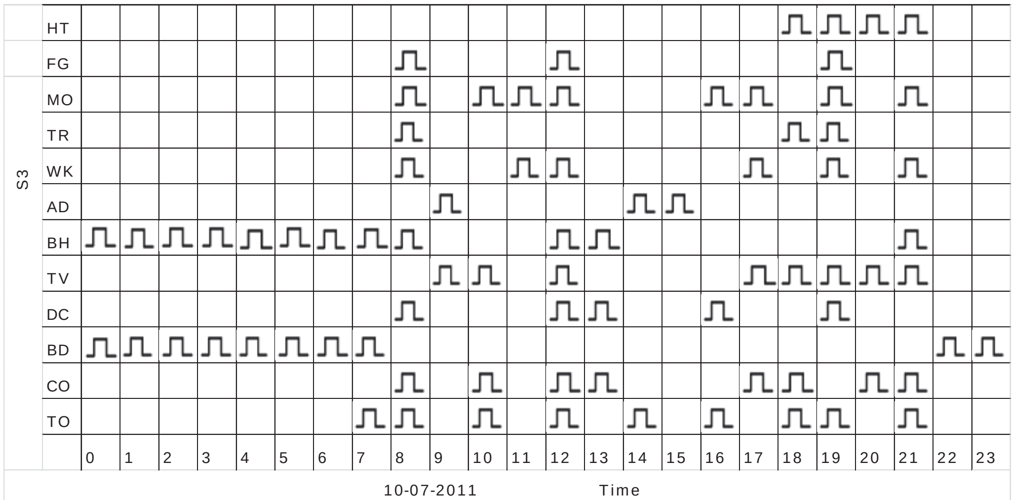


Figure 6.10: Subject-3 Real-time sensor activity status

6.3.3.3. Active duration of the appliances

Figure 6.11 shows the results of the percentage usage duration of the appliance operations in one day of weekdays.

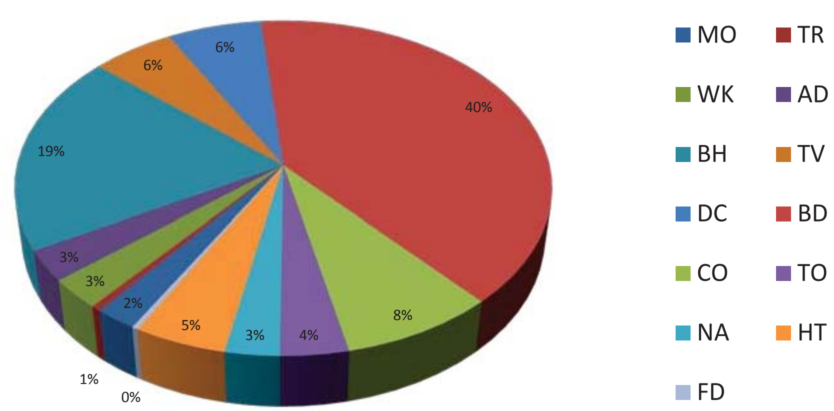


Figure 6.11: Percentage use of different appliances at subject-3 house

6.3.3.4. Wellness Determination of the Subject-3

The wellness function of the inhabitant based on Inactive measurement (β_1) of appliances is shown in table 6.8.

Table 6.8: Wellness function β_1 measurement for subject-3

Date	Time No Appliance used	Max Time No Appliance used during trial run	β1
17/07/2011(Sun)	0:21:16	0:44:10	0.5184906
18/07/2011(Mon)	0:15:59	0:31:56	**0.499478**
19/07/2011(Tue)	0:12:16	0:56:01	0.7810176
20/07/2011(Wed)	0:16:32	0:47:36	0.6526611
21/07/2011(Thu)	0:04:12	1:03:12	0.9335443
22/07/2011(Fri)	0:19:47	0:51:26	0.6153597
23/07/2011(Sat)	0:23:45	0:45:37	**0.479357**

Active duration of every sensor is recorded during one week of trial run and is shown in table 6.9.

Table 6.9: Maximum active duration of the appliances during one week trial run

Date/Appliance	Active Duration(hh: mm: ss)											
	Bed	Toilet	Chair	TV	Couch	Microwave Oven	Bedroom Heater	Water Kettle	Room Heater	Toaster	Fridge	Drawer Cabinet
10/07/2011(Sun)	10:06:00	0:22:20	0:15:45	1:26:50	0:47:45	0:20:15	8:12:23	0:42:10	3:10:12	0:02:12	0:05:46	0:01:02
11/07/2011(Mon)	9:50:10	0:18:35	0:25:35	1:45:20	2:45:50	0:31:20	8:45:45	0:50:12	3:12:45	0:02:13	0:05:45	0:01:12
12/07/2011(Tue)	8:20:10	0:16:45	0:35:28	1:15:10	1:30:10	0:18:21	9:10:12	0:32:46	2:36:48	0:02:12	0:06:53	0:00:52
13/07/2011(Wed)	9:45:50	0:17:55	0:30:20	0:45:50	1:55:20	0:21:15	8:15:36	0:36:12	3:23:49	0:02:12	0:04:45	0:01:03
14/07/2011(Thu)	9:35:25	0:13:20	0:38:45	2:55:30	1:20:10	0:05:21	8:26:10	0:41:12	3:59:45	0:04:42	0:07:00	0:00:52
15/07/2011(Fri)	10:15:25	0:19:45	0:28:35	1:40:20	2:30:45	0:11:02	8:06:02	0:46:37	2:56:47	0:00:00	0:06:14	0:048
16/07/2011(Sat)	9:55:15	0:12:55	0:24:30	1:50:10	1:10:35	0:21:15	8:36:12	0:29:13	2:10:12	0:00:00	0:03:49	0:02:45
Maximum	10:15:25	0:22:20	0:38:28	2:55:30	2:45:50	0:31:20	9:10:12	0:50:12	3:59:45	0:04:42	0:07:00	0:02:45

The maximum duration of each appliance is derived from this data. During the testing phase β2 are calculated using the eq. (5.2) and are shown in table 6.10.

Table 6.10: Subject-3 maximum active duration of the appliances and β_2 values during one week testing phase

Date/Appliance	Active Duration(hh: mm: ss)											
	Bed	Toilet	Chair	Couch	Microwave	TV	Bedroom Heater	Water Kettle	Room Heater	Toaster	Fridge	Drawer Cabinet
	β_2	β_2	β_2	β_2	β_2	β_2	β_2	β_2	β_2	β_2	β_2	β_2
17/07/2011(Sun)	9:45:22,	0:18:45,	0:14:35,	0:45:35,	0:15:45	0:40:12	8:21:22	0:44:56	2:45:10	0:00:00	0:05:45	0:01:23
	1.048829	1.160448	1.620884	1.725126	1.497340426	1.770940171	1.0887556	1.10491368	1.31108794	2	1.17857143	1.4969697
18/07/2011(Mon)	8:14:28,	0:22:15,	0:17:25,	2:10:40,	0:28:11	1:56:12	7:56:11	0:45:50	2:23:10	0:00:00	0:03:53	0:01:56
	1.196534	0.981343	1.542894	1.21206	1.100531915	1.337891738	1.13452684	1.08698539	1.40285019	2	1.4452381	1.2969697
19/07/2011(Tue)	9:30:57,	0:16:05,	0:10:30,	1:55:15,	0:18:25	1:36:12	8:15:19	0:55:10	3:23:10	0:02:12	0:04:47	0:00:48
	1.072255	1.25	1.72487	1.305025	1.412234043	1.451851852	1.09975161	0.90106242	1.1525895	1.53191489	1.31666667	1.70909091
20/07/2011(Wed)	8:50:45,	0:17:10,	0:18:25,	2:45:30,	0:31:45	2:46:12	8:15:21	0:35:15	3:59:12	0:02:12	0:02:12	0:01:01
	1.137576	1.205224	1.516898	1.00201	0.986702128	1.052991453	1.09969102	1.29780876	1.00229406	1.53191489	1.68571429	1.63030303
21/07/2011(Thu)	9:10:30,	0:19:15,	0:19:55,	2:15:20,	0:17:25	2:46:12	9:46:17	0:58:20	3:13:10	0:02:13	0:03:49	0:00:58
	1.105484	1.115672	1.490901	1.18392	1.444148936	1.052991453	0.93441779	0.83798141	1.19429962	1.52836879	1.4547619	1.64848485
22/07/2011(Fri)	9:40:20,	0:14:55,	0:15:45,	0:55:40,	0:08:10	1:55:12	8:12:12	0:48:12	2:19:10	0:00:00	0:03:25	0:02:02
	1.057007	1.339552	1.594887	1.664322	1.739361702	1.343589744	1.10541621	1.03984064	1.41953424	2	1.51190476	1.26060606
23/07/2011(Sat)	10:45:52,	0:18:35,	0:25:20,	0:35:40,	0:18:45	2:10:12	8:26:10	0:31:45	3:45:10	0:02:12	0:04:45	0:01:46
	0.950521	1.160448	1.334922	1.784925	1.401595745	1.258119658	1.0800315	1.36752988	1.06082725	1.53191489	1.32142857	1.35757576

The graph with the calculated β_2 values during one week testing phase is shown in figure 6.12.

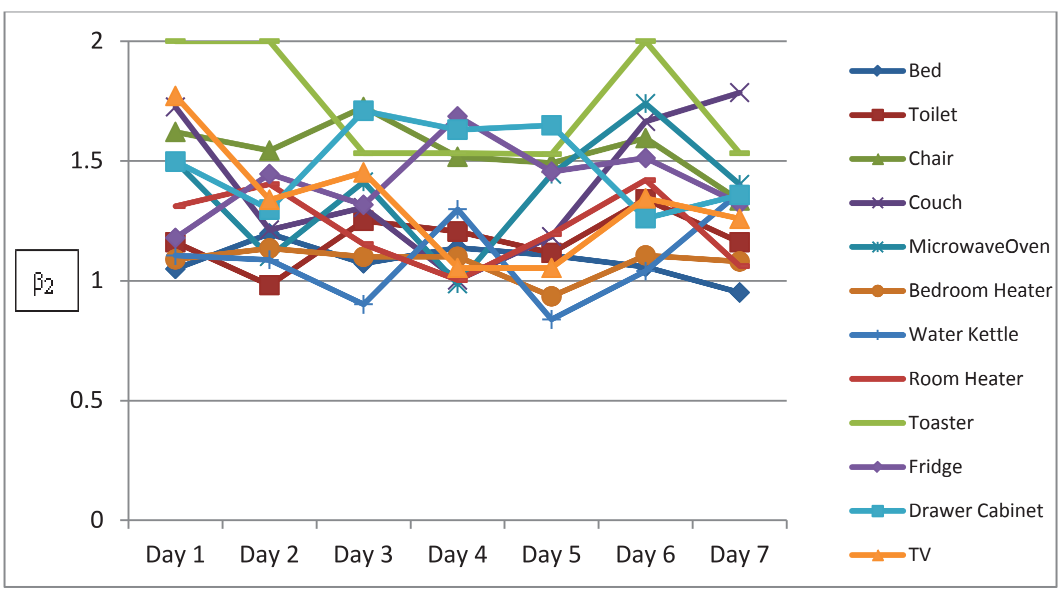


Figure 6.12: β_2 values during one week test run of the system

6.3.3.5. Observations

It can be observed from the table 6.8 there the wellness function β_1 is not in the safe zone (i.e. >0.5). The system has generated an alarm and a warning text message was sent in this instance.

6.3.4. Trial 4

The system was installed in a single bed room house, whose inhabitant is a 66 years old male living alone.

6.3.4.1. Sensor Installation

The appliances that are monitored using the wireless sensors in this home are microwave oven, toaster, water kettle, bed room heater, room heater, television, dining chair, bed, couch, drawer cabinet and toilet.

6.3.4.2. Activity Pattern

Based on the sensor usage times the activity pattern of the subject-4 is estimated in day of the week. Figure 6.13 depict the real time active status of the sensors at the subject house.

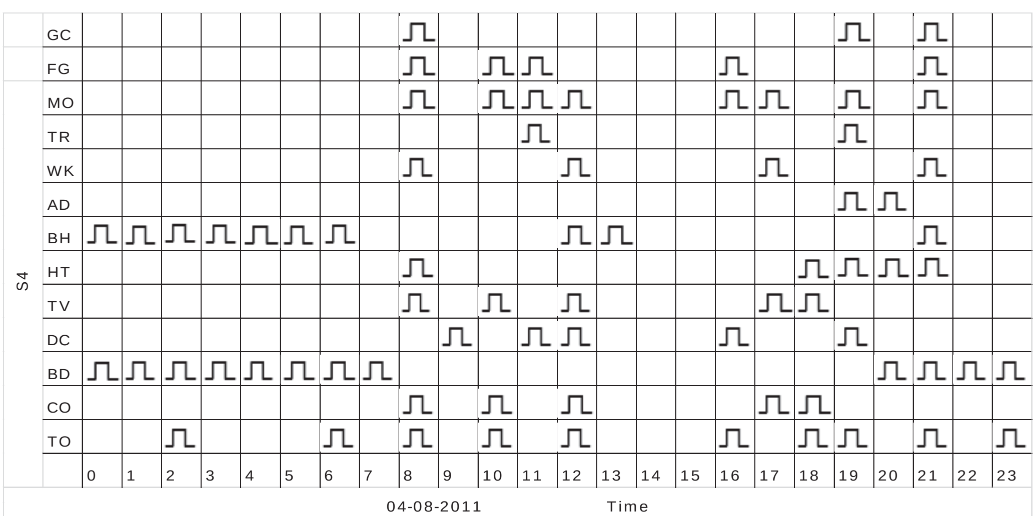


Figure 6.13: Subject-4 Real-time sensor activity status

6.3.4.3. Active duration of the appliances

Figure 6.14 shows the results of the percentage usage duration of the appliance operations in one day of weekdays.

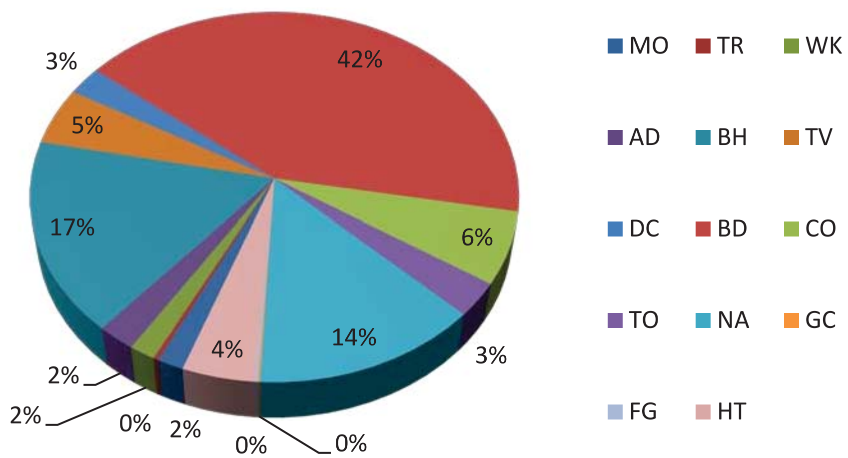


Figure 6.14: Percentage use of different appliances at subject-4 house

6.3.4.4. Wellness Determination of the Subject-4

The wellness function of the inhabitant based on Inactive measurement (β_1) of appliances is shown in table 6.11.

Table 6.11: Wellness function β_1 measurement for subject-4

Date	**Time No Appliance used**	**Max Time No Appliance used during trial run**	β_1
31/07/2011(Sun)	0:23:16	1:22:15	0.717122594
01/08/2011(Mon)	0:45:33	2:15:12	0.663091716
02/08/2011(Tue)	0:51:45	2:56:12	0.706299659
03/08/2011(Wed)	0:01:12	2:16:23	0.991201271
04/08/2011(Thu)	2:00:00	2:15:22	**0.113518838**
05/08/2011(Fri)	0:26:12	1:12:12	0.637119114
06/08/2011(Sat)	0:52:12	1:49:56	0.525166768

Active duration of every sensor is recorded during one week of trial run and is shown in table 6.12.

Table 6.12: Subject-4 maximum active duration of the appliances during one week trial run

Date/Appliance	Active Duration(hh: mm: ss)											
	Bed	Toilet	Chair	TV	Couch	Microwave	Bedroom Heater	Water Kettle	Room Heater	Toaster	Fridge	Grooming Cabinet
24/07/2011(Sun)	9:05:15	0:18:35	0:34:15	0:57:45	0:42:55	0:08:42	10:21:15	0:22:15	1:15:10	0:16:12	0:05:45	0:03:25
25/07/2011(Mon)	8:35:45	0:14:05	0:18:10	1:25:10	1:17:23	0:20:56	10:59:41	0:04:21	1:45:20	0:03:35	0:03:53	0:02:45
26/07/2011(Tue)	9:15:30	0:16:30	0:14:20	1:45:20	0:45:30	0:21:15	9:25:12	0:28:42	0:45:50	0:03:30	0:04:47	0:02:15
27/07/2011(Wed)	8:56:40	0:11:25	0:16:30	0:48:52	1:25:15	0:04:21	8:45:45	0:26:33	2:55:30	0:06:12	0:02:12	0:03:21
28/07/2011(Thu)	8:20:10	0:15:18	0:18:45	1:05:20	1:40:15	0:16:21	8:56:12	0:31:19	1:50:10	0:04:42	0:03:49	0:03:15
29/07/2011(Fri)	9:24:35	0:17:30	0:22:30	1:10:15	0:45:35	0:31:01	9:10:12	0:24:56	1:40:20	0:00:00	0:03:25	0:04:45
30/07/2011(Sat)	9:15:05	0:19:24	0:16:40	1:36:25	1:12:20	0:24:56	8:12:23	0:21:12	1:26:50	3:30:05	0:04:45	0:03:05
Maxium	9:24:35	0:19:24	0:34:15	1:45:20	1:40:15	0:31:01	10:59:41	0:31:19	2:55:30	0:16:12	0:05:45	0:04:45

The maximum duration of each appliance is derived from this data. During the testing phase β_2 are calculated using the eq. (5.2) and are shown in table 6.13.

Table 6.13: Subject-4 maximum active duration of the appliances and β_2 values during one week testing phase

Date/Appliance	Active Duration(hh: mm: ss)											
	Bed β_2	Toilet β_2	Chair β_2	Couch β_2	Microwave β_2	Bedroom Heater β_2	Water Kettle β_2	TV β_2	Room Heater β_2	Toaster β_2	Fridge β_2	Grooming Cabinet β_2
31/07/2011(Sun)	10:02:35	0:28:36	0:24:45	1:10:45	0:15:10	8:52:47	0:16:11	1:55:10	1:15:10	0:14:23	0:03:53	0:03:20
	0.932694	**0.525773**	1.27737	1.294264	1.51101558	1.19236502	1.48323576	0.90664557	1.57169991	1.11214	1.32463768	1.298246
01/08/2011(Mon)	9:24:56	0:19:25	0:16:20	0:45:28	0:16:22	9:30:53	0:12:15	2:24:23	1:26:50	0:03:20	0:08:56	0:04:46
	0.99938	0.999141	1.523114	1.546467	1.47232671	1.13461004	1.60883449	0.62927215	1.50522317	1.794239	0.44637681	0.996491
02/08/2011(Tue)	9:30:12	0:22:30	0:22:45	0:50:28	0:23:56	8:25:45	0:13:30	1:10:23	0:45:50	0:00:00	0:04:10	0:02:22
	0.990052	0.840206	1.335766	1.496592	1.22837184	1.23334428	1.56891964	1.3318038	1.73884141	2	1.27536232	1.501754
03/08/2011(Wed)	9:45:20	0:18:45	0:18:50	1:25:30	0:25:01	9:45:10	0:12:15	1:34:10	1:15:40	0:03:21	0:03:25	0:04:21
	0.963247	1.033505	1.450122	1.147132	1.19344438	1.11295824	1.60883449	1.10601266	1.5688509	1.79321	1.4057971	1.084211
04/08/2011(Thu)	8:50:10	0:16:30	0:25:45	0:35:45	0:25:58	8:19:09	0:15:21	2:14:10	0:56:59	0:02:13	0:03:32	0:04:42
	1.060959	1.149485	1.248175	1.643392	1.16281569	1.24334908	1.50984566	0.72626582	1.67530864	1.863169	1.38550725	1.010526
05/08/2011(Fri)	9:45:20	0:26:45	0:27:30	1:15:10	0:21:36	8:56:12	0:06:48	2:35:12	2:30:10	0:00:00	0:03:49	0:03:25
	0.963247	**0.621134**	1.19708	1.250208	1.30360021	1.18718577	1.78286323	**0.52658228**	1.14434948	2	1.33623188	1.280702
06/08/2011(Sat)	9:55:36	0:17:30	0:32:38	1:20:50	0:22:59	8:13:19	0:15:25	2:35:12	1:45:20	0:03:25	0:05:21	0:02:13
	0.945063	1.097938	1.047202	1.193682	1.25900054	1.25219171	1.50771687	**0.52658228**	1.39981007	1.789095	1.06956522	1.533333

The graph with the calculated β_2 values during one week testing phase is shown in figure 6.15.

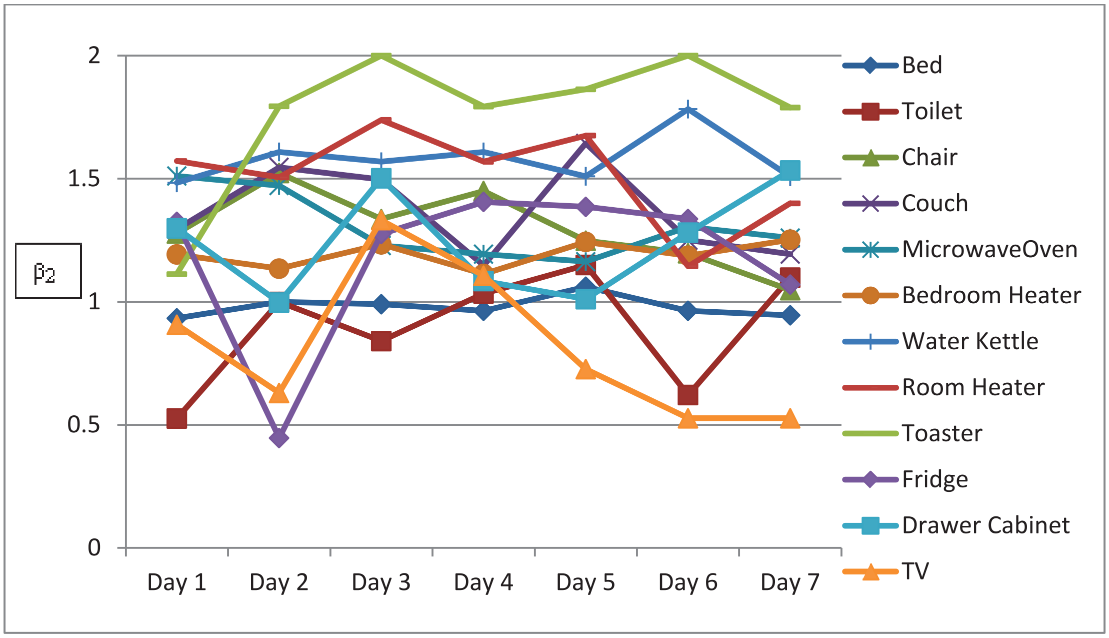


Figure 6.15: β_2 values during one week test run of the system

6.3.4.5. Observations

It can be observed from the table 6.11 there is an instance (value denoted in bold) where β_1 value is less than 0.5. The subject-4 went out to for shopping for about three hours. An alarm was generated and warning text message was sent by the system in this instance. From the table 6.13, the β_2 value was also less than 0.5 for two instances. The television was turned on for time exceeding the active maximum time of this appliance. So an alarm was triggered and subsequently disabled by the subject-4 for both instances.

6.4. Issues Encountered

Real-time activity behaviour recognition of the inhabitant and determination of wellness function of the inhabitant using the activity of appliances was encouraging as the system was stable in executing the tasks for weeks of testing.

But some practical issues that are encountered while installing the elderly activity monitoring system at different subject houses are,

1. Attachment of electrical sensor to the TV electrical plug point.
2. Placement of the force sensor beneath the bed.
3. Frequent ON and OFF status from the electrical (TV) and force sensors (Bed, Couch).
4. Bed too heavy to lift for placing force sensor correctly in order to read status.
5. No status change from Bed, Couch because of heavy weight.
6. Unable to plug Toilet force sensor to electrical point.
7. Some electrical sensor like TV and microwave were always ON due to the make feature of the respective electrical device.

6.5. Conclusion

The system has been tested in real time environment, issues regarding the system installation have been discussed in detail in this chapter. The smart home monitoring system has been trialled and evaluated on four different homes with elderly inhabitants. The installation issues that were faced, real time captured sensor data, inhabitant's activity pattern and interpreting the wellness function of the inhabitant has been practically demonstrated by the system.

By augmenting the wellness functions gave intelligence to the system for determining the habitual behaviour of the inhabitant. By these intelligent features the system is able to identify the abnormal behaviour of the inhabitant just by monitoring the usage of the daily household appliances.

Chapter 7: Conclusions and Suggestions for Future Work

7.1. General Conclusions

This thesis has undertaken a fundamental study to develop an in-house sensing system based on wireless sensor networks to monitor elderly. The wireless elderly monitoring system demonstrates that smart, simple sensor devices can be used to recognize activities of daily living and life style of elderly person living alone. The system is becoming more complete as more intelligent features are added to detect the daily activity patterns efficiently. Even though it uses a limited number of sensors, it can capture the abnormality in a person's daily routine by recognizing the use of appliances necessary for daily living, thus determining the life style of elderly person living alone. The system can be installed/ maintained in residential environments without any complexity. Moreover, the proposed sensing system presents an alternative to sensors that are perceived by most people as invasive such as use of cameras and microphones, making the sensors are almost invisible to the user thereby increasing the acceptance level to use the system in a house hold environment. The system can be easily installed in an existing home environment with no major modifications or damage.

The developed system continuously monitor the activity of the elderly person staying alone and generate the sensor activity pattern to analyse and foresee the changes in daily activities of the elderly person. In the near future, the generated activity pattern related to weekdays and weekends will be used to predict the unusual behaviour of the elderly person based on the classification model of regular and irregular sensor activity. Results of Real-time activity behaviour recognition of the inhabitant were encouraging. Classification of abnormal situation based on multi-level check method was validated with machine learning methods. Integration of wellness function in the developed software system was effectively able to determine the abnormal situation of the inhabitant.

Chapter 1 gave a brief introduction elderly population growth across the world. Statistics discussed in this chapter shows that there is increasing number of elderly people around the world and this is not going to change. At old age, elderly people are not physically strong enough and are prone to different types of accidents, creating the need to increase hospital care. In some situation they are not allowed to be at their own home. If they prefer to live alone they do however require constant monitoring so that help can be provided immediately in times of dire needs. The best solution is a wireless solution as it allows the units to be small, easy to install, and much more convenient. By integrating sensing in the house hold devices would allow people to be monitored constantly. The benefit by this approach is to help increase health monitoring of elderly people.

Chapter 2 discusses the review of research in the field of the smart home monitoring. Various issues, methodologies and methods involved in developing the in this field are reviewed and discussed. Modern smart sensors, together with advanced wireless communication technology, can assist in building systems that can be deployed to monitor people non-invasively in real time. Such systems are cost effective, easy to install and maintain and provide a great sense of security to not only the person living alone but also to the family and care givers. It is envisaged that with the rapid increase of the population of the aged people in the world, such systems will find wide acceptance and become prevalent.

This chapter details several of the sensors which can be used effectively to build a smart home monitoring system. The design and various issues involved in developing and integrating the sensors has been detailed. More specifically reviews on Smart homes using audio – visual based systems, wearable sensors and sensors for tracking/ monitoring various appliances in a home are discussed.

Chapter 3 details of the design and implementation of the first prototype of the wireless sensor network based home monitoring system. This wireless monitoring system called “Selective Activity Monitoring (SAM) system”. SAM is an electronic system designed to support people who wish to live alone but, because of age, a health problem or disability, there is some risk in this which worries their family or friends. The system offers such people an unobtrusive safety net which monitors the activity of appliances throughout the house and contacts family members or close friends upon unusual activity. The system is completely customizable, allowing the user to select which appliances to monitor and exactly what is classified as unusual behaviour.

Detection devices for general equipment (such as the kettle and toaster) act as a medium between the power socket and the equipment to be monitored, installation is as simple as plugging in an extension cord. The detection devices detect the flow of electrical current through the appliance and can therefore determine whether the appliance is active or inactive. Information relating to the activity of appliances around the home is transmitted to a personal computer via a radio frequency communications protocol, the data is then examined for unusual activity and logged for possible future reference. The SAM system is capable of wirelessly sending a text message to a specified cell phone number, this allows the system to send for help, should help be required. This system is a proof of concept that has been successfully designed and fabricated.

In Chapter 4 development of ZigBee based smart home monitoring system for elderly monitoring has been discussed. A comparative study and reason choosing ZigBee based communication for the system is discussed. A brief review on the ZigBee architecture and ZigBee for elderly home monitoring is discussed. An intelligent home monitoring unit based on ZigBee wireless sensors has been designed and developed to assist and monitor the inhabitant living in smart environment. The system works on the principle of using sensor units to monitor the basic household appliances used for day-to-day life of the elderly person being monitored. A central coordinator of the sensors collects the data from the sensors connected to various appliances.

Electrical appliance monitoring unit has been modified to monitor more than one appliance to reduce the sensor-count. The electrical appliance monitoring unit is fabricated to accommodate three different electrical appliances on a single power inlet, having the intelligence to detect which particular device is ON and for how long it is used. The new version of bed monitoring sensor incorporated with monitoring system to detect the abnormalities in the person's daily sleep window period. A temperature-humidity sensor unit and contact sensor has been added to the system to detect the inhabitants patter more effectively. The panic button is modified to send not only emergency message bit also to deactivate any false alarms raised.

Chapter 5 describes the wireless sensors setup, communication and an intelligent process for person's activity behaviour detection. In this chapter the set up and configurations required to analyse the activity of a person are discussed. Integrated wireless sensors unit are fabricated to function properly with the house-hold appliances in turn are used for identifying and recognizing the habitual nature of the elderly person. Based on a survey among inhabitants I found out that it has a huge acceptability to be used at home.

The intelligent software, along with the electronic system, can monitor the usage of different household electronic appliances and recognize the activity pattern in real time. Also, the system interprets all the essential elderly activities such as preparing breakfast/lunch/dinner, showering, rest room use, dinning, sleeping and self-grooming. Basically, the system functions on the usage of electrical and non-electrical appliances within a home. At hardware level, wireless sensor network with ZigBee components are connected in form of star topology and a central coordinator of the sensors collect the data from the sensors connected to various appliances of the smart home. The developed intelligent program continuously reads the data from the coordinator and efficiently stores on the system for further data processing in real time.

The data processing involves steps for check on the knowledge base for determining the normal activity pattern of the inhabitant. In this system, required numbers of sensors for monitoring the basic activity of inhabitant are used as this is sufficient for monitoring essential activities of elderly behaviour

Chapter 6 discusses the experimental results that are obtained using the developed software. The software for the system is augmented with wellness functions provided the intelligence for determining the habitual behaviour of the inhabitant. This can be extended for predicting the abnormal behaviour of the inhabitant in a smart home environment. Also, the system can be executed for required number of months to derive the optimal maximum utilization of the appliances used by the inhabitant then test for the efficiency of the wellness functions to predict the abnormal behaviour of the inhabitant in using the daily household appliances.

7.2. Suggestion for Future Work

The work conducted in this thesis has focused on the development of a wireless sensors network based smart home monitoring system for elder-care. Various design intricacies, hardware and software level analysis, and experimental tests have been undertaken to achieve the research objectives. As a result a wireless sensors network based smart home monitoring system for elder-care has been successfully developed to deploy in a real-life scenario. Further, more areas have also opened for investigation in the future. In the conclusion of this thesis, several areas are suggested here for future research on the topic.

1. The nature of the system lends itself to being expanded further to create a more versatile system. As the wireless sensor network is scalable, there is need to include sensors related to remaining house-hold appliances at elderly house in order to study highly structured behavioural pattern for more precise abnormal detection.
2. Extensive analyses need to be conducted in predicting the abnormal situation of the inhabitant for the developed system.
3. The sensor should be reduced in size drastically by using only ZigBee modules. It has been noticed that the need of a microcontroller can be eliminated by using the ZigBee chip efficiently. The ideal design of the monitoring system would hide the sensor components from the inhabitant almost completely.

4. The sensors need to be designed with more precision, enabling to be installed in a house-hold easily.

References

1. United Nations (UN), "World Population Aging 1950-2050", Department of Economic and Social Affairs New York, 2002, retrieved from http://www.un.org/esa/population/publications/worldageing19502050/ on 01, July, 2011.
2. Bloom D.E., Canning D. & Finlay J.E, "Population aging and economic growth in Asia", The Demographic Transition in the Pacific Rim, NBER-EASE Volume 19, 2009.
3. N. Barr, P. Diamond, "The Economics of Pensions." Oxford Review of Economic Policy, volume 22(1), pp. 15–39, 2006.
4. "Why population aging matters – A global perspective", National Institute on aging, National institutes of health, U.S. Department of Health and Human Services, 2008.
5. D.E. Bloom, D. Canning, P.N. Malaney, "Demographic Change and Economic Growth in Asia", Centre for International Development, Harvard University, Cambridge, MA, Working Paper No. 15, 2000
6. Population Division, Population Estimates and Projections Section, Fact Sheet, Series A, 7 March 2007 "World Population Prospects: The 2006 Revision"
7. Koontz, D. "Life expectancy", retrieved from http://en.wikipedia.org/wiki/Life_expectancy on 14, June 2011
8. "Life expectancy- North South gap in life expectancy is narrowing fast", retrieved from http://ucatlas.ucsc.edu/life/index.html on July 30, 2010.
9. M.A. Khawaja, "Elderly New Zealanders on the Move", Geo-demographics of Ageing in Australia Symposium, Brisbane, 1999.
10. "Demographic Aspects of New Zealand's Ageing Population", Statistics New Zealand, March 2006, retrieved from

http://www.stats.govt.nz/browse_for_stats/people_and_communities/older_people/demographic-aspects-nz-ageing-population.aspx on 14, May 2011 .

11. C. Lin, S. Wang, "Beyond Smart: Enabling Cognition in a Wireless Home Network Environment," Proceedings of Asia-Pacific Services Computing Conference, 2008. APSCC '08. IEEE, Yilan, 9-12 December 2008, pp. 1246-1251.
12. G. Demiris, M. Skubic, M. Rantz, J. Keller, M. Aud, B. Hensel, Z. He, "Smart home sensors for the elderly: a model for participatory formative evaluation," in Proceedings of IEEE EMBS Int. Spec. Topic Conf. Inf. Technol. Biomedical, Douliu, Taiwan, April, 2006, pp. 1–4.
13. B.G. Celler, N.H. Lovell, D.K. Chan, "The Potential Impact of Home Telecare on Clinical Practice", Centre for Health Telematics, University of New South Wales, Sydney, Med. J. Aust, 171, 10, November, 1999, pp 518-521.
14. A. Yilmaz, O. Javed, and M. Shah, "Object tracking: A survey," ACM Journal on Computer Surveys, vol. 38, no. 4, Dec. 2006.
15. Surveillance works: Look who's watching, IEEE Signal Process. Mag., vol. 22, Mar. 2005.
16. N. T. Siebel, S. Maybank, "The advisor visual surveillance system", Proceedings of. ECCV 2004 Workshop Applicat. Comput. Vision (ACV), 2004. Prague, Czech Republic, May 11-14, 2004, pp. 201-206.
17. A. Hampapur, L. M. Brown, J. Connell M. Lu, H. Merkl, S. Pankanti, A. W. Senior, C.F. Shu, and Y. l. Tian, B, "Multi-scale tracking for smart video surveillance", IEEE Trans. Signal Process., vol. 22, Feb. 2005, pp. 38 - 51.
18. S. Velalstin and P. Remagnino, "Intelligent Distributed Video Surveillance Systems". Herts, U.K. Proceedings of IEEE Intelligent Systems, Special Issue on Homeland Security, October – November, 2005 pp. 126 - 141.
19. M. M. Trivedi, S. Park, "Video analysis of vehicles and persons for surveillance", Intelligent Security Informatics, 2007, pp. 407 - 424.
20. M. Shah, O. Javed, K. Shafique, "Automated visual surveillance in realistic scenarios", IEEE Multimedia, vol. 14, no. 1, pp. 30–39, 2007.
21. R. Collins, A. Lipton, T. Kanade, H. Fujiyoshi, D. Duggins, Y. Tsin, D. Tolliver, N. Enomoto, and O. Hasegawa, "A system for video surveillance and

monitoring", Robotics Inst., Carnegie–Mellon Univ., Pittsburgh, PA, Tech. 12, May 2000.

22. P. C. Ribeiro and J. Santos-Victor, "Human activity recognition from video: Modeling, feature selection and classification architecture", Proceedings of Human Activity Recognition Model. (HAREM 2005), September 9th, 2005, Oxford, UK

23. M. Quaritsch, M. Kreuzthaler, B. Rinner, H. Bischof, and B. Strobl "Autonomous Multicamera Tracking on Embedded Smart Cameras," EURASIP Journal on Embedded Systems, vol. 2007, Article ID 92827, pp. 1-10.

24. J. Schiff, M. Meingast, D.K. Mulligan, S. Sastry, K. Goldberg, "Respectful cameras: detecting visual markers in real-time to address privacy concerns," Intelligent Robots and Systems, 2007. IROS 2007. IEEE/RSJ International Conference on , Oct. 29 2007-Nov. 2 2007,California, USA, pp. 971-978

25. F. Dufaux and T. Ebrahimi, "Scrambling for video surveillance with privacy", in Proceedings of Conference on Computer Vision Pattern Recognition Workshop Privacy Res. Vision (CVPRW-PRIV), Washington, DC, 2006, pp. 160.

26. R. Gross, L. Sweeney, F. de la Torre, and S. Baker, "Model-based face de-identification", in Proceedings of Conference on Computer Vision Pattern Recognition Workshop Privacy Res. Vision (CVPRW-PRIV), Washington, DC, 2006, pp. 161.

27. A. Senior, S. Pankanti, A. Hampapur, L. Brown, Y.-L. Tian, A. Ekin, J. Connell, C. F. Shu, and M. Lu, "Enabling video privacy through computer vision", IEEE Security Privacy Journal, vol. 3, no. 3, 2005, pp. 50–57.

28. R. Cucchiara, A. Prati, and R. Vezzani, "A system for automatic face obscuration for privacy purposes", Pattern Recognit. Lett., vol. 27, no. 15, Nov. 2006, pp. 1809–1815.

29. M. Tabar, A. Keshavarz, and H. Aghajan, "Smart home care network using sensor fusion and distributed vision-based reasoning", in Proc. ACM Int. Workshop Video Surveil. Sensor Netw. (VSSN 2006), October 27, 2006, Santa Barbara, CA, USA, pp. 145-154.

30. H. K. Aghajan, J. C. Augusto, C. Wu, P. J. McCullagh, and J.-A. Walkden, “Distributed vision-based accident management for assisted living”, in ICOST, Lecture Notes in Computer Science, T. Okadome, T. Yamazaki, and M. Makhtari, Eds. Berlin, Germany: Springer, 2007, vol. 4541, pp. 196–205.
31. A. Keshavarz, A. Maleki-Tabar, andH. Aghajan, “Distributed vision-based reasoning for smart home care”, Proceedings of ACM SenSys Workshop on Distributed Smart Cameras (DSC’06), Oct. 2006, Boulder, CO, USA, pp. 62-66.
32. R. Cucchiara, A. Prati, and R. Vezzani, “A multi-camera vision system for fall detection and alarm generation”, Journal on Expert System, vol. 24, no. 5, Nov. 2007pp. 334–345.
33. A.G. Hauptmann, J. Gao, R. Yan, Y. Qi, J. Yang, H.D. Wactlar, “Automated analysis of nursing home observations”, Journal on Pervasive Computing., vol. 3, no. 2, April – June, 2004, pp. 15–21.
34. A. Williams, D. Xie, S. Ou, R. Grupen, A. Hanson, and E. Riseman, “Distributed smart cameras for aging in place”, Proceedings of Workshop Distrib. Smart Cameras (DSC 2006), 2006 Boulder, CO, USA, pp. 161-169.
35. U. Toereyin, Y. Dedeoglu, and A. Enis Cetin, “HMM based falling person detection using both audio and video”, Proceedings of IEEE International Workshop on Human-Computer Interaction, October 21, 2005, Beijing, China, pp. 211—220.
36. W. Wolf, B. Ozer, and T. Lv, “Smart cameras as embedded systems”, Computer Journal, vol. 35, no. 9, 2002, pp. 48–53.
37. D. Dietrich and G. Heinrich, “Embedded Vision System,” EURASIP Journal on Embedded Systems, vol. 2007, Article ID 34323, 2007, 2 pages.
38. M. Bramberger, A. Doblander, A. Maier, B. Rinner, and H. Schwabach, “Distributed embedded smart cameras for surveillance applications”, IEEE Computer, vol. 39, Feb. 2006.
39. C. Pierre, B. François, “Embedded Active Vision System Based on an FPGA Architecture,” EURASIP Journal on Embedded Systems, vol. 2007, Article ID 35010, 2007, 12 pages.

40. R. Kleihorst, A. Abbo, B. Schueler, and A. Danilin, “Camera mote with a high-performance parallel processor for real-time frame-based video processing”, in Proc. ACM/IEEE Int. Conf. Distrib. Smart Cameras (ICDSC-07), Vienna, Austria, September 25-28, 2007, pp. 69-74.
41. S. Hengstler, D. Prashanth, S. Fong, and H. Aghajan, “ MeshEye: A hybrid-resolution smart camera mote for applications in distributed intelligent surveillance”, in Proc. 6th Int. Conf. Inf. Process. Sensor Network. (IPSN ’07), New York, 2007, pp. 360–369.
42. B. Raducanu, S. Subramanian, P. Markopoulos, “Human presence detection by smart devices”, Proceedings of 4th Int. ICSC Symp. on Engineering of Intelligent Systems ,Island of Madeira, Portugal, 2004, pp. 1–8.
43. H. Nait-Charif, S.J. McKenna, “Activity summarisation and fall detection in a supportive home environment”, Proceedings of 17th Int. Conf. on Pattern Recognition (ICPR 2004), Cambridge, UK, 23-26 August 2004, pp. 323–326.
44. J. Han, B. Bhanu, “Human activity recognition in thermal infrared imagery”, Proceedings of Conf. on Computer Vision and Pattern Recognition (CVPR2005), 20-26 June 2005, San Diego, US, pp. 17–24.
45. M. Ogawa, T. Togawa, "Monitoring daily activities and behaviours at home by using brief sensors," 1st Annual International, Conference On Micro technologies in Medicine and Biology, April, 2000 , Lyon, France, pp. 611–614.
46. M. Igawa, R. Suzuki, S. Otake, T. Izutsu, T. Iwaya, T. Togawa, "Long term remote behavioural monitoring of elderly by using sensors installed in ordinary houses," Proceedings of IEEE 2nd Annual International conference on Micro technologies in Medicine & Biology, IEEE-EMB, Madison, US, April, 2002, pp. 322–325.
47. A. Rajgarhia, F. Stann, J. Heidemann, “Privacy-sensitive monitoring with a mix of IR sensors and cameras”, Proceedings of 2nd Int. Workshop on Sensor and Actor Network Protocols and Applications, August, 2004, Boston, US, pp. 21–29.
48. R. Ungrangsi, A. Trachenberg, D. Starobinski, “An implementation of indoor location detection systems based on identifying codes”, Proceedings of Int.

Conf. on Intelligence in Communication Systems (INTELLCOMM 2004), Bangkok, Thailand, November 23-26, 2004, pp. 175–89.

49. M. Hazas, A. Ward, “A high performance privacy-oriented location system” Proceedings of 1st Int. Conf. on Pervasive Computing and Communications (PerCom 2003), Texas, US, 23-26 March 2003, pp. 216–23.
50. D.H. Wilson, “Assistive intelligent environments for automatic health monitoring”, PhD Thesis Carnegie Mellon University, 2005
51. M.L. Wang, C.H. Huang, H.Y. Lin; , "An Intelligent Surveillance System Based on an Omnidirectional Vision Sensor," Proceedings of 2006 IEEE Conference on Cybernetics and Intelligent Systems, Bangkok, Thailand, 7-9 June 2006, pp.1-6.
52. E. Menegatti, A. Scarpa, D. Massarin, E. Ros, E. Pagello,"Omnidirectional Distributed Vision System for a Team of Heterogeneous Robots," Proceedings of Conference on Computer Vision and Pattern Recognition Workshop, 2003. CVPRW '03, vol.7, 16-22 June, 2003, Madison, Wisconsin, USA, pp. 87-94.
53. R. Jafari, “Medical embedded systems,” Ph.D. dissertation, University of California, Los Angeles, 2006.
54. S. Krco, "Implementation solutions and issues in building a personal sensor network for health care monitoring," 4th International IEEE EMBS Special Topic Conference on Information Technology Applications in Biomedicine, 2003., Piscataway NJ , 24-26 April 2003, pp. 350- 353.
55. N. Maglaveras, “Citizen Health system: Tele-health homecare”, Studies in Health Technology and Informatics, 2003, volume 92, pp. 117-125.
56. S. L. Mitchell, J.N. Morris, P.S. Seal, “Terminal care for persons with advanced dementia in the nursing home and home cap settings”, Journal of Palliative Medicine, volume 7(6), April, 2000, pp. 808—8l6.
57. J.K. Wu, L. Dong, W. Xiao, “Real-time Physical Activity classification and tracking using wearable sensors”, Proceedings of the 6th International Conference on Information, Communications & Signal Processing, Dec. 2007, Page(s): 1 – 6.
58. Z. Peng, C. Ming, "A remote health care system based on wireless sensor networks," Proceedings of 12th International Conference on Computer

Supported Cooperative Work in Design, 2008, CSCWD-2008, Xi'an, China, 16-18 April 2008, pp. 1102-1106.

59. Z. Bin, H.B. Li; R. Kohno, "IEEE Body Area Networks for Medical Applications," Proceedings of 4th International Symposium on Wireless Communication Systems, 2007, ISWCS 2007, Trondheim, Norway, 17-19 October, 2007, pp. 327-331.

60. O.C. Omeni, O. Eljamaly, A.J. Burdett, "Energy Efficient Medium Access Protocol for Wireless Medical Body Area Sensor Networks", Journal on Medical Devices and Biosensors, 2007, pp. 29-32.

61. F. Cavallo, M. Aquilano, L. Odetti, M. Arvati, M.C. Carrozza, "A first step toward a pervasive and smart ZigBee sensor system for assistance and rehabilitation". IEEE 11th International Conference on Rehabilitation Robotics, Kyoto International Conference Centre, Japan, June 23-26, 2009, pp. 632-637.

62. J.Y. Jung, J.W. Lee, "ZigBee Device Design and Implementation for Context-Aware U-Healthcare System," Proceedings of Second International Conference on Systems and Networks Communications, 2007. ICSNC 2007, French Riviera, France. Aug. 2007, pp.22, 25-31.

63. S. Masashi, I. Masahide, Y. Yukie, A. Nobuyoshi, "Health Support System for Diabetes Prevention using Networked Health-monitoring Equipment", Proceedings of Pervasive Computing Technologies for Healthcare conference, Munich, Germany, May, 2010, pp. 1-5.

64. H. Hongwei, Y. Xu, H. Yan, S. Mubeen, Z. Hongke, "An Elderly Health Care System Using Wireless Sensor Networks at Home," Proceedings of Third International Conference on Sensor Technologies and Applications, 2009, SENSORCOMM '09, Glyfada, Greece, 18-23 June 2009, pp. 158-163.

65. H. Sugano, T. Tsujioka, T. Inoue, S. Nakajima, S. Hara, H. Nakamura, K. Takeuchi, "Clinical tests and evaluations of a Wireless ECG sensor for realization of ubiquitous health care systems," Proceedings of 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Buenos Aires, Argentina, 31, August, 2010- 4, September, 2010, pp. 2030-2033.

66. T. Kozaki, S. Nakajima, T. Tsujioka, T. Inoue, H. Nakamura, K. Takeuchi, S. Hara, "Estimation of human movements from body acceleration monitoring for ubiquitous health care," The 12th International Conference on Advanced Communication Technology (ICACT), 2010, Paris, France, volume 1, 7-10 February, 2010, pp. 430-435.

67. C. Gopalsamy, S. Park, R. Rajamanickam, and S. Jayaraman, “The wearable motherboard: The first generation of adaptive and responsive textile structures (ARTS) for medical applications,” Journal on Virtual Reality, vol. 4, 2000, pp. 152-168.

68. S. Park, S. Jayaraman, "Smart Textile-Based Wearable Biomedical Systems: A Transition Plan for Research to Reality," IEEE Transactions on Information Technology in Biomedicine, volume 14, no.1, ISSN: 1089-7771, January, 2010, pp. 86-92

69. S. Park, S. Jayaraman, “Enhancing the quality of life through technology: The role of personalized wearable intelligent information infrastructure,” Journal IEEE Eng. Med. Biol., volume 22, no. 3, May/June, 2003, pp. 41–48.

70. M. Beigl, H.W. Gellersen, A. Schmidt, “Mediacups: Experience with Design and Use of Computer-Augmented Everyday Artefacts,” Comp. Net., Special Issue on Pervasive Computing, vol. 35, no. 4, Mar. 2001, pp. 401–409.

71. A Schmidt, K Aidoo, A Takaluoma, “Advanced Interaction in Context, “1st Int’l. Symp.Handheld and Ubiquitous Comp. (HUC ’99), Karlsruhe, Germany, LNCS 1707, Springer-Verlag, LNCS 1707, Sept. 2000, pp. 89-101.

72. Y. Kaddourah, J. King, and A. Helal, “Cost-precision tradeoffs in unencumbered floor-based indoor location tracking,” in Proceedings of the 3rd International Conference on Smart Homes and Health Telematic (ICOST '05), Sherbrooke, Québec, Canada, July 2005, pp. 253-271.

73. Helal. S, Mann. W, El- Zabadani. H, King. J, Adour. Y, Jansen. E, "The Gator Tech Smart House: a programmable pervasive space," Computer Journal, vol.38, no.3, March 2005, pp. 50- 60.

74. M.H. Jones, R.A. Goubran, F. Knofel, "Identifying movement onset times for a bed-based pressure sensor array," Proceedings of International Workshop on

Medical Measurement and Applications, Benevento, April, 2006, pp. 111 – 114.

75. N.M. Barnes, N.H. Edwards, D.A.D. Rose, P. Garner, “Lifestyle monitoring technology for supported independence”, Journal on Computer Control Eng. Volume 9 (4), May, 1998 pp. 169–174.

76. Nasution A.H., Emmanuel S., “Intelligent Video Surveillance for Monitoring Elderly in Home Environments”, Proceedings of IEEE 9th Workshop on Multimedia Signal Processing, Italy, 2007, MMSP 2007, Page(s): 203 – 206.

77. D.J. Patterson, D. Fox, H. Kautz, M. Philipose, "Fine-grained activity recognition by aggregating abstract object usage," Proceedings of Ninth IEEE International Symposium Wearable Computers, 2005, Osaka, Japan, 18-21 Oct. 2005, pp. 44- 51.

78. S. S. Intille, K. Larson, J. S. Beaudin, J. Nawyn, E. M. Tapia, and P. Kaushik, “A living laboratory for the design and evaluation of ubiquitous computing technologies,” Proceedings of Human Factors in Computing Systems Conference, New York, NY, June, 2004, pp. 104-110.

79. C. Kiluk, “Method in alarm system, including recording of energy consumption”, US Patent No. US4990893, 5th February 1991.

80. J. Li, L Da-You, Bo Yang, “Smart Home Research”, Proceedings of 2004 International Conference on Machine Learning and Cybernetics, 2004, shanghai, China, Volume 2, 26-29 Aug. 2004, pp. 659 - 663.

81. S. Helal, "Programming pervasive spaces," Pervasive Computing journal, IEEE, vol.4, no.1, Jan.-March 2005, pp. 84- 87.

82. S. Helal, B. Winkler, Choonhwa Lee, Y. Kaddoura, L. Ran, C. Giraldo, S. Kuchibhotla, W. Mann, "Enabling location-aware pervasive computing applications for the elderly," Proceedings of the First IEEE International Conference on Pervasive Computing and Communications, 2003. (PerCom 2003), Texas, 23-26 March 2003, pp. 531- 536.

83. C.D. Kidd, R.J. Orr, G.D. Abowd, C.G. Atkeson, I.A. Essa, B. MacIntyre, E. Mynatt, T.E. Starner, W. Newstetter,” The aware home: a living laboratory for ubiquitous computing research”, Proceedings of 2nd International Workshop

on Cooperative buildings (CoBuild'99)" , Pittsburgh, USA, March, 1999, pp. 31-38.

84. J. Krumm, S. Harris, B. Meyers, B. Brumitt, M. Hale, S. Shafer, "Multi-camera multi-person tracking for EasyLiving", Proceedings of 3rd IEEE International Workshop on Visual Surveillance, Dublin , Ireland, May, 2000, pp. 3–10.

85. M.J. Rantz, K.D. Marek, M. Aud, H.W. Tyrer, M. Skubic, G.Demiris, A. Hussam, "A technology and nursing collaboration to help older adults age in place", Nurs Outlook, volume 53 (1), September, 2000, pp. 40–45.

86. V. Stanford, "Using pervasive computing to deliver elder care," Journal on Pervasive Computing, IEEE , vol.1, no.1, Jan-Mar 2002, pp. 10- 13.

87. H.W. Tyrer, M. Alwan, G. Demiris, Z. He, J. Keller, M. Skubic, M. Rantz, "Technology for Successful Aging," Proceedings of 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2006, EMBS '06, 30, New York, USA, August, 2006 – 3, September, 2006, pp.3290-3293.

88. D. J. Cook, S. Das, Book on Smart Environments: Technologies, Protocols and Applications. JohnWiley and Sons, 2004

89. G. Abowd, C. Atkeson, A. Bobick, I. Essa, B. Mynatt, and T. Starner, "Living laboratories: The Future Computing Environments group at the Georgia Institute of Technology", Proceedings of the Conference on Human factors in computing systems (2000), The Hague, The Netherlands,pp. 215-216 .

90. M. Addlesee, R. Curwen, S. Hodges, J. Newman, P. Steggles, A. Ward, and A.Hopper, " Implementing a sentient computing system", IEEE Computer Journal, Volume 34(8), August 2001, pp. 50–56.

91. M. Bennewitz, W. Burgard, S. Thrun, "Learning motion patterns of persons for mobile service robots," Proceedings of IEEE International Conference on Robotics and Automation, ICRA '02, vol.4, 2002, Washington, DC, April, 2002, pp. 3601- 3606.

92. M. Mozer. "The neural network house: An environment that adapts to its inhabitants", Proceedings of the American Association for Artificial

Intelligence Spring Symposium on Intelligent Environments, Austin, Texas, January, 2000, pp. 110–114.

93. A. P. Glascock, D. Kutzik: “Moving Telematics from the Laboratory to a Truly Enabling Technology within the Community”, Toward a Human-Friendly Assistive Environment. D. Zhang, M. Mokhtari, editors, Assistive Technology Research Series 14, IOS Press, Amsterdam, The Netherlands, April, 2004, pp. 145-154.

94. E. Munguia Tapia, S. S. Intille, and K. Larson, "Activity recognition in the home setting using simple and ubiquitous sensors", Lecture Notes in Computer Science-Activity Recognition in the Home Using Simple and Ubiquitous Sensors , Springer Berlin / Heidelberg, Vol. 3001, 2004, pp. 158-175.

95. A. Dey, J. Mankoff, G. Abowd, “Distributed Mediation of Imperfectly Sensed Context in Aware Environments”, GVU Technical Report GIT-GVU-00-14. September 2000.

96. N. A. Streitz, C. Röcker, Th. Prante, D. van Alphen, R. Stenzel, C. Magerkurth, “Designing Smart Artifacts for Smart Environments”. IEEE Computer Journal, Vol 3, March, 2005. pp. 41-49.

97. M. Román, C.K. Hess, R. Cerqueira, A. Ranganathan, R.H. Campbell, and K. Nahrstedt, “Gaia: A Middleware Infrastructure to Enable Active Spaces”. IEEE Journal on Pervasive Computing Volume 1(4), 2002, pp. 74-83.

98. M. Philipose, K.P. Fishkin, M. Perkowitz, D.J. Patterson, D. Fox, H. Kautz, D. Hahnel, "Inferring activities from interactions with objects", Proceedings of IEEE Pervasive Computing, vol.3, no.4, October-December, 2004, pp. 50- 57.

99. H. Hagras, V. Callaghan, M. Colley, G. Clarke, A. P. Cornish, H. Duman, "Creating an ambient-intelligence environment using embedded agents," Intelligent Systems, IEEE , vol.19, no.6, November –December, 2004, pp. 12-20.

100. D.J. Cook, M. Youngblood, E.O. Heierman, K. Gopalratnam, S. Rao, A. Litvin, F. Khawaja,"Mav-Home: an agent-based smart home," Proceedings of the First IEEE International Conference on Pervasive Computing and

Communications, 2003, (PerCom, 2003), Texas, 23-26 March 2003, pp. 521-524.

101. K. Hara, T.Omori, R. Ueno, “Detection of unusual human behavior in intelligent house”, Proceedings of the 12th IEEE Workshop on Neural Networks for Signal Processing, France, 2002, Page(s): 697-706.

102. D.B. Percival, A.T. Walden, “Wavelet methods for time series analysis, Cambridge, Cambridge University Press”, 2000, ISBN: 9780521640688.

103. D. Lymberopoulos , A. Bamis , T. Eixeira , A. Savvides , “BehaviorScope: Real-Time Remote Human Monitoring Using Sensor Networks”, Proceedings of the International Conference on Information Processing in Sensor Networks, IPSN '08, April 2008, Page(s): 533-534.

104. S. Nourizadeh, C. Deroussent, Y.Q. Song, J.P. Thomesse, "Medical and Home Automation Sensor Networks for Senior Citizens Tele-homecare," Proceedings of IEEE International Conference on Communications, Dresden, Germany, 14-18, June, 2009, pp. 1-5.

105. Zhongna Z., Wenqing D., Eggert J., Giger J.T., Keller J., Rantz M., Zhihai He., “A real-time system for in-home activity monitoring of elders”, Proceedings of the Annual International Conference of IEEE Engineering in Medicine and Biology Society, EMBC 2009, 3-6 Sept. 2009, Page(s):6115-6118.

106. M. Katsukura, M. Nakata, Y. Itou, N. Kushiro, "Life pattern sensor with non-intrusive appliance monitoring," Digest of Technical Papers International Conference on Consumer Electronics, 2009. ICCE '09, Penang, Malaysia, 10-14 January, 2009, pp. 1-2.

107. A.M. Adami, T.L. Hayes, M. Pavel, Unobtrusive monitoring of sleep patterns, in: Proceedings of 25th Annual International Conference of the IEEE EMBS, Cancun, Mexico, September 17–21, 2003, pp. 1360–1363.

108. Tekscan. (2009) FlexiForce force sensors, Retrieved October 25, 2009, from http://www.tekscan.com/flexiforce/flexiforce.html

109. N. Baker, "ZigBee and Bluetooth strengths and weaknesses for industrial applications," Computing & Control Engineering Journal, vol.16, no.2, pp. 20-25, April-May 2005.

110. S. Safaric, K. Malaric, “ZigBee wireless standard”, Multimedia Signal Processing and Communications, 48th International Symposium ELMAR-2006, Zadar, Croatia, June 2006, pp. 259-262

111. IEEE: IEEE Std 802.15.4™-2003, Retrieved from http://standards.ieee.org on 25 April 2010.

112. M. Clendenin, “ZigBee's improved spec incompatible with v1.0”, EE Times Europe, Retrieved from http://eetimes.eu/showArticle.jhtml?articleID=193006080 on 13 janurary 2010.

113. ZigBee Alliance, ZigBee Specification, December 1, 2006, retrieved from www.zigbee.org.

114. Walko, “ZigBee PRO standard gets the all clear”, EE Times Europe, [online]. Available: http://eetimes.eu/showArticle.jhtml?articleID=202401851.

115. Gupta, Sen Gourab, and Tin Chew Moi. Embedded Programming with Field Programmable Mixed-Signal μControllers. 2005.

116. Digi. “XBee® & XBee-PRO® 802.15.4 OEM RF Modules - Digi International.” http://ftp1.digi.com/support/documentation/90000982_B.pdf ,accessed on July 22, 2011

117. MaxStream X-CTU software for configuring and testing MaxStream radio modems, http://www.digi.com/support/kbase/kbaseresultdetl.jsp?kb=125

118. G. Ding, Z. Sahinoglu, B. Bhargava, P. Orlik, and J. Zhang, "Reliable Broadcast in ZigBee Networks," Proceedings of the 2nd Annual IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks, California, USA, September 2005, pp. 510-520

119. Tien-Wen Sung, Ting-Ting Wu, Chu-Sing Yang and Yueh-Min Huang, “Reliable Data Broadcast for Zigbee Wireless Sensor Networks”, International journal on smart sensing and intelligent systems, vol. 3, no. 3, September 2010, pp. 504 – 520

120. A. da Silva et al., “Decentralized Intrusion Detection in Wireless Sensor Networks,” Proc. 1st ACM Int’l. Workshop. QoS & Sec. in Wireless and Mobile Networks, Califonia, USA, 2005, pp. 16–23.

121. H.I .Witten, E. Frank, “Data Mining: Practical machine Learning tools and techniques”, Morgan Kaufmann Publications, 2005

122. J. Ayres, J. E. Gehrke, T. Yiu, and J. Flannick. "Sequential Pattern Mining Using Bitmaps", In Proceedings of the Eighth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining. Edmonton, Alberta, Canada, July 2002, pp. 23-32.

Appendix 1

Date:

DAILY ACTIVITY QUESTIONNAIRE

All questions contained in this questionnaire are strictly confidential

Name (Last, First, M.I.):	☐ M ☐ F	DOB:
House-hold Status ☐ Living alone ☐ Living with someone		

DAILY ACTIVITY

Question		
1	What time do you usually wake up	
2	Please list the activities you immediately do after you wake up (E.g. turning on the lamp, toileting) * Please mention the time	
3	What time you make breakfast	
4	List the appliances you usually use for making breakfast	
5	Please list the activities you immediately do after the breakfast * Please mention the time	
6	List the appliances/ furniture you usually use after breakfast (E.g. TV, sitting on couch)	
7	What time you cook your lunch	
8	List the appliances you usually use for cooking lunch (E.g. Microwave Oven, Fridge, Kettle, Dining chair)	
9	Please list the activities you do after lunch * Please mention the time	
10	List the appliances/ furniture you usually use after breakfast (E.g. Bed, sitting on couch)	

11	What time you cook your Dinner	

Question		
12	List the appliances you usually use for cooking dinner (E.g. Microwave Oven, Fridge, Kettle, dining chair)	
13	Please list the activities you immediately do after the dinner * Please mention the time	
14	List the appliances/ furniture you usually use after dinner (E.g. TV, sitting on couch)	
15	Please list the activities you do before going to bed * Please mention the time	
16	What time you usually go to bed at night	
17	List the appliances/ furniture you usually use before going to sleep (E.g. Bed Lamp, Shelf Drawer)	

Appendix 2

SENSOR SOFTWARE CODE

Current Sensor

```
//-----------------------------------------------------------------------------------
// Includes
//-----------------------------------------------------------------------------------
#include <c8051f020.h>                    // SFR declarations
#include <stdio.h>
#include <string.h>
#include <stdlib.h>


//-----------------------------------------------------------------------------------
// Global CONSTANTS
//-----------------------------------------------------------------------------------


#define BAUDRATE     9600           // Baud rate of UART in bps
#define SYSCLK       22118400         // External crystal oscillator frequency


#define INT_DEC      256             // Integrate and decimate ratio
#define SAR_CLK      250000          // Desired SAR clock speed

#define SAMPLE_DELAY 250               // Delay in ms before taking sample

#define ANALOG_INPUTS 8              // Number of AIN pins to measure
                                      // (min=1, max=8)
#define SAMPLE_RATE 25000

int name = 16;
int active;
//long t_offset= 131;


int send_delay=2000;

unsigned short i =0;
int k =0,j=0;
int Result1;
unsigned int max=50;

long adc_result;
bit adc_ready = 0;


#define FREQUENCY       10           // Frequency of output waveform in Hz


idata char received_byte;
idata unsigned short new_cmd_received;

idata unsigned long Result[ANALOG_INPUTS];             // ADC0 decimated value, one for each
                                       // analog input
idata unsigned char amux_input=0;            // index of analog MUX inputs
idata unsigned char amux_convert=0;

idata static unsigned long accumulator[ANALOG_INPUTS] ={0L};
                                       // Here's where we integrate the
idata char out[30];                                  // ADC samples from input AIN0.0
```

```
idata unsigned short p_string = 0;
idata char s_buffer[10];
//idata char cmd[20];
idata int max_len=2;
idata unsigned char UART =0;

idata short error = 0;

//----------------------------------------------------------------------------
// Global Defines
//----------------------------------------------------------------------------
#define LCD_DAT_PORT P6 // LCD is in 8 bit mode
#define LCD_CTRL_PORT P7 // 3 control pins on P7
#define RS_MASK 0x01 // for assessing LCD_CTRL_PORT
#define RW_MASK 0x02
#define E_MASK 0x04
//----------------------------------------------------------------------------
// Global MACROS
//----------------------------------------------------------------------------
// original delays [1]
#define pulse_E();\
                small_delay(5);\
                LCD_CTRL_PORT = LCD_CTRL_PORT | E_MASK;\
                small_delay(5);\
                LCD_CTRL_PORT = LCD_CTRL_PORT & ~E_MASK;\

//-------------------------------------------------------------------------------------
// Function PROTOTYPES
//-------------------------------------------------------------------------------------
void PORT_Init (void);
void Timer3_Init (int counts);

//void Timer3_ISR (void);
//void Timer2_ISR (void);
void ACD0_Init(void);


void small_delay (char d); // 8 bit, about 0.34us per count @22.1MHz
void large_delay (char d); // 16 bit, about 82us per count @22.1MHz
void huge_delay (char d); // 24 bit, about 22ms per count @22.1MHz

char lcd_dat (char c); // write data to the LCD controller
void lcd_cmd (char cmd); // write a command to the LCD controller
void lcd_busy_wait (void); // wait until the LCD is no longer busy
void lcd_init (void); // initialize the LCD to 8 bit mode
void lcd_puts (char string[]);
void lcd_clear (void); // clear display
void lcd_goto(char addr); //Set Cursor

void Set_DACs(void);

void Init_UART0(void); //-- configure and initialize the UART0
//void UART0_ISR(void); //-- ISR for UART0

void OSCILLATOR_Init (void);

void Wait_MS (unsigned int ms);


void cut_cmd(short start, short end);

//char putchar (char c);

void send_serial(char string[]);
//-------------------------------------------------------------------------------------
// MAIN Routine
//-------------------------------------------------------------------------------------
void main (void) {
```

```
   // disable watchdog timer
   WDTCN = 0xde;
   WDTCN = 0xad;

   new_cmd_received = 0;
   received_byte = 0;

   OSCILLATOR_Init ();
   PORT_Init ();

   ACD0_Init();
   AD0EN =1;
   Init_UART0();
   Timer3_Init(SYSCLK/SAMPLE_RATE);


   Wait_MS(5000);EA = 1;
   while (1) {                            // spin forever

               if(adc_ready==1)
               {
                       EA=0;


                               if ( Result[6] < 3300)
                               {

                                       sprintf(out,"%02d-%d#",name,0);
                                       }


                                       else if ( Result[6] >= 3300)
                                       {
                                               sprintf(out,"%02d-%d#",name,1);
                                               }



                               for(i=0;i<ANALOG_INPUTS;i++)
                               {
                                       if(Result[i]>99999)
                                               Result[i]=99999;
                                       if(Result[i]<=0)
                                               Result[i]=0;
                               }


                               send_serial(out);


                       Wait_MS(send_delay);
                       adc_ready=0;
                       EA=1;
               }



        }


}

//-----------------------------------------------------------------------------
// PORT_Init
//-----------------------------------------------------------------------------
//
// Configure the Crossbar and GPIO ports
//
```

```
void PORT_Init (void)
{
   XBR0 = 0x04;                                                  // enable UART0
   XBR1 = 0x00;
   XBR2 = 0x40;                       // Enable crossbar and weak pull-ups

   P0MDOUT |= 0x01;                                              //enable TX0 as a push-pull
o/p
   P1MDOUT |= 0x40;                   // enable P1.6 (LED) as push-pull output
                                                                            // 01000000

   P2MDOUT = 0x00;
   P3MDOUT = 0x00;

   P74OUT |= 0x48;                                               //01001000 1:= Push-Pull

   P4 |= 0xFF;
   P5 |= 0x0F;                                                   //00001111 - LED & Buttons


}

//-----------------------------------------------------------------------------
// Timer3_Init
//-----------------------------------------------------------------------------
//
// Configure Timer3 to auto-reload and generate an interrupt at interval
// specified by <counts> using SYSCLK/12 as its time base.
//
void Timer3_Init (int counts)
{
   TMR3CN = 0x00;                     // Stop Timer3; Clear TF3;
                                      // use SYSCLK/12 as timebase

   TMR3RL  = -counts;                 // Init reload values
   TMR3    = 0xffff;                  // set to reload immediately
   EIE2   |= 0x01;                    // enable Timer3 interrupts
   TMR3CN |= 0x04;                    // start Timer3
   EIP2|=0x03;                                                   //Set Interrupt priotity of
ADC and Timer3 to high


}

//-----------------------------------------------------------------------------
// Interrupt Service Routines
//-----------------------------------------------------------------------------

//-----------------------------------------------------------------------------
// Timer3_ISR
//-----------------------------------------------------------------------------
// This routine changes the state of the LED whenever Timer3 overflows.
//
void Timer3_ISR (void) interrupt 14
{
   TMR3CN &= ~(0x80);                    // clear TF3



}

void ACD0_Init(void)
{

        REF0CN=0x07;     // enable temp-sensor & on-chip VREF
        //ADC0CN =0x05;  // ADC0 disable
        ADC0CN = 0x04;                     // ADC0 disabled; normal tracking
                                      // mode; ADC0 conversions are initiated
                                      // on overflow of Timer3; ADC0 data is
                                      // right-justified
        //AMX0SL=0x02;   // Select AIN0.2 ADC mux output
```

```
        AMX0SL = 0x00;                      // Select AIN0.0 pin as ADC mux input
                                       // ISR will change this to step through
                                       // inputs
        //ADC0CF=0x86;  // ADC vonversation clock = SYSCLK / 16 PGA gain = 0.5
        AMX0CF = 0x00;                      // AIN inputs are single-ended (default)
        ADC0CF = (SYSCLK/SAR_CLK) << 3;     // ADC conversion clock = 2.5MHz
        ADC0CF |= 0x00;                     // PGA gain = 1 (alternativ = 2 := 0x02)
        EIE2|=0x02;             // enable ADC interrupts

}

void ACD0_ISR(void) interrupt 15 using 1
{

   unsigned     long temp;

   EA=0;
   AD0INT = 0;                         //clear ADC conversion complete overflow

   j++;

   if(j<=INT_DEC)       //from 0-255
        {
                accumulator[amux_input] += ADC0;
        }
   else
   {
        j=0;
    amux_input ++;                      // step to the next analog mux input

    if(amux_input >= 8)     // reset input index if the last input
        {                               // was just read
        amux_input=0;
                adc_ready=1;                    // reset input index back to AIN0.0
                }
        AMX0SL = amux_input;

   }

        if (j == 0)                                 // If zero, then post result
    {

            temp = accumulator[amux_input]>>8;

                        {
                        Result[amux_input] = temp; //Copy decimated values into Result
                        }
                        accumulator[amux_input] = 0L;                   // Reset
accumulators
                        if(amux_input==2)
                        {
                                adc_result=Result[amux_input];
                        }
        }
        EA=1;

}

void small_delay(char d)
{
        while (d--);
}

void large_delay(char d)
{
        while (d--)
        small_delay(255);
}

void huge_delay(char d)
```

```
{
        while (d--)
        large_delay(255);
}


//-------------------------------------------------------------
void Init_UART0(void)
{


   SCON0   = 0x50;                     // SCON0: mode 1, 8-bit UART, enable RX
   TMOD    = 0x20;                     // TMOD: timer 1, mode 2, 8-bit reload
   TH1 = - ((long) (SYSCLK/BAUDRATE)/16);;     // set Timer1 reload value for baudrate
   TR1    = 1;                         // start Timer1
   CKCON |= 0x10;                      // Timer1 uses SYSCLK as time base
   PCON  |= 0x80;                      // SMOD00 = 1
   TI0    = 1;                         // Indicate TX0 ready
                       // Indicate TX0 ready
        PCON |= 0x80;   //SMOD0=1 UART0 baud rate divided by 2 disabled

        IE |= 0x10;
        IP |=0x00; //Enable UART interrupt und set high priority level

        RI0=0; //clear received interrupt flag

}
//-------------------------------------------------------------

void UART0_ISR(void) interrupt 4
{
//-- pending flags RI0 (SCON0.0) and TI0(SCON0.1)

        if ( RI0 == 1)
        {
           received_byte= SBUF0;
           s_buffer[p_string] = received_byte;
           if(p_string==0)
           {
                //s_buffer="0";
           }
    /* Wenn nicht das Ende der Zeichenkette erreicht wurde,
       dann weiteres Zeichen senden */
        if ( received_byte!=0x0D && received_byte!='-' ) {

                        p_string++;
                }
                else {

        // Flag setzen, das der String gesendet wurde
                new_cmd_received=1;
                s_buffer[p_string]='\0';
                 //-- clear the flag
                //printf("Message");
        // Interrupt deaktivieren

        }
                RI0 = 0;
        }
}
//-------------------------------------------------------------

void OSCILLATOR_Init (void)
{
   int i;                              // delay counter

   OSCXCN = 0x67;                      // start external oscillator with
                                       // 22.1184MHz crystal

   for (i=0; i < 256; i++) ;           // wait for oscillator to start
```

```
   while (!(OSCXCN & 0x80)) ;           // Wait for crystal osc. to settle

   OSCICN = 0x88;                       // select external oscillator as SYSCLK
                                        // source and enable missing clock
                                        // detector

}


void Wait_MS(unsigned int ms)
{

   CKCON &= ~0x20;                      // use SYSCLK/12 as timebase

   RCAP2 = -(long)(SYSCLK/1000/12);           // Timer 2 overflows at 1 kHz
   TMR2 = RCAP2;

   ET2 = 0;                             // Disable Timer 2 interrupts

   TR2 = 1;                             // Start Timer 2

   while(ms)
   {
      TF2 = 0;                          // Clear flag to initialize
      while(!TF2);                      // Wait until timer overflows
      ms--;                             // Decrement ms
   }

   TR2 = 0;                             // Stop Timer 2

}


void send_serial(char string[])
{
    //SBUF=printf("%d\n",P1);
int t=0;
        SBUF = '0';
        while(!TI);
        TI=0;


        while(string[t]!='\0')
        {

                SBUF=string[t];t++;
        while(!TI);
        TI=0;
        }



}
```

Bed Sensor

```
//-----------------------------------------------------------------------------
// Includes
//-----------------------------------------------------------------------------
#include <c8051f020.h>                     // SFR declarations
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
```

```c
//-----------------------------------------------------------------------------------
// Global CONSTANTS
//-----------------------------------------------------------------------------------


#define BAUDRATE     9600           // Baud rate of UART in bps
#define SYSCLK       22118400         // External crystal oscillator frequency


#define INT_DEC      256             // Integrate and decimate ratio
#define SAR_CLK      250000          // Desired SAR clock speed

#define SAMPLE_DELAY 250               // Delay in ms before taking sample

#define ANALOG_INPUTS 8              // Number of AIN pins to measure
                                      // (min=1, max=8)
#define SAMPLE_RATE 25000

int name = 10;
int active;
//long t_offset= 131;


int send_delay=2000;

unsigned short i =0;
int k =0,j=0;
int Result1;
unsigned int max=50;

long adc_result;
bit adc_ready = 0;


#define FREQUENCY       10          // Frequency of output waveform in Hz

idata char received_byte;
idata unsigned short new_cmd_received;

idata unsigned long Result[ANALOG_INPUTS];            // ADC0 decimated value, one for each
                                      // analog input
idata unsigned char amux_input=0;            // index of analog MUX inputs
idata unsigned char amux_convert=0;

idata static unsigned long accumulator[ANALOG_INPUTS] ={0L};
                                      // Here's where we integrate the
idata char out[30];                                      // ADC samples from input AIN0.0


idata unsigned short p_string = 0;
idata char s_buffer[10];
//idata char cmd[20];
idata int max_len=2;
idata unsigned char UART =0;

idata short error = 0;

//-----------------------------------------------------------------------------
// Global Defines
//-----------------------------------------------------------------------------
#define LCD_DAT_PORT P6 // LCD is in 8 bit mode
#define LCD_CTRL_PORT P7 // 3 control pins on P7
#define RS_MASK 0x01 // for assessing LCD_CTRL_PORT
#define RW_MASK 0x02
#define E_MASK 0x04
//-----------------------------------------------------------------------------
// Global MACROS
//-----------------------------------------------------------------------------
```

```
// original delays [1]
#define pulse_E();\
                small_delay(5);\
                LCD_CTRL_PORT = LCD_CTRL_PORT | E_MASK;\
                small_delay(5);\
                LCD_CTRL_PORT = LCD_CTRL_PORT & ~E_MASK;\

//-----------------------------------------------------------------------------------
// Function PROTOTYPES
//-----------------------------------------------------------------------------------
void PORT_Init (void);
void Timer3_Init (int counts);

//void Timer3_ISR (void);
//void Timer2_ISR (void);
void ACD0_Init(void);


void small_delay (char d); // 8 bit, about 0.34us per count @22.1MHz
void large_delay (char d); // 16 bit, about 82us per count @22.1MHz
void huge_delay (char d); // 24 bit, about 22ms per count @22.1MHz


void Set_DACs(void);

void Init_UART0(void); //-- configure and initialize the UART0
//void UART0_ISR(void); //-- ISR for UART0

void OSCILLATOR_Init (void);

void Wait_MS (unsigned int ms);


void cut_cmd(short start, short end);

//char putchar (char c);

void send_serial(char string[]);
//-----------------------------------------------------------------------------------
// MAIN Routine
//-----------------------------------------------------------------------------------
void main (void) {


   // disable watchdog timer
   WDTCN = 0xde;
   WDTCN = 0xad;

   new_cmd_received = 0;
   received_byte = 0;

  // unsigned int count = 0;

   OSCILLATOR_Init ();
   PORT_Init ();
   //lcd_init();
   ACD0_Init();
   AD0EN =1;
   Init_UART0();
   Timer3_Init(SYSCLK/SAMPLE_RATE);


   Wait_MS(5000);EA = 1;
   while (1) {                            // spin forever

                if(adc_ready==1)
                {
                        EA=0;
```

```
                                for(i=0;i<ANALOG_INPUTS;i++)
                                {
                                        if(Result[i]>99999)
                                                Result[i]=99999;
                                        if(Result[i]<=0)
                                                Result[i]=0;
                                }


                                sprintf(out,"%d-%04lu#",name,Result[6]);
                                send_serial(out);

                                //lcd_puts(out);

                        Wait_MS(send_delay);
                        adc_ready=0;
                        EA=1;
                }


        }


}

//-----------------------------------------------------------------------------------
// PORT_Init
//-----------------------------------------------------------------------------------
//
// Configure the Crossbar and GPIO ports
//
void PORT_Init (void)
{
   XBR0 = 0x04;                                                         // enable UART0
   XBR1 = 0x00;
   XBR2 = 0x40;                           // Enable crossbar and weak pull-ups

   P0MDOUT |= 0x01;                                                     //enable TX0 as a push-pull
o/p
   P1MDOUT |= 0x40;                       // enable P1.6 (LED) as push-pull output
                                                                                   // 01000000
   P2MDOUT = 0x00;
   P3MDOUT = 0x00;

   P74OUT |= 0x48;                                                      //01001000 1:= Push-Pull

   P4 |= 0xFF;
   P5 |= 0x0F;                                                          //00001111 - LED & Buttons


}

//-----------------------------------------------------------------------------------
// Timer3_Init
//-----------------------------------------------------------------------------------
//
// Configure Timer3 to auto-reload and generate an interrupt at interval
// specified by <counts> using SYSCLK/12 as its time base.
//
void Timer3_Init (int counts)
{
   TMR3CN = 0x00;                         // Stop Timer3; Clear TF3;
                                          // use SYSCLK/12 as timebase

   TMR3RL  = -counts;                     // Init reload values
   TMR3    = 0xffff;                      // set to reload immediately
   EIE2   |= 0x01;                        // enable Timer3 interrupts
   TMR3CN |= 0x04;                        // start Timer3
   EIP2|=0x03;                                                          //Set Interrupt priotity of
ADC and Timer3 to high
```

```
   }

//-----------------------------------------------------------------------------
// Interrupt Service Routines
//-----------------------------------------------------------------------------

//-----------------------------------------------------------------------------
// Timer3_ISR
//-----------------------------------------------------------------------------
// This routine changes the state of the LED whenever Timer3 overflows.
//
void Timer3_ISR (void) interrupt 14
{
   TMR3CN &= ~(0x80);                    // clear TF3



}

void ACD0_Init(void)
{

        REF0CN=0x07;     // enable temp-sensor & on-chip VREF
        //ADC0CN =0x05;  // ADC0 disable
        ADC0CN = 0x04;                      // ADC0 disabled; normal tracking
                                       // mode; ADC0 conversions are initiated
                                       // on overflow of Timer3; ADC0 data is
                                       // right-justified
        //AMX0SL=0x02;   // Select AIN0.2 ADC mux output
        AMX0SL = 0x00;                      // Select AIN0.0 pin as ADC mux input
                                       // ISR will change this to step through
                                       // inputs
        //ADC0CF=0x86;   // ADC vonversation clock = SYSCLK / 16 PGA gain = 0.5
        AMX0CF = 0x00;                      // AIN inputs are single-ended (default)
        ADC0CF = (SYSCLK/SAR_CLK) << 3;     // ADC conversion clock = 2.5MHz
        ADC0CF |= 0x00;                     // PGA gain = 1 (alternativ = 2 := 0x02)
        EIE2|=0x02;              // enable ADC interrupts

}

void ACD0_ISR(void) interrupt 15 using 1
{

   unsigned      long temp;

   EA=0;
   AD0INT = 0;                         //clear ADC conversion complete overflow

   j++;

   if(j<=INT_DEC)       //from 0-255
        {
                accumulator[amux_input] += ADC0;
        }
   else
   {
        j=0;
    amux_input ++;                      // step to the next analog mux input

    if(amux_input >= 8)     // reset input index if the last input
        {                               // was just read
        amux_input=0;
                adc_ready=1;                    // reset input index back to AIN0.0
                }
        AMX0SL = amux_input;

   }

        if (j == 0)                             // If zero, then post result
```

```
    {

            temp = accumulator[amux_input]>>8;
                        //if(temp>=Result[amux_input]-100 || temp<=100)
                        {
                        Result[amux_input] = temp; //Copy decimated values into Result
                        }
                        accumulator[amux_input] = 0L;                    // Reset
accumulators
                        if(amux_input==2)
                        {
                                adc_result=Result[amux_input];
                        }
        }
        EA=1;

}

void small_delay(char d)
{
        while (d--);
}

void large_delay(char d)
{
        while (d--)
        small_delay(255);
}

void huge_delay(char d)
{
        while (d--)
        large_delay(255);
}

void Init_UART0(void)
{


   SCON0   = 0x50;                      // SCON0: mode 1, 8-bit UART, enable RX
   TMOD    = 0x20;                      // TMOD: timer 1, mode 2, 8-bit reload
   TH1 = - ((long) (SYSCLK/BAUDRATE)/16);;      // set Timer1 reload value for baudrate
   TR1    = 1;                          // start Timer1
   CKCON |= 0x10;                       // Timer1 uses SYSCLK as time base
   PCON  |= 0x80;                       // SMOD00 = 1
   TI0    = 1;                          // Indicate TX0 ready
                      // Indicate TX0 ready
        PCON |= 0x80;    //SMOD0=1 UART0 baud rate divided by 2 disabled

        IE |= 0x10;
        IP |=0x00; //Enable UART interrupt und set high priority level

        RI0=0; //clear received interrupt flag

}
//--------------------------------------------------------------

void UART0_ISR(void) interrupt 4
{
//-- pending flags RI0 (SCON0.0) and TI0(SCON0.1)

        if ( RI0 == 1)
        {
           received_byte= SBUF0;
           s_buffer[p_string] = received_byte;
           if(p_string==0)
           {
                //s_buffer="0";
           }
    /* Wenn nicht das Ende der Zeichenkette erreicht wurde,
```

```
       dann weiteres Zeichen senden */
        if ( received_byte!=0x0D && received_byte!='-' ) {

                        p_string++;
                }
                else {

        // Flag setzen, das der String gesendet wurde
                new_cmd_received=1;
                s_buffer[p_string]='\0';
                 //-- clear the flag
                //printf("Message");
        // Interrupt deaktivieren

        }
                RI0 = 0;
        }
}
//----------------------------------------------------------------

void OSCILLATOR_Init (void)
{
   int i;                              // delay counter

   OSCXCN = 0x67;                      // start external oscillator with
                                       // 22.1184MHz crystal

   for (i=0; i < 256; i++) ;           // wait for oscillator to start

   while (!(OSCXCN & 0x80)) ;          // Wait for crystal osc. to settle

   OSCICN = 0x88;                      // select external oscillator as SYSCLK
                                       // source and enable missing clock
                                       // detector

}


void Wait_MS(unsigned int ms)
{

   CKCON &= ~0x20;                     // use SYSCLK/12 as timebase

   RCAP2 = -(long)(SYSCLK/1000/12);          // Timer 2 overflows at 1 kHz
   TMR2 = RCAP2;

   ET2 = 0;                            // Disable Timer 2 interrupts

   TR2 = 1;                            // Start Timer 2

   while(ms)
   {
      TF2 = 0;                         // Clear flag to initialize
       while(!TF2);                     // Wait until timer overflows
      ms--;                            // Decrement ms
   }

   TR2 = 0;                            // Stop Timer 2

}


void send_serial(char string[])
{
    //SBUF=printf("%d\n",P1);
int t=0;
        SBUF = '0';
        while(!TI);
        TI=0;
```

```
        while(string[t]!='\0')
        {

                SBUF=string[t];t++;
        while(!TI);
        TI=0;
        }

}
```

Temperature-Humidity Sensor

```
// Includes
//-----------------------------------------------------------------------------------
#include <c8051f020.h>                    // SFR declarations
#include <stdio.h>
#include <string.h>
#include <stdlib.h>

//-----------------------------------------------------------------------------------
// Global CONSTANTS
//-----------------------------------------------------------------------------------


#define BAUDRATE     9600           // Baud rate of UART in bps
#define SYSCLK       22118400         // External crystal oscillator frequency


#define INT_DEC      256             // Integrate and decimate ratio
#define SAR_CLK      250000          // Desired SAR clock speed

#define SAMPLE_DELAY 250               // Delay in ms before taking sample

#define ANALOG_INPUTS 8              // Number of AIN pins to measure
                                      // (min=1, max=8)
#define SAMPLE_RATE 25000

int name = 31;
int devicetemp;
//long t_offset= 131;


int send_delay=30000;

unsigned short i =0;
int k =0,j=0;
unsigned int max=50;

long adc_result;
bit adc_ready = 0;


#define FREQUENCY       10           // Frequency of output waveform in Hz
idata char received_byte;
idata unsigned short new_cmd_received;

idata unsigned long Result[ANALOG_INPUTS];            // ADC0 decimated value, one for each
                                       // analog input
idata unsigned char amux_input=0;            // index of analog MUX inputs
idata unsigned char amux_convert=0;

idata static unsigned long accumulator[ANALOG_INPUTS] ={0L};
                                       // Here's where we integrate the
idata char out[30];                                  // ADC samples from input AIN0.0
```

```c
idata unsigned short p_string = 0;
idata char s_buffer[10];
//idata char cmd[20];
idata int max_len=2;
idata unsigned char UART =0;

idata short error = 0;

//-----------------------------------------------------------------------------
// Global Defines
//-----------------------------------------------------------------------------
#define LCD_DAT_PORT P6 // LCD is in 8 bit mode
#define LCD_CTRL_PORT P7 // 3 control pins on P7
#define RS_MASK 0x01 // for assessing LCD_CTRL_PORT
#define RW_MASK 0x02
#define E_MASK 0x04
//-----------------------------------------------------------------------------
// Global MACROS
//-----------------------------------------------------------------------------
// original delays [1]
#define pulse_E();\
                small_delay(5);\
                LCD_CTRL_PORT = LCD_CTRL_PORT | E_MASK;\
                small_delay(5);\
                LCD_CTRL_PORT = LCD_CTRL_PORT & ~E_MASK;\

//--------------------------------------------------------------------------------------
// Function PROTOTYPES
//--------------------------------------------------------------------------------------
void PORT_Init (void);
void Timer3_Init (int counts);
void ACD0_Init(void);


void small_delay (char d); // 8 bit, about 0.34us per count @22.1MHz
void large_delay (char d); // 16 bit, about 82us per count @22.1MHz
void huge_delay (char d); // 24 bit, about 22ms per count @22.1MHz

char lcd_dat (char c); // write data to the LCD controller
void lcd_cmd (char cmd); // write a command to the LCD controller
void lcd_busy_wait (void); // wait until the LCD is no longer busy
void lcd_init (void); // initialize the LCD to 8 bit mode
void lcd_puts (char string[]);
void lcd_clear (void); // clear display
void lcd_goto(char addr); //Set Cursor

void Set_DACs(void);

void Init_UART0(void); //-- configure and initialize the UART0
void OSCILLATOR_Init (void);
void Wait_MS (unsigned int ms);
void cut_cmd(short start, short end);
void send_serial(char string[]);
//--------------------------------------------------------------------------------------
// MAIN Routine
//--------------------------------------------------------------------------------------
void main (void) {


   // disable watchdog timer
   WDTCN = 0xde;
   WDTCN = 0xad;
   new_cmd_received = 0;
   received_byte = 0;
   OSCILLATOR_Init ();
   PORT_Init ();
    ACD0_Init();
   AD0EN =1;
   Init_UART0();
   Timer3_Init(SYSCLK/SAMPLE_RATE);
```

```
   Wait_MS(5000);EA = 1;
   while (1) {                           // spin forever

                if(adc_ready==1)
                {
                        EA=0;

                                Result[6]=(Result[6]*2400)/4095; //Temperatur
                                Result[6]=(Result[6]-509)*10000;
                                Result[6]=Result[6]/645;
                                Result[6]=Result[6]+74;
                                Result[7]=Result[7]*2400/4095; //Humidity

                                Result[7]=(Result[7]-958)*1000;
                                Result[7]=Result[7]/307;
                                Result[7]=Result[7]*10000/(10546-22*Result[6]/100); // temp-
compensation

                                for(i=0;i<ANALOG_INPUTS;i++)
                                {
                                        if(Result[i]>99999)
                                                Result[i]=99999;
                                        if(Result[i]<=0)
                                                Result[i]=0;
                                }

                                sprintf(out,"%03d-%05lu-%05lu#",name,Result[7],Result[6]);
                                send_serial(out);
                                wait_MS(send_delay);
                        adc_ready=0;
                        EA=1;
                        huge_delay(255);
                }

        }

}

//-----------------------------------------------------------------------------
// PORT_Init
//-----------------------------------------------------------------------------
//
// Configure the Crossbar and GPIO ports
//
void PORT_Init (void)
{
   XBR0 = 0x04;                                        // enable UART0
   XBR1 = 0x00;
   XBR2 = 0x40;                    // Enable crossbar and weak pull-ups

   P0MDOUT |= 0x01;                                    //enable TX0 as a push-pull
o/p
   P1MDOUT |= 0x40;                // enable P1.6 (LED) as push-pull output
                                                                   // 01000000
   P2MDOUT = 0x00;
   P3MDOUT = 0x00;

   P74OUT |= 0x48;                                     //01001000 1:= Push-Pull

   P4 |= 0xFF;
   P5 |= 0x0F;                                         //00001111 - LED & Buttons


}

//-----------------------------------------------------------------------------
// Timer3_Init
//-----------------------------------------------------------------------------
```

```
//
// Configure Timer3 to auto-reload and generate an interrupt at interval
// specified by <counts> using SYSCLK/12 as its time base.
//
void Timer3_Init (int counts)
{
   TMR3CN = 0x00;                      // Stop Timer3; Clear TF3;
                                       // use SYSCLK/12 as timebase

   TMR3RL  = -counts;                  // Init reload values
   TMR3    = 0xffff;                   // set to reload immediately
   EIE2   |= 0x01;                     // enable Timer3 interrupts
   TMR3CN |= 0x04;                     // start Timer3
   EIP2|=0x03;                                                 //Set Interrupt priotity of
ADC and Timer3 to high

   }

//-----------------------------------------------------------------------------
// Interrupt Service Routines
//-----------------------------------------------------------------------------

//-----------------------------------------------------------------------------
// Timer3_ISR
//-----------------------------------------------------------------------------
// This routine changes the state of the LED whenever Timer3 overflows.
//
void Timer3_ISR (void) interrupt 14
{
   TMR3CN &= ~(0x80);                     // clear TF3



}

void ACD0_Init(void)
{

        REF0CN=0x07;    // enable temp-sensor & on-chip VREF
        ADC0CN = 0x04;                         // ADC0 disabled; normal tracking
                                       // mode; ADC0 conversions are initiated
                                       // on overflow of Timer3; ADC0 data is
                                       // right-justified
                AMX0SL = 0x00;                      // Select AIN0.0 pin as ADC mux input
                                       // ISR will change this to step through
                                       // inputs
        AMX0CF = 0x00;                         // AIN inputs are single-ended (default)
        ADC0CF = (SYSCLK/SAR_CLK) << 3;        // ADC conversion clock = 2.5MHz
        ADC0CF |= 0x00;                        // PGA gain = 1 (alternativ = 2 := 0x02)
        EIE2|=0x02;             // enable ADC interrupts

}

void ACD0_ISR(void) interrupt 15 using 1
{

   unsigned     long temp;

   EA=0;
   AD0INT = 0;                         //clear ADC conversion complete overflow

   j++;

   if(j<=INT_DEC)       //from 0-255
        {
                accumulator[amux_input] += ADC0;
        }
   else
   {
        j=0;
```

```
    amux_input ++;                      // step to the next analog mux input

    if(amux_input >= 8)      // reset input index if the last input
        {                              // was just read
        amux_input=0;
                adc_ready=1;                     // reset input index back to AIN0.0
                }
        AMX0SL = amux_input;

   }

        if (j == 0)                                 // If zero, then post result
    {

            temp = accumulator[amux_input]>>8;
                        {
                        Result[amux_input] = temp; //Copy decimated values into Result
                        }
                        accumulator[amux_input] = 0L;                    // Reset
accumulators
                        if(amux_input==2)
                        {
                                adc_result=Result[amux_input];
                        }
        }
        EA=1;

}

void small_delay(char d)
{
        while (d--);
}

void large_delay(char d)
{
        while (d--)
        small_delay(255);
}

void huge_delay(char d)
{
        while (d--)
        large_delay(255);
}


void Init_UART0(void)
{


   SCON0   = 0x50;                     // SCON0: mode 1, 8-bit UART, enable RX
   TMOD    = 0x20;                     // TMOD: timer 1, mode 2, 8-bit reload
   TH1 = - ((long) (SYSCLK/BAUDRATE)/16);;     // set Timer1 reload value for baudrate
   TR1    = 1;                         // start Timer1
   CKCON |= 0x10;                      // Timer1 uses SYSCLK as time base
   PCON  |= 0x80;                      // SMOD00 = 1
   TI0    = 1;                         // Indicate TX0 ready
                     // Indicate TX0 ready
        PCON |= 0x80;    //SMOD0=1 UART0 baud rate divided by 2 disabled

        IE |= 0x10;
        IP |=0x00; //Enable UART interrupt und set high priority level

        RI0=0; //clear received interrupt flag

}
//------------------------------------------------------------

void UART0_ISR(void) interrupt 4
```

```
{
//-- pending flags RI0 (SCON0.0) and TI0(SCON0.1)

        if ( RI0 == 1)
        {
           received_byte= SBUF0;
           s_buffer[p_string] = received_byte;
           if(p_string==0)
           {
                //s_buffer="0";
           }
    /* Wenn nicht das Ende der Zeichenkette erreicht wurde,
       dann weiteres Zeichen senden */
        if ( received_byte!=0x0D && received_byte!='-' ) {

                        p_string++;
                }
                else {

        // Flag setzen, das der String gesendet wurde
                new_cmd_received=1;
                s_buffer[p_string]='\0';
                 //-- clear the flag
                //printf("Message");

        // Interrupt deaktivieren

        }
                RI0 = 0;
        }
}
//-------------------------------------------------------------

void OSCILLATOR_Init (void)
{
   int i;                              // delay counter

   OSCXCN = 0x67;                      // start external oscillator with
                                       // 22.1184MHz crystal

   for (i=0; i < 256; i++) ;           // wait for oscillator to start

   while (!(OSCXCN & 0x80)) ;          // Wait for crystal osc. to settle

   OSCICN = 0x88;                      // select external oscillator as SYSCLK
                                       // source and enable missing clock
                                      // detector

}


void Wait_MS(unsigned int ms)
{

   CKCON &= ~0x20;                     // use SYSCLK/12 as timebase

   RCAP2 = -(long)(SYSCLK/1000/12);          // Timer 2 overflows at 1 kHz
   TMR2 = RCAP2;

   ET2 = 0;                            // Disable Timer 2 interrupts

   TR2 = 1;                            // Start Timer 2

   while(ms)
   {
      TF2 = 0;                         // Clear flag to initialize
      while(!TF2);                     // Wait until timer overflows
      ms--;                            // Decrement ms
   }
```

```
   TR2 = 0;                            // Stop Timer 2

}


void send_serial(char string[])
{
    //SBUF=printf("%d\n",P1);
int t=0;
        SBUF = '0';
        while(!TI);
        TI=0;


        while(string[t]!='\0')
        {

                SBUF=string[t];t++;
        while(!TI);
        TI=0;
        }
        }
```

Appendix 3

Input File

1 1 10
1 1 25
1 1 11
1 1 12
1 1 17
1 1 19
1 1 15
1 1 25
1 1 10
1 1 16
1 1 26
2 1 26
2 1 10
2 1 11
2 1 25
2 1 12
2 1 17
2 1 16
2 1 14
2 1 25
2 1 10
2 1 19
3 1 18
3 1 19
3 1 10
3 1 25
3 1 13
3 1 11
3 1 16
3 1 10
3 1 26
3 1 19
3 1 14
4 1 10
4 1 25
4 1 12
4 1 13
4 1 17
4 1 18
4 1 10
4 1 12
4 1 14
4 1 18
5 1 19
5 1 26
5 1 10

5 1 25	6 1 14
5 1 11	6 1 16
5 1 13	6 1 15
5 1 10	7 1 18
5 1 16	7 1 10
5 1 14	7 1 25
6 1 10	7 1 13
6 1 12	7 1 12
6 1 25	7 1 11
6 1 11	7 1 17
6 1 13	7 1 19
6 1 10	7 1 10
6 1 17	7 1 18

Appendix 4

Output File

10 - 7

10 11 - 6

10 11 12 - 4

10 11 12 13 - 2

10 11 12 13 14 - 1

10 11 12 13 14 15 - 1

10 11 12 13 14 15 16 - 1

10 11 12 13 14 15 16 17 - 1

10 11 12 13 14 15 16 17 25 - 1

10 11 12 13 14 15 16 25 - 1

10 11 12 13 14 15 17 - 1

10 11 12 13 14 15 17 25 - 1

10 11 12 13 14 15 25 - 1

10 11 12 13 14 16 - 1

10 11 12 13 14 16 17 - 1

10 11 12 13 14 16 17 25 - 1

10 11 12 13 14 16 25 - 1

10 11 12 13 14 17 - 1

10 11 12 13 14 17 25 - 1

10 11 12 13 14 25 - 1

10 11 12 13 15 - 1

10 11 12 13 15 16 - 1

10 11 12 13 15 16 17 - 1

10 11 12 13 15 16 17 25 - 1

10 11 12 13 15 16 25 - 1

10 11 12 13 15 17 - 1

10 11 12 13 15 17 25 - 1

10 11 12 13 15 25 - 1

10 11 12 13 16 - 1

10 11 12 13 16 17 - 1

10 11 12 13 16 17 25 - 1

10 11 12 13 16 25 - 1

10 11 12 13 17 - 2

10 11 12 13 17 18 - 1

10 11 12 13 17 18 19 - 1

10 11 12 13 17 18 19 25 - 1

10 11 12 13 17 18 25 - 1

10 11 12 13 17 19 - 1

10 11 12 13 17 19 25 - 1

10 11 12 13 17 25 - 2

10 11 12 13 18 - 1

10 11 12 13 18 19 - 1

10 11 12 13 18 19 25 - 1

10 11 12 13 18 25 - 1

10 11 12 13 19 - 1

10 11 12 13 19 25 - 1

10 11 12 13 25 - 2

10 11 12 14 - 2

10 11 12 14 15 - 1

10 11 12 14 15 16 - 1

10 11 12 14 15 16 17 - 1

10 11 12 14 15 16 17 25 - 1

10 11 12 14 15 16 25 - 1

10 11 12 14 15 17 - 1

10 11 12 14 15 17 25 - 1

10 11 12 14 15 25 - 1

10 11 12 14 16 - 2

10 11 12 14 16 17 - 2

10 11 12 14 16 17 19 - 1

10 11 12 14 16 17 19 25 - 1

10 11 12 14 16 17 19 25 26 - 1

10 11 12 14 16 17 19 26 - 1

10 11 12 14 16 17 25 - 2

10 11 12 14 16 17 25 26 - 1

10 11 12 14 16 17 26 - 1

10 11 12 14 16 19 - 1

10 11 12 14 16 19 25 - 1

10 11 12 14 16 19 25 26 - 1

10 11 12 14 16 19 26 - 1

10 11 12 14 16 25 - 2

10 11 12 14 16 25 26 - 1

10 11 12 14 16 26 - 1

10 11 12 14 17 - 2

10 11 12 14 17 19 - 1

10 11 12 14 17 19 25 - 1

10 11 12 14 17 19 25 26 - 1

10 11 12 14 17 19 26 - 1

10 11 12 14 17 25 - 2

10 11 12 14 17 25 26 - 1

10 11 12 14 17 26 - 1

10 11 12 14 19 - 1

10 11 12 14 19 25 - 1

10 11 12 14 19 25 26 - 1

10 11 12 14 19 26 - 1

10 11 12 14 25 - 2

10 11 12 14 25 26 - 1

10 11 12 14 26 - 1

10 11 12 15 - 2
10 11 12 15 16 - 2
10 11 12 15 16 17 - 2
10 11 12 15 16 17 19 - 1
10 11 12 15 16 17 19 25 - 1
10 11 12 15 16 17 19 25 26 - 1
10 11 12 15 16 17 19 26 - 1
10 11 12 15 16 17 25 - 2
10 11 12 15 16 17 25 26 - 1
10 11 12 15 16 17 26 - 1
10 11 12 15 16 19 - 1
10 11 12 15 16 19 25 - 1
10 11 12 15 16 19 25 26 - 1
10 11 12 15 16 19 26 - 1
10 11 12 15 16 25 - 2
10 11 12 15 16 25 26 - 1
10 11 12 15 16 26 - 1
10 11 12 15 17 - 2
10 11 12 15 17 19 - 1
10 11 12 15 17 19 25 - 1
10 11 12 15 17 19 25 26 - 1
10 11 12 15 17 19 26 - 1
10 11 12 15 17 25 - 2
10 11 12 15 17 25 26 - 1
10 11 12 15 17 26 - 1
10 11 12 15 19 - 1
10 11 12 15 19 25 - 1
10 11 12 15 19 25 26 - 1
10 11 12 15 19 26 - 1
10 11 12 15 25 - 2
10 11 12 15 25 26 - 1
10 11 12 15 26 - 1

10 11 12 16 - 3
10 11 12 16 17 - 3
10 11 12 16 17 19 - 2
10 11 12 16 17 19 25 - 2
10 11 12 16 17 19 25 26 - 2
10 11 12 16 17 19 26 - 2
10 11 12 16 17 25 - 3
10 11 12 16 17 25 26 - 2
10 11 12 16 17 26 - 2
10 11 12 16 19 - 2
10 11 12 16 19 25 - 2
10 11 12 16 19 25 26 - 2
10 11 12 16 19 26 - 2
10 11 12 16 25 - 3
10 11 12 16 25 26 - 2
10 11 12 16 26 - 2
10 11 12 17 - 4
10 11 12 17 18 - 1
10 11 12 17 18 19 - 1
10 11 12 17 18 19 25 - 1
10 11 12 17 18 25 - 1
10 11 12 17 19 - 3
10 11 12 17 19 25 - 3
10 11 12 17 19 25 26 - 2
10 11 12 17 19 26 - 2
10 11 12 17 25 - 4
10 11 12 17 25 26 - 2
10 11 12 17 26 - 2
10 11 12 18 - 1
10 11 12 18 19 - 1
10 11 12 18 19 25 - 1
10 11 12 18 25 - 1

10 11 12 19 - 3
10 11 12 19 25 - 3
10 11 12 19 25 26 - 2
10 11 12 19 26 - 2
10 11 12 25 - 4
10 11 12 25 26 - 2
10 11 12 26 - 2
10 11 13 - 4
10 11 13 14 - 3
10 11 13 14 15 - 1
10 11 13 14 15 16 - 1
10 11 13 14 15 16 17 - 1
10 11 13 14 15 16 17 25 - 1
10 11 13 14 15 16 25 - 1
10 11 13 14 15 17 - 1
10 11 13 14 15 17 25 - 1
10 11 13 14 15 25 - 1
10 11 13 14 16 - 3
10 11 13 14 16 17 - 1
10 11 13 14 16 17 25 - 1
10 11 13 14 16 18 - 1
10 11 13 14 16 18 19 - 1
10 11 13 14 16 18 19 25 - 1
10 11 13 14 16 18 19 25 26 - 1
10 11 13 14 16 18 19 26 - 1
10 11 13 14 16 18 25 - 1
10 11 13 14 16 18 25 26 - 1
10 11 13 14 16 18 26 - 1
10 11 13 14 16 19 - 2
10 11 13 14 16 19 25 - 2
10 11 13 14 16 19 25 26 - 2
10 11 13 14 16 19 26 - 2

10 11 13 14 16 25 - 3
10 11 13 14 16 25 26 - 2
10 11 13 14 16 26 - 2
10 11 13 14 17 - 1
10 11 13 14 17 25 - 1
10 11 13 14 18 - 1
10 11 13 14 18 19 - 1
10 11 13 14 18 19 25 - 1
10 11 13 14 18 19 25 26 - 1
10 11 13 14 18 19 26 - 1
10 11 13 14 18 25 - 1
10 11 13 14 18 25 26 - 1
10 11 13 14 18 26 - 1
10 11 13 14 19 - 2
10 11 13 14 19 25 - 2
10 11 13 14 19 25 26 - 2
10 11 13 14 19 26 - 2
10 11 13 14 25 - 3
10 11 13 14 25 26 - 2
10 11 13 14 26 - 2
10 11 13 15 - 1
10 11 13 15 16 - 1
10 11 13 15 16 17 - 1
10 11 13 15 16 17 25 - 1
10 11 13 15 16 25 - 1
10 11 13 15 17 - 1
10 11 13 15 17 25 - 1
10 11 13 15 25 - 1
10 11 13 16 - 3
10 11 13 16 17 - 1
10 11 13 16 17 25 - 1
10 11 13 16 18 - 1
10 11 13 16 18 19 - 1
10 11 13 16 18 19 25 - 1
10 11 13 16 18 19 25 26 - 1
10 11 13 16 18 19 26 - 1
10 11 13 16 18 25 - 1
10 11 13 16 18 25 26 - 1
10 11 13 16 18 26 - 1
10 11 13 16 19 - 2
10 11 13 16 19 25 - 2
10 11 13 16 19 25 26 - 2
10 11 13 16 19 26 - 2
10 11 13 16 25 - 3
10 11 13 16 25 26 - 2
10 11 13 16 26 - 2
10 11 13 17 - 2
10 11 13 17 18 - 1
10 11 13 17 18 19 - 1
10 11 13 17 18 19 25 - 1
10 11 13 17 18 25 - 1
10 11 13 17 19 - 1
10 11 13 17 19 25 - 1
10 11 13 17 25 - 2
10 11 13 18 - 2
10 11 13 18 19 - 2
10 11 13 18 19 25 - 2
10 11 13 18 19 25 26 - 1
10 11 13 18 19 26 - 1
10 11 13 18 25 - 2
10 11 13 18 25 26 - 1
10 11 13 18 26 - 1
10 11 13 19 - 3
10 11 13 19 25 - 3
10 11 13 19 25 26 - 2
10 11 13 19 26 - 2
10 11 13 25 - 4
10 11 13 25 26 - 2
10 11 13 26 - 2
10 11 14 - 4
10 11 14 15 - 1
10 11 14 15 16 - 1
10 11 14 15 16 17 - 1
10 11 14 15 16 17 25 - 1
10 11 14 15 16 25 - 1
10 11 14 15 17 - 1
10 11 14 15 17 25 - 1
10 11 14 15 25 - 1
10 11 14 16 - 4
10 11 14 16 17 - 2
10 11 14 16 17 19 - 1
10 11 14 16 17 19 25 - 1
10 11 14 16 17 19 25 26 - 1
10 11 14 16 17 19 26 - 1
10 11 14 16 17 25 - 2
10 11 14 16 17 25 26 - 1
10 11 14 16 17 26 - 1
10 11 14 16 18 - 1
10 11 14 16 18 19 - 1
10 11 14 16 18 19 25 - 1
10 11 14 16 18 19 25 26 - 1
10 11 14 16 18 19 26 - 1
10 11 14 16 18 25 - 1
10 11 14 16 18 25 26 - 1
10 11 14 16 18 26 - 1
10 11 14 16 19 - 3

10 11 14 16 19 25 - 3
10 11 14 16 19 25 26 - 3
10 11 14 16 19 26 - 3
10 11 14 16 25 - 4
10 11 14 16 25 26 - 3
10 11 14 16 26 - 3
10 11 14 17 - 2
10 11 14 17 19 - 1
10 11 14 17 19 25 - 1
10 11 14 17 19 25 26 - 1
10 11 14 17 19 26 - 1
10 11 14 17 25 - 2
10 11 14 17 25 26 - 1
10 11 14 17 26 - 1
10 11 14 18 - 1
10 11 14 18 19 - 1
10 11 14 18 19 25 - 1
10 11 14 18 19 25 26 - 1
10 11 14 18 19 26 - 1
10 11 14 18 25 - 1
10 11 14 18 25 26 - 1
10 11 14 18 26 - 1
10 11 14 19 - 3
10 11 14 19 25 - 3
10 11 14 19 25 26 - 3
10 11 14 19 26 - 3
10 11 14 25 - 4
10 11 14 25 26 - 3
10 11 14 26 - 3
10 11 15 - 2
10 11 15 16 - 2
10 11 15 16 17 - 2
10 11 15 16 17 19 - 1
10 11 15 16 17 19 25 - 1
10 11 15 16 17 19 25 26 - 1
10 11 15 16 17 19 26 - 1
10 11 15 16 17 25 - 2
10 11 15 16 17 25 26 - 1
10 11 15 16 17 26 - 1
10 11 15 16 19 - 1
10 11 15 16 19 25 - 1
10 11 15 16 19 25 26 - 1
10 11 15 16 19 26 - 1
10 11 15 16 25 - 2
10 11 15 16 25 26 - 1
10 11 15 16 26 - 1
10 11 15 17 - 2
10 11 15 17 19 - 1
10 11 15 17 19 25 - 1
10 11 15 17 19 25 26 - 1
10 11 15 17 19 26 - 1
10 11 15 17 25 - 2
10 11 15 17 25 26 - 1
10 11 15 17 26 - 1
10 11 15 19 - 1
10 11 15 19 25 - 1
10 11 15 19 25 26 - 1
10 11 15 19 26 - 1
10 11 15 25 - 2
10 11 15 25 26 - 1
10 11 15 26 - 1
10 11 16 - 5
10 11 16 17 - 3
10 11 16 17 19 - 2
10 11 16 17 19 25 - 2
10 11 16 17 19 25 26 - 2
10 11 16 17 19 26 - 2
10 11 16 17 25 - 3
10 11 16 17 25 26 - 2
10 11 16 17 26 - 2
10 11 16 18 - 1
10 11 16 18 19 - 1
10 11 16 18 19 25 - 1
10 11 16 18 19 25 26 - 1
10 11 16 18 19 26 - 1
10 11 16 18 25 - 1
10 11 16 18 25 26 - 1
10 11 16 18 26 - 1
10 11 16 19 - 4
10 11 16 19 25 - 4
10 11 16 19 25 26 - 4
10 11 16 19 26 - 4
10 11 16 25 - 5
10 11 16 25 26 - 4
10 11 16 26 - 4
10 11 17 - 4
10 11 17 18 - 1
10 11 17 18 19 - 1
10 11 17 18 19 25 - 1
10 11 17 18 25 - 1
10 11 17 19 - 3
10 11 17 19 25 - 3
10 11 17 19 25 26 - 2
10 11 17 19 26 - 2
10 11 17 25 - 4
10 11 17 25 26 - 2

10 11 17 26 - 2

10 11 18 - 2

10 11 18 19 - 2

10 11 18 19 25 - 2

10 11 18 19 25 26 - 1

10 11 18 19 26 - 1

10 11 18 25 - 2

10 11 18 25 26 - 1

10 11 18 26 - 1

10 11 19 - 5

10 11 19 25 - 5

10 11 19 25 26 - 4

10 11 19 26 - 4

10 11 25 - 6

10 11 25 26 - 4

10 11 26 - 4

10 12 - 5

10 12 13 - 3

10 12 13 14 - 2

10 12 13 14 15 - 1

10 12 13 14 15 16 - 1

10 12 13 14 15 16 17 - 1

10 12 13 14 15 16 17 25 - 1

10 12 13 14 15 16 25 - 1

10 12 13 14 15 17 - 1

10 12 13 14 15 17 25 - 1

10 12 13 14 15 25 - 1

10 12 13 14 16 - 1

10 12 13 14 16 17 - 1

10 12 13 14 16 17 25 - 1

10 12 13 14 16 25 - 1

10 12 13 14 17 - 2

10 12 13 14 17 18 - 1

10 12 13 14 17 18 25 - 1

10 12 13 14 17 25 - 2

10 12 13 14 18 - 1

10 12 13 14 18 25 - 1

10 12 13 14 25 - 2

10 12 13 15 - 1

10 12 13 15 16 - 1

10 12 13 15 16 17 - 1

10 12 13 15 16 17 25 - 1

10 12 13 15 16 25 - 1

10 12 13 15 17 - 1

10 12 13 15 17 25 - 1

10 12 13 15 25 - 1

10 12 13 16 - 1

10 12 13 16 17 - 1

10 12 13 16 17 25 - 1

10 12 13 16 25 - 1

10 12 13 17 - 3

10 12 13 17 18 - 2

10 12 13 17 18 19 - 1

10 12 13 17 18 19 25 - 1

10 12 13 17 18 25 - 2

10 12 13 17 19 - 1

10 12 13 17 19 25 - 1

10 12 13 17 25 - 3

10 12 13 18 - 2

10 12 13 18 19 - 1

10 12 13 18 19 25 - 1

10 12 13 18 25 - 2

10 12 13 19 - 1

10 12 13 19 25 - 1

10 12 13 25 - 3

10 12 14 - 3

10 12 14 15 - 1

10 12 14 15 16 - 1

10 12 14 15 16 17 - 1

10 12 14 15 16 17 25 - 1

10 12 14 15 16 25 - 1

10 12 14 15 17 - 1

10 12 14 15 17 25 - 1

10 12 14 15 25 - 1

10 12 14 16 - 2

10 12 14 16 17 - 2

10 12 14 16 17 19 - 1

10 12 14 16 17 19 25 - 1

10 12 14 16 17 19 25 26 - 1

10 12 14 16 17 19 26 - 1

10 12 14 16 17 25 - 2

10 12 14 16 17 25 26 - 1

10 12 14 16 17 26 - 1

10 12 14 16 19 - 1

10 12 14 16 19 25 - 1

10 12 14 16 19 25 26 - 1

10 12 14 16 19 26 - 1

10 12 14 16 25 - 2

10 12 14 16 25 26 - 1

10 12 14 16 26 - 1

10 12 14 17 - 3

10 12 14 17 18 - 1

10 12 14 17 18 25 - 1

10 12 14 17 19 - 1

10 12 14 17 19 25 - 1

10 12 14 17 19 25 26 - 1

10 12 14 17 19 26 - 1

10 12 14 17 25 - 3

10 12 14 17 25 26 - 1

10 12 14 17 26 - 1

10 12 14 18 - 1

10 12 14 18 25 - 1

10 12 14 19 - 1

10 12 14 19 25 - 1

10 12 14 19 25 26 - 1

10 12 14 19 26 - 1

10 12 14 25 - 3

10 12 14 25 26 - 1

10 12 14 26 - 1

10 12 15 - 2

10 12 15 16 - 2

10 12 15 16 17 - 2

10 12 15 16 17 19 - 1

10 12 15 16 17 19 25 - 1

10 12 15 16 17 19 25 26 - 1

10 12 15 16 17 19 26 - 1

10 12 15 16 17 25 - 2

10 12 15 16 17 25 26 - 1

10 12 15 16 17 26 - 1

10 12 15 16 19 - 1

10 12 15 16 19 25 - 1

10 12 15 16 19 25 26 - 1

10 12 15 16 19 26 - 1

10 12 15 16 25 - 2

10 12 15 16 25 26 - 1

10 12 15 16 26 - 1

10 12 15 17 - 2

10 12 15 17 19 - 1

10 12 15 17 19 25 - 1

10 12 15 17 19 25 26 - 1

10 12 15 17 19 26 - 1

10 12 15 17 25 - 2

10 12 15 17 25 26 - 1

10 12 15 17 26 - 1

10 12 15 19 - 1

10 12 15 19 25 - 1

10 12 15 19 25 26 - 1

10 12 15 19 26 - 1

10 12 15 25 - 2

10 12 15 25 26 - 1

10 12 15 26 - 1

10 12 16 - 3

10 12 16 17 - 3

10 12 16 17 19 - 2

10 12 16 17 19 25 - 2

10 12 16 17 19 25 26 - 2

10 12 16 17 19 26 - 2

10 12 16 17 25 - 3

10 12 16 17 25 26 - 2

10 12 16 17 26 - 2

10 12 16 19 - 2

10 12 16 19 25 - 2

10 12 16 19 25 26 - 2

10 12 16 19 26 - 2

10 12 16 25 - 3

10 12 16 25 26 - 2

10 12 16 26 - 2

10 12 17 - 5

10 12 17 18 - 2

10 12 17 18 19 - 1

10 12 17 18 19 25 - 1

10 12 17 18 25 - 2

10 12 17 19 - 3

10 12 17 19 25 - 3

10 12 17 19 25 26 - 2

10 12 17 19 26 - 2

10 12 17 25 - 5

10 12 17 25 26 - 2

10 12 17 26 - 2

10 12 18 - 2

10 12 18 19 - 1

10 12 18 19 25 - 1

10 12 18 25 - 2

10 12 19 - 3

10 12 19 25 - 3

10 12 19 25 26 - 2

10 12 19 26 - 2

10 12 25 - 5

10 12 25 26 - 2

10 12 26 - 2

10 13 - 5

10 13 14 - 4

10 13 14 15 - 1

10 13 14 15 16 - 1

10 13 14 15 16 17 - 1

10 13 14 15 16 17 25 - 1

10 13 14 15 16 25 - 1

10 13 14 15 17 - 1

10 13 14 15 17 25 - 1

10 13 14 15 25 - 1

10 13 14 16 - 3

10 13 14 16 17 - 1

10 13 14 16 17 25 - 1

10 13 14 16 18 - 1

10 13 14 16 18 19 - 1

10 13 14 16 18 19 25 - 1

10 13 14 16 18 19 25 26 - 1

10 13 14 16 18 19 26 - 1

10 13 14 16 18 25 - 1

10 13 14 16 18 25 26 - 1

10 13 14 16 18 26 - 1

10 13 14 16 19 - 2

10 13 14 16 19 25 - 2

10 13 14 16 19 25 26 - 2

10 13 14 16 19 26 - 2

10 13 14 16 25 - 3

10 13 14 16 25 26 - 2

10 13 14 16 26 - 2

10 13 14 17 - 2

10 13 14 17 18 - 1

10 13 14 17 18 25 - 1

10 13 14 17 25 - 2

10 13 14 18 - 2

10 13 14 18 19 - 1

10 13 14 18 19 25 - 1

10 13 14 18 19 25 26 - 1

10 13 14 18 19 26 - 1

10 13 14 18 25 - 2

10 13 14 18 25 26 - 1

10 13 14 18 26 - 1

10 13 14 19 - 2

10 13 14 19 25 - 2

10 13 14 19 25 26 - 2

10 13 14 19 26 - 2

10 13 14 25 - 4

10 13 14 25 26 - 2

10 13 14 26 - 2

10 13 15 - 1

10 13 15 16 - 1

10 13 15 16 17 - 1

10 13 15 16 17 25 - 1

10 13 15 16 25 - 1

10 13 15 17 - 1

10 13 15 17 25 - 1

10 13 15 25 - 1

10 13 16 - 3

10 13 16 17 - 1

10 13 16 17 25 - 1

10 13 16 18 - 1

10 13 16 18 19 - 1

10 13 16 18 19 25 - 1

10 13 16 18 19 25 26 - 1

10 13 16 18 19 26 - 1

10 13 16 18 25 - 1

10 13 16 18 25 26 - 1

10 13 16 18 26 - 1

10 13 16 19 - 2

10 13 16 19 25 - 2

10 13 16 19 25 26 - 2

10 13 16 19 26 - 2

10 13 16 25 - 3

10 13 16 25 26 - 2

10 13 16 26 - 2

10 13 17 - 3

10 13 17 18 - 2

10 13 17 18 19 - 1

10 13 17 18 19 25 - 1

10 13 17 18 25 - 2

10 13 17 19 - 1

10 13 17 19 25 - 1

10 13 17 25 - 3

10 13 18 - 3

10 13 18 19 - 2

10 13 18 19 25 - 2

10 13 18 19 25 26 - 1

10 13 18 19 26 - 1

10 13 18 25 - 3

10 13 18 25 26 - 1

10 13 18 26 - 1

10 13 19 - 3

10 13 19 25 - 3

10 13 19 25 26 - 2

10 13 19 26 - 2

10 13 25 - 5

10 13 25 26 - 2

10 13 26 - 2

10 14 - 5

10 14 15 - 1

10 14 15 16 - 1

10 14 15 16 17 - 1

10 14 15 16 17 25 - 1

10 14 15 16 25 - 1

10 14 15 17 - 1

10 14 15 17 25 - 1

10 14 15 25 - 1

10 14 16 - 4

10 14 16 17 - 2

10 14 16 17 19 - 1

10 14 16 17 19 25 - 1
10 14 16 17 19 25 26 - 1
10 14 16 17 19 26 - 1
10 14 16 17 25 - 2
10 14 16 17 25 26 - 1
10 14 16 17 26 - 1
10 14 16 18 - 1
10 14 16 18 19 - 1
10 14 16 18 19 25 - 1
10 14 16 18 19 25 26 - 1
10 14 16 18 19 26 - 1
10 14 16 18 25 - 1
10 14 16 18 25 26 - 1
10 14 16 18 26 - 1
10 14 16 19 - 3
10 14 16 19 25 - 3
10 14 16 19 25 26 - 3
10 14 16 19 26 - 3
10 14 16 25 - 4
10 14 16 25 26 - 3
10 14 16 26 - 3
10 14 17 - 3
10 14 17 18 - 1
10 14 17 18 25 - 1
10 14 17 19 - 1
10 14 17 19 25 - 1
10 14 17 19 25 26 - 1
10 14 17 19 26 - 1
10 14 17 25 - 3
10 14 17 25 26 - 1
10 14 17 26 - 1
10 14 18 - 2

10 14 18 19 - 1
10 14 18 19 25 - 1
10 14 18 19 25 26 - 1
10 14 18 19 26 - 1
10 14 18 25 - 2
10 14 18 25 26 - 1
10 14 18 26 - 1
10 14 19 - 3
10 14 19 25 - 3
10 14 19 25 26 - 3
10 14 19 26 - 3
10 14 25 - 5
10 14 25 26 - 3
10 14 26 - 3
10 15 - 2
10 15 16 - 2
10 15 16 17 - 2
10 15 16 17 19 - 1
10 15 16 17 19 25 - 1
10 15 16 17 19 25 26 - 1
10 15 16 17 19 26 - 1
10 15 16 17 25 - 2
10 15 16 17 25 26 - 1
10 15 16 17 26 - 1
10 15 16 19 - 1
10 15 16 19 25 - 1
10 15 16 19 25 26 - 1
10 15 16 19 26 - 1
10 15 16 25 - 2
10 15 16 25 26 - 1
10 15 16 26 - 1
10 15 17 - 2

10 15 17 19 - 1
10 15 17 19 25 - 1
10 15 17 19 25 26 - 1
10 15 17 19 26 - 1
10 15 17 25 - 2
10 15 17 25 26 - 1
10 15 17 26 - 1
10 15 19 - 1
10 15 19 25 - 1
10 15 19 25 26 - 1
10 15 19 26 - 1
10 15 25 - 2
10 15 25 26 - 1
10 15 26 - 1
10 16 - 5
10 16 17 - 3
10 16 17 19 - 2
10 16 17 19 25 - 2
10 16 17 19 25 26 - 2
10 16 17 19 26 - 2
10 16 17 25 - 3
10 16 17 25 26 - 2
10 16 17 26 - 2
10 16 18 - 1
10 16 18 19 - 1
10 16 18 19 25 - 1
10 16 18 19 25 26 - 1
10 16 18 19 26 - 1
10 16 18 25 - 1
10 16 18 25 26 - 1
10 16 18 26 - 1
10 16 19 - 4

10 16 19 25 - 4

10 16 19 25 26 - 4

10 16 19 26 - 4

10 16 25 - 5

10 16 25 26 - 4

10 16 26 - 4

10 17 - 5

10 17 18 - 2

10 17 18 19 - 1

10 17 18 19 25 - 1

10 17 18 25 - 2

10 17 19 - 3

10 17 19 25 - 3

10 17 19 25 26 - 2

10 17 19 26 - 2

10 17 25 - 5

10 17 25 26 - 2

10 17 26 - 2

10 18 - 3

10 18 19 - 2

10 18 19 25 - 2

10 18 19 25 26 - 1

10 18 19 26 - 1

10 18 25 - 3

10 18 25 26 - 1

10 18 26 - 1

10 19 - 5

10 19 25 - 5

10 19 25 26 - 4

10 19 26 - 4

10 25 - 7

10 25 26 - 4

10 26 - 4

11 - 6

11 12 - 4

11 12 13 - 2

11 12 13 14 - 1

11 12 13 14 15 - 1

11 12 13 14 15 16 - 1

11 12 13 14 15 16 17 - 1

11 12 13 14 15 16 17 25 - 1

11 12 13 14 15 16 25 - 1

11 12 13 14 15 17 - 1

11 12 13 14 15 17 25 - 1

11 12 13 14 15 25 - 1

11 12 13 14 16 - 1

11 12 13 14 16 17 - 1

11 12 13 14 16 17 25 - 1

11 12 13 14 16 25 - 1

11 12 13 14 17 - 1

11 12 13 14 17 25 - 1

11 12 13 14 25 - 1

11 12 13 15 - 1

11 12 13 15 16 - 1

11 12 13 15 16 17 - 1

11 12 13 15 16 17 25 - 1

11 12 13 15 16 25 - 1

11 12 13 15 17 - 1

11 12 13 15 17 25 - 1

11 12 13 15 25 - 1

11 12 13 16 - 1

11 12 13 16 17 - 1

11 12 13 16 17 25 - 1

11 12 13 16 25 - 1

11 12 13 17 - 2

11 12 13 17 18 - 1

11 12 13 17 18 19 - 1

11 12 13 17 18 19 25 - 1

11 12 13 17 18 25 - 1

11 12 13 17 19 - 1

11 12 13 17 19 25 - 1

11 12 13 17 25 - 2

11 12 13 18 - 1

11 12 13 18 19 - 1

11 12 13 18 19 25 - 1

11 12 13 18 25 - 1

11 12 13 19 - 1

11 12 13 19 25 - 1

11 12 13 25 - 2

11 12 14 - 2

11 12 14 15 - 1

11 12 14 15 16 - 1

11 12 14 15 16 17 - 1

11 12 14 15 16 17 25 - 1

11 12 14 15 16 25 - 1

11 12 14 15 17 - 1

11 12 14 15 17 25 - 1

11 12 14 15 25 - 1

11 12 14 16 - 2

11 12 14 16 17 - 2

11 12 14 16 17 19 - 1

11 12 14 16 17 19 25 - 1

11 12 14 16 17 19 25 26 - 1

11 12 14 16 17 19 26 - 1

11 12 14 16 17 25 - 2

11 12 14 16 17 25 26 - 1

11 12 14 16 17 26 - 1
11 12 14 16 19 - 1
11 12 14 16 19 25 - 1
11 12 14 16 19 25 26 - 1
11 12 14 16 19 26 - 1
11 12 14 16 25 - 2
11 12 14 16 25 26 - 1
11 12 14 16 26 - 1
11 12 14 17 - 2
11 12 14 17 19 - 1
11 12 14 17 19 25 - 1
11 12 14 17 19 25 26 - 1
11 12 14 17 19 26 - 1
11 12 14 17 25 - 2
11 12 14 17 25 26 - 1
11 12 14 17 26 - 1
11 12 14 19 - 1
11 12 14 19 25 - 1
11 12 14 19 25 26 - 1
11 12 14 19 26 - 1
11 12 14 25 - 2
11 12 14 25 26 - 1
11 12 14 26 - 1
11 12 15 - 2
11 12 15 16 - 2
11 12 15 16 17 - 2
11 12 15 16 17 19 - 1
11 12 15 16 17 19 25 - 1
11 12 15 16 17 19 25 26 - 1
11 12 15 16 17 19 26 - 1
11 12 15 16 17 25 - 2
11 12 15 16 17 25 26 - 1
11 12 15 16 17 26 - 1
11 12 15 16 19 - 1
11 12 15 16 19 25 - 1
11 12 15 16 19 25 26 - 1
11 12 15 16 19 26 - 1
11 12 15 16 25 - 2
11 12 15 16 25 26 - 1
11 12 15 16 26 - 1
11 12 15 17 - 2
11 12 15 17 19 - 1
11 12 15 17 19 25 - 1
11 12 15 17 19 25 26 - 1
11 12 15 17 19 26 - 1
11 12 15 17 25 - 2
11 12 15 17 25 26 - 1
11 12 15 17 26 - 1
11 12 15 19 - 1
11 12 15 19 25 - 1
11 12 15 19 25 26 - 1
11 12 15 19 26 - 1
11 12 15 25 - 2
11 12 15 25 26 - 1
11 12 15 26 - 1
11 12 16 - 3
11 12 16 17 - 3
11 12 16 17 19 - 2
11 12 16 17 19 25 - 2
11 12 16 17 19 25 26 - 2
11 12 16 17 19 26 - 2
11 12 16 17 25 - 3
11 12 16 17 25 26 - 2
11 12 16 17 26 - 2
11 12 16 19 - 2
11 12 16 19 25 - 2
11 12 16 19 25 26 - 2
11 12 16 19 26 - 2
11 12 16 25 - 3
11 12 16 25 26 - 2
11 12 16 26 - 2
11 12 17 - 4
11 12 17 18 - 1
11 12 17 18 19 - 1
11 12 17 18 19 25 - 1
11 12 17 18 25 - 1
11 12 17 19 - 3
11 12 17 19 25 - 3
11 12 17 19 25 26 - 2
11 12 17 19 26 - 2
11 12 17 25 - 4
11 12 17 25 26 - 2
11 12 17 26 - 2
11 12 18 - 1
11 12 18 19 - 1
11 12 18 19 25 - 1
11 12 18 25 - 1
11 12 19 - 3
11 12 19 25 - 3
11 12 19 25 26 - 2
11 12 19 26 - 2
11 12 25 - 4
11 12 25 26 - 2
11 12 26 - 2
11 13 - 4
11 13 14 - 3

11 13 14 15 - 1
11 13 14 15 16 - 1
11 13 14 15 16 17 - 1
11 13 14 15 16 17 25 - 1
11 13 14 15 16 25 - 1
11 13 14 15 17 - 1
11 13 14 15 17 25 - 1
11 13 14 15 25 - 1
11 13 14 16 - 3
11 13 14 16 17 - 1
11 13 14 16 17 25 - 1
11 13 14 16 18 - 1
11 13 14 16 18 19 - 1
11 13 14 16 18 19 25 - 1
11 13 14 16 18 19 25 26 - 1
11 13 14 16 18 19 26 - 1
11 13 14 16 18 25 - 1
11 13 14 16 18 25 26 - 1
11 13 14 16 18 26 - 1
11 13 14 16 19 - 2
11 13 14 16 19 25 - 2
11 13 14 16 19 25 26 - 2
11 13 14 16 19 26 - 2
11 13 14 16 25 - 3
11 13 14 16 25 26 - 2
11 13 14 16 26 - 2
11 13 14 17 - 1
11 13 14 17 25 - 1
11 13 14 18 - 1
11 13 14 18 19 - 1
11 13 14 18 19 25 - 1
11 13 14 18 19 25 26 - 1
11 13 14 18 19 26 - 1
11 13 14 18 25 - 1
11 13 14 18 25 26 - 1
11 13 14 18 26 - 1
11 13 14 19 - 2
11 13 14 19 25 - 2
11 13 14 19 25 26 - 2
11 13 14 19 26 - 2
11 13 14 25 - 3
11 13 14 25 26 - 2
11 13 14 26 - 2
11 13 15 - 1
11 13 15 16 - 1
11 13 15 16 17 - 1
11 13 15 16 17 25 - 1
11 13 15 16 25 - 1
11 13 15 17 - 1
11 13 15 17 25 - 1
11 13 15 25 - 1
11 13 16 - 3
11 13 16 17 - 1
11 13 16 17 25 - 1
11 13 16 18 - 1
11 13 16 18 19 - 1
11 13 16 18 19 25 - 1
11 13 16 18 19 25 26 - 1
11 13 16 18 19 26 - 1
11 13 16 18 25 - 1
11 13 16 18 25 26 - 1
11 13 16 18 26 - 1
11 13 16 19 - 2
11 13 16 19 25 - 2
11 13 16 19 25 26 - 2
11 13 16 19 26 - 2
11 13 16 25 - 3
11 13 16 25 26 - 2
11 13 16 26 - 2
11 13 17 - 2
11 13 17 18 - 1
11 13 17 18 19 - 1
11 13 17 18 19 25 - 1
11 13 17 18 25 - 1
11 13 17 19 - 1
11 13 17 19 25 - 1
11 13 17 25 - 2
11 13 18 - 2
11 13 18 19 - 2
11 13 18 19 25 - 2
11 13 18 19 25 26 - 1
11 13 18 19 26 - 1
11 13 18 25 - 2
11 13 18 25 26 - 1
11 13 18 26 - 1
11 13 19 - 3
11 13 19 25 - 3
11 13 19 25 26 - 2
11 13 19 26 - 2
11 13 25 - 4
11 13 25 26 - 2
11 13 26 - 2
11 14 - 4
11 14 15 - 1
11 14 15 16 - 1
11 14 15 16 17 - 1

11 14 15 16 17 25 - 1

11 14 15 16 25 - 1

11 14 15 17 - 1

11 14 15 17 25 - 1

11 14 15 25 - 1

11 14 16 - 4

11 14 16 17 - 2

11 14 16 17 19 - 1

11 14 16 17 19 25 - 1

11 14 16 17 19 25 26 - 1

11 14 16 17 19 26 - 1

11 14 16 17 25 - 2

11 14 16 17 25 26 - 1

11 14 16 17 26 - 1

11 14 16 18 - 1

11 14 16 18 19 - 1

11 14 16 18 19 25 - 1

11 14 16 18 19 25 26 - 1

11 14 16 18 19 26 - 1

11 14 16 18 25 - 1

11 14 16 18 25 26 - 1

11 14 16 18 26 - 1

11 14 16 19 - 3

11 14 16 19 25 - 3

11 14 16 19 25 26 - 3

11 14 16 19 26 - 3

11 14 16 25 - 4

11 14 16 25 26 - 3

11 14 16 26 - 3

11 14 17 - 2

11 14 17 19 - 1

11 14 17 19 25 - 1

11 14 17 19 25 26 - 1

11 14 17 19 26 - 1

11 14 17 25 - 2

11 14 17 25 26 - 1

11 14 17 26 - 1

11 14 18 - 1

11 14 18 19 - 1

11 14 18 19 25 - 1

11 14 18 19 25 26 - 1

11 14 18 19 26 - 1

11 14 18 25 - 1

11 14 18 25 26 - 1

11 14 18 26 - 1

11 14 19 - 3

11 14 19 25 - 3

11 14 19 25 26 - 3

11 14 19 26 - 3

11 14 25 - 4

11 14 25 26 - 3

11 14 26 - 3

11 15 - 2

11 15 16 - 2

11 15 16 17 - 2

11 15 16 17 19 - 1

11 15 16 17 19 25 - 1

11 15 16 17 19 25 26 - 1

11 15 16 17 19 26 - 1

11 15 16 17 25 - 2

11 15 16 17 25 26 - 1

11 15 16 17 26 - 1

11 15 16 19 - 1

11 15 16 19 25 - 1

11 15 16 19 25 26 - 1

11 15 16 19 26 - 1

11 15 16 25 - 2

11 15 16 25 26 - 1

11 15 16 26 - 1

11 15 17 - 2

11 15 17 19 - 1

11 15 17 19 25 - 1

11 15 17 19 25 26 - 1

11 15 17 19 26 - 1

11 15 17 25 - 2

11 15 17 25 26 - 1

11 15 17 26 - 1

11 15 19 - 1

11 15 19 25 - 1

11 15 19 25 26 - 1

11 15 19 26 - 1

11 15 25 - 2

11 15 25 26 - 1

11 15 26 - 1

11 16 - 5

11 16 17 - 3

11 16 17 19 - 2

11 16 17 19 25 - 2

11 16 17 19 25 26 - 2

11 16 17 19 26 - 2

11 16 17 25 - 3

11 16 17 25 26 - 2

11 16 17 26 - 2

11 16 18 - 1

11 16 18 19 - 1

11 16 18 19 25 - 1

11 16 18 19 25 26 - 1

11 16 18 19 26 - 1

11 16 18 25 - 1

11 16 18 25 26 - 1

11 16 18 26 - 1

11 16 19 - 4

11 16 19 25 - 4

11 16 19 25 26 - 4

11 16 19 26 - 4

11 16 25 - 5

11 16 25 26 - 4

11 16 26 - 4

11 17 - 4

11 17 18 - 1

11 17 18 19 - 1

11 17 18 19 25 - 1

11 17 18 25 - 1

11 17 19 - 3

11 17 19 25 - 3

11 17 19 25 26 - 2

11 17 19 26 - 2

11 17 25 - 4

11 17 25 26 - 2

11 17 26 - 2

11 18 - 2

11 18 19 - 2

11 18 19 25 - 2

11 18 19 25 26 - 1

11 18 19 26 - 1

11 18 25 - 2

11 18 25 26 - 1

11 18 26 - 1

11 19 - 5

11 19 25 - 5

11 19 25 26 - 4

11 19 26 - 4

11 25 - 6

11 25 26 - 4

11 26 - 4

12 - 5

12 13 - 3

12 13 14 - 2

12 13 14 15 - 1

12 13 14 15 16 - 1

12 13 14 15 16 17 - 1

12 13 14 15 16 17 25 - 1

12 13 14 15 16 25 - 1

12 13 14 15 17 - 1

12 13 14 15 17 25 - 1

12 13 14 15 25 - 1

12 13 14 16 - 1

12 13 14 16 17 - 1

12 13 14 16 17 25 - 1

12 13 14 16 25 - 1

12 13 14 17 - 2

12 13 14 17 18 - 1

12 13 14 17 18 25 - 1

12 13 14 17 25 - 2

12 13 14 18 - 1

12 13 14 18 25 - 1

12 13 14 25 - 2

12 13 15 - 1

12 13 15 16 - 1

12 13 15 16 17 - 1

12 13 15 16 17 25 - 1

12 13 15 16 25 - 1

12 13 15 17 - 1

12 13 15 17 25 - 1

12 13 15 25 - 1

12 13 16 - 1

12 13 16 17 - 1

12 13 16 17 25 - 1

12 13 16 25 - 1

12 13 17 - 3

12 13 17 18 - 2

12 13 17 18 19 - 1

12 13 17 18 19 25 - 1

12 13 17 18 25 - 2

12 13 17 19 - 1

12 13 17 19 25 - 1

12 13 17 25 - 3

12 13 18 - 2

12 13 18 19 - 1

12 13 18 19 25 - 1

12 13 18 25 - 2

12 13 19 - 1

12 13 19 25 - 1

12 13 25 - 3

12 14 - 3

12 14 15 - 1

12 14 15 16 - 1

12 14 15 16 17 - 1

12 14 15 16 17 25 - 1

12 14 15 16 25 - 1

12 14 15 17 - 1

12 14 15 17 25 - 1

12 14 15 25 - 1

12 14 16 - 2

12 14 16 17 - 2

12 14 16 17 19 - 1

12 14 16 17 19 25 - 1

12 14 16 17 19 25 26 - 1

12 14 16 17 19 26 - 1

12 14 16 17 25 - 2

12 14 16 17 25 26 - 1

12 14 16 17 26 - 1

12 14 16 19 - 1

12 14 16 19 25 - 1

12 14 16 19 25 26 - 1

12 14 16 19 26 - 1

12 14 16 25 - 2

12 14 16 25 26 - 1

12 14 16 26 - 1

12 14 17 - 3

12 14 17 18 - 1

12 14 17 18 25 - 1

12 14 17 19 - 1

12 14 17 19 25 - 1

12 14 17 19 25 26 - 1

12 14 17 19 26 - 1

12 14 17 25 - 3

12 14 17 25 26 - 1

12 14 17 26 - 1

12 14 18 - 1

12 14 18 25 - 1

12 14 19 - 1

12 14 19 25 - 1

12 14 19 25 26 - 1

12 14 19 26 - 1

12 14 25 - 3

12 14 25 26 - 1

12 14 26 - 1

12 15 - 2

12 15 16 - 2

12 15 16 17 - 2

12 15 16 17 19 - 1

12 15 16 17 19 25 - 1

12 15 16 17 19 25 26 - 1

12 15 16 17 19 26 - 1

12 15 16 17 25 - 2

12 15 16 17 25 26 - 1

12 15 16 17 26 - 1

12 15 16 19 - 1

12 15 16 19 25 - 1

12 15 16 19 25 26 - 1

12 15 16 19 26 - 1

12 15 16 25 - 2

12 15 16 25 26 - 1

12 15 16 26 - 1

12 15 17 - 2

12 15 17 19 - 1

12 15 17 19 25 - 1

12 15 17 19 25 26 - 1

12 15 17 19 26 - 1

12 15 17 25 - 2

12 15 17 25 26 - 1

12 15 17 26 - 1

12 15 19 - 1

12 15 19 25 - 1

12 15 19 25 26 - 1

12 15 19 26 - 1

12 15 25 - 2

12 15 25 26 - 1

12 15 26 - 1

12 16 - 3

12 16 17 - 3

12 16 17 19 - 2

12 16 17 19 25 - 2

12 16 17 19 25 26 - 2

12 16 17 19 26 - 2

12 16 17 25 - 3

12 16 17 25 26 - 2

12 16 17 26 - 2

12 16 19 - 2

12 16 19 25 - 2

12 16 19 25 26 - 2

12 16 19 26 - 2

12 16 25 - 3

12 16 25 26 - 2

12 16 26 - 2

12 17 - 5

12 17 18 - 2

12 17 18 19 - 1

12 17 18 19 25 - 1

12 17 18 25 - 2

12 17 19 - 3

12 17 19 25 - 3

12 17 19 25 26 - 2

12 17 19 26 - 2

12 17 25 - 5

12 17 25 26 - 2

12 17 26 - 2

12 18 - 2

12 18 19 - 1

12 18 19 25 - 1

12 18 25 - 2

12 19 - 3

12 19 25 - 3

12 19 25 26 - 2

12 19 26 - 2

12 25 - 5

12 25 26 - 2

12 26 - 2

13 - 5

13 14 - 4

13 14 15 - 1

13 14 15 16 - 1

13 14 15 16 17 - 1

13 14 15 16 17 25 - 1

13 14 15 16 25 - 1

13 14 15 17 - 1

13 14 15 17 25 - 1

13 14 15 25 - 1

13 14 16 - 3

13 14 16 17 - 1

13 14 16 17 25 - 1

13 14 16 18 - 1

13 14 16 18 19 - 1

13 14 16 18 19 25 - 1

13 14 16 18 19 25 26 - 1

13 14 16 18 19 26 - 1

13 14 16 18 25 - 1

13 14 16 18 25 26 - 1

13 14 16 18 26 - 1

13 14 16 19 - 2

13 14 16 19 25 - 2

13 14 16 19 25 26 - 2

13 14 16 19 26 - 2

13 14 16 25 - 3

13 14 16 25 26 - 2

13 14 16 26 - 2

13 14 17 - 2

13 14 17 18 - 1

13 14 17 18 25 - 1

13 14 17 25 - 2

13 14 18 - 2

13 14 18 19 - 1

13 14 18 19 25 - 1

13 14 18 19 25 26 - 1

13 14 18 19 26 - 1

13 14 18 25 - 2

13 14 18 25 26 - 1

13 14 18 26 - 1

13 14 19 - 2

13 14 19 25 - 2

13 14 19 25 26 - 2

13 14 19 26 - 2

13 14 25 - 4

13 14 25 26 - 2

13 14 26 - 2

13 15 - 1

13 15 16 - 1

13 15 16 17 - 1

13 15 16 17 25 - 1

13 15 16 25 - 1

13 15 17 - 1

13 15 17 25 - 1

13 15 25 - 1

13 16 - 3

13 16 17 - 1

13 16 17 25 - 1

13 16 18 - 1

13 16 18 19 - 1

13 16 18 19 25 - 1

13 16 18 19 25 26 - 1

13 16 18 19 26 - 1

13 16 18 25 - 1

13 16 18 25 26 - 1

13 16 18 26 - 1

13 16 19 - 2

13 16 19 25 - 2

13 16 19 25 26 - 2

13 16 19 26 - 2

13 16 25 - 3

13 16 25 26 - 2

13 16 26 - 2

13 17 - 3

13 17 18 - 2

13 17 18 19 - 1

13 17 18 19 25 - 1

13 17 18 25 - 2

13 17 19 - 1

13 17 19 25 - 1

13 17 25 - 3

13 18 - 3

13 18 19 - 2

13 18 19 25 - 2

13 18 19 25 26 - 1

13 18 19 26 - 1
13 18 25 - 3
13 18 25 26 - 1
13 18 26 - 1
13 19 - 3
13 19 25 - 3
13 19 25 26 - 2
13 19 26 - 2
13 25 - 5
13 25 26 - 2
13 26 - 2
14 - 5
14 15 - 1
14 15 16 - 1
14 15 16 17 - 1
14 15 16 17 25 - 1
14 15 16 25 - 1
14 15 17 - 1
14 15 17 25 - 1
14 15 25 - 1
14 16 - 4
14 16 17 - 2
14 16 17 19 - 1
14 16 17 19 25 - 1
14 16 17 19 25 26 - 1
14 16 17 19 26 - 1
14 16 17 25 - 2
14 16 17 25 26 - 1
14 16 17 26 - 1
14 16 18 - 1
14 16 18 19 - 1
14 16 18 19 25 - 1
14 16 18 19 25 26 - 1
14 16 18 19 26 - 1
14 16 18 25 - 1
14 16 18 25 26 - 1
14 16 18 26 - 1
14 16 19 - 3
14 16 19 25 - 3
14 16 19 25 26 - 3
14 16 19 26 - 3
14 16 25 - 4
14 16 25 26 - 3
14 16 26 - 3
14 17 - 3
14 17 18 - 1
14 17 18 25 - 1
14 17 19 - 1
14 17 19 25 - 1
14 17 19 25 26 - 1
14 17 19 26 - 1
14 17 25 - 3
14 17 25 26 - 1
14 17 26 - 1
14 18 - 2
14 18 19 - 1
14 18 19 25 - 1
14 18 19 25 26 - 1
14 18 19 26 - 1
14 18 25 - 2
14 18 25 26 - 1
14 18 26 - 1
14 19 - 3
14 19 25 - 3
14 19 25 26 - 3
14 19 26 - 3
14 25 - 5
14 25 26 - 3
14 26 - 3
15 - 2
15 16 - 2
15 16 17 - 2
15 16 17 19 - 1
15 16 17 19 25 - 1
15 16 17 19 25 26 - 1
15 16 17 19 26 - 1
15 16 17 25 - 2
15 16 17 25 26 - 1
15 16 17 26 - 1
15 16 19 - 1
15 16 19 25 - 1
15 16 19 25 26 - 1
15 16 19 26 - 1
15 16 25 - 2
15 16 25 26 - 1
15 16 26 - 1
15 17 - 2
15 17 19 - 1
15 17 19 25 - 1
15 17 19 25 26 - 1
15 17 19 26 - 1
15 17 25 - 2
15 17 25 26 - 1
15 17 26 - 1
15 19 - 1
15 19 25 - 1

15 19 25 26 - 1

15 19 26 - 1

15 25 - 2

15 25 26 - 1

15 26 - 1

16 - 5

16 17 - 3

16 17 19 - 2

16 17 19 25 - 2

16 17 19 25 26 - 2

16 17 19 26 - 2

16 17 25 - 3

16 17 25 26 - 2

16 17 26 - 2

16 18 - 1

16 18 19 - 1

16 18 19 25 - 1

16 18 19 25 26 - 1

16 18 19 26 - 1

16 18 25 - 1

16 18 25 26 - 1

16 18 26 - 1

16 19 - 4

16 19 25 - 4

16 19 25 26 - 4

16 19 26 - 4

16 25 - 5

16 25 26 - 4

16 26 - 4

17 - 5

17 18 - 2

17 18 19 - 1

17 18 19 25 - 1

17 18 25 - 2

17 19 - 3

17 19 25 - 3

17 19 25 26 - 2

17 19 26 - 2

17 25 - 5

17 25 26 - 2

17 26 - 2

18 - 3

18 19 - 2

18 19 25 - 2

18 19 25 26 - 1

18 19 26 - 1

18 25 - 3

18 25 26 - 1

18 26 - 1

19 - 5

19 25 - 5

19 25 26 - 4

19 26 - 4

25 - 7

25 26 - 4

26 – 4

Appendices 5