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Zigbee Based Home Automation and Agricultural Monitoring System

A mesh networking approach for autonomous and manual system control

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***Abstract— Today's generation of electronic devices are more enhanced and capable than the previous ones with* exciting changes in technology has seen to control a variety of home devices with the help of a home automation system. These devices can include lights, fans, doors, surveillance systems and consumer electronics. However along with the smartness and intuitiveness we want a system which is economic as well as low power consuming. ZigBee technology collects and monitors different types of measurements that reflect energy consumption and environment parameters. This paper details the designing of a protocol to monitor various environmental conditions in a home. We are using advanced technology of Micaz motes (which have their own routing capabilities), NESC language programming and Moteworks (used as a data acquisition platform**).

***Index Term** — MEMS; Tiny OS (Tiny Operating Systems); SoC (System on Chip); WSN (Wireless Sensor Networks); IEEE 802.15.4; LR-WPAN (Low Rate Wireless Personal Area Networks); WiFi (Wireless Fidelity); XBee (Zigbee); OTAP (Over The Air Programming)*

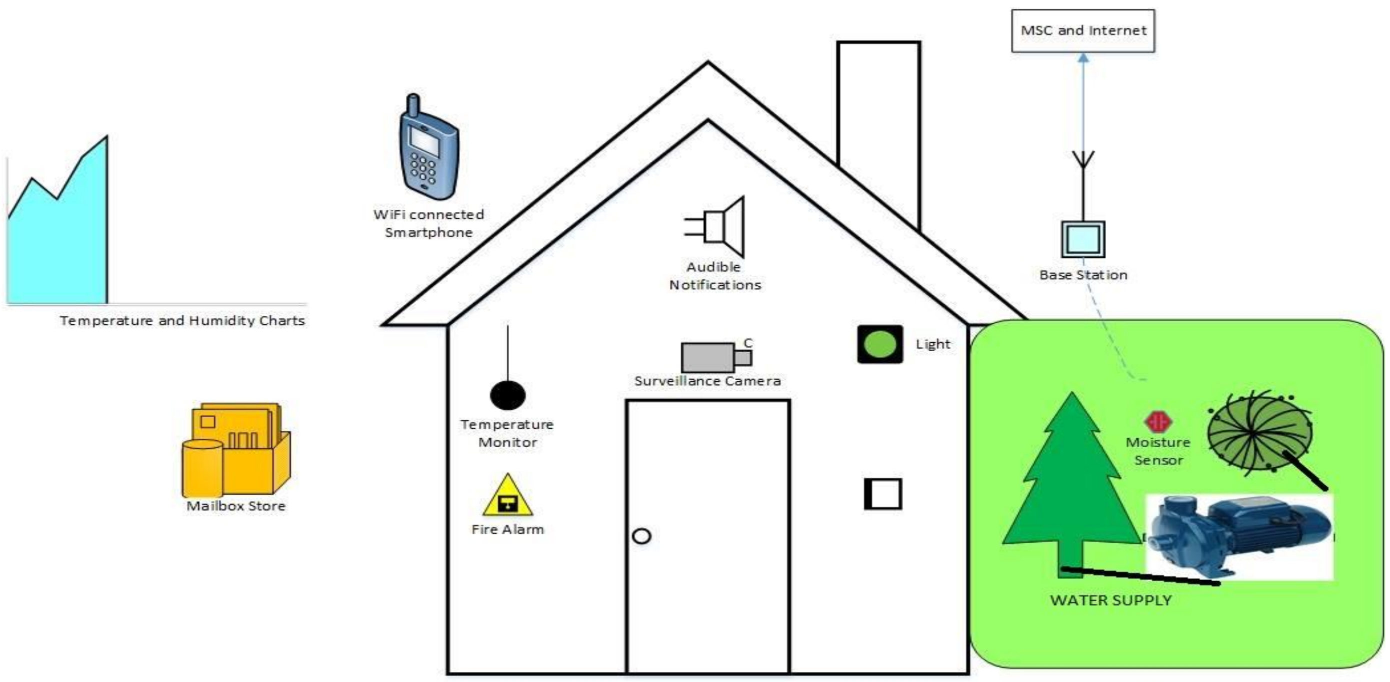
I. INTRODUCTION

New generation electromechanical automation systems aim at real time data processing and transmission to a remote location for monitoring and sensing which aids in the domain of knowledge to the end user about the respective region where the system is currently deployed. Various communication standards and platforms have been devised in previous decades to turn such concepts into reality along with tremendous progress in semiconductor and MEMS technologies over the past decade has led to production of inexpensive sensors and microcontroller platforms which can be easily interfaced with each other. Many such startups are now also dealing with these technologies and rolling out products which have unique features like insignificant power consumption resulting in prolonged battery life, low maintenance modules with added short circuit prevention, encrypted data transmission standards for software level security and use of biometric data of intended user for counterfeiting rate.

Many such examples can be quoted, like NEST which is a subsidiary under Alphabet Inc. which initially started as a thermostat controller for indoor heating systems but now has a product ecosystem consisting of Thermostat, Smoke + CO alarm and Camera which in tandem for their platform Home/Away Assist which tries to tackle the issue of conventional geo-fencing HAS by recognizing a close group of maximum 10 users under NEST protect app family accounts which can be recognized as authentic users too in case the primary phone is drained out of battery.

Present day approaches for home automation systems includes improvement of basic device interoperability through research and standards as well as monolithic system to integrate multiple devices for specific tasks.. The remote sensing options were already available but we have pursued the aim of creating automation and manual control too. The project was developed keeping account of current barrier, providing an adaptable, low cost system that the end user can oneself install, configure, upgrade and control, consisting of server and diverse systems. Contemporary approaches include remote controlling and sensing which can be implemented using convectional devices like smartphones and personal computers. These solutions provide facility to end user to remotely access their home. Additionally, latest features can be introduced using future update roll outs to make system self-adaptive.

The paper introduces the concept of home automation and agricultural monitoring services using the WSN technology platform to achieve the primary need of the smart, durable, efficient and adaptive control over the target environment. Actuators and sensors work in parallel to realize the simulation of remote environment and taking required decisions accordingly through the computation algorithm.



A. CONTRIBUTION

In this paper proposed an automated system based on Wireless Sensor Networking which can be accessed and controlled at any remote location resulting in real time responses. This purposes is achieved using MoteWorks, a data acquisition platform developed by Memsic Inc. which supports mesh networking and mote monitoring to store the data into a PSQL ODBC database. In this paper an energy efficient and self-adaptive environment is being implemented to reduce the manual requirement and enhance the output efficiency by providing accurate results in a regular span of time resulting in better analysis and precise actions. Here in case of a system failure an additional feature remote sensing and controlling using smart phones has been added to secure the system working. System is self-efficient to gather data from displaced nodes at the base station where MDA300CA has been interfaced which operates upon Tiny OS Software and respond accordingly in form of appliance controlling on the basis of the values obtained and the threshold value already set without any external assessment. In this paper the developed a proposed model to establish an environment in which any kind of break in, theft or any malfunction such as fire, gas leakage and water leak can be easily detected and the requisite actions can be taken instantly.

B. OVERVIEW

The paper is divided from here onwards into the following sections with a small description of each:

1. ZigBee and Hardware – It deals with running SoC platform specifications along with attached sensor board modules and wireless interface technology used.
2. Development Platform – Software suite used for the programming and data acquisition with the underlying language base used to program individual motes and OS running them.
3. System Model – Sheds light upon overall layout of device and sensor ecosystem created, through a detailed graphic to aid visual learning about the working.
4. Mathematical Modelling – Contains equations used related to ZigBee protocol and others.
5. Algorithm – Charts logical behavioral flow of system for unique conditions.
6. Simulation Parameters – Listed derived results are discussed across various standards of measurements and category classifications.
7. Result Analysis – Screenshots of output and practical working are shared and compared with previous application cases.
8. Conclusion and Future work – Future scope related to the concerned field and usage scenario with end user usage experience as conclusion.
9. Reference – Enlists publication, image, document and other sources used in creation of this paper.

II. ZIGBEE AND HARDWARE

A. ZIGBEE PLATFORM

The 802.15.4 IEEE platform is a infrastructure less based protocol serves the foundation for ZigBee platform which specifies the physical and media access control layer standards for LR-WPAN networks. It's maintained and published by ZigBee Alliance which provides support for upper networking layers according to the SoC intended.

This mesh networking targeted standard works on ISM band frequency range (2.4 GHz, 714 MHz, 868 MHz, 915 MHz) with data rate encompassing 20 kbps (868 MHz) to 250 kbps (2.4 GHz). Numerous routing protocols like flooding, TEEN, APTEEN, LEACH have been proposed but till now no perfect one has been accepted by the industry. The device class is divided into physical and logical types with further into FFD and RFD which serve unique purposes individually. The nodes act as whether in sensing or control mode then it's under RFD and FFD's are responsible for routing functions catering child devices under the cluster with FFD as cluster head.

It finds wide applications in fields of animal tracking, home automation, industrial control, medical health monitoring and numerous others.

B. MEMSIC WSN KIT

B.1 MICAZ Mote

MICAZ mote is specifically designed for wireless sensor networks having its own router capabilities to communicate with the surrounding nodes and use IEEE 802.15.4 (specifies the physical layer and media access control for low rate wireless personal area network) protocol for setting up a low manufacturing cost and power efficient, battery-operated networks.

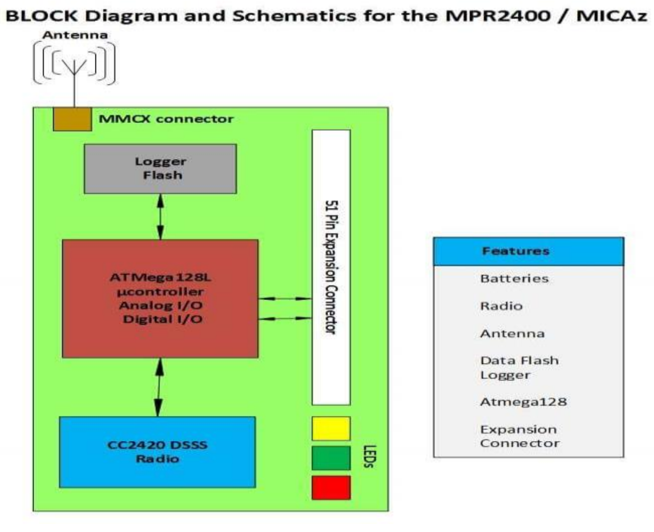


Fig. 2 MPR2400 component block view

MICAZ mote comprises of MPR2400CA platform based on the Atmel ATmega128L microcontroller as depicted in Fig. 1 which uses its internal flash memory to run mote works. MPR2400CA platform simultaneously communicates with surrounding nodes and runs sensor applications. MICAZ motes uses wireless ad hoc networking using mesh topology to set up an autonomous network and provides data rate of 250 kbps among nodes and base station to interface wide range of external peripherals.

B.2 MIB520CB

MIB520CB acts as an USB connector for MICAZ motes for communication and in system programming purposes. MICAZ motes when connected with MIB520CB acts as a base station and helps to collect data from all other motes present in the system. MIB520CB extend two different kind of ports one for in system mote programming and another for data communication over USB with baud rate of 57.6K and when connected with USB port doesn't require external power source.

B.3 MTS420

MTS420 is a surrounding monitoring sensor which can be easily deployed in remote locations as it requires very low maintenance and have an extended battery life. MTS420 provides wide range of features such as temperature/ humidity/ pressure (300mbar to 1100mbar) sensors and light intensity, along with dual axis accelerometer. Along with above mentioned features MTS420 also have GPS module to get coordinates of the motes.

B.4 MDA300CA

MDA300CA is an extremely flexible data acquisition board having temperature and humidity sensors embedded on its platform and offers a wide range of features on board such as ADC channels, digital I/O channels, two relay channels (one open and one closed) and supports external I2C interface. MDA300CA have 64K EEPROM to store the data measured by the sensors. MDA300CA operates using Tiny OS software.

III. DEVELOPMENT ENVIRONMENT

A. MOTEWORKS

This is a data acquisition platform developed by Memsic Inc. which supports mesh networking and mote monitoring to store the data into a PSQL ODBC database. The overall software kit is divided into 3 separate tiers: mote, server, client. Mote tier supports multi-hop, non-infrastructure, ad-hoc, mesh networking protocol for LR-WPAN wireless networks based on ZigBee. The motes communicate via multi hop communication for improved reliability and radio coverage which are connected to PC via MIB520CB gateway which is equipped with antenna to remotely program motes and the comes under Xmesh Mote Tier.

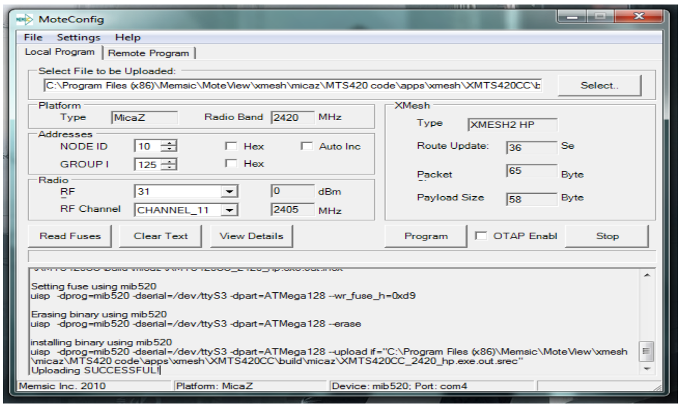


Fig. 3 MoteConfig

Server tier manages SQL database under applications interfacing with mesh to higher level layers and outside apps via terminal exchange.

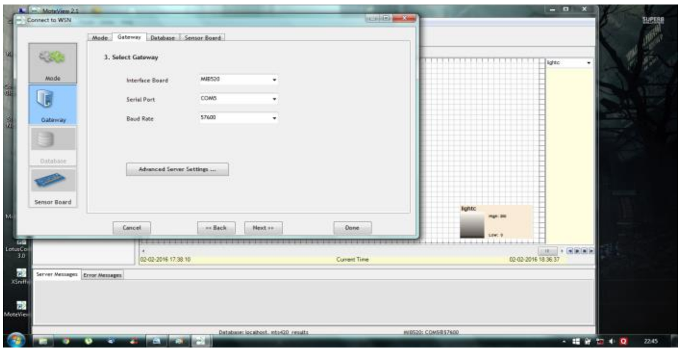


Fig. 4 MoteView

For end to end solution across all the tiers to the user or developer, the Client tier comes to the service which displays statistical information straight from sensors in form of text or graphic charting with the capability of rendering past event readings through fetching database. Individually node can be updated and configured based on sensor board attached and communication channel attached respectively through programming via gateway as shown in Fig. 2

The software package provided by Memsic can be subdivided into the respective components as follows:

Table no. 1

TinyOS and MoteWorks tools	An event-driven OS for wireless sensor networks; tools for debugging.
nesC compiler	An extension of C-language designed for TinyOS
Cygwin	A Linux-like enivreonment for Windows
AVR tools	A suite of software development tools for Atmel's AVR processors
Programmer's notepad	IDE for code compilation and debugging
XSniffer	Network monitoring rool for RF environment
Moteconfig	GUI environment for Mote Programming and OTAP
LotusConfig	GUI environment for Lotus Programming
Graphviz	To view files made from make docs

B. TinyOS

The environment selected for the current work in TinyOS which is supports by the MEMSIC kit. The protocol shown here suits the network and routing requirements of the design and the deployment of motes. The whole operation is shown by the application layer which is in direct contact with the user or administrator. The advantage of using the TinyOS is that it is open source and is easily available in the internet. The language used here is NesC which is used to program the motes. The TinyOs is easily compatible with the motes, is event-driven in nature. The libraries used here are available default and are used in the code by direct programming and including them.

As per the data of [19], three IDEs (integrated development environments) are available for the TinyOS, to be used in Eclipse:

- YETI 2, ETH Zurich
- XPairtise
- TinyDT

These plugins are included in Eclipse in order for them to run.

The version of TinyOS used for this paper is 2.1.2.

The range of using microprocessors in TinyOS is right from 8-bit architecture to 32-bit architecture and from 2KB RAM to 32MB RAM (or more) respectively.

C. NESC

For programming motes, a new language ecosystem has been created which is focused on a component and interface driven methodology. It provides an easier linking model than C and derives it's features from C, C++ and Java with the aim of building components just like in Java objects for which can be compiled into complete concurrent systems for robust embedded network systems.

Program writing involves writing components and wiring them often known as interfaces occurring at compile time and bidirectional in nature. It builds up into a concurrency model for monitoring hardware event handlers and tasks as per the respective sensor module.

Here Fig. 4 shows Ubuntu 9.10 with working Tiny os 2.x install running in Virtual Box. Eclipse was installed in the machine with Yeti2 development plugin to identify and acquire NesC libraries and syntax for the further code development.

IV. SYSTEM MODEL

The motes are programmed using pre written programs so that one of them acts as a server and others acts as nodes. The gateway has functions like collection of data from different nodes and to pass the data to base station.

The communication between motes and base station is done using Xbee protocol and that between the Base Station and acquisition board is also based on Xbee. The devices are operated using specific conditions and are connected to the acquisition board MDA300CA which Fig. 5 describes. Now the data acquisition board is connected to the internet using WiFi so that anyone can control it.

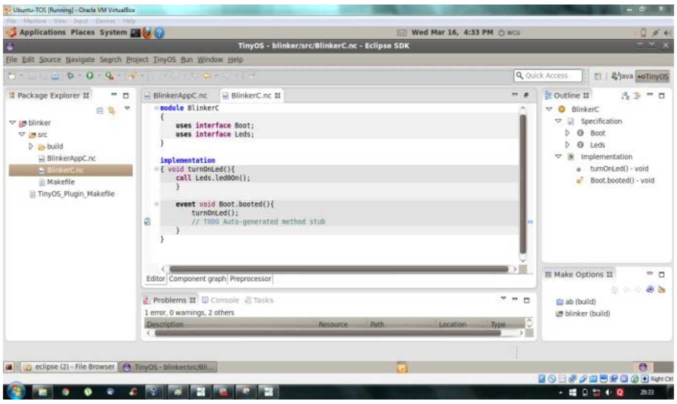


Fig. 5 Eclipse + Yeti2 running in UbunTos virtual machine

The NesC was run into a UbunTos (Ubuntu + TinyOS) virtual machine with Eclipse installed alongwith Yeti2 Plugin installed for NesC syntax recognition and compilation.

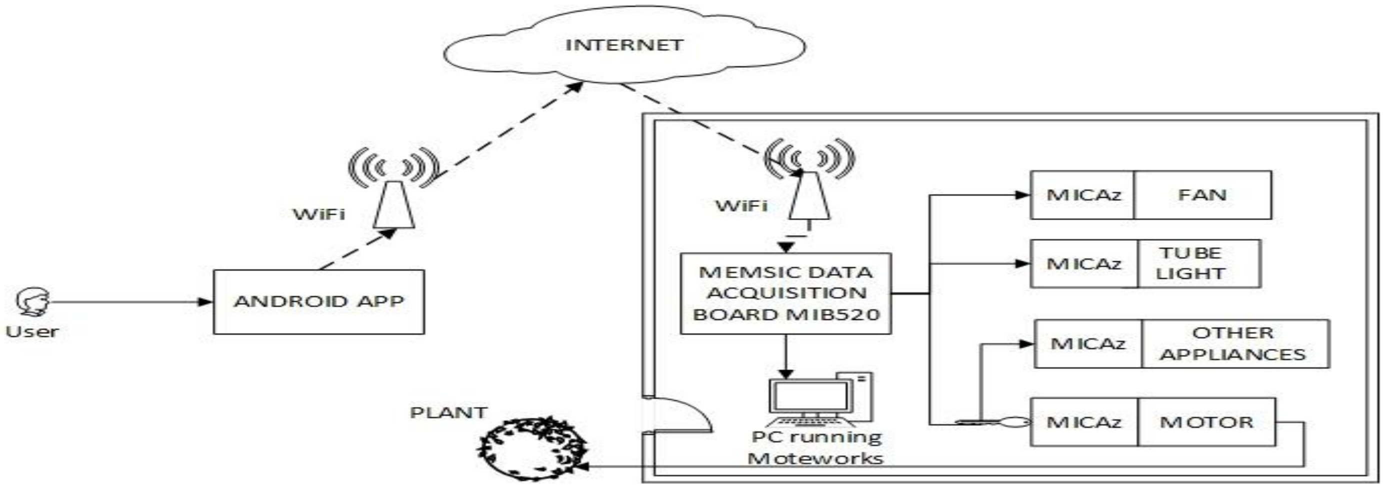


Fig. 6 System working layout

V. MATHEMATICAL MODELLING

Numerous parameters are dealt with during discussion about Zigbee transmission technology. Some of them are :

1. Battery Consumption of onboard radio – power usage of a Zigbee radio can be broken down into a combination of it's unique states.

$p_{con} = p_{tx} + p_{rx} + p_{Sleep} + p_{idle}$ ----- 1

Where p= E/t

2. The battery lifetime in hours could be calculated using the following formula:

$$t = \frac{i_c}{i^n}$$

---------------------2

3. Power loss which is crucial in designing battery extensive systems, can be calculated for communication technologies which utilize ISM band is:

$$PL(dB) = -10\log\left(\frac{G_T G_R \lambda^2}{(4\pi)^2 d^2}\right)$$

----3

Table no. 2

p_{Con}	total power consumption
p_{tx}	transmitted signal power
p_{rx}	received signal power
p_{Sleep}	sleep state power

p_{idl}	idle state power is no packets are transmitted or received
t	battery life time in Hours
i_c	battery Capacity in mAh
i	load current in mA
n	peukert's exponent, it ranges from 1 to 1.3, where 1 is the nominal value
PL	path loss
G_T	transmitter antenna gain
G_R	receiver antenna gain
λ	frequency of wave
d	transmission distance
E	Energy consumption

Table no. 2

VI. ALGORITHM

Algorithm description is presented here through flow chart both for automated and manual control override.
The user must interfere in case of any sensor/mote failure which is notified through the app or if he would like to personalize the appliance properties to a different one than the preset.

It's evident from the Fig. 6 that user connects to the system through any wireless network which in turn send command data to Base station mote via Ethernet connected PC and those are forwarded to respective motes through OTAP.

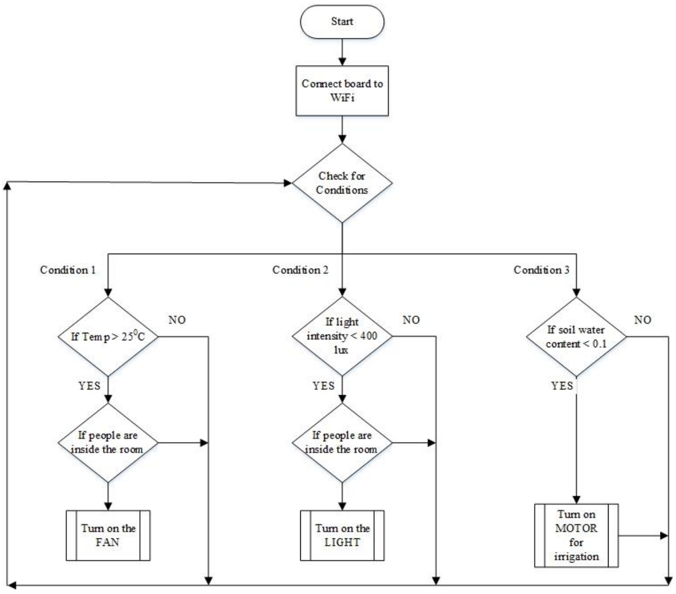
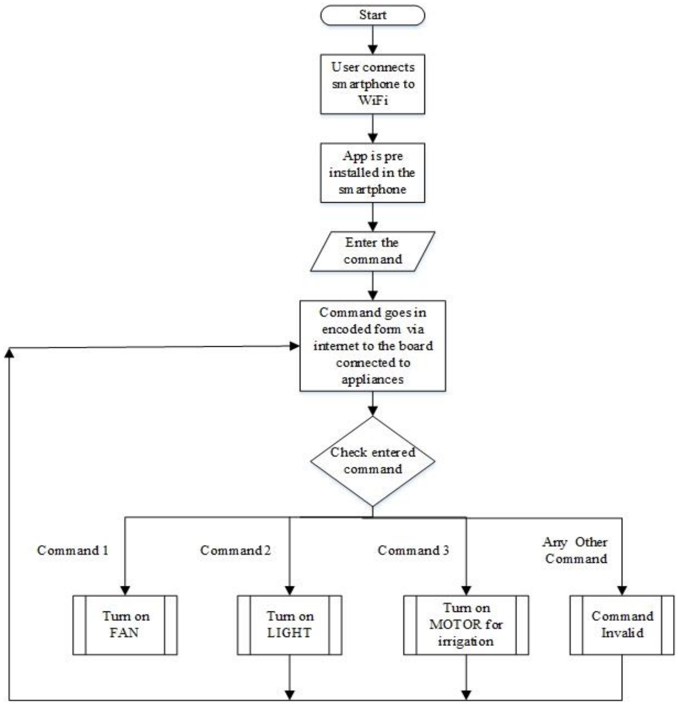


Fig. 7 Flow chat for manual control

The autonomous programming model as shown in Fig .7 is based on the context aware computing of motes i.e. respective property of room (humidity, temperature and moisture level here) is monitored through sensor with personalized threshold values already stored and appliance properties are customized accordingly.



PSEUDO CODE: Smart Home Control

```
if (device state==1) //while device is on state
{
        //code for connection establishment
        // Fan control
        if (room temp > 25⁰C)
        {
                if(no of people in room > 0)
                { turnonfan(); }
        }
        // Light control
        if (light intensity < 400 lux)
        {
                if(no of people in room > 0)
                { turnonlight(); }
        }
        //Irrigation
        if (soil water content < 0.1)
        { turnonmotor(); }
}
```

VII. SIMULATION PARAMETERS

Simulated result is benchmarked upon various parameters which may vary as per respective sensor module type, some of them can be listed for MTS 420CC used are:

1. Humidity / Temperature (C) – It uses SHT 11 single chip sensor module for calibrated digital output values.
2. Barometric Pressure (mba) – Intersema M55ER SMD Hybrid peizoresistive sensor and 3-wire ADC interface.

3. Light intensity (Lux) – TLS2250 digital sensor with dual photodiode provides effective 12 – Bit dynamic range.
4. Acceleration (g) – MEMS micromachined 2 – Axis, +/- 2g capable of tilt detection, movement, vibration and seismic mesaurements.
5. GPS – Leadtek GPS – 9546 or uBlox LEA-4A provides antenna power and serial data at USART1 for positional detection.

VIII. RESULT ANALYSIS

Using the values obtained from the MoteView we can take the decision for automation. The decision is made as per the pseudo code given above.

The motes give the value to the base station which is responsible for accumulation of data. This data has some value like voltage, humidity, temperature, etc. As per the pseudo code we have made an algorithm which turns on the peripheral devices as per specific conditions as in Fig. 8 & 9 data is monitored on a continuous time scale basis. An example can be seen as that if temperature of room is greater than 25^0C, it means that the room is hot and fan should be turned on. However, to save power we must see that whether people are there in the room or not. If people are present in the room (which is observed by PIR sensor) then the fan is turned on. Similar is the case when humidity is greater than 30% which is uncomfortable for humans.
Similarly, other peripherals like light, motor are controlled based on simple reasoning and human habitable conditions.
From the above simulation results we can see that we have taken a few of possible parameters and according to human comfort have taken proper steps to ensure the same in form of home automation.

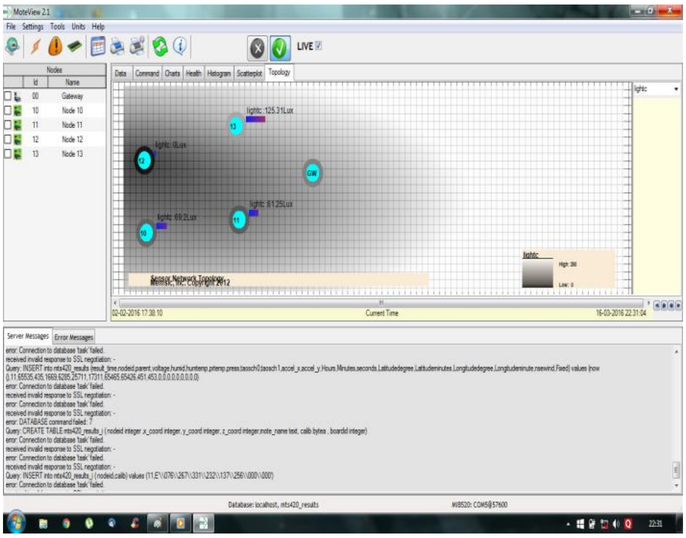


Fig. 9 MoteView with mote topology graphview

The whole system was built with sensors and actuators connected to Arduino for autonomous and manual control. Some of the pictures are attached here:

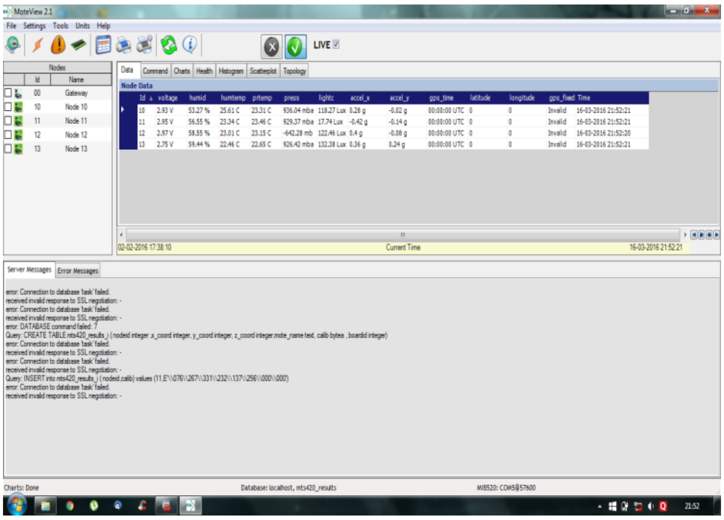


Fig. 10 MoteView displaying data acquired from sensors

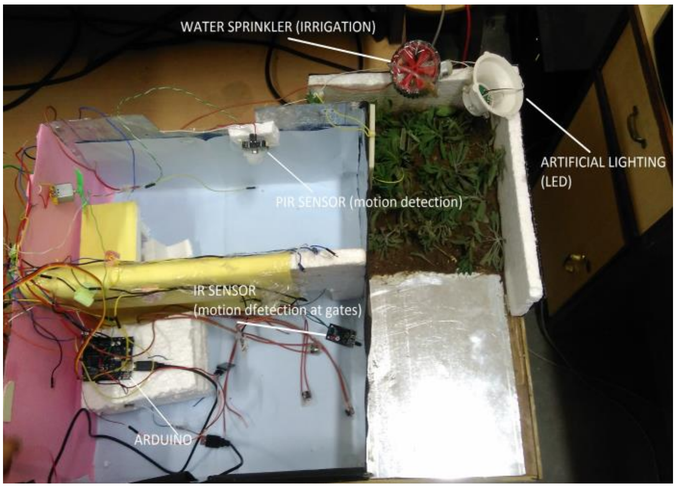


Fig. 11 Detailed view of hardware model

Fig. 12 Agricultural model

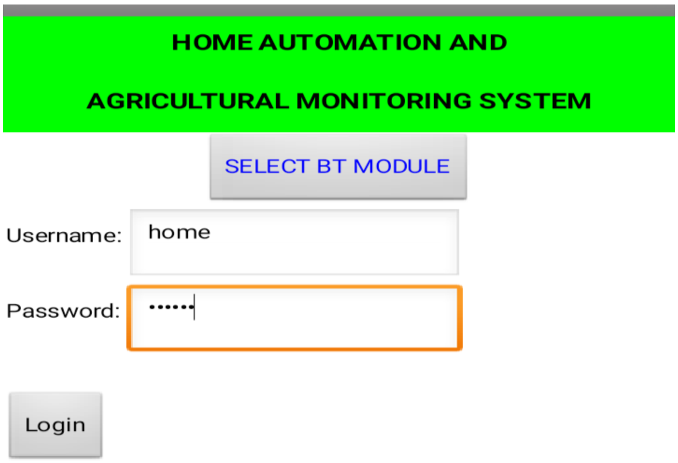


Fig. 13 Mobile app login page

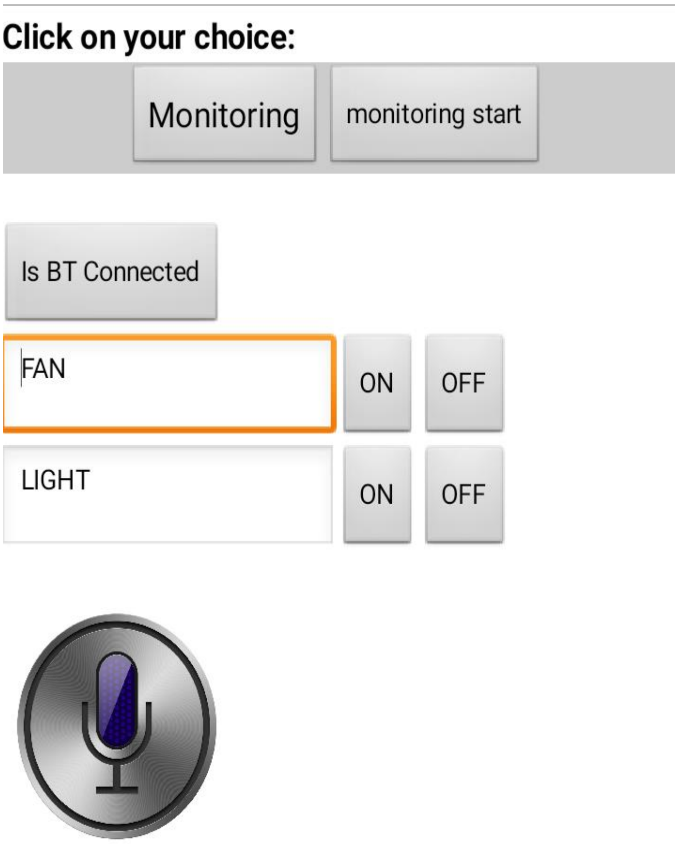


Fig. 14 User mode select menu

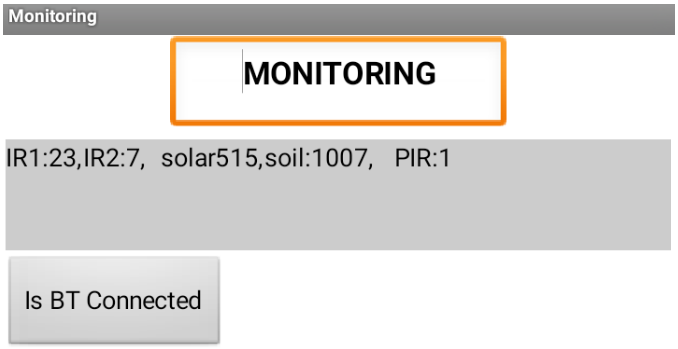


Fig. 15 Sensor data being monitored from app over Bluetooth

IX. CONCLUSION AND FUTURE WORK

With an upward trend in Home Automation we require a system capable of simultaneously sensing and monitoring the environment and acting accordingly in real time to provide safe and secure surroundings. Early HAS specifically relied on appliance interfacing and controlling but now the prime focus has shifted to get a secure and energy efficient environment which is being realized using WSN and ZigBee technology. In this paper, ZigBee platform along with MICAZ motes + MPR 2400CA sensor module has been implemented to obtain a self-forming non-infrastructure based network which can use various kinds of topologies as suited and capable of monitoring surroundings on a continuous time lapse and can take decisions as per requirement. One major concern of such systems is energy efficiency and with component based onboard power switching, power consumption has been substantially reduced providing an extended life and low maintenance cost. Home Automation requires the user to have continuous update and can access the system from any remote location, using MIB520CB gateway with LAN connected PC running as remote server linked to authenticated home owner, user can continuously control the system by giving commands in real time, being present anywhere in the world and also get push notifications on smartphone for any activities.

The forthcoming substantial advancement in sensor nodes will help to overcome the issues related to WSN with improved fault tolerance, context awareness, power management, Quality of Service and security aspects. The upcoming developments in sensor nodes will produce relevant devices which may be used in applications like cognitive sensing, spectrum management, time-crucial systems, mobile micro-machines, smart rotating building control, structural health monitoring, environment friendly and adaptive systems, cold chain management.

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