Smart Home
(Devices, Applications and their Potential Benefits and Challenges)

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Abstract— **this study surveys a range of devices and applications based on information and computer technologies to automate their control houses and related activities which together form what are called Smart Home systems. The aim of this research is to explore examples of such devices and applications used to provide smart home technologies and their benefits and challenges to users. Interviews were administered to 18 users of Smart Home technologies. The participants were selected randomly by purposive sampling on the basis of having and using a smart home technology, and with the goal of ascertaining which types of this technology are being used, their modus operandi, and their benefits and any implementation issues. This was complemented by exploring the systems through watching and observing online videos of people using them. The findings reveal a varied number of Smart Home systems being used for automating household operations. The primary reasons for using them are their efficiency and simplicity of operation in spite of being challenged by their high costs. In relative order, the greatest perceived benefits of a smart home system for the participants in order were convenience, energy savings, the security it can provide, and simplicity of control. The greatest challenges were cost, design aspects, technical challenges, and lacking in meeting special user needs.**

Keywords—Smart Home, home automation, Internet of Things

I. Introduction

The development of new technologies in the electronic and digital world have made the possibility of having a smart home a real possibility for many people. This concept was first realised in the early 20th century with home automation or labour-saving appliances, such as washing machines, dishwashers and dryers, but the protocol (X10) for using Smart Home systems as recognised today for controlling devices remotely was developed in 1975. It then became a reality in many homes by the end of 20th century and during the start of the 21st century [1] when there were enormous revolutions in communication and information technologies.

A smart home refers to a house (or home) that utilises concepts of information technology, and applies them in monitoring the home environment, controlling electrical appliances, and for relaying of information pertaining to those appliances to the outside world, mostly to the user of such a home [1]. And according to the Smart Homes Association, a Smart Home technology is characterised by "the integration of technology and services through home networking for a better quality of living" [2]. That is, the technology integrates various existing technologies in such a way that they are networked and function together to improve the occupants' living quality.

This technology is designed for improving the comfort of the home, guaranteeing security, aiding in convenience, and for enhancing entertainment and happiness for its users. These systems can span from simple applications such as lighting controls in a room according to the presence of natural light to more complex computer networks that call for application of the concept of artificial intelligence, such as in identifying the people present in the room. Initially, most systems concentrated on controlling lighting and heating circuits, but Smart Home technology has since developed to enable control of almost any electrical device within a home environment [3].

In recent years, the implementation of smart homes has increased greatly. This is largely attributable to its simplicity and the ease with which people can nowadays access and implement new technologies. The emergence of tablet and smartphone connectivity has greatly increased these levels of simplicity. Electricity is the major factor in the emergence of smart home technologies since virtually all smart home operations rely primarily on electricity for their operation [4].

A smart home in itself appears to be 'intelligent' through the aid of its computer systems [5]. It can monitor several aspects of day-to-day life. For instance, it can be programmed to know when it is the appointed time to switch on security lights and when to switch them off. The entry of a burglar into the home can be set as a trigger for an alarm, and a suitable response can then be made at that time. In the presence of a fire, alarm bells can be triggered, and an appropriate response, for example turning on the fire extinguishers, can then be activated in order to put the fire out. Some applications can even go to the extent of profiling people entering a house, and

conveying that information to relevant parties [6].

This research paper focuses mainly on the several applications of smart home technologies. Examples of such applications are identified, and the role of each application and its role and mode of operation is explored. Wherever possible, suggestions are also given on areas for possible improvement in the selected applications. The paper also identifies and explains the benefits that smart home users have already enjoyed. It then attempts to show that people's way of living has indeed been positively enhanced by the use of smart home technologies.

In the next section, there will be a literature review which discusses the working of a smart home system in addition to its purpose. The section also ventures into the emerging technologies and introduces the idea of their application, which links into the methodology section of this paper. It further explores different smart home devices and their applications. Lastly, the benefits and challenges of smart home systems are analysed and recommendations for further research are identified.

II. LITERATURE REVIEW

A. Working of a Smart Home System

Smart homes organise the communication between electronic devices that are present in a home, whether it is most or all of them. A common technology used for sending coded signals is a Powerline Carrier System (PCS) in which the signals are sent along the existing electrical wiring of the house and programmable switches or outlets are used [2]. Many household electronics work under four protocols of communication that are compatible with many communication devices, such as cellphones, landlines and Internet access devices. These four protocols of communication are the X-10, UPB, Z-Wave and the EnOcean [7].

The X10 protocol works with PCS for remotely controlling plugged-in devices using short bursts of Radio Frequency (RF). The main limitation of X10 is that the communications are sometimes unreliable due to the presence of noise from other powered devices using the same electrical lines. Other protocols, such as Z-wave and ZigBee are newer alternatives that do not rely on the power lines but on radio waves for communication. Of these, Z-Wave uses a source routing algorithm for determining the fastest route for communicating, and ZigBee relies on the mesh networking concept. Another Insteon uses a wireless network, as it provides greater flexibility when placing devices although this also introduces potential interference problems.

Owners of homes always want to establish a similar protocol of communication for all the electronic devices situated on the smart network. From here, the home system will send T-coded signals via a home's writing. This home's writing moves through outlets and switches that are operating the electronic devices. This is how the control is achieved [4]. The above-mentioned protocols only provide the essential technology for enabling communication by smart home systems. A smart home system also has sensors, actuators, and other middleware besides the presence of a network to make it work [8]. A sensor collects data and processes it intelligently to derive useful inferences and provide input about the current state, and an actuator is a device that brings about a change in the environment.

B. Purpose of a Smart Home System

The main objectives of a home network system are to increase the automation of a home, the effective management of energy, and a reduction in environmental emissions [9].

Home automation – As noted previously, this is the main aim of a smart home system. People would want to move away from the use of traditional manual controls in their homes to a system whereby such operations are controlled automatically. People may desire to have a home, for instance, in which they do not have to physically turn on lights at night; they do not have to physically open or lock their gate or doors whenever they are in or out; and they do not have to detect a fire on their own but instead have systems which can detect the presence of fire and respond automatically.

People would always want simplicity and efficiency around them. They need to relax and let other operations which they would have otherwise done performed automatically through using smart home appliances.

Energy management – This is normally achieved through designing efficient home appliances, improving awareness of customers on the issue of energy management and deployment of energy management systems (EMS) in smart homes.

In regard to the designing of efficient appliances, it is observed that the general efficiency of appliances is low. This is due to delays in replacement of older, less effective appliances with newer and more efficient ones. Customers therefore ought to consider the energy management of a smart home appliance before purchasing it so as to ensure they buy energy efficient appliances. Their extent of awareness of energy requirements and the respective costs of electricity should be a key factor in determining what to buy. Electricity consumption meters are always useful for installing so that consumers know precisely how much electricity they have used. It should be noted that nearly all smart home appliances rely on electrical energy for their operation. The conservation of energy therefore plays an important role as a main element in decision making.

Reduction in environmental emissions - Emissions, especially carbon dioxide emissions, are the most common contributors to global warming today. Monitoring the energy consumption of energy saving appliances in a smart home can go a long way in ensuring that the environment is conserved. For instance, if less electricity is used, then less carbon dioxide emission would be produced while generating the electricity.

C. Emerging Technologies

The Internet of Things (IoT) is a paradigm that describes objects with the capability to communicate intelligently with each other, which is made possible by processors, sensors and actuators in them. This is an emerging and promising way of interconnecting technologies that could enhance the working of a smart home system further. Reference [14] surveyed the key technologies involved that make IoT possible. An IoT arrangement is distinguished from other smart home systems by operating wirelessly mainly using the IP stack, and enabling the interconnected objects to be located in geographically dispersed locations. Other non-IP channels that may be used include Bluetooth, RFID (Radio Frequency Identification), and NFC (Near Field Communication).

Although the researchers proposed their own taxonomy for IoT technologies, a typical IoT architecture has the following three layers:

(1) A perception layer – The physical layer with sensors to sense physical parameters or identify other smart objects around.

(2) A network layer – This interconnect the smart objects and network devices, and is also used for transmitting and processing data.

(3) An application layer – This delivers application specific services to users.

Additional layers proposed by others include a transport layer, in which sensor data is transferred between the perception and processing layers; a processing layer, which stores, analyses and processes data from the transport layer, and a business layer, which manages the whole IoT system. Another way of characterising the architecture is by distinguishing between the user layer for managing input devices and user interfaces, a communication layer dealing with output devices according to the communication protocol, and an HMI (Human Machine Interface) layer for supervising the whole system by converting user events into actions [15]. In short, an IoT or smart home system is usually composed of modular components.

A newer communication network devised specially for smart home systems, called a HAN (Home Area Network), is capable of providing two-way communication between all devices, and it supports metering infrastructure and distributed energy generation and storage [16]. It also supports a range of wired and wireless communication protocols including WiFi, RFID, Bluetooth, GPRS, SPI, PLC, RS485, I$_2$C and Homeplug. A HAN network is defined by a network operating system, network management software, nodes, endpoints, and a communication gateway. Two types of HAN network architectures have been developed, namely, utility managed for monitoring and controlling smart home appliances through a private network, and a more capable consumer managed architecture based on a common gateway hub that functions as an intermediate device.

An important concern for all the components of a smart home system in terms of operation is their interoperability and method of control. Interoperability affects the effectiveness and efficiency of the system, and it enables mutual recognition and continuous data transference between the devices [17]. Lack of interoperability and integration could cause delays in response times and make it difficult for the system to work harmoniously as a whole. Reference [18] suggest to ensure interoperability and network collaboration by mapping data with device functions, correlating these functions with smart home functions, and specifying the information to be sent or received. A data aggregator for processing incoming data from different networks irrespective of the means of transmission (either wired or wireless) can also enhance interoperability. Besides network operation, other important technical considerations for a smart home system are energy efficiency, reliability and security. With respect to the latter for instance, since many smart home systems are being used for security purposes, they can only ensure security if they are themselves secure from any interference.

Applications of smart home technologies are covered further on, but generally, they may be categorised under energy management, health care, media consumption, and security and surveillance. Furthermore, a smart home may thus be defined as "a concentrator and disseminator of information and services that intends to cover the totality of a home's functional areas..." [17]. Four key factors are contributing to advancements in smart home technologies. These are (1) increasing miniaturisation of semiconductors, (2) greater processing power of micro-controllers, (3) integration of signal conditioning in small sensor nodes, and (4) advancements in wireless technologies. Developments in all four areas are helping to bring smart home technologies into the hands of common citizens.

III.   METHODOLOGY

In order to explore examples of Smart Home application technologies and their potential benefits for users, interviews were carried out among a randomly selected sample of 18 students. These were masters level students studying in the Information Systems and Technology Department at Claremont Graduate University in California in 2016 who were also possessors and users of a Smart Home technology. The goal was to know what types of Smart Home technologies are being used, to find out their mode of operation and the subsequent benefits or any issues gained from their implementation and use. The same systems were also explored by watching and observing online videos of people using them.

IV.   SMART HOME APPLICATIONS

During the research, several examples of Smart Home operations were found to be available. The table below lists a range of typical Smart Home devices that were encountered during the study and their main function. They are categorised

according to the generic areas identified earlier with the exception of health care. Some of these devices and applications are then described and examined in detail.

Table 1: Typical Smart Home devices and their main functions

Device	Function (automatic)
Energy Management	
HVAC	Regulation of temperature
Lighting control	Control of lights presence and intensity
Swimming pool heaters	Manage temperature of water
Sprinkler systems	Water sprinkling in yards depending on moisture content
Media Consumption	
Audio systems	Distributing audio such as music from a single stereo to any room in the house
Channel modulators	Delivers a video signal from camera or television station to other television sets in the house
Security & Surveillance	
Cameras	Tracking interior or exterior of home either continuously or when motion occurs and even it's dark outside
Video door phone	Provides photo of who is at the door
Door handle (biometric access control)	Opening doors relying on fingerprints or codes
Fire alarm	Raise alarm in case of fire outbreak

A. Lighting

Control systems that are capable of controlling electric lights in the household can be used with household lighting. According to Duke [5], controls can be made to periodically control time on a set cycle or on sensing that there is nobody in the room. For electrically controlled lamps, their brightness can be controlled depending on the task being performed at that time. Also, their colour can be controlled depending on the task [5]. This control can be done either via an Internet connection or it can be managed remotely thorough a wireless control. Also in this category is the control for natural lighting. Here, the control of electric window shades is managed according to the condition of intensity of natural light.

B. Security

Detection items such as gas leakage alarms, fire alarms or water leakage alarms can be integrated into a smart home application. For fire alarms, a response mechanism can also be mounted so as to automatically respond to a fire alarm. The most common response of a fire alarm is the use of an automatic water sprinkler. This can help to completely put out the fire or at least suppress its effects while help is sought [1].

A smart home automation system can also allow for the operation of remote security camera surveillance via the Internet. Even while in a workplace, one can monitor the security cameras in their home, and thus in case of any burglary, for example, they can report the matter to the relevant authorities without necessarily being at home at the time [4]. Alternatively, through the help of the home automation system, they can command the locking of all the windows and perimeter doors, and thus make it difficult for any intruder to enter or leave the house. This greatly improves home security.

C. Domotic

According to Sobh [10], domotic refers to the use of artificial intelligence in homes. For instance, facial recognition systems can be installed in homes such that upon the entry of each person, personal profiling is activated automatically. Information on the identity of the person is then transmitted to the users. This type of technology is normally used in areas where access is deliberately limited to specific people and thus access has to verified first before allowing entry.

V. SMART HOME DEVICES

A. Intercoms

This is an application that allows for communication between different rooms via the use of a microphone or telephone. This might happen in the form of an alarm transmission from one room to another or by permitting intercommunication between people in different rooms [7]. This is usually a case found in relatively large buildings where it is time consuming to travel from room to room for relaying information. This is a type of application that enhances the simplicity of operations.

B. Audio and Video

In the audio category, audio switching as well as distribution of audio is possible [7]. In audio switching, the selection of the audio source to be played is determined automatically. Also, audio distribution permits the source to be heard in a selected number of rooms, regardless of whether it is a single or multiple rooms. In the video category, a video source is permitted for viewing on either a single or on multiple TV sets depending on the specification of the user as per Juang [7].

C. Climotics

This is a smart home application that is aimed at dealing with daily weather changes, such as changes in humidity and temperature variations [5]. HVAC (Heating, Ventilation and Air Conditioning) control systems are used in this case. For

instance if there is an undesirable rise in temperature in a room, these devices sense the rise, and in response they initiate the running of air conditioning and ventilation systems in the room until a normal temperature is maintained. If the fans, for instance, are already running, then their speeds can be increased automatically so as to lower the temperature to within the range of tolerance. Conversely, a reverse process can occur when the temperature is low by reducing their speed, and in case of the temperature being very low, heating systems such as heaters may also be turned on automatically.

The HVAC systems can also initiate an automatic closing or opening of windows according to the internal temperature and humidity conditions. This in turn helps to achieve normalcy in those conditions. Apart from the above applications, there are also further smart home applications that were discovered during this research that may be relevant. These and other frequently used applications include the following:

- Use of automatic coffee pots in kitchens
- Sprinkler systems in yards
- Swimming pool pumps and their heaters

The figure below shows a sample of a Smart House control system structure. It shows the components of a LabView smart home system and its remote control. This system has the following LabView components: Internal lighting system, external lighting system, fire alarm system, burglar alarm system, and temperature system.

Figure 1: Sample of a Smart House control system structure
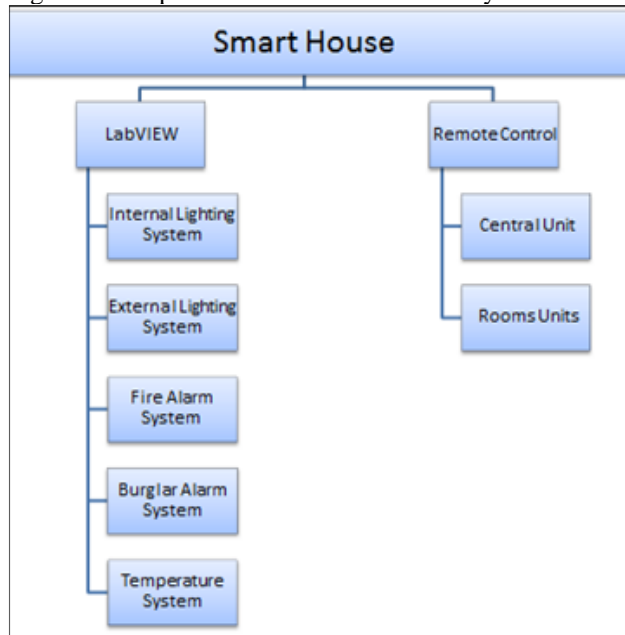
A.   *Potential Benefits of a Smart Home System*

Smart Home technologies are often promoted on the basis of their ability to provide convenience in controlling devices, especially for people like the elderly and those who need to have such control from outside of their home, and in providing energy efficiency savings. Furthermore, they provide potential benefits of comfort, security, and simplicity of control. This research revealed the following four major benefits of implementing a Smart Home system:

Convenience: This is achieved by making the household self-sufficient in performing routine tasks automatically. It may only require a simple press of a button and the operation is then done instantly. One can, for instance, turn off lights that were left on moments after leaving the house without having to physically come back and perform the operation [5].

Energy saving: The costs of electricity can be significantly reduced with the adoption of smart home systems. This is possible by stopping standby energy consumption. Many operations in the house can run at optimum energy levels since they will be shut down automatically and easily whenever they are not in use [1].

Security guarantee: This is a major breakthrough in smart home applications. Fire alert alarms, burglar alarms and door access alarms can all be installed and directly accessed and controlled via the use of a smartphone. This enables one to track the events around their homes even when they are not physically present at those places. Also, for today's home automation devices, they usually come with SMS/email alerts. This enables users to easily alert the respective emergency departments, for example, police or fire departments. In some applications, lighting systems can be automatically switched on as one approaches the perimeter, and this also increases their level of security [11].

Simplicity of control: Once home control systems have been installed, all the control operations become very easy to control. One only requires the touch of a button to control such elements as temperature, lighting or even entertainment [10]. Figure 2 below shows a sample of a Smart Home system controller showing simplicity of control.

Figure 2: Sample of a Smart Home system controller

B. Challenges of a Smart Home System

Installing smart home devices and applications as described above can appear to be a very expensive project to undertake. However, the benefits derived from such systems surpass their costs [10]. Moreover, the continuously advancing technology and the continuous rise in the demand for smart home products has led to a reduction in the prices of these items, which are thus becoming more affordable to many. Most prior studies have concentrated on use and benefit aspects of the technology, rather than on challenges.

Besides the issue of cost of implementation and use, certain other barriers are also faced prior to installation. Reference [12] identified several critical issues through interviewing 16 households before they installed a Smart Home system for the first time and when they had to make key decisions such as which devices to install, and where and how to position them.

The findings revealed appreciation among the interviewees for functional aspects, as well as for the possibility for improved living, but they also had a number of concerns. These concerns relate to hardware and software aspects of the technology, design aspects of acceptability and usability, and complexity in homes.

The technical challenges include reliability issues, interoperability and compatibility with other systems and future installations. Design challenges were found to include user friendliness; security, trust and data protection issues; lack of transparency from both developers and suppliers, and complexity of the technology that overpowered users. The third category of home related issues include the ability of the technology to align with and adapt to the needs of everyday life; dealing with periodic changes, unpredictable routines, conflicting roles, improvisation, exceptions and special social arrangements.

VII. CONCLUSION

From the above research, it is clear that smart home applications are being used widely in today's world. Because of the numerous benefits attributed to this continuously developing and expanding field, many people have opted to embrace it fully. With the aid of such technology and applications, it is shown that people can nowadays monitor and control the activities in their homes without necessarily being physically present at the time [13]. Of greatest importance to smart home systems for many of the respondents is the guarantee of security. The research revealed that the number of accidents occurring at homes has greatly decreased, and much of this is attributed to the application of a smart home system.

That people can now control many of their household operations with a simple touch of a button has positively and greatly affected the lives of people, both socially and economically. In particular, less time wastage in controls means more time can be saved for other productive activities, which in turn can potentially increase productivity and raise the living standards of homeowners.

Of particular importance is the impact that smart home systems have had on elderly people in society [6]. Previously, it was a big challenge for elderly people to perform their daily routine tasks, such as turning the lights on and off due to their advanced ages, and thus minimal movement or even a complete lack of it. However, with the introduction of this technology, they can now comfortably enjoy their everyday activities without struggling to perform such tasks.

In spite of realizing the potential benefits of smart home technologies, not all households are 'smart homes'. This is greatly attributed to the high initial cost of installing smart home devices [10]. It is therefore the role of the relevant stakeholders to ensure that the prices of such items are affordable because, as noted, they ensure maximum security, and the security of the nation and the world at large starts with security of the home.

VIII. RECOMMENDATIONS FOR FURTHER RESEARCH

This paper provided only a brief survey of Smart Home system and related emerging technologies focusing on the types of devices and applications available, and on the potential benefits they provide. The methodology was restricted to the interview method complemented by observations of their use. The research can therefore be extended in several ways. More research can be undertaken on not only pre-installation but also post-installation challenges, focusing for instance, on technological or usability issues, and by comparing alternative Smart Home technology solutions, including devices and applications to help decide in their implementation. Furthermore, it is recommended to involve

other research methods, such as a survey of usage, or a technical comparison to establish certain of its potential benefits.

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