Smart Home Environment for Mild Cognitive Impairment Population

by Himanshu Thapliyal, Rajdeep Kumar Nath and Saraju P. Mohanty

Abstract— **The intermediate stage between the expected cognitive decline of normal aging and the more-serious decline of dementia is defined as Mild cognitive impairment (MCI). The cognitive changes caused by MCI are serious enough to be noticed by the individuals experiencing them or to other people, but the changes are not severe enough to interfere with daily life or independent function. The early symptoms of MCI starts with the individuals inability to remember important information such as appointments, conversations or events such as a person may forget to turn off the lights, take medicine and other important daily activities. However, such symptoms are considered as a sign of normal aging, these symptoms can also get worse over time thereby leading to conditions like dementia. Considering the fact that there is a thin line between normal aging and MCI, it is difficult for individuals to discern between the two conditions. Moreover, if such symptoms of MCI are not diagnosed in time, it may lead to more serious and permanent conditions. However, if these symptoms are detected in time and proper care and precaution are taken, steps could be taken from getting situation worse. Hence a smart home environment which keeps tracks of the daily living of the individual, unobtrusively is a possible solution to improve care and quality of life.**

I. Introduction

Owing to the rapid development in medical science the life expectancy of the people has increased significantly. People aged 65 and above is considered as the fastest growing population in present day world especially in the Americas, Europe and Asia. US Census Bureau has reported that the number of people over the age of 60 is expected to reach 1.2 billion by 2025 [1]. However, on the flip side, aging population are prone to be a victim of chronic illness, dementia or Alzheimer's disease. The transition from intact cognition to being cognitively impaired is often a slow process and cannot be detected directly as the decline in cognition does not interfere with the person's daily living. This state of cognitive decline is termed as Mild cognitive impairment. Mild cognitive impairment (MCI) often goes unnoticed until serious cognitive damage starts to take place and leads to situations like dementia or Alzheimer and such a situation leads to damage beyond repair. Hence early detection of MCI can prevent the damage to the extent of no return [2]. Proper care taken at the early stages, can reduce the plight of both the aging population and their care giver.

In this paper we discuss the functionalities of an IoT based preventive and diagnostic smart home environment for MCI population, (*Preventive and Diagnostic MCI System* (**PDMS**)). Figure 1 shows the functional capabilities of a smart home system that is targeted to assist aging population in the preventive approach to cognitive decline.

- ***Diagnosis***: This phase focus on the diagnostic aspect of PDMS. The main function of this phase is to keep track of independent living of a person to detect unusual level of activity. The common diagnostic methods are track of daily living, feedback from family or relatives, medical history, assessment of mental status and evaluation of mood [3]
- ***Prevention and care***: After the analysis of the data collected from the diagnosis phase is shared with the personal care giver and thus steps can be taken to provide necessary prevention and care.

It is to be noted that the two phases are continuous process and are connected by analysis and classification phase which focuses on the analysis of the data collected in the diagnosis process by machine learning techniques to determine and track the progression of MCI. Figure 2 shows the inter-relation between the three phases. In Figure 2, the data from the diagnostic phase is transferred to the analysis and classification phase for analysis of the data collected. From the analysis and classification phase the result is transferred to the prevention and care phase which checks the status of the state of the patient and if any other data is necessary to be collected for further evaluation. Accordingly changes are made in the diagnostic phase to provide assistance and proper evaluation of the patient's state of mind

A. *IoT and PDMS*

The Preventive and diagnostic MCI system is in compliance with the IoT protocol. The four layers of IoT are: *object sensing layer*, *data exchange layer*, *information integration layer*, *application service layer* [4]. The object sensing layer sensing the physical objects and obtains data; the data exchange layer handles transmission of data; the information integration layer handles recombination, analysis of the data collected from various sources; the application service layer provides content services for various users. In PDMS, the diagnostic phase functions as the object sensing layer. The data from the object sensing layer is transferred via the data exchange layer to the Analysis and classification phase which functions as information integration layer. The prevention and care phase is analogous to application service layer. This concept is illustrated in figure 3

B. *Smarthome: A platform for aging in place*

The concept of 'Aging in place' calls forth a smart home living environment to provide assisted living facility for the aging population in their own home. As people grow old their

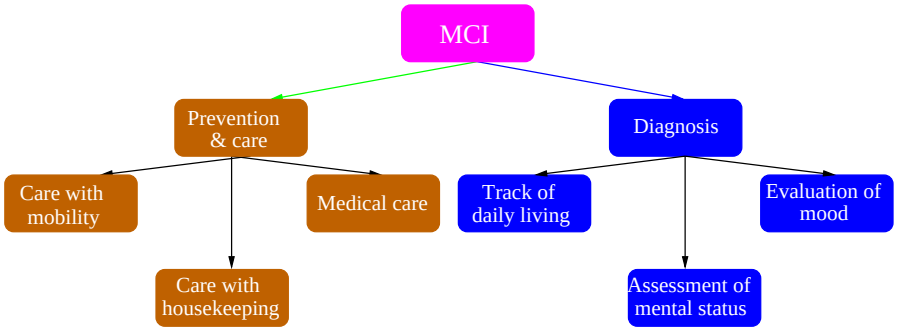

Fig. 1: Functional capabilities for a preventive and diagnostic smart home for MCI population

functional capabilities becomes limited in many aspects. In many cases this decline is so gradual and intermittent that it goes undetected in most of the cases till the problem becomes so severe that it gives to permanent conditions which are not reversible. One kind of such conditions is Mild cognitive impairment (MCI) which results in serious conditions like dementia, Alzheimer etc. Before the advent of smart devices and IoT into the health domain, informant feedback i.e feedback from friends or relatives was the primary diagnostic method for detecting MCI. However, such methods are not reliable and as the cognitive decline associated with MCI is so subtle, its possible that these symptoms goes unnoticed by friends or families. Also, for people living alone, there is no reliable source for information regarding the cognitive status of the person. With the leverage of smart components, activities of daily living can be tracked and information collected regarding the activities of a person in his daily life can provide useful information regarding the cognitive status of a person which otherwise goes unnoticed. Therefore requirement of a smart home environment to track the daily living for the detection of MCI is important to improve the quality of life for aging population. People affected with MCI display unusual level of activity than that of their cognitively intact counterpart. For example, walking speed and variability in walking speed have been found to be a good measure to differentiate older adults with MCI [5] [6] [7]. Similarly in [8], hand washing is said to be a potential surrogate marker for dementia. Activity recognition, therefore can be said to be a powerful indicator and parameter for detecting early symptoms of MCI.

The rest of the paper is organized as follows: Section II presents a brief background on activity monitoring and recognition, section III discusses about the basic activities of daily living, section IV discusses the instrumental activities

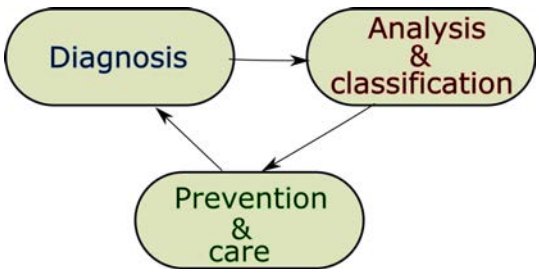

Fig. 2: Inter-relation between the three phases

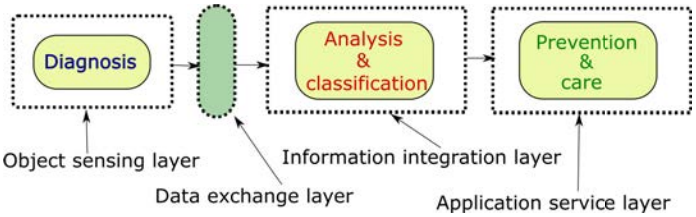

Fig. 3: Phases of PDMS as IoT layers

of daily living, section V discusses some of the wireless protocols for connectivity in smart home, section VI discusses the research scope and conclusion.

II. Activity Monitoring and Recognition

Monitoring the activity of a person or having information about the activity of a person has been the most common form of diagnostic procedure for all kinds of ailments. For example information about past eating habits can help diagnose the reason and the possible solution for stomach disorder. Cognitive illness is no exception in this context and researchers have successfully used activity recognition to diagnose and characterize cognitive decline. Many smart home projects for elderly have the functionality of activity recognition, not only for cognitive disability but also for other sorts of disability.

Data is collected through sensors (smart phone sensors, body sensors, environmental sensors etc.). The data is then processed and classified (Hidden Markov Model, Support Vector Machine etc.). The classified data is then compared with the standard test data (data showing normal activity) to discern the abnormal activities from the normal. This is illustrated in Figure 5 [9]

The data collection is done by various sensors. Different types of sensors have been used in different smart home projects to keep track of activities and for data collection. The types of sensor that have been used can be classified into four categories: video sensor, audio sensor, wearable sensors and environmental sensors. The type of sensors to be used depends on the requirements of the smart home. For example, Zhang et al in [10] have used environmentally placed sensors to determine activities of daily living. In [11] a multi sensor approach has been used to for the determination of activity recognition. In [12], audio technology has been used to promote well being and reliance. In [7], video analysis has

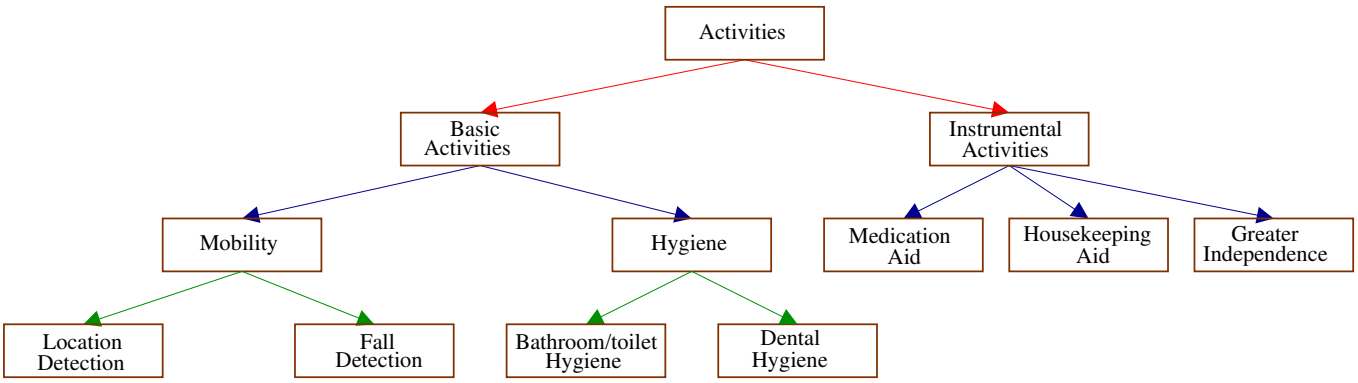

Fig. 4: Activity recognition and aids

been used to analyze hand washing behavior in older adults. Environmental and wearable sensors are the top choice for many smart home environment. The obvious reason being that in case of audio and video sensors, privacy of the concerned people is compromised. Also, it is easier to integrate wearable and environmental sensors together as compared to integrating video or audio sensors with wearable or environmental sensors. It is to be noted that, video and audio sensors are most suited for specific activity recognition and not wide range. For example in [8], automated video is implemented only for analyzing hand washing behavior.

A person's capability of independent living is measured by his ability of completing basic activities of daily living. The basic activities of daily living are those which people tend to do everyday and does not require any assistance from others and they are identified as bathing, personal hygiene, dressing, toilet hygiene, functional mobility and self feeding [13]. Other than basic activities, there are instrumental activities of daily living which are not necessary for fundamental living but allows an individual more independence in community living and a greater sense of independence [14] [15]. IADLs include activities such as cleaning, cooking, shopping etc. Although instrumental activities are not as essential as basic activities, however the inability to perform instrumental activities does not label an individual as "Independent". Such inability of performing instrumental activities can be an indication of probable loss of the ability of performing basic activities. Hence, it is necessary that instrumental activities be monitored not only for the sake of diagnosis but also for providing assistance. The activities that will be discussed in this article is illustrated in Figure 4.

III. Basic activities of daily living

It is said that among the six basic activities, the loss of functionality follows the order hygiene $->$ toilet/bathroom use/locomotion $->$ eating [16]. Retrospecting the experience drawn from real life, we see that it is indeed true. It makes sense that improper and unsafe use of bathroom or other appliance usually happens when the mobility of the person is hindered. Hence it can be said that keeping track of mobility of a person can provide us with significant information about the cognitive status of a person and also to determine the type

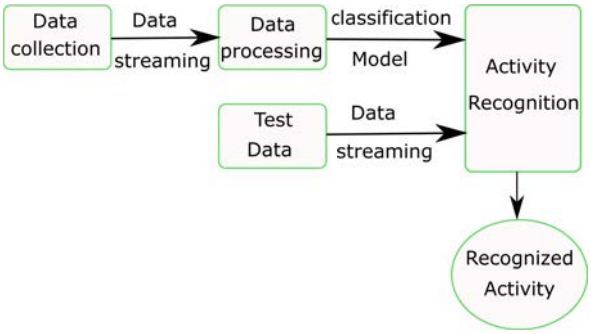

Fig. 5: Process of activity recognition

of assistance that is required to provide to improve the quality of life.

The ability to perform mobility around the house is an important basic activities. In this context, two major functionality of a smart home system is its ability to detect location of an individual and detection of fall.

A. *Location Detection*

Various smart home project employed various methods for detecting location of a person. For example in CASAS smart home architecture [17], infrared sensors were used. The infrared sensors were placed on the ceiling which are capable of detecting presence or motion within their range. Ultrasonic sensors can also be used to detect motion. The receiving side of the ultrasonic sensor can be placed in fixed location around the house and the individuals can wear a tag that transmits sound signals which are received by the receiver and the location can be identified. For example, Gator Tech smart home [18] initially incorporated the use of ultrasonic sensors to detect motion by placing a set of ultrasonic transceiver pilots in the ceiling, The users wore vests attached with transceiver tags which responds to the chirp. However, the inconvenience associated with wearing a special clothing all time and the expense of requiring many such expensive pilots made them opt for using pressure sensors. Pressure sensors were embedded on the floor that is capable of detecting footsteps.

E-domotica	Tynetec	Kinesis
Intelligent acceleration sensor & button	Dual axis accelerometer sensor	Inertial sensors for mobility assessment
Automatic alarm system upon fall detection	Provides reactive & preventative telecare solutions	Provides fall risk & frailty scores alongside fall detection
Wireless connection using Z-wave & Automatic battery reporting	Daily battery self-test & low battery reporting	Secure, integrated solution to backup data to remote server via Wi-Fi

TABLE I: E-domotica, Tynetec and Kinesis fall detectors

B. Fall Detection

Detection of fall is also another important feature a smart home environment should have. Weak and imprecise mobility often increases the possibility of fall. Considering the fact that fall can be quite dangerous, immediate attention is required. A fall can be detected either by using environmental sensors or wearable sensors. Generally two types of environmental sensors are used for detection of fall: video sensors and proximity sensors. However, both of these have disadvantages and are not suitable for a smart home home platform. For example, one common issue with both the video sensors and proximity sensors are that they have a limited range. Fall cannot be detected once the individual is out of range from either the camera or proximity sensor. Moreover, another problem with video based sensor is the intrusion of privacy and proximity sensor are not that accurate even in controlled setting [19] [20]. To detect fall, wearable sensors are most preferred. Fall detectors come in the shape of a bracelet which can be easily worn by individuals (adds to the style and also safety). Table I shows the feature description of E-domotica [21], Tynetec [22] and Kinesis [23] fall detectors. In [24], voice based fall detection system has been proposed which uses Amazon Echo as the voice interface.

Apart from the devices listed above, there are plethora of other devices which can detect fall. For example, Vigi'Fall is another wearable fall detection system. This device uses infra-red sensors placed externally with specific data fusion algorithm to improve reliability.

Fig. 6: E-domotica [21]: Easy care fall detector (Courtesy of E-domotica)

C. Bathroom and Toilet hygiene

One of the first thing an individual does after waking up is go the bathroom, use the toilet, brush and get a shower. These simple day to day task are actually not so simple for older adults living alone in the house. Bathroom hygiene is among the first of the hygienes to get compromised. Naturally it's taxing for older people to take care of the toilet and clean it regularly and especially for those with cognitive impairment may even forget to wash hands or the unhygienic condition of the bathroom may simply skip their attention. In this context, the use of smart toilet can monitor your health and provide feedback and that are capable of cleaning itself. For example Toto Intelligence Toilet II is capable of measuring blood pressure, weight, body temperature etc. and records the data for analysis and reports them to the caregiver or the person responsible. It uses WiFi to talk to the home network. Similarly, Kohler's Numi smart toilet is equipped with a self-cleaning bidet and a dryer. It is also capable of adjusting water temperature and pressure [25] 7. Google is also taking a leap in the area of smart bathroom. The patent filed by Google shows that it has sensors placed in every potential corner of the bathroom to monitor the health of the patient. For example, it has sensors placed on bath mat to measure the heart rate of the individual by measuring body's electrical pattern [26]. These progress in smart bathroom shows the numerous benefits that can be achieved with the popularization of smart bathrooms for rapidly increasing aging population and also their caregivers. With the advent of smart home, people won't have to go the doctor's office for check up and in fact with the use of smart bathrooms, daily update about the patient's health is possible which will ensure proper and detailed care.

D. Dental hygiene

Dental hygiene forms an important aspect of hygiene. This is very important especially when it comes to aging population who are most vulnerable to tooth decay as aging population with cognitive impairment might forget to brush their teeth or might not brush properly. However, smart tooth brush available has made it a lot easier for both the user and caregiver to monitor the brushing habits. For example, Philips Sonicare FlexCare [28] launched by Philips Sonicare is embedded with a variety of sensors to keep track of how the person is brushing his/her teeth. This smart tooth brush provides intervention if the user is brushing too little or scrubbing too much. This device connects to an app via bluetooth and the data collected from the brushing activity can be send to the dentist for examination. Another smart toothbrush with similar feature as that of Sonicare FlexCare is the kolibree [29] which is

Fig. 7: Numi intelligent toilet [27] (Courtesy of Kohler team)

equipped with 3-D motion sensors, accelerometer, gyroscope and magnetometer.

IV. Instrumental Activities of Daily Living

The main objective of smart home environment is improving the quality of life by providing more independence and better care. For example, cooking, managing finances, business, medication, ability to move around community are cognitively challenging tasks. The ability to perform these tasks with minimum supervision from another human being, will not only make our life meaningful and happening but also can reduce burden on the family members and physician as well as cut on huge expenses spend on old care home each year. A study conducted in 2010 shows that healthcare expense for people aged 65 years or older was $18424 per person: five times compared to children ($3628) and triple for working age individual ($6125) [30]. Moreover, when it comes to MCI, the instrumental activities are particularly affected in MCI [31]. The basic activities remain stable for a long time even with MCI. So, for early diagnosis of MCI, it is necessary that the instrumental activities be tracked to detect early signs of cognitive decline.

A. *Medication Aid*

A majority of the older adults specifically aged 65 or above are usually in some kind of medication where they are required to take medication in specific time of the day and in specific dosage. However, adults with mild cognitive impairment are very likely to forget to take medicine on time. There are various devices that provide timely reminder to individuals about their medicine and dosage. For example, e-pill MedSmart Automatic Pill Dispenser [32] reminds patient to take medications. This device is very convenient to use. This device reminds individual when it's time to take medicine by setting up reminder alarm with flashing light and sound alert. This device has a circular tray to organize pills and the tray rotates and all medication for a particular time is made available. Also e-pills are also available that can monitor patient's health from within the body. For example, Proteus

Fig. 8: Philips sonicare toothbrush [28] (Courtesy of Philips)

is an electronic pill that has a tiny ingestible sensor. This sensor transmits vital information about the patient's health and transmits the information wirelessly to a patch on user's body and ultimately to an app in the user's mobile device. The sensor is cheap and the patch needs to be replaced every seven days [33]. Helius is another e-pill developed by Proteus Digital Health which can keep track of vital health information like heart rate, temperature, activity and rest pattern and also informs the caregiver if the patient is taking medicine at the proper time [34]

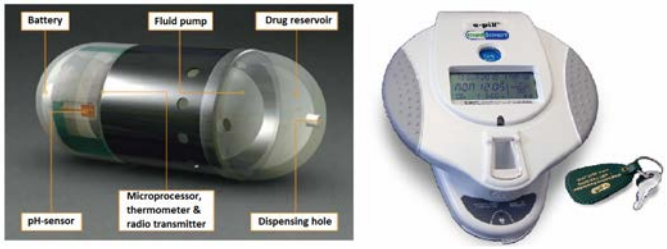

Fig. 9: MedSmart pill dispenser [32] (Courtesy of MedSmart) and e-pill [34]

B. *Assistance with housekeeping*

Other instrumental activities that an individual tends to do everyday are the cooking and house keeping activities. There are many subtle things related to these activities that make these tasks complicated for people with cognitive disability. For example, an individual might forget about groceries and other important household items. It is quite possible that they might fail to follow the specific nutrition prescribed by the physician. Tasks like cooking and housekeeping are especially taxing for people with cognitive impairment because they often have problems remembering a sequence of steps,

do proper planning etc. However, the numerous IoT devices available today can transform your kitchen into a smart kitchen thereby solving the problems faced by people with cognitive impairment. It is not convenient for older adults with disability to go for shopping and even if it is, it is quite possible that they might not remember all the items that they might need for the house hold. There are many devices for providing assistance with shopping. For example, amazon dash wand [35] is a wifi connected barcode scanner with voice capabilities that is able to prepare a shopping list by scanning bar codes and saying out name loud. The device is integrated with AmazonFresh (Amazon's online grocery delivery service). The device is portable and can be stuck to any metallic surface like the refrigerator. Similarly, Hiku [36] is another device for providing shopping assistance which is also voice enabled and can be attached to any metallic surface. Another subtle thing to consider in this case is that the individual might not be capable of keeping track of inventory. Neo is a powerful mobile device developed by Psion Teklogix [37] capable of inventory tracking which uses bluetooth connectivity. Safety is also another matter of concern especially when it comes to people with cognitive disability. It is quite possible that they might forget to turn off the stove which is quite risky. Devices like kepler and Birdi can be used in smart homes to detect abnormalities in the quality of air like smoke, natural gas, temperature etc. Both these devices are connected via wifi to smart phones. In case of potential threat, Birdi alerts the caregiver or the person authorized via a text message or automated call [38] [39].

C. *Greater Independence*

Considering higher degree of independence for older adults who might have to leave the house for completing some tasks, such as shopping, community gathering etc which can be quite dangerous for people with cognitive disability. For example, let us consider a person Mr X who lives in a smart home. Mr X decides to take a walk in the evening for some fresh air and change of space. Supposing the patient is suffering from state of dementia or Alzheimer, it is quite possible that Mr. X forgets the way to his home. Even worse, when a older person gets lost and can't find his way home, it is quite possible that he might get panicked and nervous resulting in high heart rate, increased blood pressure. All these factors might lead to a heart attack or stroke. All these could have been avoided if Mr X had used tracking devices that can send real time update to the caregiver. Also, a added safety measure would be to have wearable that can keep track of the vital functions of the body such as heart rate, blood pressure etc and alert the caregiver in case of any of any abnormality. There are various location tracking devices available with numerous functionality. For example, PocketFinder [40] is a small waterproof location tracking device that is capable of viewing address, altitude, distance from the address and the speed of the object and alerts the caregiver or the person concerned in case of any abnormality. This case is illustrated in Figure 10.

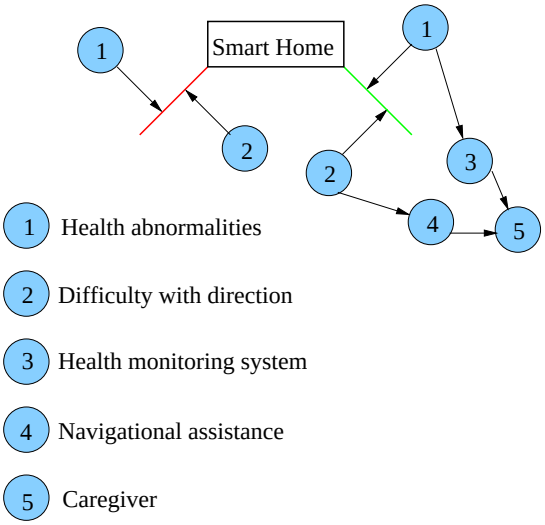

Fig. 10: Greater independence with and without assistance

V. Connectivity in Smart Home

The main objective for a smart home environment in particular to PDMS is unobtrusive data collection by sensors and proper integration and compatibility among among different sensors collecting information about the subjects activity. While one particular activity may not be entirely reliable and sufficient for proper diagnosis and analysis, it is necessary that various sensors be engaged to ensure proper diagnostic set up. However, while engaging several sensors has its own challenges. To support dis-aggregated computing, many of the traditional activities of an operating system must be supported through a Middleware [41]. Also, when new sensors are required to be integrated in to the system, it is required that the integration be easy without requiring to make major changes to the overall network. In this respect it is necessary to choose proper network protocol that will be able to meet this necessity. Most of the sensors communicate with each other or the hub via wifi or bluetooth connectivity. Two other protocols that are getting a lot of attention are the Z-wave and ZigBee wireless protocol.

A. *ZigBee*

ZigBee is an IEEE 802.15.4-based specification well suited for high level communication protocol for home automation, medical device data collection etc. ZigBee technology is simpler and less expensive than other IoT protocols such as Bluetooth or Wi-Fi. The ZigBee wireless protocol is an excellent choice for a preventive and diagnostic smart home system owing to its reliability, interoperability, low power and higher standards of security. ZigBee is projected to play an important role in the adoption of assistive technology by fostering safe, healthy and independent living conditions for the disabled or elderly. ZigBee technology can be applied to monitor chronic diseases like Alzheimer, dementia, Parkinson etc. ZigBee provides a plethora of devices to for aging population as shown in Table II [42].

The various devices provided by ZigBee can be set up in home environment to collect data specific for different

Device	Device Function	Device	Device Function
ILAH	Aggregates events from multiple sensors	*Motion sensor*	Detection of movement
Adherence Monitor	Records medication usage	*Property Exit sensor*	Detects exit of occupant from house
Fall sensor	Fall detection	*Contact closure sensors*	Detects opening or closing of doors, windows etc.
PERS sensor	Raise an alarm	*Usage sensor*	Detects abnormal usage patterns
Smoke sensor	Detects smoke	*Switch use sensors*	Detects usage of switch
CO sensor	Detects carbon monoxide	*Dosage sensor*	Tracks dosage of medicine
Water sensor	Detects unexpected presence of water	*Temperature sensor*	Temperature monitoring
Gas sensor	Detects levels of gas above safe limits	*Enuresis sensor*	Detects occurance of involuntary urination

TABLE II: Aging Independently sensors provided by ZigBee

purpose. For example Figure 11 shows an example of a smart home setting using sensors such as usage sensor, switch use sensor, motion sensor are used to collect data data regarding patients activity. For example usual or abnormal usage of objects at home for e.g chair, table etc are collected through usage sensor. The usage of switch sensor is used to track the usage of switch and the motion sensor is used to detect presence of people in its vicinity. Also, patients vital signs such as heart rate, temperature, blood pressure etc are monitored by using sensors attached to the body. All the information collected by the medical sensors is time-stamped and securely forwarded to a gateway that functions as a patient monitoring system. Additionally, the gateway forwards the aggregated information in a secure way to a database server. The information stored in the database server can be accessesed by the medical personnel and the family to monitor the progress of the disease.

ZigBee wireless technology has been used by researcher to build smart home architecture for aging population. For example CASAS smart home architecture [43] is a light weight smart home design which provides smart home capabilities without additional training also used ZigBee protocol in their design.

B. *Z-wave*

Z-Wave is low power two-way wireless technology that is designed and optimized mainly for smart home application.

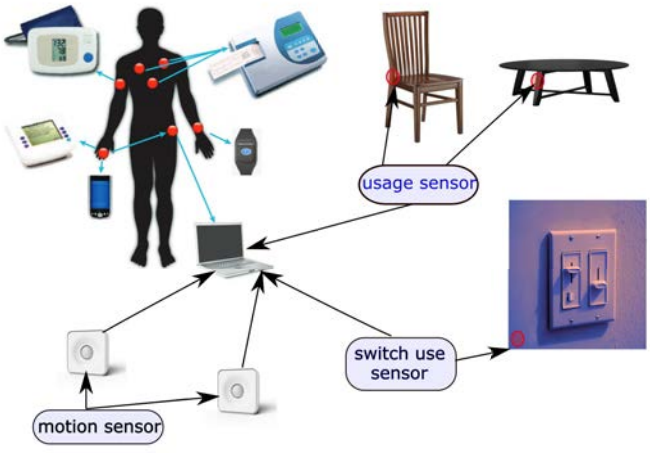

Fig. 11: Example of patient monitoring smart home system using ZigBee wireless technology

The low-power feature of Z-wave devices allow battery driven devices such as door/window sensors, door locks, motion sensors etc. to operate for multiple years without replacement. Z-wave provides a wide range of product variability of which smart hubs, voice control and smart sensors are of special interest. Example of smart hub solutions provided by Z-wave plus are Samsung SmartThings Hub [44], Wink HUb 2 [45] etc. Nexia home intelligence [46] is a good home automation system which is based on Z-wave technology. Nexia is built on an open architecture platform which makes it compatible with products from a number of different manufacturers. Although there have been a number of academic and practical security researches on home automation systems based on ZigBee and X10 protocols, research is still in its infancy to analyze the stack layers of Z-Wave protocol. This is because the analysis of the stack layers of Z-wave protocol requires the design of a radio packet capture device and related software to intercept Z-Wave communications [47] [48].

VI. Research Scope and Conclusion

With the ever increasing aging population and need for immediate health care, there are plenty of research opportunities in this direction of providing efficient and reliable health care to the aging population. As discussed in Section I, the three main functions of a preventive and diagnostic smart home environment: (i) Diagnosis, (ii) Analysis and classification, (iii) Prevention and care. All these phases together constitute the complete functionalities of a Preventive and Diagnostic MCI System (PDMS). Research is being carried independently in each of the three phases to improve the quality of life. For example, research in the diagnosis phase include the design of smart devices with better and multiple capabilities, integration with various smart devices together in providing a complete health care solution to the aging population. Research in analysis and classification refers to the analysis of the data collected through sensors, implementing and developing efficient machine learning techniques for data processing. Research in prevention and care refers to the development in providing immediate care and providing proper feedback based on the result obtained in the analysis and classification phase. Smart home should have the feature of scalability as with time, new features might be needed to add to the functionalities of smart home. Also, installation of new features in a smart home should not be too cumbersome or expensive. Although a lot of work has been done in the area of smart home but most of them are in controlled laboratory setting or even there are smart

homes functioning in real life situation, the features are still limited and does not provide real independence in all respect. The battle between needs and availability will continue with needs always keeping a step ahead of availability. We have come along a long way in providing better care to the aging population and this endeavor will continue to improve the quality of life for the elderly.

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