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RFID Systems in Healthcare Settings and Activity of Daily Living in Smart Homes: A Review

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Abstract

Elderly inhabitants have a strong influence to healthcare facilities globally in the last few years as a result of the high demand on the healthcare services and the gap between the services provided by caregivers and the increasing number of older people. Radio Frequency Identification (RFID) technologies have been increasingly adopted in smart homes and used widely for indoor localisation. These technologies have been benefiting to healthcare domain where they improve the quality of services delivering by healthcare providers. This article presents a comprehensive review on RFID systems and healthcare research works in smart homes. We also compare RFID-based solutions in healthcare and distinguish challenges of smart home technologies in indoor environment. We also discuss research challenges related to Activity in Daily Living (ADL) in smart homes for wellbeing.

Keywords

RFID, Smart Homes, Healthcare, Activity of Daily Living, Localisation

1. Introduction

Aged-related symptom, such as dementia has increased the demands on healthcare facilities globally, resulting in further cost due to staying longer in aged care homes. In worldwide terms, the entire estimated expenditures of dementia were US $815 billion in 2015 [1]. There are more than 46.8 million people suffering from dementia today, and that number is predicted to increase to 74.7 million in

2030 and 131.5 million by 2050 [1]. Traditional healthcare services for elders or age-care homes are generally expensive; that adds high costs for seniors' families and their local governments. It is essential that governments and healthcare providers worldwide find efficient solutions as an alternative to the traditional healthcare systems [2].

The smart homes concept is formally defined as places of residence that are outfitted with computers and technological devices. They aim to provide not only the comfort, convenience, and safe environment, but also the improvement of life quality, and assistance to occupants on a daily basis as well as connecting them to the world beyond [3]. Research in smart homes focuses on building technologically advanced systems. Smart environments include applications that monitor the elderly unobtrusively via connection sensors, and warn them or their healthcare providers about abnormal conditions [4].

Smart homes have been increasingly considered as a feasible option for healthcare monitoring and services for the elderly as well as for disabled people who prefer to stay comfortable in their own homes. Ambient assisted living *Radio Frequency* based technologies help to recognise the daily life activities, and they also monitor the elderly's behavioural movements by measuring a set of daily living specified activities, such as standing, sitting, lying, walking, and interaction with furniture or objects. The technologies can potentially assist impaired individuals, such as people suffering from Dementia, in their residential living [5].

Location based-systems in smart homes healthcare are one of the new areas on which Internet of Things (IOT) is focusing [6]. The advancement in pervasive healthcare has changed the perception of healthcare services. Pervasive computing healthcare technologies aim to assist elderly and impaired individuals in their living, particularly easing their daily activities and performing domestic tasks conveniently. Researchers in the pervasive computing field have been investigating several indoor localisation techniques and technologies to improve the accuracy of the locations of target individuals.

This survey paper summarises the state-of-the-art researches in smart homes for healthcare. It also reviews the current challenges for smart homes and RFID for healthcare systems as well as Activity of Daily Living (ADL).

2. The Radio Frequency Identification

RFID is a new and promising technology, which is adapted in many life applications. It has interested several researchers in the field of indoor localisation due to its desirable characteristics such as identification, tracking, detects multiple objects at same time and ability to read multiple Smart homes users at the same time. Numerous studies in Smart homes have exploited the RFID-based technology for finding auspicious indoor positioning solutions for healthcare facilities [3] [7] [8] [9].

RFID technology enables tracking individuals and objects in an indoor environment automatically and independently; based on the communication model and via radio waves (between readers and tags). It works by sending and receiving a unique identity of persons and objects wirelessly by using radio waves. The RFID system consists of readers, tags and data collection modules. The readers can be static or mobile. There are two methods for tracking. In the first method, the reader can be installed in a static location inside the household (such as wall, table or kitchen) to sense the movement of RFID tags. Then the reader searches for the tags which are either attached to objects or carried by the person. In the second method, the portable reader detects the static tags in certain positions while the RFID reader can be carried by individuals [10] [11].

There are three main categories of RFID tags including active, passive and semi. Active RFID tags have an internal battery to power themselves continuously. They have the greatest range of all three of the types [11]. However, active tag lifetimes are limited, and they rely on how much energy is stored in the internal batteries. The maintenance and intrusiveness in active tags is much bigger than their passive counterparts. Further, it contributes to radio, and it is sensitive in harsh environments. The price of active tags and the maintenance cost are relatively higher than other types. Semi RFID tags (battery-assisted passive BAP), also have an internal battery to power the internal circuity [11]. It does not add radio noise and has alonger reading range with a memory to store more data. Nevertheless, because it has a battery which is a larger size, quite expensive, limited battery life.

Passive RFID tags have no internal battery. They are smaller in size and are much cheaper than active or semi-active tags. Notably, passive RFID tags are powered by the radio waves that are emitted by the antennas, and so they do not have internal sources of power and it does not add radio noise with a good resistance performance in harsh environments. The tags are widely adapted in many applications such as when applied to objects (cups, a kettle or furniture) in Smart homes [5]. The drawbacks about passive RFID tags that they require higher power interrogators, small memory with a limited amount of data to be stored and low reading ranges. Table 1 provides a technical performance comparison between the three main RFID tags type.

3. Smart Homes

3.1. What Is Smart Homes

The term Smart home was officially coined in the 1980s by the American Asso-

Table 1. Comparison between the three main RFID tags type.

Tag type	Size	Wight	Cost	Reduce noise	Lifetime	Sensitivity (harsh environment	Reading range	Memory
Active tag	×	×	×	×	×	×	√	√
Semi-active	×	×	×	√	×	×	√	√
Passive tag	√	√	√	√	√	√	×	×

ciation of House Builders, even though the concept of wired homes was founded in the 1960s [12]. Smart homes are equipped with computing and information communication technologies to respond to the needs of occupants to stay safe, comfortable, secure, independent and healthy, This is achieved through the management of the advancement in technologies and to connect homes to the beyond the world [13]. Smart homes also monitor elderly individuals in real time for their daily life activities. The system works by utilising sensors and tracking technologies to locate and track objects as well as individuals in the indoor environment [14]. Smart home environments are designed to provide interactive and sensing technologies to facilitate the living support and health monitoring for elders inside residential homes so that they can live independently [15].

3.2. Smart Homes in Healthcare Domain

Smart homes for healthcare aim to provide autonomous support for: 1) people living at their residence, 2) elderly and impaired individuals who live independently and require constant health care, and 3) people who suffering from numerous pathologies and handicaps such as chronic diseases that require them to stay at hospital or at a placement in a caregiver's home [16]. The technology could potentially improve living quality for elders and disable individuals. Healthcare Smart homes are also defined as a specialised area of smart environments by integrating sensors and actuators to allow communication with inhabitants and localise the subjects intelligently that can support the daily life activity [16].

Since the 1990s, ubiquitous homes have been studied by several researchers who have proposed promising contributions in healthcare and in supporting impaired individuals. Chan *et al.* [17] reviewed other relevant aspects in Smart homes such as human activity recognition and the efficiency of implemented sensor systems. The authors argued that smart homes are one of the favourable, cost-effective solutions for home care for the elderly and people with disabilities.

3.3. Healthcare Challenges in Smart Homes

Smart homes are built to facilitate assist in the daily lives of impaired individuals. Nevertheless, researchers are facing challenges to deliver an integrated solution. Smart homes have become a feasible and cost-effective aid to assist impaired individuals and to live independently. Nevertheless, there are major issues with Smart homes which are outlined below.

3.3.1. Affordability

Although researchers have introduced cheap Smart homes health systems that could potentially reduce the cost of health care, affordability in Smart homes is still a hard task to achieve. Smart homes should be designed to minimise the installation cost of components and to Smart homes allowing the reuse of the smarty space components and objects and consequently reducing the final cost

[18]. Smart home devices, such as sensors, system components and system tools, and applications should also reduce the computational time as well as minimising the cost of implementing the system [19].

3.3.2. Reliability

Reliability and usability are important issues to determine whether or not a solution is applicable for healthcare in Smart homes. Demiris revealed that there were significant reliability and user-friendly concerns when using Smart homes technologies in residential homes. The devices and technologies need to be user-friendly so that elderly people can use them on a daily basis without hassle. Adequate training is crucial for elderly users, and the systems should not obstruct user's movements or daily activities. Smart environments will also help patients and older residents in emergency situations, analyze their daily life patterns, physical movements and reliably monitor physiological parameters such as blood pressure [17].

3.3.3. Robustness

Finding a means to address accuracy and the robustness of activity recognition is a current pressing issue in the Smart home field. At this stage, the infrastructure of a smart home must be designed to perform well to face several sources of data or distinguish between different sources. If the proposed approach ignored the accuracy factor and robustness in activities recognition problem that could contain similar activities, and also perform in various ways as well as account for different users, then unaccountable activities would show up as noise in the data. In most cases, this noise in the data will lower the accuracy and robustness of the system to recognise the activity.

3.3.4. Ethical and Legal Challenges

Privacy is a crucial element when building or adopting Smart homes. Technologies such as sensors and cameras could lead to privacy issues due to the constant surveillance and monitoring required. Consequently, these technologies are less likely to be a feasible solution. Unfortunately, there is still limited regulation on the patients' rights to protect them from malpractice related issues [17] [20].

3.4. Smart Homes Projects in Healthcare

A number of later research projects have utilised Smart homes solutions to benefit impaired individuals, the elderly and patients who require continuous health care support. These projects are summarised in **Table 2**.

Researchers at the University of Missouri, USA developed a cost effective project called "Aging in place" to assist seniors when living independently at home [21]. The CASAS [22] project at the University of Washington aimed to detect activity patterns using data mining techniques. It also created an automation of policies that helped understand the change in activity patterns. The University of Texas at Arlington introduced the Mav Home smart home project that acted as a rational agent to maximise an inhabitant's living conditions and minimize operational costs [23]. The Smart Condo at the University of Alberta,

Table 2. Smart homes for healthcare projects.

Project	Target	Description
Aging in Place [22]	Impaired Elders	Early illness detection
CASAS [23]	Residents Daily activities	Home automation and pattern discovery
MavHome [24]	Home Inhabitant	Rational agent, inhabitant action prediction
TREVA [25]	Subject (elderly) smart environment	Wellness status monitoring system
ENABLE [26]	People with dementia	Assistive technology for dementia patients
Smart House [27]	Older people	Lifestyle monitoring, detection of panic alarms
Ubiquitous Home [28]	Living family members	Home context-aware service, real life data collecting
Intelligent Sweet Home [29]	Home inhabitant	Intelligent, interaction and interface system (hand gesture recognition)
Welfare Techno Houses [30]	Human behaviour	Monitoring human behaviour in daily life
SPHERE [31]	Aging people with chronic health conditions	Manage people/elders care and well-being at home environment

Canada [31] developed a simulated Smart home that integrated intelligent technologies such as wireless sensors to assist in remote monitoring, improving the quality of living for chronically ill patients and reducing the time spent in the hospital.

Several smart home projects have been introduced in ambient assisted living situations in Europe. Gloucester's Smart House [26], a community contribution project, targeted the increase of the demographic changes of the elderly throughout the Telecare system, which is based on life style monitoring. SPHERE [30] by the University of Bristol in the UK aims to help people suffering from chronic health conditions by predicting falls, strokes and to detect periods of depression or anxiety using computer-based therapy as well as analyzing human eating behaviour. Another project named, TREVA [24] is a smart home station that monitors long-term physiological and psychosocial variables. It helps study the well-being of the individuals, including the slow development and deterioration and their vital signs such as; beat-to-beat RR intervals, activity level, and blood pressure. PROSAFE [32] aimed to target long-term care and was used as a multi-sensor to monitor elderly people continuously. The system monitors the mobility changes and signals of activities, and it sent alarms in case of emergencies.

Other notable works in Europe are presented at [25] [33] [34]. Enable project [25] aimed to provide assistive technologies that were designed to increase the independent living for people suffering from dementia. Devices were easily installed to assist the patients without technical supporters. PAMAP [33] was an Information Communication Technology (ICT) based system that targeted the physical activity of elderly individual's in clinical environments and on a daily basis. Similar projects such as (HMFM, HOPE and HERA [34]) were innovative ICT service systems focused on ambient assisted living (AAL) and cost-effective solutions.

In Asia, many smart home projects have been carried out by researchers. In Japan, the Ministry of International Trade and Industry developed a series of 13 research examples for one project called "Welfare Techno Houses" [29]. This project aimed to monitor human behaviour on a daily basis in terms of improving the quality of life for both mental and physical health using a combination of infrared and magnetic positioning sensors. Ubiquitous Home [27] is a home context-aware service oriented which was designed to support seniors in real life to help them to live independently in their homes. It integrated devices and sensors with existing data network infrastructure. Intelligent Sweet Home was introduced to provide an easy living environment for the inhabitants by giving the subjects the freedom of movement using hand gesture recognition [28].

In Australia, Celler *et al.* [35] proposed a system that showed the interaction between participants and environments while it examined the health status of elderly participants by monitoring their activity remotely in a smart environment. Researchers also introduced a smart home model that helps the elderly in their life and support their needs based on simple approaches using a hidden semi-Markov [36].

3.5. RFID Technology in Healthcare

RFID technology enables tracking individuals and objects in an indoor environment automatically and independently, based on the communication model and via radio waves (between readers and tags). It works by sending and receiving a unique identity of persons and objects wirelessly by using radio waves. The RFID system consists of readers, tags and data collection modules. The readers can be static or mobile. There are two methods for tracking. In the first method, the reader can be installed in a static location inside the household (such as wall, table or kitchen) to sense the movement of RFID tags. Then the reader searches for the tags which are either attached to objects or carried by the person. In the second method, the portable reader detects the static tags in certain positions while the RFID reader can be carried by individuals [10] [11].

In the healthcare domain, RFID technology has been adapted by caregivers to reduce the gap for health care progression and improve patients care. RFID systems have tremendous benefits in smart home healthcare particularly, 1) RFID tags are fairly small and easy to attach to objects (Drugs container, medical supplies, wheelchair, kittle cups, furniture, etc.) and 2) they are light and practical enough to be worn by individuals. Smart home healthcare can provide facilities and real-time tracking for elders and patients through the use of RFID. RFID chips can provide a highly accurate location of patients, and they also collect information for health care professionals. RFID technologies are potentially applicable for the indoor object and subject localisation and recognition of activity and user interaction with household objects. It works by categorising the information from RFID sensors to define the nature of daily life activities on a daily basis.

Smart homes health based monitoring system with RFID consists of several components that are combined in one context-aware system (see Figure 1). The architecture includes three main layers as shown in Figure 2.

3.5.1. Sensing Layer

This layer consists of RFID physical components which sense the movement and targeted objects (e.g. Medical equipment). Furthermore, it captures the data from the individuals and detects their health status for further processing. The layer collects the information from RFID devices in the test bed from either environmental (e.g. RFID sensors) or wearable sensors (e.g. RFID and accelerometer). RFID Static Environmental Sensors are commercially available with various

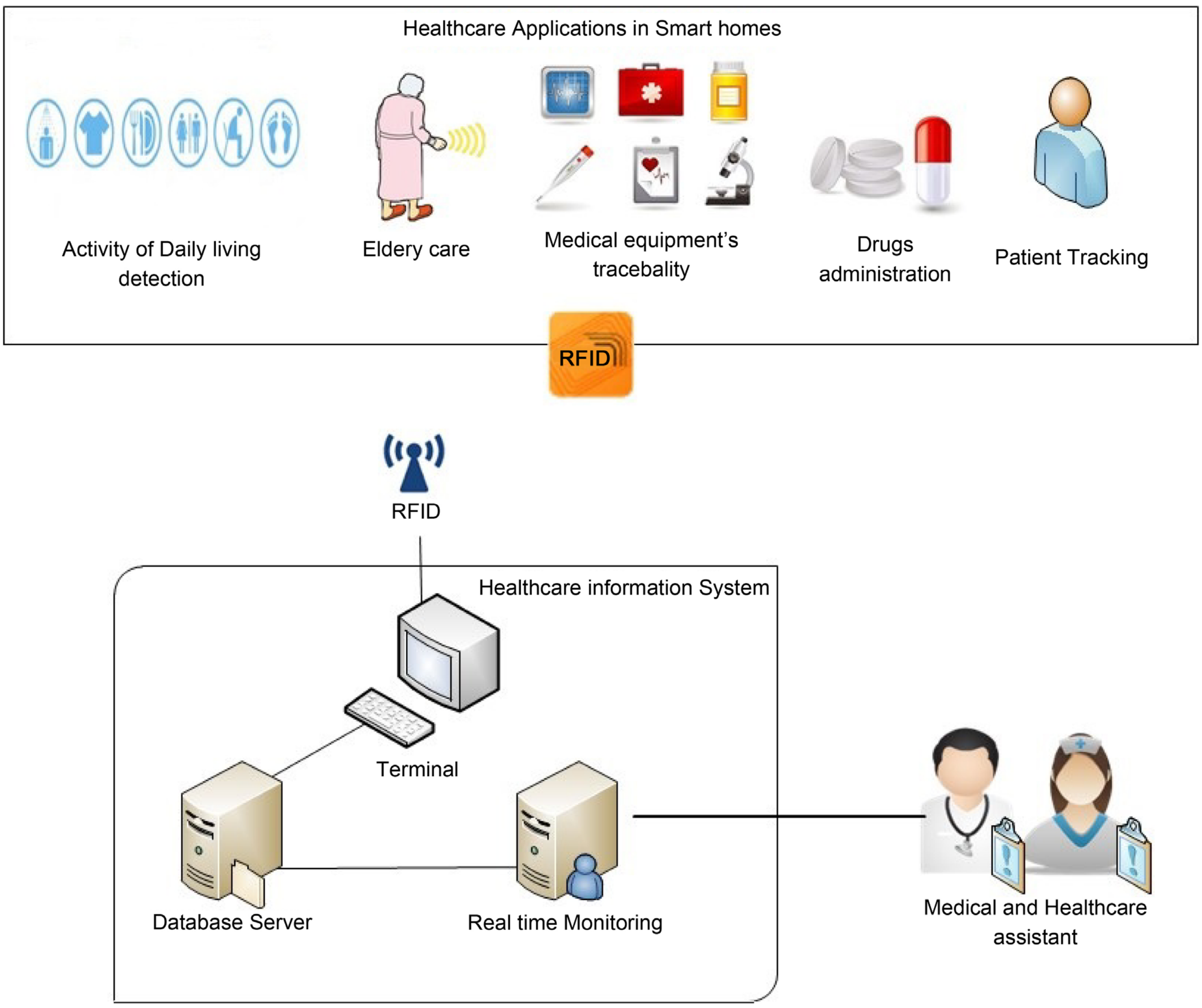

Figure 1. Components of RFID system in smart homes healthcare applications.

Figure 2. RFID-based perception of smart homes for health.

functionalities. RFID Wearable Sensors can be worn by the participants to measure a person's interactions with home objects and track body movement or to detect a fall, etc.

3.5.2. Middleware Layer

The raw data from the physical layer is now translated to the context using inference engines that describe the condition of the individuals. The classifiers filter and categorize the data to a particular context such as position and movement of the person [37]. Data reduction and data analysis are also processed in this layer. The software in this layer may combine multiple sensors to analyze a data stream intelligibly [38]. The inference engines are considered as a knowledge representation in the middleware layer as the main component of the RFID systems [39].

3.5.3. Service Layer

RFID Health information systems in the service layer store the information about an individual's health and physical condition (e.g. Health database server) which will be accessible by medical staff and caregivers in queries [39] throughout real time monitoring servers. The context-aware reasoning module assists the end users of their health care needs in various ways such as a notification or warning in case of risks. It also notifies the caregivers of the health of individuals through monitoring and assessment consoles [38]. These consoles help the health care researchers and practitioners to monitor the patients and to provide the patients' health status and medical information. The service layer allows the caregivers to interact remotely with the patients and assist them when dealing with abnormal health conditions.

Context-aware for healthcare has significantly enhanced the quality of healthcare services and facilitated services delivering in healthcare smart home. It is apparent in RFID-based solutions and researches which are improving the advancement in the field. Table 3 summarizes early contribution of RFID smart home projects in healthcare and wellbeing.

4. Activity in Daily Living in Smart Homes for Healthcare

The concept of Activity in Daily Living (ADL) refers to the things that we do in our daily life and daily self-care activities such as feeding, bathing, dressing, grooming, work, homemaking and leisure [40]. These activities define the ability to live in residential homes independently. ADLs are categorized into two main groups, basic ADLs (BADLs) and instrumental ADLs (IADLs). BADLs are the

Table 3. Comparison between various RFID-based solutions in healthcare.

Authors	Application	Purpose	Tracking method	Benefit
Bouchard *et al.* [5]	Activity of Daily Living	Human activity recognition	Passive RFID	Real-timelocalisation and activity detection
Neuhaeuser *et al.* [42]	Activity of Daily living	Object of daily living interaction	Passive RFID	Optimise ADL recognition Wearable RFID reader
Hoque *et al.* [43]	Movement recognition	Detect body direction while sleeping	WISP RFID/ accelerometers	Affordable and detect wider range of ADL
Zhou & Ranasinghe [44]	Patient tracking	monitor elders wandering off in nursing homes	Passive RFID	Use inexpensive tags
Qu, Simpson, & Stanfield [45]	Medical equipment tracking	Track Medical equipment in Hospital	Passive RFID	Increase the nursing staff productivity and increase equipment utilization
Parlak *et al.* [46]	Activity recognition	Human activity recognition in trauma resuscitation	Passive RFID	Recognizing high-level human activities during trauma resuscitation
Alsinglawi *et al.* [2]	Indoor localisation	Tracking in Smart homes Healthcare	Passive RFID	Tracking elderly for wellbeing

basic domestic and necessary human activities for individuals' daily routines including mobility, eating, drinking, sleeping, dressing, bathing and going to the bathroom, etc. IADLs are other tasks that are not crucial for life. However, IADLs comfort the elderly and impaired individuals such as housework, preparing food, medication, exercising, shopping, ironing, sweeping and telephoning.

The recognition of human activities in indoor environments is a difficult task to achieve [41]. ADL focuses on addressing the challenges and finding solutions for understanding human activity in smart environments. Ubiquitous environments like Smart homes have facilitated the daily activities detection, assisted participants with housekeeping tasks as well as helped the impaired individuals and elderly to live comfortably and independently. Various environmental sensors such as RFID, wearable sensors, and vital signs sensors have been deployed in SH solutions to collect data such as location, movement patterns and patient status. The data is then translated to descriptions of activities using models and algorithms within context-aware systems and computerized applications.

4.1. Sensors for Activity in Daily Living

There are three main groups of sensors for human activity recognition including wearable based, physical environment based and other sensors as following.

4.1.1. Physical Environment Based Sensors

Types of sensors such as RFID, Proximity, Pressure, Zigbee, and Wifi can be used to detect the interaction between the human and the environment around them [47]. Environmental variable based sensors use the raw data from sensed objects to assume the nature of activity undertaken by the individuals [47]. The distributed sensors detect the activity by entities and their interaction with objects. The data is collected by the ubiquitous sensors and is then sent to a local server for further processing.

4.1.2. Wearable Based Sensors

Wearable sensors such as inertial sensors, accelerometers, electromechanical switches, goniometers and pedometers gyroscopes are body-attached sensors and are considered one of the most common sensors for human activity recognition. They are used to recognise the motions of a human body and to support the human recognition movements as well as falls detection using wireless monitoring systems [48]. The devices are designed to continuously measure physiological data (vital signs of thehuman body) and biomechanical data. Analysing such data will help to identify human activities in daily living and translate them into a meaningful form using pattern recognition [49].

4.1.3. Other Activity Recognition Sensors

Camera based sensors, which are widely used for human activity recognition within a finite sensing coverage are those sensors which rely on the cameras recording and video sequences to recognise the human activity using computer vision algorithms [47]. Video sensors such RGB video [50], RGB-D video [51] and depth images sensors [52] are common types of visual sensors and broadly accepted in human activity recognition with good recognition rates. However, they are costly, have high energy consumption and also require frequent maintenance and are subjected to privacy related concerns.

4.2. Problems Related to Activity of Daily Living in Healthcare

4.2.1. Activity Misclassification

This problem happens when the method cannot distinguish the types of ADLs, *i.e.* BADLs or IADLs [53].

4.2.2. Specifics Activities

Some of the BADL activities such as making a sandwich and making toast are usually classified as the same. However, they are different activities and need to be identified differently in the discriminated model [54].

4.2.3. Ambiguous Activities

These occur when activities that are not predefined previously in the training model appear. These also happen when several sensors and objects are activated at the same time so that the system reports the same activity from different sensors. For example, most of the systems classify the sleeping activity as sleeping while we cannot justify whether a person is sleeping or reading a book or watching TV [55] [56].

Some of the current issues [53] [54] [55] related to ADLs in Smart homes are summarized in **Table 4**.

Table 4. Issues related to ADLs in smart homes.

Activity	Activity level	Nature of problems
Ironing	IADL	Misclassified between two different activities (e.g. confusion between ironing and dressing)
Dressing	BADL	Misclassified (e.g. confusion between ironing and dressing)
Washing Dishes	IADL	Misclassified (e.g. confusion between washing dishes and clothes)
Brushing teeth	BADL	Misclassified (e.g. confusion between brushing teeth and washing dishes)
Sleeping	BADL	Ambiguous with other activity (e.g. ambiguity between recognising sleeping from reading a book or lying in bed or watching TV)
Making sandwich/toast	BADL	Specific activity (e.g. most systems cannot distinguish between particular food activities such as making a sandwich from making toast)

4.3. Research Challenges in ADL

ADL detection is still a hard task to achieve in Smart homes in regards to the healthcare requirements. Many approaches have been introduced towards solving ADL recognition problems; however, there are still limitations. Table 5, summarizes some of current challenges [57] [58] of ADLs from the literature.

5. Conclusion and Future Outlook

In this paper, we reviewed the current state-of-the-art works in Smart homes in the healthcare domain. We discussed the most popular radio frequency technologies and projects in indoor positioning. Among those RFID systems employed in Smart home environments, we have compared them based on performance criteria such as Affordability, Reliability, and Robustness. There is a trade-off between these metrics. A solution of a more accurate system in terms of detecting and localizing people and their movement will typically increase the cost and complexity.

We also reviewed the challenges that are faced by Smart homes in the healthcare domain. The paper analyzed the activity of daily living and the importance of predicting the nature of the different activity that is performed by individuals for a better understanding of human activity recognition. The study indicated that there were limitations in RFID healthcare solutions in Smart homes and challenges facing ADL recognition in Smart home settings.

The advancement of indoor positioning with Radio Frequency sensing technologies and the development of human activities detection techniques in Smart homes have facilitated the way people live and complete their daily tasks. However, there are still several challenges which need to be addressed by researchers, particularly.

Table 5. Current research challenges in ADLs.

Challenge	Description
Accuracy and Robustness in Activity Recognition	Some human activities can be carried out by different humans at different times. The actions that are taking place rather than evaluate how correctly the activity was carried out as well as other qualitative information
High-Level and Long-Term Activity Monitoring	Monitoring high-level activity in large scale dataandreal-world scenario is still difficult to achieve, and it needs proper formalisation of the activities; Long term activities usually include several sub-activities that may perform in different order
Multi-User and Multi-Sensor Activity Monitoring	In the lab experiments, the data are usually collected by single user activity. However, in the in real life scenario activities can be performed by multiple users concurrently and there may have interaction between them; Multiple sensors still research challenge
Real World Data Collection	Most of experiments and ADL activities are carried out in laboratories where designs the solutions are based on lab settings. The activities that performed in the lab are also based on the lab environment
Behaviour Trend Profiling and Analysis from monitoring sensor	Long-term monitoring postures some of the challenges such as data labelling and that cause issue of profiling and analysis with data integration
Affective States Detection	How successfully we perform and identify affective states (e.g. happiness, sadness, anger.). Activities in monitoring human physiological parameters could contribute significantly to behaviour trend analysis
Distinguishing between Fall and ADL Events	Distinguishing between fall and the ADL events still poses challenges, though each event has distinct characteristic signatures in the sensor data

- Developing new algorithms to enhance the accuracy of tracking individuals and detecting human activities in real time.
- Using new cost-effective technologies (e.g. RFID) to allow real test scenarios in residential homes within clinical trials or healthcare.
- The deployment of large-scale tests with real objects enables different scenarios in real life settings for analyzing human behaviour over the long term.
- Authentication methods should be considered in the deployment of a smart home system with different levels and forms of security.
- Use of video cameras where the data collected might be misinterpreted or misused. Therefore, there is need for developing non-invasive solutions to address these challenges.

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