Aging Clinical and Experimental Research
https://doi.org/10.1007/s40520-020-01545-9

REVIEW

Internet of things (IoT) applications for elderly care: a reflective review

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Received: 14 November 2019 / Accepted: 30 March 2020
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Abstract
Increasing in elderly population put extra pressure on healthcare systems globally in terms of operational costs and resources. To minimize this pressure and provide efficient healthcare services, the application of the Internet of Things (IoT) and wearable technology could be promising. These technologies have the potential to improve the quality of life of the elderly population while reducing strain on healthcare systems and minimizing their operational cost. Although IoT and wearable applications for elderly healthcare purposes were reviewed previously, there is a further need to summarize their current applications in this fast-developing area. This paper provides a comprehensive overview of IoT and wearable technologies' applications including the types of data collected and the types of devices for elderly healthcare. This paper provides insights into existing areas of IoT/wearable applications while presenting new research opportunities in emerging areas of applications, such as robotic technology and integrated applications. The analysis in this paper could be useful to healthcare solution designers and developers in defining technology supported futuristic healthcare strategies to serve elderly people and increasing their quality of life.

Keywords Internet of things · IoT · Wearable electronic devices · Aged population · Geriatric health ·

Introduction

Due to improvements in medical sciences and technologies [1], the elderly world population is estimated to increase from 8.5% of the total population in 2015 to 12% and 16.7% in the years 2030 and 2050, respectively [2]. This group, generally, requires more medical resources in terms of medicine, nurses or physicians, especially if they want to maintain their independent lifestyle. Consequently, the increase in older population and their medical requirements have put the healthcare system under extra pressure in different ways such as increased medical expenses and greater occurrence of chronic diseases [3]. Human resource and financial constraints may limit healthcare services or their quality for older adults.

IT technologies could potentially transform healthcare; they may reduce strain on healthcare and its resources, allow providing better care and cost saving by taking routine care to home, thus reduce hospital expenditure [3, 4]. Examples of such technologies are Internet of Things (IoT) and wearable technologies that could offer promising solutions for elderly healthcare. These technologies have drawn substantial attention recently and could assist with several scenarios in elderly healthcare. They also have the potential to improve the quality of life for the elderly and allow them to maintain their independent lifestyle [5].

IoT is an broad term that embraces sensing devices and technologies such as sensors, RFID, GPS, infrared and wearable technologies. The concept of IoT is equipping everyday objects with sensing, networking, and processing capabilities to enable them to interact with each other and services on the Internet to accomplish some useful purposes [6]. IoT is a wide-ranging technology which represents 6Cs: convergence, communication, connectivity, computing, collections and content for the purpose of allowing people to connect with anyone or anything, anytime, anywhere, through any network and any services [7]. Elena-Lenz [8] also stated

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Published online: 10 April 2020

most important elements for a device to become the thing in IoT include properties such as Intelligence, Connectivity, Sensing, Expressing, Energy and Safety. IoT connects physical and virtual objects in a way that they can exchange and combine data to develop wide-ranging solutions for people and environment, enabling them to provide more efficient and effective services [1].

Wearable devices are a part of IoT systems which can be worn by the people for monitoring the physical activities and physiological data. These devices are embedded with sensors and analytic algorithms that enabled them to track, analyse and guide users' behaviour [9], vital signs or movement. The applications of IoT/wearable technology for elderly healthcare have been investigated by different researchers before. However, most studies were discrete focusing on a single area of application or one type of IoT/wearable device. Therefore, there is a lack of a comprehensive picture of their usage and applications for elderly healthcare.

The objective of this paper is to aggregate the previous studies in this field to create a comprehensive picture of the current or potential applications of IoT/wearable technology for elderly/geriatric healthcare. The outcome of this research could be useful for researchers to further work on IoT applications. The healthcare planners can use these ideas to consider using effective systems to reduce healthcare austerity, promote service delivery to the elderly and increase their quality of life.

In this article, the research background and motivation are discussed in section two and then followed by the research methodology in section three. The research findings and limitations are discussed in sections four and five, respectively. Finally, the article is concluded in section six.

Research background and motivation

IoT has tremendous potential to revolutionise healthcare systems and meet customer demand. IoT can transform healthcare and make it more efficient, effective and smarter. Thus, IoT applications can support healthcare services and ultimately expand their usage to a wider population. In particular, IoT and its sub-technologies such as wearable technology are promising for remote monitoring including elderly needs to support their independent lifestyle at home [10].

The motivation for performing this reflective review is based primarily on the demographics of older populations. This sector of society is increasing in size and becoming a common healthcare challenge. In most countries, the older adults' population is growing and it is becoming a common healthcare challenge. In an international scope, there is a substantial shift in demographics towards increase in ageing population. It is expected that between 2015 and 2050 the number of the aged population (over 60) will double and reach 22 percent of the total world population [11]. In New Zealand, by 2035, the percentage of adults over 65 years will be almost one-fourth of the overall population [12]. This older population will require health support due to geriatric health conditions or syndromes, such as hearing loss or cataracts, or due to chronic diseases, such as diabetes and dementia. In the meantime, it is forecasted that within the next 10–15 years, more people will suffer from non-communicable diseases [13]. In this respect, in the US, around 80% of the population over 65 would have at least one chronic condition [14]. Lastly, due to the healthcare requirements of the older populations, governments healthcare expenditure is rising significantly. In New Zealand, people over 65 (15% of the population) use 42% of the health services [12]. The Centres for Medicare and Medicaids Services reported that US Medicare expenses grew from 3.5% in 2013 to 4.2% in 2017 reaching to US$705.9 billion [15].

Considering the above motivation and the potential features of IoT, it is believed that IoT could provide effective solutions for elderly. With the IoT based remote monitoring features, it could reduce healthcare and costs by avoiding hospital admission, provide healthcare services for remote patients in remote areas, and help people to maintain their independent lifestyle, while their healthcare status is being monitored.

For elderly healthcare, IoT could cover a wide range of applications. However, current applications and studies of IoT in healthcare, especially for geriatric care, are aimed at limited areas and cases [3]. Many studies focused mainly on technological aspects, lacking user-focused applications. For example, Ann and Theng [16] reviewed human activity recognition based on the type of devices used and deliberated on the advantages and disadvantages of devices. Nguyen et al. [3] reviewed IoT applications in elderly healthcare based on Chronic Patients Healthcare Monitoring, Aged Care Monitoring, and Emergency Applications. Ahmadi et al. [17] have analyzed the applications of IoT in healthcare based on IoT architecture.

This paper is aims to conduct a comprehensive umbrella overview of the IoT applications and identify current or any emerging areas of IoT application in elderly healthcare.

Research methodology

The research design used to address the research objective was an umbrella review method on published articles in the field of IoT/wearable technology and their applications in elderly healthcare. This method was considered suitable for this research as umbrella review is suggested by [18] when the intention of the research is aggregating findings from multiple reviews with the aim of integrating all the past results into one accessible and usable report. This method

is suitable when the research area has a fragmented overall picture and integration and providing a general picture is required.

In this method, the relevant data from the selected scientific databases were gathered using a combined coding method. This method was used to create comprehensive background knowledge of the field and the possible process of creating a new perspective.

The phases of the method are discussed in the following sub-sections.

Data collection

A literature search was conducted in PubMed, IEEE, SpringerLink and Scopus databases. The search was limited to the review studies only; the aim was getting more comprehensive background information of the field. The search queries includes all possible combinations of the following keywords searching terms in all the databases: "Internet of Things" OR "IoT" OR "Wearable" OR "Sensor" AND "Elderly" OR "Older Adult" OR "aging population" AND "Review".

In the initial stage, 184 articles were collected from all the databases and inserted into a dataset created in Endnote software. Within the initial screening of the articles' titles, six duplicate articles were identified and removed. Then, after skimming the abstracts and based on the exclusion criteria (Table 1), a further 27 papers were excluded. The breakdown of these exclusion criteria is presented in Fig. 1.

From 151 articles, 79 of which were excluded after skimming the full-text and based on the defined exclusion criteria. Finally, 54 articles met the inclusion criteria and have been considered for full review and analysis. The overall procedure of the study selection process and its details are shown in Fig. 1.

Pilot test

From the data set of 54 articles, 10 articles were selected randomly to start a pilot test. Thematic analysis was used to identify the current areas of IoT applications in elderly healthcare. The articles were read in detail to identify application areas, monitored data types and types of IoT/wearable used in elderly healthcare. Within this pilot test, seven main areas of IoT and wearable technology applications and some sub-areas were identified. These areas help us to lead the research in the data analysis phase. This pilot test conducted in NVivo, qualitative data analysis software. Besides the application's areas, two categories have defined: monitored data types and IoT/wearable device types.

Table 1 Exclusion criteria

	Exclusion criteria
1	Articles which are not in English
2	Studies with a purely technological focus
3	Studies with a medical focus only
4	Articles with policy and standards perspective
5	Pure computer focus—networking, protocols, types and designs studies
6	Smart home studies with no discussion on healthcare
7	Articles with low emphasis on elderly people

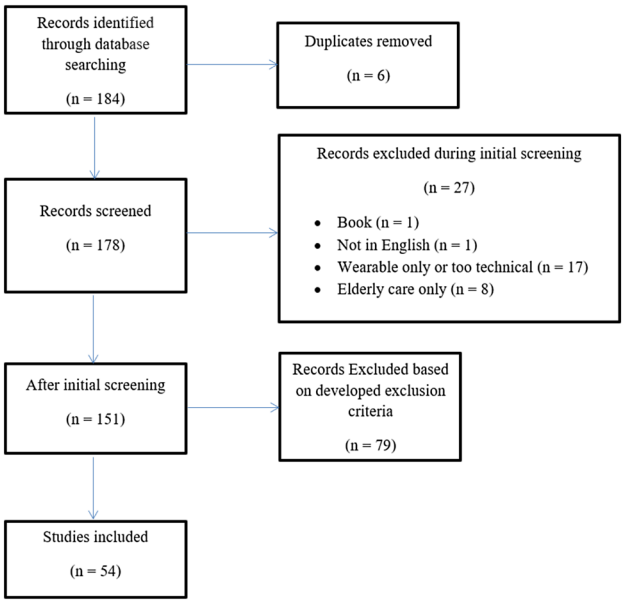

Fig. 1 Study process

Coding and data analysis

This stage extracted information from raw data and grouped relevant information into the pre-defined categories. In this stage, a number of new categories emerged. In this process, a combined method of deductive and inductive coding was followed. The deductive method is the use of pre-developed categories as a guide for the coding process, while inductive coding is exploratory research without having pre-defined categories [19]

At the start, seven main areas of IoT/wearable devices application in elderly healthcare were identified in the pilot test and were used as a pre-developed codebook for deductive coding. As the coding process proceeds, the new areas of applications were found and added as new codes, i.e., process of inductive coding. The combined coding method helped the researcher at the early coding stage with a deductive coding method and to explore the emerging codes in a later stage with inductive coding method. This coding process and data analysis were conducted using NVivo.

Data interpretation

The applications of IoT for elderly care were categorized and defined based on the coded data. The main findings of the analysis, the current and the emerging areas for IoT application in elderly healthcare, were aggregated, defined and built into a hierarchical framework represented in Fig. 2.

Findings and discussion

The main research findings can be classified into three categories of IoT/wearable technologies' applications in elderly healthcare, types of monitoring data and types of IoT/wearable devices in elderly healthcare. These categories are discussed in the following sub-sections.

Areas of IoT/wearable technology applications in elderly healthcare

From the analysis, among all IoT applications, remote monitoring is one of the most promising applications, especially for the older people who require constant attention and seek independent living, while they are required to have continuous health monitoring. In this regard, *q* relatively high number of the IoT/wearable technology applications for elderly healthcare were focused on monitoring and supporting elderly people to have a safe and independent lifestyle.

On the other hand, there are a number of IoT applications that attracted less attention, while they also have the potential to be useful for elderly wellbeing. For example, prevention of pressure ulcers has an important implication for elderly patients suffering from chronic diseases. 50% of critically ill patients and more than 70% of elderly patients in USA were found to be suffering from a pressure ulcer, which may lead to severe septicemia and death [20].

Some IoT devices were also underrated and paid less attention but they have the potential to help elderly people and bring significant changes to their lives. For instance, implantable bladder sensors could measure bladder urine volume and pressure with no risk of infection caused by traditional methods such as catheters [21]. This technology can be applied to help stroke patients suffering from urinary incontinence to save them from the inconvenience of catheter insertion and improve their quality of life.

In overall, 11 areas were identified, where IoT/wearable devices can be used to monitor and support elderly people. The complete hierarchy of areas of application is shown in Fig. 2. Moreover, an overview of the areas, their definitions and several examples for their applications are presented in Table 2.

Aged care monitoring

Aged care monitoring is the area where IoT devices and systems were used to monitor health status and general well-being of elderly people. Example applications include ambient assisted living, active ageing, therapy and entertainments, communication and social activities, monitoring health status, diet and body weight. The main objectives of this group of applications are group monitoring, improving quality of life, promote living safely and independently.

Aged care monitoring is the most popular application area and promoting safe and independent living for elderly people. It is the most popular example among aged care monitoring methods. Brownsell, Hawley [33] mentioned that elderly people preferred to stay at home, and were prepared to accept technology if it would help them to live independently [10]. In this category, one popular application is Ambient Assisted Living (AAL) which is a concept of monitoring and providing assistance for elderly people to live independently and comfortably. AAL systems monitor elderly's daily activities and detects abnormal conditions and emergency situations and helps the elderly's daily life. By doing so, AAL can improve the quality of life of elderly people as well as the caregiver.

Chronic patient healthcare monitoring

This area includes the IoT applications for monitoring and supporting elderly people with chronic diseases, such as diabetes mellitus and heart disease. These applications can be applied in the development of home based-health monitoring systems, for elderly patients with chronic diseases, disabilities that want to maintain their independent lifestyle [3]. This could be a great solution for elderly villages or houses as it could support simultaneous monitoring of several people.

Kalid et al. [34] stated that the use of remote monitoring not only can reduce the mortality rate and hospital admission and readmission rate but also is effective in treating chronic diseases. An example is a mobile application named MAHI can collect blood glucose data from Bluetooth glucometer and share the information on a website to get advice from caregivers [32].

Furthermore, if mental health problems in the elderly become chronic, such as depression and anxiety, they could be noticed by measuring slight differences in activities in long-term data [1].

Human activity recognition

Human Activity Recognition (HAR) and monitoring in elderly's daily living is another important function. By monitoring elderly people's activities continuously, the system can detect abnormal conditions and can reduce the effects

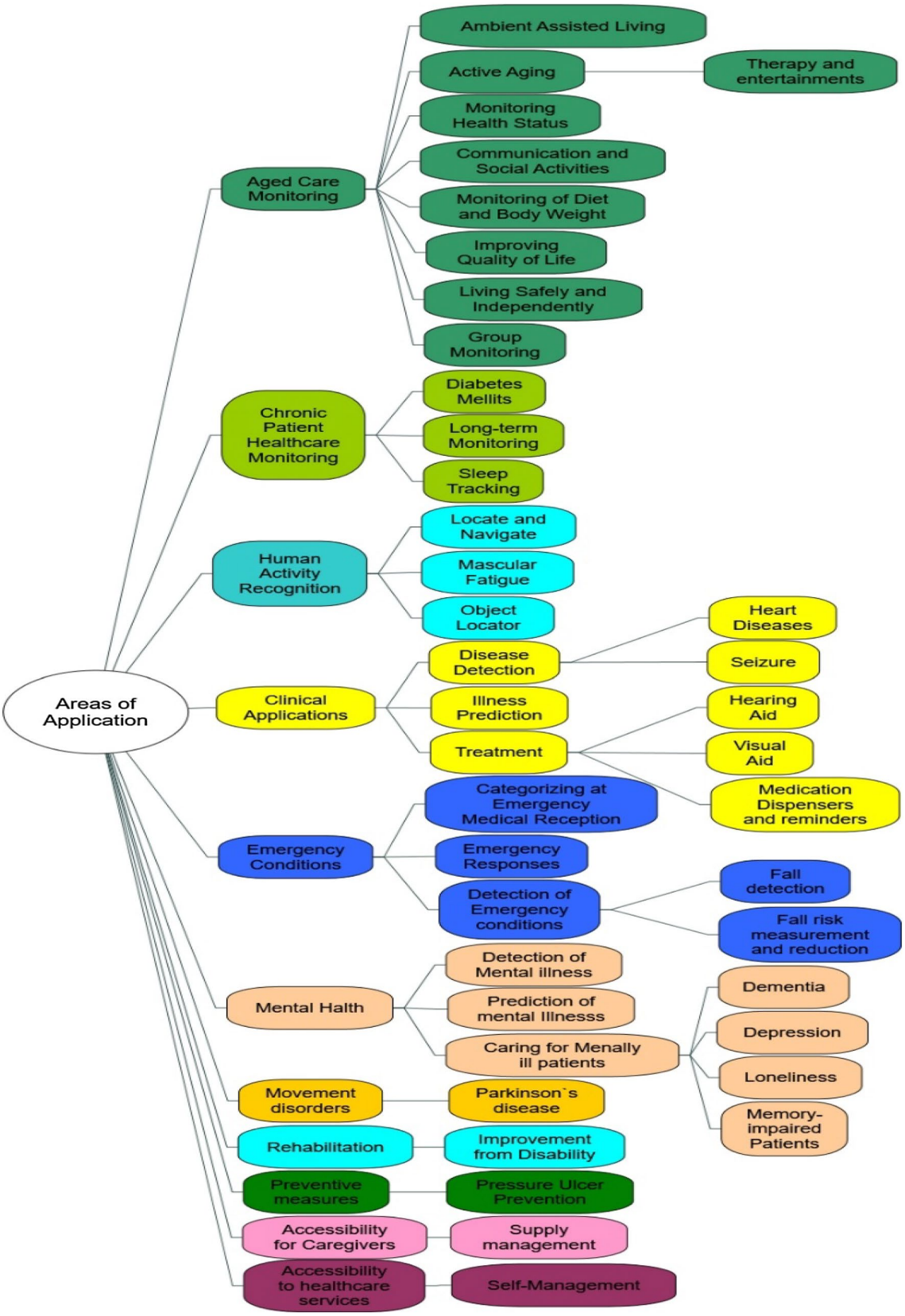

Fig. 2 Areas of IoT/wearable applications for elderly healthcare

Table 2 IoT areas of applications for elderly healthcare

No.	Application area	Definition	Examples of application	Data types
1	Aged care monitoring	Monitoring health status and general wellbeing of elderly people	Ambient assisted living [22] Monitoring health status [23] Communication [24]	Activity Movement Social engagement
2	Chronic patient healthcare monitoring	Monitoring the elderly with chronic diseases	Telehealth systems can be used for monitoring of chronic elderly patients [25]	Vital Signs ECG Blood Glucose
3	Human Activity Recognition (HAR)	Activity detection, classification and pattern recognition [26]	HAR is can be integrated into smart homes for monitoring the daily activities of older adults [16]	Activity Movement
4	Clinical Applications	The application of IoT in clinical settings such as disease detection, prediction and treatment	Reminding the elderly with chronic diseases to take the correct medication at the right time is shown to be very effective for elderly people [27]	Vital signs Movement Activity Nutrition Medication
5	Emergency conditions	Use of technology to predict, detect and respond to emergency situations faced by elderly people	Smart home support elderly people with various form of emergency services such as fall prevention and alerts [24]	Fall detection Activity
6	Mental Health	Use of IoT/wearable technology for prediction, detection and caring mental health conditions of elderly people	A simple panic button can provide mentally assurance for elderly and family members regarding emergency situations [28]	Stress Behavior Activity Emergency conditions
7	Movement disorders	Monitoring and detection of abnormal movements of elderly people	With the use of wearable sensors which have high ability to detect gait changes can even have better accuracy than human [29]	Gait Movement Fall detection
8	Rehabilitation	Wearable sensors used for different types of rehabilitation-related processes	Tele-rehabilitation can support elderly people to live independently at home and reduce the chance of re-hospitalizations [30]	Video and audio streaming
9	Preventive measures	Use of IoT in providing preventions to elderly people from harmful conditions	Pal et al. [5] proposed the use of IoT in designing fall prevention systems for elderly	Fall detection Activity Social activities
10	Accessibility to healthcare services	Technology makes healthcare services available for elderly people from everywhere even in remote areas	Telecare [31]	Video streaming
11	Accessibility for caregiver	Transmitting the collected data to the server and make available for healthcare personals	Planning of elderly healthcare with the help of the information [32]	Vital signs Fall detection body weight mobility

of unpredictable events such as sudden falls [35]. HAR can also detect the location of the elderly and provide navigation assistance to prevent straying. Object locator can help the elderly to find their household and personal items easily [24].

Clinical applications

Clinical applications of IoT in elderly healthcare include disease detection and diagnostics, illness prediction, and treatment. Technology can provide a more precise diagnosis and effective management of many diseases [23]. For instance system can detect seizure and warn the elderly, and send alerts to caregivers [32]. Telehealth and its sub-categories such as tele-consultation and tele-diagnosis, provide specialist consultation to elderly patients who cannot come to the medical centers, through communication devices [27].

Emergency conditions

The application of IoT in emergency conditions includes fall detection, fall risk management, emergency responses, and categorising the patients at emergency medical reception based on the conditions' severity. One of the emerging and popular applications in this category is fall detection. This application recently gains a huge interest globally, since falls can cause severe medical problems for elderly people [3] and its prevention could potentially prevent some other problems in elderly care.

To address this issue, different types of research have been carried out to develop a fall detection system and sending the information to the emergency response center. Some researches tried to predict fall by calculating the risk of fall and some have tried to reduce the risk. A system composed of all four elements of fall risk prediction and reduction, fall detection and emergency response when falls occur could be developed to provide assurance to elderly people.

Moreover, communication is an essential part of aged care monitoring and emergency applications. Most of the elderly people need to be in contact with their family members and caregivers. This is also useful in emergency conditions when a patient needs to get swift support.

Mental health

IoT technology is used for detection, prediction, and caring for the mental illnesses of elderly patients. Azimi et al. [1] mentioned that many types of mental health problems might be detected or even predicted by observing variations in daily activities in long-term monitoring.

Dementia is a popular area in this application group. In these applications, technology is being applied to support patients with dementia or other mental health issues. For example, a smart robot is very helpful as a friend for elderly people with dementia by reducing stress, promoting a positive mood, and reducing loneliness [5]. This helps them to have a more active social life.

Movement disorders

Wearable sensors can provide continuous gait analysis for elderly patients not only in the health centre but also in their home [29]. The data gathered from this kind of technology can be used to detect movement disorders in elderly people and provide early assistant. Wearable sensors based gait analysis technology can also be useful for balance and gait training in elderly people. Patients with Parkinson's disease face gait problems and these problems can be addressed by wearable technology.

Rehabilitation

Many aspects of rehabilitation services, such as giving feedback to elderly patients and caregivers, or assessing the effectiveness of the rehabilitation process [36], or assisting disabled patients can be facilitated by the use of wearable devices. Sharma et al. [37] mentioned that older adults and patients suffered from a stroke can benefit from autonomous hip joint exoskeletons, which can help people during the rehabilitation process.

Preventive measures

IoT can monitor and prevent certain harmful conditions from happening. For example, the risk of developing pressure ulcers is high in elderly patients with chronic disease, and they can lead to chronic infection and may die from septicemia [20]. This kind of problem can be addressed by the use of pressure sensors to know the pressure points of the elderly patients based on various positions and prevent the development of pressure ulcers. In addition, the data of pressure distribution can be used in designing mattresses and wheelchairs for elderly people with chronic diseases [38].

Accessibility to healthcare services

Mobile health technologies can be used to provide faster healthcare services at ease to elderly patients living in hard to reach areas [31]. Moreover, elderly people can learn a lot of health information and promotion services [39], enabling themselves for self-management of some illness conditions. The use of pedometer-driven walking intervention from a self-management course, in patients with osteoarthritis of the knee, was proven to be more effective than health education alone [40].

Accessibility for caregivers

Wearable technology together with the smartphone allows the healthcare providers to remotely provide monitoring and treatment to elderly patients in real-time [32]. Physicians can get access to health data of elderly people and provide feedback through the web browser. The smartphone can also be configured to detect emergency situations such as falls, abnormal heart rate, and send alerts to the caregiver as well as the medical centre [32].

Types of data collected

Data collection is one of the main functions of IoT devices and collected data can be used for different purposes, depends on the applications and objectives. Based on this study's results, the identified IoT/wearable applications are normally gathering five types of data: Biomechanical and physiological data, mobility measurement, cholesterol, electrocardiogram (ECG), and Vital signs (discussed in Table 3).

Regarding the type of data, mobility measurement seems to be the most commonly used data type. As Celler et al. [41] noted, mobility is the most profound parameter to detect variations in health, and with the availability of technology and sensors nowadays, measuring mobility can detect not only the health status but also emergency conditions such as falls.

Types of IoT devices used in elderly healthcare

Many forms of IoT/wearable devices can be used to address the needs of elderly healthcare. This research study identified 10 devices' types which were used in many aspects of elderly healthcare (Table 4). Smart Home system is the most popular. Based on the needs to monitor and support elderly people at home to have a safe and independent life and the type of data needed to gather, smart home technology is a perfect fit as the solution.

Telehealth technologies such as telemedicine, telecare, and telemonitoring were also being used widely for providing effective and efficient healthcare services to elderly people living in a remote area. Albahri et al. [43] mentioned that telemonitoring is effective in chronic disease management of elderly patients as well as efficient lowering mortality rates and hospitalization. Elderly who wants to live independently and safely at home can be empowered by telecare system [3].

Robotic technologies

Robotic technology would be the most automated way to manage elderly healthcare. It would be a mix of multiple technologies executed to support a robotic function. It could be used for different purposes such as (1) assisting the elderly; (2) providing reminders and instructions for daily life and safety; (3) monitoring the wellbeing and activities of elderly; (4) providing companionship, entertainment and social support [44]. Bogue [45] has also mentioned three types of robots which could be useful in elderly care: (1) the robotic wheelchairs and exoskeletons, (2) companion robots, (3) assistive robots and household robots. In general, robots are expected to be helpful in performing physical tasks which the elderly patients cannot do by themselves. Some functions such as monitoring the wellbeing and activities of elderly and providing companionship can be done by other technologies (e.g., Smart phones and Internet of Things).

Telepresence robotic technology is the use of technologies to create a sense of physical presence at a remote location, allowing care givers to interact and present with the elderly people virtually from a robot body [46–48]. Koceski and Koceska [46] provided the description of the robot and

Table 3 Types of data collected

No.	Data types	Definition	Examples of application
1	Biomechanical and Physiological data	Biomechanical data is the data of external body movement and activities Physiological data is the data of physiology of body such as heart rate, and temperature	Data collected can be used to gain insights on the elderly's health status [4]
2	Mobility measurement	Measuring and recording movement and activities of elderly people	Mobility data can provide an overall status of elderly health and can be used to predict and detect illnesses at an early stage [4]
3	Cholesterol	Measurement of blood cholesterol level	Monitoring of cholesterol in elderly with many chronic diseases such as diabetes and heart diseases [26]
4	ECG	Recording and detecting abnormal ECG signals	ECG of elderly with heart disease can be monitor continuously using a wearable device and detect emergency conditions like heart attack [32]
5	Vital signs	Vital signs include blood pressure, pulse rate, respiratory rate and temperature [42]	Early detection of illness and reduce re-hospitalization can be achieved by constant observing of vital signs of elderly people [3]

Table 4 Types of IoT used

No.	Device type	Definition	Examples of application	Data types
1	Smart home	"Health smart homes provide a complete picture of a subject's health status, by monitoring the subject's mobility and their interactions with their environment" [4]	Monitoring people in the house and surrounding for the safety of elderly residents and automatic performance of certain jobs which the elderly cannot do by themselves [24]	Activity Movement Fall detection
2	Smart clothing	Sensors embedded in clothes to gather biomechanical and physiological data of the subject	Smart clothing enables to get precise positioning, tracking physical activity, and monitoring vital signs in real-time setting [35]	Biomechanical Physiological
3	Tele-care	Monitoring and providing assistance to the elderly in the home environment using telecommunication technologies and IoT	Tele-care applications enable the elderly to stay safely and independently in their homes [3]	Video and audio streaming ECG Vital signs
4	Tele-monitoring	Monitoring of elderly people with chronic diseases for long-term	Tele-monitoring allows older adults to stay independently in their home and is a time-efficient method for caregivers [4]	Vital signs
5	Telemedicine	Monitoring and treatment of elderly diseases using IoT and telecommunication technologies	Telemedicine provides continuous care approach in chronic disease management [43]	Vital Signs ECG Blood Glucose
6	Virtual assistive companion	Supporting elderly people with virtual assistive technology	Augmented-reality app in iPhone can support elderly people by interacting with the environment [32]	Image and video streaming
7	Wearable ECG	Continuous monitoring ECG of elderly people	In a system, ECG signals are analyzed by a mobile phone, and if there is an abnormality, ECG is sent to the health centre for secondary analysis [32]	ECG
8	Implantable Bladder Sensor	The sensor is implanted in the bladder to measure urine volume and pressure	Implantable bladder sensor could reduce the risks of infection relative to catheters [21]	Urine volume Pressure in bladder
9	Internet of Things	IoT used for various aspects of elderly healthcare	IoT-based remote monitoring systems can address the needs of older adults [1]	Weight Diet Activity
10	Robotic	The use of robotic technology in elderly healthcare	Robots can be used to meet the requirements of elderly people such as staying active or getting social life [27]	

human–robot interaction: autonomy and human control authority, which are important to consider in developing the robot. The authors have also studied the acceptance of robot assistive telepresence by the caregivers and the elderly patients using four experiments. The experiments include allowing both elderly patients and caregivers to drive the robot, and to perform functions such as electrocardiograph (ECG) measurement, video conference session, taking up and carry small objects. The robot can also remind the elderly to take medication at the right time. With proper training and assistance, all the participants successfully preformed the given tasks, and the analysis of the robot acceptance questionnaires shows that the users accepted the telepresence robotic technology.

Another popular application of robotic technology in elderly healthcare is robot therapy, where robots are used as substitutes for pets in animal-assisted therapy for providing psychological support to elderly patients. Older adults can get depression easily due to many factors such as loss of family, friends and ability to perform physically and mentally [49]. The robots designed for the purpose of mental support cannot provide physical services but can offer pleasure, relaxation, and companionships. According to Shibata and Wada [49], the use of robot therapy in dementia patients has resulted in positive effects.

Tanabe et al. [50] propose a smart home environment model created by integrating different types of robots for elderly care. The Robotic Smart Home (RSH) project includes mobility and a transfer assist system, operational assist system, and information assist system integrated together to develop a comfortable and safe home environment. The rehabilitation robots are also known as activity assist robots (AARs) primarily includes four categories: independent assist, exercise assist, care assist, and cognition/emotion assist. With the integrated system, the RSH has addressed independent assist, care assist and cognition/emotion assist for elderly patients.

The robotic technologies were expected to be very helpful for disabled patients and elderly patients, and the development of technologies has allowed the robots to become smarter. However, current robotic technologies are still immature for elderly healthcare in terms of usefulness and cost-effectiveness compared to Internet of Things and Smart phone technologies.

Integrated approaches

The integration of technologies is a must to provide effective solutions for the health scenario. Camarinha-Matos et al. [51] proposed a theoretical architecture of an ambient assisted living ecosystem for integrated care of elderly people using technology (AAL4ALL). The architecture is organised into three layers: (1) Support Infrastructure Layer, (2) Services Layer, and (3) AAL Ecosystem Layer. AAL4ALL included both formal and informal care networks regarding elderly care allowing all stakeholders to co-exist within the AAL4ALL ecosystem.

The integrated elderly healthcare services can be achieved by the use of ICT with lower costs on public healthcare systems. Miori and Russo [52] created a Social Internet of Things (SIoT) for improving the quality of life of elderly people. The name of IoT framework is SmartSMILE (Socialize MIddLeware for the Elderly) which is the core module of Elderly monitor service. The SmartSMILE is designed for two aims: (1) to collect and gather data from elderly people through wearable sensors and sensors put in the elderly's environments and sent to health service providers for analysis and monitoring, (2) to ensure the safety of elderly in working and living environments by guaranteeing them that the system will automatically alert the operator, care providers or family members in case of emergencies. The advantage of the SmartSMILE is that it has been designed to allow easy integration or removing of new services and devices in the IoT framework.

Talpur et al. [53] designed and implemented an elderly monitoring system using Zigbee network. The system works in three tiers. Tier-1 collects ECG, blood pressure and body temperature from the elderly people through Body Sensor Network (BSN), and patients' smartphone to store and send the health data to the database servers. Tier-2 consists of Medical information servers, where all the health information is stored. Health information platform (HIP) is also embedded in the Tier-2 databases servers for storing the health information in the form of Electronic health records (EHRs). The role of HIP and EHR is to analyze the personal patient data and identify critical warning results for the doctors to act quickly in case of emergency situation. Tier-3 includes monitoring authorities: Doctors, Family members, and Operators. The authors have claimed that the ZigBee-based elderly care system can guarantee the integrated elderly care and comprehensive remote health information management, even though they have included only three types of sensors for gathering patient vital information.

Rodrigues et al. [54] reviewed technologies and systems based on IoT for healthcare from the most recent publications and products. They have discussed about remote healthcare monitoring system architecture which includes integration of a number of sensors attached to patient's body (e.g., ECG, Breathing airflow sensor, Electromyography (EMG), Position sensor, Galvanic Skin Response (GSR) skin sensor, Pulse, oxygen and blood sensors, blood pressure sensors and body temperature sensors). They also mentioned the importance of smartphone in collecting, storing and exchanging medical data as well as healthcare information from the providers. The authors have reviewed many different AAL systems, and wearable smart devices which can be

used for healthcare of elderly people. They have concluded that there are many IoT services and applications available for using in healthcare services but are developing in isolated manner.

Marcos-Pablos and García-Peñalvo [55] have done a systematic literature review on technological ecosystems in care and assistance domain. The findings revealed that most of the systems have not been implemented in real world and were not developed specifically from platform architecture of care and services. More over the systems failed to take account of medical standards. The authors concluded much work needs to be done to allow technology implementation in elderly care to be usable.

In summary, these results show that the applications of IoT/wearable technology were increasingly being used in elderly healthcare and expected to grow. Attention must be given to all areas of applications to have comprehensive healthcare for elderly people. Together these findings provide important insights into current trends of research in IoT applications to elderly healthcare and potential future areas of research which can have an enormous impact on elderly healthcare and quality of life of elderly people.

Conclusion and future research

The purpose of this research is to present potential IoT/wearable technology applications in elderly healthcare. This study has identified 11 main areas of IoT applications in elderly healthcare as well as types of data collected and types of IoT devices used. One of the most significant findings to emerge from this study is the hierarchy for areas of such applications. The findings of this research provide many emerging areas of applications compared to other literature [1, 3]. Moreover, the results of this research give better insights to existing areas of applications as well as opens new research opportunities in emerging areas such as robotic technology. The next step in this research could be to include more data about emerging areas by updating keywords and address the weakness of the coding method and build up NVivo skill to gain a deeper understanding and more comprehensive results.

During analysis, the researcher has noticed that all of the articles were discussing IoT/wearable application from a technology point of view. Very little collaboration of people from the clinical site was found. Future research should focus on the uses of IoT/wearable technology from a clinical point of view. In addition, cost-effectiveness and usability of IoT technology also need to be investigated to have meaningful use.

Funding None.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author declares that they have no conflict of interest.

Ethical approval This article is a review work and does not contain any studies with human participants.

Statement of human and animal rights This article does not contain any studies with human participants performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

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