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A Survey on the Internet of Things Solutions for the Elderly and Disabled: Applications, Prospects, and Challenges

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Abstract – Advances in technology has not only led to the start of innovative solutions and new business opportunities in different sectors but also reduced manpower needs and operational costs. Furthermore, the quality of provided services has been improved. Therefore, recently, the Internet of Things (IoT) has gained a great momentum as a key enabling technology for a wide range of health care applications, especially for the elderly and disabled. Although, solutions based on IoT technology have started to support the elderly and disabled in many areas of their life and work and the IoT helps improve quality of life for the elderly and disabled, the amount of data collected by the IoT has increased tremendously and surpassed the expectations. This makes it necessary to investigate approaches and solutions in order to efficiently utilise large amounts of data, especially in health care applications. In this paper, we are first going to review existing approaches and IoT solutions specifically proposed and designed for the elderly and disabled. Then, we are going to investigate prospects and research challenges in the use of the IoT in the services designed for elderly people and people with disabilities to provide an insight into future research opportunities.

Index Terms – The Internet of Things, Elderly people, People with disabilities, Research challenges, Future research directions.

1. INTRODUCTION

The Internet of Things (IoT) can be described as the network of things embedded with electronics, sensors, network connectivity, and software. IoT creates opportunities for better and seamless integration between computer-based systems and the physical world. When augmented with sensors and actuators, it becomes an instance of the more general class of cyber-physical systems since each thing is uniquely identifiable and can interoperate within the existing network infrastructure. Since the IoT results in improved efficiency, accuracy and economic benefits, it is estimated that the IoT will consist of billions of objects in a few years. IoT solutions enable to collect all kinds of information from a few bytes to several megabytes depending on the application requirements. Different from the traditional telemetry applications, at the moment, timely data can be provided by IoT services to the users.

Life expectancy all around the world is becoming higher. In some high-income countries, most elderly care is funded by government grants and property taxes and care costs paid by elderly people themselves are subsidized and based on specific rates [1]. Some municipalities have been opting to privatise some parts or all of their elderly care services and allowing private care providers to operate with specific business models. Although the municipalities always have overall responsibility for funding home help or allocating a place in a specific housing facility, the recipient of such services can choose either home help or special housing to be provided by public or private operators. Considering the cost of services provided by the municipalities, home help provides many benefits in terms of both cost and manpower [1, 2]. To this end, one of the main goals of home care services is to help people with disabilities

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and elderly people live independent lives by providing various forms of support to make their lives easier so that they can continue to live in their own homes as long as possible [3]. In this respect, IoT is as a revolutionary way to provide independent living opportunities to and help improve their quality of life. IoT solutions can potentially offer a number of independent living opportunities such as controlling front doors and lights and this way, quality of life for clients and peace of mind for caregivers can be provided. Since some of the elderly and disabled rely entirely on their family members for their assisted care needs, their family caregivers may have high emotional stress. Therefore, scalable and viable solutions to meet this demand are needed.

Considering the increasingly elderly population and large numbers of disabled, the cost of care can be significantly reduced by using mobile technology and wireless integration [4, 5]. For instance, wireless home automation solutions focus on enabling the elderly and people with disabilities to live at their homes instead of a health care facility. Equipped with Bluetooth sensors that can be placed on different items such as doors, key chains and pillboxes, such solutions enable to track movements or lack of elderly people. If preferred, Global Positioning System (GPS) technology can precisely document location information of the monitored person, log activity, and report it to his/her family members. This is especially important for elderly or disabled people who do not prefer leaving their homes even if they do not live in an urban area and do not have easy and quick access to health care services or family members. If they are not monitored, cognitive and physical decline can happen. In addition to such home solutions designed to provide independent living for the elderly and disabled, there are some IoT solutions designed for health care industry. For instance, by installing eye control units in hospitals, patients with limited motor function can be enabled to have more control over their hospital environment via access to nurse request functions, light, temperature, TV. Taking longer life spans combined with the retirement of the baby boomers and their children into consideration, while the elderly can greatly benefit from ease of care, the governments can benefit in a reduction of cost for taking care of their elderly and disabled citizens [6].

As it is well known, compared to other age groups elderly people are more prone to most health problems. The adverse effects of unforeseeable events such as sudden illnesses and falls can be prevented or alleviated to some extent with real-time monitoring and alarm systems [7]. Moreover, most of those systems also allow their users to communicate their urgent needs to the health care provider using specific pre-recorded audio messages played via smart phone screens [8].

In recent years, progress in wearable devices and sensor technologies has started to improve the prospects of health care services for assisting the elderly and disabled. Since most of the elderly suffer from age-related health problems, using wearable technologies health care providers monitor their vital signs continuously and comfortably [2]. In this paper, we review state-of-the-art IoT solutions and applications that can be used for elderly and disabled care and investigate prospects and research challenges. The rest of this paper is as follows. The second section presents the background of this work as well as related works on IoT solutions and various applications designed for the elderly and disabled. The third section is devoted to research challenges. The fourth section focuses on future research directions. Finally, the last section concludes this paper.

2. IOT SOLUTIONS AND APPLICATIONS FOR THE ELDERLY AND DISABLED

Physical, psychological and cognitive health of the elderly is negatively affected due to aging [8]. Similarly, some people face some sort of disability that affects their social life and make them highly dependent on the others. Since functional capacities of the disabled and elderly are severely impacted, novel technology solutions can be helpful [9, 10]. For this aim, in recent years, many information technology enabled devices have been designed and IoT is one of the most interesting paradigms developed for monitoring and control applications in this domain. In this section, we will discuss IoT based solutions and applications that have been developed to help or empower elderly people or people with disabilities.

One of the driving ideas behind IOT solutions and applications is ubiquitous sensors. If those sensors are worn or put on until they become pervasive, they can enable everything interacted with to have the potential to offer us more insight for our daily activities [8]. Especially, elderly people or people with disabilities could benefit more than the rest from those sensors, which can make their lives easier and create significant improvements in their lives. One of the most apparent ways for IoT to impact people with disabilities is to extend their reach. A number of connected devices controlled via mobile phones, tablets or other devices allow people with physical limitations to interact with certain things or objects around. However, developers of the mobile device applications designed for those goals should spend significant time to make the user interfaces (UIs) simple and intuitive. Another technology with a great potential to empower people with some type of vision impairment is iBeacons, Apple's implementation of Bluetooth low energy wireless technology to provide location based services to iOS based devices such as iPhones and iPads. In a shopping mall or store, iBeacons could assist vision-impaired shoppers by alerting them when they come in close proximity to items on their shopping lists. For people with vision impairments, iBeacon technology can also assist with indoor navigation by giving audio instructions and enabling them to move into proximity of their desired items. For people with vision and hearing impairments, another great application of

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IoT technology is smart insoles. Smart insoles are designed to help the wearers navigate without looking at their smart phones for directions. By vibrating, smart insoles let the wearers know where to go and make recommendations for specific locations based on the wearers' learned behaviour.

In the last couple of decades, smart home solutions, one of the most common implementation fields of IoT, started to offer various tools for people with disabilities to live more independently. By the use of smart home solutions, people with disabilities take control of home applications, can turn on and off lights, and are able to find out who knocks on the door. Most houses were not built with people with disabilities in mind; hence, those people cannot turn the lights on and off, since the switches are beyond their reach. Even if the switches are lower than usual, they are still high for people who use an electrical wheelchair. Therefore, usually people with disabilities rely on someone else. However, thanks to IoT based novel solutions, they can turn the lights on and off, if they have Internet-connected lights that can be controlled using smart phones. Smart phones can be used to turn a floor fan on and off, adapt heating and lighting, or a voice activated TV guide can be used to change channels. Similarly, people with walking disabilities no longer need to get up answer the door and instead of doing this they can remotely open the locks and invite their guests in. Due to the way home automation solutions has developed, almost all home appliances can be controlled from a central unit. Even, by taking the daily habits of their users into consideration, smart homes can begin learning for themselves. This is especially useful for people who have difficulty in coordinating their routines or suffer from memory loss. To sum up, potential benefits and practical uses of smart home solutions are numerous.

Different from smart home solutions which consist of environmental controls, lighting sensors, motion sensors, automated timers and video cameras, and allow controlling home appliances by the use of smart phones and other mobile devices [8], assistive domotics, a set of novel home automation solutions focusing on making people with disabilities and elderly people to remain at home, comfortable and safe, has started to become a feasible option for elderly people and people with disabilities who do not prefer moving to health care facilities. Solutions provided by assistive domotics generally rely on Bluetooth sensors to track movements in the home, or lack thereof, of elderly people.

As abovementioned, relying on the application of home automation solutions, assistive domotics focuses on enabling elderly people or people with disabilities to live at their home instead of a health care facility and has two basic forms: embedded health systems and private health networks. While the former rely on sensors and microcontrollers in home appliances, devices, furniture, and clothing, which gather data that is analysed to diagnose specific diseases and recognise risk patterns, the latter rely on wireless technology to connect portable devices and keep data in a in-home health database. By the services provided by assistive domotics, elderly people and people with disabilities can maintain their safety and independence, and instead of moving to health care facilities, they stay in their homes where they generally feel more comfortable. Importantly, the transition to health care facilities may result in a lot of anxiety [11]. Assistive domotics can delay, even prevent this anxiety. To sum up, for the disabled and elderly, assistive domotics not only gives opportunity for independence but also provides many types of emergency assistance systems, security features such as wireless remote entry control systems to allow viewing who is at the door and open the door remotely, privacy features such as automatically locking doors and shutting blinds, alerts, fall prevention, and automated timers. The following briefly reviews several ways assistive domotics help or assist with independent living.

2.1. Emergency Assistance and Response

Emergency assistance and response systems are the key component in the design of assistive domotics [12]. The first generation of emergency assistance and response systems consist of personal alarm systems and emergency response phones [12]. A typical system in this generation consists of a mini wireless pendant transceiver and a central unit plugged into a phone jack, with a microphone and loudspeaker. If the pendant is activated, a 24/7 control centre which has some information about the monitored person, such as medical symptoms and medication allergies, is called. Then the control centre speaks to the monitored person to identify whether he/she needs help. If help is needed, emergency services are dispatched. In addition to the features of the first generation of emergency assistance and response systems, the second generation can automatically generate alarms and alerts if unexpected significant changes are noticed in the monitored person's vital signs [12]. This generation of emergency assistance and response systems consist of an antenna, which the monitored person holds over his/her implanted cardiac device to send data over the phone line, are typically fully integrated into a home network, and enable health care providers to remotely monitor their patients. The data collected by these systems can also be accessed by the monitored person and family members. This generation of emergency assistance and response systems can also rely on smart vests or smart shirts which measure heart rate, electrocardiogram results, temperature, respiration and a few other vital functions [13] and alert the health care provider in case of a serious problem. In addition to the features of the second generation emergency assistance ad response systems, the third generation help people with disabilities and elderly people deal with isolation, loneliness and depression by connecting them with other disabled individuals or elderly through the Internet [12, 2]. On the other hand, the most basic solutions only provide a panic

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button that can immediately notify family members or health care providers of an emergency.

2.2. Memory

Considering the cognitive impairment in elderly people, automatic reminder systems are another important solution for the elderly. They make specific announcements about taking medicine, doctor's appointments, and everyday activities and tasks such as locking doors, closing the blinds, turning off the stove, eating lunch and walking the dog over an intercom depending on users' preference. Some user activities such as turning on/off the lights or controlling room temperature can be automatically performed. While these systems are a potential application area of IoT technology, IoT based simpler and cheaper solutions such as a wristwatch with text message and medical alert can function as a reminder system.

2.3. Medication Assistance

Medication dispensing devices allow necessary medications to be taken at appropriate times and can be quite useful for the elderly who live alone [12]. They can be used alone or be complemented with other solutions such as glucose monitors, blood pressure and pulse monitors and digital thermometers [2]. Talking glucose monitors designed for diabetic patients allow the users to test their blood sugar level and take the appropriate injection. High body temperatures can be recognised by digital thermometers and if necessary doctors can be alerted [14]. Automatic blood pressure and pulse monitoring systems dispense hypertensive medications if needed. In recent years, spoon-feeding robots have been designed, too. IoT technology can be used in all these device categories. Figure 1 lists common health care services and applications for elderly people [14].

2.4. Eyesight and Hearing

Enhanced alarms on doors, doorbells, home appliances, and smoke detectors alert people with hearing or visual impairments about home-related incidents.

2.5. Video Monitoring

Video monitoring allows remote viewing for carers in addition to monitoring the outside and inside of a home.

In addition to the abovementioned functions, assistive domotics may also include others such as a smart nutrition advisor system provided by a local grocery store to facilitate advice on food choices and home delivery and a home health station connecting to a wellness call centre [2]. Considering the numerous solutions provided by assistive domotics, in recent years, many products have begun to penetrate the market. For instance, Lively, a product designed for the elderly, enables medication reminders, daily activity sharing and step counting in addition to providing immediate and easy communications to emergency services and contacts with the touch of a button

[15]. Evermind enables carers and people with disabilities and elderly people living independently to monitor the usage of common home appliances and medical equipments. The sensors found in it track if powered medical equipments like wound care pumps or respiratory devices are in use and home appliances are switched off and on [15]. Daily Routine, an application created by SmartThings, helps carers stay connected to elderly people or people with disabilities by generating immediate alerts when they deviate from common daily routines [15]. Slip & Fall, also created built by SmartThings, using motion sensors, placed throughout the home, monitors motion and sends alerts to carers if an elderly person slips and/or falls or there is not any movement for a predetermined period of time [15].

Domestic robots connected to the home networks can perform some duties or chores or help to perform them. As well as domestic robots, recently a number of dedicated robots have been designed to help to manage medications and alert a remote home care provider if the patient will possibly miss his/her medicine dose. An example of dedicated robots is the Care-Providing robot FRIEND shown in Figure 2, a semi-autonomous robot designed and developed at the University of Bremen to support elderly people and people with disabilities in their daily activities such as preparing and serving a meal [16].

Wearable technologies, also called wearable gadgets, are a category of technology devices that can be worn by consumers and can be categorised into three main types: real-time vital sign monitoring, activity recognition and indoor positioning [17, 18]. In addition to ensuring that sudden events will raise alarms, devices designed for activity recognition helps to guide people' activities so that dangerous behaviours can be avoided. To realise these, a set of sensors except for cameras are placed around the house to track normal routine of elderly people. This way it can be detected if the monitored person has not gotten out of bed for a longer period or he/she skipped a meal and a notification by text, email or telephone call is triggered when something is out of the ordinary. Since real-time vital sign monitoring allows easy and continuous monitoring of some vital signs [19], it is important for the elderly. Devices developed for this purpose can keep elderly people safe and notify family members if something is wrong. They can be worn as a wristband or vest, performs some functions such as electrocardiogram and rhythm monitoring, aim to predict the early signs of ill health, and have the chance to prevent the worse. Such body worn sensors allow the elderly to remain active and independent while their general health is being continuously monitored since the data is wirelessly delivered to the mobile health (mHealth) platform used by the physicians. Positioning refers to the process of precise localisation and is highly important for elderly people and their family members. Considering the fact that elderly people have tendency to fall and injure themselves, emerging active

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protection solutions typically in the form of smart garments can be quite useful. Uses three dimensional (3D) sensors to determine falls and crashes in progress, they detect a fall before the monitored person hit the floor and then deploys wearable airbags in textile in order to prevent hip fractures.
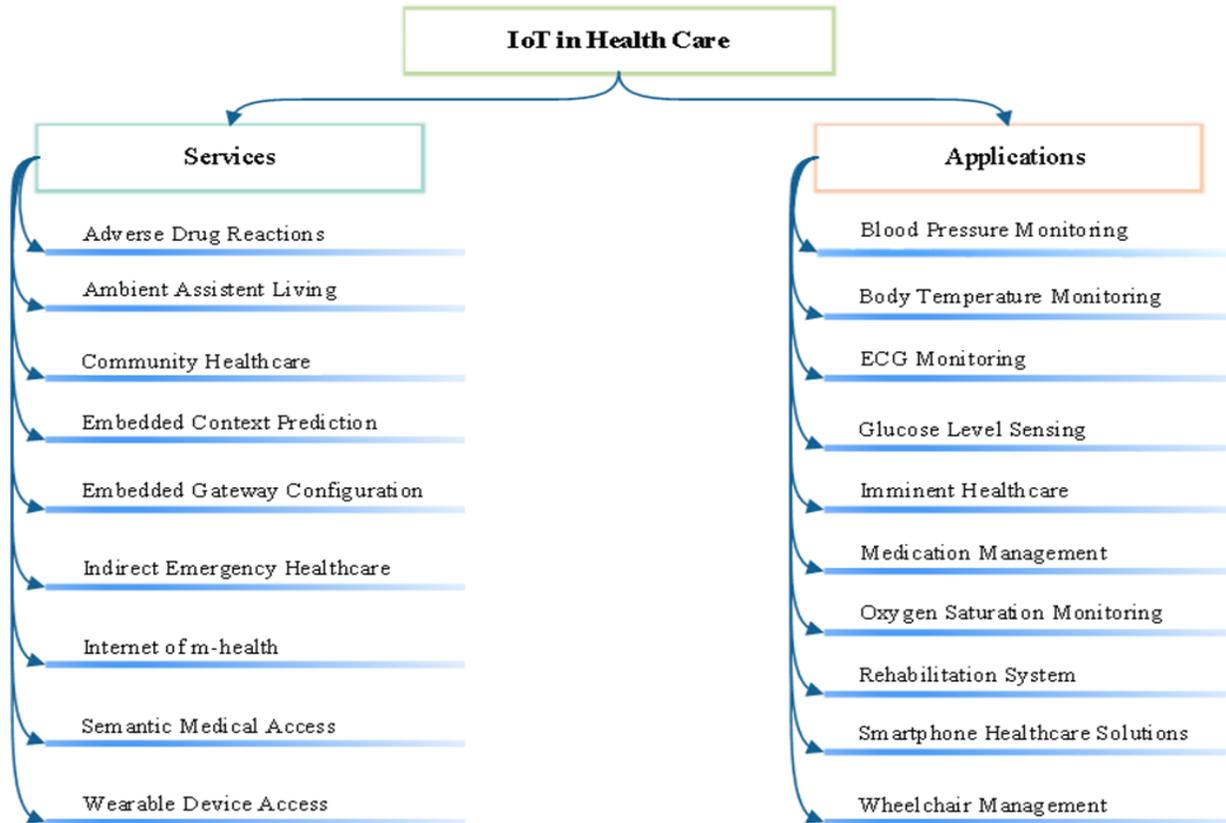

Figure 1. A schematic view of common IoT health care services and the applications supported by these services for the elderly (in alphabetical order)

Fig. 2. The Care-Providing robot FRIEND [16]

3. RESEARCH CHALLENGES

Because of the urgent need for more health care options for the increasing number of elderly people and people with disabilities, there has been an increasing interest from policy makers and industry in designing and developing IoT solutions. Although this increasing interest in IoT technology has helped to design novel solutions and propose state-of-the-art applications for the elderly and disabled, it has generated opposition. People opposed to the idea state that those solutions and applications are useful if they can be adjusted and accommodated to meet the individual needs of each user [2]. In reality, this is true since many of the UIs designed to be used in IoT solutions for the elderly and disabled do not consider functional limitations associated with age and cognitive impairments of each user are different [12]. Moreover, even if the UIs are designed to be as simple as possible, since elderly people have often difficulty using electronic devices, making the IoT solutions user-friendly is rather difficult. Worse, existing IoT solutions have ignored the human factor largely and have often viewed the ageing person as a malfunctioning machine whose deficiencies must be diagnosed and solved by means of technological solutions [20].

Innovative solutions that support and improve the quality of life of elderly people and people with disabilities exploit emerging technologies [21, 22] such as IoT since IoT paradigm offers many opportunities. However, comprehensive behavioural analysis of elderly people is needed and therefore a fundamental aspect is to explore the use of innovative solutions that are based on IoT [23, 24]. Moreover, IoT paradigm poses some other challenges. Most importantly, designers of IoT devices face a technological challenge: how to make those devices self-powering. It is a burden and inconvenient to recharge several devices.

In the last couple of years, security challenge received considerable attention in the IoT space. Therefore, strong security audits are an important part of value proposition for IoT solutions, IoT ecosystem and overall control framework [25]. If consumers prioritise security over low price and broad choice in devices, some brands and models will be success [26]. The reason why security is a challenge in the IoT domain is there are many standards that can be chosen. While some IoT devices use old and well-established standards with some security shortcomings such as Bluetooth, Wi-Fi and IEEE 802.15.4, others use proprietary or semi-proprietary standards such as ZigBee, Z-Wave, Clear Connect, Insteon Dual Band, and Google Thread [27]. Luckily, compared to IoT's native low-level protocols, the encryption, authentication, and authorisation protocols are well higher in the IP protocol stack. It is well known that IPv6 is an important part of the IoT domain. The key challenge in the successful migration to IPv6 is the adoption of two-factor credentials for enrolling and controlling devices [27, 28].

Another important challenge with the deployment of IoT solutions is the limited radio spectrum. Due to the expected increase in the number of wireless devices, more radio spectrum will be used. Since mobile wireless devices use licensed spectrum and Wi-Fi devices use unlicensed spectrum, spectrum allocation should be harmonised across the globe [28]. The fact that makes spectrum allocation more challenging is that the lifetime of IoT devices is longer than mobile phones. For instance, 2G wireless support was shut down by some operators in Europe.

Despite the numerous potential benefits and demonstrated effectiveness of IoT solutions, in most of the cases, the adoption of them has been significantly slow. Because, while IoT solutions are useful to both elderly people and people with disabilities and their family members, especially elderly people are generally slow to adopt emerging technologies and they are concerned about their privacy [2]. In IoT based solutions designed for elderly people, IoT devices unobtrusively capture personal data about location, daily habits and health for recognising behavioural changes in elderly people automatically. Then, the data is sent to a central server, or shared with other IoT devices or third party solution providers. On the other hand, most of the devices lack large displays or touch screens to enable the users to allow collecting data and analysing or sharing it with third party solution providers; hence, informing the users about possible future uses and obtain their consent about the data to be collected and transmitted. If their privacy concerns are addressed, elderly people readily accept technologies which offer them physical activity, function, and independence. Although even if privacy concerns have limited adoption, they can be overcome using different strategies. In this respect, encryption techniques can be quite useful to reduce risks by making data anonymous in the data transmission and processing chain [25]. However, although IoT applications present many security risks to both users and to IoT solution providers, most IoT devices do not have the processing capabilities to do this. Unauthorised access may be realised to IoT devices by cybercriminals or local wireless communications can be intercepted so that sensitive data can be acquired. Cybercriminals may attack attractive targets such as application servers or cloud based servers that collect very large quantities of data. Similarly, they can take control of local IoT networks or IoT devices. Encrypting data can reduce those information security risks. However, most IoT devices lack the computing capacity to implement advanced encryption techniques. In this respect, information security risks can be minimised if IoT designers consider security issues such as creating access control lists to limit access to their devices, implementing multiple layers of defence against threats, collecting only essential data and updating software regularly to patch existing vulnerabilities [25-28].

Standards and interoperability are other important issues in the deployment of emerging technologies such as IoT. If IoT

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devices working together do not use the same standard, due to the interoperability issue, extra gateways are required to allow data compatibility. Moreover, if a company dominates the IoT market, varying data standards can force consumers to select one family of products. Worse, if users are not able to transfer their data easily when one device is replaced with another from a different manufacturer, the data accumulated over time will possibly be useless. Although the need for developing technological standards to promote IoT solutions has been pointed out many times, much of the current development has resulted in vertical markets, in which specific methodologies to network topology and transmission may be followed. Therefore, public authorities should start to promote standards and interoperability in terms of different IoT aspects, encourage consensus on standards, and commission related projects [28].

The cost of IoT solutions and applications for the elderly presents a challenge, since although they are cheaper than the conventional solutions and the costs of health care facilities, most governments currently provides no assistance to elderly people or people with disabilities who prefer these systems. Last but not least, although the biggest concern is the possible replacement of carers by technology [12], novel solutions and applications proposed and designed in this domain should be seen as something that augments human care, but they will possibly never replace it.

4. FUTURE RESEARCH DIRECTIONS

Unexpected hazards and security breaches and are more distressing for people with disabilities and even can be life threatening. For instance, elderly people might leave the gas on and forget about it through cooking a meal. If such a situation occurs, the owner or its carer is directly alerted via their smart phones and a potential disaster is prevented. In addition to addressing such needs, IoT technology can also be used in different types of solutions to provide preventive measures against any break attempts and increased peace of mind in terms of home security and defence. For example, before they can be opened, smart locks require an identity check. Smart locks are sometimes combined with a camera situated by the front door so that before allowing entry it is possible to find out the visitor's identity. Although it is not precisely known how IoT technologies can break the accessibility barriers, it is well known that the fundamental element in the design and development of IoT-enabled environments is inclusive design.

Houses are not often built with people with disabilities in mind. Therefore, some types of everyday activities can become a chore and this kind of setbacks makes the majority of elderly or disabled people are unable to live alone. However, emerging remotely accessed technology solutions can create a big difference in the lives of those people and can enable those people to become more autonomous and independent. Considering the fact that more people nowadays reach 80 and beyond and most of them currently have little or no independent mobility, IoT based solutions can help them to continue to live a fulfilling life. The architectures which integrate technology and consumer demands with a new vision should be designed for elderly people and people with disabilities for enabling convenient living, managing disease, and promoting vitality [2].

One emerging technology with the ability to deal with multiple issues in the IoT domain is Software Defined Network (SDN). With SDN, it is possible to partition networks into zones of security and performance, which outsources a host of problems to service providers. To address the issues in the IoT domain, another promising solution is cloud computing.

5. CONCLUSION

Being the network of things embedded with electronics, sensors, network connectivity, and software, IoT is a computing concept which describes the idea of physical objects being connected to the Internet and being able to identify themselves to other devices. IoT creates opportunities for better and seamless integration between computer-based systems and the physical world. Since IoT solutions allow collecting all kinds of information depending on the application requirements and this way helps creating innovative solutions and new opportunities in different sectors in addition to reducing man power needs and operational costs, IoT results in high quality services with improved efficiency, accuracy and economic benefits. Therefore, it is highly possible that IoT will consist of billions of objects in a few years.

While IoT aims at keeping us healthy and simplifying our lives at home and in the office, it can easily be applied to empowering those with disabilities and enhancing the quality of life of the elderly. In recent years, rapid and considerable growth of the aged population has given rise to a great increase in the demand for health care services and IoT has started to be the key enabling technology for a wide range of health care applications that support the elderly and disabled in many areas of their life and work. Everybody agrees that empowering the elderly and disabled to live independently instead of health care facilities both provides cost savings and has significant potential to enhance quality of life and provide relief for family members.

However, although IoT solutions can highly enhance quality of life for the elderly and disabled, the amount of data collected by those solutions has increased extremely and excelled the expectations. Therefore, those solutions should be supported by innovative approaches to use large amounts of gathered data efficiently. This paper firstly reviews existing state-of-the-art IoT solutions and approaches proposed and designed for the elderly and disabled. Then, it investigates prospects and research challenges in those solutions to provide an insight into future research opportunities.

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