Smart cities to improve mobility and quality of life of the visually impaired

Smart Cities to Improve Mobility and Quality of Life of the Visually Impaired

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Abstract

The rapid pace of innovation and advances in technological research has given hope to the visually impaired, to find ways to move around smart cities and have a better quality of life (QoL). There are around 110 million people suffering from visual impairments worldwide and research will continue to be adapted to find innovative solutions to provide a journey closer to total accessibility for the visually impaired. It has been identified through various studies that the requirements of people with visual impairment fall into two major categories. Firstly, the ability to recognise people, leading towards social interactions. Secondly, the ability to carry out routine activities seamlessly without any hindrance. Through the use of artificial intelligence, availability of data, high bandwidth, large number of connected devices and the collaboration of the citizens in a smart city, the life of the Visually Impaired Persons (VIPs) can be improved by providing them with more independence and safety. Moreover, smart cities also support the concept of sustainable economic growth as well as well-being of its citizens, therefore its development relies on strong ICT infrastructure. With a rise in smartphones, wearable devices, and the surge in the adoption of Artificial Intelligence (AI), Internet of Things (IoT), and Virtual and Augmented Reality (VR)/(AR) have provided aspiration for VIPs to lead a better QoL. A number of studies have already tested the use of these technologies

and have showed optimistic results. The main sectors that could be improved to cater for the visually impaired in smart cities are public areas, transportation systems, and the home systems. This chapter provides a comprehensive review and recommendations on how a smart city can provide a better QoL for the visually impaired in the near future.

I. Introduction

Visual function is classified according to 4 levels by the World Health Organisation (WHO): normal vision, moderate vision, severe vision and blindness [1]. With approximately 38 million people suffering from blindness worldwide and another 110 million suffering from visual impairment, research has focused on providing solutions, which would allow those affected to improve their mobility and to independently achieve daily activities, such as walking around cities safely, and to perform other everyday tasks [2]. Visually impaired persons (VIPs) face various difficulties when it comes to urban mobility. The rapid pace of innovation and advances in technological research have given hope to the visually impaired in terms of finding ways to move around smart cities and have a better Quality of Life (QoL). The term “smart city” was coined in the early 1990s to emphasise on how city growth was pivoting towards technology, modernisation and globalisation [3]. Recent technological advancements have provided new opportunities for building smart cities catering to an elderly population and also to citizens with disabilities. The average age of the UK population is increasing and therefore, it is likely that the number of people with low vision or other visual impairment will increase concomitantly. In today’s busy world, having access to information, performing everyday tasks independently or engaging in education or employment is crucial. It is important to allow those people whose sight is deteriorating to have a normal life. With the help of ubiquitous computing, the engagement and interaction of visually impaired with other humans as well as their surroundings are achievable anytime and anywhere. The concept of ‘ubiquitous computing’ can be defined as a model of human to computer interaction in which the technology suits the natural environment of humans [4] [5]. The invention of smartphones as well as the continuous innovations in areas such as Internet of Things (IoT), artificial intelligence (AI), augmented and virtual reality (AR/VR), cloud computing, embedded systems, remote sensors, wireless networks and robotics have provided a remarkable cluster of functionalities and opportunities, which can support the mobility of VIPs in a smart city setting [6].

Furthermore, the amalgamation of the aforementioned technologies in a smart city setting would transform the lives of people with functional dependencies. Examples of the healthcare applications that would benefit from the stated technologies include: remote health monitoring using wearable devices, remote diagnosis, remote surgery, and instant access to the emergency services etc. The ultimate goal of smart healthcare in a smart city setting is to bring healthcare to the user's home and bridge the gap between terrestrial boundaries [6] [5]. For visually impaired, smart cities have the potential to improve their QoL, reducing the challenges associated with their routine activities. Because, we are only now witnessing the beginning of the development of smart cities such as in Dubai, Singapore, New York and China, current and future cities will continue to be adapted and tested, thereby potentially providing an experience closer to total accessibility for the visually impaired if there is continual investment in this sector. In such complex ecosystems, specific sectors such as healthcare, education, environmental infrastructure and other public services are in need to fulfil the specific needs of the population [7]. Smart cities also support the concept of sustainable economic growth as well as the wellbeing of their citizens [8]. They include, for example, more efficient ways of lighting up buildings, leading towards a greener environment; safer public spaces and more interaction for the physically disabled [8]. Their development relies on strong network infrastructure, the Internet or Web 2.0 and their success depends upon the collective intelligent workforce designing initiative, and cost-effective solutions. The European Commission is investing up to €1 billion in supporting the European Innovation Partnership on Smart Cities and Communities (EIP-SCC) that helps bring together industries and citizens in at least 300 cities [9] and the visually impaired will be one of the beneficiaries of this project.

In recent times, the advancements in Information and Communication Technology (ICT) and its associated services have facilitated in creating a more cost-effective and sustainable environment. The implementation of ICT in a smart city context can provide personalised health care, social services and intelligent community services, to name just a few [6]. There are currently a number of EU projects working on the theme of Ambient Assisted Living (AAL) to improve QoL of the visually impaired, utilising ICT applications. The aim of such projects is to increase the level of autonomy indoors as well as outdoors, allowing them to carry out their daily activities without constraints. With the evolution of emerging IoT-enabled wireless technologies, the surge in the adoption of Artificial Intelligence (AI) and big data analytics, the ability to recognise people or to carry out routine activities can be envisaged as feasible [10].

Common problems of those with affected sight are lack of independency or mobility, social isolation and feeling insecure [5] [11]. Social interaction plays a significant role in maintaining good physical, mental and emotional health for visually impaired, as demonstrated through research [6]. Thus, one of the key aspects of healthy life is to remain socially active and to maintain relationships. Thanks to the development of new technologies, VIPs are increasingly able to make social contact, communicate with family and friends in new ways, participate in their communities, and share learning, skills and experiences with others [6]. In order to decrease the fear of isolation for the visually impaired while simultaneously improving their mobility, smart cities would provide modern assistive technologies both indoors and outdoors so that the visually impaired can benefit from full inclusion and integration in society [12] [13]. There are a number of opportunities as well as challenges in shaping these technologies and this chapter provides comprehensive review and recommendations on how a smart city can provide a better QoL for the visually impaired in the near future. This article delineates the areas into the following main categories 1) public areas 2) transport systems and 3) smart homes. The rest of the chapter is organized as follows. Section II provides related work. Section III discusses the application of crowdsourcing to help visually impaired in smart cities. In Section IV, we have presented IoT-based scenarios to assist visually impaired. Section V elaborates on potential AI and VR/AR enabled solutions. Finally, Section VI concludes the chapter.

II. Related Work

There is a huge potential to improve mobility of the visually impaired persons to allow them to detect obstacles by making use of Internet of Things (IoT), sensors, among other latest technologies, in a smart city setting. A number of studies have already tested the use of these technologies and have showed possible ways of improving the independency of visually impaired persons. This section describes some existing solutions to help those people and also shows how a smart city could improve on these solutions and design its infrastructure to cater for an elderly population with disabilities, focussing on the visually impaired.

1. Public Areas in Smart Cities for the visually impaired

Some of the challenges faced by the elderly and visually impaired in cities and societies today are mainly associated with mobility and navigating through known and unknown obstacles. In public areas of smart cities, ICT solutions can help in mitigating the aforementioned challenges by providing solutions such as [6]:

a) Audible and vibrotactile signals based augmented systems for pedestrians, which would provide precise information about their location.
b) Mobile assisted product recognition system for accessible shopping.
c) Mobile assisted city apps adapted to visually impaired users.

The use of white canes or tactile devices are among existing solutions but VIPs, very often still need support from the others. In his study, Ramadhan [2] developed a wearable smart system that consisted of a microcontroller board, different sensors, cellular network and a solar panel. This system was used to track the path of the VIPs and alert them by a sound emitted through a buzzer as well as wrist vibration in case the VIPs are in a noisy surrounding. The device also triggers an alarm if it detects that the person has tripped over to alert people nearby and can send the location information to their registered caregiver, if requested by the VIPs. The sensors, operating only in a range between 2 cm and 4 m, include solar chargeable battery. However, the solution still needs to be improved to detect obstacle up to the head level, as currently, the user is wearing the device on his wrist. The system is also not capable of detecting fire, water, holes and stairs. With the application of AI and object recognition as explained later in this chapter, the system can thus be improved to recognise the routes of users around smart cities thus facilitating the mobility of the visually impaired. For example, in a smart city setting where the network infrastructure is strong, assistive technologies can be exploited to help people move around. They can rely on devices and transport systems having voice command functions to enter their destination. Smart cities could also have touristic areas having a voice describing the scene to help the VIPs to visualise some places and feel included in their environment. These could be smart devices embedded with AI technologies such as image recognition that offer auditory clues to citizens. Google is currently developing an Android platform called Lookout [14], that will work with a camera device that can be fitted in a shirt of the visually impaired to help them identify money, receive spoken navigational instructions and recognise colour of objects. Similarly, smart cities can make use of related technologies both indoors and outdoors to better guide the visually impaired.

Applications such as Seeing Eye GPS or BlindSquare are both mobile applications that make use of the Global Positioning System (GPS) to inform users of their location to move from point A to B. However, they lack accuracy when navigating inside train stations and shopping malls where the signals' strength is low. Here, Small Cells can be utilised to boost signal strength. Small Cells are low power base stations that can be installed in public spaces in a plug-and-play manner. Smart cities have the possibilities of equipping the buildings with beacon powered devices. Beacons are low-cost small transmitters that can be fitted inside buildings and they can send real-time information to mobile devices via Bluetooth low energy. Beacons work both indoors and outdoors and can be placed, for example, at bus stops, entrances to buildings and train platforms to inform VIPs about specific areas. VIPs can therefore be notified via vibration or sound through their mobile device. One existing example of the use of beacons is from the city of Warsaw in Poland, whereby the city has developed a network of hundreds and thousands of beacon sensors to help the visually impaired to move around independently [15]. Nearly 85% of Warsaw's visually impaired population reported having a strong dependence on family members or friends in order to carry out daily routine tasks while over 80% are unemployed. The "Virtual Warsaw" project is expected to be completed in the city and extended to another 24 municipalities by 2021 [15]. Another application of beacons to help the visually impaired has been deployed in the WAYFINDR application, which sends the user information about his proximity via audio instructions [16].

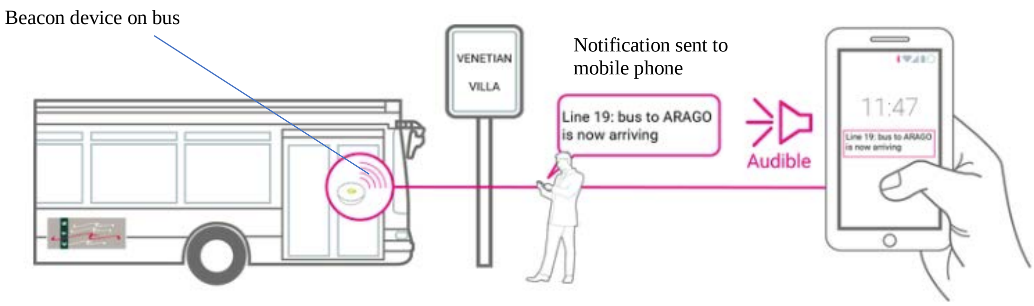

Figure 1: Use of beacons as potential solution [17].

Smart cities can also provide urban smart furniture or tactile floor to facilitate the movement of those with visual impairment. Tactile paving compensates for the absence of any kerbs and the visually impaired can make use of the information underfoot. However, it is important to note that this might not be beneficial to elderly citizens or those who suffer from diabetes, for example, as they may have reduced sensitivity in their foot [18]. Use of blister paving can provide warning of potential hazards or for amenity purposes to give guidance. Smart cities could use a combination of Radio Frequency identification Devices (RFID) tags and GPS to allow white cane users to receive guidance when approaching places like markets, cafes, theatres or subway stations. The use of mobile and talking tactile maps should be provided to VIPs to improve their independence when moving around towns and cities. The physical maps could be designed so that they provide information about position of beacons as previously described. The maps could further be linked to a mobile application to allow its citizens to feel confident when travelling alone in the city.

Smart cities can also provide the latest technologies such as VoiceOver screen reader to allow VIPs to do their food shopping or go to the bank to deal with financial matter. Supermarkets can be equipped with devices to count money or recognise notes, differentiate between various products, and all of these can be improved by using AI-based image recognition technologies. The OS X developed by Apple is already equipped with VoiceOver technologies, which allow users to have their text and application controls spoken aloud. At present, the visually impaired are provided with various mobile applications, which they can use on their personal mobile devices to allow them to carry out daily tasks. A smart city, on the other hand, should provide services and applications that are user-friendly, as operating a complicated application can be overwhelming for VIPs.

2. Transport Systems in Smart Cities for the visually impaired

Another area whereby smart city can be developed for the visually impaired is the public transport sector. Transportation presents various challenges within the local, regional, national and international levels [19]. In recent years, mobile applications have already helped the disabled to use the public transport in a more effective way by receiving notifications from their mobile devices near bus stops to be alerted when a specific bus is approaching. However, many of the visually impaired still need human guidance to help them identify the correct bus otherwise, they have to stop some buses to enquire about the destination from the bus driver. Another challenge faced by VIPs is the presence of more than one bus line at a busy bus station therefore, making it hard for them to get into the proper one. Applications like CittaMobi has been used by visually impaired Brazilians so far to receive real-time vehicle scheduling, best routes for their journeys and other convenient tools as described by some of its users [19][20]. However, this application could be improved by letting the drivers receive more information about the passengers to fill the gap of the lack of interaction amongst services, users and applications [19], which can be achieved in a smart city thanks to the sharing of data. Another application called GeorgiePhone, developed in the UK mainly for people suffering from low vision consists of a bus tracking system, among other functionalities, to locate nearest bus stop, read aloud the bus stop name every time the bus stops and indicates bus arrival schedules. Yet another system, Mobi+ project, implemented in the city of Clermont-Ferrand in France, provides an effective bus access service to people with disabilities and wheelchair users. The project consisted of a wireless communication module with data exchange functionalities between buses and stations, and multi alarm notification and multi sensor surveillance to inform the disabled passengers about the arrival of buses [21]. RFID readers can be placed at smart bus stops so that when passengers with a disability scan their ticket on these machines, the bus drivers are automatically updated about their passengers, improving data exchange and making provisions for those in need [21]. Since the elderly population is increasing at a fast pace, it is more likely that the population of the functionally dependent individuals will also increase in the next decade, hence more effective transport solutions need to be developed as part of any smart city development project. Having access to move independently will also improve the QoL of the visually impaired as some studies show [22][21].

Ubiquitous computing is also being adapted by car manufacturers in their design of the future automobiles with an aim to provide those affected with low vision such as the elderly population to be able to drive safely on the streets. Driverless car technologies take the needs of the visually impaired into account. Self-driving cars make use of radars and lasers to check and make sure that the roads are clear (Google self-driving car). A survey carried out with 38 visually impaired participants by the researchers at University of Florida showed optimistic results. Survey concluded that VIPs endorsed the idea of self-driving cars, which they believe would overcome the challenges associated with their mobility [23]. However, the survey highlighted some concerns about the development of such technologies in terms of situational awareness, verification of desired location, parking options, safety and roadside assistance. The participants mentioned that there was a lack of consideration in the needs of the individuals with visual impairment. In a smart city environment, legal and regulatory issues related to self-driving cars need to be addressed and the citizens will need to be trained to respect the laws. The automated cars will need to effectively operate beside other non-autonomous cars, which often are driven by unpredictable drivers who might not always be following the laws. These smart cars will also need to be supported by high bandwidth mobile networks since these vehicles work by collecting data from an array of sensors. Currently these vehicles are also limited in terms of data they can collect and they are not equipped to know if there is a road blocked 10 metres ahead. Subsequently, they still rely on human judgement when things have not been planned in advance. However, in a smart city environment, these smart cars can access data from other vehicles, also known as Vehicle-to-Vehicle communication (V2V) and from roadside units that can provide information about traffic, weather, blocked roads among other information [24][25].

There have been some privacy and cybersecurity risks that have been already raised when it comes to the development of such transport systems [26]. If proper protocols are implemented, then in the long term, the use of smart vehicles can reduce environmental degradation with low emission of toxic gases and lower energy consumption. Studies also show that the use of automated vehicles by the elderly with low vision has the potential to reduce the amount of road accidents since they rely on AI to interpret data and make decisions while adapting to changing conditions and eliminating human error [27].

3. Homes of the visually impaired in Smart Cities

Smart cities also include the way homes are designed, which are commonly referred to as 'smart homes'. Smart home is considered as an advanced automated or controlled home as it makes use of AI technologies to become dynamic, more intelligent and learn from the users' daily activities thus allowing the visually impaired to live independently [6]. Moreover, in the context of healthcare, smart homes will transform the way healthcare services are provided to their residents. Citizens with functional dependencies including those with visual impairment will be able to remotely connect to their preferred clinic in the comfort of their home. Solutions such as wearable sensors and sensor-based surveillance system in a smart home setting will keep track of their health and notify emergency services, should immediate medical intervention is required. Smart health integrated in a smart home setting is a key player in reducing routine outpatient appointments, which in turn reduces the needless travel to the hospital, addressing the mobility issue associated with VIPs [6]. Existing projects, for example, the GIRAF++ project aimed to offer an independent living experience to elderly citizens with low vision. It consisted of sensors that could be implanted in smart homes to detect whether a person had issues with moving around, if he fell and also monitored some basic health vital signs. The web enabled devices provide clear benefits and motion sensors like the Microsoft Kinect can recognise gestures of the visually impaired to perform some remote tasks. It also has the ability to detect objects and faces as stated in another study [28]. Using such technologies can reduce indoor accidents and help finding objects around the house if they are not in their usual place. Providing home Ambient Assisted Living (AAL) to help the visually impaired is a challenge and homecare systems need to be adapted to the growing elderly population by making use of the recent development in ICT [29]**.** Due to the rise in the numbers of visually impaired, there are more and more demands for informal carers such as family and friends to look after them and these carers' coping capacity is decreasing [30] [31].

Smart cities should comprise of smart homes and buildings equipped with audio and vibrotactile systems to improve the QoL and independency of its citizens. Besides, smart homes for the visually impaired can be built to be able to support them with mobility inside their own house by making use of automated and smart devices. There are various tasks that could be automated in a smart home environment whereby the visually impaired citizen would not need to displace to complete a task. When it comes to regulating the temperature of the indoor heating system, with a simple voice command, the visually impaired can increase, decrease, switch on or turn off the heater in a smart home. Another popular tool that is useful for the visually impaired is the voice command assistant such as “Amazon Echo Dot” or “Google Home” to access music, audio books, news or weather updates. There are ways for the visually impaired of getting notified about events in the house so they do not need to move around to inspect things. For example, a water leak can be detected by sensors, switching of the oven can be done remotely via a smart switch or even closing the gates can be achieved by automation. These are existing technologies that need to be considered to make a home smarter. People with low vision in a smart home would not need to switch on/off the lights as the presence of someone can be detected by passive infrared technologies. Window motors and sensors can be installed to be able to be remotely controlled by wall switches, which monitors the status of windows. Home appliances can be linked to smart switches that can also send notifications to remind the user to remotely turn them off. For the security and safety of the visually impaired, smart smoke and C02 detectors can even be connected to different devices and warn the user or a caregiver in case smoke has been detected in the room.

Furthermore, when it comes to daily tasks such as gardening and cleaning, which involves the physical displacement of the visually impaired, these can be enhanced by the use of robot floor cleaning or lawn mowers. A number of assistive technology tools have been implemented by some companies such as Smartn Ltd that allowed the disabled to reshape their routine and lead a more independent life [32]. Some of these tasks were impossible prior to the advent of smart homes concept, which rely hugely on the good network infrastructure.

The goal of designing smart homes is to safeguard the VIPs’ wellbeing in their own homes. Smart homes are embedded with assistive technologies, which enable them to provide such users with opportunities of independent living and reduce social isolation. Despite the fact that smart homes are stationary in nature, users inside these homes are mobile, thus they would benefit from the embedded technologies around them [5].

4. *Mobile Assistive Vision Support Systems for Obstacle Detection and Space Perception*

Over the years, assistive technologies have gone through several stages and forms starting from a simple typewriter that helps VIPs in writing to state-of-the-art mobile phone applications specifically developed for VIPs to ‘see’ and understand their surroundings.

Obstacle detection when navigating through urban spaces and space perception when navigating through open spaces are the two main solutions provided by mobile assistive technologies. The subsequent sections dilate upon the aforementioned solutions, providing examples and use cases [5]:

a) *Obstacle Detection*

This solution comes under independent and safe navigation for VIPs. The concept of safe navigation ensures that timely warning messages are sent to the respective users in order to make them aware of possible hazards in their path [5]. Traditional white cane obstacle detection method is relatively inexpensive but it requires intensive training and significant effort by the user, who struggles to explore the area ahead of him. In Section V, we have determined the challenges associated with the white cane approach. In the literature, several mobile assistive approaches of obstacle detection and avoidance have been proposed as augmented versions of white cane method.

One such innovative approach is called SmartVision. It is a smartphone-based navigational support system, which operates by tracking the travelling path along with detecting the obstacles, utilising navigation map. Such navigational system surpasses the limited observational capabilities of white cane by providing real-time and precise information about the obstacles en route [5]. SmartVision is an outdoor use case that requires GPS support, which is prone to attenuation particularly in adverse weather conditions. In such case, the system would be regarded as unsafe for the VIPs. The risk of signal loss can be mitigated by using RFID tags instead of GPS. The RFID reader embedded within the white cane would detect RFID tags from its surroundings (e.g. pavements). In addition, there is a 3D camera (that is called a stereo camera, which consists of two lenses to stimulate the human binocular vision and capture 3D images), connected at the height of the chest, a portable small computer worn in the shoulder, an earphone, and a small four button device to explore navigation menu. The addition of an audio interface provides verbal information about the route, obstacles en route as well as the points of interest (e.g. restaurants) en route. The vibrating device attached to the handle of the white cane works alongside audio interface to alert VIPs about the approaching obstacle. A similar prototype can be used in an indoor scenario, where Wi-Fi and Global Information System (GIS) can be utilised that will enable VIPs to actively interact socially and obtain information inside their homes [5].

The EU funded EVA project which stands for "Extended Visual Assistant", has overcome one of the 21st century challenge in helping the visually impaired to have a better QoL. The project has developed a high-tech glass with online connectivity, which was a low-cost solution as compared to trained guide dogs and also had low energy consumption. With a stylish design, the glasses have a discrete camera, microphone, speaker and control buttons [33]. It has been mentioned that the glasses will be able to even detect the proximity of cars in the future, allowing the visually impaired to even detect electric cars, which are usually more silent. This could reduce the number of road accidents while detecting a number of obstacles automatically and warning VIPs.

b) Space Perception

In the previous system, we discussed navigation solutions that offer obstacle detection and avoidance. It is important to highlight that the navigation systems should not only focus on finding routes, but also it should be able to perceive, interpret and comprehend information about VIPs' surroundings. Therefore, solutions incorporated under space perception systems such as MobileEye, and LocalEyes would help VIPs with their perception [5].

The goal of MobileEye is to allow VIPs to perceive, understand and interact with their surroundings especially in situations where they are traveling alone. This can be carried out through the embedded cameras in mobile phones as well as the use of text to speech conversion technology. Four subsystems are incorporated under MobileEye, which target different needs of VIPs: 1) a mapper designed to distinguish among different colours, 2) a software-based magnifier, used to facilitate reading, 3) a pattern recognition device to recognise objects such as money, and 4) a document retriever device used to extract a document out of many from a database by simply scanning the keywords. The operations of the described software above are triggered through a voice message. The camera is activated by pressing double clicks in order to get working. Also, the software automatically switches off after being idle for 2 minutes. However, the software can be further improved by increasing the response time as well as by including the vibrational feature.

The other system in the space perception is called the LocalEyes, which operates through GPS, provided with multimodal user-friendly interface. The services provided through LocalEyes include information about the points of interest such as restaurants, coffee shops, pharmacies, shopping markets, etc.

III. Crowdsourcing to Help the Visually Impaired in Smart Cities

Crowdsourcing, which is another key factor in the development strategies of smart cities for the visually impaired, has gained some interests since the term was coined in the past decade. Crowdsourcing is a distributed problem-solving model achieved by the collaboration of various individuals via web-based platforms [34]. It is regarded as an alternative to enable public engagement and for decision making. The EU in particular, has raised particular interests of using crowdsourcing methods for finding innovative solutions. One example of the use of crowd to help people with low vision is the "Be My Eyes" software program which allows people with sight issues to request the help of someone who has no visual impairment and previously signed up as a volunteer via the platform. The software matches the person with a volunteer who can respond to help. Requests can range from checking expiry dates, distinguishing between colours, reading instructions or navigating new surroundings. The visually impaired person simply has to point the phone to the object or anything he needs assistance with. The application currently has over 1 million volunteers to help over 100 000 visually impaired people in 150 countries [35]. Similarly, in a smart city environment, the government needs to encourage its citizen to collaborate via crowdsourcing to help the ones in need. The government infrastructure of smart cities should be accountable, responsive and transparent. Smart city crowdsourcing plays a vital role and can help in participatory planning including the concept of open government, citizen reporting and can facilitate citizen to government support [36]. It does not only relate to technology but focusses on collaborative approaches that create new ideas, increase efficiency while saving resources. Crowdsourcing could be exploited to develop solutions for the visually impaired people to navigate around in a smart city. This could be to help them locate landmarks for example, by combining Google Street View (GSV) and online crowdsourcing as stated in a study carried out in a study in the US [37]. The study was carried out with 18 people with visual impairments to inform the design of the proposed tool. The work uses the collection of landmark descriptions such as bus stop signs, benches, mail box, traffic poles, shelters, or other physical objects, inserted by crowd workers in GSV. A smart device can then use GPS and text to speech to describe the necessary information to the visually impaired. A smart city should be able to provide similar information to the visually impaired in the future. Another example is the "Mobile Crowd Assisted Navigation" mobile application developed and tested by a group of researchers to assist people with low vision to navigate around. Reliable directions are given by an online volunteer community in real time via four arrow keys indicating right, left, forward or stop, which are then converted to audio instructions to the user [38].

Smart cities could help the visually impaired in different ways. We discussed earlier that the infrastructure and transportation system of a smart city are among the most important factors that could help them lead a better lifestyle with improved mobility. The other identified capabilities can involve sectors in energy and utilities, public safety, health, housing, education [39]. Healthcare professionals have been estimated to be the fastest growing workforce in the United States and they are important assets in a smart city since in the next decade the elderly and the disabled population will increase [39]. To facilitate the jobs of these healthcare professionals and to make maximum use of the limited resources, hospitals and other health infrastructure should exploit the use of Internet of Things (IoT) and smart mobile health technologies to support real time data, alerts and personalised educational materials for the citizens including the visually impaired. There are already an estimated of 36 million units of monitoring devices as of today as compared to only 3 million units in 2011 [39]. Future smart cities need to support the use of medical devices on the move for better monitoring and lower costs on hospital admissions for those suffering from chronic diseases. The collection of patients' data via the IoT technologies can further help innovators to improve existing systems using the large sets of available data and also allow the visually impaired to understand their personal health better. This will encourage independent living. The visually impaired population suffering from chronic conditions would be able to have significant health benefits and would not need to pay regular visits to the hospital for check-ups since these could be achieved in their home via the use of approved Bluetooth enabled medical devices such as blood pressure monitor, digital thermometers, ECG via a smart vest or weight scale that can send data automatically to a secure cloud.

Smart cities have the potential to decrease social isolation and empower the visually impaired in various ways. Although many of these solutions have already been developed, many of them did not feature the security aspects and have not yet been tested or evaluated on a large scale. It is a key role of the government to allow the social innovation and invest in some of the technologies to improve the world of the visually impaired. By providing the collection of data and connectivity, smart cities will provide new ways of interaction, lifestyle management and enable independent living. Through machine-machine communication, real-time monitoring, strong network infrastructure and crowdsourcing, smart cities can address some of the current problems faced by those with vision issues.

IV. Internet of Things Applications for the Visually Impaired

1. IoT Architecture

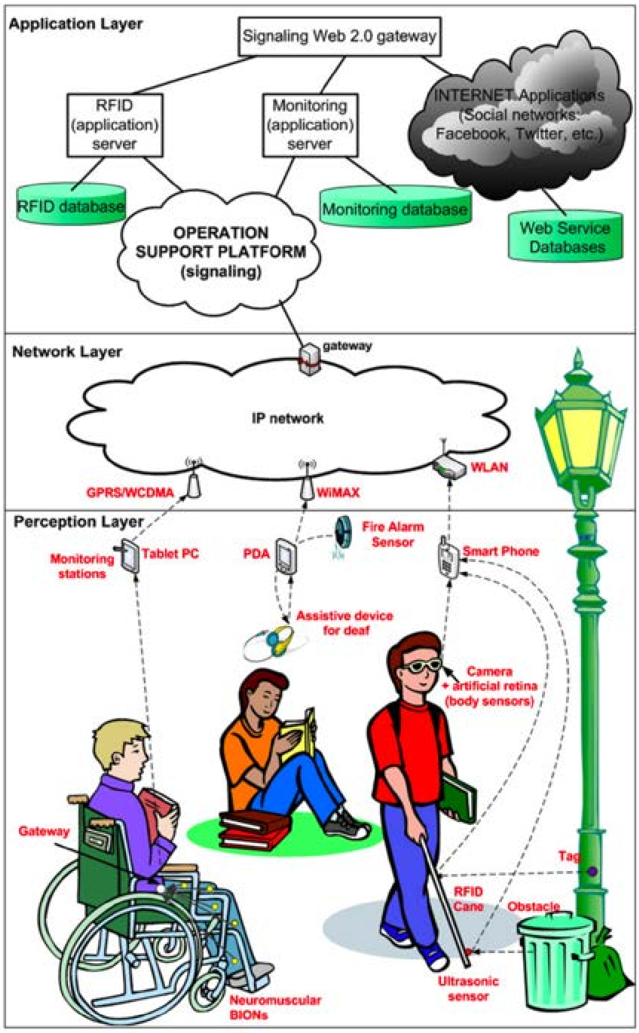

Figure 2: IoT Layer Architecture [40].

IoT architecture consists of several layers to facilitate a cross-layer communication due to the different representation required at each layer. As mentioned in [40], the IoT architecture consists of three layers as shown in Figure 2. These layers include perception layer, network layer, and application layer. Each layer’s function is briefly described as follows:

a) Perception layer: the main function of this layer is to identify the types of objects and to collect perceptive information. This layer is constructed of sensors, actuators, controlling and monitoring devices (e.g., smartphones, tablets, PCs, PDAs, etc.), RFID tags and readers / writers.
b) Network layer: the main function of this layer is to transmit information obtained from the perception layer. In addition, this layer is responsible to establish the connectivity of the devices in the perception layer. Moreover, network layer deals with the functionalities associated with wired and wireless network as well as the internet.
c) Application layer: this layer consists of innovative and smart solutions that employ IoT technology to support user applications.

Besides, the authors in [40] introduced several IoT applications for people with disabilities. These applications tend to show how IoT devices interact with each other to facilitate real-life scenarios such as smart shopping, smart learning and smart home.

a) Independent Shopping Scenario

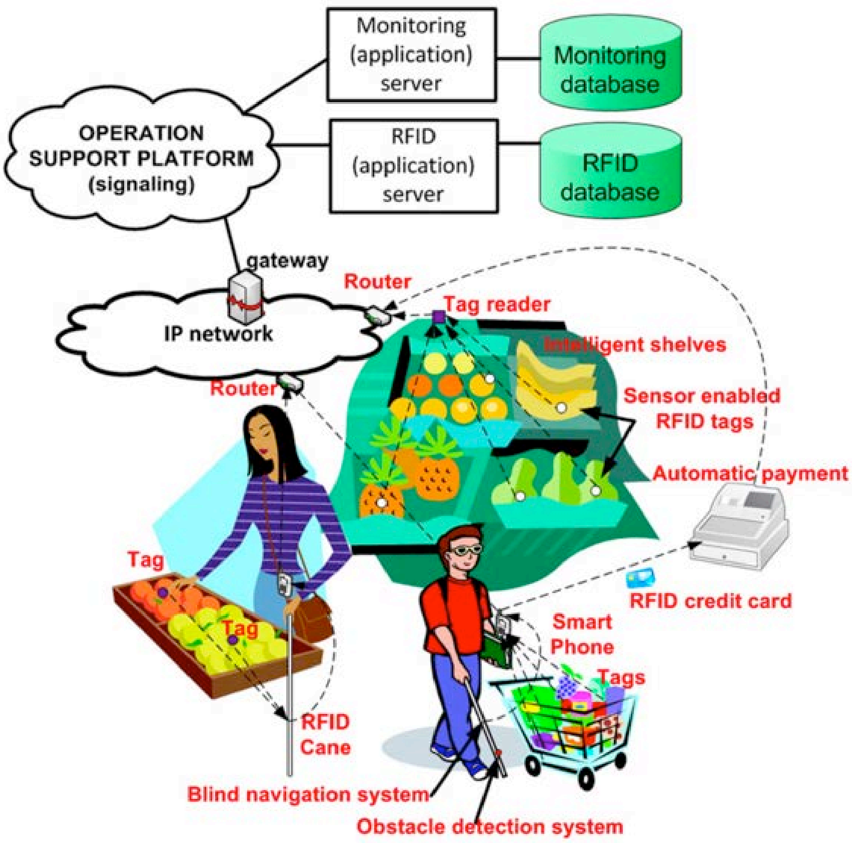

Figure 3: Shopping scenario [40].

Independent and safe mobility while shopping are the two main requirements for VIPs in this particular scenario. According to a survey, VIPs stated that shopping centre has the most challenging environment in terms of space perception and in-store navigation, leading towards a difficult shopping experience [5].

IoT-based smart shopping as shown in Figure 3 meets the requirements of independent shopping and safe mobility by providing in-store navigation system specifically designed for VIPs. In addition, RFID tags distributed within the shopping centre connect to the RFID reader embedded in the smart white cane, which further connects to the VIPs smartphone via Bluetooth. This entire setup helps VIPs to keep track of their position and assisting them with efficient in-store navigation [40].

b) Smart Learning Scenario

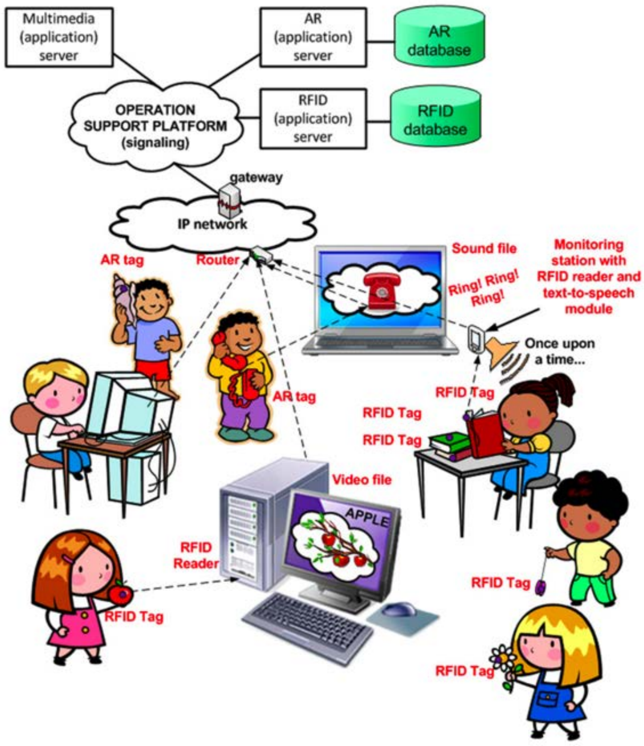

Figure 4: Smart learning scenario [40].

The smart learning scenario, as shown in Figure 4, has been proposed by the authors in [40], who highlighted the importance of designing smart interactive play environment as well as environmental learning systems for kids with concomitant impairments. Their proposed design stimulates language and communication skills. The play and learning system consist of RFID technology, which is employed to distinguish between different objects such as toys. Moreover, the RFID tags attached to the toys are used to support kids with concomitant impairments including visual impairment. [40]. The proposed system is user-friendly, where RFID reader is used to scan the tag, send the tag ID to the linked software, which in turn provides audible information about the scanned object.

c) Domestic Environment Scenario

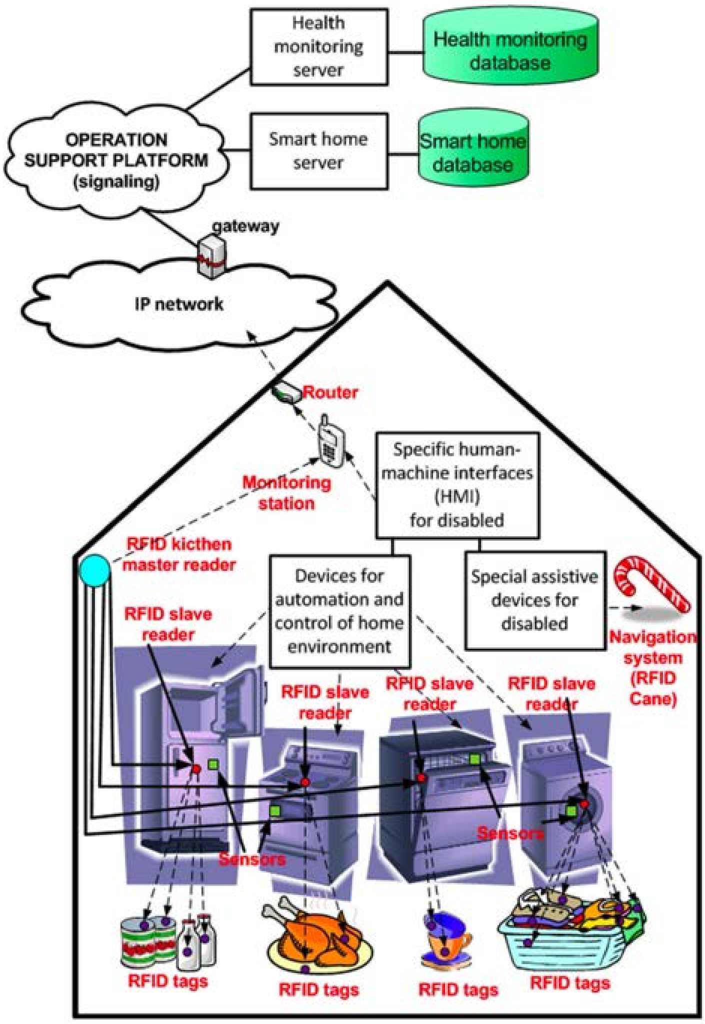

Figure 5: Domestic environment scenario [40].

Figure 5 shows the integration of technology and services in a smart home setting. Usually, a smart home involves an interaction of the objects using the home networking systems in order to enhance the QoL. Home automation and control features are enabled by using devices such as automated appliances in kitchens, light and door controllers, indoor temperature controllers, water temperature controllers, and home security devices [40]. The automated devices in smart homes are operated by sensors and actuators, which are embedded within home appliances. These embedded sensors monitor the environmental conditions, process information collected via IoT devices, and communicate with other devices through wireless networks. After gathering information, local or cloud-based servers process the gathered information to provide a suitable service to the users. For instance, in case fire is detected, actuators are triggered to cope up with such emergency situation [40].

V. Artificial Intelligence (AI), Virtual Reality (VR) and Augmented Reality (AU) Solutions for the Visually Impaired

Presently, there has been an increasing interest in applying AI and machine learning methods to the development of algorithms that will complement our lives. The aforementioned claim is supported by research, which states that AI along with machine learning is more reliable, consistent and efficient than the human brain, and that too without any mood swings [41]. But what do we mean by AI? AI is an umbrella term, which is a sub-category of computer science. It encompasses the machine learning algorithms, robotics, expert systems and language processing [42]. The terms AI and machine learning are interchangeably used and are often targeted towards the same goal (e.g. facilitating humans in an intelligent and efficient way without human intervention). Augmented Reality (AR) and Virtual Reality (VR) are also the next step in providing effective support to the visually impaired inside their homes, whilst navigating on the streets or within a smart environment [43][44]. VR is a completely simulated environment, which does not link with the real world. It provides interactive computer-generated environment that allows users to perform a number of tasks. VR is successfully used for flight and driving simulators, training in medicine and overcoming a number of psychological issues. However, despite its excellent features, it is very limited for VIPs. On the other hand, AR combines simulation and overlays with real world environment. A new concept has emerged called Mixed Reality (MR), where not only digital simulation is merged with the real world but also the digital objects can interact with each other. Microsoft introduced HoloLens mixed reality glasses in 2016, which were expensive with high resource requirements [45]. Many other companies have also invested in this sector and a number of AR glasses are available from manufacturers such as Google Glass, Epson Moverio etc that provide solutions to the visually impaired when it comes to mobility. The HoloLense and Google Glass like technologies maybe integrated with Google maps where VIPs can navigate through streets while AR glasses can read signs and provide feedback to the user about their surroundings.

AI, AR and VR are no longer in the future. It is very much in our present and has been widely adopted in the recent years. The classic examples of AI-based applications that most of us are unaware of, are right in front of us. These include Apple's Siri, Tesla's self-driving and collision detection, Facebook's face recognition software. Netflix's movie recommendations, your bank's fraud detection mechanism, to name just a few [41]. Healthcare is one of many domains in which AI is prevailing. Revolutionising the way healthcare delivery is provided to the patients. In terms of diagnostic precision, these intelligent systems imitate medical expert's perception of diagnostic experience and provide diagnosis with a high degree of accuracy. An eye-opening demonstration between human doctors and AI assisted machines was carried out in Royal College of Physicians. Based on 100 sample medical scenarios, the AI-enabled machines scored better than human doctors in terms of diagnostic accuracy with a high score of 98 percent [46].

Similarly, persons with functional disabilities, such as visual impairment will benefit from AI. However, such AI methods need to be embedded onto the state-of-the-art IoT devices in order to fully exploit AI capabilities. Furthermore, it is essential for AI-enabled devices to aid in real-time as non-real-time support may not serve the purpose of anytime and anywhere access defined earlier in this chapter. Although emerging technologies such as IoT may provide backend information and data, the front end or consumer-centred device would be AR-based smart glasses, providing valuable information to users during their daily routine inside and outside their homes.

Researching through the literature and as described earlier in this chapter, we found that there are studies, which contemplated to provide improved QoL for visual impaired. Such studies utilised ultrasonic sensors, microcontrollers, webcams, and audio feedback mechanisms to help in navigating through the obstacles [47]–[52]. However, they proposed bulky prototypes, which questioned the aspects of usability and user experience. In addition, these studies lacked the integration of AI in their tactile vision systems. Besides, the concerns of mobility and affordability were also associated with the proposed systems.

In recent times, AI-enabled intelligent vision systems have gained in popularity in academic, research and industrial communities, jointly working together to improve QoL for those with visual impairment. Innovative AI-based solutions, which mostly emphasize on navigation and obstacle detection have been proposed. These include: road crossing assistance; guide drones; locating and identifying bus stops; navigational tools to transverse between indoor and urban outdoor spaces; computer vision and VR/AR tools to complement human vision; to name just a few. The success of the aforementioned projects was made possible due to the advent of emerging IoT devices (e.g. Image and object capturing devices), and AI and machine learning techniques (e.g. neural networks, Fuzzy Inference Systems and deep learning etc.). Besides navigation and obstacle detection, social interaction is another paradigm that has found hope in AI-enabled solutions to cater for VIPs. Solutions such as 'Social Assistant', which incorporate cameras and vibrating belts as input devices have been found useful in providing visual cues corresponding to facial expressions, hand gestures, and head nodding of the social partner. The responses provide feedback verbally to the person with visual impairment.

Furthermore, in the years to come, the concept of AI-enabled 'Social Assistant' will be evolved into AI-enabled 'Personal Assistant' that would already know the voice, facial and physical attributes of people you interact with regularly. Embedded expression recognition features would recognise facial expressions (e.g. angry and humours expressions). Moreover, finding people would be possible. Such intelligent solutions are revolutionary when it comes to visual impairment, leading towards improved QoL. However, these require further testing and validation in terms of user acceptance and satisfaction, which is a gap that needs to be filled.

The concept of smart cities is a new paradigm that aims to overcome the aforementioned gap by endorsing the idea of smart living, utilising the best available features of AI, such as pattern recognition, expert prediction and robotics etc. Furthermore, smart homes, smart streets and smart transportation being the sub-categories of smart cities will revolutionise ambient assisted living especially for VIPs. In a smart city setting, the connectivity between IoT-enabled smart devices and the next generation wireless networks along with the concept of context-awareness will play an indispensable role to augment the QoL of VIPs. According to [50], the term context refers to "any information that can be used to characterise the situation of an entity, where an entity can be a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves". The distinctive features of context-aware systems are the ability to operate without user interaction as well as the ability to gather contextual information from user's environment and adapt to it accordingly. Such systems can be easily integrated into a smart city setting, which make them a suitable candidate for healthcare applications and in particular, for assisted ambient living for the visually impaired.

Considering user's environment, where the user is a person with visual impairment, the following characteristics have been identified that influence context-awareness. These include:

a) Physical and temporal characteristics (e.g. location).
b) Social Interactions
c) Economic characteristics (e.g. affordability)
d) Competency (e.g. ability to carry out a task)
e) Technical characteristics

The government, businesses and policy makers need to incorporate the identified characteristics in a smart city context to provide a good interaction between the visually impaired citizens and their environment.

Traditional white cane stick and guide dogs form basis for the AI-enabled systems to learn from. Primarily, white cane sticks and guide dogs are widely used by visually impaired for navigation and detect obstacles in their surroundings. White cane sticks only detect obstacles below the waist-line and does not provide precise information about user's surrounding, such as irregular objects, objects above waist-level and the distance between the user and the object. To answer the above limitations, Smart sticks and guide drones have been proposed. Such innovative solutions are indeed a step forward in reducing injuries associated with traditional vision support systems. However, these proposals are not completely AI-enabled, which is a major research gap, especially in a smart city context, which is all about AI-enabled smart living. To attain user acceptance with respect to AI-enabled smart sticks and guide drones, the following requirements need to be met:

a) Provide Real-time feedback, which should be haptic or tactile to ensure timely steering.
b) Provide contextual information about the user's environment.
c) Provide pattern recognition feature to identify obstacles and/or objects.
d) Provide precise distance information between the user and the obstacle.
e) Provide information to other commuters about their presence in vicinity.
f) Provide reliability.
g) Aid in terms of verbal as well as sensory instructions/commands.
h) Provide distinction between different objects as well as people.

Microsoft has recently launched "Canetroller", a virtual haptic cane, which provides visually impaired users with different types of feedback namely vibrotactile, spatial 3D auditory and resistance feedback in a virtual environment setup [53]. Participants could use the virtual cane to identify virtual objects such as a crossing, a bin or a table in a virtual environment set up in an empty room. The study showed that Canetroller was a promising tool that enabled visually impaired participants to navigate through virtual spaces and this could help them for orientation and mobility training [53].

Furthermore, for designing AI-enabled vision support systems, it is crucial to involve VIPs in the design process themselves. Such methodology will enable developers to customise the design that would suit their requirements. In addition, it may be necessary to bring their carers on board in the design process as they will provide input for the AI system to understand and prioritise the activities that visually impaired 'can do' and 'cannot do' on their own. Once the user requirements have been gathered, customising an AI-based solution should be straightforward, be it in any domain that is – indoors and outdoors. Elaborating on the AI aspect of the smart cities further, it is important for AI-enabled devices and/or software to be trained in order to replicate traditional approaches used by visually impaired intelligently and without much of human intervention.

VI. Conclusion

The features that should be considered to build smart cities for VIPs include smart homes, smart transportation, social interactions, and smart healthcare, which need to be supported by a proper legislation. In a smart city setting, VIPs located indoors should be able to identify obstacles and the distance in between them, switch on and off appliances, and capture anomalies. Outdoors, they should be guided through pedestrian crossings, and ultimately be provided an optimal route to the desired destination without any hindrance. When using public transportation, they should identify bus stops, be notified about bus arrival, and be directed towards vacant seat.

Smart city adoption is inspired by the fact that the QoL of people will be enhanced, and make the environment more disabled-friendlier. Technological advancements can enhance the ability of individuals to fully participate in social activities and live independently. Going towards this direction will provide ease of accessibility and support for all level of citizens. Moreover, the ICT-based technologies implemented in the smart cities make them more manageable by deploying sensing and monitoring capabilities along with utilizing data-driven approaches. In a generation of connected technologies, our developed smart cities will show its readiness and potential to align with such evolution and facilitate the path towards technological future.

With the advent of AI, artificial and tactile intelligent vision systems must incorporate image recognition features, obstacle detection, collision detection and fall detection in a single prototype. In addition, such prototypes should be user-friendly, accessible and adhere to safety, security and privacy requirements. While there are a number of technologies available in the market which offer promising future for the application of AR in a smart city for the visually impaired, it is far from the reach of normal consumer due to a number of constraints including high prices, limited programs and lack of research by the industry. The size of the proposed

AR glasses is also a consideration as they need to accommodate a camera, projection display, battery and the processor.

The adoption of smart city is still in its infancy as far as assisted living for visually impaired is concerned. For an intelligent vision support system, it is important to recognise and prioritise the essentials that VIPs would associate with their improved QoL. Besides, user acceptance in terms of accessibility, privacy and security are pre-requisites for such intelligent and guided vision support systems to find sustainable success in the field of healthcare.

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