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ABSTRACT

Since the assistive devices used to support disabilities for enhancing life style, intelligent assistive technologies for the visual impairments have been widely developed. However, this study examined how to enhance the usability for the visually impaired users while navigating with intelligent assistive device and establish the essential features which is required to assistive technology for the users. To evaluate the features, three standards (Accessibility, Depth of Information, Obstacle Detection) have been derived and through the principles of universal design systems which has positive relation with the standards have been analysed. The evaluation of the systems showed positive relationship between the three standards and enhancing usability, therefore successfully identified the essential features: system should be able to use in both indoor and outdoor area; system should use tactile or acoustic sense but also need an accurate supplement of the disturbing conditions; system should alert detailed information in real-time.

1 INTRODUCTION

With the interest in investing in Assistive devices has increased, the government has established sustainable development goals (SDGs) and has thus established the implementation of rehabilitation and assistive services (Tebbutt *et al.*, 2016:5). The definition of assistive technology (AT) which had used comes from US Public Law (PL) 100-407, the Technical Assistance to the States Act in the United States (Cook and Polgar, 2015:17):

"Any item, piece of equipment or product system whether acquired commercially off the shelf, modified or customized that is used to increase, maintain or improve functional capabilities of individuals with disabilities."

According to World Health Organization (WHO), Global Cooperation on Assistive Technology (GATE) has programmed to give the opportunity to the disables and aged individuals to afford qualified assistive technology (Boot *et al.*, 2017:1). With the vast development and implementation of portable devices, technologies and software have been created to assist blind users. However, still there is not a clear consensus in the literature on the essential features required by blind users, and how intelligent devices can deliver this. The aim of this study is to compare the technology and systems for visually impaired users, then find the fundamental features that will enhance targeted users to increase the use of ATs. By this evaluation, providing a comprehensive overview with a result of an analysis, which should identify effective future research areas in the field. Thus, visually impaired users can travel as self-control, autonomy, and confidence will obtain by using highly maintained ATs.

Therefore, this paper will conduct three key standards which will be used to compare the technologies in the literature review and methodology, while analysing the assistive systems for the visual impairments in discussion chapter, then finally, evaluate how to improve usability for sustainable development, and present reliable future research directions.

2 LITERATURE REVIEW

2.1 INTRODUCTION

Intelligence assistive technology for global positioning system (GPS) is usually smart devices which can interact with blind individuals to detect obstacles while moving to another point, while navigation system for sighted people are focusing on amount of information that includes maps, personalised database and additional information which can directly be connected to a possible follow-up actions: building information, traffic, and public transportation. Moreover, by storing preferences within the GPS system, and being available to interlock with other applications, GPS device has steadily increased its usability. Navigating method for visually impaired individuals, however, can be divided into traditional assistance and intelligence assistance. For traditional methods, guide dogs, a sighted guide and blind cane are the main examples, while for digital-assistive devices, the most common technologies are based on the tactile and auditory senses; therefore, mobile applications, alternative mobility devices such as wearable devices and electronic aids are used commonly (Hersh and Johnson, 2008; Cook and Polgar, 2015:336).

This literature review will analyse the limitations of each intelligent assistive navigating device for the blind by comparing different type of device such as application in mobile gadget and wearable devices, then evaluate which possible solutions could enhance usability will be examined. Firstly, this literature review will define the definition of global positioning system and determine the major system and functions of GPS handheld gadgets for non-visually impaired users with including limitations in section 2.2. Following this section, it will introduce the essential elements for the blind while navigating, and aid navigation methods. In section 2.4, two methodology will be discussed to solve the current intelligent assistive device. Finally, a summary will be given, with mentioning possible solutions in the conclusion of this literature review. This literature review, therefore, aims to identify the necessary factors for the blind, draw up a methodology for comparative analysis, and evaluate it in the Discussion section.

2.2 Intelligence Navigation Tools for Non-Visually Impaired Users

The Global Positioning System (GPS) is a satellite constellation, developed by U.S. Department of Defence to replace the TRANSIT system which was the first positioning system called Navy Navigation Satellite System (NNSS) (Hofmann-Wellenhof *et al.*, 2012:3; Bock and Melgar, 2016:2). The TRANSIT system was firstly used for determining the coordinates of ships and aircraft, but soon the system became to use for both navigating and surveying purpose (Hofmann-Wellenhof *et al.*, 2012:3). However, due to the two critical shortcomings in TRANSIT system, GPS were developed, and this new system complemented earlier problems and began to support military, civilian positioning, timing, and navigating (*ibid*:3; Bock and Melgar, 2016:2). According to Bock and Melgar's article (2016:2), estimating time bias and triangulate 3D position is essential while navigating, therefore civilian can receive accurate information. By using GPS-based navigation system, users could explore an unknown environment to a known destination (Baker, 1982, cited in Erçevik Sönmez and Erinsel Önder, 2019:103).

2.2.1 Intelligence Navigation Systems for Sighted Users

Application with GPS system and associated geographic databases, can point the location by the latitude and longitude, which will provide a name to those coordinates (May and LaPierre, 2008:272). To provide unlimited geographic information, 'Google Earth' used a client-based program, developed in 2004 and open to public in 2006 for free (Ballard, 2012:115). A client-based program basically provides combining satellite images of the earth and add infrastructure information and then, users can individually include additional photos by accessing to personal account (*ibid*). Google Map, however, is a web-based service, developed in a following year, can provide a web-based satellite image when users input their destination and as Google Map and

Google Earth is provided by Google, map users could access to the Google Earth by their account (*ibid*).

On the other hand, applications can operate in wearable devices (e.g. smart watch) which are affordable, portable, and attachable as embedded or accessory devices (Chen *et al.*, 2016: 1521; Dehghani *et al.*, 2018:481). As Benson *et al.* (2018:124) mentioned in their systematic review, these devices estimate the movement pattern of the user with all types of individuals in real-world settings, and store them in the database, enabling users to take care of their health, and to track their location. Additionally, since Hsiao (2017:186) argued about the smartwatch which can connect with mobile phones and interact specific information such as personal schedules and GPS data, intelligent wearable technologies represents assistive devices for many different disabled users, old generations, and younger generations.

2.2.2 Navigation Functions and Hardware

According to Retscher (2016:1), navigation can be divided in indoor positioning and outdoor environment navigation. It mentioned that outdoor navigation is dominated by Global Navigation Satellite System (GNSS) based system while indoor navigation is defined as a covered structure that has no overall solution that able a single technology to travel that area (*ibid*). however, devices use radio waves, acoustic signals, and sensorial technologies to provide accurate information for both indoor and outdoor environment (*ibid*). In terms of technologies that use radio waves can be divided technologies based on Oxley (2017:5): Radio-frequency identification (RFID); Radiodetermination-satellite service (RDSS); Cellular networks; Wireless sensor networks (WSNs); Wireless local area networks (WLANs). Among these technologies, RFID technology have 10 cm of accuracy and benefits on line of sight, therefore it could be classified to wireless technology (ibid). More specifically, recently developed UHF RFID band which has specified in high gain and a wide read range are being used in various navigation devices (Benmessaoud *et al.*, 2015:4). Users should learn the accurate reading range whereas cannot provide information, additionally, while travelling outdoor area, the location should be noticed to visually impaired users to contact with the reader (*ibid*:1).

Thus, beacon technology has been used in similar purpose with RFID (Liu and Hsieh, 2018:1). As beacon is a product that uses low-power Bluetooth technology, it has been used broadly, not only navigating, but also payment, tracking items therefore some devices focus on specific purposes such as shopping or museum tour (ibid; Tapu *et al.*, 2018:2).

Meanwhile, navigation devices seem to use various hardware, used to use smartphone-based technology, but since wearable devices developed, due to its portability, the use of navigating with wearable devices has been increased (Dehghani *et al.*, 2018:1).

2.3 Navigation Intelligent Assistive Technologies for Visually impaired Users

2.3.1 Fundamental Information for the Blind users

Schinazi *et al.*, had reported the spatial navigation in their paper with fundamental features for the blind while finding ways (2016:38). According to Schinazi, visually impaired navigators recognise the path firstly, then mapping it in virtually (ibid:43). Therefore, visual impairments need to measure spatial learning throughout the whole path to assess learning potential without sight (ibid:47). This study also addressed three technological approaches when targeted users use navigation ATs. First, non-invasive technologies including SSDs which assist to learn the natural ability to adapt the received surrounding information, Secondly, invasive technologies which can alert the damaged areas, finally, general navigation aids that can enhance users to achieve spatial information by using functioning senses (ibid:46). While Cook and Polgar also discussed some necessary functions that systems should obtain to be used effectively by blind users (2015:339). As a result, explanation of spatial details and obstacles that can damage area or user itself should be provided by the system wile navigating to the destination.

2.3.2 Assistive Technologies and Fundamental Features

Since traditional assistive devices are still used broadly, in this section, distinguishing the traditional method with each limitation, then find fundamental features that had used in both traditional method and intelligent ATs will examined below.

2.3.2.1 Traditional Assistive Methods

Traditional assistants are basically guide dog and white cane. These methods have both limitations, however according to Cook and Polgar, most of the developed electronic travel aids (ETAs) are designed to be used for supplement of these traditional methods rather than replace it (2015:337).

Sensor	Cost	Type	Usability
Guide dog	High	Genesis	Not easily available; needs carer
White cane	Low	Mechanical	Slow and can only find obstacles through touch

Figure 1. Traditional Navigation Assistive methods with Cost, Type, and Usability.

Adapted from: Cook and Polgar*.,* 2015

2.3.2.2 Sense

With the development of ATs, especially for the blind users, replacing sight sense to other sense is available. According to Tapu *et al.*, current navigation ATs used to consist various senses such as acoustic, tactile, and assistive technology for sights: video camera (2018:2).

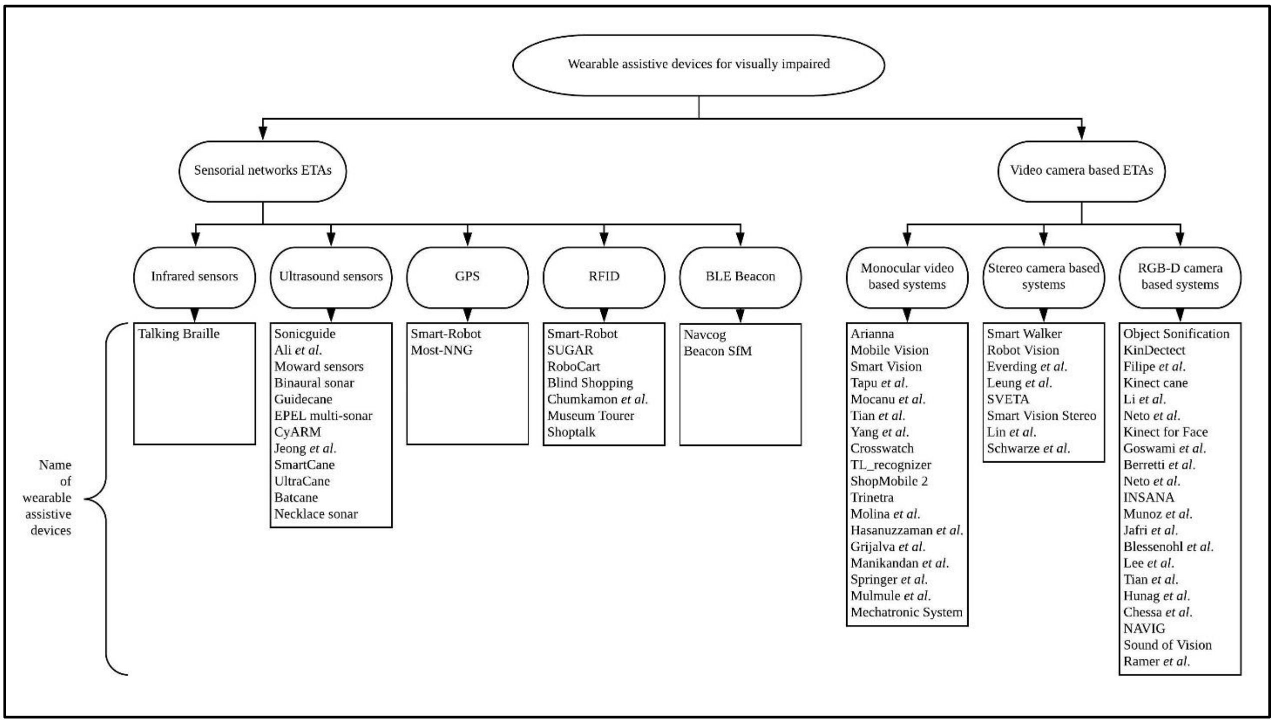

Figure 2. Wearable assistive devices for visually impaired

Adapted from: Tapu *et al.,* 2018

Figure 2 shows wearable devices for visually impaired users; however, it includes smartphone-based technology due to combined systems. Acoustic sense is in other word voice assisted technology, and according to Noorithaya *et al.*, the method that of voice assisted technology can divided in two method which are alert function and text-to-speech function (2014:179). Both technologies are used to send the information to user, however alert function only send the sound that not includes any information, but user could identify that new situation has happened, while text-to-speech includes surrounding data (ibid).

2.4 Factors Required for Technical Analysis of Assistive Technologies

According to various studies, navigation ATs had tested the proposed design of AT whether it contains high accessibility, reliable information and range of information, and obstacle detection which are also mentioned in the report by Schinazi *et al.* (Schinazi *et al.*, 2016:38; Coughlan and Shen, 2013; Munoz *et al.*, 2016).

According to Ding *et al.*, the feature in terms of using RFID technology to visually impaired users to navigate outdoor environment, various features were required to be considered (2007:2059).

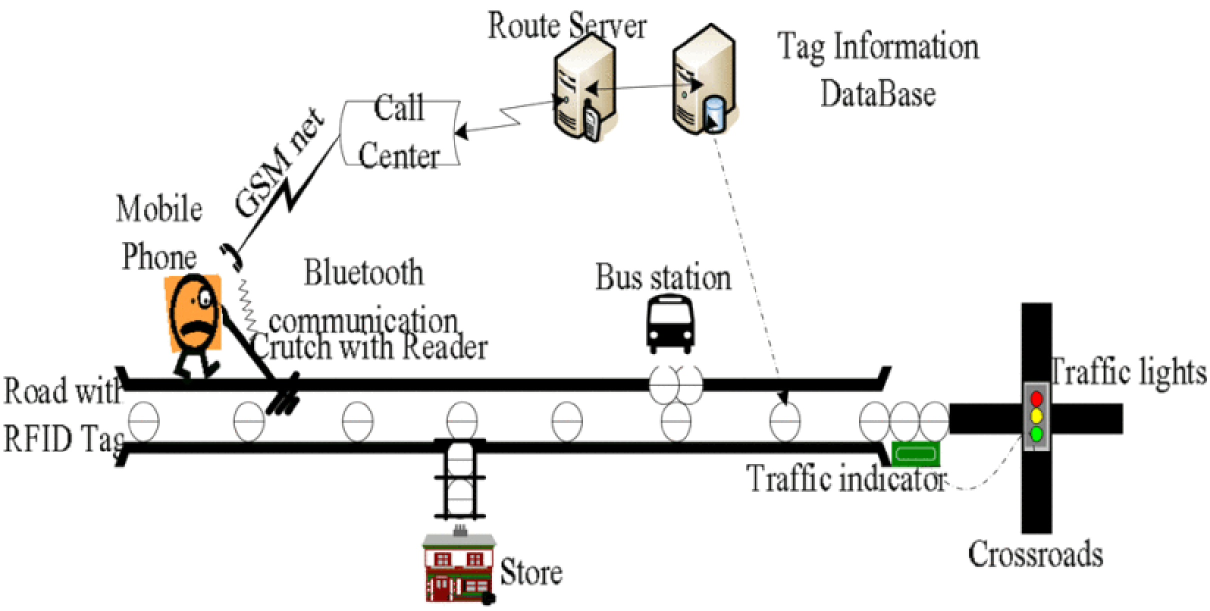

Figure 3. The road frame of blind navigation technology using RFID.

Adapted from: Ding et al., 2007

RFID tags are the fundamental requirement; however, the system should be considered the traffic signs and traffic light which can be classified in obstacle and damageable environment (ibid). Moreover, Akbar and Misman reported the error in meters while blind users use mobile phone applications in an outdoor and indoor area, unless tested result would not be reliable when using the technology in real-life (2018:197).

2.5 CONCLUSION

Based on literatures, ATs could divide in smartphone-based system and wearable devices, while both technologies could commonly use wireless functions and sense to send the accurate information to users. To discuss the critical analysis in the discussion chapter, three standards have been introduced based on Cook and Polgar, and Tapu et al, and Schinazi *et al.* Therefore, Accessibility, depth of information which includes both the range of information and reliable information, and finally obstacle detection will be used throughout the discussion to analyse ATs include systems that was reported in figure 2.

3 METHODOLOGY

3.1 THE SCOPE OF THE STUDY

This study is conducted by secondary research to identify main features that enhance usability of navigation ATs. Although the target of the study was limited to the lifelong blind in the conception phase, to increase applicability, the scope was broadened to people who are visually impaired. In terms of intelligent ATs with variety of capabilities, to recommend to current users and propose future studies, this study only extracted and analysed systems that are under eight years old.

3.2 SOURCES USED IN LITERATURE REVIEW

The sources used in this research were obtained through a rigorous search of academic databases, notably Science Direct and IEEE, Springer, Wiley Online Library as well as organisations dedicated to visual impairment and assistive technologies, such as US National Library of Medicine National Institutes of Health, and MDPI.

3.3 Analysis of Discussion

According to literature in chapter 2, through the analysis of relevant literature on this subject, it has been confirmed that specific analytical conditions, closely related to enhancing usability are necessary. Thus, the analysis condition is conceived in combination with the conditions analysed by Tapu *et al.*, and principles of universal design (Tapu *et al.*, 2018:11; Mace, 1997). These characteristics can be divided in three criteria: Accessibility, Depth of Information, and Obstacle Detection. Each fundamental condition includes the principles introduced by Mace (1997).

Meanwhile, features used in Tapu *et al.*, will used to make a detailed analysis in three conditions. Finally, to evaluate and analyse intelligent ATs efficiently, critical comparison has been done as the process listed below.

a. Distinguish highly accessible ATs when using mobile devices, wearable devices, and RFIDs.
b. For mobile devices, divide the applications by 'RFID functions', then define the accessibility of the device and application by comparing some applications.
c. To deduct suitable ATs, distinguish the most highly accessed mobile applications, and identify both deficiency conditions and superior conditions of the chosen application.
d. Repeat b. and c. for Wearable devices.
e. Define the suitable device and application that possess high accessibility by comparing each application from two types of hardware: mobile phone, and wearables.
f. Repeat a. to e. for each analysis conditions: depth of information, obstacle detection.
g. Collect the technologies derived from the three analysis criteria.
h. Identify technologies that meet all three criteria or meet one or more.
i. Make a recommendation of those technologies.

4 Discussion

4.1 Introduction

As reported in Chapter 3, the three conditions (Accessibility, Depth of information, and Obstacle detection) extracted in the 7 principles of the universal design serve as criteria for analysing each of the individual assistive technologies in this Discussion chapter. To enhance the usability, firstly, features from each ATs will be distinguished, and the features of each analysis, condition are then separated and compared to other ATs which can therefore define the deficiency part that requires complement. However, by comparing the use of wireless function and additional criteria to establish the relationship between the features and wireless will be examined in each evaluation, therefore the usable ATs will be deducted at the end of this chapter.

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4.2 Evaluation of Accessibility

Three additional standards which can help further analysis of accessibility of two systems (smartphone-based system and wearable devices) are (Tapu *et al.*, 2018):

Portability	The system should be light, ergonomic and easy to wear
Friendliness	The system should be easy to learn without any medium or long-term dedicated training
Usable area	The system should function in both, indoor and outdoor scenes

Portability describes how convenient the system or device is when it comes to use by visually-impaired users, while friendliness describes whether it requires an extensive training period for users to use the system skilfully or users may have no problem to start using the system directly. Finally, a usable area describes the available area that system works, therefore, divided by indoor, outdoor, and both indoor and outdoor areas. By analysing with these standards, systems and devices could be evaluated that has high accessibility to targeted user or not.

4.2.1 Smartphone-based System

The table below has four criteria: wireless, usable area, friendliness, and portability. Systems in this part, are basically using a smartphone while travelling, however, it includes smartphone-based systems, therefore, some systems could have additional wearables. The first criteria divide the system that uses a wireless function or not to identify the process of the system. Using the wireless function affects usability because the method of reading data is different compared to non-wireless devices. After dividing wireless function, usable area, friendliness and portability will be compared.

Most of the systems have mentioned directly about their level of friendliness and portability in their paper, however, some level of those factors had decided based on the description of the system interface and database.

Table 1. Analysis of Smartphone-based Blind Navigation Assistance to define the Accessibility

Adapted from: Benmessaoud *et al.*, 2015; Coughlan and Shen, 2013; Ishihara *et al.*, 2017; Tapu *et al.*,2013; Tapu *et al.*,2018

System name (Year of publication)	Usable area	Wireless	Friendliness	Portability
Mobile Vision (2012)	Indoor	No	Low	High (no extra equipment is needed)
Crosswatch (2013)	Indoor/Outdoor	No	Low	High (no extra equipment is needed)
Tapu *et al.* (2013)	Indoor/Outdoor	No	High	Moderate (Equipment: Chest mounted harness, and bone conducting headphones)
BlindeDroid (2015)	Indoor/Outdoor	Yes (Beacon)	Low	High
Benmessaoud *et al.* (2015)	Indoor	Yes (RFID)	Moderate	High
Beacon SfM (2017)	Indoor/Outdoor	Yes (Beacon)	High	High

Based on Table 1, applications can be divided in using wireless function and not using wireless function while blind navigating. In terms of applications that does not apply any wireless function, Tapu *et al.*, presents highest accessibility. It is possible to use in both indoor and outdoor environment, with high friendliness this system requires additional wearable device. By using chest mounted harness to fix smartphone, the system could obtain high friendliness unlike other smartphone-based systems. Due to the interface of smartphone, using smartphone for travelling requires additional training which is the major consideration point for friendliness, but with using additional equipment, this system can reject training time.

On the other hand, applications which use wireless functions are divided with using beacon technology or RFID technology. In terms of Beacon technology, based on its c does not require users to learn the exact location of the beacon device, therefore considered to have high friendliness level compared to RFID technology.

Based on this analysis of a range of systems, the ones by Tapu et al (2013) and Beacon SfM (Ishihara *et al.*, 2017) are identified as the most accessible designs (see Table 1). These perform best in terms of usable area, friendliness, and portability. Assistant technology used beacon system has high level of both friendliness and portability including both indoor and outdoor navigation, while technology introduced by Tapu *et al.*, produce high friendliness with moderate level of portability as it requires wearables. The limitation of the assistive technology proposed by Tapu *et al.* is that wearing additional equipment is necessary while the purpose is essential for obtaining accurate environmental information by taking surrounding images, therefore considered that rejecting or replacing the equipment is not acceptable.

4.2.2 Wearable Device

In this Chapter, analysis sensorial network systems and video camera base systems in one table, then evaluate devices that has high accessibility. Sensorial network systems have five type of sub division, however due to the old proposed date and by extracting wearable devices, ultrasound sensors are the only available sensorial systems to analyse in this chapter. While video camera-based system, it is possible that combining senses with using camera therefore three criteria that used in smartphone-based system and additional criteria for identifying sensor type is analysed below.

Table 2. Analysis of Wearable Devices use Ultrasound Sensor for Blind Navigation to define the Accessibility.

Adapted from: Jeong *et al.*, 2016; Villamizar *et al.*, 2013; Wahab *et al.*, 2011

System name (Year of publication)	Usable area	Wireless	Sense type	Friendliness	Portability
SmartCane (2011)	Indoor/Outdoor	No	Tactile, Acoustic	High	High (Optional earphones)
Necklace sonar (2013)	Indoor/Outdoor	No	Tactile	High	Moderate (Use white cane)
Jeong *et al.* (2016)	Indoor/Outdoor	No	Tactile, Acoustic	Moderate	Moderate (guide device)

Three systems which is divided in ultrasound sensors, commonly applied any wireless functions, however covers both indoor and outdoor area. The type of sense that each system used for sending ultrasound sensor is acoustic and tactile, while the guide device which introduced by Jeong *et al.*, applied both sense by using controller button. However, in terms of level of friendliness, proposed guide device is considered to have a moderate level due to the controller which requires an extensive training. Although the interface of the guide device seems to be like traditional cane, the bottom of the device is designed in round shape so that can roll the pathway which also requires training for users. The portability level of this device is considered to a moderate as necklace sonar, however, in case of smart cane, ultrasound wave is applied in traditional white cane by using intuitive acoustic sense, therefore considered to have high level in both criteria.

Table 3. Analysis of Wearable Devices use Video Camera for Blind Navigation to define the Accessibility.

Adapted from: Caraiman *et al.*, 2017; Du Buf *et al.*, 2011; Li *et al.*, 2016; Mocanu *et al.*, 2016; Schwarze *et al.*, 2015; Tian *et al.*, 2013

System name (Year of publication)	Usability	Wireless	Sensor type	Friendliness	Portability
Smart Vision (2011)	Indoor/Outdoor	Yes (RFID)	Acoustic	moderate	Moderate (Equipment: white cane, passive RFID tags)
Tian *et al.* (2013)	Indoor	No	Acoustic	Low	Moderate (Equipment: Sunglasses, Optional earphones)
Schwarze *et al.* (2015)	Outdoor	No	Acoustic	Moderate	Low (Equipment: Helmet and white cane)
INSANA (2016)	Indoor	No	Acoustic	High	Low (Equipment: Tango Android tablet, Chest mounted harness, Optional white cane)
Mocanu *et al.* (2016)	Indoor/Outdoor	No	Acoustic	High (Smartphone embedded system)	Moderate (Equipment: Belt)
Sound of Vision (2017)	Indoor/Outdoor	No	Tactile	High	Moderate (Equipment: Acquisition device attached to headgear, recommended to use white cane)

Table 4 indicates wearable assistant devices using video camera, but still, a method of transmission using sensory system is including. The initial difference between using ultrasound sensor and using video camera is the use of wireless. Smart Vision used wireless function, especially the RFID tags, which affects the level of portability and friendliness. Smart Vision use passive RFID tags without mobile phones which can reduce the size of carrying on items, however considered to reduce the convenience while carrying therefore has moderate level on portability factor and using mobile application requires higher training then carrying RFID tags.

On the other hand, other devices use any wireless function, but devices proposed by Tian *et al.*, Schwarze *et al.*, and INSANA system focus on one type of area especially device by Tian *et al.*, and INSANA is dedicated for indoor use, although the portability level is not considered to be high. However, as INSANA requires multiple equipment that cause reducing portability, that equipment enable detailed and intuitive use. Wearable device proposed by Mocanu *et al.*, used smartphone embedded system; not smartphone-based system therefore not listed above. As the video camera is built in smartphone, this system requires accurate method to take a video therefore use a belt which could fix the mobile phone. However, the chosen method to send information to user is acoustic, therefore it is considered to have high level of friendliness.

In assistive wearable devices, high accessibility had indicated in devices that include no wireless function (see Table 2 and 3). Three devices that shaded with light orange, commonly shows high friendliness although different types of device were applied. Video camera base devices shows slightly low portability level due to the equipment that assist video shooting. Since Smartcane had considered to have both high level on friendliness and portability, still psychological problem of receiving information through ultrasound exists as a limitation.

4.2.3 Conclusion

Based on the above analysis of a range of wearable devices and smartphone-based systems, smart cane (Wahab *et al.*, 2011) and Beacon SfM (Ishihara *et al.*, 2017) are defined as the most accessible designs (see Table 4).

Table 4. Summary of Assistive Technologies (ATs) for both Smartphone-based system and wearable devices to evaluate the Accessibility.

Adapted from: Caraiman *et al.*, 2017; Ishihara *et al.*, 2017; Mocanu *et al.*, 2016; Tapu *et al.*, 2013; Wahab *et al.*, 2011

System name (Year of publication)	Usable area	Wireless	Sense type	Friendliness	Portability

SmartCane (2011)	Indoor/Outdoor	No	Tactile, Acoustic	High	High (Optional earphones)
Tapu *et al.* (2013)	Indoor/Outdoor	No	-	High	Moderate (Equipment: Chest mounted harness, and bone conducting headphones)
Mocanu *et al.* (2016)	Indoor/Outdoor	No	Acoustic	High (Smartphone embedded system)	Moderate (Equipment: Belt)
Beacon SfM (2017)	Indoor/Outdoor	Yes (Beacon)	-	High	High
Sound of Vision (2017)	Indoor/Outdoor	No	Tactile	High	Moderate (Equipment: Acquisition device attached to headgear, recommended to use white cane)

In terms of distinguishing the relationship between the use of wireless function and both friendliness and portability, as wireless functions require additional training to users (learning the maximum distance of RFID tag read-range or learn how to divide essential information and subsidiary information), it affects negative impact on friendliness. Moreover, if the system designed to operate RFID tags or Beacon system, mobile application or tag adaptor is necessary. Despite these limitations, as the read-range and data transfer rate have positive relationship, developing tag antenna which affect the maximum power transfer may increase the read-range (Ennasar *et al.*, 2014:1).

4.3 Evaluation of Depth of Information

The additional standards in terms of evaluating the depth of information are listed below (Tapu *et al.*, 2018):

Processing speed	The system should function in real-time and to alert immediately the user about an obstacle situation
Coverage distance	The maximum distance between the user and an object for which detection can be performed, and the distance of available error if it is noticed

Processing speed represents flexibility in use and perceptible information because real-time response effects on reliability and increasing reliability could result the increase of flexibility. Coverage distance include the length of error, also affects flexibility and reliability, for instance, as the maximum distance increase, data can be collected before users reach their destination, improving the speed at which data is collected, while at the same time, being able to obtain accurate information in a coverage distance, therefore enabling flexible access to information.

4.3.1 Smartphone-based System

Table 5 compares processing speed and coverage distance in terms of smartphone-based assistive devices.

Table 5. Analysis of Smartphone-Based Blind Navigation Assistance to define the Depth of Information.

Adapted from: Benmessaoud *et al.*, 2015; Coughlan and Shen, 2013; Ishihara *et al.*, 2017; Tapu *et al.*,2013; Tapu *et al.*,2018

System name (Year of publication)	Wireless	Processing speed	Coverage distance
Mobile Vision (2012)	No	8 frame per second (fps)	3.5 meter (m)
Crosswatch (2013)	No	-	1 m
Tapu *et al.* (2013)	No	7 fps	2 m
BlindeDroid (2015)	Yes (Beacon)	XML files with a cache: immediately send info	Tested distance: maximum 7.6 m (error: 0.47 m)

Benmessaoud *et al.* (2015)	Yes (RFID)	Efficiency: 86.13 %	- Read-range: 21.44 m - Distance between the transmitter antenna and the tag: 1 m - Reflection coefficient: less than (-)10 dB
Beacon SfM (2017)	Yes (Beacon)	Localize one image: Mean 1.41 s	Short-range passive communication: 0.30 m (error: 0.45 m)

Systems which have no wireless functions have indicates the processing speed by using frame per second (fps) units, while devices that use wireless technologies does not mention directly because Beacon and RFID tags represents immediate response when user attach the appropriate tag at the transmitter or when user entered the Beacon zone. The maximum 21.44 m coverage distance was available by the device introduced by Benmessaoud *et al.* with dedicating 86.13 percent of efficiency rate. However, this device can have (-)10 dB for reflection coefficient, in other words, the distance of read-range can have (-)10 dB errors. While in terms of systems with no use of wireless function, Mobile Vision possess fastest processing time by 8 fps and largest coverage range for 3.5 meter.

4.3.2 Wearable Device

In this section, analysing will be discussed in same process as in section 4.2.2. However, processing speed and coverage distance can consider in multiple factors, therefore overall data which has a connection with the standard will mentioned in the table.

Wearable devices which use ultrasound sensor usually calculate its processing speed by using kilometre per hour (km/h), and meter (m) unit was used for coverage distance.

Table 6. Analysis of Wearable Devices use Ultrasound Sensor for Blind Navigation to define the Depth of Information.

Adapted from: Jeong *et al.*, 2016; Villamizar *et al.*, 2013; Wahab *et al.*, 2011

System name (Year of publication)	Wireless	Sense type	Processing speed	Coverage distance
SmartCane (2011)	No	Tactile, Acoustic	-	Detect range: 1 m
Necklace sonar (2013)	No	Tactile	Cannot detect the object when it crosses the sensor at speeds larger than 1m/s (Convert: 3.6 km/h) (regular	Factory specification detection range: 6 m and an angle of 35 degrees Outdoor detection range: maximum 3 m (average 1.5 m)

			walking speed does not affect detecting)	
Jeong *et al.* (2016)	No	Tactile, Acoustic	3 km/h (12.5 times performed in a second)	2 m and an angle of 30 degrees (error of distance: less than 2 cm)

According to the table 6, Necklace sonar process cannot detect the object which has more than 1m/s speed and it can be converted to 3.6 km/h, in other word, the processing speed should take longer than the object appears. In terms of coverage distance, device can be set up to 6m range with an angle of 35 degree, however by user testing, maximum 3m is suitable detection range. While the processing speed of the device by Jeong *et al.*, was shortest for 3 km/h and the device can perform 12.5 times per second, however the result was not calculated in real situation testing therefore necklace wearable assistant is considered to have qualified depth of information.

On the other hand, wearables which use video camera for navigating calculate the processing speed by frame per second (see table 7).

Table 7. Analysis of Wearable Devices use Video Camera for Blind Navigation to define the Depth of Information.

Adapted from: Caraiman *et al.*, 2017; Du Buf *et al.*, 2011; Li *et al.*, 2016; Mocanu *et al.*, 2016; Schwarze *et al.*, 2015; Tian *et al.*, 2013

System name (Year of publication)	Wireless	Sensor type	Processing speed	Coverage distance
Smart Vision (2011)	Yes (RFID)	Acoustic	5 fps	2 m
Tian *et al.* (2013)	No	Acoustic	- (not tested)	- (sight range for eyeglasses)
Schwarze *et al.* (2015)	No	Acoustic	15 fps Latency time: up to 50ms	10 m (Tested up to 20 m distance include re-detecting)
INSANA (2016)	No	Acoustic	5 fps	3 m
Mocanu *et al.* (2016)	No	Acoustic	10 fps	5 m
Sound of Vision (2017)	No	Tactile	10 fps (camera -> 3D reconstruction -> 3D ground detection -> segmentation -> object detection -> information to user)	5-10 m

Timing the frame of the video can cause total processing speed because devices are operated based on the video it took. Except device introduced by Tian *et al.*, the processing speed was calculated highest in the device suggested by Schwarze *et al.* for 15 fps. This system also showed the largest coverage distance among other devices for 10m. The similar result was showed in Sound of Vision (2017) by 5 to 10m distance range, however as Schwarze *et al.* had calculated re-detecting distance which tested up to 20m distance, the largest range of use should be considered in the device by Schwarze *et al.*

4.3.3 Conclusion

As the analysing of the depth of information is vital point for the blind while navigating, multiple factors was considered during the analysing process. The major point to notice in this section is that each device uses different unit, uses different calculation and diverse methods on both processing speed and coverage distance, however, most systems address the explanation about two factors.

Table 8. Summary of Assistive Devices for both Smartphone-based system and wearable devices to Evaluate the Depth of Information

Adapted from: Benmessaoud *et al.*, 2015; Schwarze *et al.*, 2015; Tapu *et al.*,2018; Villamizar *et al.*, 2013;

System name (Year of publication)	Wireless	Sensor type	Processing speed	Coverage distance
Mobile Vision (2012)	No	-	8 frame per second (fps)	3.5 meter (m)
Necklace sonar (2013)	No	Tactile	Cannot detect the object when it crosses the sensor at speeds larger than 1m/s (Convert: 3.6 km/h) (regular walking speed does not affect detecting)	Factory specification detection range: 6 m and an angle of 35 degrees Outdoor detection range: maximum 3 m (average 1.5 m)
Benmessaoud *et al.* (2015)	Yes (RFID)	-	Efficiency: 86.13 %	- Read-range: 21.44 m - Distance between the transmitter antenna and the tag: 1 m - Reflection coefficient: less than (-)10 dB
Schwarze *et al.* (2015)	No	Acoustic	15 fps Latency time: up to 50ms	10 m (Tested up to 20 m distance include re-detecting)

The most effective depth of information for assistive device is in highlight (see table 8), which are both wearable assistants. Although this comparison seems to have limitations because of different units and factors are used to examine the speed and distance range, mobile devices had little information about the processing speed and present relatively short coverage distance, therefore necklace sonar and wearable device proposed by Schwarze *et al.*, are evaluated to have the largest depth of information.

4.4 EVALUATION OF OBSTACLE DETECTION

Finally, the obstacle detection will be evaluated in this section. The additional standards are listed below (Tapu *et al.*, 2018):

Robustness	When it comes to receiving information, users should not be disturbed in any environmental perturbations
Detective	The system should be able to detect any type of object regardless its position, shape, size, and should consider road condition

Robustness represents fluent information sending process which has also relation with perceptible information, therefore may have a correlation between the factors which used in section 4.3. However, the level of robustness affects the detect rate and error of detecting, in other words, the tolerance of error could be affected by how high the system considers robustness. As a result, by comparing these factors, overall obstacle detection will be derived. The level of robustness can be decided when the ATs have various test results. Therefore, the system which does not have any conditions for robustness does not mean that it cannot detect or cannot be processed smoothly, however did not tested with various conditions to tackle obstacles.

4.4.1 Smartphone-based System

Smartphone-based ATs have few experiments compare to wearables as it shown in table 9, 10. As indicated in the table 9, in terms of applications which use wireless functions present disturbing conditions or detective conditions. The reason of it is the purpose of the developing the system and using wireless technologies because the advantages of using beacon or RFID is sending accurate information of the area rather than navigating without facing problems by surrounding environment.

Table 9. Analysis of Smartphone-Based Blind Navigation Assistance to define the Obstacle Detection

Adapted from: Benmessaoud *et al.*, 2015; Cecílio and Furtado, 2015; Coughlan and Shen, 2013; Ishihara *et al.*, 2017; Tapu *et al.*,2013; Tapu *et al.*,2018

System name (Year of publication)	Wireless	Robustness	Detective
Mobile Vision (2012)	No	High	-
Crosswatch (2013)	No	Low (noise issues are not been tested)	Moderate (two types of crosswalk markings, the presence of walk signal lights in real time, Alignment information is obtained to user)
Tapu *et al.* (2013)	No	High	Any shape, Any size, Static and Dynamic, Any position
BlindeDroid (2015)	Yes (Beacon)	-	Low (wall conditions)
Benmessaoud *et al.* (2015)	Yes (RFID)	Reflection coefficient: (-)10 dB (no test has been processed in real-world or places that has environmental perturbations)	-
Beacon SfM (2017)	Yes (Beacon)	-	A-KAZE system was used (High detection rate for: Bikes, Boat, UBC, Trees, Synthetic Rotation sequences (Alcantarilla and Bartoli, 2013:9))

On the other hand, based on applications without wireless functions, Tapu *et al.*, presents high level of robustness and can detect any shape, size, movement, and position while navigating. Although the system did not mention what conditions they considered to increase the level of robustness, as the application can detect almost every type of obstacle, the level should be higher than other systems.

4.4.2 Wearable Device

In terms of wearable ATs especially devices that use ultrasound sensor, robustness can be explained by using frequency of ultrasound wave if the system set the conditions of noise in surrounding area. Detective factor can be explained in various way, however, because by this analysing, the relation with the tolerance for error should discussed, conditions which limit detecting obstacle can explain the detect factor for wearable devices.

Table 10. Analysis of Wearable Devices use Ultrasound Sensor for Blind Navigation to define the Obstacle Detection

Adapted from: Jeong *et al.*, 2016; Villamizar *et al.*, 2013; Wahab *et al.*, 2011

System name (Year of publication)	Wireless	Sense type	Robustness	Detective
SmartCane (2011)	No	Tactile, Acoustic	Moderate Size-40 kHz frequency (Audible noises: less than 20 kHz, Industrial noises: use MHz units)	Object distance: detect until 4 feet Road conditions: water sensor (detect only the water is over 0.5cm)
Necklace sonar (2013)	No	Tactile	Tested: 25-43 obstacles (pedestrians, open umbrellas, carts, curbs, traffic signs, telephone booths, traffic lights)	Indoor: detection avoidance rate: more than 80% Outdoor: more than 75%
Jeong *et al.* (2016)	No	Tactile, Acoustic	Detecting range: walking path, overhang, down step	Tested: 5-7 obstacles, Low avoidance for overhanging object

Based on table 10, considered conditions for increasing robustness are audible noises, pedestrians, traffic lights, walking path include down steps and normal objects that can exist while travelling. Additionally, as these devices use tactile or acoustic sense when sending signal to user, device such as smartcane and device that proposed by Jeong *et al.*, should consider noises from surrounding environment. In terms of necklace sonar, by testing in both indoor and outdoor area, it presents different detecting rate (however both rates are over 75 percent) but considered various conditions which can easily meet in real situation.

On the other hand, wearable ATs that use video camera to enhance the quality of surrounding information, indicates different trend about detective factor (see table 11).

Table 11. Analysis of Wearable Devices use Video Camera for Blind Navigation to define the Obstacle Detection

Adapted from: Caraiman *et al.*, 2017; Du Buf *et al.*, 2011; Li *et al.*, 2016; Mocanu *et al.*, 2016; Schwarze *et al.*, 2015; Tian *et al.*, 2013

System name (Year of publication)	Wireless	Sensor type	Robustness	Detective
Smart Vision (2011)	Yes (RFID)	Acoustic	Low	Any size Any shape Static and Dynamic Ground level
Tian *et al.* (2013)	No	Acoustic	- (Indoor navigating)	Geometric Specific shape Large size Static Any position in indoor area - Door detection with protruding object detection: 89.5% (false positive rate: 2.3%) - Door position detection: average 95.3%

				- Door signage recognition: 71%
Schwarze *et al.* (2015)	No	Acoustic	Moderate (environmental noise had not impact navigating)	Any size Any shape Static and Dynamic Any position
INSANA (2016)	No	Acoustic	Moderate (noise filter function is available)	Any shape Any size Static Any position
Mocanu *et al.* (2016)	No	Acoustic	High (motion, lighting intensity, trembled and cluttered images)	Any shape Any size Static and Dynamic Any position
Sound of Vision (2017)	No	Tactile	Moderate (lighting conditions)	Any shape Any size Static and Dynamic Any position

Most of the devices present that it can detect most objects, in other words, detecting rate does not affect by the shape, size, movement, or position of the object. Except wearable device that proposed by Tian *et al.* (did not consider any condition because the device will only use in indoor environment), Mocanu *et al.*, tested their device in largest conditions with including trembled or cluttered images. This factor should be considered in use of camera because the quality of image that shoot by the device could affect processing time, accuracy of information.

4.4.3 Conclusion

Based on three tables above (table 9, 10, 11), devices with the highest interference capacity have derived:

Table 12. Summary of Assistive Devices for both Smartphone-based system and wearable devices to Evaluate the Obstacle Detection

Adapted from: Mocanu *et al.*, 2016; Tapu *et al.*,2013; Villamizar *et al.*, 2013

System name (Year of publication)	Wireless	Sensor type	Robustness	Detective
Necklace sonar (2013)	No	Tactile	High Tested: 25-43 obstacles (pedestrians, open umbrellas, carts, curbs, traffic signs, telephone booths, traffic lights)	Indoor: detection avoidance rate: more than 80% Outdoor: more than 75%
Tapu *et al.* (2013)	No	-	High	Any shape Any size Static and Dynamic Any position
Mocanu *et al.* (2016)	No	Acoustic	High	Any shape Any size

			(motion, lighting intensity, trembled and cluttered images)	Static and Dynamic Any position

Each system represents each type of system (smartphone-based system, ultrasonic sensor, video camera-based system), and two type of ATs are being highlighted based on accurate information then another device. However highlighted devices also have possible limitations. In terms of necklace sonar, as this system detect surrounding environment by ultrasound wave, although it can detect various objects, system can only send distance information by tactile sense, and to overcome the lack of obstacle information, using own white cane was recommended, however still white cane and necklace cannot detect numerous objects which is in same distance from user and not in the ground. Another device which use video camera and send information by acoustic sense, presents high level of robustness and detective factor. Despite this, as the system use acoustic sense while sending information to user, noises condition should be considered.

5 RESULTS AND FUTURE RESEARCH

Throughout the Discussion chapter, three evaluation of has been examined: Accessibility, Depth of Information, Obstacle Detection. The purpose of each evaluation was to distinguish what is needed to enhance each standard, which as a result, can establish the main element that maintains high usability. Therefore, to certify the three criteria, chosen systems will compared together:

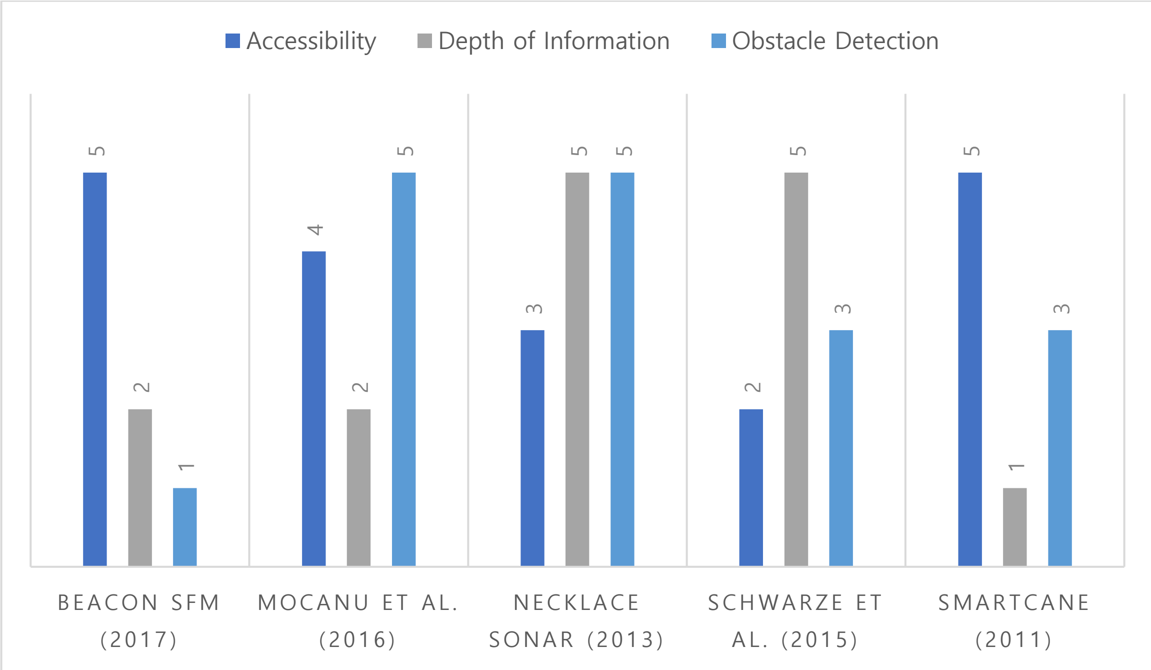

Figure 1. Comparison of Intelligent Assistive Technologies that considered to consist High Accessibility, Depth of Information, and Obstacle Detection.

Figure 5 indicates five intelligent ATs which was selected in each section 4.2.3, 4.3.3, 4.4.3 with the level of three different criteria by giving score from 1 to 5: 5 for the system that had highest level of features until each conclusion, 4 for the system that had high level of features compared to other systems but not until the conclusion, 3 for the system which had higher than moderate level of features, 2 for the system that had lower then moderate level of features, 1 for the system that had no data of at least one feature. Adapted from: Table 1 to Table 8.

According to figure 5, the overall score was highest in necklace sonar (2013), which use ultrasound sensor with tactile sense. Except Beacon SfM (2017) and SmartCane (2011) which has score 1 due to no data, other systems have at least one more criterion that is over 3, therefore three criteria have positive relationship with enhancing usability. Additionally, by analysing all standards with detailed factors, identification of the essential features was available: system should be able to use in both indoor and outdoor area; system should use tactile or acoustic sense but also need an accurate supplement of the disturbing conditions; system should alert detailed information in real-time. Finally, future research should maintain the overall limitations that was derived in the discussion chapter especially in terms of detecting obstacles, considering the error of the system should be considered to enhance usability.

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