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Outdoor Mobility Assistive Technologies for People with Vision Impairment or Blindness – A State of the Art

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Abstract:
World Health Organization (WHO) estimated that about 1.3 billion people live with a level of vision impairment. Outdoor mobility represented a big challenge for people with vision impairment or blindness (VIB). Developing assistive technologies (ATs)to facilitate the mobility of people with VIB represents a vital solution since the last two decades. Researchers investigate in detecting and avoiding static and dynamic obstacles in the indoor and outdoor environments.However, many of the proposed systems have not been addressing user requirements.The purpose of this paper is to stimulate researchers for more work to overcome the challenges of outdoor mobility of people with VIB. The studyselected academic research from the most recently proposed mobility ATs. Then, itclassified themtechnically, based on the used technology to; camera, sensors and combination of camera and sensors. Next, it presented the general features and weaknesses of each technology. Finally, itillustratedthe strengths and drawbacks of each AT, depending on the technical factors and the users' acceptance from the authors' points of view. Consequently, this work explains the reasons behind the rare use of the current ATs.

Keywords: *Assistive Technology, Outdoor Mobility, Vision Impairment or Blindness.*

1. INTRODUCTION

WHO statistics published in October 2018, showed that globally, 217 million has moderate to severe vision impairment,and 36 million people are blind,WHO (2018). Many researchers from different disciplines developed ATs to enhance the quality lives of people with vision impairment or blindness (VIB). Outdoor mobilityrepresents a big challenge because it directly affects the independence and safetyof the people with VIB, Hersh M. andJohnson M. (2008). Therefore, a massive number of mobilityATs were developedsince 2000. The studies investigated in different aspects, for instance; the environment; indoor/outdoor, the obstacles types; static/dynamic and the feedback; acoustic/haptic.Although some proposed ATs accomplished promising results, the majority of the VIB people are still relying on the traditional guides; white cane and dogsMocanu Tapu and Zaharia (2016),Lin, Lee and Chiang(2017),Velázquez et al. (2018).

This paper demonstrated the strengths and weaknesses of some selected proposed mobility ATs from the technical aspects and human aspects. Which may motivate the researchers for further studies to solve the shortcomings in the mobility ATs. Especially

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that,this field still represents a significant research topic scientifically and commercially.

The remainder of the paper is organized as follows. Section 2reviews the related works. Section 3 discusses the paper contributions. Finally, Section 4 presents the conclusion.

2. Related Works

Outdoor Mobility for VIB represents traveling on familiar and unfamiliar routes in the urban environment. It involves activities associated with safe traveling, for instance; walking, avoiding obstacles, in addition to the navigation and orientation to reach the right destination by the desired route,Hersh M. and Johnson M. (2008).

This paper investigates some existing ATs proposed to assist people with VIB to achieve safe and independent outdoor mobility. The study emphasizes the features of the ATs from two factors, i.e.,technical factors and human factors.Therefore, the systems were technicallyclassified into; camera-based, sensors-based and a combination of camera and sensors-basedTapu, Mocanu, and Zaharia (2018).We chose this classification because the AT inherits the technical capabilities and limitations from the used technology,for instance,environment, obstacle type, and coverage distance.

Equally important, the user's acceptance of the AT,which is primarily determined bythe designcompatibility with the user expectations,Pissaloux (2017). Different designs were proposed, such as cane, glasses andnovel wearable device. Theusers' acceptancein this paper focus on; the detection level, weight, and cost.Based on theresearch worksand commercial products, the acceptableweight is about 500 grams, andthe affordablecostis aroundUS $400.

2.1. Camera-Based ATs

These ATs depend on a camera to capture the scene, which is implemented using computer vision or machine learning algorithms to get the visual information. Such systemsshowed good resultsin detecting static and dynamic obstaclesin both indoor and outdoor environments. As well as, the detection distance can reach 10 meters. In contrast, it is difficult for the camera to detect the staircases and to distinguish between the foreground and background of the scene.

The chest wearable AT proposed by Elmannai and Elleithy (2018)(Figure 1a),robustly detects static and dynamic obstacles and works in indoor and outdoor environments. In addition to itslightweight, 180 gm, and affordable cost US $250. Nevertheless, it is unable to determine an accurate distance between the user and the object. Moreover, it cannot distinguish between the foreground and background or detect the stairs and holes. Similarly, the helmet with two cameras presented by Schwarze et al. (2015) (Figure 1b), detects obstacles effectively, and it overcomes the foreground/background problem.In contrast, it is unable to detect drop-offs, holes, stairs,nor crosswalks. As well as, the camera motion caused by the head affects the results. Additionally, the 50ms latency was considered themain system's restriction from the authors' point of view.Likewise,a smartphone application connected to a server designed byLin et al. (2017)(Figure 1c) isdeveloped todetect seven static obstacles, i.e.,person, car, bus, motorcycle, bicycle, potted plant and pier. Besides the limited number of obstacles, the recognition rate was 60% only.

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a. Wearable device, Elmannai&Elleithy (2018) b. Helmet, Schwarze et al. (2015) c. Smartphone with a server, Lin et al. (2017)

Figure 1 - Camera-Based ATs

2.2. Sensors-Based ATs

The ATs in this category uses one or more sensor(s) to collect environmental data. Three types of sensors are used in the mobility ATs; ultrasonic, infrared (IR) and scanner. The sensors main strength is;the determination of an accurate distance between the object and the user Robinson (2015). However, the detection distance of the sensors investigated in this paperdoes not exceed 4 meters. Moreover, each type of sensors has its barriers. The ultrasonic sensors are inappropriate for dynamic objects detection Fu, Damei and Zhao (2016). Also, they are sensitive to weather conditions. Whereas the IR sensors are unsuitable for the outdoor environment because of their sensitivity to the sunlight and inability to work in a dark environment. Unlike the scanners, where the highcost representsthe main shortcoming, Zhu Yi and Guo (2016).

Thecane designed by Guevarra, Camama and Cruzado (2018) (Figure 2a) accurately detects obstacles and returnsaudio feedback to inform the user to which direction he/she should move.Conversely,the delay of response time is1.864 seconds,the cane weight is 2.8kg and the long training sessions represent the main drawbacks of this AT. Similarly, the cane with ultrasonic sensors proposed by Mala, Thushara and Subbiah (2017)(Figure 2b), robustly detects the obstacles and has a lightweight; 57 grams. However, lack of information such as; obstacles types and detection distance represents its shortcomings.As well as, the samedata are missed in the glasses with three ultrasonic sensors designed by Zhou, Li and Zhou (2017) (Figure 2c).Where the sensors detect the obstacles and the smartphone returns speech feedback. In another scenario,Ramadhan (2018) (Figure 2d), proposed awrist-wearable device, that contains ultrasonic sensors. The detection experiments showed high performance, but this AT was unable to detect stairs nor the objects at the head level.

One more caneAT combinesthe ultrasonic with IR sensorsbuilt byS. Keishnakumar and B Mridha (2017) (Figure 2e). Despite the good detection results, lack of data, such as the environment, stick's weight and cost; form theflaws. Another canewith two IR sensors was introducedbyDhod, Singh, and Kaur (2017)(Figure 2f). This cane detects water, pits and objects. However, besidesthe IR limitations,the detection distanceis 1.5 meters only.

The AT proposed by Ton et al. (2018)(Figure2g) used light detection and ranging(LIDAR)sensor. Although LIDAR returns accurate spatial data, i.e., angle, distance; the 13 seconds scanning time of the user’s frontal area and the cost which exceeds \$2.5K made this AT a less attractive option.

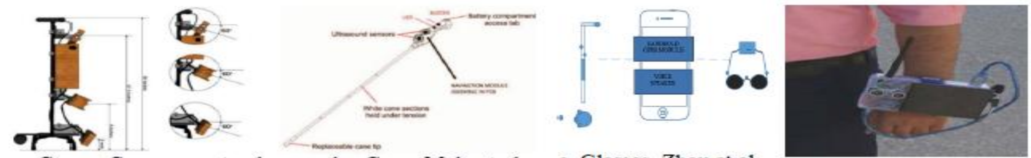
a. Cane, Guevarra et al. (2018)
b. Cane, Mala et al. (2017)
c. Glasses, Zhou et al. (2017)
d. Wearable device, Ramadhan (2018)
e. Cane, S. Keishnakumar (2017)
f. Cane, Dhod et al. (2017)
g. Wearable device, Ton et al. (2018)

Figure 2- Sensors-Based ATs

2.3. Camera and Sensors-Based ATs

Some researchers developed ATs by merging camera with sensor(s) technologies. Although the systems combine the strength of both technologies, each framework still has shortcomings.

The system proposed by Mocanu et al. (2016) (Figure 3a), combines a smartphone camera with four ultrasonic sensors ina highly effective belt. It detects dynamic and static objects and works in indoor and outdoor environments. However, the system unable to prioritizing the detected obstaclesaccording to their danger. As well as,the feedback system blocks the user's ears from the surrounding sounds.

The secondAT developedby Ponnada et al. (2018) (Figure3b), merged a cane with sensors and a smartphone camera. The system shows good results in detecting static objects, staircases andmanhole. However, it is unable to detect the dynamic obstacles.


a. Belt, Mocanu et al. (2016)
b. Cane, Ponnada et al. (2018)

Figure 3 - Camera and Sensors Based ATs

3. DISCUSSION

This study investigated in 12outdoor mobility ATs for people with VIB.The systems areanalyzedaccording to technical factors and human factors. Table 1 illustratesthe ATs criteria.

The former systems showed several robust points in both factors. Where the experiments of obstacles detections,got a rate exceeded 90% in some systems.Moreover, some test subjects returned positive feedback about the design, weight and cost.However, each system contains technical limitationsand/orweak acceptance among the target group.

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The main technical restrictionswerethe inefficiency of detecting obstacles, inappropriate for the outdoor environmentand insufficient detection distance. Although the camera-based system showed strength in detecting obstacles, the limitation in detecting stairs and holes in addition to the failure at distinguishing between foreground and background was obvious,Elmannai and Elleithy (2018). In contrast, the sensors-based systems return the accurate distance between the user and the obstacle. However, the ultrasonic sensors performed poorly at the dynamic obstacles detection and they are impacted negatively by the weather conditions,Fu, Damei and Zhao (2016). The infrared sensors are sensitive to sunlight and unable to work in a dark environment,in addition to the detection rang less than 3 meters, Dhod, et al. (2017).

Thehumanity factorssignified by;the designbarrier which is denoted by the heavyweight and the disability to detect obstacles at different body levels. Cane usually detect obstacles at the knee level only. Where head-worn ATs are unable to detect objects below the waist. Pissalouxexpressed, “*paying attention to design will lead to a better device that is more likely to be used by a significant number of people*,” Pissaloux (2017). Moreover, feedback that blocks the sounds of the surrounding environment at all former systems with the unaffordable cost at some systems augmented the unacceptance factor, Ton et al. (2018).

4. CONCLUSION

Outdoor mobility of people with VIB represents a significant factor in augmenting their independence and self-confidence. Instead of feeling unable to explore anunfamiliar environment. Although a massive number of ATs were developed during the last two decades, none of them represents a common solution among the community of people with VIB.There is a necessityfor a reliable, accessible and effective AT to fulfill the targets’ group mobility needs. Thus, this field of research still required further efforts to overcome the existing challenges.

Table 1.Comparisonof Mobility ATs Criteria

Category	**Reference**	**Human Factors**				**Technical Factors**		
		Design*	**Feedback***	**Cost***	**Weight***	**Environment***	**Obstacle Type***	**Distance**
Camera-Based	Elmannai and Elleithy (2018)	Chest WD	Audio	AF	Light	In/out	S/D	< 9 m
	Schwarze et al. (2015)	Helmet	Audio	NM	NM	Out	S/D	10 m
	Lin et al. (2017)	Smartphone App. with a Server	A&V	NM	Light	Out	Static	4 m
Sensors-Based	Guevarra et al. (2018)	Cane with US	Audio	NM	Heavy	NM	S/D	NM
	Mala et al. (2017)	Cane with US	A&V	Low	Light	NM	NM	NM
	Zhou et al. (2017)	Glasses with US	Audio	NM	NM	Out	NM	NM
	Ramadhan	Wrist WD with	A&V	AF	Light	Out	NM	3 m

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	(2018)	US						
	Keishnakumar, B Mridha (2017)	Cane with US&IR	Audio	NM	NM	NM	S/D	3 m
	Dhod et al. (2017)	Cane with IR sensors	Audio	Low	NM	In/Out	NM	1.5 m
	Ton et al. (2018)	WD with LIDAR	Audio signal	V.Ex	Light	NM	Static	4 m
Camera and Sensors-Based	Mocanu et al. (2016)	Belt with US and smartphone	A&V	AF	Light	In/Out	S/D	10 m
	Ponnada et al. (2018)	Cane with smartphone and US	A&V	Low	Light	Out	Static& Manhole	3 m

Note:- * means WD: wearable device – AF: affordable – V.Ex: very expensive – In/out: indoor/outdoor – S/D: Static and dynamic – NM: not mentioned – A&V: Audio and vibration – US: ultrasonic – IR: infrared

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