Bulletin of the JSME Vol.10, No.7, 2016
Journal of Advanced Mechanical Design, Systems, and Manufacturing

Conceptual design and implementation of electronic spectacle based obstacle detection for visually impaired persons

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Received 15 December 2015

Abstract
In this paper, the design and implementation of a spectacle based obstacle detection system is described. The usage of spectacle based obstacle detection system would help the visually impaired person to scan the surrounding especially at the upper body level from having head level collision. Four pieces of distance measurement sensors is proposed in the travel aid in order to detect the obstacle in each direction including front, down, left and right. If the distance measurement sensor detects an obstacle, the warning system will be activated and a warning signal on the location of the obstacle will be given to the user. The warning devices designed and implemented in the system are audio and vibration warning system. The usage of both warning devices can be switched on either as a single headphone audio or a vibration warning device depending on users' preference and environment. For example, if the user is joining a crowded environment such as market or bus terminal, they are recommended to change and use only the vibration warning device, whereby their stereo hearing sense will be used to capture the sound around them. An evaluation on the developed electronic spectacle was also done in order to produce an effective, reliable and light wearable device.

Key words : Visually impaired person, Obstacle detection, Upper body, Warning system, Electronic spectacle

1. Introduction

The World Health Organization (WHO) has released the statistics on people with disabilities around the world, which are approximately more than one billion people from the overall world's population. Among that, the disabled people living in developing countries are around 80%. The increment of these statistics is because of increased aging population, health condition and greater accessibility to facilities (World Health Organization, 2011). In addition, even though Malaysia has about 30 million population, there are only 480 thousand disabled people, instead of the 3 million people, who are registered until August 2013. The disabled people in this country cannot be shown by statistics since they remain imperceptible in most of the developing countries. The real statistics data on disabled people cannot be obtained correctly since there is lack of connection between the disabled people with the local authorities which normally happens in developing countries (Kassim et al., 2015a).

Based on the Convention on the Rights of Disabled Association of the United Nations, disabled people need to be prioritized and get more consideration from the local authority and government to develop a high quality of life in a country. The disabled people need to feel the same chances with normal people such as accessibility, flexibility, health, education, occupation and involvement in the administrative, economic and social fields (Guerrnsey et al., 2007). There are few categories of disabled persons, which are hearing impaired, visually impaired, physically impaired, and mental impaired and etc. which is recognized by the United Nations. However, amongst all of the categories of disabled people,

Paper No.15-00720
[DOI: 10.1299/jamdsm.2016jamdsm0094]

those who are always in dangerous situations is the visually impaired as they cannot recognized their surroundings (Kassim et al., 2013a). In a study by Francois Champoux, it was shown that the visually impaired is better in localizing sound and able to differentiate the frequencies of the sounds in the surrounding environment (Acoustical Society of America, 2012). However, if the obstacles do not produce any sound, which are static obstacles such as wall or stair, it is difficult for the visually impaired to recognize the location of the obstacles.

Conventionally, the visually impaired persons depend on canes or guide dogs to help them travel to a destination correctly and safely. Nevertheless, the normal cane or guide dogs are only helpful if the way to the desired location is commonly used or well-known. The infrastructures and facilities that are not designed and developed for the disabled people can be difficult to use, especially if the environment is new to them. The disabled cannot travel independently without proper guidance or device (Kassim et al., 2013b). Furthermore, the white cane can only detect obstacles by direct touch, and this situation is too dangerous for them since the obstacles are too close. Thus, some researches have been conducted on the support for the visually impaired. Devices which have been previously studied include the Guide cane (Borenstein and Ulrich, 1997), Robotic-cane (Lacey and Dawson-Howe, 1998), NavBelt (Shoval et al., 1998), electric wheelchair (Hara et al., 2008), BLi-NAV (Santhosh et al., 2010) and My 2nd Eye (Kassim et al., 2011). In addition, some basic skills are required for visually impaired person to travel independently. Bousbia-Salah et al., (2007) mentioned that obstacle detection and avoidance are very important skills for visually impaired persons to avoid obstacles, including the static and moving obstacles.

Moreover, most of the travel aids that have been studied are normally used to help the user to detect obstacles at the lower level part of their bodies and have limitations (Kassim et al., 2012a). A study by the Acoustical Society of America showed that mobility-related accidents experienced by visually impaired persons are crucial and occur frequently, especially head level collisions since the visually impaired persons usually use long cane or guide dog. From 300 interviewed respondents, 13% had experienced head level accidents at least once a month and 7% had experienced falls while walking at least once a month (Manduchi and Kurniawan, 2011). Hence, the demand to protect the upper body level of visually impaired persons is really important. Besides, the visually impaired consists of experienced and inexperienced persons who suddenly go blind due to illness such as diabetes or glaucoma and accident. Inexperienced visually impaired persons will have a hard time to start a new life after being blind suddenly. The enhancement of other senses still need some experience and time in order to get familiar with the new environments.

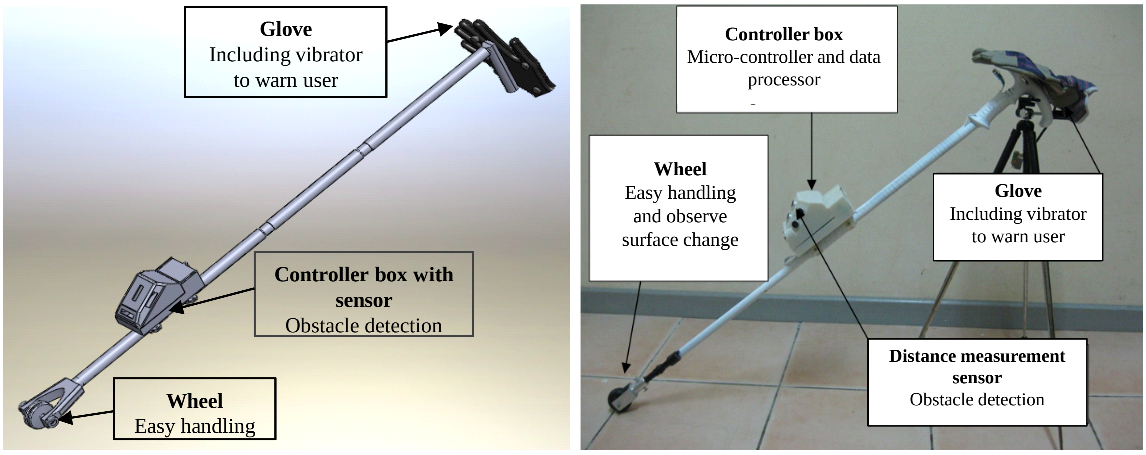
Therefore, the usage of spectacle type obstacle detection system will help them to scan the surrounding especially for the upper body level from encountering head level collision. The design and implementation of the spectacle based obstacle detection system is the focus of this paper. Four pieces of distance measurement sensor are proposed in the travel aid in order to detect obstacles in each direction, such as front, down, left and right. If the distance measurement sensors detect an obstacle, the warning system will be activated and a warning signal about the location of the obstacle will be given to the user. The warning devices that are designed and implemented in the system are audio and vibration warning systems. The usage of both warning devices can be switched to either as a single headphone audio or a vibration warning device depending on users' preference and environment. For example, if the user enters into a crowded environment such as marketplace or bus terminal, they are recommended to change and use only the vibration warning device, whereby their stereo hearing sense will be used to capture the sounds around them. An evaluation on the developed electronic spectacle was also done in order to produce an effective, reliable and light wearable device.

The arrangement of this paper is as follows: Section 1 presents an introduction to the problem and the challenges faced by visually impaired people. Section 2 highlights previous studies related to travel aids for visually impaired people. Section 3 deliberates on the developed electronic spectacle with the selection of the main electronic components in the proposed design for obstacle detection purposes. Section 4 discloses the design implementation involved in this study, while Section 5 elaborates the performance evaluation results on the developed electronic spectacle with warning device and finally, the conclusion and future tasks of this study.

2. Previous works

Previously, the development of travel aid device to assist the visually impaired persons to travel alone has been conducted (Kassim et al., 2011). This study is based on statistical studies by the World Health Organization (WHO) statistics and a collaboration study with the Society of Blind Malaysia (SBM) including Malaysian Association for the Blind (MAB) regarding the major problems faced by visually impaired persons in Malaysia. From the interview session, the visually impaired persons normally face difficulties when they travel alone without any guidance by helper or guide dogs. The basic problem that is always faced is obstacle detection and avoidance in order to travel and reach a destination safely. Severe accident and injury can be caused by accidental fall and collision with obstacles. Therefore, some concepts need to be understood and fulfilled in order to design and develop the travel aid suitable for the visually impaired persons. The technology requirements that need to be fulfilled include real time guidance, portability, power limitation, appropriate interface, continuous availability, no dependence on infrastructure, low cost solution and minimal training (Kassim et al., 2015b). By fulfilling these entire requirements, the visually impaired person can travel independently without depending on human or guide dogs and the accidental rate can be reduced.

In the brainstorming stage, an electronic device that can detect an obstacle existing around the user using non-contact approach was proposed. Thus, the design of an electronic device using distance measurement sensors in order to detect the obstacle was done. It was different from the conventional white cane, which needs to touch an obstacle in order to recognize the obstacle and its location. The proposed electronic white cane which was designed by using SOLIDWORKS is shown in Fig. 1(a), while the developed and fabricated electronic white cane is shown in Fig. 1(b). After the first prototype was developed, some discussions and interviews with 30 participants who are visually impaired and partially blind from SBM and MAB were done in order to verify and obtain some feedbacks based on the perspective of visually impaired persons. Numerous feedbacks were received from the discussion. Some of the main feedbacks are classified into a SWOT analysis table. Figure 2 shows the customer analysis based on SWOT analysis concept, which concludes the users' feedback.



(a) Designed electronic white cane

(b) Developed electronic white cane

Fig. 1 Designed and developed electronic white cane

Strength New technology using sensor application and vibrator. Non-contact approach. Easy to identify obstacle using vibrator. No need to swing cane. Low cost product.	Weakness Need to wear glove. Quite weight. Not easy to carry when unused. Not waterproof.
Opportunity White cane only cover for lower body level. No protection for upper body level. Currently not many competitors.	Threat Easy to copy. Niche market.

Fig. 2 Target user feedbacks using SWOT analysis

[DOI: 10.1299/jamdsm.2016jamdsm0094]

Then, the idea selection was finalized by changing the idea from electronic white cane to electronic spectacle, as there is no device or tool to detect obstacles in the upper body level for visually impaired persons after the feedbacks were concluded. Hence, the development of a new travel aid device was conducted, which started by designing a spectacle type obstacle detection system for the upper body level. The concept of obstacle detection system using spectacle was triggered through some observations on the visually impaired, as they always wear black spectacle while traveling in order to protect their eyes from hitting an obstacle directly. By applying the distance measurement sensor inside the spectacle, they can avoid from hitting the obstacle. The first prototype, which has been designed and developed based on the electronic spectacle concept is elaborated in next section.

3. Development of an Electronic Spectacle

3.1. System configuration

Figure 3 shows the overall system construction to be used in the design of an electronic spectacle. All of these electronic components need to be included inside the system. The electronic components used were microcontroller, distance measurement sensors, voice module, rechargeable battery, headphone, vibrator and wireless module. The microcontroller functions as the head of the system as it contains memory and program to communicate with other hardware. In addition, there are two types of warning system, the vibration warning system and the audio warning system, included inside the overall system since visually impaired persons are very sensitive to tactile and hearing senses. Four pieces of vibrators and a single headphone are used. The warning signal strength is generated by using the Pulse Width Modulation (PWM). It is given to the user based on the distance of obstacles to the device, as measured by the distance measurement sensor.

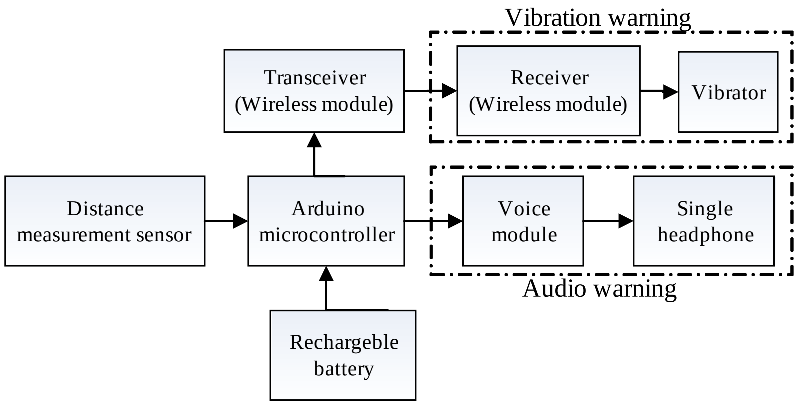


Fig. 3 System overview of developed electronic spectacle

Furthermore, four pieces of distance measurement sensors are used inside the electronic spectacle to detect obstacles in the forward, right, left and down directions. Each direction responds to each vibrator that has been installed. Data from the distance measurement sensor are transmitted and processed inside the microcontroller. If the measured data for each distance measurement sensor are more than the set threshold, the vibrator and single headphone will not be activated. If the captured data are lesser or equal to the set threshold, the vibrator and single headphone will be activated through the microcontroller and vibration will be generated. Meanwhile, the power source for the electronic spectacle is supplied by a rechargeable battery that can be easily recharged and replaced while traveling in the outside environment.

3.2. Electronic components selection

All of the electronic components need to be selected wisely in order to develop a user-friendly, reliable and mobile travel aid device for the visually impaired. First, the selection of the distance measurement sensor, which is a key technology used in the system was done. Regarding the types of distance measurement sensor, three types of sensor were compared in order to select the best sensor for the system. Few studies have also been done to evaluate the performance of different distance measurement sensors in order to detect objects of different materials (Kassim et al., 2013c). The selection of sensor depended on its features such as measurement range, accuracy, cost, weight, size and energy consumption. The distance measurement sensors which were compared include ultrasonic sensor, infrared sensor and laser range finder.

The ultrasonic sensor is commonly applied in many applications since it functions by transmitting an ultrasonic sound through transmitter and measures the required time for the sound to return to the receiver. One of the applications

[DOI: 10.1299/jamdsm.2016jamdsm0094]

is the car parking sensor system, where the ultrasonic sensor is mounted on each edge of a car bumper to protect the body of the car from colliding with obstacles (Kassim et al., 2012b). The infrared sensor is a combination of signal processor, location sensitive gauge and laser emitting diode. The laser is transmitted and reflected when the laser hits an obstacle. In case of no object, the light will not be reflected. The usage of infrared sensor is quite limited since it is easily affected by other light sources. Few studies on object reflectivity have related the color of the object and the adoption of the triangulation method (Yaacob et al., 2012).

On the other hand, the laser range finder is a type of optical distance sensor by using light (laser). The laser range finder scanned the surrounding to measure the distance for object detection in two-dimensions. All types of distance measurement sensors with their specifications are listed in Table 1. From Table 1, a comparison was made and the weightage for each sensor specification are shown in a pair-wise comparison table in Table 2. By using the pair-wise comparison table, the weightage of each feature was determined using Eq. (1).

Table 1 Comparison of sensors and specifications

Sensor type.		Ultrasonic sensor	Infrared sensor	Laser range finder
Model no.		MB1003	GP2Y0A21YK	URG-04LX
Figure				
Manufacturer		MAXBOTIX	SHARP	HOKUYO
Supply voltage	VDC	2.5 to 5.5	4.5 to 5.5	5
Range	cm	15 to 645	10 to 80	2 - 400
Supply current	mA	2	33	500
Weight	g	4.3	5	160
Size (L x W x H)	mm	20 x 22 x 15	29.5 x 13 x 13.5	50 x 50 x 70
Volume	mm^3	6,600	5,177.3	175,000
Price	USD	20 to 40	15 to 30	1000 to 1500

Table 2 Pair wise comparison table

Features		A	B	C	D	E	F	Votes (v)	Weightage (w)
Accuracy	A	-	B	A	A	A	A	4	0.267
Range	B	-	-	B	B	B	F	4	0.267
Size	C	-	-	-	D	C	C	2	0.133
Weight	D	-	-	-	-	D	F	2	0.133
Cost	E	-	-	-	-	-	E	1	0.067
Energy consumption	F	-	-	-	-	-	-	2	0.133
Total votes (T_v)								15	1.000

$$\text{Weightage(w)} = \frac{\text{Votes(v)}}{\text{Total votes}(T_v)} \tag{1}$$

For the distance measurement sensor, accuracy (A) and range (B) had the highest weightage, while cost (E) had the lowest weightage to determine the best sensor to be used. Based on the weightage of each feature, the specification of each sensor was compared and the point was given, as shown in the weighted objective table in Table 2. If the specification of the sensor was the best, three points were given, while if the specification of the sensor was the lowest, one point was given. After comparing all features, the total scores were calculated in order to select the best distance measurement sensor based on the algorithm in Eq. (2). Finally, the best distance measurement sensor was chosen by referring to the highest total score based on the weighted objective table, as shown in Table 3. For this project, the ultrasonic sensor was chosen because it acquired the highest point compared to other shortlisted sensors and was used in this application.

$$\text{Total score}(T_s) = \sum \text{Score(s)} \cdot \text{Weightage(w)} \tag{2}$$

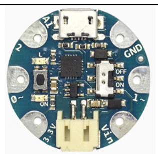
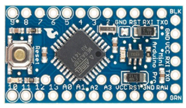
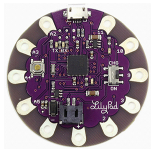
The selection of microcontroller is important and was based on having a compact size, light in weight, fast processing time and sufficient input/output (I/O) ports to develop the obstacle detection and warning device. Few microcontrollers

Table 3 Weighted objective table

Features		Weightage (w)	Ultrasonic sensor score (s)	Infrared sensor score (s)	Laser range finder score (s)
Accuracy	A	0.267	2	1	3
Range	B	0.267	3	1	2
Size	C	0.133	3	2	1
Weight	D	0.133	3	2	1
Cost	E	0.067	2	2	1
Energy consumption	F	0.133	3	2	1
Total score (T_s)			2.666	1.466	1.801

were considered for the system such as AVR microcontroller and PIC microcontroller, which are easy to be programmed. In recent years, the Arduino platform, which uses AVR microcontroller, is broadly used in embedded system. The Arduino platform with its specification was shortlisted for selection as shown in Table 4. From the shortlisted boards, Arduino Promini was selected because of its small size based on the volume calculation as shown in Table 4. In addition, Arduino Promini is also light in weight and has enough I/O pin for the application, which uses four pieces of ultrasonic sensor to be mounted on the analog input. Besides, since the clock speed and memory were the same for all boards, they were not considered for the selection.

Table 4 Arduino board comparison and specifications

Model		GEMMA	Promini	LilyPad
Figure				
Microcontroller		ATtiny85	ATmega32u4	ATmega328
Operating voltage	VDC	3.3	3.3	3.3
Digital I/O pin	num	3	14	9
Analog input	num	1	6	4
DC current / pin	mA	20	40	40
Clock speed	MHz	8	8	8
Flash memory	kB	8	32	32
Weight	g	2	2	5
Size	mm	28 x 6.5 (D x H)	33 x 18 x 2 (L x W x H)	36 x 6.5 (D x H)
Price	USD	10	10	25

In addition, the type of battery including battery capacity, light-weight and compact size were considered for power supply. In this project, three types of battery were considered, namely Lithium-ion (Li-ion) battery, Lithium Polymer (Li-Po) and Li- ion battery which is inside an external battery package. All batteries were selected based on the same capacity, which is about 2200 mAh. Table 5 shows a comparison and the specification of the rechargeable battery that would be selected. If the battery capacity increases, the battery size also increases and longer lifetime can be provided. On the other hand, the volume of each rechargeable battery was also considered in order to select the best rechargeable battery for the system. In term of battery weight, the Lithium-ion battery was the lowest, but it did not include the recharging circuit compared to the Li-ion battery in an external battery package.

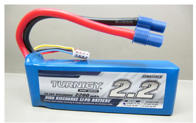
Therefore, since the Lithium-ion (Li-ion) battery and Lithium Polymer (Li-Po) battery consist of battery without charger and have incompatible input voltage with the microcontroller and ultrasonic sensor, Li-ion or external battery would be the best rechargeable battery for the system. If the battery is depleted of power, it can be easily recharged using a USB-connected charge system such as from a personal computer or any USB connector. Furthermore, it also can be replaced easily with other external battery if the battery capacity decreased and the cost of unit is low with stable performance.

3.3. Proposed detection range

The proposed electronic spectacle was designed like a sunglass since visually impaired persons usually wear it when

[DOI: 10.1299/jamdsm.2016jamdsm0094]

Table 5 Rechargeable battery comparison and specifications

Figure				
Manufacturer		TRUSTFIRE	TURNIGY	OEM
Charging mode		Li-Ion Charger	Li-Po Charger	USB charger
Output current	A	5.2	44	0.8
Capacity	mAh	2600	2200	2600
Input voltage	VDC	3.7	11.1	5
Output voltage	VDC	4.2	5.3	5.3
Weight	g	46.5	185	57
Size	mm	18.6 × 65.2 (D x H)	103 x 33 x 24	97 x 25 x 22
Price	USD	10	22	6

travelling outside. The proposed directional angle and areas for mounting the distance measurement sensor inside the spectacle is illustrated in Figs. 4(a) and 4(b). The safety zone threshold for each distance measurement sensor was decided based on human walking speed, which is 4 km/h ≈ 1 m/s. Thus, the threshold or limit is 1.5 m in order to ensure safety for the visually impaired while using the electronic spectacle. In addition, the threshold or limit need to be more than 1 m based on previous results and surveys (Kassim et al., 2015b). Hence, the alert system is used to warn the user when the distance between the user and the object is 1.5 m. The system flowchart of the warning mechanism is shown in Fig. 4(c), whereby each warning device will be activated when the distance between the obstacle and the user is less than the threshold. The threshold of each distance measurement sensor is set at 1.5 m for the top, right and left directions. Meanwhile, the threshold of the distance measurement sensor for down direction is set at 2.0 m based on the calculation using the trigonometric function. At the same time, the type of obstacles can be recognized using the collaboration between the top and down sensors. For example, an obstacle such as a wall or a big obstacle will be identified by both the top and down sensors at the same time. Else, an obstacle is identified perhaps as a floating object, such as tree branches or the rear of a truck, if only the top sensor observes the obstacle. Moreover, an obstacle is identified possibly as a small object on the ground, such as rock or table, if only the down sensor spots the obstacle.

Furthermore, the usage of left and right sensors can also be optimized by the visually impaired such as wall following robot where the visually impaired person can follow the wall at the right or left side of the user to reach the desired destination. From Fig. 4, the down sensor was designed to deviate downward 30° horizontally. The down sensor angle is set for detecting obstacles above the abdomen. The obstacle range that can be sensed by the front sensor is at 1.5 m away. Obstacles in the range of 0.85 m below the head level until the abdomen level can be detected, while obstacles below 0.85 m from the head level are detected using the white cane. This is assumed for visually impaired people with an average height of 1.7 m. The trigonometrical method which is applied for detection angle calculation is shown in Eq. (3).

$$\theta = \tan^{-1}\frac{\text{Opposite}}{\text{Adjacent}} = \tan^{-1}\frac{\text{Height of head to abdomen level}}{\text{Distance of obstacle to front sensor}} = \tan^{-1}\frac{85}{150} = 29.5^\circ \approx 30^\circ \qquad (3)$$

4. Design implementation using SOLIDWORKS and rapid prototyping machine (RPM)

After the selection of electronic components and detection range, the design and development of the spectacle type device for visually impaired persons were conducted. Figures 5(a) to 5(f) illustrate the designed electronic spectacle by using SOLIDWORKS software for each direction. However, the connection to the rechargeable battery is not shown in Fig. 5 because the external battery is connected to the electronic spectacle and placed inside the user's shirt pocket. If the rechargeable battery is designed to be located inside the electronic spectacle, the size of the electronic spectacle becomes bulky and heavy. Therefore, by applying the TRIZ (Theory of Inventive Problem Solving) concept when two contradictions is existed in the system. For example. the weight of the spectacle worsens if all operations are included in the electronic spectacle. Here, the worsening feature is weight of stationery (2) and improving feature is ease of operation (33). The solutions recommended through the TRIZ matrix were segmentation (1), universality (6), the other way around (13) or self-service (26) (Yeoh et al., 2009). In this case, segmentation was selected and the electronic spectacle was

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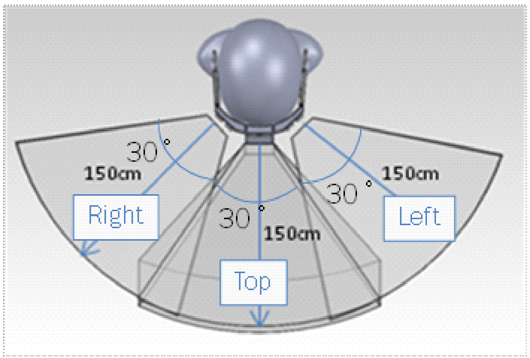
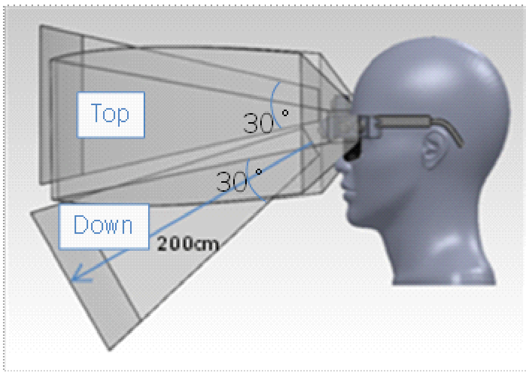
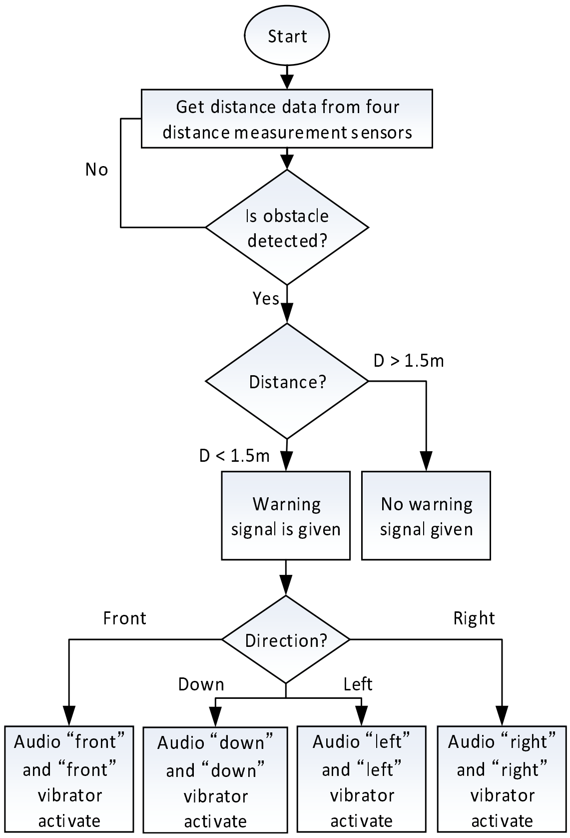


(a) Top view

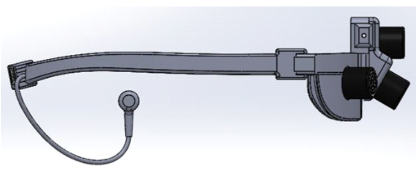


(b) Side view

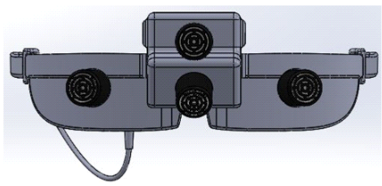


(c) System flowchart

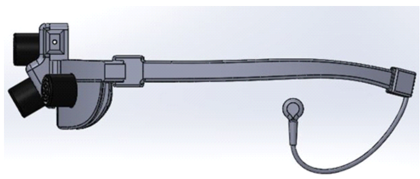
Fig. 4 Detection range and system flowchart



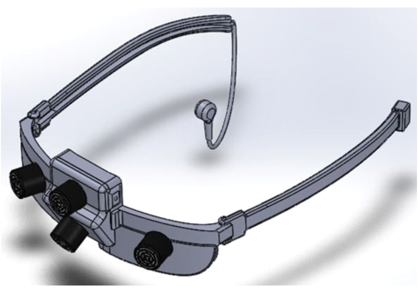
(a) Right side view



(b) Front view



(c) Left side view



(d) Isometric view (Left)

(e) Isometric view (Top)

(f) Isometric view (Right)

Fig. 5 Designed electronic spectacle using SOLIDWORKS

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divided into independent parts, which are the spectacle part and the rechargeable battery part.

In addition, the rechargeable battery is connected through a mini USB which is mounted at the end of the left side handle. The spectacle handle can be adjustable in order to fit different users. Also, the rechargeable battery using Lithium ion battery including the rechargeable function can be directly recharged using a USB connector through a USB adapter or a notebook. A single earphone is mounted on the right side handle in order to give the beeping sound alert to the visually impaired person. The reason of using a single earphone in this system is because the visually impaired usually use their hearing sense in order to know the environment. If a stereo earphone is applied, the person cannot sense the environment while using this electronic spectacle. The placement of the ultrasonic sensors in this prototype refers to the angle range that the device should detect. Meanwhile, the left and right ultrasonic sensors are set to 45° from the spectacle center point in order to detect obstacle within shoulder and arm of user. Therefore, collision between obstacle and both left and right shoulders can be avoided. In addition, Fig. 6 shows an exploded view of the designed electronic spectacle.

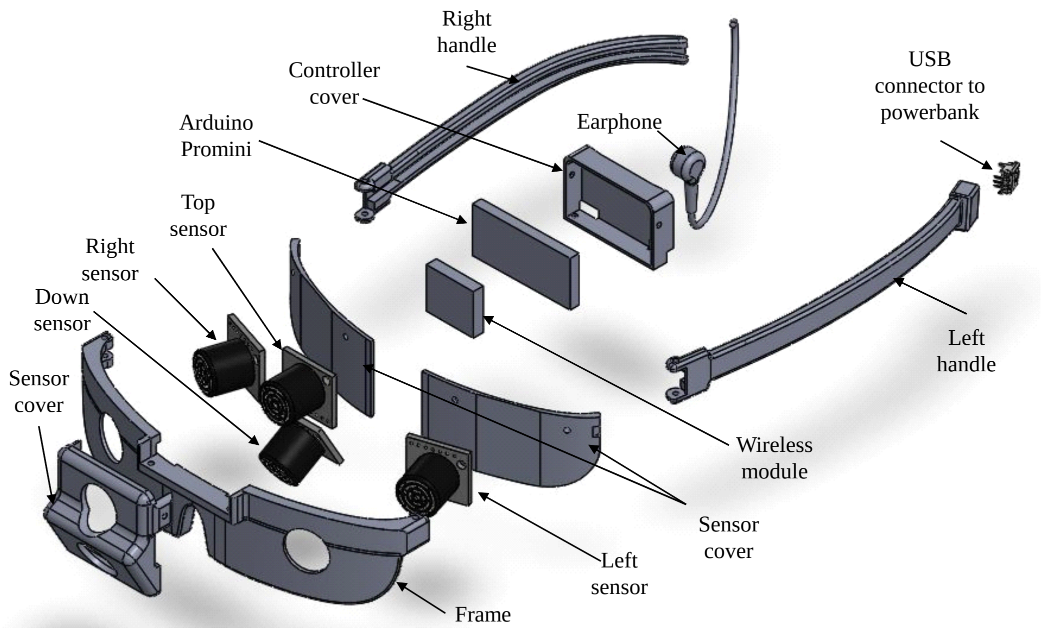


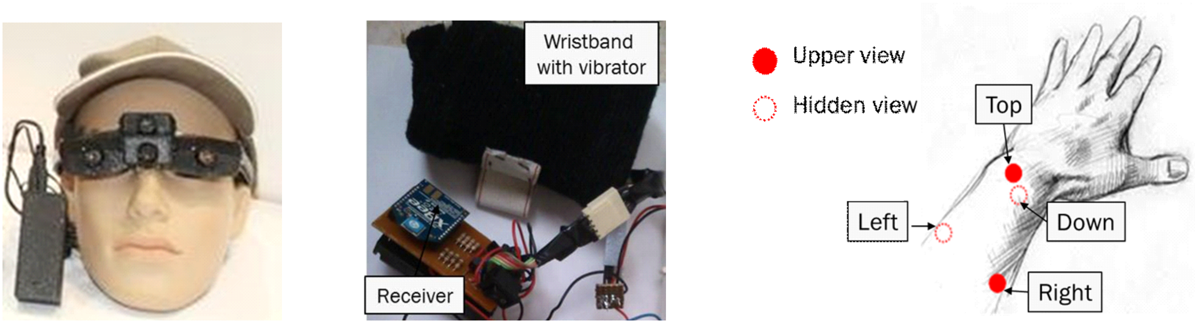
Fig. 6 Explode view of electronic spectacle

As a result, the developed electronic spectacle was fabricated, including the rechargeable battery, using the rapid prototyping machine (RPM) as shown in Fig. 7(a). Meanwhile, Fig. 7(b) shows the wristband, including the vibrator, that is used to give vibration alert to the user. This wristband is worn at the user's wrist and the location of the vibrator is determined as in Fig. 7(c). The reason why this design was proposed is because it is not preferred for the visually impaired person to wear a glove which consists of vibrators. Besides, the vibrator cannot be mounted on the electronic spectacle directly because it can give vibration impact to the head and eye of visually impaired person. Therefore, the wireless connection between the vibration system inside the wristband to the electronic spectacle is developed, which receives commands from the microcontroller when an obstacle is detected. By using the vibrator alert, the deaf-blind people can also benefit since they cannot hear the sound from the audio warning alert. Meanwhile, the usage of both warning devices can be switched to either as a single headphone audio or a vibration warning device depending on users' preference and environment. For example, if the user goes into a crowded environment such as marketplace or bus terminal, they are recommended to change and use only the vibration warning device, while their stereo hearing sense is used to capture the sounds around them.

After the overall system was constructed, the firmware was inserted into the microcontroller and a basic testing was conducted such as the functionality of the system. Then, if the prototype functions well, further evaluation process will be performed such as the detection range of distance measurement sensor, effectiveness of warning signal consisting of vibration and audio warning signals, battery level indicator and user-friendliness through experiments and surveys. All experimental results will be concluded and improvements on the concept and design will be decided. And finally, the design improvement will be carried out and the implementation of design changes will be done. After the design changes have been done, a new prototype will be fabricated and tested again until the design is optimized in term of functionality,

[DOI: 10.1299/jamdsm.2016jamdsm0094]

durability, usability and effectiveness.



(a) Fabricated electronic spectacle

(b) Vibration warning wristband

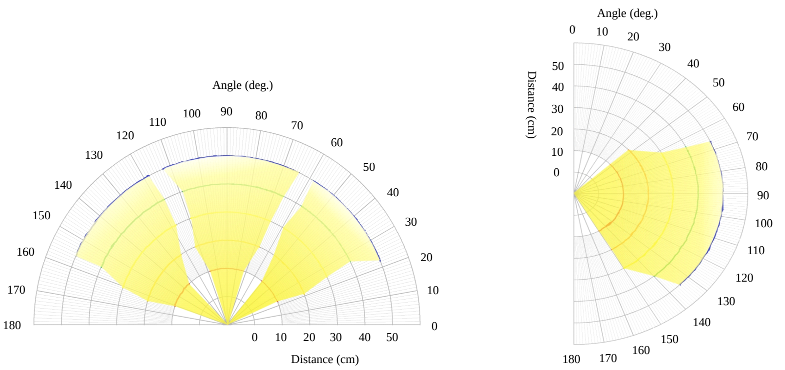
(c) Vibrator location

Fig. 7 Fabricated travel aid device for upper body level

5. Performance evaluation of electronic spectacle

5.1. Blind spot evaluation result

From the experiments done, the blind spot of the device was evaluated. Figure 8(a) is a detection range that shows the results of the experiment for front, left and right sensors. The results show that the angle detection range for the device increased proportionally to the distance from the device. The results show that there were two blind spots for the designed device. For the left sensor, the beam line was not smooth and the distortion occurred at the distance between 0.1 m and 0.2 m. The distortion also occurred for the right sensor at a distance of 0.4 m. Figure 8(b) shows the detection range for front and down sensors. This graph shows the vertical sensor detection range, which is the range of detection in front of the user. The graph shows that the detection range decreased inversely proportional to the distance. In addition, two distortion occurred between the distance of 0.2 m and 0.3 m. The blind spot occurs because the strength of the sonar signal is concentrated at the center of the beam and with some lobes beside it. The lobe has a weak signal. For the distortion case, the obstacle is in the lobe area of the ultrasonic sensor. Meanwhile, the sensor beam for Maxbotix's ultrasonic sensor is shown in Fig. 9.



(a) View of front, right and left sensor

(b) View of front and down sensor

Fig. 8 Blind spot experimental result

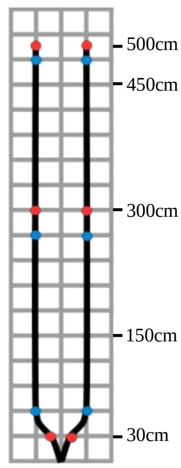


Fig. 9 Sensor beam (Maxbotix)

5.2. Response time of vibration warning device by user

In order to evaluate the effectiveness of the designed and developed electronic spectacle, the implementation of the electronic spectacle for visually impaired persons was conducted. Twenty respondents participated in this experiment to ensure that the experiment was successfully conducted. In this experiment, users' response time to differentiate the direction of an obstacle accurately and quickly when the vibration warning device is activated was evaluated. This aspect

[DOI: 10.1299/jamdsm.2016jamdsm0094]

is one of the main features requiring verification in order to evaluate the safety zone by using decision of threshold that resulting from the distance between an obstacle and the user. As part of the evaluation process, an explanation on the operating manual and the direction of each distance measurement sensor, including the vibration motor tested in the experiment was given to the participants earlier.

Firstly, one vibrator was selected and activated, and each respondent was required to differentiate the location of the vibrator and the direction of the obstacle. Then, when the respondent answered the location of the vibrator precisely, the response time was recorded and the vibrator was deactivated. This step was repeated with all respondents to verify the time taken by all respondents. At the end of the experiment, the result was compiled and a graph of the experimental result is drawn and illustrated in Fig. 10. The x-axis indicates the time taken by respondents to differentiate the location of the obstacle and the y-axis indicates the number of respondents for each duration. Almost all respondents took around 1.5 s to localize the vibrators mounted on the wristband and recognize the direction of the obstacle correctly. Nevertheless, the time taken for respondents to localize the vibrator was about 1.8 s in average. In conclusion, the user requires around 1 s to 2 s in order to recognize the location of the obstacle and this result need to be considered in order to implement better alert system, directional angle and warning distance based on the walking speed of the visually impaired.

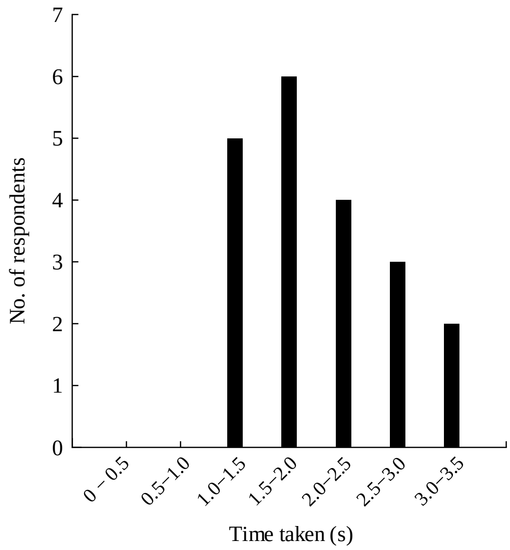


Fig. 10 Time response by respondent for vibration warning system

6. Conclusions

In this paper, a design concept and implementation of an electronic spectacle for the visually impaired to detect the obstacles at the upper body level are described. The electronic cane was proposed at first. However, since the electronic device for the upper body level does not exist, it needs to be designed and developed through discussion with the visually impaired persons from SBM and MAB. By using appropriate electronic components such as microcontroller, distance measurement sensor, vibrator, single headphone etc., the overall system configuration was constructed. Suitable distance measurement sensors, which are the main component, were compared and selected by using a pair-wise comparison table, and the ultrasonic sensor was selected. Then, the designed electronic spectacle was fabricated successfully with a weight about 90 g without battery and the vibration warning system. Finally, an evaluation of the blind spots and the effectiveness of the vibration alert system developed for the electronic spectacle was done. Based on the evaluation, few blind spots were found. However, the area of the visually impaired spots are not severe and are still considerable to be used in the design.

Acknowledgement

This project was funded by the Knowledge Transfer Programme Grant under the Ministry of Higher Education Malaysia and the Economic Planning Unit bearing the grant no. FK-DG/3 (UTEM-13). This project is also a collaboration between Universiti Teknikal Malaysia Melaka and Tokushima University, Japan.

[DOI: 10.1299/jamdsm.2016jamdsm0094]

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[DOI: 10.1299/jamdsm.2016jamdsm0094]