

Automated Walking Guide to Enhance the Mobility of Visually Impaired People

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Abstract—This paper has shown the implementation detail of a spectacle prototype to assist the visually impaired people with safe and efficient walking in the surrounding's environment. The walking guide uses three pieces of ultrasonic sensors to identify the obstacle in three directions: front, left and right. In addition, the system can detect potholes on the road surface using another ultrasonic sensor and convolutional neural network (CNN). The CNN runs on an embedded controller to identify obstacles on the surface of the road. Images are trained initially using a CNN on a host computer and are then classified on the embedded controller in real-time. The experimental analysis reveals that the proposed system has 98.73% accuracy for the front sensor with an error rate of 1.26% when the obstacle is at 50 cm distance. In addition, the proposed system obtains the accuracy, precision and recall of 92.67%, 92.33% and 93% respectively for image classification. The experimental study also demonstrates how the developed device outperforms prominent existing works.

Index Terms—Obstacle detection, pothole detection, visually impaired people, convolutional neural network, ultrasonic sensor.

I. INTRODUCTION

ONE of the major daily problems encountered by visually impaired people is unsafe mobility [1]. They fail to detect and avoid obstacles in their path, thus causing them emotional suffering, undercutting their independence, and exposes them to injuries [2]. A recent statistics from World Health Organization (WHO) show that there are approximately 253 million individuals around the world who are visually impaired. There are 217 million individuals with vision impairment, while 36 million people are blind [3]. The visual impairment is turned into a matter of great concern as the number of visually impaired people tends to increase by 2 million per decade. The number of blind people is estimated to double by 2020 [3].

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People with vision impairment and vision ailments need help to perform day-to-day tasks, such as walking and exploring unfamiliar environments [4]. Vision impaired individuals need assistance to perform their daily schedule, particularly in navigation. When individuals with vision impairment are in new or unfamiliar environments, they need to identify obstacles and other interferences [5] to allow a secure navigation. Research is focusing on this problem to develop supporting devices or assistants for individuals with visual impairment [6]. Few navigation devices are currently available for visually impaired people. Seeing-eye dogs and white canes are the most important devices. However, their performance is limited in terms of speed, coverage and the ability which are generally available for people with actual eyes [7], [8]. A cane can only detect obstacles at knee level and cannot detect head level obstructions [9]. In addition, it can only detect an obstacle within a short range (1 m). Seeing-eye dogs are a great navigation tool, but unable to detect overhanging obstacles, and need intensive training which is a tedious job for the visually impaired [10]. Furthermore, the cost of seeing-eye dogs is very high compared to other aids.

K-Sonar Cane [11] uses an adjustable sound frequency to provide feedback on obstacle distance to detect floor and head level obstructions. CyARM [12] is a scheme for handheld obstacle detection. Most walking assistants are developed with feedback signals based on obstacle detection [13]–[15]. The available devices for these individuals are in various forms like smart canes, smart glasses, handheld tools and different wearable formats. However, the acceptance rate of the available devices, among these individuals, is relatively low due to its complicated use, big size, excessive cost and heavy weight [16]. The walking assistants that are developed with the combination of several electronic sensors have been shown to be accurate on enhancing the vision impaired individual's daily activities [17]. Electronic travel aids, which are developed based on computer vision [18], are able to detect obstacles more simply and accurately than sensor based devices.

To enhance the mobility of the visually impaired people, previously we have introduced few methods as illustrated in [19] for front obstacle detection, and in [20] for front obstacle and road surface smoothness detection. These systems are capable of detecting obstructions in front of a person and generating a warning that notifies users but are unable to detect potholes on the road surface. The system developed in [21] was able to identify potholes but was only modeled in simulation. In this paper, we have introduced a spectacle prototype

which is capable of detecting obstacles in front, left and right of a user. In addition, we have shown an approach for detecting potholes using image processing. A CNN is used in combination with a sonar sensor for classifying road surfaces to find possible obstructions.

The rest of the paper is organized as follows. Section II describes the summary of the state of the art covering the recent developments in this field. The proposed methodology, for obstacle and pothole detection using sensors and CNN, is demonstrated shortly in Section III. The implementation details with the design of the prototype are described in Section IV. The experimental findings of the developed system is outlined in Section V. Section VI concludes the paper.

II. OVERVIEW OF THE STATE OF THE ART

Several assistants were developed to guide people with visual impairments to navigate safely. For a long time, many organizations have been working to develop cost-effective supportive devices for the individuals. The work related to this area is briefly described as follows.

A. Obstacle Detection and Avoidance

Several sensors are used to develop various kinds of supportive devices to offer obstacle detection and avoidance services. Ultrasonic sensors are commonly used among available sensors such as infrared sensor, laser sensor, dynamic vision sensor and time-of-flight distance sensor for obstacle detection. Most walking guides are developed using ultrasonic sensors [22]–[24] for the visually impaired people. Some assisting devices were introduced based on different sensor-based methods like infrared sensor [2], [25], laser sensors [26], dynamic vision sensors [27], wave radar [28], [29] and camera based method [30]–[32]. The systems, which were developed for obstacle detection and/or avoidance, are outlined shortly as follows.

Lee *et al.* [33] used camera and ultrasonic sensors to design a device mounted on a pair of glasses for the people with visual impairment. The developed system recognized certain color-coded markers within a 15m range using a recognition algorithm. Ultrasonic sensors are used in the front, left and right directions to identify obstacles. The detection rate for obstacles is achieved about 80% and 70% for normal and faster speed respectively. However, the system has a trade-off alongside the power demand. Ton *et al.* [34] proposed a LIDAR assist sensing scheme for visually impaired people which provide the spatial information to these individuals using a LIDAR sensor and the feedback signal is achieved through stereo sound. The system can detect obstacles in different angular direction and horizontal distance. However, the system cannot return better signal (some distortions occur from the original message) in case of body movement and needs long time training for usability.

For visually impaired people, Ramadhan [14] introduced a wearable system to aid them in walking through streets and public places. The system comprised of microcontroller board, Global System for Mobile communications (GSM) and Global Positioning System (GPS) modules, ultrasonic sensor,

accelerometer, voice recognition sensor, buzzer and a solar panel. The system used ultrasonic sensor to detect the obstacles on the track and notified the users through alarm generated by buzzer. The users can send a phone message along with their location to their family members when they are in stumbles. However, the system cannot detect the presence of water and fire, potholes and staircases as well as head level obstacles. Andò *et al.* [35] introduced a haptic tool to provide notifications to the users with the presence of obstacles. The developed system is integrated with a short cane, ultrasonic sensors and vibration motors. The sensitivity of the right, left and center positions' obstacles are achieved 0.830, 0.735 and 0.803 respectively whereas the individual specificity are 0.827, 0.924 and 0.835 respectively. With a few trials, the system is tested.

Jiang *et al.* [36] developed a wearable tool to assist the people with visual impairment using binocular vision sensors. The images are captured and sent to the cloud for computing from the real-world environment. The data are processed using CNN and the results are returned to the users that can help them in navigation. The system can detect around 10 objects. The precision and recall achieved by the proposed system are of 0.675 and 0.287 which are comparatively low. Li *et al.* [37] presented vision-based navigation system to aid individuals with visual impairment in indoor environments. The scheme proposed to use a time-stamped Kalman filter map (TSM-KF) algorithm with RGB-D camera to detect and avoid obstacles. The users are informed of obstacles with speech, audio and haptic signal. The system cannot perform at transportation terminals and cognitive mapping. Ye *et al.* [38] proposed a navigation tool named as co-robotic cane (CRC) to assist the visually impaired people in navigation. The cane comprised of a 3-D camera, a Gumstix Overo AirSTORM COM computer and a three axis gyroscope. The system is capable of detecting stairway, parallelepiped, doorway, hallway, table, computer monitor, wall and ground in indoor environment using Gaussian mixture model (GMM). However, the performance of the system degrades when the swing speed become higher ($> 30^\circ/\text{s}$).

B. Pothole Detection

There is a recommendation from specialists on orientation and mobility [39] that there is a lack of devices to differentiate between potholes and rough pitches and this inability restricts secured mobility. The systems that are developed for pothole detection are outlined as follows.

Madli *et al.* [40] provided a scheme for autonomous vehicles for automatic pothole and hump detection. The proposed scheme used GPS to take the potholes and humps' geographic position coordinates that include the potholes and humps' depth and height. The sensed data are warehoused in a cloud storage. The road data remains stored in a database for a specific place. When monitoring on the road, an aware notification is sent to the driver using a smartphone application. However, users cannot achieve well experience about the system as it is not integrated with Google maps. Dhiman and Klette [41] developed a pothole detection system for road safety using computer vision and deep learning techniques. The work

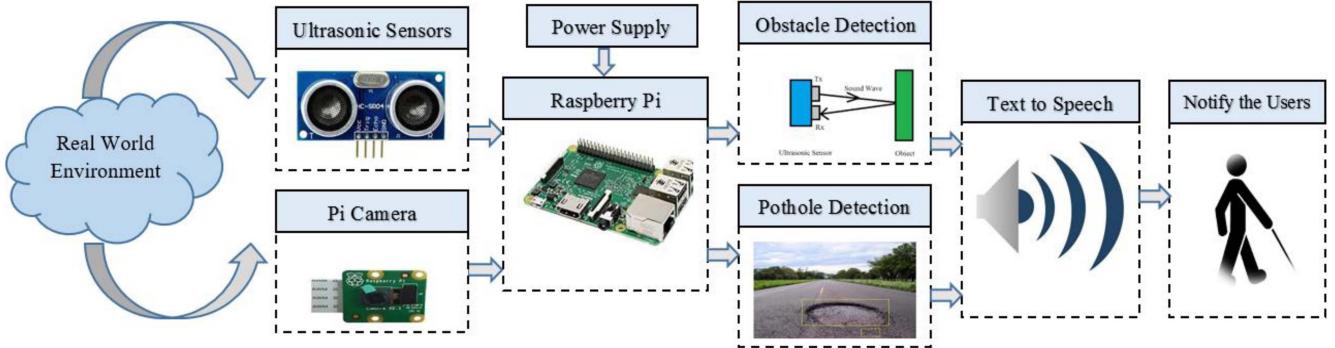


Fig. 1. System architecture of the proposed automated walking guide for the visually impaired people.

proposed four diverse approaches for pothole detection. Among these approaches, two are based on computer vision like as Single-Frame Stereo-Vision and Multi-Frame Fusion. The remaining two are based on deep learning such as Transfer Learning with Mask R-CNN and Transfer Learning with YOLOv2. The performance of the system is measured in terms of few online datasets. The data are collected from Challenging Sequences for autonomous driving (CCSAD), German Aerospace Centre (DLR), Sunny Dataset, PNW Dataset and seven different cities of Japan. The highest sensitivity and precision achieved by the proposed system are 97.1% and 96.2% respectively for Transfer Learning with Mask R-CNN. However, the system is unable to detect irregular forms of pothole. Pan *et al.* [42] introduced a pothole and crack detection scheme for asphalt pavement for transportation system. In this scheme, multispectral pavement images are used to detect the pavement with pothole using machine learning algorithms. The data from the real-world environment are collected utilizing unmanned aerial vehicle (UAV). The highest accuracy, achieved by the system, is 98.83% with 0.09 sec running time using random forests. However, the system cannot capture the cracks where the width is lesser than 13.54 mm and it is due to the spatial resolution limitation. Harikrishnan and Gopi [43] implemented a road surveillance scheme which is capable of detecting the potholes and humps on the road surface. The vibration (along the z-axis) of the autonomous vehicle is collected through the accelerometer of smartphone. The hindrances (pothole or humps) are identified with the help of x-z filtering. The scheme also determined the depth and altitude of the humps and potholes. The proposed system cannot identify expansion joints, holes in manhole and pipeline.

III. PROPOSED WALKING GUIDE METHODOLOGY

In the proposed system, real-world data is collected using ultrasonic sensors and a digital camera. Then the data from sensors is processed in an embedded controller for obstacle detection and the images from camera are compared with the pertained model for potholes classification. The overall system architecture of the developed prototype is shown in Fig. 1. The system sends an audio feedback signal to the user. The system comprised of two modules which are described as follows.

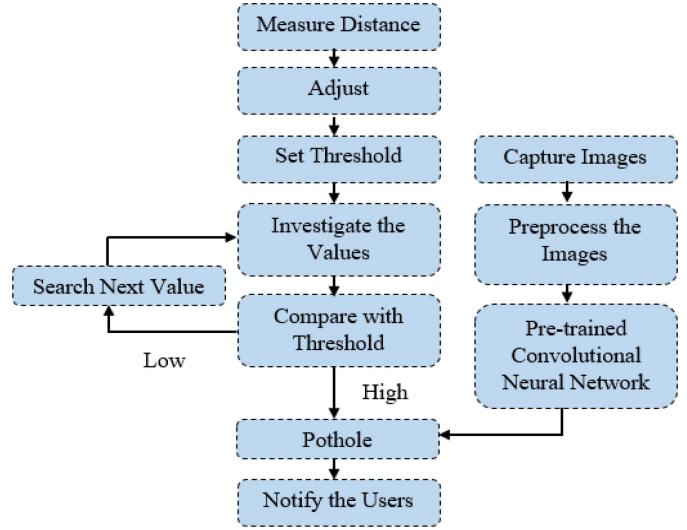


Fig. 2. Pothole detection procedure of the proposed automated walking guide for the visually impaired people.

A. Obstacle Detection Module

Three ultrasonic sensors are utilized for obstacle detection to assist the people with vision impairment in the proposed system. These sensors detect obstacles to the left, front, and right directions respectively. The distances from the hindrances to the persons are measured.

B. Pothole Detection Module

For pothole detection, a hybrid approach with the combination of sensor and CNN is used. The pothole sensor facing towards the ground is attached to the spectacle prototype. The camera captures the images and checked with a pertained model that has already been developed in a host computer. The pothole detection procedure of the developed system is shown in Fig. 2.

1) Pothole Detection Using Threshold Values: The sonar sensor measures the distance from the spectacle to the ground. A threshold value is set and compared with the current distance. If it exceeds the threshold, it is considered as pothole. The threshold value calculation procedure considers the different scenarios of wearing the prototype.



Fig. 3. Sample images from the dataset: (a) Dataset: non-pothole [44] (b) Non-pothole collected using camera and (c) Dataset: pothole [45] (d) Pothole collected using camera.

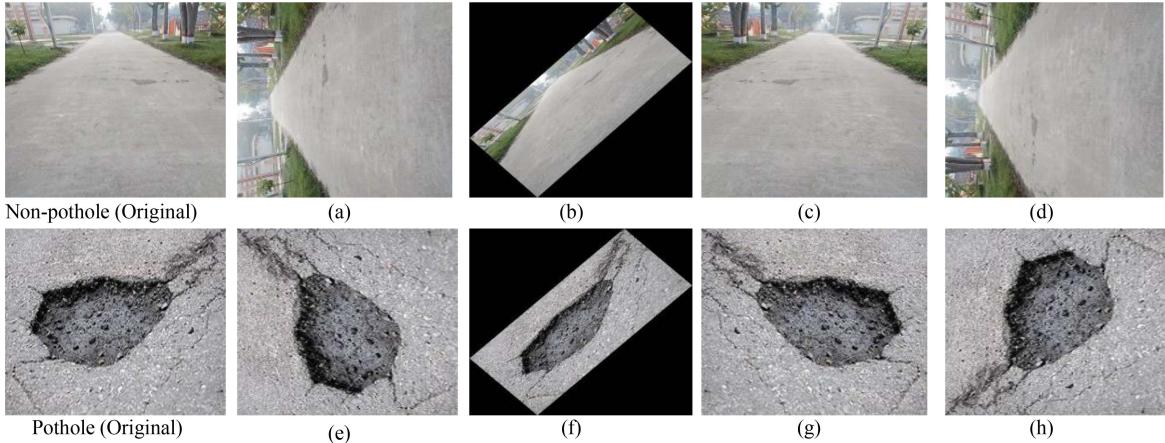


Fig. 4. Sample images after applying data augmentation technique. (a), (e). 90^0 rotation (b), (f). 45^0 rotation (c), (g). Flip left to right (d), (h). Transpose.

The setting of the threshold value may be misguided by a single value. Hence, a sequence of values is noted in different directions in front of the pothole. We have considered 10 values to set the threshold. The average value for setting the threshold is calculated by (1).

$$\text{Avg} = \sum_{i=1}^n \text{distance}_i / n \quad (1)$$

where, n is the number of distances.

The threshold value is set by repeating the process multiple times and the average value which is recorded maximum times is set as threshold as shown in (2).

$$\text{Threshold} = \text{Maximum}(\text{Avg}) \quad (2)$$

2) Pothole Detection Using CNN:

a) *Dataset collection and preparation:* The non-pothole road surface dataset is obtained from the KITTI ROAD dataset [44] containing 289 images. The road surface pothole dataset is obtained from the dataset of pothole detection [45] containing 90 images. In the dataset, the total number of

images is 379. The size of the retrieved non-pothole images is 1242×375 . However, the pothole images are of different sizes. To collect the data from the real-world environment, we have used a Raspberry Pi (RPi) camera with resolution 3280×2464 pixels. The data are collected in different weather conditions on different days and at different times of a day. The road surface dataset, that is collected using camera, contains 200 images for pothole and 100 images for non-pothole. The benchmark images and surrounding's images (collected using camera) are used so that the device can be properly suited in any environmental condition. In the dataset, the total number of images is 679, and some of which are shown in Fig. 3.

Data augmentation techniques have been applied in order to prevent the network from over fitting. Data augmentation [46] is a way to generate new data by rotating the image, moving the left/right/top/bottom image by a certain amount, flipping the image horizontally or vertically, shearing or zooming the image, cropping, padding, scaling and translation. The data augmentation techniques that are used in this paper are: the rotation of 90° and 45° , flipping from left to right and transposing. The overall process is illustrated in Fig. 4.

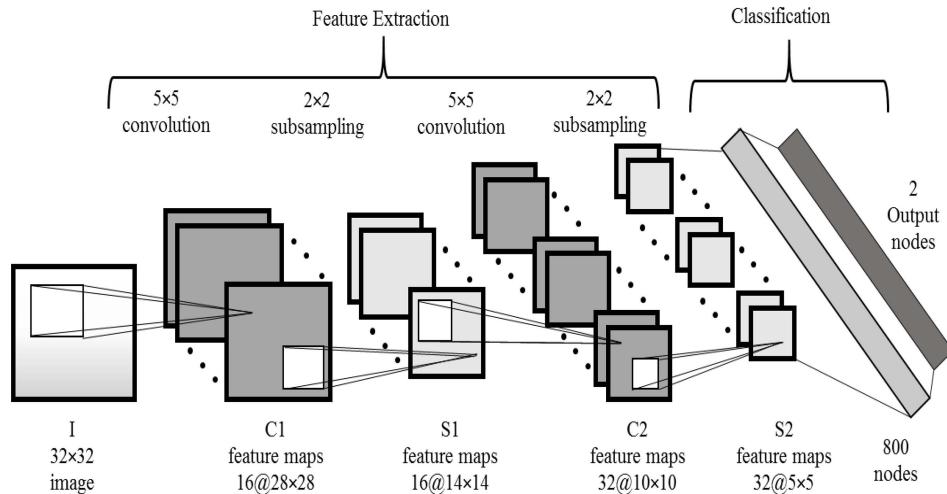


Fig. 5. CNN structure for pothole classification.

Finally, we have generated 3000 images from the dataset. Now, the datasets contain 1500 images for non-pothole and 1500 images for pothole. The datasets are partitioned into (80-20)% training-testing segments where the training set comprises of 2400 images and 600 images are included in the testing set. The collected data are in different resolutions, shapes and sizes. Hence, pre-processing is done on the collected data to bring them to same format that makes it easy to fit into CNN. At last, all images are resized into 32×32 dimensions for proper input.

b) Convolutional neural network: The convolutional neural network structure used two convolution layers and two subsampling layers each succeeding only one convolution layer for pothole classification. Fig. 5 shows the CNN structure for pothole classification considered in this work.

The kernel size remains fixed for both convolution layers and is 5×5 where the size of the pooling area is 2×2 in both subsampling layers. The number of input images is 32×32 and these input images are considered as 1024 linear nodes on which convolution process is to be accomplished. Convolution operation with kernel spatial dimension 5 converts 32 spatial dimensions to 28 ($32 - 5 + 1$) spatial dimension [47] where the size of the image is 32×32 and the size of the kernel is 5×5 . Hence, the convolutional layer (C1) with a kernel size of 5×5 and 16 kernels gives an output of 28×28 in first convolution. The max pooling procedure is used with the size of 2×2 and we used ReLU as an activation function.

The feature maps of size 28×28 are subsampled by a 2×2 window and 16 feature maps with size 14×14 are achieved in subsampling layer S1. The output data from S2 is convoluted with 32 filters of size 5×5 in convolution layer C2. The output data in C3 are 32 feature maps of size 10×10 . The output data from past layer is subsampled by a 2×2 window to generate 32 new feature maps with a size of 5×5 in subsampling layer S2. Lastly, hidden layer nodes are connected to the 2 output layer neurons to classify images into 2 classes. In the output layer, the sigmoid classification is used. Potholes in the output layer are determined from a specific neuron and non-potholes from another neuron are determined. When the value of the pothole

neurons generates 1, the value of other neurons becomes 0. The kernels are updated along with the hidden-output weights while the training proceeds with 100 iterations.

c) Performance evaluation: Several metrics are used in this paper to evaluate the performance of the proposed pothole detection system. These metrics are: accuracy, precision, recall and F1 score. The necessary formulas to derive the values of these metrics are illustrated in this paper as well. Samples with absence of potholes are considered as negative class, and samples with presence of potholes are considered as positive class.

IV. IMPLEMENTATION DETAILS

We have used a computer powered by Intel Core i7 with 8 GB RAM to develop the CNN model for pothole detection. In addition, Scikit-learn is used in python's programming language as an open-source machine learning library. Spyder is an integrated development environment that is also used to fulfill our objective. The overall system was run in Raspberry Pi 3 Model B+. The detailed description of the implementation phase is outlined as follows.

A. Construction of the Prototype

The prototype consists of four ultrasonic sensors, a Raspberry Pi 3, a headphone to alert the users and a battery for power supply. The frame of the walking guide is shown in Fig. 6. From Fig. 6, it can be observed that the arm of the spectacle is in x-axis direction. The length, height and width of the arm are 11.40 cm, 6.52 cm and 2.50 cm respectively on the exterior side. In the interior side, the length and height are of 9.75 cm and 5.54 cm individually. In the z-axis, the height is about 5.33 cm. The upper and lower length along y-axis are 13.43 cm and 14.41 cm respectively. Four holes are created for ultrasonic sensors where three of them detect the obstacles in front, left and right directions. For pothole detection, one hole is created for the ultrasonic sensor which is facing towards ground. The length, width and thickness of the hole, created for ultrasonic sensor are about 4.3 cm, 2.0 cm

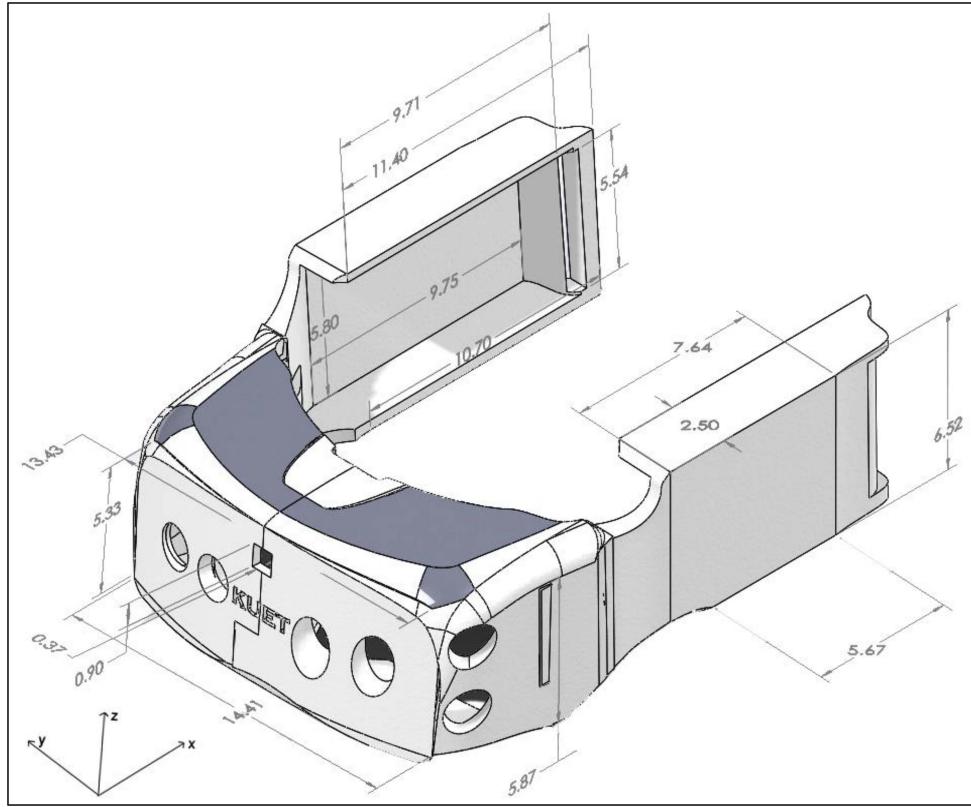


Fig. 6. Schematic diagram of the developed walking guide for the visually impaired people.

and 1.5 cm respectively. In the middle of the frame, a hole is created for the RPi camera with 0.90 cm height and width and the thickness of this hole is about 0.37cm. The dimension of the camera board is about 2.5 cm × 2.3 cm × 0.9 cm and it is located at the interior of the frame.

B. System Implementation

The walking guide is implemented in the form of a spectacle prototype in which four ultrasonic sensors, an RPi camera, RPi controller, battery and headphone are used. From Fig. 7, it can be shown that three ultrasonic sensors are used to detect obstacles along the front, left and right directions and the remaining one is used for pothole detection facing towards ground. The RPi camera is located at the middle point of the prototype. The RPi and battery for power supply are positioned at the right and left arm of the spectacle. In order to develop the model of the spectacle, the amount of Polylactic acid (PLA) material is needed as approximately 254gm.

The communication between the users and the prototype is carried out using a headphone that transmits the audio message with the presence of obstacles on the way to walk. The module, Text to Speech (TTS) is used for generating audio messages from the text. Different kinds of audio messages, which are played as feedback, are shown in Table I. If there is no obstacle found in any direction then any direction can be used for the navigation by the users. In this scenario, we have disabled the text input for “No obstacle” that indicates that no hindrances are now in the way of walking; users can move in any direction. The proposed system suggests users

(visually impaired) the free path which they can follow for safe navigation.

V. EXPERIMENTAL RESULTS ANALYSIS

The developed system is evaluated both for obstacle and pothole detection. Each part of the prototype is evaluated individually and the overall system is tested after assembling all the parts. The experiment was performed in real environment to evaluate the performance of the system. We considered outdoor environment as it contains both obstacle and pothole. In this experiment, we have considered three obstacles with a dimension of (45 x 60 x 90 cm) to represent real-life hindrances that the user might face. The three obstacles are used as hindrances towards three directions namely front, left and right respectively. To conduct the experiment, we have marked seven regions in the front side and these regions are also repeated for left and right direction. The initial region is marked at 50 cm and the final region is at 350 cm having 50 cm interval between the regions.

The obstacles are positioned at varying lengths ranging from region 1 to region 7 in each direction. In each case, the data are collected from the developed prototype. To research with pothole, we have considered a road surface that contains 4 potholes on the surface which are of circular and rectangular shape. It is noted that the potholes are created virtually. Afterward, the experiment is done with the ultrasonic sensor and camera module used for pothole detection. Camera module continuously captures images and sent them to CNN for checking the presence of potholes.

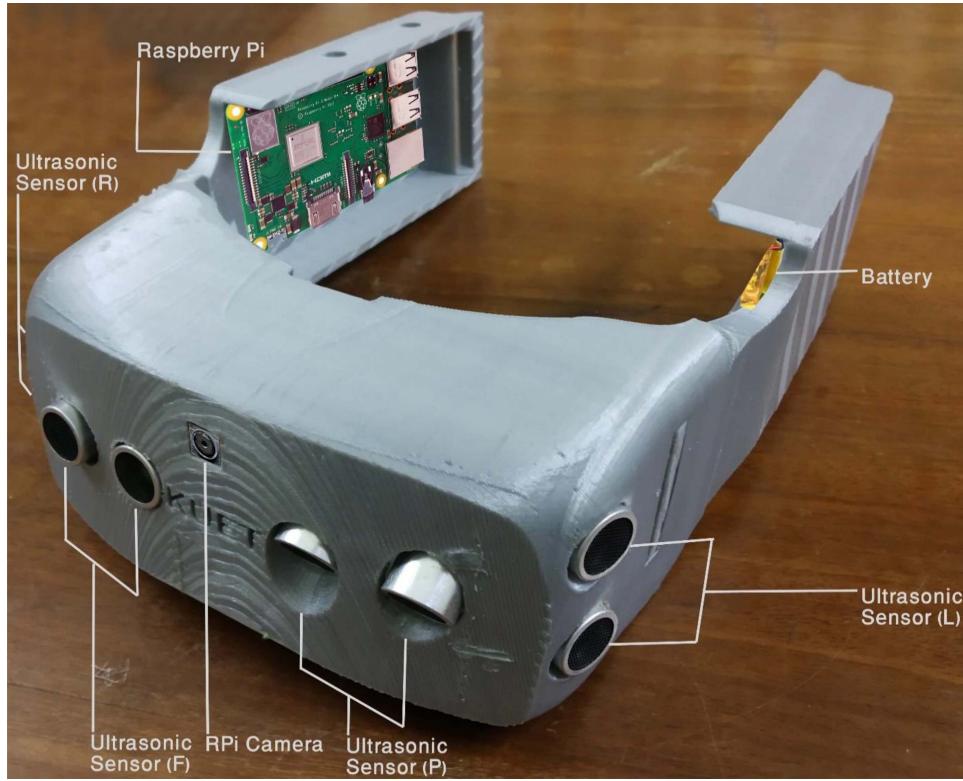


Fig. 7. Prototype of the developed walking guide for the visually impaired people.

TABLE I
AUDIO FEEDBACK SIGNALS

Obstacle Situation	Audio Message
Obstacle located on right	Move front or left direction
Obstacle located on left	Move front or right direction
Obstacle located in front	Move left or right direction
Obstacle located on left and right	Move front direction
Obstacle located in front and right	Move left direction
Obstacle located in front and left	Move right direction
Obstacle located in front, left and right	Stop. All directions are blocked
Pothole detected	Pothole

A. Obstacle Detection

The data are collected for front, left and right ultrasonic sensors by positioning obstacles in different orientations. For each interval, we have taken data for five times and calculated the average value of these data. We have also estimated the accuracy, error rate, standard deviation and variance of observed data. The collected data from each sensor (with aforementioned value) are represented in Table II, Table III and Table IV.

The comparison between actual distance and observed distance for front, left and right sensors are depicted in Fig. 8(a), Fig. 8(b) and Fig. 8(c) respectively. These representations demonstrate the distortion of the observed distance to the real distance. The deformity is shown to be not severe, and the observed distance is acceptable. Right sensor distortion is reasonably higher than other sensors. In addition, the value of the distortion from the actual distance rises in a positive approach with the increment of actual distance.

The accuracy and error rate along with the distance for all sensors are shown in Fig. 9 and Fig. 10 respectively. From Fig. 9, it can be noted that the highest accuracy of 98.73% is achieved by the front sensor when the actual distance is 50 cm. In addition, the highest accuracy obtained by the left and right sensors are 98.66% and 98.64% respectively at the same distance. The accuracy is decreased with the increase of distance. The highest error rate found at the actual distance of 350 cm is about 4.74% for right sensor. The front and left sensors obtain the highest error rate of 4.41% and 4.51% respectively at the same distance (350 cm). From Fig. 10, it can be observed that with the increase of distance, the error rate becomes high.

Standard deviation and variance are two closely associated measures of deviation. The lower value of standard deviation depicts the narrower deviation from the mean value. The variance measures the average unit to which each value varies from the mean. The larger value of the variance represents the greater data range in the overall system. The standard deviation and variance of the data collected by the developed system are illustrated in Fig. 11 and Fig. 12. From Fig. 11 and Fig. 12, it can be observed that the lower values of standard deviation and variance are achieved when the hindrances are very near to the users. These values are increased with the increase of obstacles' distance. The lowest standard deviation and variance that are obtained by the front sensor of the system are 0.51 and 0.26 respectively. It represents that the observed distance, in case of front sensor, is very close to the average value. The highest value of standard deviation and variance are obtained 4.91 and

TABLE II
REAL TIME DATA COLLECTED USING FRONT ULTRASONIC SENSOR

Actual Distance (cm)	Observed Distance (cm)					Average (cm)	Accuracy (%)	Error (%)	Standard Deviation	Variance
	1	2	3	4	5					
50	49.01	50.07	49.09	49.75	48.92	49.368	98.73	1.26	0.51	0.26
100	97.32	98.25	99.08	97.86	96.1	97.72	97.72	2.27	1.11	1.23
150	148.15	147.41	144.29	145.29	146.15	146.25	97.50	2.49	1.55	2.43
200	196.17	192.17	195.25	193.13	193.19	193.98	96.99	3.00	1.66	2.75
250	242.35	240.29	244.12	243.01	241.19	242.19	96.87	3.12	1.50	2.25
300	291.8	286.55	292.07	285.1	283.44	287.79	95.93	4.06	3.94	15.52
350	331.07	337.14	332.21	339.16	333.22	334.56	95.58	4.41	3.43	11.82

TABLE III
REAL TIME DATA COLLECTED USING LEFT ULTRASONIC SENSOR

Actual Distance (cm)	Observed Distance (cm)					Average (cm)	Accuracy (%)	Error (%)	Standard Deviation	Variance
	1	2	3	4	5					
50	49.74	50.01	49.77	48.06	49.08	49.33	98.66	1.33	0.79	0.62
100	99.26	98.24	98.06	97.55	95.32	97.68	97.68	2.31	1.46	2.13
150	148.07	145.08	143.28	147.4	146.64	146.09	97.39	2.60	1.92	3.71
200	195.7	192.15	190.38	194.1	196.61	193.78	96.89	3.10	2.55	6.50
250	245.27	237.12	243.19	238.19	243.41	241.43	96.57	3.42	3.56	12.69
300	290.09	284.34	291.37	288.58	285.06	287.88	95.96	4.03	3.08	9.50
350	340.43	333.76	331.45	330.18	335.14	334.19	95.48	4.51	3.98	15.90

TABLE IV
REAL TIME DATA COLLECTED USING RIGHT ULTRASONIC SENSOR

Actual Distance (cm)	Observed Distance (cm)					Average (cm)	Accuracy (%)	Error (%)	Standard Deviation	Variance
	1	2	3	4	5					
50	49.06	49.67	50.22	49.17	48.48	49.32	98.64	1.36	0.65	0.43
100	99.08	96.38	98.36	96.37	97.39	97.51	97.51	2.48	1.20	1.44
150	143.31	146.44	148.17	145.46	147.23	146.12	97.41	2.58	1.86	3.46
200	192.46	194.15	190.17	196.29	195.26	193.66	96.83	3.16	2.41	5.83
250	245.11	236.07	237.24	244.12	242.15	240.93	96.37	3.62	4.07	16.59
300	290.94	284.19	287.06	285.3	291.24	287.74	95.91	4.08	3.22	10.37
350	341.63	331.75	330.06	329.58	333.95	333.39	95.25	4.74	4.91	24.12

24.12 in case of right sensor and it depicts comparatively higher distortion.

B. Pothole Detection

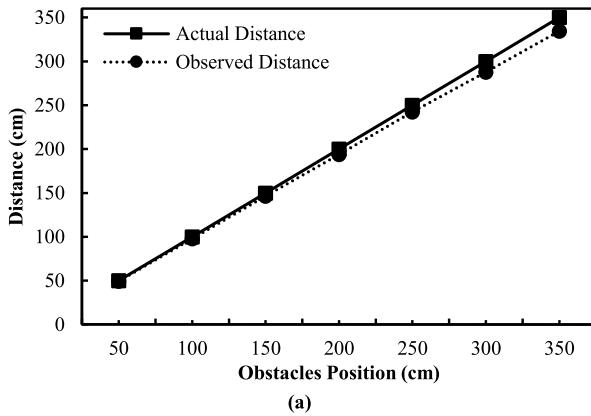
As the pothole detection system uses both ultrasonic sensor and camera, the appropriate fusion between them is necessary. For this purpose, the data using sensors and the images using camera are continuously taken. Whenever the sensor identifies a hollow signal and CNN also returns the same results indicating the pothole, an audio signal is generated to alert the users.

The pothole detection using sensor uses a generated threshold to flag potholes. The threshold values are calculated when the device is powered on and these values are set by averaging first 10 values obtained by the pothole detection sensor. Table V highlights a few trials of threshold values' measurement. From Table V, it can be observed that the threshold values for 1st, 2nd and 3rd users are 192.98 cm, 188.71 cm, and 181.86 cm respectively. The users' height that is considered for the experiment is 165 cm, 160 cm, and 152 cm for 1st, 2nd and 3rd users respectively. The threshold value varies due to the different

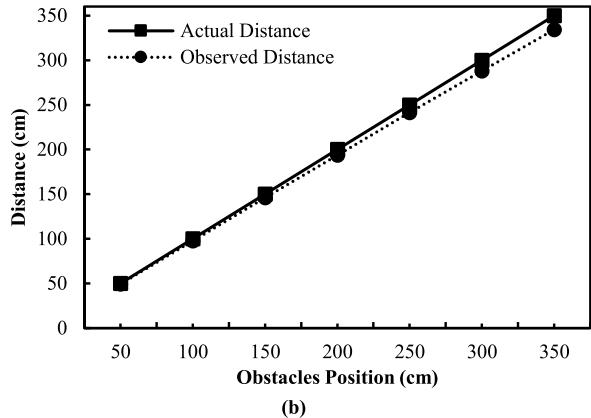
heights of the users. Any distance greater than the threshold values (192.98 cm for 1st user) depicts the presence of potholes.

CNN is trained with the sample images in a host computer. The developed model is transferred to Raspberry Pi 3 that predicts the presence of potholes by capturing a single image each time. The experimental findings indicate that CNN generates a highly accurate pothole detection scheme where 100 iterations are performed. In every iteration, we have evaluated the accuracy, precision, recall and F1 score both for training and testing phases. In training phase, among 2400 samples, 1195 are correctly identified as non-potholes, 1 is wrongly identified as non-potholes, 5 samples are wrongly classified as potholes, and 1199 are correctly identified as potholes. The overall accuracy obtained by the system is 99.75% in training phase. In addition, the precision, recall and F1 score achieved by the system are 99.58%, 99.91% and 99.75% respectively. The performance measuring parameters (metrics) for training phase are shown in Fig. 13.

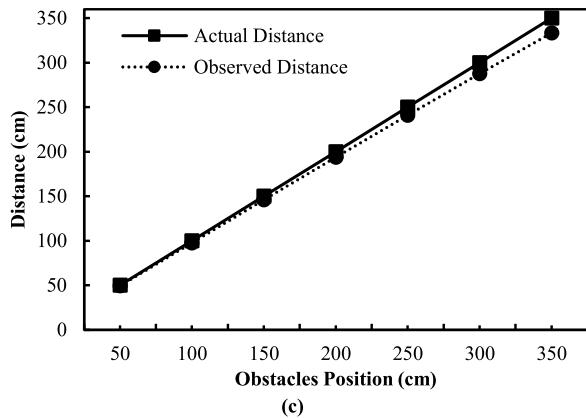
In testing phase, among 600 samples, 277 are correctly identified as non-potholes, 21 are wrongly identified as non-potholes, 23 samples are wrongly classified as potholes, and 279 are correctly identified as potholes. Using the values from



(a)



(b)



(c)

Fig. 8. Comparison between actual and observed distance. (a) Front sensor (b) Left sensor (c) Right sensor.

the confusion matrix, the performance measuring parameters (metrics) are calculated. The overall accuracy obtained by the system is 92.67% in testing phase. Besides, other metrics such as precision, recall and F1 score appraised by the system are 92.38%, 93% and 92.68% respectively. The performance measuring parameters (metrics) for testing phase are illustrated in Fig. 14.

C. Comparative Analysis

A comparative analysis between the developed walking guide and the existing electronic travel aids is illustrated here. The common requirements of electronic travel aid that are suggested by the visually impaired individuals, their caregivers,

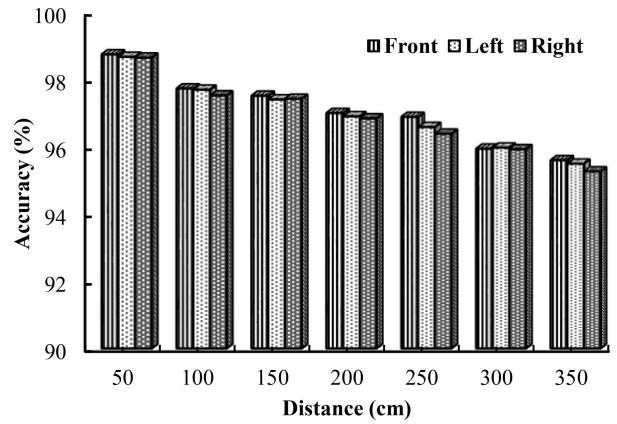


Fig. 9. The accuracy rate achieved by the developed system.

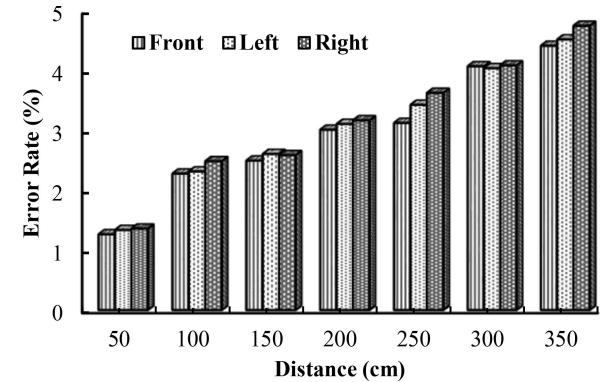


Fig. 10. The error rate obtained by the developed system.

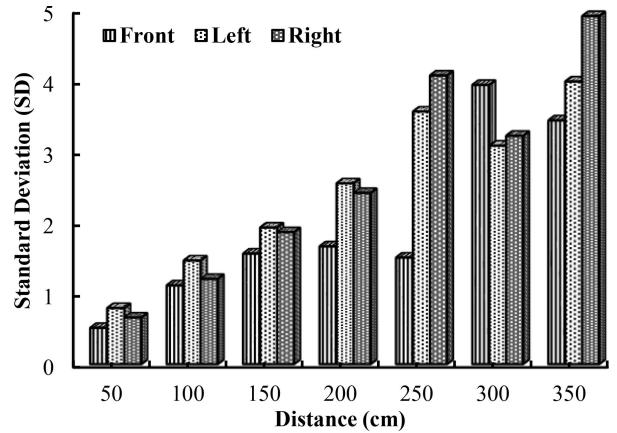


Fig. 11. Standard deviation of the data collected by the developed system.

and rehabilitation specialists [16] are adequate surrounding's information, light weight, low cost and simple carry technique.

Among existing electronic travel aids, few systems [12], [48], [49] can only detect obstacles in front of users instead of detecting all surrounding's objects. A comparative study is drawn with the existing works with respect to accuracy, cost and weight and is shown in Table VI. In case of cost analysis, the systems proposed in [16], [20], [50], [51] and [52] showed the cost of the systems as approximately \$280, \$40, \$10, \$150 and \$1790 respectively. Some of the developed systems are

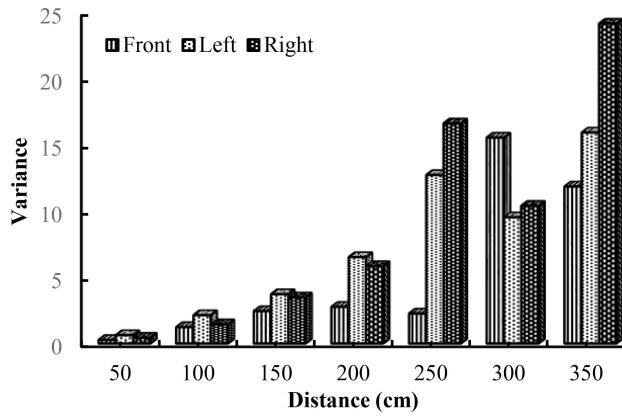


Fig. 12. Variance of the data collected by the developed system.

TABLE V
MEASUREMENT OF THRESHOLD VALUES

Users	Measurement of threshold values for different users (cm)	Threshold Values (cm)
1	192.29, 191.40, 193.87, 194.46, 194.20, 192.86, 192.02, 191.04, 193.87, 193.84	192.98
2	188.57, 186.90, 190.55, 187.81, 187.85, 189.29, 187.73, 190.26, 189.85, 188.26	188.71
3	180.59, 181.75, 181.93, 181.52, 182.81, 180.29, 181.89, 180.82, 183.38, 183.58	181.86

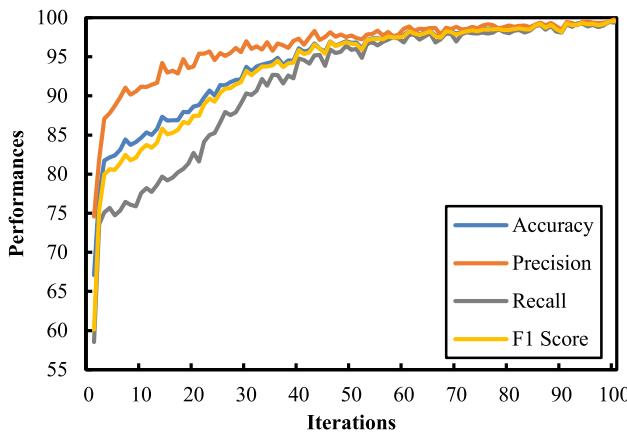


Fig. 13. Performance measure parameters of the developed system in training phase.

having overweights and some are having light weights. The weight of the systems [16], [20], [50] and [51] are of 0.503 kg, 110 g, 160 g and 1.57 kg (including a 800g vest) respectively. Comparing accuracy, the highest and lowest accuracies of the system in [48] are around 98.8 % when the obstacle was near (5 cm to users) and 62.8 % when the obstacle was far away (350 cm from users). The average accuracy achieved by the systems proposed in [20] and [51] are about 96% and 95% respectively.

The developed walking guide provides users clear and concise information about the environment in all directions. This prototype guides people to an alternative direction when an obstacle is detected. The overall cost of our developed prototype is approximately \$140 and the weight is about 360 g including all electronic components. The developed walking guide is a spectacle prototype that provides easy carrying

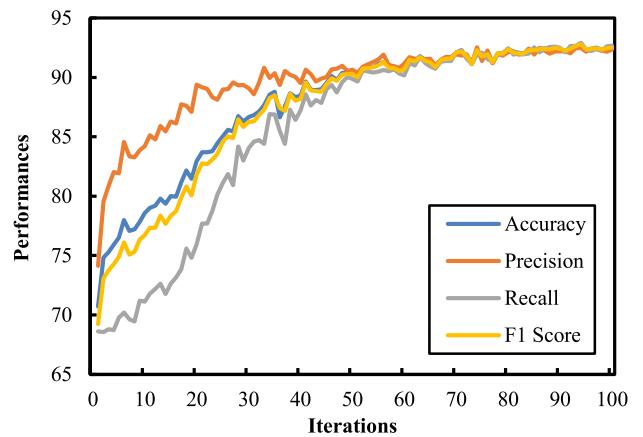


Fig. 14. Performance measure parameters of the developed system in testing phase.

TABLE VI
THE COMPARISON OF THE DEVELOPED WALKING GUIDE WITH EXISTING WORKS WITH RESPECT TO ACCURACY, COST AND WEIGHT

Authors	Accuracy (%)	Cost (\$)	Weight
Bhatlawande et al. [16]	N/A	280	0.503 kg
Sadi et al. [20]	96	10	160 g
Sharma et al. [48]	80.8	N/A	N/A
O'Brien et al. [50]	N/A	40	110 g
Kim et al. [51]	95	150	1.57 kg
Bharambe et al. [52]	N/A	1790	N/A
Developed Walking Guide	97.05	140	360 g

*N/A: Not Appropriately Defined

facilities. Also, the system is able to detect the obstacles within 3.34 m. The average accuracy obtained by the system is about 97.05% for obstacle detection and 92.67% for pothole detection. It can be noted that the developed walking guide outperforms the systems proposed by [16] and [51] in case of weight and cost. The system proposed in [20] has comparatively light weight and is less costly than our developed system. However, it can detect the front obstacles only. In addition, the system developed in [20] cannot trace the pothole on the road. Moreover, the components of the system [20] are attached with a traditional spectacle which emerges difficulties for the users to wear on and no prototype is developed or modeled in their proposal. On the contrary, our proposed walking guide is developed using 3D printer highlighting the users' requirements.

D. Usability Study

The usability and the level of comfort of the developed prototype are measured with the help of visually impaired people. For this purpose, we have performed a survey at a "madrasa and home for the blind" where 16 visually impaired people of different ages have participated in this survey. Firstly, we have introduced them to every part of the developed prototype. The participants are learnt about the feedback signal that they would hear during navigation, the position of the sensors and camera as well as how to wear the prototype. We set some



Fig. 15. A visually impaired child wears the prototype.

questionnaires for the participants to collect the expressions from them. The questionnaires are designed to get their feelings about coverage area, feedback signal, cost, weight and size of the developed system. All the participants are asked about these five key issues during the survey. The survey is conducted in outdoor environment in daylight condition. In case of coverage area, all participants have agreed that the developed prototype is able to notify them from an affordable distance. In terms of feedback signal analysis, 14 people have expressed that they have heard the audio signal properly and the remaining 2 people have missed to hear in some cases. Then we have come to know from the participants that the persons who could not hear the audio signal properly, have some hearing problems. During the survey, 11 people have responded that the cost is beyond their scope, 3 participants treated as moderate cost and the rest 2 persons have expressed that the cost is comparatively high. In case of weight, 9 people among the participants have considered the weight as tolerable, 4 people have considered the weight as moderate and the remaining 3 participants have replied negatively for the weight. The size of the prototype is felt bulky by 8 participants while 4 people have felt this as reasonable and the rest 4 have expressed that it is quite affordable.

From the survey results, it is evident that the developed prototype is able to overcome the limitations which are being faced by the visually impaired people. The feedback signal is also audible by the respondents. Both weight and cost are reasonable, while the size is a bit questionable among the survey participants.

A visually impaired child, among the participants, wore the prototype and felt happy to walk in a collision free environment. The developed prototype, with a real user, is shown in Fig. 15. The overall system has provided a good experience while testing with visually impaired.

VI. CONCLUSION

The main goal of this paper is to develop a walking guide to help vision impaired people to navigate independently in their

environment. The developed system consists of two main parts that are obstacle and pothole detection. The obstacle detection system is designed to indicate the presence of obstacles in the front, left and right directions around the surroundings. The pothole detection system detects the potholes on the road surface. The overall electronic spectacle prototype, which can be used for guiding the visually impaired individuals, is constructed in this paper. By analyzing the data from ultrasonic sensors, the distance between the obstacle and the user is calculated. The pothole images are trained initially using convolutional neural network and the potholes are detected by capturing a single image each time. The notification about the presence of obstacles and potholes is passed to the users through audio signals. The developed prototype is still a bit bulky. It can only detect the obstacles and potholes but cannot categorize the obstacles and potholes. Despite these limitations, the developed walking guide can be used as an effective supporting aid for vision impaired people.

In future, an Application Specific Integrated Circuit (ASIC), with the functionalities of the developed walking guide, can be developed to reduce the size, weight and cost of the prototype. Another recommended enhancement of this research is that semantic pixel-wise segmentation of the surroundings may contribute to categorize obstacles in the environment.

REFERENCES

- [1] V. V. Meshram, K. Patil, V. A. Meshram, and F. C. Shu, "An astute assistive device for mobility and object recognition for visually impaired people," *IEEE Trans. Human-Mach. Syst.*, vol. 49, no. 5, pp. 449–460, Oct. 2019.
- [2] R. Jafri, R. L. Campos, S. A. Ali, and H. R. Arabnia, "Visual and infrared sensor data-based obstacle detection for the visually impaired using the Google project tango tablet development kit and the unity engine," *IEEE Access*, vol. 6, pp. 443–454, 2017.
- [3] R. R. Bourne *et al.*, "Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: A systematic review and meta-analysis," *Lancet Global Health*, vol. 5, no. 9, pp. e888–e897, 2017.
- [4] E. Cardillo *et al.*, "An electromagnetic sensor prototype to assist visually impaired and blind people in autonomous walking," *IEEE Sensors J.*, vol. 18, no. 6, pp. 2568–2576, Mar. 2018.
- [5] A. Riazi, F. Riazi, R. Yoosfi, and F. Bahmeei, "Outdoor difficulties experienced by a group of visually impaired Iranian people," *J. Current Ophthalmol.*, vol. 28, no. 2, pp. 85–90, 2016.
- [6] M. M. Islam, M. S. Sadi, K. Z. Zamli, and M. M. Ahmed, "Developing walking assistants for visually impaired people: A review," *IEEE Sensors J.*, vol. 19, no. 8, pp. 2814–2828, Apr. 2019.
- [7] S. Mahmud, X. Lin, and J. Kim, "Interface for human machine interaction for assistant devices: A review," in *Proc. 10th Annu. Comput. Commun. Workshop Conf. (CCWC)*, Las Vegas, NV, USA, 2020, pp. 0768–0773.
- [8] R. Tapu, B. Mocanu, and T. Zaharia, "Wearable assistive devices for visually impaired: A state of the art survey," *Pattern Recognit. Lett.*, to be published.
- [9] N. Sahoo, H.-W. Lin, and Y.-H. Chang, "Design and implementation of a walking stick aid for visually challenged people," *Sensors*, vol. 19, no. 1, p. 130, 2019.
- [10] H. Zhang and C. Ye, "An indoor wayfinding system based on geometric features aided graph SLAM for the visually impaired," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 25, no. 9, pp. 1592–1604, Sep. 2017.
- [11] M. Hersh and M. A. Johnson, *Assistive Technology for Visually Impaired and Blind People*. London, U.K: Springer, 2010.
- [12] K. Ito *et al.*, "CyARM: An alternative aid device for blind persons," in *Proc. ACM Extended Abstracts Hum. Factors Comput. Syst. (CHI'05)*, 2005, pp. 1483–1488.
- [13] M. N. Alam, M. M. Islam, A. Habib, and M. B. Mredul, "Staircase detection systems for the visually impaired people: A review," *Int. J. Comput. Sci. Inf. Security*, vol. 16, no. 12, pp. 13–18, 2018.

- [14] A. J. Ramadhan, "Wearable smart system for visually impaired people," *Sensors*, vol. 18, no. 3, p. 843, 2018.
- [15] Z. Bauer, A. Dominguez, E. Cruz, F. Gomez-Donoso, S. Orts-Escalano, and M. Cazorla, "Enhancing perception for the visually impaired with deep learning techniques and low-cost wearable sensors," *Pattern Recognit. Lett.*, to be published.
- [16] S. Bhatlawande, M. Mahadevappa, J. Mukherjee, M. Biswas, D. Das, and S. Gupta, "Design, development, and clinical evaluation of the electronic mobility cane for vision rehabilitation," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 22, no. 6, pp. 1148–1159, Nov. 2014.
- [17] K. Patil, Q. Jawadwala, and F. C. Shu, "Design and construction of electronic aid for visually impaired people," *IEEE Trans. Human-Mach. Syst.*, vol. 48, no. 2, pp. 172–182, Apr. 2018.
- [18] A. Aladrén, G. López-Nicolás, L. Puig, and J. J. Guerrero, "Navigation assistance for the visually impaired using RGB-D sensor with range expansion," *IEEE Syst. J.*, vol. 10, no. 3, pp. 922–932, Sep. 2016.
- [19] M. M. Kamal, A. I. Bayazid, M. S. Sadi, M. M. Islam, and N. Hasan, "Towards developing walking assistants for the visually impaired people," in *Proc. IEEE Region 10 Human Technol. Conf. (R10-HTC)*, Dhaka, Bangladesh, 2017, pp. 238–241.
- [20] M. S. Sadi, S. Mahmud, M. M. Kamal, and A. I. Bayazid, "Automated walk-in assistant for the blinds," in *Proc. Int. Conf. Elect. Eng. Inf. Commun. Technol.*, Dhaka, Bangladesh, 2014, pp. 1–4.
- [21] M. M. Islam and M. S. Sadi, "Path hole detection to assist the visually impaired people in navigation," in *Proc. 4th Int. Conf. Elect. Eng. Inf. Commun. Technol. (iCEEiCT)*, Dhaka, Bangladesh, 2018, pp. 268–273.
- [22] M. Khanom, M. S. Sadi, and M. M. Islam, "A comparative study of walking assistance tools developed for the visually impaired people," in *Proc. 1st Int. Conf. Adv. Sci. Eng. Robot. Technol. (ICASERT)*, Dhaka, Bangladesh, 2019, pp. 1–5.
- [23] M. M. Rahman, M. M. Islam, and S. Ahmed, "'BlindShoe': An electronic guidance system for the visually impaired people," *J. Telecommun. Electron. Comput. Eng.*, vol. 11, no. 2, pp. 49–54, 2019.
- [24] M. A. Habib, M. M. Islam, M. N. Kabir, M. B. Mredul, and M. Hasan, "Staircase detection system for visually impaired people: A hybrid approach," *Revue d'Intelligence Artificielle*, vol. 33, no. 5, pp. 327–334, 2019.
- [25] M. A. Rahman, M. S. Sadi, M. M. Islam, and P. Saha, "Design and development of navigation guide for visually impaired people," in *Proc. IEEE Int. Conf. Biomed. Eng. Comput. Inf. Technol. Health (BECITHCON)*, Dhaka, Bangladesh, 2019, pp. 89–92.
- [26] M. M. Rahman, M. M. Islam, S. Ahmed, and S. A. Khan, "Obstacle and fall detection to guide the visually impaired people with real time monitoring," *SN Comput. Sci.*, vol. 1, no. 4, pp. 1–9, 2020.
- [27] L. Everding, L. Walger, V. S. Ghaderi, and J. Conradt, "A mobility device for the blind with improved vertical resolution using dynamic vision sensors," in *Proc. IEEE 18th Int. Conf. e-Health Netw. Appl. Serv. (Healthcom)*, Munich, Germany, 2016, pp. 1–5.
- [28] N. Long, K. Wang, R. Cheng, W. Hu, and K. Yang, "Unifying obstacle detection, recognition, and fusion based on millimeter wave radar and RGB-depth sensors for the visually impaired," *Rev. Sci. Instrum.*, vol. 90, no. 4, 2019, Art. no. 044102.
- [29] N. Long, K. Wang, R. Cheng, K. Yang, W. Hu, and J. Bai, "Assisting the visually impaired: Multitarget warning through millimeter wave radar and RGB-depth sensors," *J. Electron. Imag.*, vol. 28, no. 1, pp. 1–15, 2019.
- [30] K. Qian, W. Zhao, Z. Ma, J. Ma, X. Ma, and H. Yu, "Wearable-assisted localization and inspection guidance system using egocentric stereo cameras," *IEEE Sensors J.*, vol. 18, no. 2, pp. 809–821, Jan. 2018.
- [31] S. Mahmud *et al.*, "A multi-modal human machine interface for controlling a smart wheelchair," in *Proc. IEEE 7th Conf. Syst. Process Control (ICSPC)*, Melaka, Malaysia, 2019, pp. 10–13.
- [32] C. Ye and X. Qian, "3-D object recognition of a robotic navigation aid for the visually impaired," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 26, no. 2, pp. 441–450, Feb. 2018.
- [33] C. Lee, P. Chondro, S. Ruan, O. Christen, and E. Naroska, "Improving mobility for the visually impaired: A wearable indoor positioning system based on visual markers," *IEEE Consum. Electron. Mag.*, vol. 7, no. 3, pp. 12–20, May 2018.
- [34] C. Ton *et al.*, "LIDAR assist spatial sensing for the visually impaired and performance analysis," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 26, no. 9, pp. 1727–1734, Sep. 2018.
- [35] B. Andò, S. Baglio, V. Marletta, and A. Valastro, "A haptic solution to assist visually impaired in mobility tasks," *IEEE Trans. Human-Mach. Syst.*, vol. 45, no. 5, pp. 641–646, Oct. 2015.
- [36] B. Jiang, J. Yang, Z. Lv, and H. Song, "Wearable vision assistance system based on binocular sensors for visually impaired users," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 1375–1383, Apr. 2019.
- [37] B. Li *et al.*, "Vision-based mobile indoor assistive navigation aid for blind people," *IEEE Trans. Mobile Comput.*, vol. 18, no. 3, pp. 702–714, Mar. 2019.
- [38] C. Ye, S. Hong, X. Qian, and W. Wu, "Co-robotic cane: A new robotic navigation aid for the visually impaired," *IEEE Syst., Man, Cybern. Mag.*, vol. 2, no. 2, pp. 33–42, Apr. 2016.
- [39] E. Pissaloux and R. Velazquez, *Mobility of Visually Impaired People: Fundamentals and ICT Assistive Technologies*. Cham, Switzerland: Springer, 2018.
- [40] R. Madli, S. Hebbar, P. Pattar, and V. Golla, "Automatic detection and notification of potholes and humps on roads to aid drivers," *IEEE Sensors J.*, vol. 15, no. 8, pp. 4313–4318, Aug. 2015.
- [41] A. Dhiman and R. Klette, "Pothole detection using computer vision and learning," *IEEE Trans. Intell. Transp. Syst.*, early access, Aug. 6, 2019, doi: [10.1109/TITS.2019.2931297](https://doi.org/10.1109/TITS.2019.2931297).
- [42] Y. Pan, X. Zhang, G. Cervone, and L. Yang, "Detection of asphalt pavement potholes and cracks based on the unmanned aerial vehicle multispectral imagery," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 11, no. 10, pp. 3701–3712, Oct. 2018.
- [43] P. M. Harikrishnan and V. P. Gopi, "Vehicle vibration signal processing for road surface monitoring," *IEEE Sensors J.*, vol. 17, no. 16, pp. 5192–5197, Aug. 2017.
- [44] J. Fritsch, T. Kühl, and A. Geiger, "A new performance measure and evaluation benchmark for road detection algorithms," in *Proc. 16th Int. IEEE Conf. Intell. Transp. Syst. (ITSC)*, Hague, The Netherlands, 2013, pp. 1693–1700.
- [45] *Pothole Detection Dataset*. Accessed: Dec. 10, 2018. [Online]. Available: http://people.eft.unsa.ba/~aakagic/pothole_detection/
- [46] A. Miko and M. Grochowski, "Data augmentation for improving deep learning in image classification problem," in *Proc. Int. Interdiscipl. PhD Workshop (IIPHDW)*, Swinoujscie, Poland, 2018, pp. 117–122.
- [47] R. B. Hegde, K. Prasad, H. Hebbar, and B. M. K. Singh, "Feature extraction using traditional image processing and convolutional neural network methods to classify white blood cells: A study," *Aust. Phys. Eng. Sci. Med.*, vol. 42, no. 2, pp. 627–638, 2019.
- [48] S. Sharma, M. Gupta, A. Kumar, M. Tripathi, and M. S. Gaur, "Multiple distance sensors based smart stick for visually impaired people," in *Proc. IEEE 7th Annu. Comput. Commun. Workshop Conf. (CCWC)*, Las Vegas, NV, USA, 2017, pp. 1–5.
- [49] S. Bhatlawande, M. Mahadevappa, and J. Mukhopadhyay, "Way-finding electronic bracelet for visually impaired people," in *Proc. IEEE Point Care Healthcare Technol. (PHT)*, Bangalore, India, 2013, pp. 260–263.
- [50] E. E. O'Brien, A. A. Mohtar, L. E. Diment, and K. J. Reynolds, "A detachable electronic device for use with a long white cane to assist with mobility," *Assist. Technol.*, vol. 26, no. 4, pp. 219–226, 2014.
- [51] C.-G. Kim and B.-S. Song, "Design of a wearable walking-guide system for the blind," in *Proc. 1st Int. ACM Convent. Rehabil. Eng. Assist. Technol. Conjunction 1st Tan Tock Seng Hospital Neurorehabil. Meeting*, 2007, pp. 118–122.
- [52] S. Bharambe, R. Thakker, H. Patil, and K. M. Bhurchandi, "Substitute eyes for blind with navigator using android," in *Proc. Texas Instrum. India Educ. Conf.*, Bangalore, India, 2013, pp. 38–43.