A Deep Learning-Based Smart Assistive Framework for Visually Impaired People

Yar Muhammad
School of Computer Science and Engineering,
Beihang University, Beijing, China.
Email: yarkhan@buaa.edu.cn

Mian Ahmad Jan
Department of Computer Science,
Abdul Wali Khan University Mardan, Pakistan.
Email: mianjan@awkum.edu.pk

Spyridon Mastorakis
College of Information Science and Technology,
University of Nebraska Omaha, United States.
Email: smastorakis@unomaha.edu

Bakht Zada
School of Computer Science and Engineering,
Beihang University, Beijing, China.
Email: bakhtzada8c@gmail.com

2022 IEEE International Conference on Omni-layer Intelligent Systems (COINS) | 978-1-6654-8356-8/22/$31.00 ©2022 IEEE | DOI: 10.1109/COINS54846.2022.9854984

***Abstract*— According to the World Health Organization (WHO), there are millions of visually impaired people in the world who face a lot of difficulties in moving independently. They always need help from people with normal sight. The capability to find their way to their intended destination in an unseen place is a major challenge for visually impaired people. This paper aimed to assist these individuals in resolving their problems with moving to any place on their own. To this end, we developed an intelligent system for visually impaired people using a deep learning (DL) algorithm, i.e., convolutional neural network (CNN) architecture, AlexNet, to recognize the situation and scene objects automatically in real-time. The proposed system consists of a Raspberry Pi, ultrasonic sensors, a camera, breadboards, jumper wires, a buzzer, and headphones. Breadboards are used to connect the sensors with the help of a Raspberry Pi and jumper wires. The sensors are used for the detection of obstacles and potholes, while the camera performs as a virtual eye for the visually impaired people by recognizing these obstacles in any direction (front, left, and right). The proposed system provides information about objects to a blind person. The system automatically calculates the distance between the blind person and the obstacle that how far he/she is from the obstacle. Furthermore, a voice message alerts the blind person about the obstacle and directs him/her via earphones. The obtained experimental results show that the utilized CNN architecture AlexNet yielded an impressive result of 99.56% validation accuracy and has a validation loss of 0.0201%.**

***Index Terms*; Convolutional Neural Network; Raspberry Pi; Ultrasonic Sensors; way finding system; situation awareness; smart cane.**

I. Introduction

People with disabilities experience a variety of everyday barriers and problems, such as daily mobility and speaking with others, that limit their ability to connect and interact with the environment around them on their own. To solve these issues and to enhance the living standard of people with physiological disabilities, there is a need to develop new digital solutions. The use of proper auxiliary equipment can have a significant influence on an individual's ability to maintain their independence and enhance their quality of life. Visual impairment refers to vision loss (completely blind or legally blind) and is indeed a serious issue. Visual impairment makes it tough for blind people to move around independently, especially in new places, that they have not seen before. According to the WHO, more than 2.2 Billion people have vision impairment problems, of which 1 billion have been avoided or are still unaddressed [1]. Distance and close vision impairments are the two types of vision problems. Distance vision problem is further divided into mild, moderate, severe, and complete blindness, with visual acuities of less than 6/12, 6/18, 6/60, and 3/60, respectively. Visual acuity (Eyesight) is the measurement of visual sharpness in which the first digit represents the distance in meters between the Snelling chart and the patients while the second digit specifies where a normal-sighted individual, with a visual acuity of 6/6, should stand to view the similar chart. People with a closed vision problem, on the other hand, have eyesight less than N6 or N8, where N stands for near vision and the digit illustrates the letter size. In this case, the evaluation distance is about 40 centimeters.

The world is facing numerous challenges in the field of eye care, including treatment, a shortage of trained eye care providers, and a lack of integration of the eye care system into the healthcare system. A survey was released on World Sight day to alert the public about the increasing number of vision impairment and blindness problems caused by numerous eye disorders such as Presbyopia, which affects 1.8 billion people and occurs at a young age, Myopia, which affects 2.6 billion people, cataract, which affects 65.2 million people, and corneal opacity, which affects 6.9 million people [2]. A visually impaired person faces numerous challenges such as human recognition, documentation (writing, reading), finding the pathway, etc., that necessitate the assistance of a sighted person for him/her to find his/her way. Further, due to the unfamiliar environment and places that have not been visited previously, blind people are unable to find their way. Disabled people normally use a white cane or walking cane to find their way and to identify the obstacles in their way. This is indeed a serious issue, as every time it is difficult to carry a fully sighted individual for help in finding the way or to carry the walking cane each time to find the way. To overcome this issue, this study proposes an intelligent approach that will help visually impaired people find their way without the assistance of an individual or walking cane.

978-1-6654-8356-8/22/$31.00 ©2022 IEEE

The primary contributions of this study are listed as follows:

- The Raspberry Pi and ultrasonic sensors are used to design a smart blind device that will assist visually impaired people in finding obstacles in their way and help them not fall. The ultrasonic system emits energy waves that reflect from obstacles on any side i.e. left, right, and front to assist the visually impaired person in detecting the obstacle within the defined range. The distance between the visually impaired person and objects is calculated using the ultrasonic sensor's starting and ending pulses.
- A buzzer sensor is used to alert the blind person if there is an obstacle in his/her way. The obstacles can be stairs, walls, cars, buses, pillars, etc. If the obstacle is too close to the blind person, the proposed system will generate a voice message and activate a buzzer to alert the visually impaired person about the obstacles. In addition, with the inclusion of voice message support, the proposed system can provide full support for obstacle avoidance.
- A modified deep learning (DL) model, i.e. AlexNet, is used for the detection of objects (pillars, walls, cars, stairs, and buses). The performance of the proposed DL model was superior as compared to the earlier approaches in terms of all the utilized performance measures. The proposed module will be beneficial for people who are visually impaired. It will make the lives of blind individuals easier and will assist them to find ways in daily life.

The remaining paper is structured as follows: the literature review is illustrated in Section 2, and details of the proposed methodology for CNN (AlexNet) are shown in Section 3. Section 4 is about the experimental results and analysis of the results, and finally, we conclude our paper in Section 5.

II. Literature Review

Without the assistance of computational technology based systems, daily navigation for blind and visually impaired persons, particularly in unfamiliar areas, might be a daunting endeavor. Various attempts have been made by different researchers all over the world to propose a design that assists the visually impaired people in detecting obstacles in their ways by using various electronic technologies. Some of these works are focused on microcontrollers, and some of them have used Global System for Mobile Communications (GSM) and Global Positioning System (GPS) technology, but the majority of them have used the ultrasonic sensors to detect obstacles. All of these efforts are focused on assisting blind people in detecting obstacles, rather than assisting them in navigating on their own. For example, Batavia et al. [3], proposed a distance-dependent method based on a camera, with background motion measured using homographic transforms. Hesch et al. [4], proposed a design model that consists of a 2-dimensional laser scanner, foot mounted pedometer, and 3 axis gyroscopes for the aid of visually impaired people in an indoor environment. They presented 2-layered estimators in their proposed system. In the first estimated layer, the blind cane location was tracked in the last layer, and second layer estimated to find the location of the person. In another study, B. Li et al. [5], designed a device that involves an RGB-D camera for the environment perception. In their developed system they imposed three things i.e. self-localization, obstacle detection, and object recognition. In self-localization, the depth has been perceived based on the tracking technique on color information. Obstacle detection and recognition provides meaningful information to the visually impaired people and recognized the obstacle such as stairs, and doors, etc. K. Yang et al. [6], proposed a method for obstacle prevention devices to help visually impaired persons. They have implemented an incremental map of the environment with the help of optical SLAM technique, to provide spatial direction and location of the visually impaired people at the same.

In another study Tapu et al. [1], designed a smartphone-assisted obstacle identification system to identify and classify various obstacles to help visually disabled individuals to walk freely and safely in an indoor and outdoor environment. They used the Lucas Kanade algorithm in their study to extract feature from image data. M. Gangawane et al. [7], designed a model that involves the head of mounted stereo vision to search ground planes and break up six-degrees-of-freedom (6DOF) into ground plane motion and planer motion which assist visually impaired people. Due to the investigation of the variation array, they evaluate the ground plane and normal to the ground plane using optical/visible data or with the IMU reading. Maidenbaum et al. [8], designed a system, based on ultrasonic sensors and a camera for obstacle detection and recognition, where the camera was used to recognize and measure the size of obstacles. Leung et al. [9], proposed a head-mounted, stereo-vision based direction system for visually disabled people. They have used visible odometry and feature-based SLAM in their proposed design system to make a 3-dimensional map for obstacle detection. Xiao et al. [10], designed a tool for vision-impaired people that was used for the context-aware navigation services. Awareness of the semantic properties of the objects in the user's environment is needed to integrate advanced intelligence into navigation. This interaction is important to enhance communication about objects and locations to make better travel decisions. S.K Raja et al. [11], created a system for visually impaired people that uses mobile computing to detect and recognize their faces. This mobile system was supported by a server-based support system. Vlaminck et al. [12], have used three ultrasonic sensors and a microcontroller to detect the object range. The Audio and vibration system was used to warn visually impaired people to avoid obstacles. Eunjeong et al. [13], proposed a novel mobile navigation device that can identify the situation and scene objects in real-time. The proposed framework classifies a user's current condition in terms of their position by analyzing streaming images. Then, using computer vision techniques, only the appropriate background objects are identified and interpreted based on the current situation.

Similarly, Ramadhan et al. [14], presented a wearable intelligent system to assist individuals with visual disability to go

978-1-6654-8356-8/22/$31.00 ©2022 IEEE

along the roads themselves, navigate in public places and seek help. The system uses a series of sensors to track the route and alert the user about the barriers. In their system the user is warned about the sound of a bolt and vibrations on the wrist, which can be useful in a noisy setting or when the user has a hearing loss. Nivedita et al. [15], designed an electronic aid device that includes a Raspberry Pi device, an ultrasonic sensor, a webcam microphone, and a Light Dependent Resistors (LDR) sensor. For obstacle detection, an ultrasonic sensor with a camera is used. The LDR sensor was used to detect the brightness of the environment to determine whether it is dark or bright. Their proposed system detects objects in inbound home environment for visually impaired people and provides feedback by voice using an earphone. M. M. Islam et al. [16], presented a Raspberry Pi-based system for blind people with unique features such as tracking objects and sending feedback via voice, as well as providing information about the environment. One of the significant feature of this work was the tracking of blind person's location and notifying the caretaker to ensure the safety of visually impaired person. Elmannai et al. [17], presented a comparison of wearable and portable assistive equipment for the people with sight problems to demonstrate the progress of the group of people in assistive technology.

C. Ntakolia et al. [18], described a novel smart assistive systems framework for visually disabled persons, which uses a user-centered designed approach to assess a collection of environmental, functional, operational, ergonomic, and optional system specifications. Visually impaired and non-visually impaired people have been engaged in a series of interviews and questionnaires, the findings of which were analyzed to form the system's criteria for both on-site and remote use. Y. A. Abdalsabour et al. [18], helped these communities in moving independently to any location by developing a system for blind people. Their study specifies three paths for visually impaired students in the University of Gezira to easily reach different places on campuses.

This study proposes an assistive smart cane based intelligent system for the visually disabled individuals using DL algorithm. Convolutional neural network (CNN) along with the transfer learning technique (Alex-Net) has been used to assist the visually disabled individuals. The proposed system performed really well in terms of accuracy and is anticipated to be of a great help for the blind people.

III. PROPOSED METHODOLOGY

This study aims to detect and recognize the obstacles in the way of visually disabled individuals based on DL techniques. The complete workflow of the proposed system is shown in Figure 1. Also, Figure 1 depicts the process of choosing the desired path as well as the steps involved in getting to the right and safe area. If a blind face up the obstacles, the proposed system will keep track of how far he/she is from the obstacle and warn him/her to change the path.

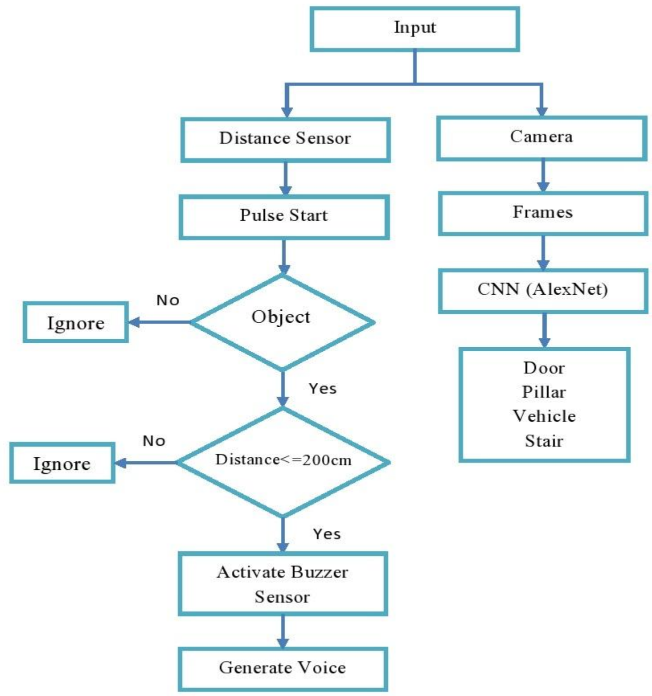


Fig.1. Flow chart of the proposed system

A. *Assistive Algorithm*

An assistive algorithm describes the destination of a visually impaired person. Every obstacle is recognized in every direction (i.e., front, left, right) and each obstacle is formatted as a statement of instructions. Thus, it is necessary to define the action first and then estimate the corresponding parameters, e.g., counts step, direction, current position. The Ultrasonic sensor information is used to calculate those parameters for this module.

Algorithm 1: Assistive Algorithm

Input: Ultrasonic sensor U, Raspberry pi, Camera, Buzzer

Output: Contains the set of instructions, I (Turn, Count, Direction, Current position)

1. Start
2. Initialize A ➔ null, Direction ➔null, step Count ➔null, current position (x, y) ➔ null;
3. ***If*** Ultrasonic sensor U <= 200cm, then Stop
4. Activate Buzzer
5. ***Else if*** *Current Direction – Previous Direction > 25*^{0} ➔ *Turn*
6. ***Else*** *Count* ➔*Continue A* ➔ *Stop Buzzer*
7. ***If*** *count A* ➔ *Continue* ***then*** *Current position* ($_{x, y}$)
8. *Count* ➔ *Count + 1, x* ➔ *Count. Cos current Direction, y* ➔ *Count. Sin Current Direction*
9. ***Else If*** *A* ➔*Turn, then previous Direction* ➔*Current Direction*
10. ***If*** *position* ➔ *Destination* ➔ *Terminate*
11. ***Else*** *Go step 3*

978-1-6654-8356-8/22/$31.00 ©2022 IEEE

B. Data Acquisition

Dataset generation or acquisition is one of the most important steps in the development of an intelligent and assistive system. The dataset was created using recorded videos with a Raspberry Pi camera, and each frame was extracted with a width and height of (640,480). The dataset consists of vehicle, stairs, doors, and pillar images. The key rule of DL is to split the data into two phases: training and testing, with 70% of the dataset being used for training and 30% for testing as shown in Figure 2.

Fig.2. Datasets Samples

C. Device Architecture

Figure 1 shows the design flow diagram, which includes a Raspberry Pi 3, Ultrasonic Sensors, camera, breadboard, Jumper wires, buzzer, and an earphone that comprise the device architecture. The breadboard is a critical component in the construction of a circuit. The breadboard acts as a link between the sensors and the Raspberry Pi. The jumper wires are used to connect the sensor to the Raspberry Pi indirectly. The Raspberry Pi has a power bank device mounted on the top to provide a specific amount of power when compared to a full-fledged desktop PC. The Raspberry Pi has four ports, forty GPIO pins, a memory card, a camera interface (CSI), and an HDMI port. Jumper wires are used to connect the sensors to the Raspberry Pi. To power the Raspberry Pi, a power bank is mounted on a wooden cane. The four ultrasonic sensors are linked to a Raspberry Pi, which requires a 5-volt power supply. Three of the four ultrasonic sensors detect obstacles from three directions (i.e., front, left, and right), while the fourth detect potholes. The visual sensor has a resolution of 5 megapixels and is directly connected to the Raspberry Pi via the camera port to detect obstacles from the front. The buzzer sensor is linked to the Raspberry Pi to alert the blind person to obstacles that require three voltages of power. The earphone is used for audio feedback and transmits a voice message to warn the visually impaired person of the presence of obstacles. It also calculates the direction and distance from the obstacles.

D. Convolutional Neural Network (CNN) architecture AlexNet

CNN Alex-Net architecture is used in this study for real-time detection and recognition of obstacles such as vehicles, doors, pillars, and stairs for visually impaired people. Alex-Net, a pre-trained model, is used to extract deep features for the classification of complex images that cannot be classified using simple handcrafted features. Figure 3 shows the architecture of the utilized pre-trained model AlexNet.

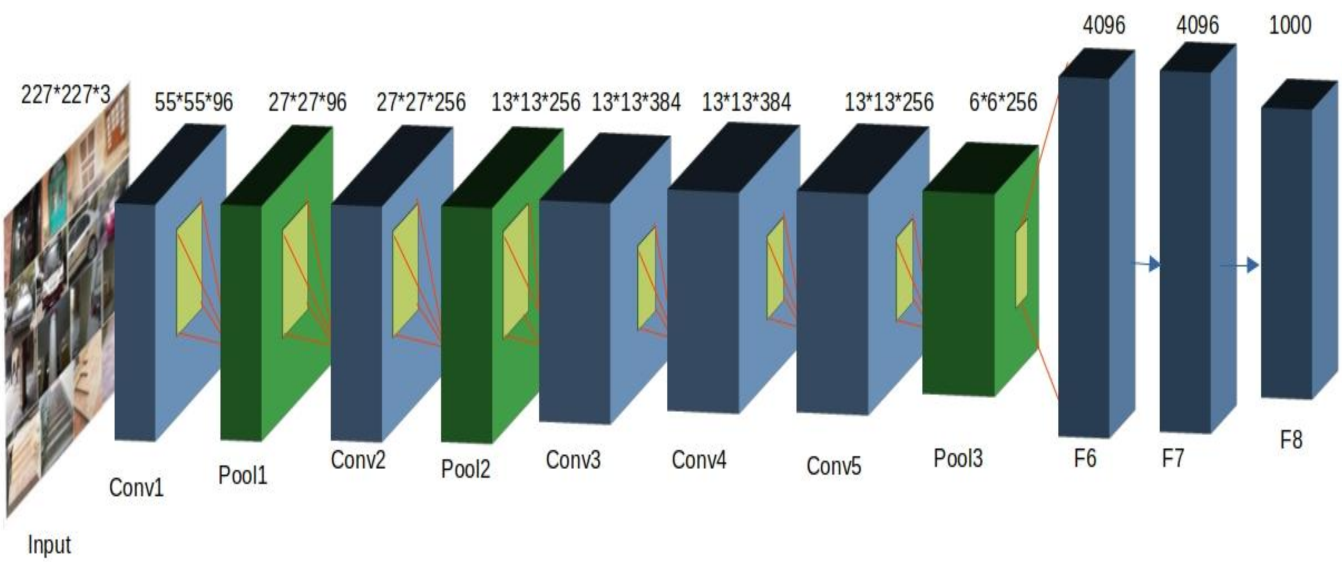


Fig.3. DCNN based Alex-Net Architecture

978-1-6654-8356-8/22/$31.00 ©2022 IEEE

IV. Experimental Results Analysis

This section of the paper represents the experimental results and the analysis of the attained results. Further, this section consists of two subsections i.e. evaluation setup and parameter settings of the proposed system and the evaluation of results attained by the proposed system.

A. Evaluation setup and parameter settings

Performance evaluation of an intelligent system/model is an important step in order to show the capability and significance of that system. This subsection illustrates the parameter settings of the utilized AlexNet architecture and the evaluation setup to track the performance of the AlexNet model. Parameter settings have a great impact on the performance, fine-tuned parameter settings improves the performance of the model. Figure 4 shows the parameter settings of the utilized AlexNet model.

Layer		Feature Map	Size	Kernel Size	Stride	Activation
Input	Image	1	227x227x3	-	-	-
1	Convolution	96	55 x 55 x 96	11x11	4	relu
	Max Pooling	96	27 x 27 x 96	3x3	2	relu
2	Convolution	256	27 x 27 x 256	5x5	1	relu
	Max Pooling	256	13 x 13 x 256	3x3	2	relu
3	Convolution	384	13 x 13 x 384	3x3	1	relu
4	Convolution	384	13 x 13 x 384	3x3	1	relu
5	Convolution	256	13 x 13 x 256	3x3	1	relu
	Max Pooling	256	6 x 6 x 256	3x3	2	relu
6	FC	-	9216	-	-	relu
7	FC	-	4096	-	-	relu
8	FC	-	4096	-	-	relu
Output	FC	-	1000	-	-	Softmax

Fig.4. Parameter settings of AlexNet model

In order to track and evaluate the performance of the utilized AlexNet model four different performance evaluation metrics are used. These performance metrics are accuracy, recall, precision and F1-score, and can be calculated via the following equations 1-4.

$$Accuracy = (TN + TP)/(TN + TP + FN + FP) \quad (1)$$

$$Recall = TP/(TP + FN) \quad (2)$$

$$Precision = TP/(TP + FP) \quad (3)$$

$$F1\text{-}Score = 2 * ((Precision * Recall)/(Precision + Recall)) \quad (4)$$

B. Experimental results evaluation

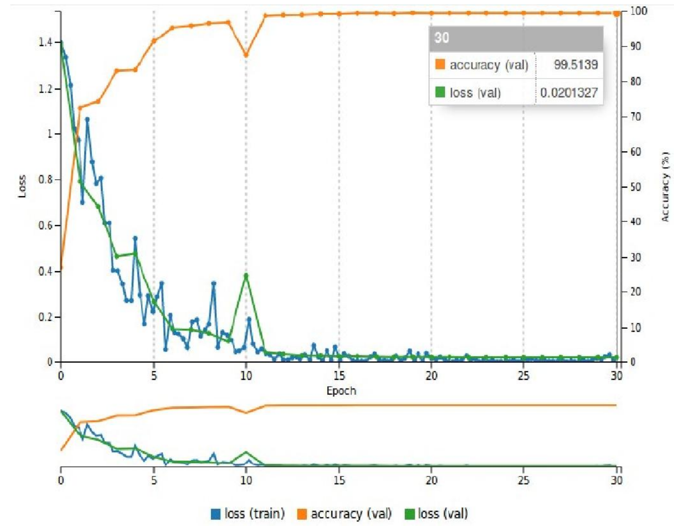
This subsection represents evaluation of the experimental results attained by the utilized AlexNet model. The designed model has been experimentally examined. The performance of the AlexNet model is evaluated in terms of different performance measures such as accuracy, recall, precision, and f1- score. Further, the confusion matrix for all the subjects has been computed. The following results explains that how the desired path can be selected and how the obstacle detection system is working. Finally, the results show that how the control system works and experiment with it. The results of the proposed system are shown in Table 1.

Table 1: Performance of the proposed system

Categories	Accuracy	Precision	Recall	F1-score
Doors	99.61	99.04	100	0.995
Pillars	99.70	99.35	100	0.997
Stairs	99.23	100	98.23	0.991
Vehicles	100	100	100	0.100
Total	99.63	99.59	99.31	0.996

From Table 1 it is clear that the proposed system performed really well on the doors, pillars, stairs, and vehicle image dataset by attaining the overall accuracy of 99.63%, 99.59% of precision, 99.31% of recall, and f1-score of 0.996. Figure 5 shows the training and validation accuracies and loss.

Figure 5. Training and validation accuracies and loss



The proposed model is based on a pre-trained Caffe AlexNet model and has the best validation accuracy. The validation accuracy of the model is 99.5139% and has a validation loss of 0.0201% as shown in figure 4. Based on the results, the AlexNet model is chosen and a computer-aided detection (CAD) system is developed using Raspberry Pi, Ultrasonic Sensors, and Camera.

The results of the proposed work is compared with the existing research works as shown in Table2.

Table 2: Comparison of performance with previous work

Categories	Accuracy	False Alarm Rate	Precision	Recall	F1-Score
[13]	97.0	0.016	NA	NA	NA
Assistive	99.56	0.0201.	99.59	99.31	0.99

The confusion matrix for the classification of the proposed DL model is also calculated for the activities of people who were visually impaired. For each activity, a comparison is made with performance matrices such as preciseness, precision, recalls and f-1 score. The confusion matrix is shown in figure 6.

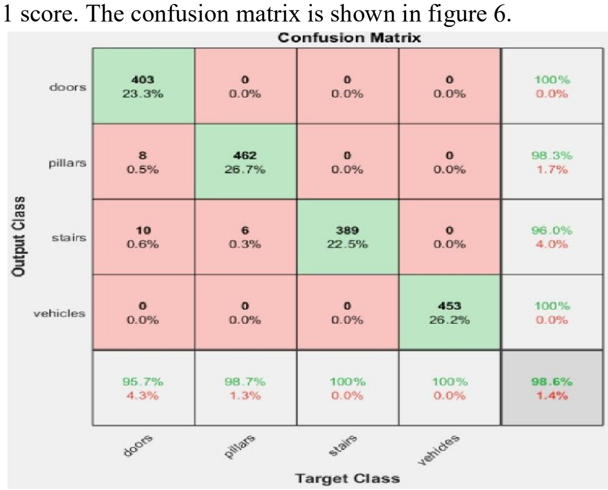


Fig.6. Confusion Matrix

The experimental results of the proposed techniques for visually impaired people can be illustrated in Table 1. The four obstacles (Vehicles, Doors, Pillars and Stairs) are recognized from the pre-trained Alex-Net architecture. The proposed technique provides an impressive result as presented in Figure 7.

Fig 7. Examples of obstacle recognition

V. COCNLUSION

This paper presents a high-level framework for using real-time localization technologies to interpret semantic entities in the physical world. With the development of such an intelligent system, we introduced an operating concept that helps visually impaired people travel on their own. Our system's capability can be measured in both indoor and outdoor environments without the aid of the guidance of a sighted person. For this purpose, three sensors are used to detect the objects in three directions i.e. (front, left, and right) and one is used to detect potholes. The visual sensor is used for the recognition of obstacles in the way of smart cane users. Overall, the proposed design system provides advantages over the traditional cane as this system is more efficient and effective as compared to the earlier approaches and designs. In the future, we aim to install GPS that will help the visually impaired person in an outdoor environment. The GPS will help the relatives and family members of the visually impaired person in tracking his/her location easily and provide guidelines according to the location and destination.

REFERENCES

[1] I. McCormick, I. Mactaggart, A. Bastawrous, M. J. Burton, and J. Ramke, "Effective refractive error coverage: an eye health indicator to measure progress towards universal health coverage," Ophthalmic & physiological optics, vol. 40, p. 1, 2020.

[2] C. T. Patel, V. J. Mistry, L. S. Desai, and Y. K. Meghrajani, "Multisensor-based object detection in indoor environment for visually impaired people," in 2018 Second International Conference on Intelligent Computing and Control Systems (ICICCS), 2018, pp. 1-4.

[3] P. H. Batavia and S. Singh, "Obstacle detection using adaptive color segmentation and color stereo homography," in Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation (Cat. No. 01CH37164), 2001, pp. 705-710.

[4] J. A. Hesch and S. I. Roumeliotis, "Design and analysis of a portable indoor localization aid for the visually impaired," The International Journal of Robotics Research, vol. 29, pp. 1400-1415, 2010.

[5] B. Li, J. P. Munoz, X. Rong, J. Xiao, Y. Tian, and A. Arditi, "ISANA: wearable context-aware indoor assistive navigation with obstacle avoidance for the blind," in European Conference on Computer Vision, 2016, pp. 448-462.

[6] K. Yang, K. Wang, L. M. Bergasa, E. Romera, W. Hu, D. Sun, J. Sun, R. Cheng, T. Chen, and E. López, "Unifying terrain awareness for the visually impaired through real-time semantic segmentation," Sensors, vol. 18, p. 1506, 2018.

[7] M. Gangawane, R. Awate, R. Suryawanshi, and R. Joshi, "Obstacle detection and object size measurement for autonomous mobile robot using sensor," Int. Res. J. Eng. Technol.(IRJET), vol. 3, 2016.

[8] S. Maidenbaum, S. Hanassy, S. Abboud, G. Buchs, D.-R. Chebat, S. Levy-Tzedek, and A. Amedi, "The “EyeCane”, a new electronic travel aid for the blind: Technology, behavior & swift learning," Restorative neurology and neuroscience, vol. 32, pp. 813-824, 2014.

[9] T.-S. Leung and G. Medioni, "Visual navigation aid for the blind in dynamic environments," in Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops, 2014, pp. 565-572.

[10] J. Xiao, S. L. Joseph, X. Zhang, B. Li, X. Li, and J. Zhang, "An assistive navigation framework for the visually impaired," IEEE transactions on human-machine systems, vol. 45, pp. 635-640, 2015.

[11] S. K. S. Raja, M. Vivekanandan, S. U. Kiruthika, and S. A. R. J. Ayshwarya, "Design and Implementation of Facial Recognition System for Visually Impaired using Image Processing," International Journal of Recent Technology and Engineering (IJRTE), vol. 8, 2019.

[12] M. Vlaminck, L. H. Quang, H. Van Nam, H. Vu, P. Veelaert, and W. Philips, "Indoor assistance for visually impaired people using a RGB-D camera," in 2016 IEEE Southwest Symposium on Image Analysis and Interpretation (SSIAI), 2016, pp. 161-164.

[13] E. Ko and E. Y. Kim, "A vision-based wayfinding system for visually impaired people using situation awareness and activity-based instructions," Sensors, vol. 17, p. 1882, 2017.

[14] A. J. Ramadhan, "Wearable smart system for visually impaired people," Sensors, vol. 18, p. 843, 2018.

[15] A. Nivedita, M. Sindhuja, G. Asha, R. Subasree, and S. Monisha, "Smart cane navigation for visually impaired," International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN, pp. 2278-3075, 2019.

[16] M. M. Islam, M. S. Sadi, K. Z. Zamli, and M. M. Ahmed, "Developing walking assistants for visually impaired people: A review," IEEE Sensors Journal, vol. 19, pp. 2814-2828, 2019.

[17] W. Elmannai and K. Elleithy, "Sensor-based assistive devices for visually-impaired people: Current status, challenges, and future directions," Sensors, vol. 17, p. 565, 2017.

[18] C. Ntakolia, G. Dimas, and D. K. Iakovidis, "User-centered system design for assisted navigation of visually impaired individuals in outdoor cultural environments," Universal Access in the Information Society, pp. 1-26, 2020.

978-1-6654-8356-8/22/$31.00 ©2022 IEEE