Empowering and Conquering Infirmity of Visually Impaired Using AI-Technology Equipped with Object Detection and Real-Time Voice Feedback System

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Abstract: The Internet of Things is emerging to be a crucial technology in aiding humans and making their lives easier. Among the human population, a large percentage of people suffer from disabilities resulting in challenges in everyday life particularly people with visual disabilities. While several inventions exist to aid people with blindness in their everyday lives, the tools are not adequate in terms of accessibility and efficiency. Smart cane is a useful technology that is being researched and developed to enhance navigation of the visually impaired through smart obstacle detection. Moreover, artificial intelligence is being incorporated in these devices to provide users with a sense of vision and allow them greater independence. However, these devices are expensive and often do not contain the desired functionality in a compact single device. The research I-CANe aims to create a low-cost, single device system that is equipped with obstacle detection and identification features to enhance navigation for users without using multiple detection devices. The cane will also incorporate wireless communications for safety features such as GPS tracking and GSM communication to allow maximum independence of the user.

Keywords: AI,; object detection ; obstacle; visually impaired; voice feedback; navigation

1. Introduction

In a 2011 report regarding disabilities all over the world, published by, WHO (World Health Organization) it was revealed that nearly 15 percent of people all over the world are suffering from some sort of disability. Moreover, the OECD (The Organization for Economic Co-operation and Development) revealed about 45-55% people are struggling in getting employed as a result of disability [1]. A Survey conducted in 39 countries suggested that nearly 285 million people are suffering from vision related diseases, while 39 million suffer from total blindness, as depicted in Figure 1. [2]. According to the 2017 report of Global Burden of Disease (GBD) [1], the third leading impairment in the world is visual impairment that is affecting the lifestyle of people.

It has also been estimated that a person becomes blind every 5s in the world [2]. Hence, it can be gleaned that a significant amount of people have to use their other senses such as hearing and feeling to navigate their way and they also have to rely on visual aid tools like guide stick and guide dogs.

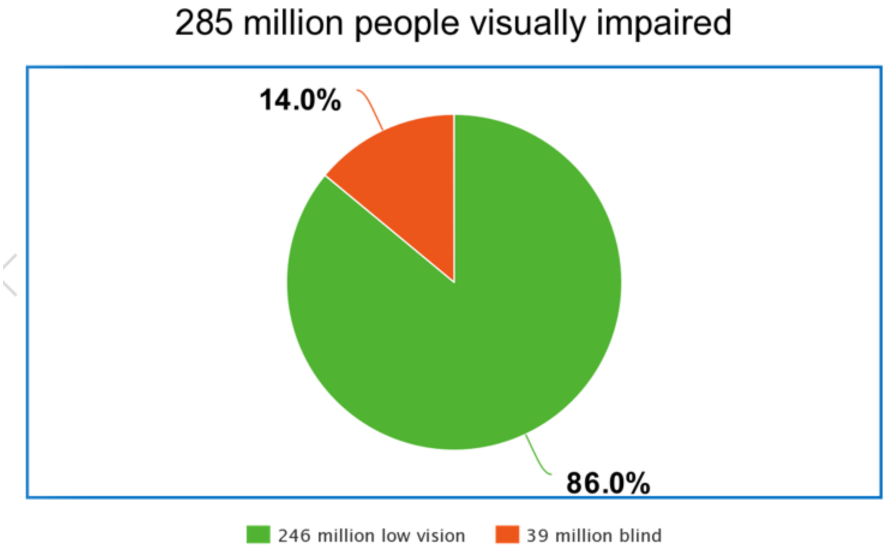

Figure 1: Global percentage of visually impaired people [2]

According to the study report of WHO financed national survey of blindness conducted in 1987-1990, 2 to 4.3% of people in Pakistan suffered from blindness. The samples and results of the survey are summarized in the table (1&2) [3].

Table 1: Number of individuals examined in each district in Pakistan

Sample No	**Province**	**City/Village**	**Rural/Urban**	**No of individuals examined**
1		Karachi	Urban slum	2,730
2		Karachi	Urban	2,198
3		Khipro	Rural desert	4,398
4	Sindh	Bir Larkana	Rural agriculture Padding growing area	3,958
5		Hub(Labeela)	Rural coastal area	2,972
6	Balochistan	Panjgoor(Makraan)	Rural mountainous	3,172
7		Kharan	Rural mountainous	6,038
8		Chitral	Rural mountainous	851
9	N.W.F.P	Mansehra	Rural	1,006
10		Peshawar	Rural/Urban	1,942/945
11		DIK	Rural	988
12		Islamabad	Urban	1,850
13	Punjab	Hummak Village , Sehala	Rural mountainous	2,000

14		Mianwali	Rural	1,950
15		Sadri Village	Rural	1,850
16		Phulwar	Rural	1,025
17		Zamani Chak Bahawalpur	Rural	1,049

Table 2: Number of individuals visually impaired

Province	**N.o of sample areas**	**Individuals examined**	**Bilateral Blindness (%)**	**Unilateral Blindness (%)**	**Partial Blindness (%)**	**Total**
Punjab	6	9,724	2.1	3.3	7.5	1,270
Sindh	4	6,652	1.1	1.6	4.1	464
N.W.F.P	4	6,690	1	2.5	2.5	402
Balochistan	3	6,091	2.6	1.8	3.6	498
Total	**17**	**29,157**	**1.7**	**2.4**	**4.8**	**2,634**

The number of this rose to 2 million people in 2019. It is also estimated that this number will rise by approximately 2.4 million in 2020 [3].

Diseases such as blindness inhibit the daily activity of a person and can put the sufferer at a disadvantage and dependent on other people. Despite many tools being created to aid the visually impaired population, these tools are often ineffective in Pakistan due to their expensive costs and hard to use system. Pakistan being a developing country, has majority of the sufferers with low income who find the available technology in the market, unaffordable and have to rely on a simple walking stick to manually navigate the way in their environment. To address this issue, we aim to create an affordable cane that allows users to utilize technology for their navigation and helps them experience a sense of independence.

Visually impaired people suffer from countless challenges in their everyday lives which prevents them from leading an independent life. Navigation is particularly problematic along with walking in public places. IoT is one identified solution to this problem that can aid these people in doing their everyday activities, independently [4].

People with blindness often use a simple white navigating cane to help them detect obstacles, while other rely on friends and family or guide dogs to help them reach their destination safely. While the white cane is a cost effective and easy to use device, it has its limitations. The cane can only detect obstacles by contact at a certain height however, it relays no information regarding the type of obstacle neither does it identify it. Moreover, it also requires physical exertion from the user [5].With the development of technology, many different types of navigational aids are now available to assist the visually impaired [6].

This paper presents I-CANe: An Intelligent Cane for the Visually Impaired which will help a blind person to navigate more effectively. Using this intelligent cane, a visually impaired person can walk without anybody's assistance. The cane can automatically detect an obstacle with the help of ultrasonic sensors attached on it and identify the obstacle using a camera attached on it. The object will then be communicated to the user to help them understand their environment and ensure an increased mobility.

The aim of this research is to develop technology for a visually impaired person to help him in navigating the way without requiring a human guide. The research will be expected to carry out the following tasks:

- To create an enhanced version of navigating cane for the visually impaired to make him/her independent
- Real time on-ground and side obstacles detection with sensors
- Front obstacle detection through vision
- Real time obstacles identification
- Provide GPS tracking of user and GSM alerts

The paper will be structured in the following manner. Section 2 introduces related work, Section 3 describes Workflow of I-CANe. Section 4 focuses on **System Design** while Section 6 discusses the experimental setup. The paper is finally concluded in the last section.

2. Related work

The smart cane is an upgraded version of the classic white cane. It is equipped with multiple sensors to detect obstacles occurring in the path. It also has the ability to detect overhanging obstacles as well as stairs. The smart stick works by interpreting the signal of an ultrasound and laser sensor in the direction pointed by VIPallows detection of obstacle in a solid angle subtended by a sensor attached to it in a direction pointed by the VIP. A feedback of intensity, inversely proportional to the distance to the obstacle is provided by the stick [7].

The *UltraCane* [8] is a *smart stick*, designed at the University of Leeds. The stick detects overhanging obstacles along with obstacles occurring in the user's path. Ultracane uses ultrasonic sensor to detect obstacles and provides user with feedback in the form of vibrations. The smart stick *K-Sonar [9]*, designed at Canterbury University, New Zealand, detects obstacles through an ultrasonic sensor that uses space point-wise sonification to reconstruct the entire obstacle at the user-end and provide and audio feedback to guide the user. The K-Sonar does not provide assistance to orientation function.The *GuideCane* [10] which is a smart cane aimed at allowing user to detect on-ground obstacles as well as specific obstacles such as stairs utilizes ultrasonic sensors attached on the end of the cane. These sensors detect obstacles and notify the user through a vibrating feedback on the grip of the cane [6]. This stick allows easy detection of obstacles to help the user avoid them. However, the Guide Cane does not provide assistance to the orientation function.The *SmartCane*, developed at the Indian Institute of Technology [11] is aimed at detecting obstacles above the knees through the means of ultrasonic sensors. However, this cane too lacks assistance regarding orientation.

The *Intelligent Cane* "iCane" [12] designed at the National Taiwan University (2005, figure 8) allows user to overcome obstacles as well as understand the orientation. The cane relies on data sent and received by the RFID tags embedded on the cane and the surroundings. The RFID reader on the cane retrieves information and provides information to the user through earphones that are connected to the cane via Bluetooth. This provides the user with useful information regarding surroundings and is particularly useful in public spaces.

Table 3: Comparison of different visual aid devices

Model	Objective	Parameters	Walking Functions	Drawbacks

UltraCane	Headlevel and groundlevel obstacle detection	Ultrasonic waves	Detection of obstacles in front of head and chest of user	Expensive, bulky
K-Sonar	Obstacle detection	Ultrasonic waves	Echolocation for front obstacle detection	Limited functionality, Bulky
GuideCane	To overcome the problems of NavBelt	Ultrasonic waves	Ultrasonic obstacle detection along with servomotor for steering user in detected direction	Does not detect overhead obstacles, no audio output
SmartCane	To detect obstacles above knees	Ultrasonic waves	Knee above obstacle detection through ultrasonic sensors	No assistance to orientation
iCane	To detect obstacles and provde envionment information	Ultrasonic waves, Radio frequency signals	Provides surrounding information to user through RFID and stores navigation data in database	Static control can cause navigation problems for user
SEES	Smart environemnt exploration along with obstacle detection	Ultrasonic waves, visible spectrum signal	obstacle detection, walked distance estimation, surface roughness estimation and traffic	Does not cater visual impairities of different levels.

			light detection.	
I-CANe	Obstacle detection and identification along with safety features	Ultrasonic waves, visible spectrum signals	Ultrasonic based obstacle detection on all four sides, vision based identifcation, GPS and GSM safety features	Limited obstacle identification, not usable in dark

The C5 laser Cane, created by Malvern Benjamin et al uses the method of optical triangulation to detect obstacles in the range of 5 to 11 feet [13]. Successful detection is indicated through a beep via the microphone.The smart vision, local navigation aid developed by Joao Jose [14] is a wearable system designed to be used along with the cane. The system proposed uses vision to identify obstacles, a GPS system to aid user in navigating path and an audio feedback system. The system designed is cheap and allows user to visualize surroundings, however the system requires user to purchase a smart cane and the smart vision device for visual aid. This makes the overall system expensive to use .

Shruti Dambhare's smart stick for blind [15], is a hypothetical system that incorporates vision-based techniques of object detection to provide real-time assistance of obstacles to the user. The stick also has a sensor unit for real-time obstacle detection with ultrasonic sensors and a GPS unit that provides navigation aid by storing locations visited by the user. The locations are stored in the memory and are used to provide alerts to the user whenever visited. The designed system was estimated to weigh 3 Kg, with a battery time of 8 hours. Sakhardande's cane is an ATMEL microcontroller-based cane that uses ultrasonic sensors to detect obstacles in a range of three meters. The user is then alerted through a buzzer and vibration system. Sakhardande's cane is an easy to use and easy to carry system that is powered by rechargeable batteries [16]. Alejandro R. Garcia Ramirez and Renato Fonseca Livramento da Silvaetal designed a voice aided electronic stick [17]. The design uses hepatic feedback system to detect obstacles. The system, however, only detects obstacles above the waistline of the user.

Ayat Nada's effective fast response smart stick [18] is designed to detect obstacles in the front, as well as detect pot-holes and water puddles. The stick is entirely based on sensors and does not utilize any object detection methods. It uses an ultrasonic sensor at a 90 cm height to detect upper obstacles and another at 30 cm height. An infrared sensor is also used to detect upwards and downwards stairs and the information is conveyed via an audio system. The ultrasonic sensor was able to detect obstacles in a range of 400 cm with a time response of 39 ms and performed better for close obstacles of less than 15 cm range, as compared to infrared sensors. Akhilesh's Assistor, [19] is an autonomous smart stick equipped with obstacle detection sensors and vision sensors to identify the obstacles. The cane is structured on servo motors to allow the movement of cane and consists of an ultrasonic sensor attached to the front. It also uses a Pixy CMUcam5 camera which takes an image of the detected obstacle to match it with an object database. The system works well in real-time, however it needs improvement in object detection in the outdoor environment. Moreover, the system proposed is expensive.

Sidhi Degaonkar's Smart walking stick powered by artificial intelligence [20] is an obstacle detecting and identifying cane. The cane uses ultrasonic sensors for obstacle detection, along with a camera that performs image recognition, collision detection and obstacle detection. The system detects obstacles, identifies them, estimates the distance and provides audio feedback to user. The system uses raspberry pi which provides a good computation power for the desired tasks, and AI cloud-based systems and API. The system consists of a 3.5-4 ft stick with the embedded system attached onto it. The device is lightweight, easy to use and affordable. It does however lack safety features like GSM alerts and GPS tracking. The system also requires an internet connection for the image processing techniques. Ballu and Yogesh proposed a smart cane [21], that incorporates features lacking in the above-mentioned canes. The raspberry pi-based cane utilizes four ultrasonic sensors to detect obstacle on all four sides and uses a camera along with AI techniques of object detection, to identify the objects detected by ultrasonic sensors. The objects detected is then conveyed to user via an audio system. The cane is also equipped with GSM and GPS modules to guide users in navigating their way through saving GPS locations on the module's memory. The system was able to detect objects and identify them in a short time .

Pruthvi.S smart blind stick using artificial intelligence consists of object detection and identification using object classifying technique [22].The device is a raspberry pi-based stick that uses one ultrasonic sensor for obstacle distance measurement and a camera for object identification. The stick utilizes YOLO object classifier on PASCAL VOC data set for object detection to create a walking stick that can detect and identify obstacles in real-time. Each cycle of taking picture, running object detection and receiving information from the ultrasonic sensors took 1.22 seconds on average. The time response varied with the number of objects in the image. The stick had a good response for use in real-time, however it lacks features useful for a visually impaired person, such as GPS location tracking, GSM alert mechanism and more sensors to identify objects on different sides and heights .

To eliminate the need of carrying a cane, Jinqiang Bai proposed smart guiding glasses for the visually impaired [23]. The glasses work on the principle of depth-based way finding. It consists of a depth camera that retrieves depth information from the surroundings and provide audio feedback to user. It also has ultrasonic sensors that can find obstacles in a range of 2.92 m. The system is compact, easy to use and is made for real-time use. This requires the design of a cane that is equipped with the required functionality and is cost-effective.

Huayao Liu's HIDA, is a wearable system which can be utilized for indoor detection and obstacle avoidance [24]. It consists of a LiDAR sensor that performs 3D point cloud instance segmentation and alerts the user through a voice feedback. The system is trained on ScanNetv2 dataset and detects with an accuracy of 43.6% mAP. However, the system requires a laptop to be carried by the user. Moreover, due to heavy processing times for point cloud segmentation, a real-time processing cannot be done.The Trans4trans is an Ai based visual assistance system which makes use of a pair of glasses and a laptop as a processing unit [25]. The system allows real-time object detection, indoors and outdoors and also allows detection of transparent objects such as glass doors. The system however relies on a laptop as a processing unit which can be heavy to carry.

NAVI, a navigation aid proposed by Tarun Sharma is a smart phone based application that does not require any additional hardware [26]. The system is trained on a dataset consisting of short videos shot by the author and it utilizes Generalized deep belief Networks for classification of objects. The system allows detection of common objects, while also determining their position through an auditory feedback system. Although the system is lightweight and cost-effective, it does rely on constant internet connection and also detects only a limited number of objects. Moreover, it does not eliminate the need of using a guide cane as it is to be used as a supplementary device along with the cane.

The intelligent navigation system by Deepak Kumar Yadev is an obstacle detection system based on Raspberry pi 3 B+, along with a camera and ultrasonic sensors connected to it [27]. Classification of objects is done using a 4 layer Convolutional Neural Network with an accuracy of 94.6% and a response time of less than 50 ms. The system detects common everyday objects with good accuracy and also provides the distance associated with the objects through an auditory system. While the system is lightweight and cheap, it is limited to common indoor objects only and does not provide functionality for outdoor objects.

Wearable vision based navigation system by Hsueh-Cheng Wang consists of a camera, a portable computing device along with a hepatic device to guide the user [28]. The system is able to pinpoint object's range and direction along with identifying some common indoor object classes such as a chair. The system uses a depth-sensor and detects objects on a depth-based approach. Overall the system achieves good accuracy, real-time operation and low cost but it lacks capability for an outdoor environment.

The mobility aid developed by Matteo Poggi performs real-time obstacle detection through a point cloud by a custom RGBD sensor [29]. The system can work in real-time and is easy to carry but it can only detect 8 classes of objects. Furthermore, it requires two systems to be used as the user has to use it along with a white cane.

Our prototype I-CANe will provide detection of obstacles on front, left and right side. Incorporation of AI will allow obstacle identification and give a sense of vision to the user. It will give the user greater independence and confidence of his or her surroundings. It will be a low cost tool.

3. Workflow of I-CANe

The basic goal of this system is to make our visually disabled user independent. The workflow is illustrated in figure 2. The workflow is divided into two parts; object detection and identification. Live feed is obtained through the raspberry pi camera in the form of images. Obstacle presence is detected through the ultrasonic sensors placed at various angles and places of the cane and their distance from the user is also communicated. Real time images are sent to the

Raspberry Pi for computation and through proposed datasets and AI operations, objects are identified. The identified labels are then converted to speech and conveyed to the user through an earpiece.

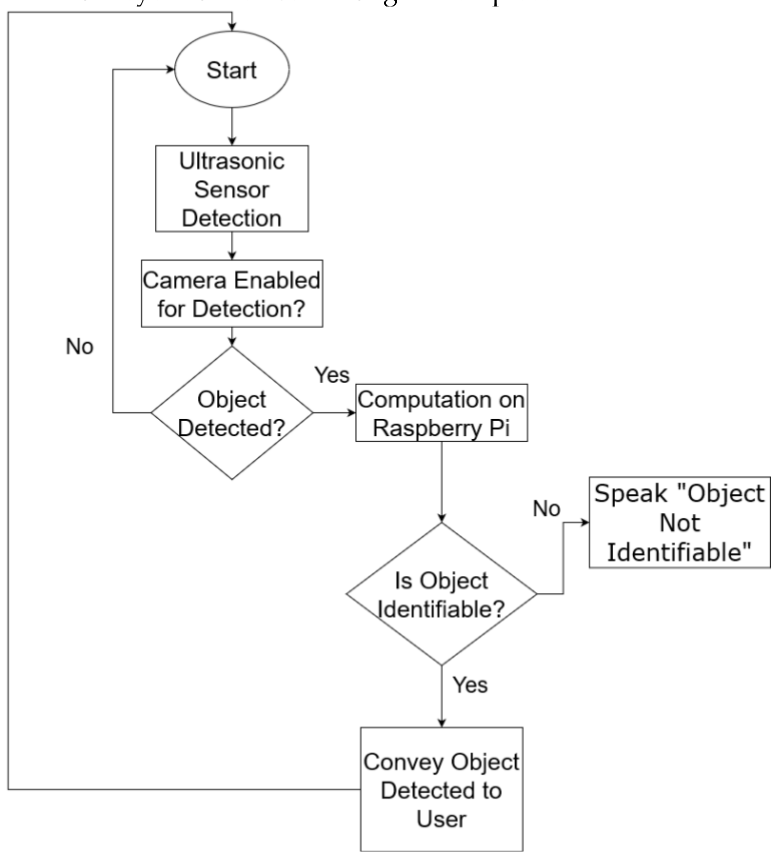

Figure 2: Workflow of I-CANe

As a safety feature, the cane will be equipped with wireless communications. A GSM module is added. The GSM module is contributing to the SOS features in case of emergency to alert the user's family members. The GPRS module is being used to provide location tracking services. Headphones are connected through the audio jack present in raspberry pi 3B.

To ensure maximum battery life and efficiency, a customized external power unit is attached to the cane. The power unit comprises of rechargeable Lithium Batteries -18650. A 3 Cell Battery Management System will act as the heart of our charging circuit. It will regulate voltage across the module to ensure all parallel batteries stay at 3.7V no more and no less. Another component added to the power unit is the buck convertor to ensure that voltage conversion between high and low voltages are done efficiently, thus extending battery life. The goals of the power unit are to make it compact and modular. The I-CANe is charged through a 12V charger connected to a wall power outlet.

4. System Design

The hardware portion of I-CANe consists of two modules; the power and the control unit as shown in figure 3. The power unit assists in prolonging the battery life of I-CANe efficiently. The control unit comprises of various modules, camera and ultrasonic sensors.

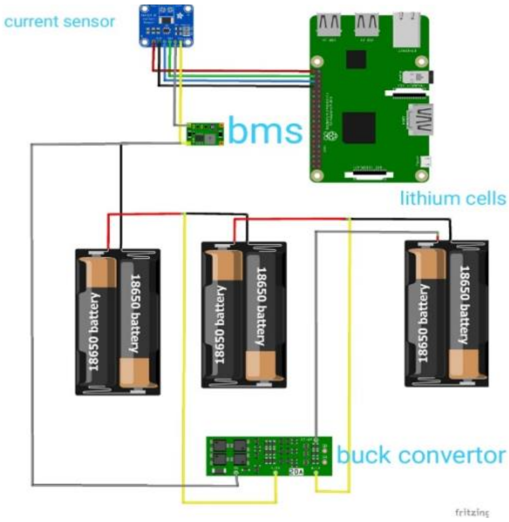

Figure 3: Diagram of Power Module

4.1 Hardware Components

I-CANe is created with a rechargeable power unit that allows user to operate the cane for up to 3 hours, before connecting it to a wall outlet for recharging. The power unit was customised to include current sensor and battery management system to notify user in case of low battery or battery malfunctions. A buck convertor is connected to prevent overvoltage while charging.

The control unit consists of a Raspberry Pi 3B+ processor with sensors attached to it. These sensors comprise of four ultrasonic sensors for obstacle detection in multiple directions, camera for obstacle identification, GPS for live location tracking and GSM for sending alerts to users.

4.2 Software Component

I-CANe is enabled with artificial intelligence to identify the objects detected by ultrasonic sensors and provide a sense of vision to the user. The software is based on YOLOV4 object detection algorithm which is pre-trained on COCO dataset to identify a vast category of objects in both indoor and outdoor environment.For I-CANe, the YOLOV4 tiny version is used due to its compact size. The tiny version provides a compressed version of the YOLOV4 object detection model that can run in real-time on embedded devices.

4.3 MS COCO Dataset

The MS COCO (Microsoft Common Objects in Context) dataset is an object detection, segmentation, Key point detection and captioning dataset which consists of 328 thousand images of 80 object classes in their natural context which are grouped in 11 super categories [21]. The classes are everyday objects that are encountered by a person. These objects consist of many common outdoor objects such as vehicles and animals, as well as indoor objects. The table below shows the categories in the COCO dataset.

Table 4: COCO dataset categories and classes

Super category	**Classes**
Person and accessory	Person, backpack, handbag, umbrella, tie, suitcase
Animal	Bird, cat, dog, horse, sheep, cow, elephant, bear, zebra, giraffe
Vehicle	Bicycle, car, motorcycle, airplane, bus, train, truck, boat

Outdoor object	Traffic light, fire hydrant, stop sign, parking meter, bench
Sports	Frisbee, skis, snowboard, sports ball, kite, baseball bat, baseball glove, skateboard, surfboard, tennis racket
Kitchenware	Bottle, wine glass, cup, fork, knife, spoon, bowl.
Food	Banana, apple, sandwich , orange, carrot, broccoli, hotdog, pizza, donut, cake
Furniture	Chair, couch, dining table, toilet, bed, potted plant
Appliance	Microwave, oven, toaster, refrigerator, sink
Electronics	TV, laptop, mouse, remote, cellphone, keyboard
Indoor Objects	Book, clock, vase, scissor, teddy bear, hair dryer, toothbrush,

The labelled dataset is a benchmark dataset that is used to evaluate performance of computer vision models and is greatly used in research purposes. It is also used for training supervised computer vision models and assess their speed and accuracy. Since most of the object detection models are trained on COCO dataset, it forms the base of these models, from which it can be used further for purposes such as transfer learning for detection of custom classes.The 2017 version of COCO dataset consists of 118,000 images for training set and 5000 images for validation set each of which has a median ration of 640x480 [21]. The dataset is suitable for our application as it can be used to detect objects in everyday context which are useful for an I-CANe user as it provides flexibility in indoor and outdoor environment. Moreover, the dataset provides a good speed and accuracy for object detection in real-time.

5. Results

- Real time testing

The testing phase of the prototype consisted of identifying obstacles through ultrasonic sensors and using the signal to trigger the R Pi camera. The camera would then take a snapshot of the obstacle and extract the region of interest from the picture i.e. the object. Once the object is detected, the user would be conveyed of the object as well as the ultrasonic measured distance of the obstacle through text-to-speech conversion. The final structure of the prototype is as shown in figure 4 and 5.

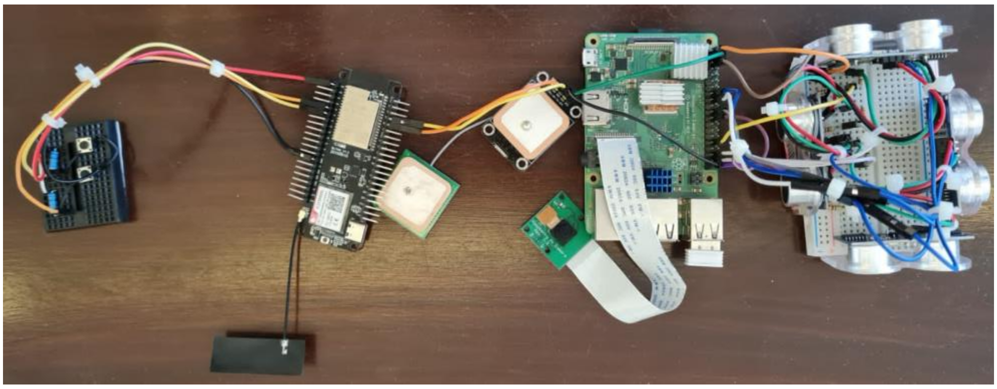

Figure 4: Circuitry of I-CANe

- Region of interest extraction

The first test consisted of observing if the camera was able to extract the region of interest from various pictures. A picture is passed to the detector and a script is run to identify the correct region and visualize it by drawing a bounding box around it. The region of interest are the objects of COCO dataset in an outdoor and indoor setting.

- Object detection

The region of interest is passed onto the classifier to detect objects. The classifier, which is trained on 80 object classes identifies predicts the object. After prediction, labels are assigned to the detected items and on the basis of those assigned labels, the predicated class is being displayed on the output picture. Again, the labels are from the 80 object categories provided in the COCO dataset.

Figure 5: Structure of I-CANe

Object detection was tested on different objects that exist in the COCO dataset. The results were as shown below.The camera was able to detect multiple objects in an image as shown in figure 6 and 7.

Figure 6: Object detection with person identification

Figure 7: Object detection outdoors

The model also performed well on outdoor scenes, as shown in figure 8,

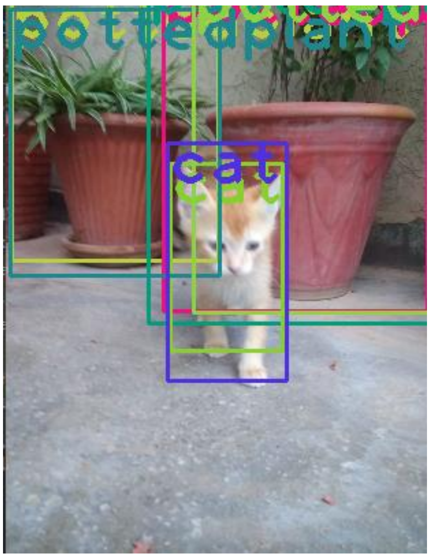

Figure 8: Object detection outdoors with multiple objects

- Voice feedback

Voice feedback is an important aspect of this research. I-CANe will be detecting objects and providing voice feedback in real-time to aid the user in navigating his or her way in a real-life setting. To test this feature of our cane, the cane was taken outdoors and used as a user would use it. When the object was detected by the ultrasonic sensor, the cane alerted the user through an ear piece. The ultrasonic sensor then triggered the camera to take a picture and identify the objects detected in it. The text labels of the object detected were converted to speech and conveyed to the user to warn about the obstacle ahead.The ultrasonic sensors also measured the distance to the nearest object and conveyed it to the user.

- Quantitative results

I-CANe uses the YOLOv4 tiny model for detecting objects in the frame of the Raspberry Pi camera. The model is pre-trained on the MS COCO dataset which consists of 118,000 images split into 5000 validation set. The images have a median ratio of 640x480, hence the images obtained from the Raspberry Pi camera were set to the same resolution. The overall accuracy obtained on the dataset is 43.55% mAP and the project was able to identify different classes of objects with an acceptable accuracy as shown in figures 9,10 below.

Furthermore, the model was also able to allow an acceptable real-time usability with an average frame rate of 1 Fps. The frame varied with the movement speed of the cane, as shown in figure (9 & 10)

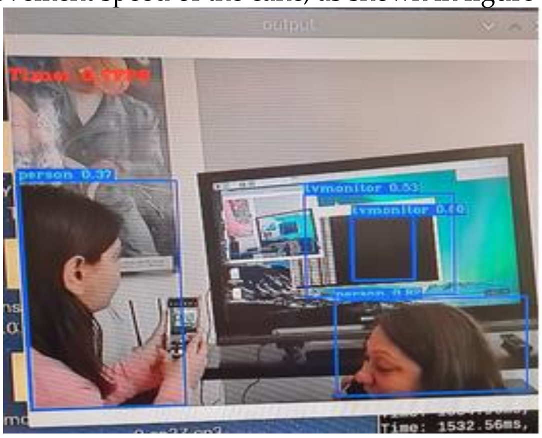

Figure 9: Multiple objects detected with different accuracies in a 0.7FPS

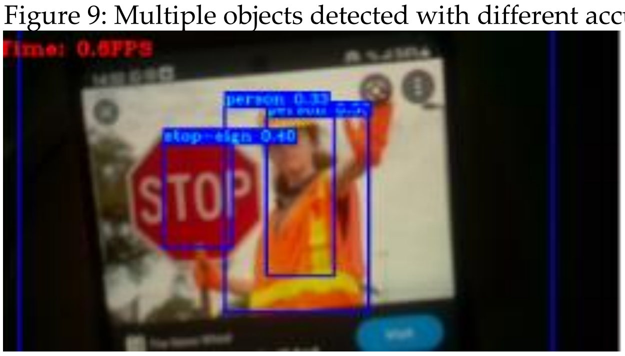

Figure 10: Multiple objects detected with different accuracies in a 0.7FPS

The ultrasonic sensors determined the position of obstacle as right, left, in front, on ground, the sensors were able to calculate the distance up to 167.53 cm. The distance was then converted to voice feedback using google gTTS library. For inclusion of results in this paper, we have added the text output of the gathered result, as seen in figure (11).

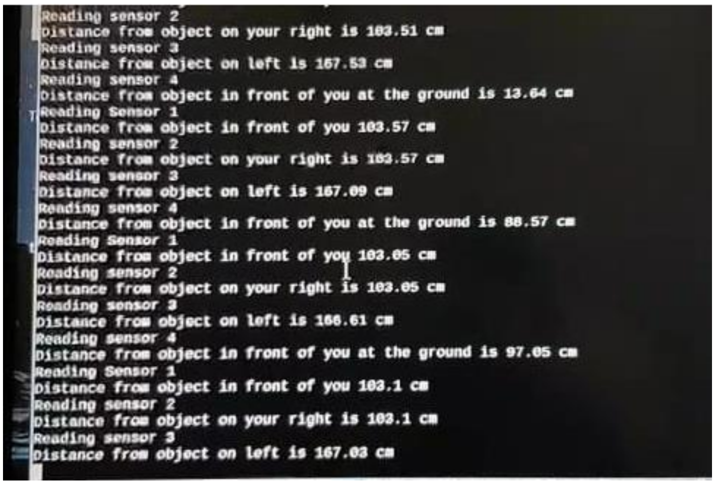

Figure 11: Distance calculated from ultrasonic sensor

3.2 System Validity

- Obstacle detection

The system was verified by assessing the working of the obstacle detection mechanism. Obstacles were detected in the range of 2 cm to 40 cm. Ultrasonic sensors on all four sides of the cane operated to notify the user of obstacles on each side. Moreover, the voice feedback was also synchronized with the ultrasonic sensor to notify user about the obstacle distance in real-time.

- Frame rate per second (FPS)

The object detection section of I-CANe can be assessed by measuring the frame rate per second of the camera. Frame rate per second refers to number of frames being recorded every second. This term is being used in films, games, videos etc. This is important for the object recognition part of I-CANe and its use in real-time. The frame rate can be calculated by:

$$\text{FPS} = (\text{start time} - \text{current time})/\text{Total number of frames} \quad (1)$$

The frame rate in our I-CANEwas 1 FPS. The FPS allowed us to validate the real-time usability of the prototype.

- Recognition accuracy

The object detection functionality in this research I-CANe utilizes YOLOv4 tiny as the object detection algorithm to identify obstacles in real-time. YOLOv4 tiny is trained on the MS COCO dataset with an accuracy of 43.55% mAP [22]. The prototype was able to detect objects from the COCO dataset. The system performed well on bigger objects like person, bench etc. However, it often had trouble in identifying smaller objects or objects that were not so clear in the camera. A higher resolution could help in identifying objects with greater accuracy.

- Price comparison

One of the aims of I-CANe was to create an economical navigation tool for the visually impaired. The cane utilized the most economic equipment available in the market. The following table summarizes the cost of the equipment.

Table 5: Cost summarization of I-CANe

Equipment	**Price (Rs)**
Raspberry Pi 3B	10,000
RPi camera	1000
Ultrasonic sensors	450
GPS module	1350
GSM module	2500

Cane structure	1500
Power Unit	2520
Miscellaneous	2000
Total =	21,320

The table below compares the price of I-CANe with other assistive technology available in the market for visually impaired people.

Table 6: Cost comparison of I-CANe with other common assistive technology

Product Name	**Features**	**Price**
weWALK	Ultrasonic object detection with vibrating mechanism	$500
BAWA cane	Head-level and ground level obstacle alert	$600
Google AI glasses	Object recognition, OCR	$2,099
Ultracane	Head-level and ground level obstacle detection	$831
Ray electronic mobility aid	Ultrasonic obstacle detection with vibration feature	$300
I-CANe	Obstacle detection, recognition, GPS and SOS features	$137

- User satisfaction

The usability of I-CANe was estimated by conducting tests of the system among a group of blindfolded users who walked with the cane in both indoor and outdoor environments. The results were evaluated on the following evaluation points:

- Purpose: The system helps me in navigating my way
- Functionality: The feedback provided by the system is helpful
- Flexibility: It is usable in both indoor and outdoor environment
- Cost: I can afford to buy this system
- Convenience: it eliminates the need for use of multiple systems

The users rated the 5 objectives on a scale of 1-10, as represented in the diagram below:

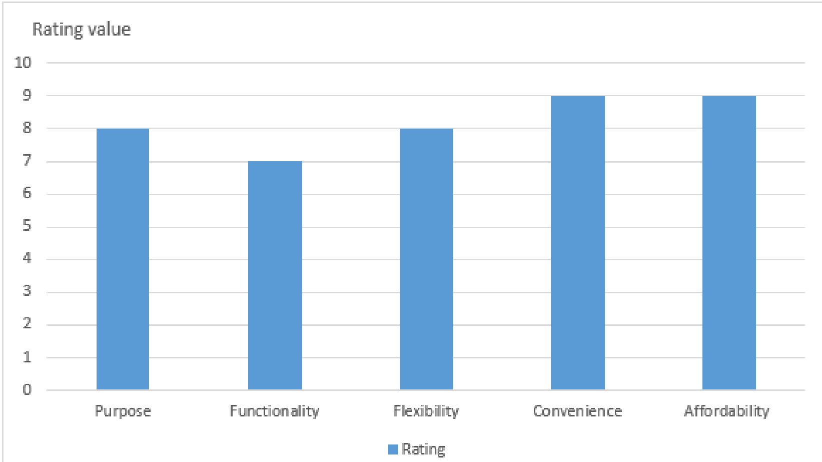

Figure 12: Results of survey to evaluate usability of I-CANe

Some of the limitations of the prototype include its inability to detect in the dark and processing load. Furthermore, the battery time can be improved and its structure improved.

While simple sensor obstacle detecting equipment are cheaper, assistive technology with enhanced functionalities such as AI integration, navigation facilities and environment flexibility come with a heavy cost that is unaffordable in developing countries. The cost of I-CANe was comparatively less than most of the assistive equipment available in the market, taking into account the range of features available in I-CANe. The costs can be improved further with customized processors and object detection algorithms.

6. Conclusion

From the work on this research and the relevant research done on it, we conclude that for an effective smart blind cane, latest technologies and functionalities need to be added to provide visually impaired users with the best possible vision experience. Through our project, we created a smart cane that incorporated features of deep learning, computer vision, embedded systems as well as wireless communications to create an all-in-one cane that has various functionalities embedded in it.

One of the aims of this research was to produce a cost effective smart cane. Our system costs were reduced significantly by utilizing low cost sensors, computing devices and a customized power unit. Moreover, by embedding the obstacle detection and identification in one device, the need for multiple devices can be eliminated which also reduces the cost burden on user.

The deep learning aspect of our research consisted of detecting objects in real-time through camera. This gives users the ability to visualize their surroundings and understand them through a voice guided mechanism. The user was notified regarding the type of obstacle as well as the distance of the obstacle. Further improvements can be made in this by adding enhanced functionality of de-tecting potholes, pavements and small obstacles like stones. Furthermore, time response can be enhanced by using the latest version of Raspberry Pi.

Conflicts of Interest

The authors declare no conflict of interest.

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