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Intelligent Navigation System for the Visually Impaired - A Deep Learning Approach

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***Abstract*—Visually impaired individuals have been gradually claiming a significant stake in the population demographics. The proposed autonomous device aims to provide a holistic solution by engineering a smart navigation system that relentlessly scans the environment, detects and classifies neighboring objects using a 4 layered Convolutional Neural Network (CNN) that has been trained on a data set containing 2513 permutations of various images of household objects that an individual may encounter in daily life. The CNN follows the 80-20 rule for testing and training the self-learning model enabling it to learn recursively from the error rate. The proposed system then calculates distances of neighboring objects from the user and provides adaptive solutions in real time to manoeuvre the user to safety by providing auditory input in a simplistic manner which considers 10-24 frames per second while drafting the kinematic response for the user. The device has achieved an unprecedented success rate of serving within a response time of less than 50 ms. The accuracy of the CNN algorithm being at 94.6%, also sets a distinguished benchmark as an object detection algorithm thereby contributing to the success in simulations of the proposed device in a constrained environment.**

***Index Terms*—Deep Learning, Object Detection, Wireless Sensors, Internet of Things, Convolutional Neural Networks, Intelligent System, Navigation System, Image Scanning, Image Processing Algorithm**

I. INTRODUCTION

The population of the visually impaired people all over the world is estimated to be 285 million out of 7.4 billion people according to the statistics provided by the World Health Organization. Problems related to navigation are faced by all the blind people because of their visual impairment. The challenges faced by the visually impaired people are tremendous. They are usually dependent on others for performing their daily tasks. Difficulties such as identification of the objects in the path and the distance at which the object is away from them which are unknown are some of the difficulties faced by the visually impaired. An automated system which will detect, recognize objects which comes in the path of the blind and convey the recognized object to the blind in the form of an audio will do a world of good to all the visually impaired around the globe. These mobility aids are important for navigation of the user in an environment. Detection of the objects is closely related with analyzing a video or analyzing an image. When the primary aim of a machine or a system is to classify an object from an image or a video, then, the newer technologies such as Deep Learning is turning out to be a favorite. One of the most representative models of Deep Learning is the Convolutional Neural Network [16]. CNN is best especially for object detection since it has the ability to recognize edges, shapes, colour and texture. There are several layers in the network where the first layer receives the input and the hidden layer also called as the convolutional layer processes the input by transforming it on the basis of a specific pattern or a feature and passes it to the following layer. While

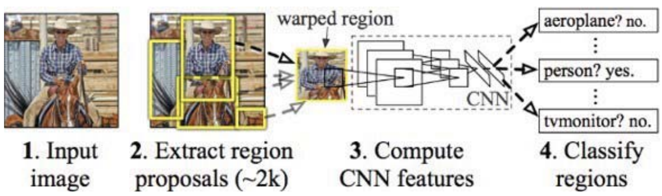

Fig. 1. Flow of CNN.[1]

maneuvering in the outside world, multiple objects will come in the path of the blind. CNN has the ability to detect the multiple objects in the frame and has a commendable effect for analyzing an image or a video. This paper presents Smart Navigation System for the Blind. This system is designed to identify the object and calculate its distance from the user by applying deep learning algorithms and by using different sensors. Real time solutions will be provided to the user depending on the type of the object which comes in the path of the user, thus, simplifying the life of the blind fraternity. The proposed model tends to exhibit the use of Deep Neural Network (DNN) and a data set which consists of images of different objects. Using this dataset and a trained model and by applying the DNN module on it, we can identify different objects in real time.[15] The object will be conveyed to the user by using an earphone or a speaker, this will be implemented by using the E-Speak feature of the raspberry pi. By using a camera we can capture image or take a video of the surrounding of the user. The distance of the object is calculated by using ultrasonic sensors. Raspberry Pi Model 3 B+ is the chosen hardware component based on the knowledge extracted from [13] on which the distance detection, object identification algorithm and sensors will be running.

II. Literature Survey

Jab noun H et. al. [2] aim to assimilate an idea that features a visually empowered system which is used in the identification of objects in immediate proximity using an algorithm named SURF. The system is basing its principle for analyzing frames on extraction of features. They used to extract feature from captured images so they give better results in machine learning algorithms. These results can give better position of objects in the frame to blind people (E.g. Images are towards left to you or toward right.)These systems tend to operate on one camera to capture images of what is intended. Multiple features are then extracted from the collected visuals and objects in the frame are identified by comparing the dimensions with the ones of predefined objects. A novel approach of visual substitution was brought forth. This system pertains to our proposed system when it comes to analysis and deciphering of the immediate neighborhood.

Menezes V et. al. [3] aim to identify and tracking the real time object is important concept in the domain of deep learning using computer vision. The author aims to use a Robot which is independent in itself to track an object in the spatial paradigm. The object, regardless of distance, can be tracked as long as it fits in the peripheral scope of the camera module being used. The author emphasizes the use of servo motors for pan and tilt. This paper educates about the positioning and placements of multiple object sensors so as to minimize the number of scans. The significance of the paper in scrutiny is that it focuses on on-board operation and processing. The gaps in said paper include reduced system stability due to increased mobility.

Tudor D et. al. [4] presents an electronic system which is created using an ATmega328p, vibrating motors and ultrasonic sensors. Two sensors along with two distinct measuring channels is used for measuring two different distances. One sensor is used for measuring the distance of object which is nearer and the other is used for distant objects. The device works on a microcontroller and uses the vibration motors for alerting and guiding the user. At the very beginning, a short ultrasonic pulse is transmitted. This pulse is reflected by an object, the reflected pulse is received by the sensor and is converted into an electric signal. Distance detection is based on the control of the vibration motor. The intensity of vibration is medium as the current controls the vibration motor. Arduino compiler was used along with a C++ class for programming this system. Karthikeyan M et. al [5] emphasize on the essentials for object tracking using Raspberry Pie module and an external camera of high resolution using deep learning. The author of this paper illustrates the know-how of hardware and the reciprocation of hardware attachments in a compact form. The paper uses a high resolution camera to track objects that are either static or in motion within the scope of it’s wide angle vision.Because of these resources there is an increase in complexity, increase in expense and the power consumption is on the higher side as well. The feed can be viewed in only one particular area, the view is not accessible if the person is in motion. To stream live video and to record it for future playback, video cameras and motion detectors are used. Motion detectors and video cameras are also used for sensing and surveillance of the environment . The playback option can be implemented in the proposed system for re-scanning. The proposed system can mimic the hardware configurations in itaˆs entirety. The author tries to solve the problem of software reliance and the hardware is independent of itself and can be powered by alternate sources. The results could be achieved as they were by the use of a Raspberry Pi Module which has on board cache and facilitates internet connectivity. It could be transmitted for processing by deep learning libraries in the proposed system or could be processed on board using Open CV for classification of objects. The experiment which substantiates the claim is a security system for surveillance. The author has based the entire project on a dependency from a stable power source. The gap being the unavailability of one. The proposed system looks to eradicate that problem by associating an alternate power source option depending on budgetary feasibility.

Jabnoun H. et. al. [6] aim to introduce a proposed system that is based on the concept of local feature extraction. SIFT algorithm is used for detecting objects. Background of the paper can be image processing and object detection. Object recognition is based on feature extraction. Areas with the most discriminative information are used. In this paper, the author’s are conveying the use of SIFT algorithm for detecting the object. SIFT which is the abbreviation for Scale Invariant Feature Transform consists of three descriptors. The first one is the Global image descriptor, the second descriptor is the local image descriptor and the third one is called the Semi-local descriptor. The main focus is on detecting the objects using the Local descriptors. This paper elaborates the use of SIFTS key points for extracting and matching the features for object identification. The author tests the application by testing it in different conditions to detect objects in video scenes.

Ani R et. al. [8] put forth Text Information Extraction as an integral part of OCR and as a primary function for any assistive reading function This is because the intelligibility of output speech can be determined by the Text Information Extraction process. This paper focuses on the quality of the text-to-speech output as well as enabling the user to generate expressive emotional synthetic speech. The author elaborates the usage of optical character recognition to detect characters from various text sources such as newspapers and converting it to voice using E-Speak. This is helpful for people who are visually impaired and can't get news updates from newspaper.

Dipali Ambadas B et. al. [9] envisages the idea of locating the position and location of movable objects by refereeing to particles of higher weight. For locating the position of objects, video analysis modelling and Bayesian filtering method is required. The method of Bayesian filters and video analysis is required for template matching of the area of interest for movable objects. Extended Kalman filter is used for tracking the location and position of the single movable object.

Vera D et. al. [10] advocates the problems faced by the blind people and how they found a solution. This paper discusses about the sensors used such as the ultrasonic sensor, rasp- berry pi, image recognition using cloud service. The Author suggested making use of four peripheral sensors. The first one is attached to the head, the second one is attached to the chest and the remaining two are attached in each leg. There is a central device which is placed near the chest. MQTT (MQ Telemetry Transport) is used to establish communication between the central device and the peripherals. For machine-to-machine communication, this protocol uses a publish or subscribe communication pattern.

Zhou X. et. al. [11] discuss about the basic requirements to detect objects using deep learning which are (i)Data-Set (ii)Network Model. Author proposes a model featuring a new dataset. This new dataset is derived from the datasets which is commonly used. The network which is used to process this new dataset is faster R-CNN. The dataset consists of 5357 images. The training set consists of 3587 images while the test set consists of 1770 images The dataset has images of the football game and faster R-CNN is made to work on that. It was observed that the players were identified from the images and other classes were recognized as well.

Jia X. et. al. [12] analyses deep learning literature and reviews it comprehensively. The algorithms of deep learning are divided into four categories which is divided on the basis of the following basic models: 1) Convolutional Neural Network, 2) Restricted Boltzmann Machines, 3) Auto-encoder, 4) Sparse coding. Overview of these deep learning approaches along with their recent developments have been provided. A brief description of the applications of the algorithm in different tasks is provided as well. The challenges faced while training the deep neural network, the challenges faced while designing the deep neural networks alongside the future trends is summarized in this paper. The author has trained the model using image net dataset and checked the solidity of each deep learning neural network.

III. EXISTING SOLUTION

Smart Blind stick is one of the solutions which is implemented to tackle the problem of the blind people [14]. While manoeuvring in the outside world the blind does not have any information about the objects in the surrounding. If a pothole or simply a hole is present in the path then the blind can have some problem as they will not be able to see it. To solve this problem, the help of ultrasonic sensors is taken to build a smart stick. An ultrasonic sensor is installed on the stick, one at the bottom of the stick and others on the body of the stick. Whenever a hole is detected the stick vibrates indicating the presence of the hole to the user. Whenever an object crosses the threshold distance then too the stick vibrates alerting the user about an object which is very close. But the smart blind stick is not able to identify the objects; it only indicates the presence of an object. For enabling a blind person to make a better decision regarding their trajectory, object detection will play a vital role. Depending upon the type of the object, the blind will have a clear opinion whether to make changes in the path or not.

Another solution which was implemented was a hands-free wearable device which was in the form of a jacket [4]. This jacket was not only designed for the blind but also for military and firefighting purposes. The jacket primarily informed the user about the presence of an object in the vicinity. It informed the user about the objects which are very close and the objects which are at some distance from the user. HC-SR04 ultrasonic sensors which works on the principle of sonar was used to determine the distance of the nearest object. Vibration motors were used so that depending on the intensity of the vibration the user could infer whether the object is at some distance or it is very close. Frequency or the intensity of the vibration from the vibration motors depends on the electrical signal or the input given to motors. A particular threshold value was set, whenever an object crossed that threshold value the vibration motor vibrated with a lot intensity, thus, alerting the user that an object is very close. On similar lines the intensity of the vibration was far less when the object was far away from that threshold value. But this jacket could only inform the user about the distance of the object and not identifying it. The jacket was heavy to wear making it difficult for the user to carry. This jacket could not identify the direction in which the object was present, thus not enabling the user to make a better decision about their trajectory.

As the jacket was heavy to wear and the direction from which the object was coming was undetected, smart glasses [7] were created in which a pair of ultrasonic sensors were installed on the glasses along with coin vibration motors which were installed at the end of the frame. The ultrasonic sensor at the front detected the presence of the object which is in front. If an object is present on the left side of the user then the left motor vibrated indicating the user to make a movement towards his right or vice-versa. The glasses are cost efficient and easy to carry. But the glasses were unable to detect the objects which were present on the left side or on the right side of the user. Here, again the type of the object was not detected and a dynamic solution which will prompt user about solutions regarding their trajectory was not implemented.

IV. Proposed System

A. System design

Solutions which were implemented primarily focused on informing the user about the presence of an object. Detection of object and the direction in which the object was present along with its distance from the user was not implemented under one roof. Smart Navigation System provides all these features in a single automated system and depending on the type of the object it provides real time solutions as well. The architecture of the system is illustrated in figure 2.

- Architecture

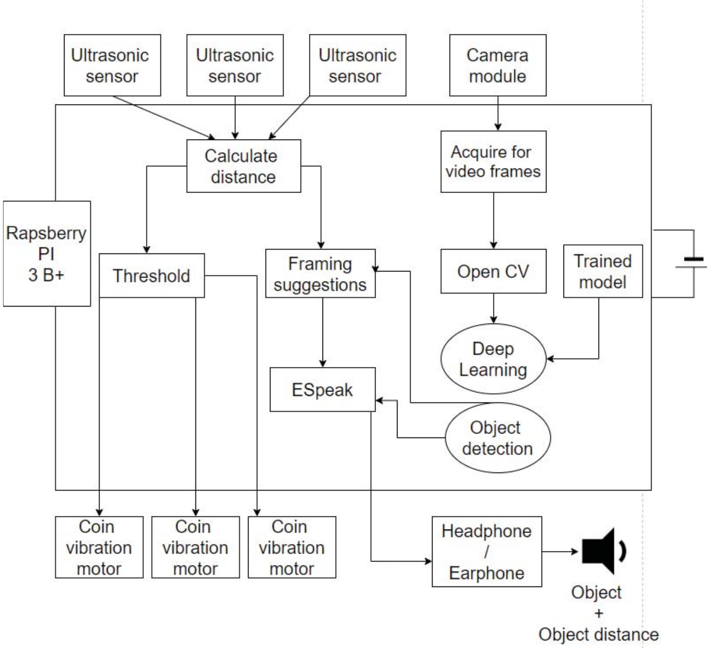

Fig. 2. Architecture.

The Smart Navigation System is broadly categorized into following parts:

- Central processing unit: Raspberry Pi is the main component of the central processing unit. Raspberry Pi b 3+ is been used which has a 1.4 GHz, 64-bit quad core processor. The camera is interfaced with the Raspberry Pi to capture video of the surroundings of the user. Raspbian-OS is the software installed in the micro SD card of the Raspberry Pi. Detection of the object from the video captured by the camera is one of the main tasks of this central processing unit. Raspberry Pi has a good processing capacity; therefore, it can run Deep Learning algorithms to serve the purpose of object detection. Measuring the distance of the object from the user is the other essential task which the central processing unit has to take care of. For measuring the distance of the object ultrasonic sensors are used. Raspberry Pi thus serves as a platform to host ultrasonic sensors. The pins of the ultrasonic sensor are connected to the i/o pins of the Raspberry thus enabling the ultrasonic sensor to perform its task in a smooth manner.

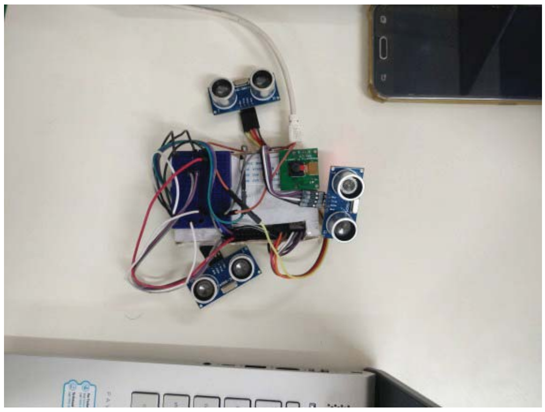

Fig. 3. Complete System with peripherals

- Peripheral unit: The peripheral unit consists of ultrasonic sensors and coin vibration motors. The ultrasonic sensor is used to measure the distance of the object from the user. Three to four ultrasonic sensors are used, the first sensor is used to measure the distance of the object which is present in front of the user, the second sensor measures the distance of the object which is to the left of the user, the third sensor takes care of the objects which are on the right side and the fourth sensor measures the distance of the object which are coming from behind. Just measuring the distance of the object is not enough, the system would be even more beneficial for the user if the direction at which the object is present is also conveyed to the user along with the distance. To cater to this requirement coin vibration motors are used. A particular threshold value is set, if the object crosses that threshold value then the vibration motor produces vibrations. For example, if an object on the right side crosses the threshold value then the motor interfaced on the right of the user vibrates informing the user about the presence of an object on the right side. Thus, the peripheral unit informs the user about the direction of the object along with its distance from the user.
- Auditory output: The peripheral unit calculates the distance of the object from the user and the central processing unit detects and identifies the object. This information is conveyed to the user in the form of an audio. Speakers, headphones or Bluetooth earphones can be used to cater this requirement. Raspberry pi comes with an 3.5 mm audio jack giving the user an option to connect wired earphones or headphones directly to the Raspberry or the raspberry has a Bluetooth connectivity option as well enabling the user to use a wireless Bluetooth earphone as well. ESpeak is an in built feature of Raspberry Pi.

It is used to convert the output of a Raspberry from console to a voice format. Using ESpeak, the identified object and its distance from the user along with a dynamic solution can be conveyed to the user in the form of an audio message and empowering the user to make a better decision regarding their trajectory.

B. Flow of the system

The conceptual schema is highlighted in figure 4 wherein the sequence of processes has been conceptualized from an algorithm's life-cycle perspective.

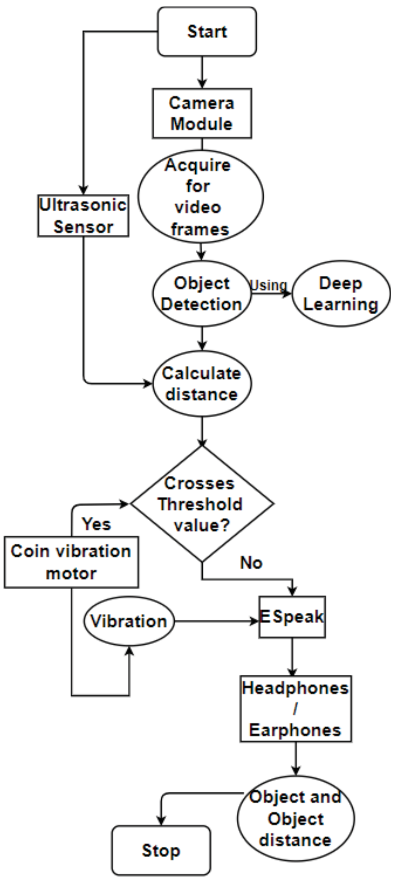

Fig. 4. Complete Flow of the system.

C. Algorithm

The flow of the algorithm is shown in figure 6. Selective search will be performed by the algorithm to generate region proposals. The likelihood of the presence of the potential objects is on the higher side in these proposed regions. Wrapping of these regions are done to get fit into CNN. Each wrapped proposal is forward propagated to CNN for extraction of features [1].

In purely mathematical terms, as per the function equation in figure 5, convolution is a function derived from two given functions by integration which expresses how the shape of one is modified by the other. The functions are explicit in nature and are mapped in one-to-one correspondence as per features of individual layers.

$$(f * g)(t) \stackrel{\text{def}}{=} \int_{-\infty}^{\infty} f(\tau)\, g(t-\tau)\, d\tau$$

Fig. 5. Convolutional Neural Network Equation

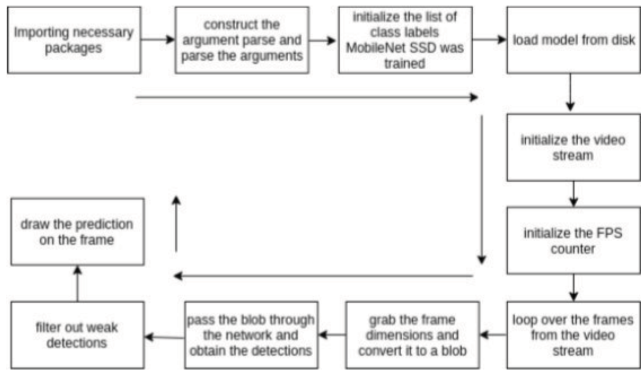

Fig. 6. Algorithm.

Score of each region is taken into consideration and the region with lesser scores are rejected. 80:20 ratio was followed were 80 % of images were used for training and 20 % were used for testing. Training was performed on a large auxiliary dataset. For training the data bounding box labels were not used. Training was performed using the open source Caffe CNN library [1].

V. RESULT AND ANALYSIS

To detect the objects which occurs in the path of the blind person, a camera was interfaced with the raspberry pi b 3+ model. Using the camera, the CNN algorithm was able to detect the objects which was placed in front of it. Along with detecting the objects the algorithm was able to give the accuracy with which it was detecting the objects. At the very beginning a human was placed in front of the camera as shown in figure 5 and observed the accuracy with which the CNN algorithm was detecting the object.

Then a bottle was placed in front of the camera as shown in figure 7 and observed the accuracy It was observed that the bottle had comparatively less accuracy value than a human. Different types of bottles were tested as well, bottles with different shape, size and colour but every time the algorithm correctly labelled the object as bottle only.

As per figure 8 a chair was then placed forth the camera to test along with a human to check whether the algorithm was able to distinguish different objects which are in the

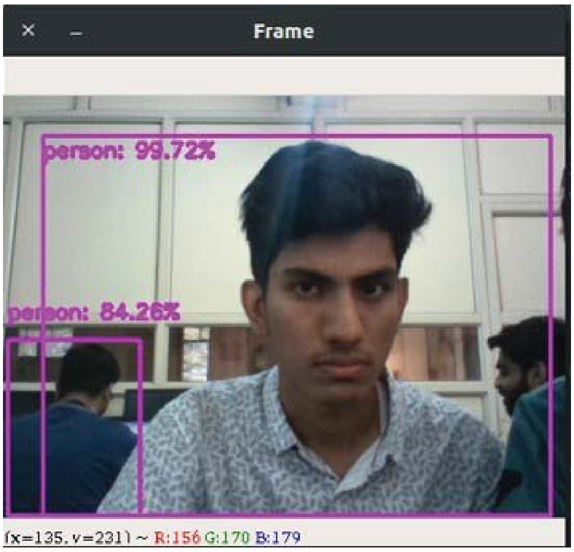

Fig. 7. Detection of person

Fig. 8. Detection of bottle

same frame. Accuracy of the all the objects in that frame was recorded

The convolutional neural network is evaluated for object detection by testing it under different situations in order to test the reliability of the algorithm. The main purpose of these tests were to find out the accuracy with which the algorithm can detect the objects. Different scenarios considered were the motion of objects, distance of the object from the camera and multiple objects in front of the camera.

- Motion vs Accuracy : This test was performed to check whether the algorithm was able to differentiate between objects which are moving at different speeds in front of the user, as in real world different objects will be moving

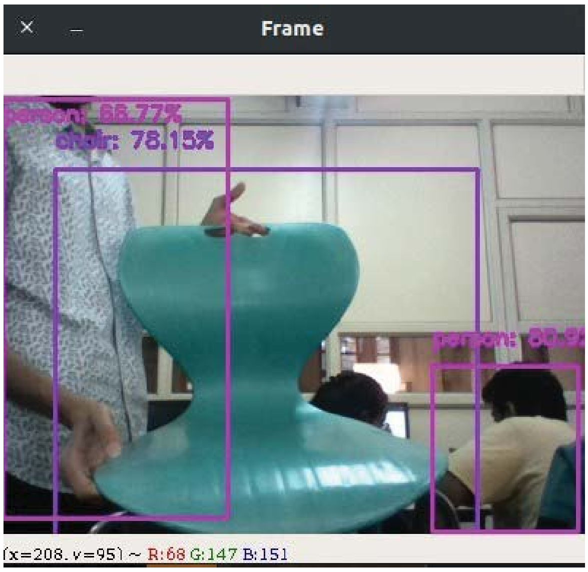

Fig. 9. Detection of chair

at relatively different speeds in front of the user. Different objects were made to move in front of the camera at different speeds. The objects chosen for this task were a human, a chair, a bike and a bottle. The speed with which the objects were moving were mainly categorized into three parts a) still, b) medium, c) fast. Firstly, the accuracy of these objects were recorded when they were still that means no movement in front of the camera.The accuracy values are shown in figure 9. Then the objects were moved at a medium pace in front of the camera and it was observed that the accuracy changed when the objects started moving. Then objects were moved at a rapid pace in front of the camera and the accuracy was observed. The results are shown in figure 10.

		Movement		
		Still	Medium	Fast
Accuracy	Person	99.81	90.53	86.1
	Bottle	89	53	39
	Bike	83	68	40
	Chair	79	54.3	34

Fig. 10. Table for Movement vs Accuracy

It is clearly observed that the objects that were still have the highest accuracy. The objects that were moving at a medium pace had comparatively less accuracy. The objects that were moving at a rapid pace had the least accuracy.

- Distance vs Accuracy : This test was performed to check whether the algorithm was able to differentiate between objects which are at some distance from the user, as in real world different objects are at different distances from

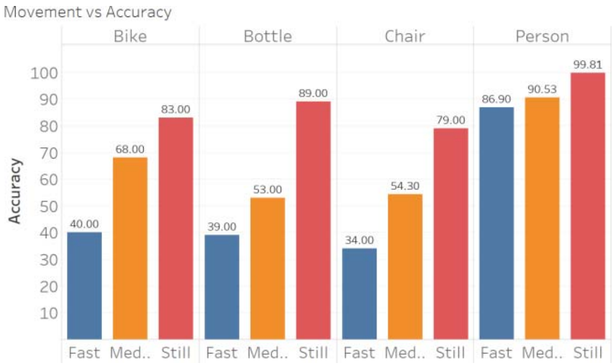

Fig. 11. Movement vs Accuracy

the user. The distances considered were at 1 meter, 3 meters and 5 meters away from the camera. The objects considered were a human, a chair and a bottle. The accuracy values are shown in figure 11. The algorithm gave highest accuracy for the objects which were only at a distance of 1 meter from the camera and gave lesser accuracy for the objects which were 3 meters apart. The results are shown in figure 12.

		Distance		
		1 Meter	3 Meter	5 Meter
Accuracy	Person	99.89	93	73.89
	Bottle	89.2	50.7	48.79
	Chair	86	48	43

Fig. 12. Table for Distance vs Accuracy

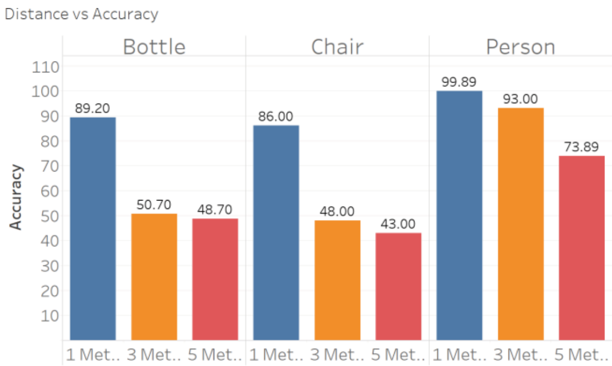

Fig. 13. Distance vs Accuracy

Thus, as the objects move further away we get less accuracy and the algorithm gives best results when the objects are close by.

- Multiple Objects vs Accuracy : This test was performed to check whether the algorithm was able to identify different objects, as in real world different types of objects may come in front of the user.In this scenario, multiple objects such as bottle, chair and a human were placed in front of the camera and the accuracy of those objects were recorded. The algorithm was able to distinguish between different objects and was able to give highly accurate values. The accuracy values are shown in figure 13. The results are shown in figure 14.

	Multiple objects		
	Person	Chair	Bottle
Accuracy	99.4	87.23	93

Fig. 14. Table for Multiple objects vs Accuracy

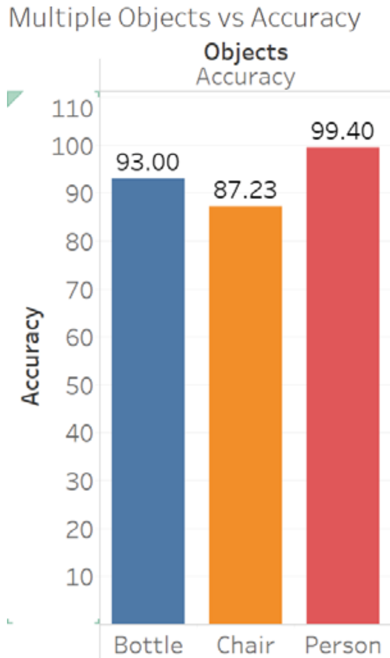

Fig. 15. Multiple objects vs Accuracy

A human was easily distinguishable and gave high accuracy value followed by the bottle and the chair. All the objects were still when this test was carried out. All the objects were at the same position and at the same distance from the camera. All the objects were then moved from there places, this time each and every object were placed on a different position. This experiment was successful as the system detected all the object distinctively even though they were a distance apart from each other. Thus, it was evident that no matter how many objects appears in front of the camera at the same time, the system was capable of detecting each and every object distinctively.

VI. Future Work

Raspberry Pi 3B+ model can process less than one frame within a second. The newer version of raspberry pi model are capable of processing frames at higher rate. Hence use of newer version of raspberry pi can lead to higher processing rate for frame and also influence the detection process.Proposed work focuses on providing suggestions to blind person after detecting the object. The algorithm performs simple search in rule base for giving suggestion to the blind person. So if learning agent or utility based agent can solve this problem so there can be a scope for improvement in existing work. So if AI (Artificial Intelligence) is taken into account then it can be improved. For the research work pertaining to the Smart Navigation System deep learning algorithms for object detection rendered previously unmatched accuracy in detecting daily life objects. The objects were detected with the help of an image repository that was created, scaled and rasterized with 2513 daily life images and processed at 10 fps or frames per second to enhance dynamic processing on a simple and cost effective hardware entity in Raspberry Pi. Real time adaptive solutions were relayed with success about the identified object to the blind user along with the distance which is calculated by the ultrasonic sensor. An SOS fail safe mechanism was also embedded in case an undetected object surpasses detection mechanism. The entire device is light weight, mobile and very cost effective - priced at under INR 3700.

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