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Development of a Sensor Assistive Walking Stick for the Visually Impaired

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Abstract. Visually impaired persons mostly depend on white canes for their maneuvering. In the last decade, numerous researches have been conducted to assist the visually impaired by developing various sensor assistive systems. However, there are several scopes of further development. This paper focuses on the development of a simple and smart walking stick with the integration of ultrasonic and camera sensors. In addition, there is a novel feedback system combining audio feedback to the ear through headphones and vibration feedback to the hand holding the stick handle. Several experimental setups are designed to validate the implementation and effectiveness of the sensors and feedback system. The percentage of accuracy in sonar sensor detection is confirmed up to 98% and the safe workspace is determined as 30x60 sq. cm. The camera sensor is used for object detection and face learning. The control system is designed to set the intensity of the vibration feedback based on the distance of the obstacle and generate an audio message about the obstacle to provide feedback to the user. The performance of the feedback system is validated by demonstrating the developed stick to the real users.

Keywords: Ultrasonic sensor, camera sensor, object detection, vibration feedback, image processing

Introduction

Blindness and visual impairment restrict the affected people from leading a regular life. Navigating becomes a big issue. Ensuring safety while out on the streets becomes difficult. Blind people have to rely on guide dogs, walking white canes, and so on. However, these white cans can only detect obstacles with physical contact. If any obstacle comes above waist height or chest height a traditional walking stick is not going to be enough. Obstacles like hanging signboards, branches of a tree are examples of such scenarios occurring. Therefore, being able to detect obstacles without any physical contact becomes necessary. Furthermore, there can be moving obstacles on the streets such as pet animals, vehicles, etc., and may come towards the person. In such cases, it would be beneficial for the blind person to know what is in front and how far it is. Several studies tried to solve these issues in different ways.

Siddhartha et al. (2018) propose an electronic smart jacket with the integration of embedded sensors and smartphones. Arduino UNO 328 works as the processing unit while power is being supplied by a battery. Ultrasonic sensors are used and the whole system is connected through a Bluetooth chip and wi-fi. The sensor was able to detect obstacles in front with 98% accuracy. Based on the detection of the sensor voice command is generated through the smartphone. Rangeetha et al. (2016) propose an Arduino-based smart walking stick for blind people to tracking bus routes. Zigbee transmitter and receiver are introduced between the bus and walking stick. Shariff et al. (2020) propose an artificial intelligence-based blind stick that has a camera, GPS tracker, different sensors. For the processing, raspberry pi is used. The article describes the process of how it can be done through obstacle detection, object detection, and location tracking. The paper also talks about the use of Jupyter notebook, python programming language, and Tensor flow for machine learning network. Budilaksono et al. (2020) gave a description based on ultrasonic sensors and their use on a walking stick to help

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the visually impaired. HC-SR04 ultrasonic sensor was used with LM2596 Regulator modules to lower voltage. A couple of sensors were linked together to detect obstacles properly. Saha et al. (2020) developed a low-cost smart walking stick for the visually impaired. Microcontroller, battery, ultrasonic sensor, and water sensor were used. Asati et al. (2019) developed an intelligent walking stick with an ultrasonic sensor, raspberry pi, vision system, audio Bazar. A total cost of Rs.5700 was needed for the development of it. Yahaya et al. (2019) developed a walking stick for the blind focused on obstacle and pit detecting with ultrasonic sensors. Nada et al. (2015) proposed a smart walking aid for the blind with the integration of infrared sensors, ultrasonic sensors, and water sensors. A comparison of using different sensors and their effects and accuracy is also noted. Raja et al. (2020) propose a shoe-based navigation system for the visually impaired in combination with ultrasonic and infrared sensors. There is a buzzer to let the person know regarding obstacles. Nabulsi et al. (2017) built an Arabic language application capable of helping blind users in real-time. The proposal is that the blind user captures his voice and sends it to prefixed volunteers. The volunteers listening to the inquiries give feedback. Shrawankar and Mishra (2018) talk about an assistive desktop navigation system for the visually impaired where they can use mouse movements to do so. Hooking, tracking, and navigation are the three phases used to achieve this. Khaliluzzaman and Deb (2018) propose a framework for detecting stair regions by utilizing two unique properties. One is the creation of three connecting points with the intersection of edge segments of horizontal and vertical parts of the stair and the other is, these edge segments are in increasing parallel order. A coordinate system is developed and used to find the distance. Quite a lot of work has been done in this field but there is still room for improvement. In this research, a simple and smart sensor assistive walking stick is proposed with a novel and hybrid feedback system. The model is designed with an ultrasonic sensor and raspberry pi camera sensor to receive input information from the environment. The vibration actuator and head-phone is used as the output of the system. Raspberry pi works as the controlling unit and a battery power up the whole system. Each component was chosen considering its cost, effectiveness and relevancy of application. Ultrasonic sensors are insensitive to light, dust, smoke, mist, vapor, lint which is a big advantage for this application. The vibration actuator is used to reflect the distance of the obstacle instantaneously. When the user activates the pi cam by pressing a switch, it takes a picture, process it and then describe the scenario through the headphone.

Materials and Methods

The overall operation method is shown in the block diagram below in Figure 1 which shows the integration of all the sensors and control system and also the feedback system.

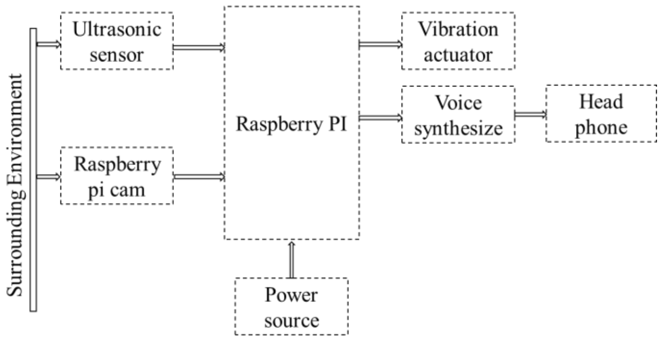

Figure 1. Operation Method diagram of the sensors with the stick

Ultrasonic sensors are capable to detect obstacles within the range of 30 to 120 cm from the stick. Through image processing with Pi Camera, the stick can detect what the object is and describe the scenario ahead. A raspberry pi processes all these components and a Power Bank powers up the whole system. The smart walking stick that is going to be proposed here consists of some sensors, obstacle detection, recognition devices.

The stick is designed and constructed based on the average sticks found in the market. The walking stick without the attachment of the sensor house is as follows. In Figure 2 it is seen that the total height up to the hand holding portion is 84 cm and the total height is 88 cm. The sensor house is attached at 76 cm from the ground with a nut and bolt being inserted to the 1st hole drilled in the stick. The height of the stick can be varied based on the height of the user.

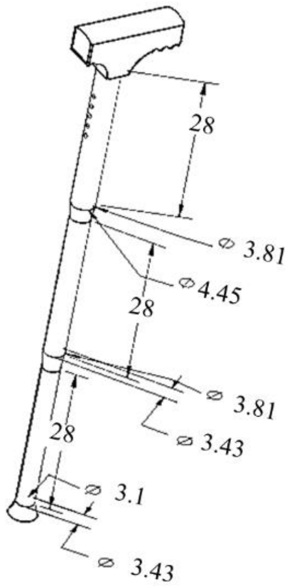

Figure 2. Solid work model of the stick with dimensions (in cm)

The sensor house shown in Figure 3 is constructed by maintaining the proper dimensions of the components that would be fit inside of it. There is a raspberry pi and a power bank inside the sensor house casing. There are a lot of ports in the raspberry pi. Those ports are necessary to connect with the power bank and the headphone or sound source.

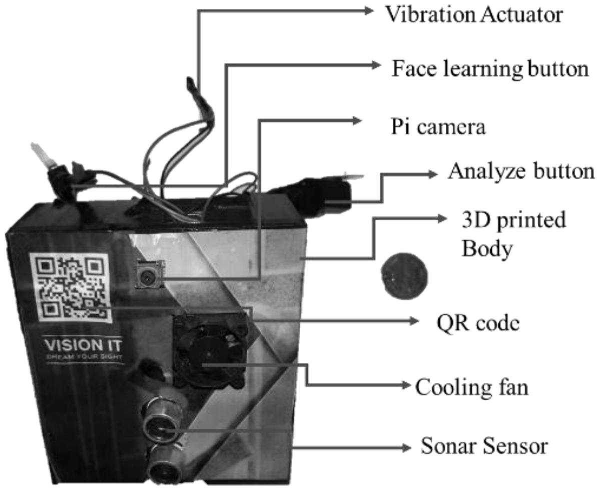

Figure 3. Actual 3D printed sensor house with cover

It has a length of 10 cm, a width of 9 cm, and a thickness of 3 cm. There is a cover on top of it which covers up the whole box. There is also a fan attached on the top of the cover which is there to cool down the raspberry pi when it gets hot. The casing with all the necessary components is set vertically with a nut and bolt with the stick. The wire with a vibration actuator comes out from the top opening. It is attached to the handle of the stick. Then on the top surface of the casing, there is a slot for a fan, a pi camera, and a sonar sensor. All these are attached there with precision.

Necessary Equipment

Ultrasonic sensor:

It is a distance measuring sensor that uses sound waves emitted from the sensors. If there is any obstacle within the specified range, the sound waves get reflected. The time required for the wave to come back is measured and based on that distance can be calculated. In this work, the HC-SR04 model is used. It is because this model gives quite accurate data and also quite cheap. It has a certain set of specifications. It can detect obstacles within a range of 2cm – 400cm.

Raspberry pi:

Raspberry pi is a small computer-like system that can process all the necessary information based on the input given to it. It works as a control unit in a system. For low space consumption and fast data processing, raspberry pi is a very suitable choice. It has a lot of applications and a lot of different features to use. In this work, there is a collaboration with a camera and sonar sensor. Normal Arduino cannot process all the necessary functions of image processing but raspberry pi can. Therefore, raspberry pi model 4 is used in this work. A memory card is inserted in the raspberry pi that has all the codes in it.

Raspberry pi camera:

It is a camera device that can capture an image and process the data to raspberry pi for further consideration. It has a very small dimension compared to a webcam or other cameras which makes it feasible for implementing in confined space.

Vibration Actuator:

It is a device that creates vibration based on the input given. It is a small coin-type vibration actuator that easily fits under the thumb. This actuator is attached to the handle of the stick to provide vibration feedback to the user.

Power Source:

A power bank is used as the power source to power up the whole system. It is connected with the port of raspberry pi with a TYPE C USB cable. It serves 2 amperes current to the raspberry pi. The power bank is a rechargeable device. A fully charged power bank can run the raspberry pi for a full day. A power bank is placed close to the raspberry pi in a casing.

Control System

Several functions are controlled with the control system of the stick. There is a certain distance for which the sonar sensor is activated and it is set by the programming system. Then there is the function of image processing. One part is object recognition which identifies what the object is. Then there is face learning which helps to learn a new face and save it. A lot of modules are imported and then attached to the whole system. The camera can identify certain objects and the system can generate sound based on that. Raspberry pi is used as the main processing unit. All the other parts are connected and processed through it. Python is used as the core programming language. A lot of packages and modules are used based on the requirements of the function. The vibration feedback is generated based on the input taken by the sonar sensor. This is set to be dynamic. Hence, continuous feedback is generated if any object comes within the predefined range of the program. Since it cannot be predetermined when any object comes in front of the blind person, the vibration feedback is provided in real-time. However, in the case of camera sensors, it is not in real-time. It needs to be activated by external means which in this case is a switch. There are two switches. One is there to capture the image and give voice feedback after image processing and object detection. But the other works for face learning and storing purpose. Since the feedback is voice generated where the user can listen to the description of what is in front, it has been programmed to be activated only the user seems fit. Making it real-time does not serve the purpose and creates continuous voice which might create more distraction for the person to navigate.

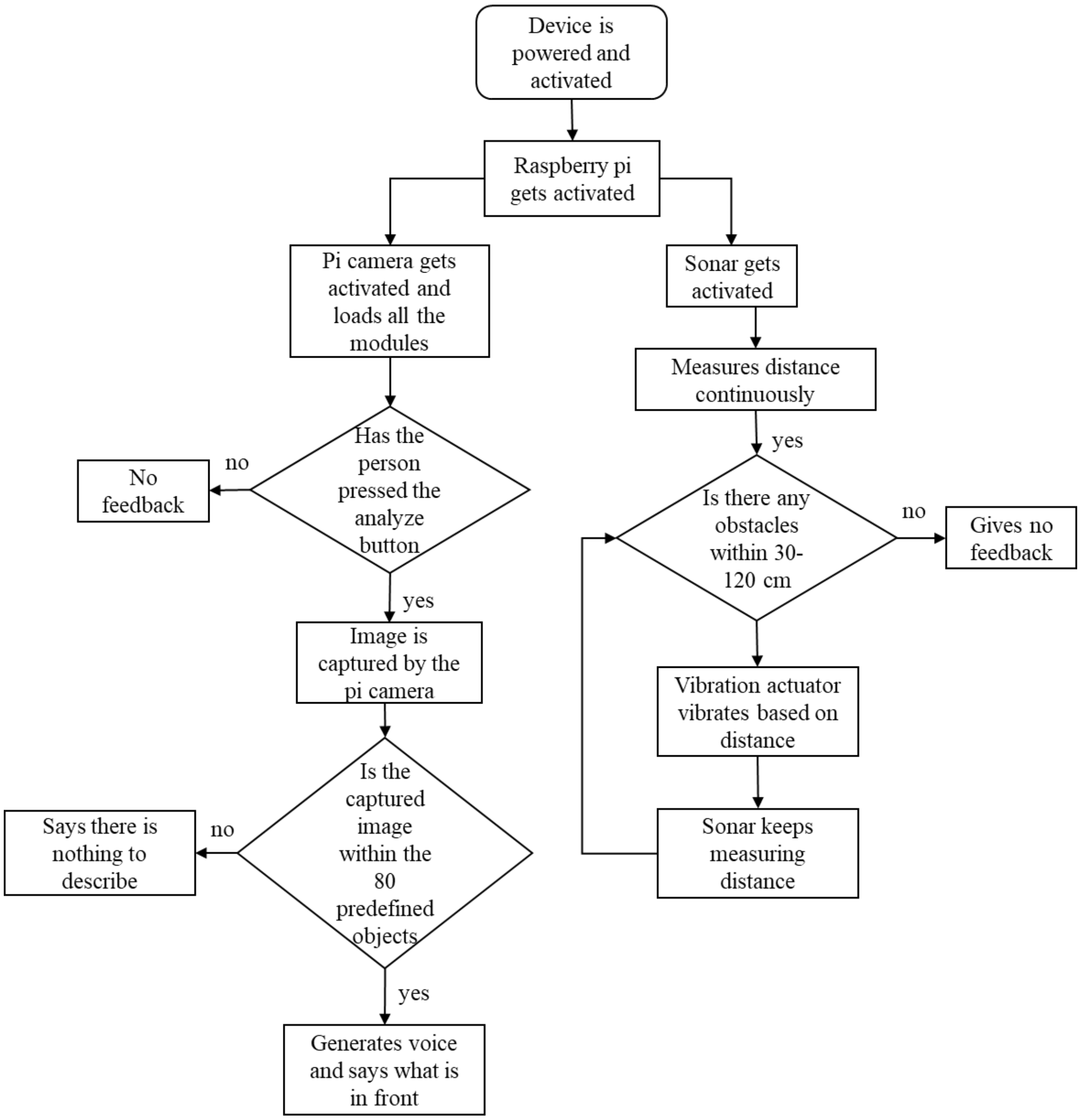

Figure 4. Flow chart of the control system

Figure 4 presents the flow chart of the whole control system in a systematic order. At first, the device is turned on and the raspberry pi gets activated. With the activation of these items, the sonar sensor starts to gather data from the surroundings and checks if there is any obstacle within 30cm to 120cm. If there is no object detected, no vibration feedback is generated. Whereas, if there is an obstacle, it gives vibration feedback. Then, with the pressing of analyzing button picture is captured. If the captured image has pre-defined objects, then it says what is in front. If there is an unknown object, it says there is nothing familiar in front to describe.

Results and Discussion

Experimental Setup and Performance

Different experimental setups for the sonar and camera sensors are used to determine the accuracy level. The changes of reading in terms of different objects and time are recorded. In all these cases the readings are satisfactory. Sonar sensor readings show 98% accuracy in case of complete solid obstacles like a wall. However, even for obstacles that are grid-like distance measurement is working just fine as mentioned below.

Distance Measurement with Sonar

Figure 5. Experimental set up for sonar sensor in case of grid-like obstacles

Table 1. Experimental data of sonar sensor for grid-like obstacle

Actual Distance (In cm)	Measured distance (In cm)	% Error	Vibration Intensity %	RPM
150	152	1.33%	0	0
135	131	2.96%	0	0
120	116	3.33%	5.87	176.1
105	107	1.90%	19.01	570.3
90	87	3.33%	32.17	965.1
75	74	1.33%	45.92	1377.6
60	58	3.33%	59.77	1793.1
45	43	4.44%	76.85	2305.5
30	29	3.33%	90.8	2724

In Table 1, it is seen that the actual and measured distance are quite similar. The intensity of vibration is increased with the decrease of distance. Graph for the first two columns and the 1st and 4th columns is drawn to visualize the whole process.

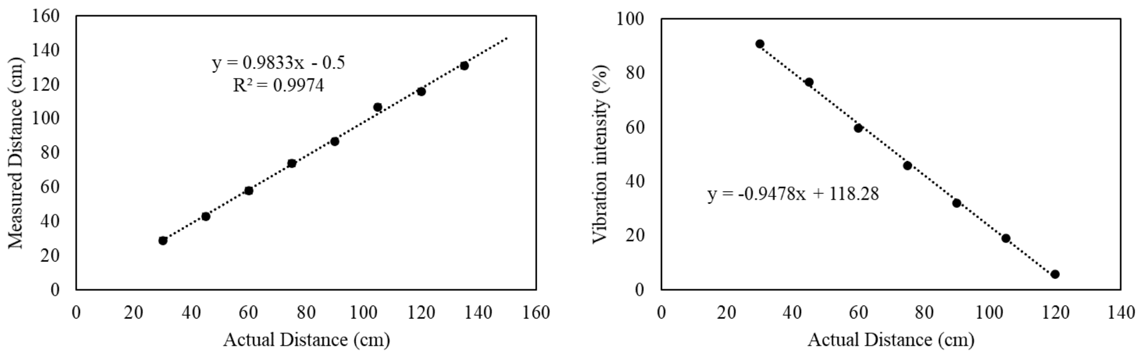

Figure 6. (a) Actual distance vs Measured distance (b) Vibration intensity vs Actual distance for grid-like obstacles

In Figure 6 (a) the trendline for actual distance and measured distance for grid-like objects is being shown. The deviation is less than 5% for most of the data points and the points are aligned with the trendline. Figure 6 (b) demonstrates that distance and vibration intensity are inversely proportional.

Defining Workspace

To find out the zone in which the sonar sensor was working another experimental setup was established.

Figure 7. Experimental set up for defining workspace for sonar

As shown in Figure 7, there was a board of 59cm x 105cm placed as an obstacle. There is an X mark given on the middle of the board. That X mark worked as a target point when the board was moved from middle to right and then from middle to left. The working range of the stick is 30cm to 120cm. Total distance was divided into 4 segments to find out the zone within which the sonar sensor can detect obstacles. 30cm, 60cm, 90cm, and 120cm are the markings for the 4 zones. Therefore, the board was placed in front and moved left and right. Now for all positions in that zone, the sonar reading is found. For the experimental setup in Figure 7, a zone box is created for the whole system, and the experimental result can be summarized as shown in Figure 8.

59 cm x 105 cm rectangular object												
	Vibration intensity for left side					X	Vibration intensity for right side					
	50 cm	40 cm	30 cm	20 cm	10 cm	Middle	10 cm	20 cm	30 cm	40 cm	50 cm	
30 cm	0	98	96.14	97.5	94.6	100	100	100	100	0		30 cm
60 cm	0	72.1	74.89	71.6	72.8	71.52	74.1	75.9	71.64	0		60 cm
90 cm	0	41.6	43.39	45.6	46.1	44.72	44.5	46.6	44.97	0		90 cm
120 cm	14.4	16.6	20.69	19	18.8	13.51	13.7	19	21.35	18.4	0	120 cm

Figure 8. Experimental data for zone creation

The 59x105 cm rectangular object was set in the place marked X. Then vibration intensity was measured by moving towards and coming back from the object. Data was taken for 30cm, 60cm, 90cm, 120cm from the box. The object was moved left to right increasing 10cm each time to find the zone within which vibration intensity can be found. 0 being the least amount of vibration intensity and 100 the maximum. The experiment was done by only standing down the middle line at 4 positions and vibration data was taken. Therefore, if any obstacle comes within a box range of 60cm x 120cm the device will be able to detect and give vibration feedback based on distance.

Real-Time Analysis

Experimental setup for real-time data was taken accordingly. In this case, there was a solid wall in front and the device was taken back and forth towards the wall and away from it. Based on that the real-time data and graph were plotted.

Figure 9. Experimental setup for real-time data

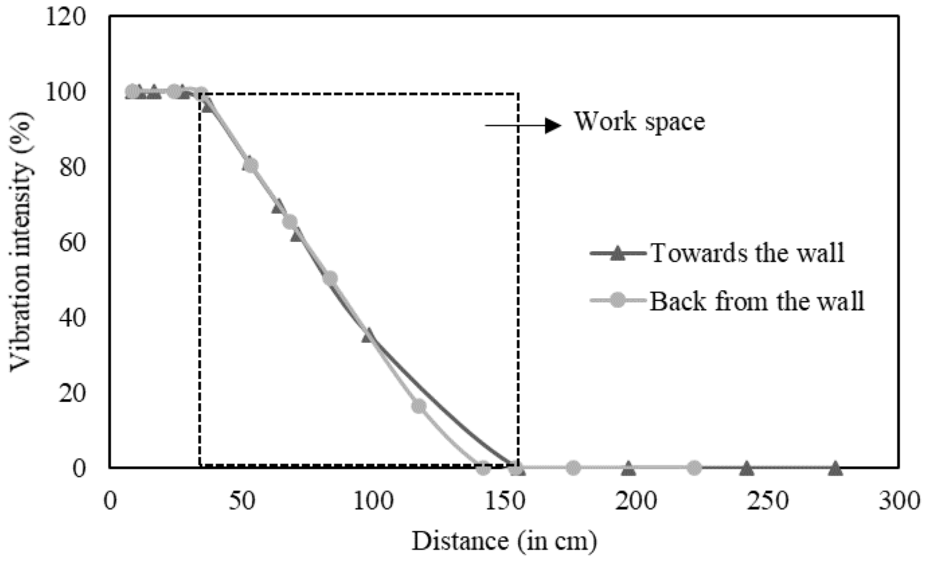

Figure 10. Real-time data comparison for going front and back with respect to the obstacle

As shown in Figure 10, the real-time data for going towards the wall and coming back from the wall is almost the same. The deviation is less than 5%.

Camera Readings:

In the case of camera integration, an object detection module was used. A TensorFlow object detection module was used to train 80 objects. Different objects were put in front of the device. Then the camera sensor was used to find out the accuracy of the object detections.

Figure 11. Experimental setup for camera readings

Another feature of the device is that it can detect what obstacle is in front and say its' name out loud. In Figure 11 it is seen that there are different types of obstacles in front of the camera.

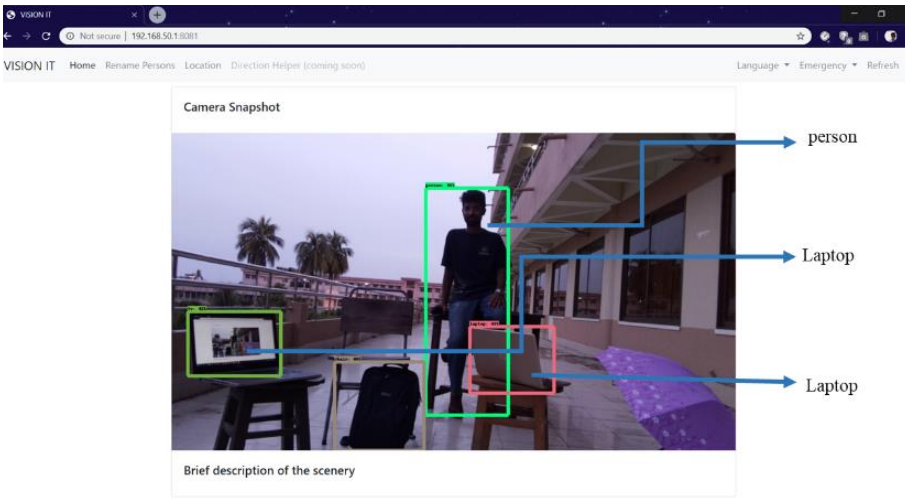

Figure 12. Object detection by image processing

Figure 12 is showing object detection by image processing. This was done at almost 6 pm. As it turns out, even in low light, it is being able to recognize what is in front. The machine learning model takes input from the captured images of the camera and says what is in front. Then there is the text to speech conversion module. By text to speech synthesis audio of the captured image is generated.

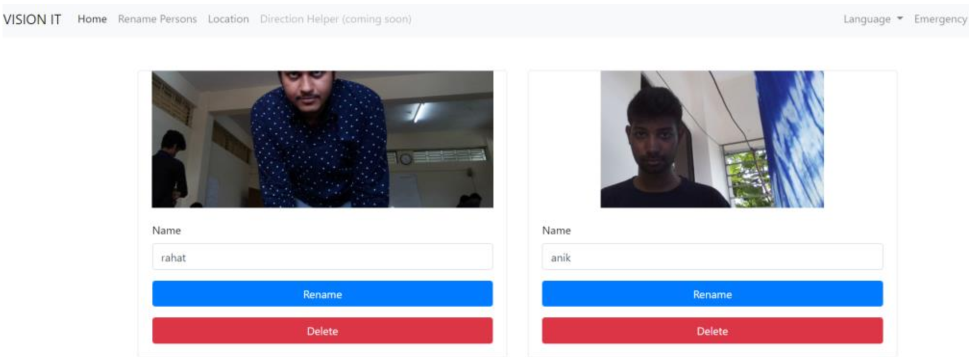

Figure 13. Face learning and storing

Figure 13 shows the face learning and storing web portal. This web portal can be accessed by connecting to the hotspot of the raspberry pi. A new face each time can be stored here after image has been clicked through the camera sensor.

Conclusion

In this research, a simple and smart assistive walking stick was made for the visually impaired. It has different features to aid the visually impaired to walk freely in day-to-day life. The sonar sensor detects the obstacle and the control system gives vibration feedback to the hand of the user by using a vibration actuator. There is a coin-type vibration motor with a maximum RPM of 3000 acts as the vibration actuator. Based on the distance of the obstacle within the range of 30cm to 120cm, the vibration actuator changes its vibration intensity. The camera can detect 80 pre-trained obstacles, detect face within the database and generate voice feedback. The power bank can keep the device running for 6 hours after which it can be recharged and used again. Reduction of the overall dimension of the sensor integration might be done by customizing PCB board as necessary instead of raspberry pi.

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