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A Hybrid Approach for Identification of Manhole and Staircase to Assist Visually Challenged

SREENU PONNADA[1], SRINIVAS YARRAMALLE[2], and MADHUSUDHANA RAO T. V.[3]
[1]Department of Computer Science and Engineering, GITAM Institute of Technology, Visakhapatnam 530045, India
[2]Department of Information Technology, GITAM Institute of Technology, Visakhapatnam 530045, India
[3]Department of Computer Science and Engineering, Vignan's Institute of Information Technology, Visakhapatnam 530046, India

Corresponding author: Sreenu Ponnada (sreenu108@hotmail.com)

ABSTRACT Recognition of an object is a bare minimum restraint for an individual in order to sort out or classify the type of the object. This situation becomes a tricky experience with respect to the blind persons; therefore, to assist visually challenged persons, in particular, while recognizing the staircases and manholes, a prototype of mobility recognition is presented using the feature vector identification and sensor computed processor Arduino chips. This prototype provides more sovereignty to the sightless people while walking on the roads and helps to pass through on their own without any backing. This prototype is developed using Arduino kit along with feature detection module and helps the visually challenged in reaching their destinations with ease. A low weight stick is built to facilitate the visually challenged people toward effective recognition of the obstacles. In order to recognize the manholes, the chip is programmed and embedded in the stick that also holds the code for detection of the staircases based on a bivariate Gaussian mixture model; speeded up robust features algorithm is considered for extraction of features. The developed model shows an accuracy of around 90% for manhole detection and 88% for staircase detection.

INDEX TERMS Arduino kit, feature selection, ultrasonic sensor, frequency spectrum, BGMM classification.

I. INTRODUCTION

Moving around unfamiliar surroundings is an exigent task for the visually impaired persons due to their deficiency in eyesight. According to the latest survey, around 1.5 million people in India are visually challenged and are facing a hardship in performing their day to day activity. This population is about 170 million worldwide and as per the latest statistics, this number is increasing by 10% annually [1].

Staircases pose a major problem in navigation, and their recognition is of prime importance for the visually impaired. Many different kinds of sensors, like monocular [2]–[5] and stereo cameras [6]–[8], depth sensors [9], [10], or laser scanning [11] devices (e.g., LiDAR), have been used for detecting staircases.

Monocular image based methods generally detect staircases by detecting non-ground plane regions and identifying pattern of concurrent lines resembling staircases in those regions. For example, [5] proposed a Gabor filter based texture detection method to detect distant staircases. They estimated the staircase pose by homograph search model. Reference [12] extended this using motion stereo. Reference [13] detected staircases only from RGB image by performing Hough transform to extract concurrent parallel lines in an edge map image resulting from Sobel operator. Reference [7] optimally detected staircase in real time using stereo imagery to estimate ground plane and temporal consistency, but did not classify up/down stairs separately. Reference [8] incorporated a stereo camera into the white cane and used actuators for guidance and distance feedback. Reference [9] proposed an RGBD image-based detection approach of stairs, pedestrian crosswalks, and traffic signs, which achieved decent detection rate in the staircase detection, but did not handle the escalator detection. However, some items which contain parallel lines such as bookshelves could be misclassified as stairs and pedestrian crosswalks. Reference [10] presented an efficient optical flow based stair tracking algorithm using Hough transform for parallel line detection and a SVM Classifier to detect indoor staircases and recognize the types of staircases by using RGBD videos captured via RGB-D camera mounted at the chest position. Reference [11] used array of Lidars and vibro-tactile units to detect obstacles and features including up/down staircases. The system is time consuming to get used to by a visually impaired user and needs to adapt to the rate of motion of the user.

In Indian context, open manholes pose another critical risk. Ultrasonic sensors have been used extensively in obstacle detection. Reference [14] proposed use of ultrasonic sensors to detect manholes. The Smart Cane [15] and the UltraCane/Batcane [16], [17] were systems that fully relied on a white cane and only used a single sonar sensor attached to a cane to detect above-knee obstacles in the direction of the cane, signaling this through a vibration. Reference [18] reviews several machine vision- based Electronic Travel Aids (ETAs) and compares them with those using other sensing techniques.

In this paper we propose a hybrid approach for detecting manholes and staircases by using both sensor and image based algorithms. We present a novel algorithm to detect and classify upward and downward staircase from high quality frames extracted from a video stream of a mobile camera using Bivariate Gaussian Mixture Model that takes as an input staircase shape and distance features extracted using the SURF algorithm. The entire processing happens on the smartphone without need of heavy computation devices or high speed 3G/4G connectivity for cloud computation. We use an array of 3 sonars (front, right and left) mounted on a white cane and managed by Arduino processor to help detect manholes and also aid in staircase navigation. We further use median based threshold using Gaussian Mixture Model for precise manhole identification.

We employ vibro-feedback mounted on the cane to warn the user of the obstacle as well as connect to smartphone via Bluetooth for audio feedback. Overall the system is lightweight and cost effective.

The rest of the paper is structured as follows. Section 2 deals with an overview of Ultrasonic sensors along with a brief introduction about Vibrators, Sensor ranges, Arduino processors and explanations along with the pin diagrams. Section 3 presents the methodology for the identification of manholes. Section 4 deals with the identification of staircases, and the extraction of the feature vectors and BGMM. Section 5 presents the derived results and experiments conducted. The final section 6 summarizes the article along with suggestions for future direction.

II. HARDWARE COMPONENTS

Ultrasonic sensor implanted in the stick spots the obstacles ahead using ultrasonic waves. If the sensor senses an obstacle the output of receiver gets activated and this change will be identified by Arduino Processor. Thus, it instantaneously alerts the person as soon as it receives the triggered output. This technique can also be used to detect manholes. The device sends the waves, depending upon the obstacle, the device generates a vibration.

A. ULTRASONIC SENSOR

These are largely used to capture the signals more swiftly, the signals from the ground level ultrasonic sensors are converted into time domain using the feature transformation. The majority of the literature in this direction [19]–[21] depicts various models based on different sets of the ultrasonic sensor and extract the signals captured using both time domain and the features extracted for identification of the object. The time domain helps to capture principle components of the segment and helps to process the signal.

Confined to the identification of correlation coefficient by the time domain, a signal can be made to sensitize and thereby help towards the replacement of the objects. However, compared to the time domain, frequency domain, acquired signals will always give better results because of the fact that they take the statistical parameters into consideration such as movements, segments, etc. Most of the research work in this area is based on Neural Networks which can in particular help to identify the 2D and 3D shape of the objects, independent of orientation and based on the echoes generated by ultrasonic sensors [22], [23].

With this advantage, some researchers have highlighted the usage of ultrasonic transducers for identifying the simple objects such as a cylinder, edge, etc. Works are also highlighted based on sonar based, particularly during the cases of corners plains and edges recognition [24]–[26].

Ultrasonic sensors are mostly considered for identifying the distance; the technical specifications of this sensor are given below

- Operating Voltage: 5V
- Static current: 2mA max
- Induction Angle: 15°
- Detection Range: 2 – 400cm
- High precision up to 3mm

FIGURE 1. Ultrasonic Ranging Module HC - SR04.

Every Ultrasonic sensor consists of 4 pins, namely, Vcc (5V), Trig, Echo, and GND (Figure. 1). Trig (trigger) aims towards sensing an ultrasonic high-level pulse for at least 10μs and the Echo pin then automatically detects the returning pulse. It also encompasses the capability of measuring the distance by calculating the echo between the sending times to the return time using the formula

$$Distance = (Time\ for\ wave\ to\ return * Speed\ of\ sound)/2 \tag{1}$$

B. VIBRATOR

A vibrator (Figure 2) is a mechanical device to generate vibrations and is mainly used to generate vibrations when the blind person is also a deaf. The vibration is often generated by an electric motor with an unbalanced mass on its driveshaft.

FIGURE 2. Vibration motor, 3 V, 150 mA, 10,000 rpm.

We use VM 0610 A 3.0 Vibrator motor operating on 3V 150mA, capable of 10,000 rpm and measures only 6mm in length. It is user-friendly motor, which can be used with a variety of products. This includes pagers, GPS devices, mobile phones or even toys.

C. SENSOR RANGE

The sensors that are considered for this article can identify the objects within the range of 3 meters and are capable of identifying the objects towards the angle of 90 degrees. In the present article, the recognition of an object is carried out by estimating the distance between the sensors. The distance is identified using the two sensors in such a way that if the value of the first sensor is higher than the other sensor it is estimated as an object. The ultrasonic sensors are attached to the PVC pipe to enhance the capturing scenarios and low pass filters are used for this purpose. Several features can be extracted using these sensors, such as mean and standard deviation. Courtesies helps to estimate the ascending and descending steps more accurately.

Several researchers have employed these sensors to augment the functionality of white cane used by visually challenged [15]–[17]. The works presented are mostly focused towards the detection of the object along with the distance, without giving the importance about the nature of the object, which in certain cases may be more significant to the user. The majority of the works developed in this regard are confined towards the identification of the objects basing on statistical approaches, where the data is classified into four types namely edge, plane, corner and cylinder [27]. Some systems were also developed with an aim to identify the activity of the people based on the trajectory that helps to classify the scenes as the indoor or outdoor [28]. Moreover, these systems cannot identify the manholes and descending staircases exactly.

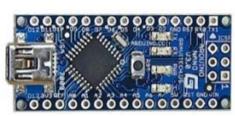

FIGURE 3. Arduino Nano 3.x board used.

D. ARDUINO

It is an open source software, which is developed by using single-board microcontrollers and microcontroller kits during the development of digital devices and interactive objects, which can sense and control objects (Figure 3). Arduino boards [29]–[32] are designed based on an array of microprocessors and controllers. These boards are embedded with a set of pins which are primarily used for the digital input and analog output (I/O). These pins can be interfaced with the variety of expansion boards (shields) and other circuits for establishing both serial communications interfaces, along with Universal Serial Bus (USB). The pre-programmed boot loader is mostly used in Arduino microcontrollers which assist during the loading of programs to the on-chip flash memory. A serial connection is considered while loading the programming codes to another computer.

HARDWARE FEATURES

- Microcontroller: ATmega328
- Operating Voltage: 5 V
- Flash Memory: 32 KB
- Clock Speed: 16 MHz
- Analog IN Pins: 8
- Digital I/O Pins: 22

FIGURE 4. Bluetooth V2.0+EDR Chip.

E. HC-05 BLUETOOTH

In order to carry out the wireless serial connection Bluetooth HC-05 module (Figure 4) is considered [19], [33] in this work. The reason for the usage of this Bluetooth module is that it establishes a master-slave configuration (by default it works as a slave and can be configured by AT commands to behave either as master or slave) which aids in better transmission during the wireless communication process. Another advantage for the usage of this Bluetooth module is that it uses a 2.4GHz radio transceiver and baseband, which enhances the data rate as it integrates Bluetooth V2.0+EDR with 3Mbps Modulation. This chip consists of an Adaptive Frequency Hopping Feature with CMOS technology.

1) HARDWARE FEATURES

- Typical −80dBm sensitivity.
- Up to +4dBm RF transmit power.
- 3.3 to 5 V I/O.
- PIO (Programmable Input/Output) control.
- UART interface with programmable baud rate.
- With integrated antenna.
- With edge connector.

2) SOFTWARE FEATURES

- Slave default Baud rate: 9600, Data bits: 8, Stop bit: 1, Parity: No parity.
- Auto-connect to the last device on power as default.
- Permit pairing device to connect as default.
- Auto-pairing PINCODE: "1234" as default.

3) PIN DESCRIPTION

The HC-05 Bluetooth Module has 6pins, significant among them are highlighted below

a: ENABLE

Communication channel fails when the enable is pulled LOW. When enabler is left open or connected to 3.3V, the communication establishes and will be communicating with other processors as long as this module remains in the HIGH position. The various commands are processed using the second pin, Vcc indicating supply of voltage and GND indicating the Ground Pin. It also uses two other pins meant for UART interface communication namely TXD and RXD.

b: STATE

It acts as a significant needle by which the process of the signal can be understood. The status of the signal is indicated as low, whenever it gets connected to another Bluetooth device. At this point, the status of the signal specifies HIGH and simultaneously whenever a LED light flashes, it indicates that the pairing has not been established. When the module is not connected to another Bluetooth device or paired with any other Bluetooth device, the signal goes Low.

c: BUTTON SWITCH

In order to establish a connection for transfer of data between the Bluetooth, first of all, the switch module in the Bluetooth device is to be set in enable mode, which is possible using AT commands. Figure 5 and Table 1 depict the schematic diagram of the connectivity of the pins.

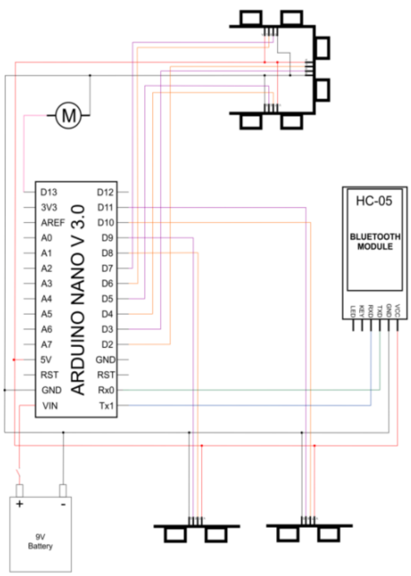

FIGURE 5. Schematic diagram.

III. IDENTIFICATION OF MAN HOLES

In order to identify the manhole, in this article, we have developed a hybrid method using the threshold values; the architecture of the recognition procedure is given in figure 6.

TABLE 1. Pin connectivity.

Arduino Pins Used	Connected Device Pin
D2	Trigger Pin of Front Sensor
D3	Echo Pin of Front Sensor
D4	Trigger Pin of Right Sensor
D5	Echo Pin of Right Sensor
D6	Trigger Pin of Left Sensor
D7	Echo Pin of Left Sensor
D8	Trigger Pin of Bottom-Rear Sensor
D9	Echo Pin of Bottom-Rear Sensor
D10	Trigger Pin of Bottom-Front Sensor
D11	Echo Pin of Bottom-Front Sensor
D13	Vibrator
Rx	Tx of Bluetooth
Tx	Rx of Bluetooth
5V	Common +5V to all Devices
GND	Common Ground(-) to all Devices

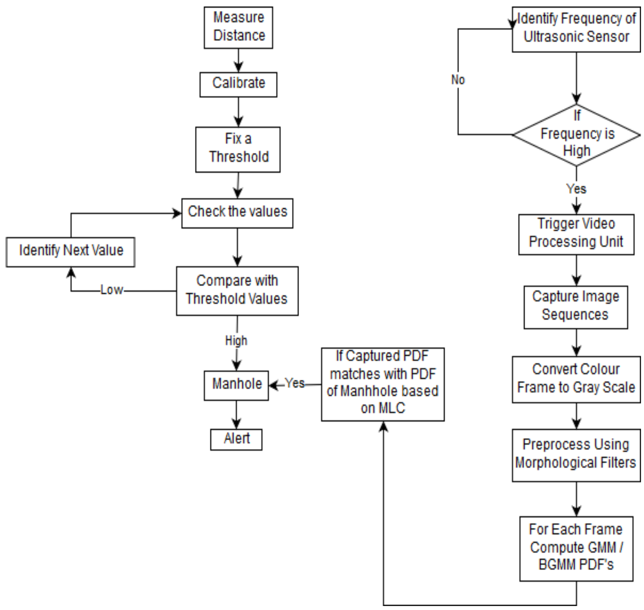

FIGURE 6. Architecture of the manhole detection.

The manhole sensor facing towards the ground is attached at the bottom of the stick. It reads the signals from time to time and whenever a vacuum is identified, it reflects the signal back through the ultrasonic waves. This vacuum is then converted into distance by considering following distance formula where speed of sound in air = *340 m/s*.

$$Distance = (speed * time)/2 \qquad (2)$$

Initially, the value of distance is divided by 2 as it is a summative distance since the ultrasonic wave travels back and forth from source to the receptor after hitting the target.

TABLE 2. Estimation of the threshold value.

Estimating the threshold value for different inputs (chosen randomly)	Threshold Values (cm) (after calculating the average value)
6,9,8,12,11,19,10,8,7, 5	9.5
3,6,9,8,7,13,12,18,15,5	10

A. THRESHOLD VALUES

A threshold value is set and is compared with the distance value. If the distance value is above the threshold (Table 2), it is considered as a manhole, else it is not. Manhole detection calculation involves the threshold value considering the various patterns of holding the stick (it is assumed that every individual holds the stick in different ways), which is then used for detecting a manhole on the user's path.

Assuming that a single value may mislead the setting of the threshold value, a sequence of ten values are recorded by considering the stick positions in different angles in front of the manhole and calculating the distance. The average value is computed using the formula depicted below.

$$Avg - value = (sum\ of\ 10\ values)/10. \tag{3}$$

The process is repeated at random several times and the maximum average value recorded is set as the threshold.

$$Threshold = maximum\ among\ the\ avg - values. \tag{4}$$

The Arduino processor helps in estimating the distance from the ground in each and every loop, and the readings of the ultrasonic sensor are computed and compared with that of the threshold values. Any value that is above the threshold value indicates the possibility of the presence of a manhole ahead of the user and the Arduino sends a value to the Android application to warn the user.

The android application is considered for alerting the user about the various signals received from the sensors. When a manhole or an obstacle is identified, a text voice is generated to alert the user and also generates a vibration sound so that the deaf person can also get an alert. The developed app also helps to provide the user with the position of the manhole (front, left or right).

TABLE 3. Estimation of the manhole.

Status	Output	Distance from ground	Result
Manhole present	"Manhole detected"	10	accurate
Manhole not present	"Manhole detected"	12	error
Manhole not present	no output	9.5	accurate

Table 3 depicts the estimation of a Threshold value for Manhole detection. The performance of the system is tested using Metrics like precision, Recall and F-Measure and the Formulas for calculating the above are given by

$$Precision = TP/(TP + FP) \tag{5}$$

Where TP denotes total number of manholes correctly classified and FP denotes wrongly classified manholes. The formula for Recall is given by

$$TP/(TP + FN) \tag{6}$$

Where FN denotes the Manholes being not detected. F-Measure is calculated using the formula

$$(Precision * Recall)/(Precision + Recall) \tag{7}$$

B. THRESHOLD IDENTIFICATION BASED ON MEDIAN VALUE

The ultrasonic sensor activates whenever it receives the pulse of 10 ms. It has two transducers; one for transmitting and second for getting the reflected waves, if the frequency of the received wave is high, the voltage divider embedded triggers the video processing unit, which starts capturing the image sequences, filtering process removes the noise and then attribute extraction is considered for object identification. In this process, the ultrasonic sensor transmits continuous signals upon the recognition of an object, a beep sound along with vibrations will be generated and automatically the camera attached to the model gets converted into video mode and starts capturing the video sequences. If the frame intensities remain stationary then the object is considered as stationery and if there is any change in frame intensity it is considered to be a moving object. The increase in the frame size confirms that objects are approaching, else moving away. In our present article, we confine to manhole identification, so only stationery objects are taken into account.

During the course of video acquisition, the color frames are changed into grey scale as intensity measurements act well in grey scale. In order to conquer the unexpected environment intensity changes, we compute the mean of every frame. We then take the average of the frames as the reference frame and compare it with the current frame to set the background and the foreground

Threshold based techniques also help to identify the background and foreground. If the computed threshold value is greater, it is assumed to be foreground else background, generally we assign the values 0 and 1 for this purpose. We manually select the threshold value. If the image is free from noise and having a uniform back ground, then median can be chosen as the threshold value.

If the camera is in motion we need to capture the object more precisely. Because the blind persons cannot stay steady, some movement is generated automatically and this movement can cause an error during object detection. In order to overcome the error, a morphological filter is considered. The morphological filter helps to remove the unwanted pixel value so that the exactness in identification is possible. The morphological closing operation is considered and applied to the structural element B, Such that $A \cdot B = (A \ominus B) \oplus B$, where the structuring element B is given by the following 3×3 matrix:

0	0	1
0	1	0
1	0	0

For accurate classification and identification of the manhole, the Gaussian Mixture Model (GMM) model is considered. The main objective behind the consideration is that, in any image under consideration, there will be finite number of Grey-level probability density functions, say 'k', and each pixel distribution can be modeled by one Gaussian function which represents one object in the image. With this assumption, the whole image can be modeled by a mixture of 'k' component Gaussian distributions in some unknown proportions π_i, $i = 1, 2, 3, \ldots, k$. The probability density function of the model is given by

$$f_i(x/\theta) = \sum_{i=1}^{k} \pi_i f_i(x_i/\theta_i) \tag{8}$$

Where x_i denotes the image pixels, π_i denotes the mixing weight, such that

$$\sum_{i=1}^{k} \pi_i = 1 \tag{9}$$

Here θ represents the parameter set and is given by $\pi_1\pi_2 \ldots \pi_k, \theta_1, \theta_2 \ldots \theta_k), f_i$ denotes the density function of the Gaussians parameterized $by\ \theta = (\mu_i, \sigma_i)$.

The database of manholes is considered as input and each of these images is modeled using the GMM, and the corresponding probability density functions are stored. Whenever the blind person navigates through the road and encounters an object, automatically the camera captures the image and processes the image. The image is clustered and the PDF of the image is obtained and based on the maximum likelihood estimate, the nearest match with that of the images in the database, a warning message is sent back to the blind along with vibrations, so that the blind person can understand that there is some obstacle ahead and he needs to be alert.

IV. STAIRCASE DETECTION

We use dual strategy to identify both ascending and descending staircases - Image based strategy for identifying staircases and ultrasonic sensor based strategy for actually navigating through the staircase.

A. SURF BASED STAIRCASE DETECTION

Since we use the camera on the mobile device, we rely upon monocular vision based approaches rather than stereo or depth sensor. In order to sense the background, Monocular Vision Based Approaches use techniques like texture segmentation [5], motion and ground plane recognition [12], inverse edge detection and identifying concurrent parallel lines [13], etc. However, in practice, ground plane detection is mostly preferred because of its simple features. Ground plane detection, segments every image into two partitions based on the features as ground and non-ground. The non-ground planes are further categorized into staircases or objects.

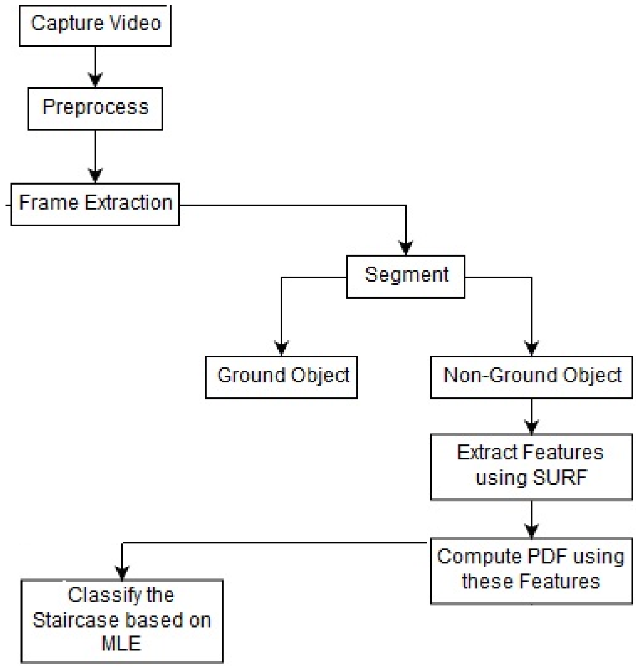

FIGURE 7. Methodology for identification of staircase based on BGMM.

The image is separated into two regions: ground and non-ground, by using the segmentation process. The possibilities of additional obstacles are checked in the non-ground region. Feature extraction process is utilized for obstacle checking. Many feature extraction models are listed in the literature [27], [28], among these methods, in this article we have considered the SURF (Speeded up Robust Features) method because of the advantages like illumination, rotation, scale and computational simplicity. The features are extracted based on the attributes like blobs, corners, etc. The features of non-ground image features are considered for the differentiation of ascending staircases and descending staircase.

Figure 7 describes the basic steps used in staircase detection, which includes video as an input and then preprocessing is done to select the high quality frames followed by segmentation and feature extraction. Segmentation divides image into two parts: ground plane and non-ground plane. Here non-ground plane will be checked further for the ascending stair case and descending stair cases. The shape of the steps and distance are considered as features, which we extract using SURF algorithm [34]. These features are useful to decide whether a staircase is ascending or descending. These features are given as the input for the Bivariate Gaussian Mixture Model [20], [21], [35] that estimates the probability density function (PDF). The PDF of both ascending and descending staircases is also considered and based on the values of the PDF, the peak is estimated and the alert is generated and is passed as a message to the visually impaired.

B. BIVARIATE GAUSSIAN MIXTURE MODEL

BGMM classifier has the ability to work with data in high dimensional space and handling of bivariate features.

TABLE 4. Manhole detection results.

CONFUSION MATRIX		OUTPUT: Manhole	OUTPUT: Not Manhole
INPUT	Manhole	**92.50%**	**7.50%**
INPUT	Not Manhole	**11.70%**	**88.30%**
Accuracy			**0.90**
Precision			**0.93**
Recall / Sensitivity			**0.89**
Specificity			**0.92**

Hence it helps to identify the steps which are ascending and descending more accurately.

The probability density function of the pixel intensities is given by

$$f(x_1, x_2) = \frac{1}{2\pi\sigma_1\sigma_2(\sqrt{1-\mathrm{p}^2})} \times e^{-\left[\frac{1}{2(1-\rho^2)}\left[\left(\frac{x_1-\mu_1}{\sigma_1}\right)^2 - 2\rho\left(\frac{x_1-\mu_1}{\sigma_1}\right)\left(\frac{x_2-\mu_2}{\sigma_2}\right)+\left(\frac{x_2-\mu_2}{\sigma_2}\right)^2\right]\right]} \tag{10}$$

Here μ_1, σ_1 are the mean and variance of the image with first features and μ_2, σ_2 are the mean and variance of the image with the second features, ρ is called the shape parameter such that $-1 <= \rho <= 1$.

C. ULTRASONIC SENSOR BASED STAIRCASE DETECTION

While the image based method alerts the presence of upward or downward staircase, precise control is needed for actual navigation through the staircase. In order to assist the visually impaired during the identification of staircase, we employ two ultrasonic sensors that can distinguish horizontal floor planes and variation of depth of these planes in case of downward staircase and presence of vertical plane in case of upward staircase. This system is built using a PVC plastic and the ultrasonic sensor which captures the signals in the form of a frequency curve, this system is developed by using an Arduino processor which acts as a processing unit for better identification. A Bluetooth device is also associated with the device so that the data can be captured and communicated to a mobile device that can provide auditory feedback in conjunction to vibro-feedback driven by the Arduino board.

V. EXPERIMENTS AND RESULTS

The developed stick can be more helpful to the visually impaired to navigate safely both indoor and outdoor. It yields excellent results in sensing the obstacle on the path of the user up to a range of three meters. The key features of the proposed system are low cost, reliability, and portability. Despite the fact that the system is equipped with sensors and other components, the PVC stick utilized for this work weighs around *600 grams*. During the experimentation process, it is observed that, whenever the sensor identifies a hollow signal, sensor gets activated and generates an audio signal announcing that a manhole is ahead. The experimentation is repeated using GMM also and the results are depicted in the Figure-9. The procedure is repeated in case of identification of staircases and in this case, BGMM is considered and basing

FIGURE 8. Inputs of manholes.

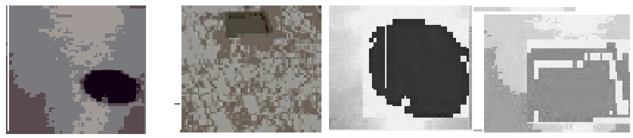

FIGURE 9. Segmented Outputs of Manholes using GMM.

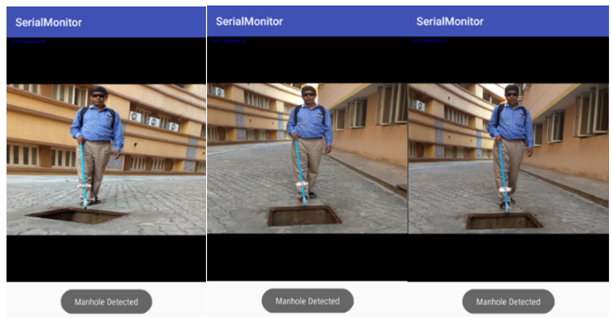

FIGURE 10. Manhole detection using the sensors mounted on the stick.

TABLE 5. Classification rates for detection of staircases and floor.

		OUTPUT: Floor	OUTPUT: Ascending Stairs	OUTPUT: Descending Stairs
INPUT	Floor	**82.0%**	**6.0%**	**12.0%**
INPUT	Asc. Stairs	**5.3%**	**93.7%**	**1.0%**
INPUT	Desc. Stairs	**5.1%**	**7.9%**	**87.0%**
Accuracy		**88%**		

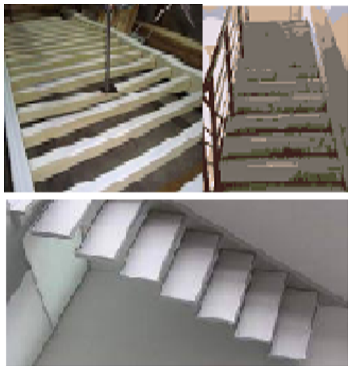

FIGURE 11. Inputs of upward and downward staircase.

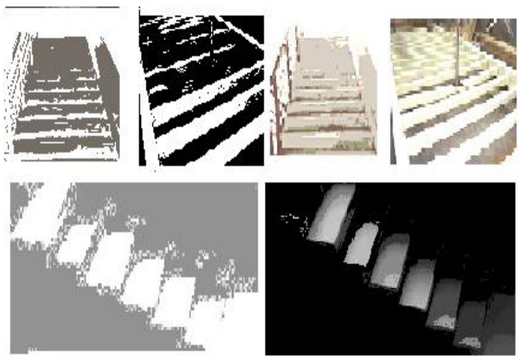

FIGURE 12. Segmented outputs of staircases using BGMM with SURF features.

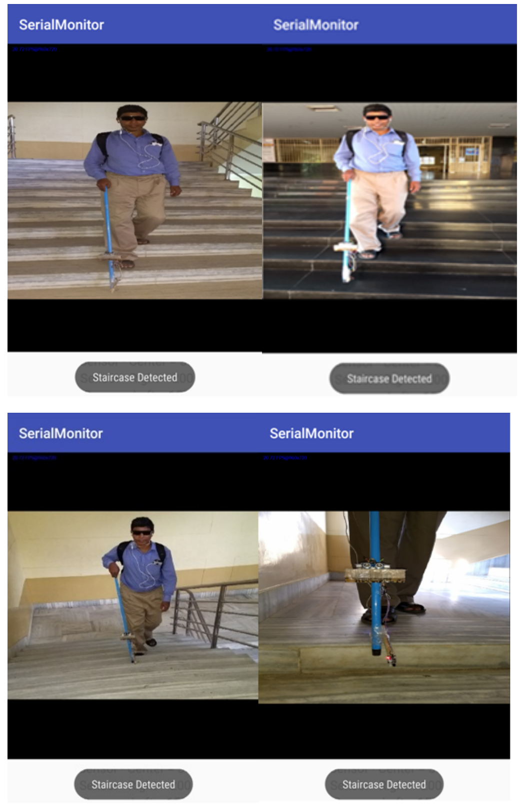

FIGURE 13. Staircase detection using stick descending staircase (top). Ascending staircase (bottom).

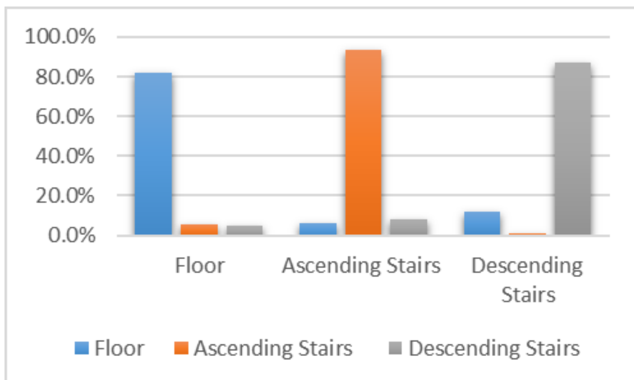

FIGURE 14. Performance of staircase detection in percentage.

the Maximum Likelihood criteria, the ascending or descending staircases are identified and the subsequent alerts are generated.

Table 4 shows the performance of manhole detection. Figures 8-10 illustrate the scenarios where manhole is successfully detected from various angles and corners. It can be observed from the results that the false positive rate and false negative ratio values are very less, which signifies the efficiency of the proposed development.

For staircase detection based on Bivariate Gaussian Distribution, our training set consists of 74 downstairs, 82 upstairs, and 62 negative training samples. These are randomly collected samples which are selected for subset classification. For the purpose of testing, we have considered 52 downstairs, 40 upstairs, and 46 negative samples, in total 138 samples were considered for the classification purpose. We have tested for estimating the accuracy of the classification model with respect to ascending and descending staircase recognition and also the efficiency in differentiating the ground and non-ground planes, the results derived are presented in Table 5. These results showcase the performance of the system in recognition of stair cases and suggest that this method can be practically implemented in the real world situations. Figures 11-14 depict the results of staircase detection.

Our work shows precision of 93.7% for ascending staircase and 82% for descending staircase as compared to 84% of the stereo image based method in [7]. Similarly our manhole detector shows a precision of 92.5% as compared to 80% for image based manhole detection presented in [35].

VI. CONCLUSION AND FUTURE WORK

The principal objective of this paper was to build up a low-cost prototype of a stick for visually impaired persons, for helping them in proper identification of manhole and staircases. In this article, a novel work is presented for the identification of the manholes and staircases for the visually impaired people using threshold-based system from data obtained through unique arrangement and placement of ultrasonic sensors for effective identification of manholes and staircases. We also trigger image based method to determine median based threshold value for identifying manholes using Gaussian Mixture Model. Furthermore, we present novel way of extracting features using SURF algorithm identification of ascending/descending staircases based on Bivariate Gaussian Mixture Model. The hybrid model not only informs the presence of manholes/staircases but also helps navigate them by real time vibration and audio alert feedback. The proposed device has been shown to work well within the budget and has achieved its major objectives – to be affordable and simple.

The developed model complemented by using the metrics like Threshold based, Precision, Recall, and F-Measure showcase good recognition accuracy. These results indicate that this method can be practically implemented in the real world situations.

The recognition accuracy of the developed models is tested against distance estimation and recognition towards the identification of ascending and descending staircases. The performance varies when we are facing an ascending staircase or a descending one. Due to the direction of the sensor, standing before a descending staircase permits us to have an overview of the entire staircase, however, due to the self-overlapping of successive steps, there will be some deviations with respect to the measurements.

Relatively, in case of ascending staircases, the proportion of uncovering reduces, since the steps stay very much close to the individual during mounting the steps and hence the recognition rate increases.

To further improve accuracy, in particular of descending staircase, we plan to use the concept of skewness and kurtosis in future. Staircases are symmetric features suggesting skewness to be less. Furthermore, perspective distortion will lead to positive kurtoses of the features outlines. Positive or negative distances can determine ascending/descending staircases and help improve accuracy of the system further.

As an extension to the work, a system need to be developed that helps the visually challenged by providing routes, mental maps which may be adequate to direct the person to the destination without any need of the navigation aid. It is also necessary to develop the system in such a way that the depth of the water can be identified using the sensors. Such system can help visually challenged to walk through during the rainy days.

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SREENU PONNADA received the B.Tech. degree in computer science engineering from the Maharaj Vijayaram Gajapathi Raj College of Engineering (affiliated to JNTUK), Vizianagaram, India, and the M.Tech. degree in computer science engineering from the Avanthi's St. Theressa Institute of Engineering and Technology (affiliated to JNTUK), Vizianagaram. He is currently pursuing the Ph.D. degree in computer science engineering with GITAM University, Visakhapatnam. He has over three years of teaching and research experience. He is currently an Assistant Professor with the Department of Computer Science and Engineering, Vishnu Institute of Technology, Bhimavaram, India. He has contributed to over seven international and national publications in the areas of artificial intelligence and mobile networks. He is particularly interested in image processing and assistive technologies involving both hardware and software components to assist the visually challenged in their daily activities.

SRINIVAS YARRAMALLE received the Ph.D. degree in computer science with a specialization in image processing from Acharya Nagarjuna University, Guntur, India. He has 22 years of teaching and research experience. He has guided 18 students for Ph.D. and is currently guiding eight scholars for Ph.D. He is currently a Professor with the Department of Information Technology, GITAM University, Visakhapatnam, India. He has published over 50 papers in various reputed international journals and conference. His current research interests are in the areas of image processing, knowledge discovery and data mining, computer vision, and image analysis.

MADHUSUDHANA RAO T. V. received the M.Tech. degree from JNT University, Anantapur, India, the B.Tech. degree from JNT University, Kakinada, India, and the Ph.D. degree in content based image retrieval from the Department of Computer Science and Engineering, JNT University, Kakinada. He is currently an Associate Professor with the Department of Computer Science and Engineering, Vignan's Institute of Information Technology, Visakhapatnam. He has published over 10 papers in national/international conferences and journals. His research interests include image processing, knowledge discovery and data mining, computer vision, and image analysis.