ISSN 2347 - 3983
Volume 8. No. 9, September 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter68892020.pdf
https://doi.org/10.30534/ijeter/2020/68892020

Smart Navigation System with Pavement Hole Estimation using Clustering Technique

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ABSTRACT

The rise in automobile industry revolutionized the Indian economy in short time. It has become one of the trivial factors for the country's growth economically. Automobiles have made their impact on betterment of the living society by being used as street washers. Automation of such vehicles results in less traffic, reduced emissions with a better transportation service. As the vehicles communicate and share information among each other, preventing the damages and public safety are ensured. Self-driving cars and connected cars have become a great area of interest and are expected to lead the automobile industry. The main aim of our work is to integrate the idea of connected car with the road infrastructure. In this paper, the system presentsthe technique that visualizes the obstacle environment in a simplified wayto extract the best outcome for monitoring the road infrastructure with clustering technique to facilitate in a better way.

Key words: Cluster,Depth, External Pi camera, Open-CV, Raspberry Pi.

1. INTRODUCTION

A smart vehicle that aims to progress the transport system have increased rapidly for peopel common use. The rapid development in technology advancement have resulted in a substantial influence on the traditional transportation system. The automation industry have expanded their innovations by introducing the automation into the conventional vehicles. As a result, there is huge revolution in the self-driving cars and connected cars. According to Grand view research, the connected car demand is forecasted to be 4.2 million by 2030 globally and by 2027,it will reach USD 212.7 billion with 22.3% of Compound Annual Growth Rate(CAGR) of as shown in figure1. Primarily, the self-navigation vehicles need an accurate prediction of the surrounding environment so as to ensure the safety of the public by preventing road accidents. Road accidents are another fundamental concern while introducing the smart vehicles. Deterioration of infrastructure such as roads that are constructed long back is the current problem in India. There is a requirement of efficient monitoring of the road infrastructureso as to ensure citizen's safety. The pavement infrastructure needs to be effectively monitored without any humanintervention. There has been drastic increase in road accidents due to poor infrastructure. If vehicles are becoming smarter, the roads should also become smart and therefore roads also need to be monitored and managed.

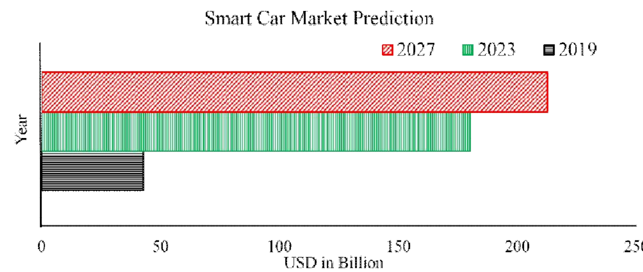


Figure 1: Market Prediction of smart car demand.

According to World Health Organization(WHO), roadaccidents are major problem as road crashes kill more than 1.25 million people, Injuries about 50 million people in a year, 90 percent of such casualties occurring in developing and advanced countries [1].In state wise Ministry of Road Transport and Highways noted number of persons injured rate death rate including pothole numbers from the year 2015 to 2017 are shown in figure 2 [1].

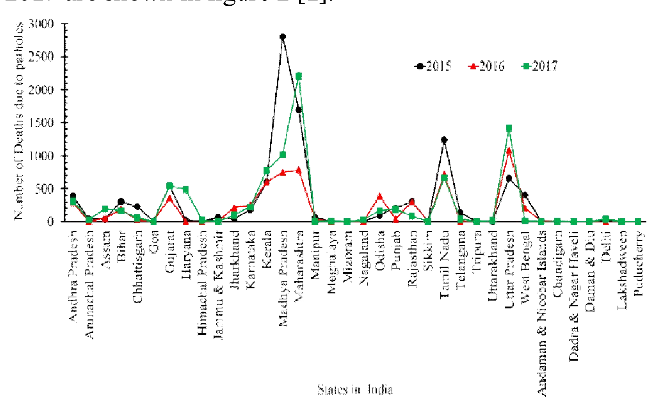


Figure 2: Number of persons injured or classified under the category of potholes from 2015 to 2017.

Worn out infrastructure of roads can lead to accidents and disasters on roads. As numbers of cars and trucks pass on the weak spots of theroad, surface damage is further increased.Estimating the damage of roads may prevent accidents which leads to the reduction of death casesand damage of automobilesproperty of nation [2].Damaged roads lead to accidents and that may lead to deaths [3].The road users feel uneasy using bumpy roads and moreover the holes present on the pathway have become a huge matter of concern.
Hence, driver's safety may be secured by introducing a real-time hole prediction system by sharing the report regarding potholes [4].Movement of heavy vehicles on roads and highways causes for pothole creation that leads to damage of vehicles, causing accidents and also need affluent repairs. There were many works on this method previously. Counting, tracking and detection from the video surveillance uses the technique of segmentation with primarily using the background subtraction method and morphological operations in order to estimate the prominent areas [5]. All those techniques were limited either to navigation or pothole detection. The method proposed here not just focusses on avoiding the obstacles but will also monitor the road infrastructure in parallel. This paper offers an inexpensive and effective way of estimating the area of the holes on roads using image clustering technique.

The technique uses a Kinect sensor and external camera to transform conventional vehicle into smart vehicle. It has produced great results already. This method is quick as it does not involve any complex computation, so the pavement holes are analyzed at that instant. In this paper, few methods of previous works are embedded to advance a new method and perform real-time processing for road infrastructure monitoring. In real-time environments, the obstacles might be misinterpreted by just classifying those using RGB data. In this method, classification technique works using pixel intensities as data points that first segment the frame into several clusters with similar pixel intensities. Use of such technique becomes easy as the complexity of hardware and computations are avoided.

2. LITERATURE REVIEW

Most of the previous works uses the sensor equipment for object detection. Lagisetty Ravikumar et al. [5] uses a stereo camera to get a three dimensional view of the environment. Stereo matching algorithm is used in this method to find the resemblance between the former and the latter frames. Feature detection technique and triangulation method are used for obstacle avoidance and least square technique is used for posing estimation by constructing a 3D frame. This method works only if the destination is known. Karthi Balasubramanian et al. in [6] used sonars and hough transform method to detect the objects. Machine vision picks up color by ignoring other objects. The averaging of pixels is done to isolate the required color pattern. Modified H-bridge circuit along with DC motors is used for navigating the robot. This method incurs loss when the wave is emitted from different directions. Alajlan et.al.in [7] used 2D- LIDAR with nine ultrasonic sensors. Increase in the hardware equipment will lead to complexity of the navigation device as this makes the model less flexible and portable.Gunjan Chughand Divya Bansalin [8] made a survey on different sensors to detect honking and bumps. The survey involved different sensors such as 3-axis accelerometer, camera, magnetometer and their challenges have been referred. Challenges such as vibration pattern, privacy attributes, location errors are addressed. They also suggested to use machine learning techniques rather than conventional thresholding methods. Emir Buzaet al. [9] proposed a spectral clustering method for pothole identification which is a density based detection technique to find the similarity matrix. The seeding method is for thresholding the detected pixels. Image segmentation and clustering finds the top seeds and extract the horizontal and vertical properties. Dhiman and R. Klette in [10] studied the pavement stress using Support Vector Machine (SVM) algorithm. Thi-Lan Leet et al. in [11] uses the depth-based obstacle interpretation indoors for visually impaired as the Kinect also works using voice commands. This feature is efficient for navigating the users. AntonioS et al. in [12] used Kinect for surveillance of the objects around it. As the Kinect is built with voice command. Most of the obstacle avoidance algorithms work on a sensor such as radars, laser range finders, sonars [13]. Rasoul Mojtahedzadeh in [14] used Kinect for daily life robot assistance. This technique is used to build vacuum cleaners or any other robots to do the household chores. He used OpenNI framework to implement this model. Kitsunezaki, Naofumi et al. in have used Kinect to perform physical rehabilitation tests such as 10-meter walk, motion measurement on the patients by using IR and depth data[15].

3. PROPOSED WORK

The method proposed in this paper is classified into two parallel processes: navigating the automobile by using the three-dimensional point data and monitoring the road infrastructure to estimate the path-hole filling material scale. Kinect Obstacle detection can identify characteristics of the obstacle [11]. Figure 3 is the layout of the proposed work that uses Kinect sensor and external camera working in parallel to locate path-hole and share requisite data.

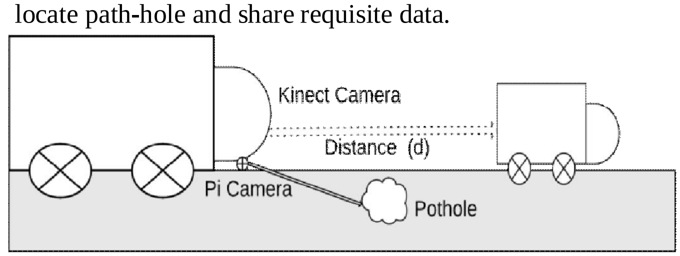


Figure 3: Cartoon model of proposed system.

3.1 Hardware Requirements

The hardware part involves connecting Kinect camera and pi camera interafacing to Raspberry pi.The hardware components interafaced to controller are shown in figure 4(b).

- Kinect Xbox 360 has an RGB camera with 640 x 480 pixel resolution and a 24-bit color range that runs at 30 frames per second (FPS) is used for point cloud based navigation model. It has a horizontal field of view which is 57^0wide and vertical field of view which is 43^0. As the depth camera can see 65 k gray shades, it can visualize the obstacle distance more precisely. It has 16-bit sensitivity and the depth feed is 11 bits.

- A Pi camera with 1080 pixels with 3.6 mm wide camera lens is used for monitoring the pavement infrastructure.
- The proposed model uses Raspberry Pi4 as a controller unit with a USB 3.0 port. It works on Raspbian operating systems installed in a 16 GB SD-card.
- Skg13BL model GPS module operating with VCC 3 volts is used to locate the geo position of the automobile.

4. METHODOLOGY

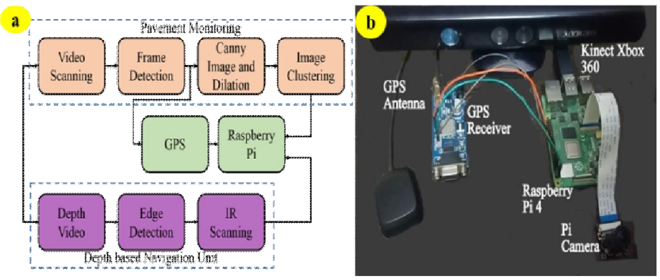


Figure 4: Proposes system (a)Block Diagram, (b) Prototype model.

The block diagram is divided into two units as shown in figure 4(a).The proposed model uses two different computations. One for pavement monitoring which involves frame extraction with contour method, Image clustering for analyzing the potholes and the other computation method for navigation using three-dimensional technique. The Contour method that is used for frame extraction distinguishes the non-pavement pixels with the pavement pixels. This step is used to grab the required frame from the streaming video. Figure 5(a) is the contour of the hole detected on the pavement and figure5(b) is the identified non-pavement pixel. Figure 5(c) is the final image grabbed that will be used for further processing.

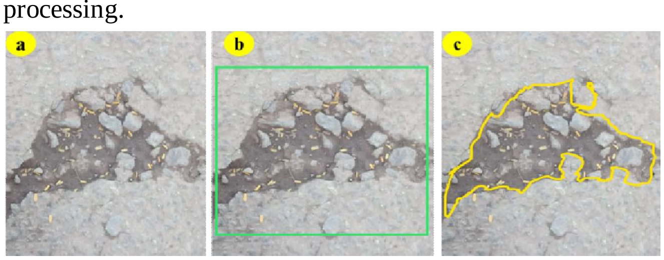


Figure 5: Video Processing of pavement holes,(a)Contour detection, (b)Hole detection, (c)Frame grabbed.

4.1 Image Clustering

The previous step results in a required frame from the video.The aim of the following step is to segment the pavement hole image and extract the corresponding pixels of that hole. This segmentated images are then undergone into morphologiacl operations so as to remove the unwanted edges from the pothole frame. In this paper, Improved K-means is the method used for image clustering. It is a centroid based algorithm or can be said as an algorithm based on distance where the distances from each data point to centroid are calculated to assign a point to a specified group cluster. It is competely similar to K-means clustering except for random initialization of centroid. The distance between the each data point and cluster are found using Euclidean Distance calculation. The Euclidean distance is given as:

$$\text{Distance(D,C)} = \sqrt{(Dx - Cx)^2 + (Dy - Cy)^2} \quad (1)$$

Where D_x,$D_y$is the X,Y coordinates of data points which are pixel intensities in a pothole image and Cx,Cy are the X,Y coordinates of the centroid of each cluster.

K-means is an iterative algorithm which partition the data into sub groups called clusters.In this work, the clustering is performed on the pothole intensity pixels and each pixel has three different dimensions namely red (R), green (G) and blue (B). The vector representation of pixel is shown in equation (2).

$$P_x = |R, G, B| \quad (2)$$

The cluster complexity is represented in equation (3).

$$C = K*N*L*T \quad (3)$$

Where N is total data points of pothole frame, K represents clusters required for pixel intensities, L is the length of vector Px, T is the iteration count.Figure 6(a) is the pothole image on road which is then clustered based on the pixel intensity using Improved K-means clustering technique. The image segmented is shown in figure 6(b).

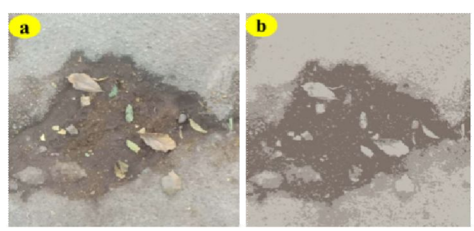


Figure 6: Clustering technique applied on pothole (a)Pothole image, (b)Segmented Pothole.

For the pothole seen in figure 6, the cluster size is considered as three. The Euclidean distance between data point and centroid are calculated. The data point that has minimum distance from the centroid is assigned. Table 1 is the gist of clustering technique.

Table 1: Assigning data points to cluster using Euclidean Distance Method.

S.no	Data Points	Euclidean Distance from Data point to Centroid1=(124.80,113.98)	Euclidean Distance from Data point to Centroid2=(166.07,159.34)	Euclidean Distance from Data point to Centroid3=(193.27,192.39)	Assigned Cluster
1	75.41,70.50	65.80	126.93	169.55	C1
2	161.16,151.65	52.37	9.12	51.87	C2
3	101.04,110.39	24.02	81.39	123.41	C1
4	223.26,219.03	143.97	87.45	40.11	C3
5	53.72,45.75	98.52	159.76	202.42	C1
6	256.78,261.62	198.03	136.70	93.94	C3
7	159.19,199.78	92.43	41.02	34.87	C2
8	132.58,157.15	43.86	33.56	70.17	C2

The plot obtained on applying clustering on the segmented image with the corresponding centroid value marked is shown in figure 7. This method is observed to be more robust as the holes on the pavement does not have any fixed shape and hence classifying them based on intensities is more reliable.

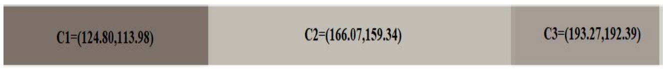


Figure 7: Resultant cluster of pothole image.

4.2 Pavement Hole Analysis using pixel conversion

The holes on pavement might be caused due to several factors such as negligence during the construction, due to natural calamities and overloading. This paper describes a method where the hole area on the pavement can be calculated. The cluster size of the detected pothole being used is three. As we are already getting the eagle view of pothole, dominant intensities will utmost be three.

Equation (4) represents the pixel area associated with the corresponding cluster. The area obtained will be in square centimeters.

$$A = Pi * (2.54 / R) \qquad (4)$$

Where A is Area of single Cluster in centimeter square, Pi is number of pixels in corresponding cluster, R is number of dots per inch of the pi camera.

4.3 Kinect video streaming

The Kinect depth sensor integrated with IR projector and a monochrome CMOS sensor will help in creating a 3D view of the obstacle. “Time of flight” method is used for calculating the obstacle distance from the camera, which helps in estimating the accident risk [21].

The Kinect camera visualizes the surrounding environment using 3D point cloud as shown in figure 8.

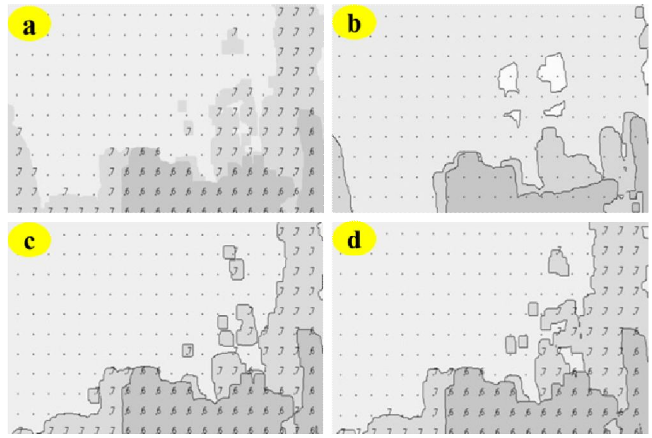


Figure 8: Visualizing the obstacle environment (a)Depth Image of environment, (b)Edge Detection of depth image, (c)Image Binning, (d)Eroded image.

5. IMPLEMENTATION

Raspberry pi4 with 3.0 as USB port is used. A GPS module is fitted to raspberry pi to get the geographic location of the automobile.

- Depth based navigation unit is used for navigating the automobile using time of flight technique [19] and Canny detection is used for motion detection in Kinect to even detect the low luminous edges.
- Pavement monitoring unit uses Pi camera to stream video continuously and clustering technique to analyze the infrastructure and potholes. Both the units run in parallel for faster computation.
- Global Positioning System(GPS) gives the geo location of the detected hole on the pavement. The GPS location is imprinted on the detected pothole frame as shown in figure 9.

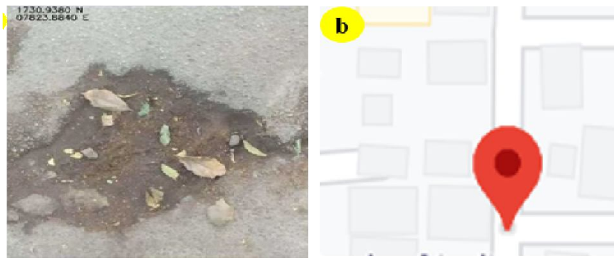


Figure 9: Location of pothole (a) Latitude and longitude values on pothole image (b) Detected pothole marked on google map.

5.1 Depth based Navigation unit

Kinect sensor streams the video in depth mode for analyzing the point cloud coordinates using the 'time of flight' technique [20].Depth mode is a form of 3 dimensional field view. The navigation process takes place based on navigation pane division as shown in figure 10 (b).

While the depth camera is streaming continuously, the morphological operation removes the small unwanted pixels. The edge detection is performed to detect the contours and the video frame is divided accordingly to further process the navigation system [27]. The whole frame is divided into eight flags horizontally and four flags vertically as seen in the figure 10 (a). The direction navigation depends on horizontal pane whereas obstacle distance is determined using vertical flags. This technique simplifies the navigation method as it has a 3 dimensional view and is more accurate compared to normal 2 dimensional object detection.

5.2 Pavement monitoring unit

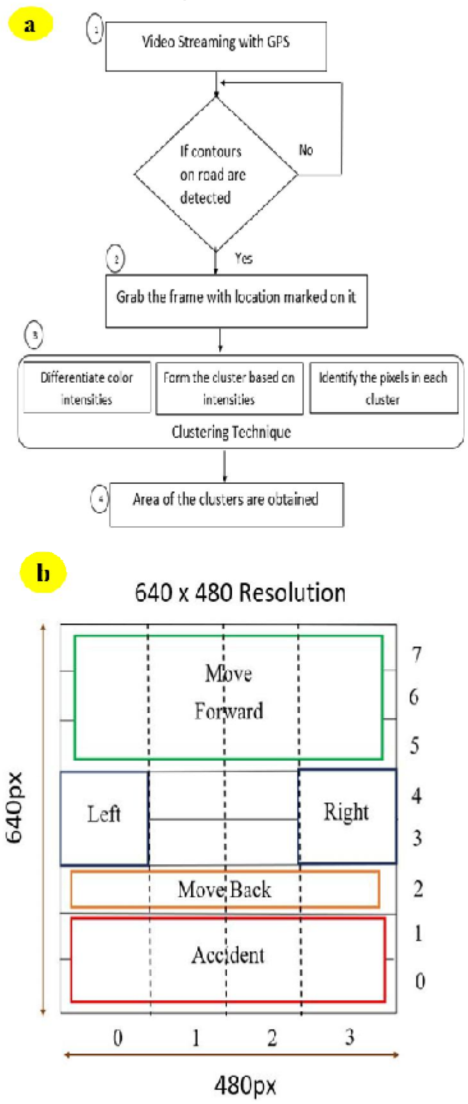


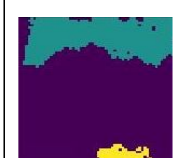
Figure 10:(a)Steps involved in Pavement monitoring. (b) Navigation pane division

Figure 10 is the workflow of the pavement monitoring systemwith 4 major steps. Pi camera streams continuously with GPS module enabled (step 1) and if any closed contours are detected, the particular frame will be grabbed and location is imprinted on the frame (step 2). The pixels are grouped based on their corresponding intensities. The grouping takes place using improved k-means clustering technique (step 3). The pixels associated with each cluster are converted into real world coordinates such as centimeters using pixel to centimeter conversion technique. Area of each cluster is finally obtained after the conversion process (step 4). Experimental Results

The proposed method is conducted on different holes on pavements. In terms of computational time, performance and exactness,the capability of the model was evaluated by comparing it with other clustering techniques as shown in table 2. Density based spatial clustering technique(DBSCAN) is a spectral clustering technique which clusters the data points based on their densities. The intensities of the holes are clustered using improved K-means clustering technique. Improved K-means is chosen over K-means purely to avoid random initialization trap, This estimation helps in road infrastructure maintenance.

6. EXPERIMENTAL RESULTS

Table 2: Model Comparison of proposed model.

Clustering Technique	K-means	K-means++	DBSCAN
Computation Time	15.17 Seconds	16.63 Seconds	4.86 Seconds
Output Visualization	Centroid based clustering 	Centroid based clustering 	Density based clustering 
Observation	Reliable even for low intensity.	Reliable even for low intensity.	Not so reliable for low intensity.

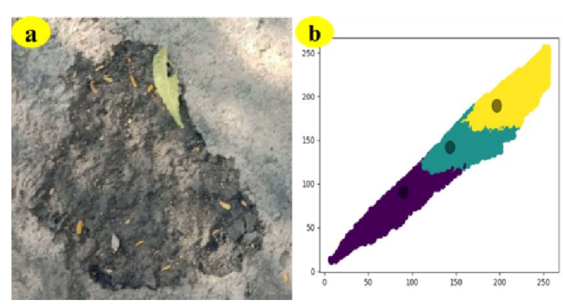


Figure 11: Extracting the clustering results(a)Detected pothole,(b)Scatter plot of the image intensities.

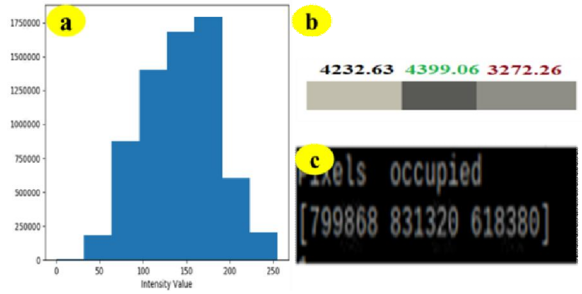


Figure 12: (a)Histogram of pixel count and pixel intensity, (b)Average pixel values, (c)Area occupied by corresponding cluster.

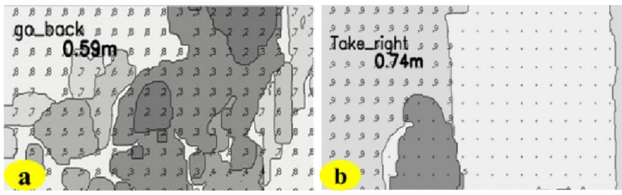


Figure 13: Navigation pane with distance of obstacle of two different scenarios.

Table 3: Distance measurement compared with kinect measurements with physically measured values.

Measurements	Kinect Distance(m^)	Measured distance(m)	Error (m^-m)
1	0.46	0.49	-0.03
2	0.51	0.53	-0.02
3	0.54	0.54	0
4	0.55	0.54	0.01
5	0.59	0.6	-0.01

Figure 11 depicts the experimental results of real-time potholes on the pavement and figure 11 is the analysis made on detected pothole. Figure 12 shows the navigation pane that directs the automobile and also shows the distance of the obstacle. Figure 13 is the observed measurement of obstacle from kinect sensor. Table 3 is the comparision of the observed physical value with obtained kinect measured value. The maximum distance of the obstacle measured is four meters precisely as shown in figure14.

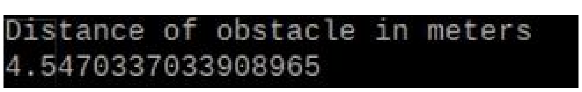


Figure 14: Distance measurement displayed in pi termial window.

7. CONCLUSION

In this work, a real-time processing for navigation system with pavement monitoring is presented. The key process is to work on depth points, segmented image and cluster the intensity points accordingly. An arrangement of Kinect Sensor and pi camera interfaced with Raspberry Pi has been presented. This paper can be used for pothole detection and distance estimation in real time using Kinect sensor. The setup can be used in anyautomobile for improvement in road infrastructure which makes the model highly accurate due to the presence of Infrared beam [27]. In order to find the reliability of the navigation model, the experiment is conducted on fifty six different samples of data and for pavement monitoring, error is estimated using standard error. Improved K-means technique has been tested on forty five different real potholes.

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