

# Automated Detection of Dry and Water-Filled Potholes using Multimodal Sensing System

SHENU P M

A Thesis Submitted to  
Indian Institute of Technology Hyderabad  
In Partial Fulfillment of the Requirements for  
The Degree of Master of Technology



Department of Electrical Engineering

June 2012

## Declaration

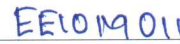
I declare that this written submission represents my ideas in my own words, and where ideas or words of others have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources that have thus not been properly cited, or from whom proper permission has not been taken when needed.



(Signature)

---

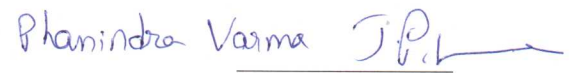
(SHENU P M)



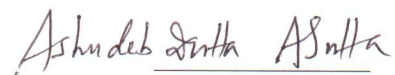
(Roll No.)

## Approval Sheet

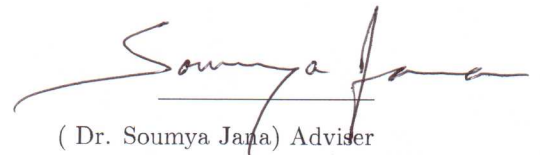
This Thesis entitled **Automated Detection of Dry and Water-Filled Potholes using Multimodal Sensing System** by SHENU P M is approved for the degree of Master of Technology from IIT Hyderabad



(Dr. Phanindra Varma Jampana) Examiner



(Dr. Ashudeb Dutta) Examiner  
Dept. of Electrical Engineering  
IITH



(Dr. Soumya Jana) Adviser  
Dept. of Electrical Engineering  
IITH

## Acknowledgements

First and foremost, I would like to thank God almighty for everything I have in life and for where I am now.

I would like to express my deep and sincere gratitude to my guide **Dr. Soumya Jana** and my co-guide **Dr. Sri Rama Murty Kodukula** for their continuous support of my M-Tech research, for their patience, motivation, enthusiasm, and immense knowledge. Their guidance helped me in all the time of research and writing of this thesis.

Besides my supervisor, I wish to express deep thank to the rest of my thesis committee: **Dr. Ashudeb Dutta** and **Phanindra Varma Jampana** for their encouragement, insightful comments, and hard questions.

I thank my fellow lab mate in IIT Hyderabad: **V.kiran kumar** for all his support in writing the thesis. A special note of thanks to **Aravinth Kumar.A.R**, **Aishwarya Prasanna Kumar** and **Karthika Vijayan** for helping me out when I faced many hurdles during my project. Also I thank my friends in IIT Hyderabad who supported me during all my hardships and for being with me always.

I owe my loving thanks to my family and friends : my father **Mr. P.P.Mathai**, my mother **Mrs. Alice K.G**, my brother **Mr. Sharoon P M** and my friends **Ms. Reeba sebastian** and **Ms. Dhanya Varghese** for supporting me spiritually throughout my life. Without their encouragement and understanding it would have been impossible for me to finish my M.Tech. A special thanks to **Mr. Tinu Thomas** for all his help and support through out the M-Tech.

# Dedication

To my parents

## Abstract

Indian roads are full of potholes and during monsoon season the potholes are filled with water. This makes it difficult for the driver to drive upon the potholed roads. So its crucial to detect water-filled potholes. Dry pothole detection has already been done using sound waves. Detection of water-filled potholes is harder. The sound waves from the ultrasonic sensor will not penetrate the water surface due to impedance mismatch of air and water. So to detect the water-filled potholes a laser beam based system is used. The frequency of the laser beam which can detect water-filled potholes need to be used. The wavelength in the range of 400 nm to 450 nm which has less absorption in water is used. This range is blue light which is least attenuated in water. So a multimodal sensing system is designed to detect both dry and water-filled potholes.

An ultrasonic sensor module which detects the range and depth of dry potholes and a blue line laser along with a camera(laser striper) which will detect the range and depth of water-filled potholes is used. By considering various factors like temperature, wavelength and attenuation, the frequency of the ultrasonic sensor is chosen to be 40kHz. By interfacing ultrasonic transducer with atmega 16 microcontroller, the distance to the pothole and the depth of the pothole is estimated and by using serial communication, the distance, depth and warning is displayed on the PC. The ultrasonic sensor module works well for the discontinuity algorithm. For the detection of water-filled potholes, a laser diode of 405nm(blue laser) wavelength is used along with a camera under laser frequency. The laser beams will illuminate the pavement surface by projecting a line pattern beam and the camera captures the image. The input fames are processed to detect the potholes and to get the maximum depth index of the pothole. The input frames are first thresholded to remove the background and to extract the laser line and this laser line is checked for deformation by using a template matching method. The deformed laser line indicates the presence of the pothle. The deformed laser line is shaded to obtain the depth map(shape of the pothole) and the maximum depth index of the pothole is estimated. The proposed analysis algorithm is capable of detecting the pothole and estimating the depth index.

# Contents

Declaration . . . . .	ii
Approval Sheet . . . . .	iii
Acknowledgements . . . . .	iv
Abstract . . . . .	vi
<b>Nomenclature</b>	<b>viii</b>
<b>1 Introduction</b>	<b>3</b>
1.1 Motivation . . . . .	3
1.2 Problem Statement . . . . .	4
1.3 Objective of the Research . . . . .	6
1.4 Organization of the Thesis . . . . .	7
<b>2 Literature Survey</b>	<b>8</b>
2.1 Introduction . . . . .	8
2.2 Pothole detection using multiple sensors . . . . .	8
2.3 Detection and collection of information by using multiple sensors . . . . .	10
<b>3 Design of the overall system</b>	<b>13</b>
3.1 Phase of project . . . . .	13
3.2 Design Requirement For Mode Of Detection . . . . .	13
3.2.1 Ultrasound . . . . .	14
3.2.2 Electromagnetic Waves . . . . .	19
3.3 Lidar Technology (Light Detection and Ranging) . . . . .	21
3.4 Multimodal Sensing system . . . . .	21
<b>4 Pothole detection using Ultrasonic Sensor</b>	<b>23</b>
4.1 Introduction . . . . .	23
4.1.1 Ultrasonic Sensor(RKI-1540) . . . . .	23
4.1.2 Design Requirement . . . . .	24
4.2 Working . . . . .	25
4.2.1 Communication Protocol . . . . .	26
4.2.2 Serial Communication . . . . .	27
4.3 Flowchart . . . . .	29
4.3.1 Flowchart of Algorithm for micro controller ATMEGA 16L . . . . .	29

4.3.2	Flowchart of discontinuity . . . . .	30
4.3.3	Flowchart of the system . . . . .	31
4.4	Description of Flowchart . . . . .	32
4.4.1	Flow chart of discontinuity . . . . .	32
4.4.2	Flowchart of the system . . . . .	32
<b>5</b>	<b>Implementation and results of ultrasonic module</b>	<b>34</b>
5.1	Prototype Picture . . . . .	34
5.2	Circuit Diagram . . . . .	35
5.3	Sensor response . . . . .	36
5.4	Experimental Results . . . . .	37
<b>6</b>	<b>Pothole detection using LIDAR technology</b>	<b>39</b>
6.1	Introduction . . . . .	39
6.2	Laser Imaging Technique . . . . .	39
6.2.1	Detecting laser beam by thresholding . . . . .	41
6.2.2	Laser line deformation detection approach . . . . .	41
6.2.3	Template Matching Method . . . . .	41
6.2.4	Depth Profile . . . . .	42
6.2.5	Maximum Depth Index . . . . .	43
<b>7</b>	<b>Results and Discussion</b>	<b>44</b>
7.1	Observations . . . . .	45
<b>8</b>	<b>Conclusion and future work</b>	<b>48</b>



# List of Figures

1.1	Pothole Schematic . . . . .	4
1.2	Normal road . . . . .	5
1.3	Dry pothole . . . . .	5
1.4	Water filled pothole . . . . .	6
3.1	Working of Ultrasound . . . . .	14
3.2	Temperature -Frequency . . . . .	15
3.3	Wavelength-Frequency . . . . .	16
3.4	Attenuation-Frequency . . . . .	17
3.5	Electromagnetic Spectrum . . . . .	19
3.6	Absorption Spectrum . . . . .	20
3.7	Electromagnetic spectrum . . . . .	20
4.1	Ultrasonic Sensor . . . . .	24
4.2	Delay schematic . . . . .	24
4.3	Basic Block Diagram . . . . .	25
4.4	Block diagram of the system . . . . .	25
4.5	Waveform of trigger and echo . . . . .	26
4.6	Asynchronous communication . . . . .	27
4.7	Serial USART . . . . .	28
4.8	Flowchart of algorithm . . . . .	29
4.9	Flowchart of discontinuity . . . . .	30
4.10	Flowchart of the system . . . . .	31
5.1	Prototype Picture . . . . .	34
5.2	Circuit Diagram . . . . .	35
5.3	Sensor Response . . . . .	36
5.4	Sensor Response . . . . .	36
5.5	Distance displayed in centimeters . . . . .	37
5.6	Depth of the pothole is displayed and warning . . . . .	37
6.1	Laser Imaging . . . . .	40
6.2	Process flow for detecting and estimating the depth of pothole . . . . .	40
6.3	Thresholding . . . . .	41
6.4	Template image . . . . .	42

6.5	Depth profile of the pothole . . . . .	42
7.1	Depth profile of dry potholes . . . . .	44
7.2	Depth profile of water-filled potholes . . . . .	45
7.3	Schematic of real and apparent depth . . . . .	45

# Chapter 1

## Introduction

### 1.1 Motivation

Traffic congestion has been increasing in India as a result of economic growth, urbanization and a rapid increase in number vehicles. The number of reported accidents is exponentially increasing due to poor road conditions. The roads are deteriorating with more usage and lesser maintenance. Due to the poor road conditions drivers find it difficult to ascertain the manholes, bumps etc. which leads to major accidents. During the rainy season, potholes get filled with water and the driver is unable to distinguish its presence or depth which can lead to life threatening calamities. It is hazardous to travel by road without any warning sign, especially during night.

In order to avoid this accidents, a warning system is required which will detect and distinguish the potholes, manholes, bumps etc. on road surface before it is encountered with so that the driver gets enough response time. For this a system should be developed which will detect the defects on the road. The prime motivation behind making a pothole detection method is to aid drivers in various aspects and thus assist them in avoiding a possible accident. All these reasons urge the need to get information of such bad road conditions that can warn the driver. A system that warns the driver about potholes in its path, well in advance so that driver gets a reasonable response time is being proposed here.

Figure 1.1 shows the road with pothole and a speed breaker. Potholes are depressions rather than protrusions. Other obstacles like people, speed breakers will not be taken into account. The algorithm used to propose the new system has certain limitations as the road is completely unstructured.

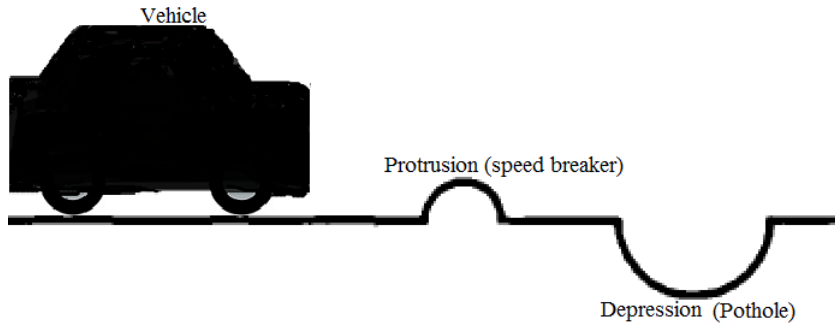


Figure 1.1: Pothole Schematic

## 1.2 Problem Statement

An advanced technique to detect both dry and water filled potholes using a multi modal sensing system is proposed. It detects and measures range and depth of dry and water-filled potholes to alert the driver in advance. Potholes are classified into shallow and deep potholes based on their characteristics. Shallow potholes are ignored and only deeper or dangerous ones which lead to major accidents are considered. The mode of detection includes a multi modal sensing system. Ultrasonic sensors using sound waves are the sensing system to detect dry potholes and obtain their range and depth. Laser diodes with camera (laser stripe) are used to detect water filled potholes by illuminating them and capturing the images of the pothole using a camera under laser frequency. By implementing feature extraction algorithm in image processing, we can detect dry and water filled potholes and calculate its range and depth. As Ultrasonic sensor cannot penetrate air-water interface, to get the depth of water filled potholes, we use laser sensor. Sound waves from the ultrasonic sensor detect only the surface of water whereas the laser beam penetrates all the way to the bottom of the pothole. By evaluating the received signal from both the sensors, the range and depth of water-filled potholes can be estimated. We cannot detect a pothole accurately using a single sensor as there are many other irregularities on the road, whether it is a pothole, crack or a hub. Hence, with the received signal from just one sensor is not enough to decide whether it is a pothole, crack or hub. To get accurate information of the pothole we need to get the profile of the pothole. For this, an array of ultrasonic detectors is to be used. This helps us acquire the profile of

the pothole

In Fig 1.2 a smooth road is considered. In this case the ultrasonic sensor signal will give the range from the road and the laser signal will give a line projection on the road. Evaluating the received signals from the ultrasonic receiver and the laser signal, we are informed of the absence of any pothole.

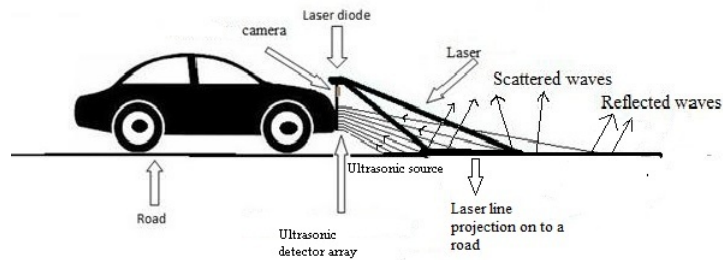


Figure 1.2: Normal road

In Fig 1.3 a dry pothole is shown. Here, the ultrasonic sensor module and laser module detect the pothole and measure the range and maximum depth of the pothole and warn the driver of its presence. By using an array of detectors, we get better output i.e., we can get the profile of the pothole. We receive many signals back from the road or pothole. Evaluating these received signals, the profile of the pothole obtained.

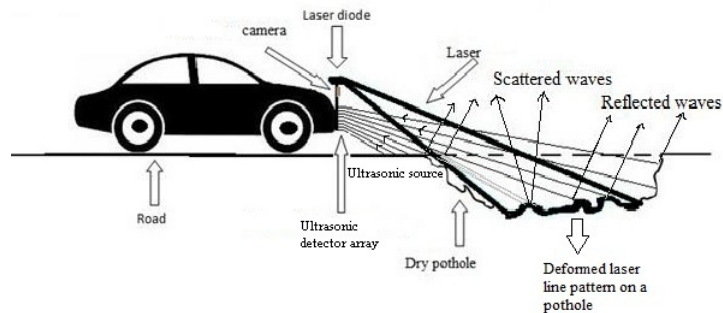


Figure 1.3: Dry pothole

In Fig 1.4 a water filled pothole is shown. In this case the ultrasonic sensor signal does not

penetrate the water surface. This gives us only the range of the pothole from the surface of water. The laser signal penetrates the water surface and gives the range from the bottom of the pothole. By implementing feature extraction algorithm in image processing we can detect the pothole, get the maximum depth of the pothole and the depth profile. Range of the pothole can be detected using ultrasonic sensor.

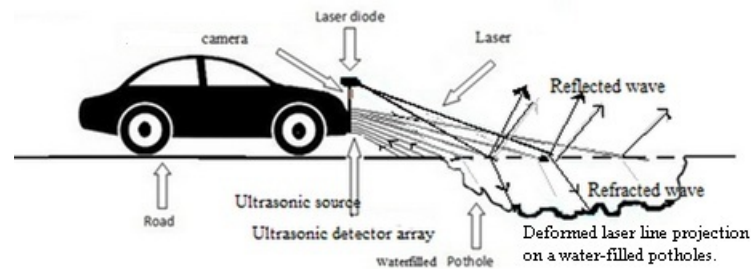


Figure 1.4: Water filled pothole

### 1.3 Objective of the Research

The main objective of this research is to develop a multi modal sensing system to detect dry and water-filled potholes.

To accomplish this, the following tasks are performed.

- Review past research efforts on pothole detection using different techniques.
- Select the sources for detection.
- Select the required frequency for the sources.
- Develop an algorithm for detection of potholes using ultrasonic sensor and to get the range and depth of the pothole.
- Implementation of the hardware of ultrasonic module.
- Develop an algorithm for laser imaging technique to detect water-filled potholes and to get its maximum depth index.
- Validate the new algorithm

## 1.4 Organization of the Thesis

In chapter 1 a brief introduction to the problem is given.

In chapter 2 the related research works on pothole detection using different techniques are described. The detection of pothole before the driver encounter it using multiple sensors and the collection of bad road condition by using different methods like GPS, Wi-Fi are described. This collected information is given to the drivers through GPS and thus they can be aware of the pothole before.

In chapter 3 the two phases of the project is described. First phase includes the design of the over all system ie the selection of the source and the selection of the frequency for the source and the second phase is the implementation of the system. The lidar technology and the multi modal system for the detection is explained in detail .

In chapter 4 the ultrasonic sensor module is described. The working of the whole module, the communication protocol of the sensor and the algorithm for pothole detection and depth calculation are explained. The serial communication for displaying the distance, depth and warning is described in detail.

In chapter 5 the circuit diagram of ultrasonic sensor is explained. The experimental results and analysis of ultrasonic sensor module is described and the obtained result is given.

In chapter 6 the Laser sensor module is described. An image processing algorithm to detect pothole and to estimate the depth index is explained. The various image processing techniques to detect the pothole is described which includes thresholding, template matching, depth map generation. The maximum depth index of the pothole is estimated.

In chapter 7 the experimental results of laser imaging technique which is done by using a laser and camera on a robot is given. The video captured is processed in matlab to detect the pothole and to get the depth of the pothole.

In chapter 8 the conclusion and future work for the pothole detection by using laser and ultrasonic sensor is described.

## Chapter 2

# Literature Survey

### 2.1 Introduction

Research work in this area falls into the following broad categories. In one, data from several vehicles are sent to a central location for road maintenance operations. In another category, research is directed towards helping the driver avoid potholes. Different techniques for detecting potholes use ultrasonic sensor, camera, laser and infra red imaging. Potholes and other obstacles are detected and the driver is alerted ahead of time. This information regarding bad road conditions like cracks, potholes etc are sent to other vehicles to alert them of the road condition, and the position is notified using GPS (global positioning system).

### 2.2 Pothole detection using multiple sensors

The pothole detection system proposed in [1] uses an ultrasonic transducer to detect potholes, ditch, bumps and other obstacle by warning the driver the difference in distance obtained. They used obstacle detection which works on the principle of SONAR. An ultrasonic transmitter emits pulses of 42 kHz at regular intervals and a receiver listens to the echo. The echo round-trip time is used to get the distance. The receiver detects abrupt changes in terrain by comparing the round-trip delays. If any difference is obtained in distance, then a depression is detected. They have used MSP430 controller for controlling the ultrasonic sensor. The Msp430 is used to control the sensor in transmitting the signal and it calculates the distance using the received echo signal. When a difference in distance is obtained ,then a clear warning is given to the driver. The difference in distance is the pothole detected. Here they have designed the system specially for pedestrian use



i.e., for visually challenged people and its a hand held device. When a discontinuity is detected , a warning is given to the user which is by using a buzzer. The sensor used here is LV Max SONAR is a sonar range finder which.which has comparative good range of detection.

The pavement pothole detection and severity measurement proposed in [2] uses a red laser sensor and a camera to capture the images of cracks, potholes etc. After the pavement images are captured, region corresponding to potholes are represented by a matrix of square tiles and the estimated shape of the pothole is determined. In this the captured images of the pavement is converted to gray scale image and this image is thresholded to obtain the region of interest. The resultant images are divided into small squares i.e., the image is divided into 625 sub-images called tiles. Each tile is 40x40 pixels which covers a 2x2 inch block on pavement surface. The decision to classify a tile as a laser line tile is based on the global mean value versus the local mean value of each tile. Any tile that has a mean value lower than the global mean value is considered as a laser line tile and labeled '1' otherwise it is labeled with '0'. Thus a tile based matrix is generated. For the laser line deformation detection, a template matching method is used. The extracted laser line is searched for any deformation. The template image is a straight line of laser. By creating the template image the input images are compared with this template image. The comparison is done in row basis. Each row is searched for deformed tile. The number of tiles in each row that differ between the input frame and the template frame are calculated. The deformed tiles in a row are stored to a new matrix. This matching process will continue until no further deformation is detected. All deformed rows are stored in a new matrix. Thus the output image will be the estimated shape of the pothole. By checking for the deformed rows in a image, the depth index can be obtained. Here the depth index is calculated by measuring the total number of distress tiles and these information is input to a three - layer feed-forward neural network for pothole severity and cracks type classification.

The FPGA based system for pothole detection proposed in [3] uses a low cost vision based driver assistance system over FPGA platform for detection and avoidance of the pothole on road. It uses an FPGA model to deploy image processing algorithm to achieve output in real time. Here a vision based approach is used since the pothole were different usually from the background surface. A CCD camera which operates in the visible spectrum band is taken as the sensing device and FPGA for video processing to detect the potholes.

## 2.3 Detection and collection of information by using multiple sensors

The continuous road damage detection using regular service vehicle proposed in [4] used a system that continuously monitors the road network for surface damage like pothole and cracks. The system consist of a structured light sensor and a camera mounted on vehicle that travel the roads on a regular basis. It makes use of sensor and equipment already present on the vehicle like GPS. Here a laser line striper which sends out a plane of red light and a camera to capture the image is used. Only the projected laser line is taken from the image and is transformed into world coordinates via triangulation. With the laser line striper one can acquire 3D images with high resolution up to few meters. Its installed inside the front bumper of a bus and another camera is used to record the images of the road. The data is continuously collected while the vehicle is on its route. In addition to the 3D data from the laser sensor and the image data, the speed of vehicle and the location is recorded by using GPS. To produce the 3D image, the speed and orientation of the vehicle is to be known. At the end of the route, the data is downloaded on a server and by final analysis, the location of the pothole, cracks are determined. The video taken by the camera was a stream of images at 15 Hz, while the stripe was taken at 120 Hz. The vehicle state is also recorded by using a GPS unit in the vehicle and the acceleration, velocity and several other quantities are recorded. The maximum speed of the vehicle was 14.8m/s. To create the 3D map of the road, the vehicle state and the several stripe of data shots is needed.

The pavement crack detection system through localized thresholding proposed in [5] considers cracks on the pavements. Many methods have been devised to identify the cracks on pavement. Here image processing is done to detect the cracks. For the use of image, external factors such as shadows and improper lighting might result in noise. Localized thresholding is implemented by dividing the images into smaller blocks and identifying a local threshold and finding the crack pixels using the threshold of each block. Correlating the intensity and the relative values of the RGB components of the image, the region of interest is obtained from the original image. The image is converted into black and white to identify the existing cracks. The image processing undergoes three phases, they are preprocessing, thresholding and post processing. The preprocessing stage involve filtering and other mechanism to convert the image into suitable form for thresholding mechanism. Thresholding

mechanism removes the background and extracts the region of interest. Localized thresholding is a method utilized to identify thresholds local to a particular area and identify the potential cracks pixels by using the classical thresholding mechanism local to a smaller area of the image. The image is converted into black and white to see the existing cracks. Then verify the continuity of cracks pixels by checking neighbourhood of each white pixel. Identify crack blocks to compress the image into smaller size by using scan lines. At last apply noise reduction and a hough transform to the final image.

The pothole detection system proposed in [6][7] is a system which is divided into 3 subsystem. First is a sensing subsystem which senses the pothole encountered by it about which it did not have the prior information. Then the communication subsystem which transfers the information between the Wi-Fi access point and mobile node. Access points broadcasts the data about the potholes in its area. When vehicle gets the data, it sees if it has sensed any pothole which access point does not have information about. If its the case, then the data is transmitted to access point as a feedback. And finally the localization subsystem which reads the data given by access points and warns the driver regarding the occurrence of pothole. The sensing system is for getting the data. Here they have used vision based and vibration based. Vision based uses a camera as sensor to scan the road for pothole. The camera captures the image and its applied to image processing algorithms like edge detection. Another method uses Accelerometer to sense the pothole. The accelerometer measure acceleration on three perpendicularly placed axis. We can characterize the pothole on the basis of the magnitude of change in reading of accelerometer. Localization subsystem consist of GPS.

Mapping city potholes proposed in [8] designed a fully automated data collection system that is installed in any automobile vehicle to monitor road or high way pavement conditions. The system records and analyse the output from an accelerometer mounted near a front wheel shock absorber. The data from the accelerometer is time and position with GPS date from a GPS unit and stored to a DOS compatible file on a compact Flash card interfaces to the internal embedded processor system. Once the data is collected, the compact Flash card is downloaded into a desktop system after which the GIS software is used to remap the GPS surface roughness data to a physical location on a user viewable city map.

In all research works only dry potholes are considered. Using different sensors like ultrasonic

sensor, camera, red laser the dry potholes can only be detected whereas water-filled potholes will be missed or remain undetected as sound waves and red laser pulses will not penetrate water surface. The collection of information of potholes by using some sensors like accelerometer, laser and recording or sending it by using Wi-Fi or GPS works well. But in the case of water-filled potholes, these systems will not work as the water-filled potholes will remain undetected by using these sensors. Thus giving wrong information. So in this work, we are considering water-filled pothole detection by using a multimodal sensing system.

## Chapter 3

# Design of the overall system

### 3.1 Phase of project

The first phase of the project involves selection of the correct source (Electromagnetic/ Ultra-sound/combined) to find the range and depth of dry and water filled potholes and the design of the overall system which includes the selection of frequency of the source for detection.

In the second phase, implementation of the overall system and an advanced algorithm for driver alert generation should be attempted.

In this section the selection of source for detection and choosing frequency for the source is discussed.

### 3.2 Design Requirement For Mode Of Detection

The important requirement of this project is the mode of detection.

While choosing the source for detection we should consider the following conditions.

- 1) It should penetrate water and should reflect from hard surface like road, rocks, bricks etc.
- 2) Attenuation coefficient should be less.

By considering these two factors, we selected two sources for detection of pothole.

- 1) Ultrasound
- 2) Electromagnetic waves

### 3.2.1 Ultrasound

Ultrasonic sensor works on a principle similar to sonar which estimates about the target by evaluating the echoes from sound waves. Ultrasonic sensors generate high frequency sound waves and the receiver evaluate the echo which is received back by the sensor as shown in Fig 3.1. Sensors calculate the time interval between sending the signal and receiving the echo to measure the distance to an object. By evaluating this time interval that is the round trip time the distance to the target and the position of the target can be obtained.

An ultrasonic pulse is generated in a particular direction. If there is any object in this path of ultrasonic pulse, the pulse will hit the object and the reflections are received back to the receiver as an echo and can be detected by the receiver. By measuring the difference in time between the transmitted pulse and the received echo and the speed of sound in that medium, we can determine how far away the object is.

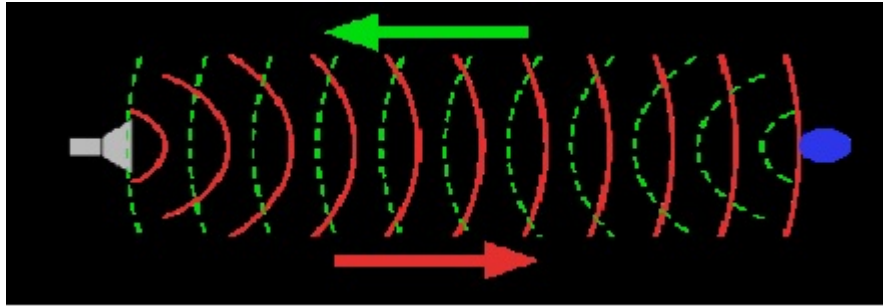


Figure 3.1: Principle of Ultrasound(Ref:[14])

Sonar is a technique that uses sound to detect objects under water and get the depth of the water. It is used in military applications to detect the underwater obstacles like submarines etc. Sonar will emit pulses towards the target and the echo signal is being received, the position and distance of the object can be evaluated. Since the application of pothole detection involves obstacle detection and range measurement, ultrasound is a good source. Ultrasonic sensor can detect dry potholes in long range even though many challenges are there. So, we are considering Ultrasonic sensor as one of the source for detection.

### Choosing frequency for Ultrasonic sensor

Ultrasonic sensors are device that uses sound waves above 20 kHz which is beyond the range of human hearing, to measure and calculate distance from the sensor to a specified target object. There need to be considered many factors for selecting an ultrasonic sensor and frequency for sensor. Frequency of ultrasonic sensor must be carefully selected to provide a proper balance between image and depth of penetration

### Speed of sound in air as a function of temperature

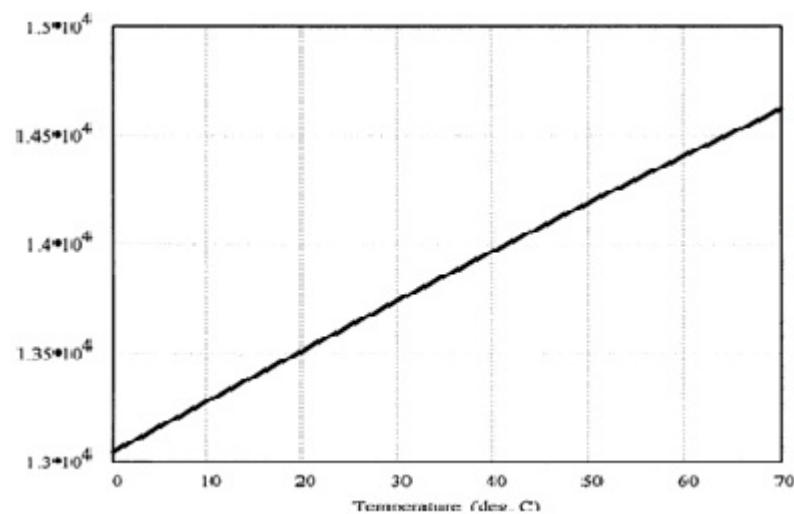


Figure 3.2: Temperature(Ref:[15])

In an echo ranging system, the time delay between the transmission of ultrasonic pulse and its return of echo to the receiver is measured. The distance to the target is computed using the speed of sound in air (the medium). The accuracy of the target measurement depends on the speed of sound used in computing. The speed of sound depends on the temperature of the medium through which the sound travels. As the temperature increases, the sound waves travel faster to and from the target as shown in Fig 3.2 . So it will seem to the sensor that the target is closer. This will give a less accurate reading of the distance.

### Wavelength of sound as a function of frequency

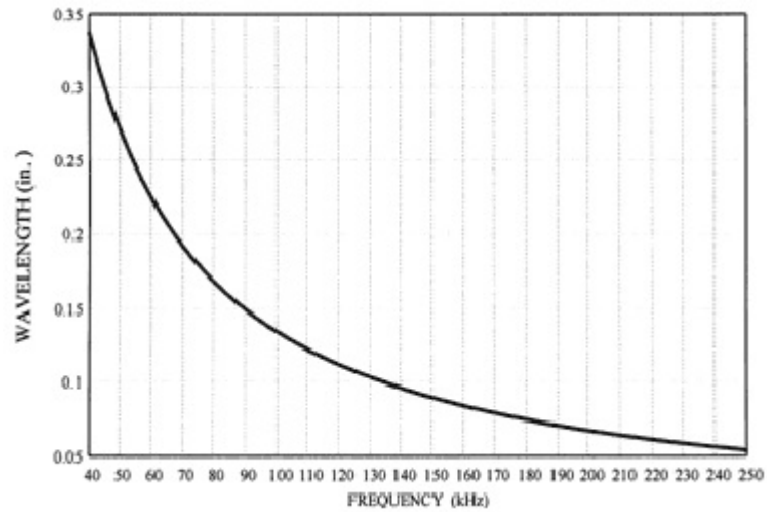


Figure 3.3: Wavelength(Ref:[15])

The wavelength of sound changes as a function of frequency as shown in Fig 3.3. Since we are not considering small potholes, the wavelength of sensor should be high enough to detect medium sized potholes which can cause accidents.

By expression,  $\Lambda = c/f$ , where  $c$ =Speed of light,  $f$ =Frequency,  $\Lambda$ = wavelength

### Attenuation of sound as a function of frequency

Ultrasonic sensors are typically operating at frequencies between 20 kHz to 250 kHz. Since we are considering long distance, low frequency ultrasound is suitable, because attenuation increases with increase in frequency as shown in Fig 3.4. So to reduce the attenuation, 40 kHz ultrasonic sensor is chosen.



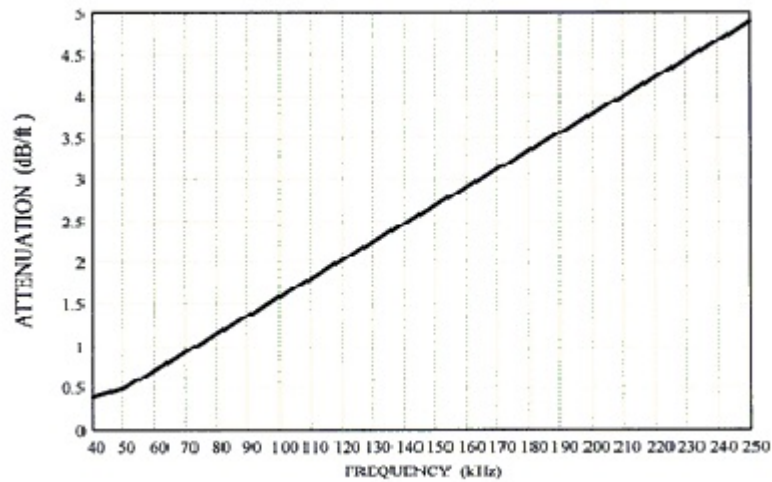


Figure 3.4: Attenuation(Ref:[15])

So 40 kHz ultrasonic sensor is suitable for this application, as its having low attenuation. As frequency increases ,the image resolution is better ,but at the same time attenuation is more. So in order to trade off between resolution and attenuation 40 kHz is chosen. For calculating the distance to the target, measure the time taken for a pulse of sound to travel to the object and back again that is

$$\text{Distance} = \text{speed} * \text{time} / 2.$$

Only low frequency ultrasounds can propagate in air at speed of 343m/s and in water at a speed of 1500m/s

### **Preliminary studies of obstacle avoidance using ultrasonic sensor**

Obstacle avoidance is a crucial factor in automated vehicle operation. Using Lego Mindstorm robot, obstacle avoidance using ultrasonic sensor is done. It has a 40 kHz ultrasonic sensor using which the obstacles in its path are avoided by sending the sound waves. It is controlled by a 32-bit ARM microprocessor programmed to detect objects and avoid them. As the range increases the detection accuracy reduces. While testing the ultrasonic sensor with water, our results show that signals are transmitted but the sound waves are attenuated in water and some are reflected away from water surface leaving no sound signals reflected back to receiver. Hence, the transmission of ultrasonic signals through air attenuates some of the sound waves and the sound waves hitting a water surface

are attenuated completely. Thus ultrasonic sensors are not suitable to detect water filled potholes.

### **Challenges of Ultrasonic Sensor**

Ultrasonic sensor is suitable for this application. But there exists a lot of challenges for ultrasonic sensor to use in air. Its performance reduces with increase in distance in air. Sound attenuates at a higher rate in air. Here we are considering two medium. So propagation of sound from one medium to other will result in attenuation, because of the difference in density of the two medium. Some of the challenges of ultrasonic sensor are described here.

It is affected by temperature fluctuation. As the temperature increases, speed of sound in air also increases giving wrong reading of range measurement. Due to the temperature fluctuation the range will not be accurate. The challenge lies in the transmission of sound at air-water interface. Air and water have very different impedance, so that a beam of sound hitting water surface is almost entirely reflected away and only a small amount enters the water. The greater the difference in impedance, the more the sound reflected rather than transmitted. The difference in acoustic impedances of air (approx. 430 Rayls) and water (approx.  $1.5 \times 10^6$  Rayls) mean that the reflection coefficient is given by  $(1.5 \times 10^6) / (1.5 \times 10^6 + 430)$  will always be close to unity i.e. complete reflection. Now given that most piezo ceramic devices also have very high acoustic impedance another challenging problem if have to propagate through air. This is because there's a large potential reflection at the piezo-air interface and then another at the air-water interface. So will end up with very little signal actually getting into the water. Thus ultrasonic sensor can be used only for detecting the dry potholes. Because of the difference in impedance of air and water, it cannot be used to detect water filled potholes.

### 3.2.2 Electromagnetic Waves

Light (laser), microwaves, x-rays, radio waves, infra-red, ultra violet and gamma rays are all kinds of electromagnetic waves. Figure 3.5 shows the Electromagnetic spectrum which includes, from longest wavelength to shortest: radio waves, microwaves, infra-red, optical, ultraviolet, X-rays, and gamma-rays. The property of the electromagnetic wave is its wavelength. The wavelength is inversely proportional to frequency, so waves with higher frequency has a shorter wavelength and vice-versa.

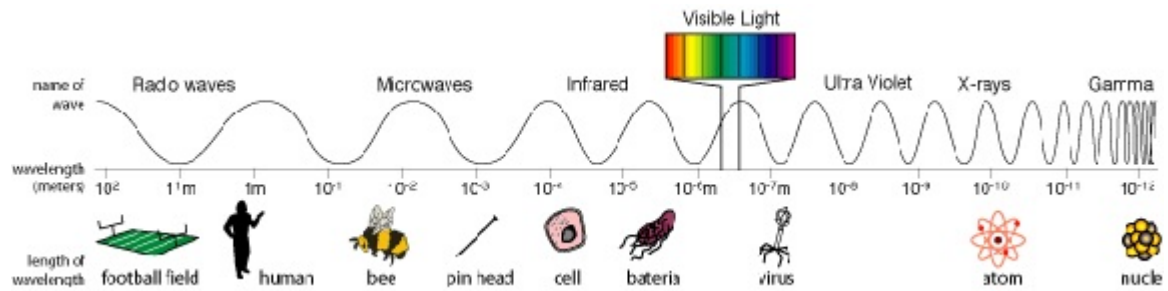


Figure 3.5: Electromagnetic Spectrum(Ref:[16])

Among this Radio wave, Micro wave and X-rays will penetrate hard surface. So they are not suitable for this application. Laser (visible light) which is having less attenuation in water and which will not penetrate hard surface is suitable.

#### Laser(VisibleLight)

Laser is a device that emits electromagnetic radiation by a process called optical amplification. Laser is a monochromatic light, that is, light of a single frequency. They are called coherent light, that is, they will not spread while travelling. Laser beams can be focused to very tiny point. Laser beams will have different patterns. It can project a point or it can give a line pattern. Laser beams can penetrate water. So for water filled potholes, laser beams are suitable. Laser signal will not pass through hard objects and laser will penetrate water with least attenuation.

## Choosing Frequency for Laser Diode

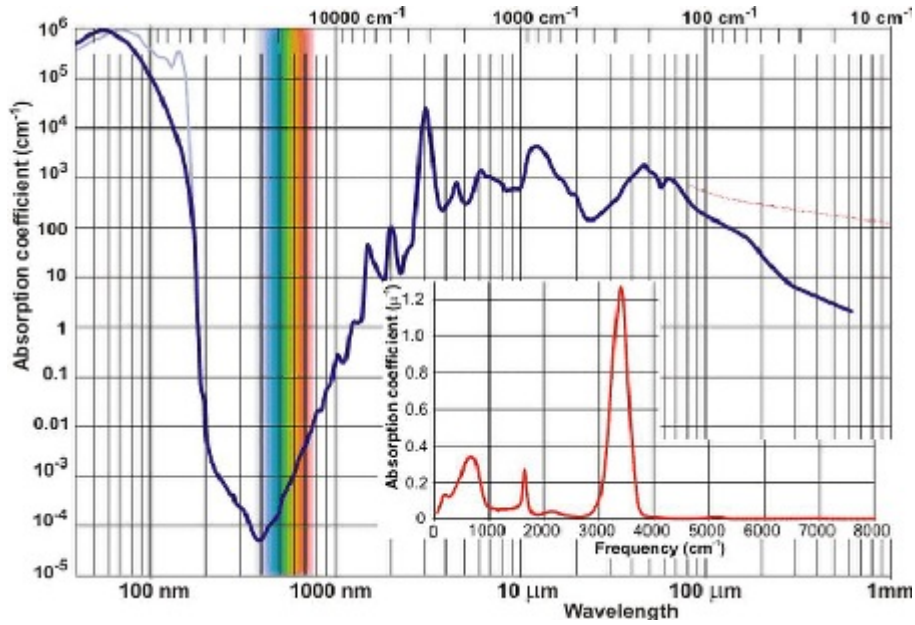


Figure 3.6: Absorption Spectrum(Ref:[17])

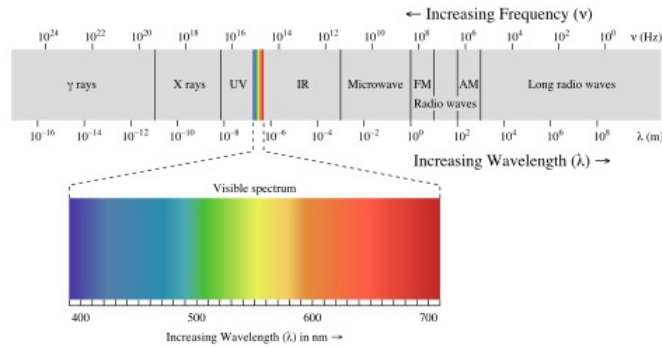


Figure 3.7: Electromagnetic spectrum(Ref: [19])

The graph shown in Fig 3.6 is absorption spectrum for water. In this spectrum a range of wavelengths are shown ie, the different colours which comes under visible light region of electromagnetic spectrum. Among the different colours of the visible region, blue light is having least absorption that is blue light suffers less attenuation in water. The absorption is greater for long wavelengths of light and less for shorter wavelength of light. The long wavelength of light will be absorbed in the surface of water and only shorter wavelength of lights can illuminate underwater objects. The absorption is less in the range of 400 nm to 500 nm as shown in Fig 3.7 and this range is blue light. Even

green light is having less absorption in water. But blue is having least attenuation. So, blue light is suitable for detection of water filled potholes as it will penetrate to the bottom of the pothole. The intensity of the light decreases with water depth. But in case of water filled potholes being not too deep, the light can reach to the bottom with good light intensity. Blue laser diodes of wavelength between 405 nm to 470 nm can be used.

### **3.3 Lidar Technology (Light Detection and Ranging)**

We use Lidar technology (light detection and ranging) in our application. It is similar to optical sensing technology that measures the distance to a target object by illuminating the object with light from a laser and using a camera to capture the images of the object. It uses visible light to detect objects with high accuracy. Lidar technology is used in aircrafts to detect targets on earth. It illuminates the objects under water and we get the image of the object, thus detecting objects underwater. Lidar technology can also be used to measure the depth of water. It has various other applications in different fields. Lidar is used in robotics for object classification, for obtaining the city and country map. Lidar can be used to create three dimensional topographical maps and for the surveys of geographical regions. In our application we consider Lidar technology for classification of potholes. We use light from a laser beam and a camera to capture the images of the road. Even Radar works in the same fashion as lidar technology which uses radio waves instead of light pulses. Both technologies evaluate distance by the time delay between transmission and reception of a reflected pulse.

### **3.4 Multimodal Sensing system**

For the detection of dry and water-filled potholes a multimodal sensing system is designed. An ultrasonic transducer of 40 kHz for detecting dry potholes and a blue laser diode of 405nm along with a camera for detecting dry as well as water- filled potholes is proposed. By using ultrasonic sensor we will get the range and the depth of dry pothole. In the case of water filled potholes, ultrasonic signals will hit the water surface and will get reflected away and attenuated in water due to impedance mismatch between air and water. Only some sound waves from the surface will get back to the receiver. Thus only the range of the water-filled pothole can be obtained. To detect

and get the depth of water-filled pothole, a blue laser beam which can penetrate the water is used. Thus the depth of water-filled potholes can be estimated. By evaluating the output from both the sensors the range and depth of the water filled pothole can be obtained.

By using one single detector will not give exact information of a pothole, because on road not only potholes, there will be many other deformations like cracks, hubs which can give wrong reading. So by using an array of detectors sensors, we will get the profile of the potholes. Thus instead of receiving one single input, multiple inputs are received by the array of detectors obtaining better output.

## Chapter 4

# Pothole detection using Ultrasonic Sensor

### 4.1 Introduction

The technique of distance measurement using ultrasonic sensor in air includes continuous wave and pulse echo technique. In pulse echo technique, a burst of sound pulses are sent through the medium and reflected by an object. The time taken for the pulses to propagate from transmitter to receiver is proportional to the distance of object. For contact less measurement of distance, the device has to depend on the target to reflect the pulses back to itself. The obstacle needs to have proper orientation. The amplitude of the received signal get attenuated and it is a function of nature of the medium and the distance between the transmitter and the obstacle. The time of flight gives the distance measurement. In the time of flight method of distance measurement, level of attenuation is high. Especially in air medium and this limits the distance range.

#### 4.1.1 Ultrasonic Sensor(RKI-1540)

The sensor used in this application is RKI-1540 [9] which is shown in Fig 4.1. The sensor uses a 5V supply. This sensor is a high performance ultrasonic range finder. It is compact and measures a wide range from 2 cm to 4 m. Its frequency is 40 kHz. This ranger is perfect for any robotic application, or any other projects requiring accurate ranging information. This sensor can be connected directly to the digital I/O lines of a micro controller and distance can be measured in time required for travelling of sound signal.



Figure 4.1: Ultrasonic Sensor[RKI-1540] [9]

### 4.1.2 Design Requirement

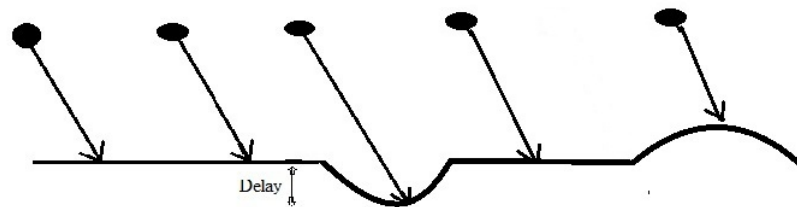


Figure 4.2: Delay schematic

In pothole detection the main factor is the delay involved. Figure 4.2 shows the schematic of delay. The timing unit should trigger the ultrasonic sensor to emit short sound pulse and the receiver listens to the echo and determines the presence of a discontinuity before it sends the next pulse i.e., the echo from road and the echo from pothole will be different. The ultrasonic sensor is placed 1m above the road on the vehicle. So the average roundtrip time is 1m. The discontinuity is the outlier from this average distance. To detect the potholes, this discontinuity should be detected. The receiver will be getting echo continuously. With the echo the distance can be calculated. Any outlier in the round-trip time is considered as a discontinuity. Hence an algorithm to detect the discontinuity is required. And when a discontinuity is detected, a clear warning has to be generated to alert the driver.



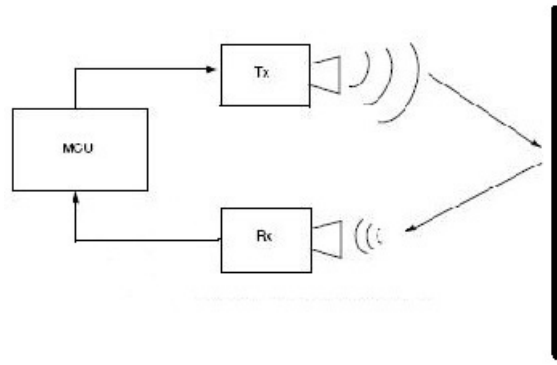


Figure 4.3: Block Diagram

The basic unit of sensor module is transmitter- receive pair and micro controller [10]. The micro controller is used to trigger the transmitter and then the transmitter will send the sound pulses. The receiver when receives the signal will be given to the micro controller for further process. Figure 4.3 shows the basic block diagram of the system.

## 4.2 Working

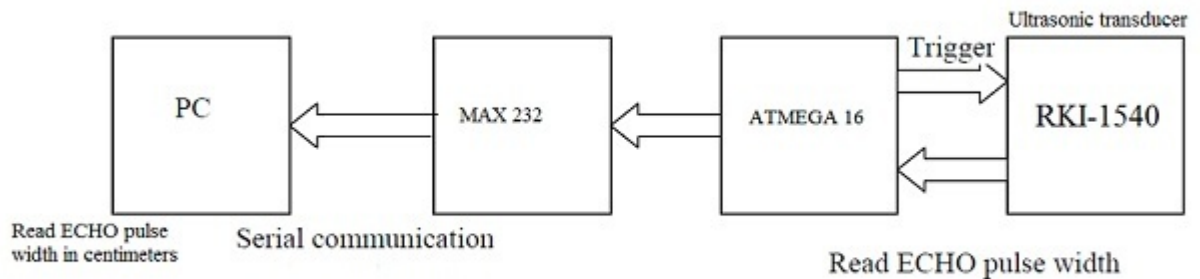


Figure 4.4: Block diagram of the system

Figure 4.4 shows the block diagram of the ultrasonic sensor module. Power up the sensor by 5VDC using pins VCC and GND. Atmega 16 (AVR family) [11] is used to control the sensor operation. Its a 40 pin DIP ( Dual In Line) package chip. A 10 us trigger input is given to the pin named Trig on the sensor by the microcontroller, to trigger the sensor. This starts one cycle of range conversion and

sends 8 bursts of sound waves of 40 kHz from the transmitter. As soon as the signals are transmitted the Echo pin on the sensor will set to high level and remains in high level until the same sound waves are received by the receiver. If the received sound waves are same as the transmitted, then the Echo pin goes to low level. This echo high time i.e., the time for which the echo pin was high, is the time which is used for calculating the distance to the road or to the pothole. The equation to calculate the distance in centimeters is

$$\text{Distance} = (\text{Echo pulse width high time} * \text{Sound Velocity (340M/S)})/2$$

If no obstacle is detected within 4M after 30 ms the echo pin will automatically go to low level. The received time is converted into distance by the micro controller and this distance is transmitted for displaying on PC. The discontinuity and warning is also displayed when detected. The discontinuity detected is the pothole depth. MAX 232 which is used for serial communication is used to transmit the data to PC. RS 232 is the standard for serial communication.

#### 4.2.1 Communication Protocol

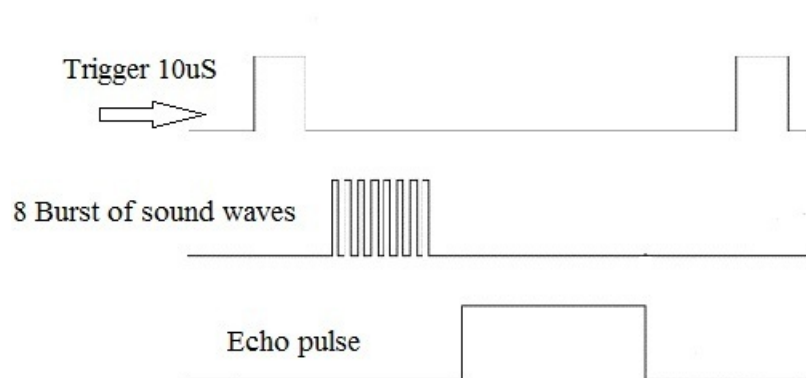


Figure 4.5: Waveform of trigger and echo

Under the control of the micro controller (trigger pulse) the sensor emits a 40 kHz sound wave. This waves travel through air, hits an obstacle and then return back to the ultrasonic receiver. The sensor will give an output echo pulse to the micro controller through the echo pin when echo is detected. Hence the distance can be calculated from the echo pulse. Figure 4.5 shows the graph of the 10 micro second trigger input to the sensor, and the burst signal which is sent by the sensor and the

echo pulse receiver back by the receiver.

## 4.2.2 Serial Communication

Serial communication [13] is the process of sending data one bit at a time continuously over a communication channel. Whereas in parallel communication the data is send as a whole.

Serial communication is of two types.

1. Synchronous Communication
2. Asynchronous Communication

In Synchronous communication the complete data is transmitted at once. It doesn't require start bit and stop bit. Its synchronized by clock. Due to the absence of start and stop bits , more bits can be send and makes the data transmission easier. Its point-point communication ie a master-slave communication.

In Asynchronous serial communication the data transfer protocol is that in which a start bit is sent prior to each byte(8 bits) or code word and a stop bit is sent after each code word. So we can understand the starting and ending of the message. The start and stop bits are the parity bits to identify the data present between the start and stop bits .

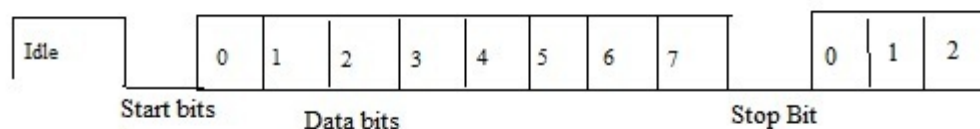


Figure 4.6: Asynchronous communication

Before transmission the transmitter and receiver should initialize the following parameters:

- duplex, half duplex or simplex.
- Baud rate( Speed or bits per second).
- The order in which the bits are sent.
- To use or not to use parity.

- If parity is used , even/odd.
- No: of stop bits.

### Serial USART

The Atmega 16 has 2 pins specially for serial communication(serial USART) ie to transfer and receive data serially. These two pins are RXD and TXD (Port D.0 and Port D.1). Pin 14 is assigned to RXD and Pin 15 is assigned to TXD. These pins are TTL compatible. So a line driver is required to make them RS232 compatible. This line driver is MAX232.

### RS232

Its a series of standards for serial binary single-ended data and control signals connecting between a DTE( data terminal equipment) and DCE( data circuit terminating equipment).

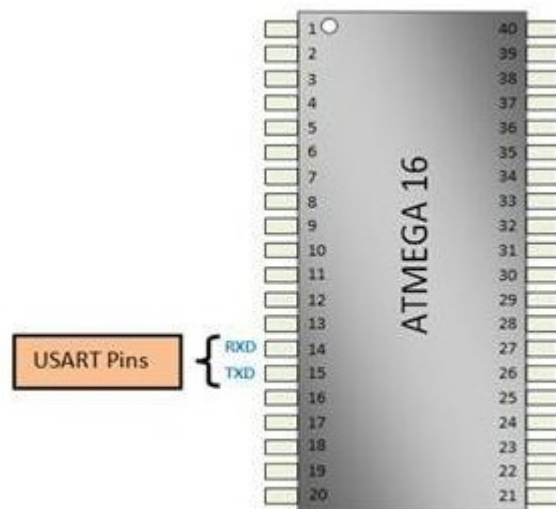


Figure 4.7: Serial USART(Ref: [13])

Atmega 16 provides asynchronous mode of communication and does not have a dedicated clock line. Synchronization is achieved by setting the baud rate , start and stop bits. Start and stop bits are used to synchronize the data frame.

One frame =Start bit + data bits + stop bit.

Baud rate is the rate at which the serial data is being transferred.

## 4.3 Flowchart

### 4.3.1 Flowchart of Algorithm for micro controller ATMEGA 16L

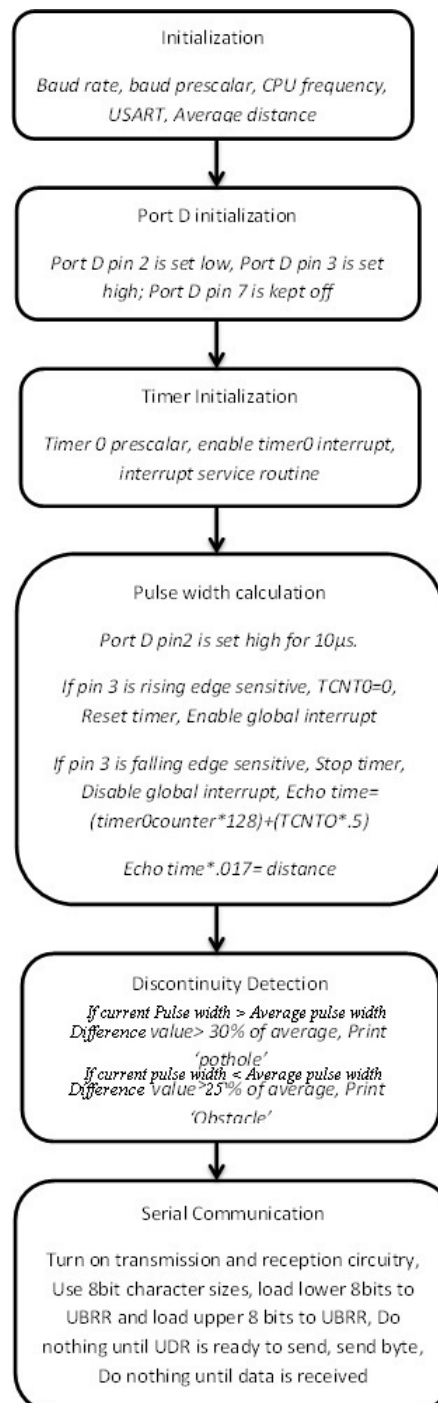


Figure 4.8: Flowchart of algorithm

### 4.3.2 Flowchart of discontinuity

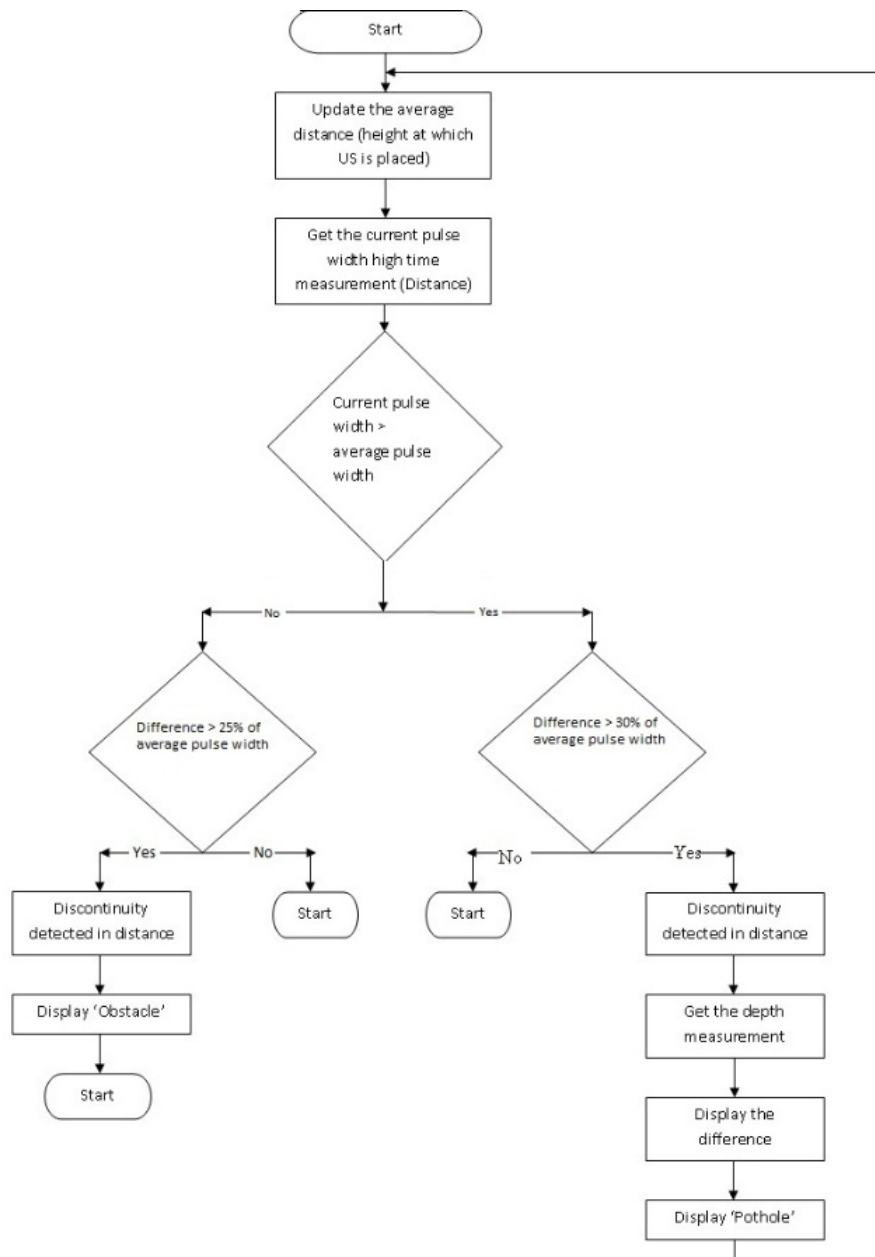


Figure 4.9: Flowchart of discontinuity algorithm

### 4.3.3 Flowchart of the system

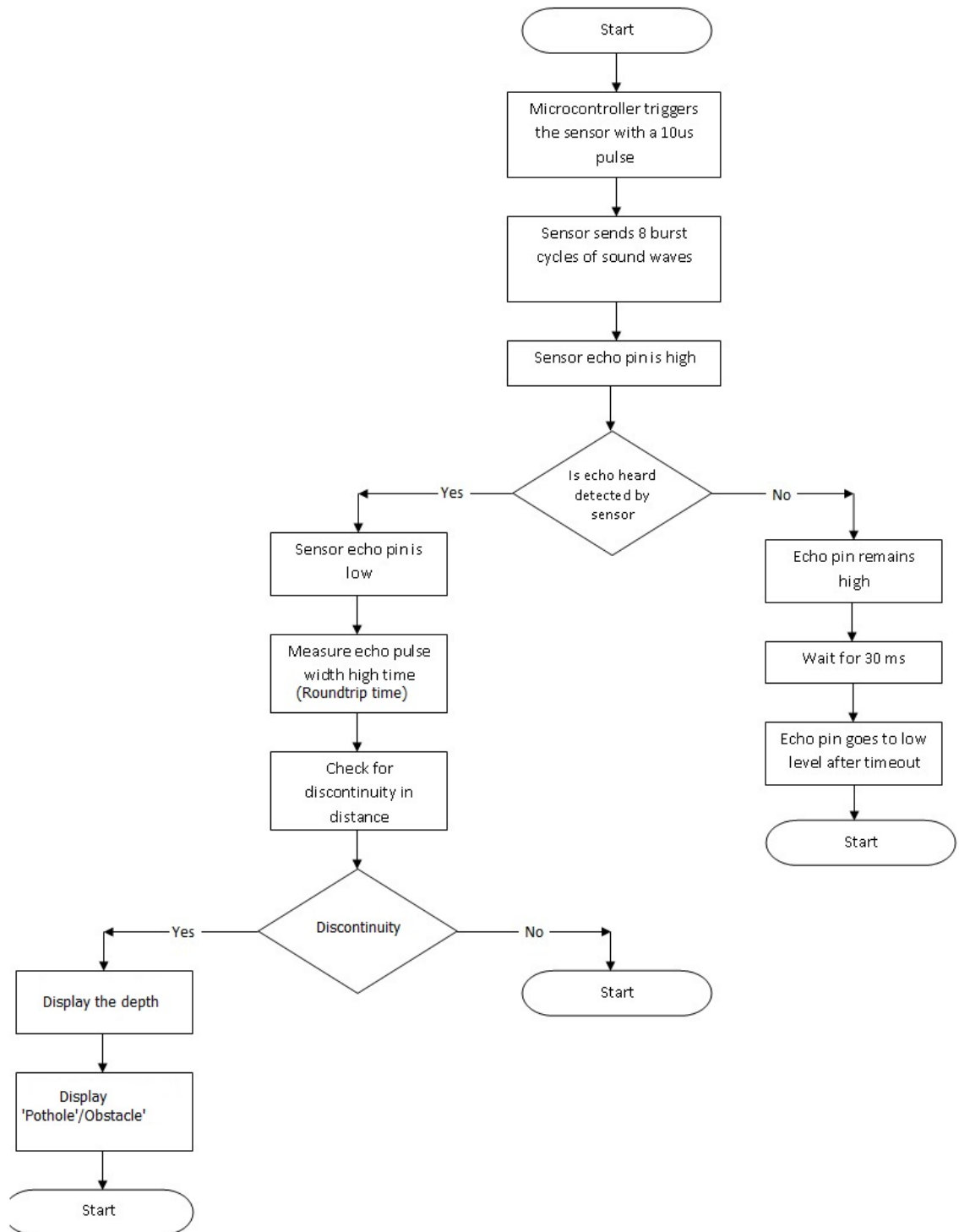


Figure 4.10: Flowchart of the system

## 4.4 Description of Flowchart

### 4.4.1 Flow chart of discontinuity

1. Update the average pulse width high time. The average distance is the height at which the ultrasonic sensor is placed on the vehicle.

2. Get the current pulse width high time measurement.

3. If the current pulse width is greater than the average pulse width time.

i) Check for the difference between the current pulse width and the average pulse width time. If the difference is greater than 30% of the average pulse width, then a discontinuity in distance is obtained i.e., a pothole is detected. Get the depth of the pothole and display the depth and warn the driver by displaying 'pothole' on PC by serial communication.

ii) If the difference is within 30% of the average pulse width, then update the average pulse width.

4. If the current pulse width is less than the average pulse width.

i) Check for the difference between the current pulse width and the average pulse width time. If the difference is more than 25% of average pulse width time, then a discontinuity is detected i.e., an obstacle or a wheel of other vehicle or a person is detected. Then warn the driver by displaying 'obstacle' on PC by serial communication.

ii) If the difference is not more than 25% of the average pulse width, wait for the next echo signal.

### 4.4.2 Flowchart of the system

1. Micro controller triggers the Ultrasonic sensor by 10 micro second pulse on the trigger pin of the sensor. This starts the range conversion and sends 8 burst of 40 kHz sound waves.

2. The echo pin on the sensor goes to high state as soon as the burst signal is sent and it will wait for the echo signal.

3. When the echo signal is received on the echo pin on the sensor, it will go to low state.

4. The micro controller will measure the echo pulse width high time i.e., the time for which the echo pin was high. It's the time taken for the sound signal to hit an object and return back to the receiver.



5. Using this time ie, the round-trip time the distance to the object is calculated. This distance in centimeter is checked for any discontinuity from the average distance.

6. If discontinuity is detected for the present distance obtained, then display the depth on PC ie, the difference in distance.

7. This discontinuity is displayed on the PC using serial communication and the discontinuity measurement is also displayed.

8. When a discontinuity is detected, 'pothole'/ 'obstacle'is printed .

## Chapter 5

# Implementation and results of ultrasonic module

### 5.1 Prototype Picture

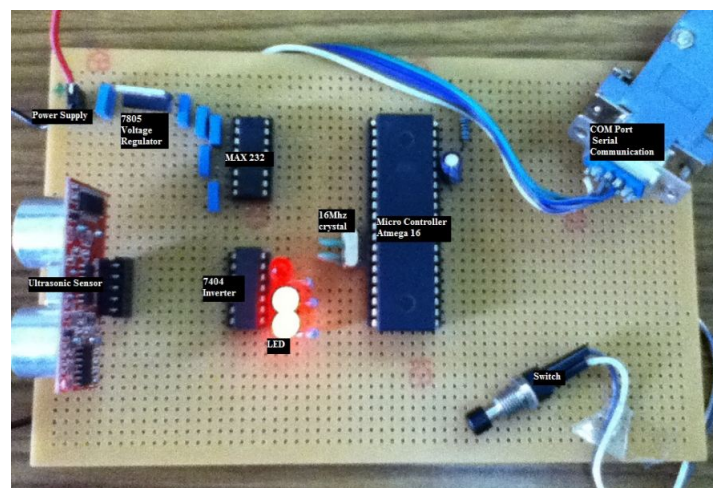


Figure 5.1: Prototype Picture

Figure 5.1 shows the prototype picture of the ultrasonic module fabricated on a PCB board. It consists of a microcontroller which is connected to a 40-pin IC holder. The ultrasonic transducer is connected to a 5-pin connector, which is connected to the microcontroller via an inverter 7404. A voltage regulator 7805 is used for regulating 5V, which is needed for the entire circuit. A switch for resetting the circuit, MAX 232, and a COM port for serial communication. LEDs are used for showing the circuit functioning.

## 5.2 Circuit Diagram

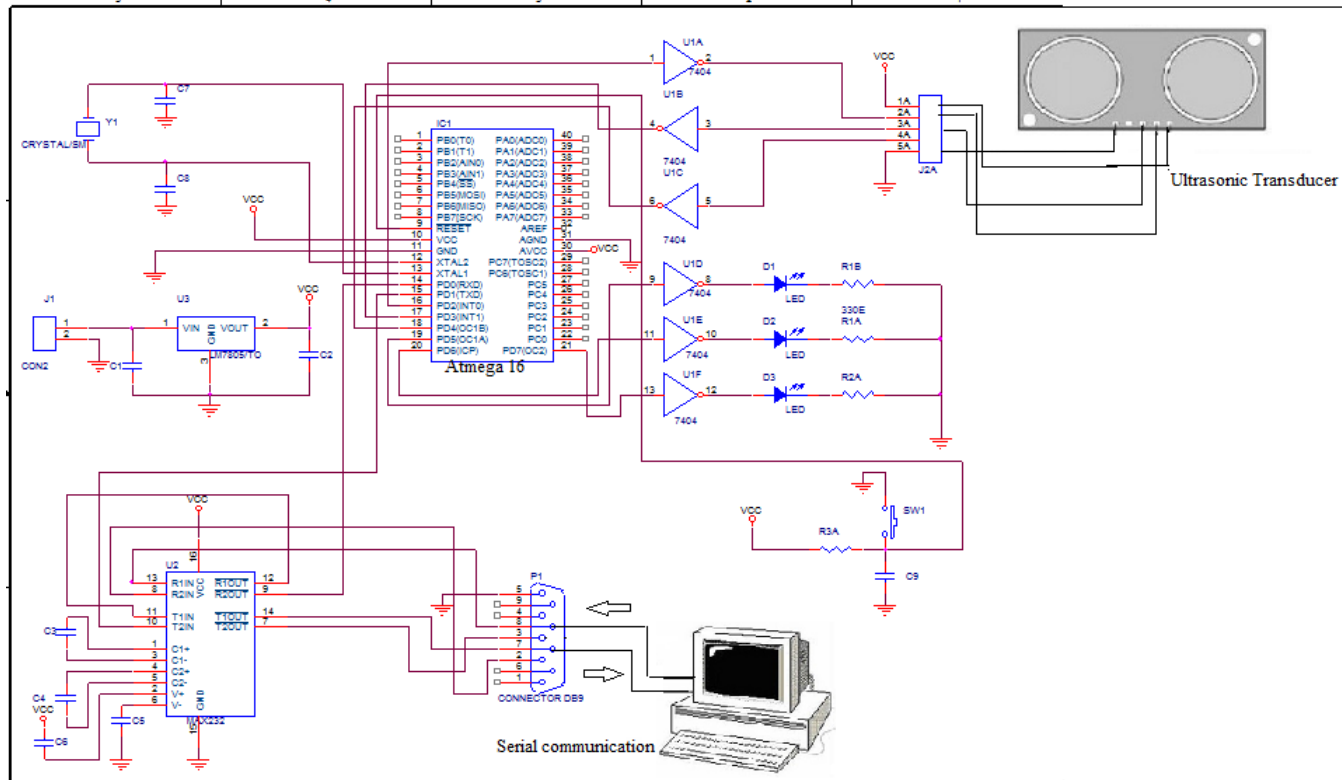


Figure 5.2: Circuit Diagram

Atmega 16 uses a 16 MHz internal clock. An external 16 MHz crystal is used which is connected to XTAL 1 and XTAL 2 pins of the microcontroller. The circuit works on 5 V DC. A voltage regulator LM 7805 is used to regulate the voltage to the circuit. 8 V DC is given to the voltage regulator and it gives 5 V DC output to the circuit. A switch to reset the circuit is connected to the RESET pin (pin 9) of the microcontroller. Port D of microcontroller is used to connect to the sensor. Port D pin 2 is connected to the 2nd pin of the sensor 'trigg' through the inverter 7404. Port D pin 3 is connected to the 3rd pin on the sensor 'echo' through 7404. Port D pin 4 is connected to the output pin on the sensor and port D pin 5, pin 6, pin 7 are connected to the 3 LEDs through the inverter. First a low pulse of 10 us duration is given to the inverter pin 1. It gives a high 10 us duration pulse to 'trigg' pin of the sensor which will trigger the sensor to emit the sound pulses. When the sound pulses are sent the echo pin on the sensor will go high. It will remain in high state until the echo is received back. This high on the sensor will give a low on the micro controller's pin 3. When the

pin on the sensor goes low, the pin on the micro controller goes to high state. Thus the echo pulse width high time is given to the micro controller to calculate the distance and the depth of pothole if any. This information is given to the MAX 232 which is for serial communication. From pin 1 of Port D (TXD) the information is given to T2IN ( pin 10) of MAX 232. This is transmitted to PC through T2OUT of MAX 232 through a COM port. RS232 is the standard of serial communication.

### 5.3 Sensor response

The figures shown below are the responses of the sensor obtained on the oscilloscope during the initial testing of sensor functionalities. The trigger signal and the echo signal for different distances are shown.

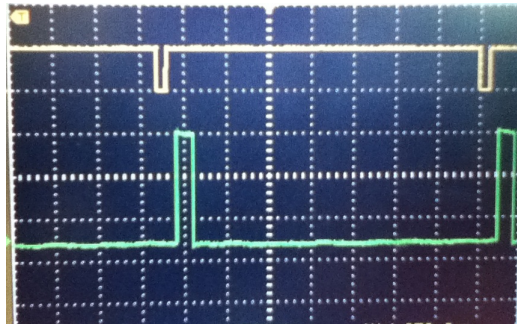


Figure 5.3: Response of trigger and echo signal for small distance

In Fig 5.3 the yellow waveform shows the trigger signal sent from the micro controller to the sensor to trigger the sensor. The green waveform shown is the echo signal received back by the receiver. Using this echo pulse width high time the distance to the object is calculated. The echo signal shown here is for small distance

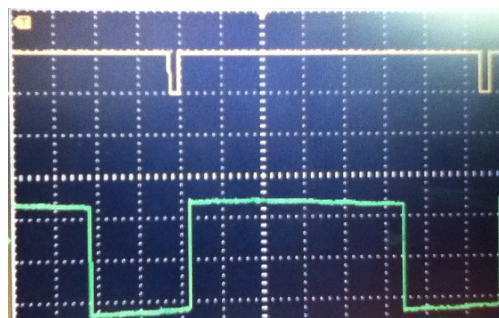


Figure 5.4: Response of trigger and echo signal for long distance

In Fig 5.4 the trigger pulse and the echo signal for a long distance is shown.

## 5.4 Experimental Results

Experiments to detect pothole and to get the depth of the pothole are done. The proposed algorithm is implemented in AVR studio 5.0.

The first experiment done is to display the distance detected by the sensor. In fig 5.5 the detected distance in centimetres are given which is obtained on PC

Distance displayed in centimeters
39cm
40cm
42cm
89cm
94cm
101cm
119cm
124cm
127cm
145cm
167cm

Figure 5.5: Distance displayed in centimetres

Distance Displayed in centimeters	Depth of pothole	Warning
25cm	05cm	
27cm	07cm	'Pothole'
26cm	06cm	'Pothole'
27cm	07cm	'Pothole'
29cm	09cm	'Pothole'
22cm	02cm	
24cm	04cm	
21cm	01cm	
19cm	-	
14cm	-	'Obstacle'
13cm	-	'obstacle'

Figure 5.6: Depth of the pothole is displayed and warning

The second experiment is the validation of the algorithm for pothole detection, depth calculation

and warning by displaying the depth and 'pothole'. Here the average distance is updated as 20 cm for lab purpose that is the height at which the ultrasonic sensor is placed on the vehicle. When an outlier from this average distance is detected, then a discontinuity is obtained. This discontinuity is the depth of the pothole. As we are considering large potholes, the outlier should be more than 30% of the average distance. So when the distance is greater than the average distance and the difference is more than 30% of the average distance, then the discontinuity detected is a pothole and its displayed on PC to alert the driver. The depth of the pothole is also displayed. When the detected distance is less than the average distance and the difference is greater than 25% of the average distance, then the discontinuity detected is an obstacle like people or wheel of vehicle in the front.

## Chapter 6

# Pothole detection using LIDAR technology

### 6.1 Introduction

Ultrasonic sensor is not a good choice for detecting a water-filled pothole. Sound waves will not penetrate water surface with less attenuation. Due to impedance mismatch, sound waves from air-water interference will be completely attenuated leaving no sound waves back to the receiver. Therefore a source which will penetrate water with less attenuation is required to detect water-filled potholes. Here we considered LIDAR technology which is used for detection and ranging using optical sources. LIDAR uses visible, Ultraviolet or near infra-red light to image objects. A narrow laser beam is used to detect the obstacle and to get its range with high resolution. In order to avoid shadowing effect, the laser line will illuminate the surface of interest using the pulses from it and a camera under laser frequency captures the image and then the image processing algorithm to detect the obstacle.

### 6.2 Laser Imaging Technique

Among the visible light frequencies, blue light (405nm) has least attenuation in water. So, blue laser is considered for our application. This laser beam penetrates through water and hits the bottom of the pothole. There will be a deformation in the laser beam which is captured by using a camera with a filter that only detects the laser beam. The laser will project a line pattern on to the pavement surface and the camera takes the images continuously. We compare the images captured with the

reference images to detect the pothole and also to estimate the depth index. The experimental setup is shown in Figure 6.1

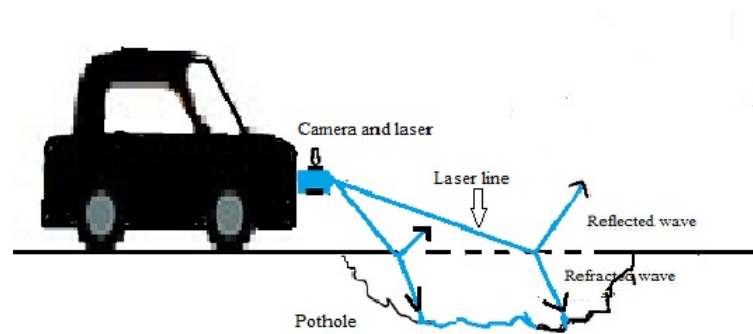


Figure 6.1: Laser Imaging

The comparison is done using feature extraction algorithm in image processing.

The detailed process flow to detect the pothole and to estimate the depth information is described as follows.

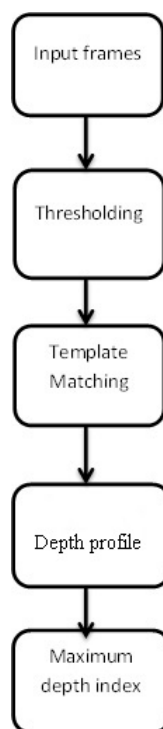


Figure 6.2: Process flow for detecting and estimating the depth of pothole



### 6.2.1 Detecting laser beam by thresholding

The first step in detecting the pothole is to extract the laser line. For that we used Thresholding [2] which is a widely used technique for image segmentation and feature extraction.

We need to differentiate laser beam from the background. For this, a threshold value is selected and the pixels with values below the threshold are given value '0' and the pixel with values above the threshold are given value '1'. We set to white all pixels that belong to a gray level interval, called the threshold interval and set all other pixels in the image to black.. The resulting image is called binary image. For colour images, three thresholds must be specified, one for each component. The threshold can be chosen manually or by using automated techniques. The processing is done on colour image , so threshold is selected accordingly to extract the laser line from the background. The images after thresholding will be free from noise since it has only two pixel values(for laser and background). Figure 6.3 shows the images before thresholding and after thresholding.

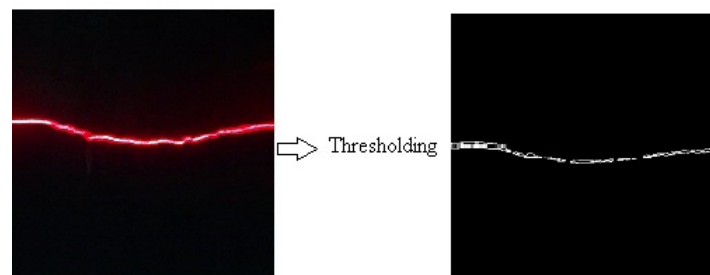


Figure 6.3: Thresholding on a coloured pothole image [2]

### 6.2.2 Laser line deformation detection approach

The resultant binary image obtained after thresholding is checked for any deformation of the laser line. The deformation of the laser line indicates the presence of a pothole. The laser line on the pothole area will be a deformed line. To detect the deformation of the laser line, a template matching method [2] is used.

### 6.2.3 Template Matching Method

Template matching method [2] is a technique used to classify objects. The matching process can be done on block or on a pixel-by-pixel basis. Image of laser line on road without pothole is taken as

our template. Laser line will be straight in this template image. The input frames are then compared with the template image to detect the deformation, which shows the presence of pothole.

Figure 6.4 shows the gray scale image and thresholded image of the template image created.

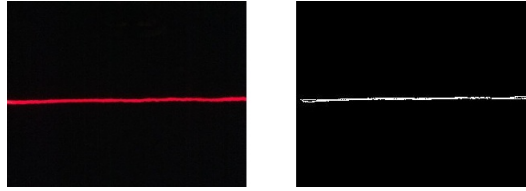


Figure 6.4: Template image

The template is moved over the image as a sliding window i.e., the template image is compared with all the input frames. Compare the rows from the beginning and check if any rows in the matrix when subtracted with the template line becomes '0', i.e. when subtracted with '1' becomes '0'. If any row becomes '0' then it's a good road i.e., the absence of pothole. When comparing the rows if non-zero elements are found in a row after a zero element, and if it continues till the end of the row, then it's the presence of pothole.

#### 6.2.4 Depth Profile

The next step after detecting the pothole is to estimate the depth. The highest non-zero row is considered as the road and assume all the lower non-zero rows as pothole. This is done by making the column corresponding to the highest non-zero element after a zero element in a row to value '1', till the lowest non-zero element and continues till the end of the highest non-zero row. This gives the depth profile of the pothole.



Figure 6.5: Depth Profile

### **6.2.5 Maximum Depth Index**

Depth information is based on the deformation that affects rows in each frame. All the frames are checked for deformation and stored frame by frame and the maximum deformation obtained in a frame is selected as the depth index of the detected pothole. The maximum deformation is shaded to get the depth profile of the pothole. The depth will be the difference between highest and the lowest non-zero row.

## Chapter 7

# Results and Discussion

The proposed algorithm is implemented in matlab R2010a over a sequence of 40 images. Blue laser is not commercially available, so experimentation is done using a red laser(650nm) as it can penetrate water filled potholes with smaller depths. The Laser is attached to the camera which is mounted on the robot. The robot on its way captures the video and this video is converted to frames. This frames are the input images for processing. Images of same pothole with water and without water are taken. This images are thresholded to extract the laser line from the background. By using the template matching method, the deformation of the laser line is detected and the deformed laser line is shaded to obtain the depth profile of the pothole. Among the different images, the one with maximum deformation is taken as the max-depth of the pothole. A set of 4 images of dry pothole and 4 images of water-filled pothole is shown here. The corresponding depth profile obtained is also displayed.

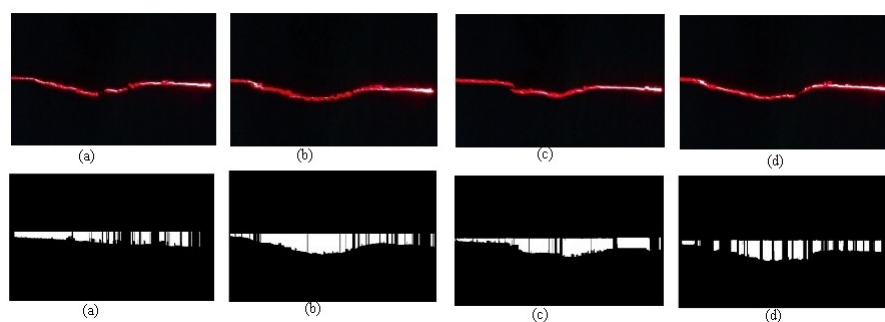


Figure 7.1: Original Image and the depth profile of dry pothole

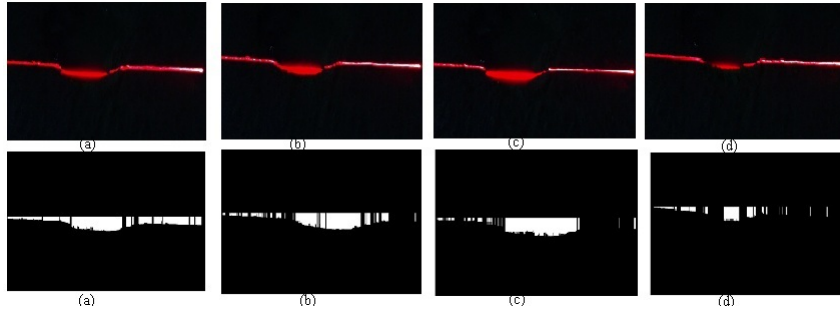


Figure 7.2: Original Image and the depth profile of water-filled pothole

## 7.1 Observations

In the case of pothole without water, the image (b) is having the maximum depth index of 106 i.e., 2.8 centimeters deep and in the case of pothole with water, image (c) is having maximum depth index of 84 i.e., 2.18 centimeters deep. The pothole with water is having less depth compared to dry one. It is because of the difference in refractive index of the two medium. For the detection of dry pothole, the depth obtained will be accurate. But for the estimation of the depth of water-filled pothole, the depth obtained by camera will not be accurate due to the difference in refractive indices of the two medium. So to estimate the depth, we need to consider the refractive index of both air and water instead of depth index alone. In the case of water-filled potholes, the obtained depth will be less than the real depth, i.e., when we observe underwater objects, we see the object closer than their real depth to the surface. This depth is the apparent depth which is viewed by the camera.

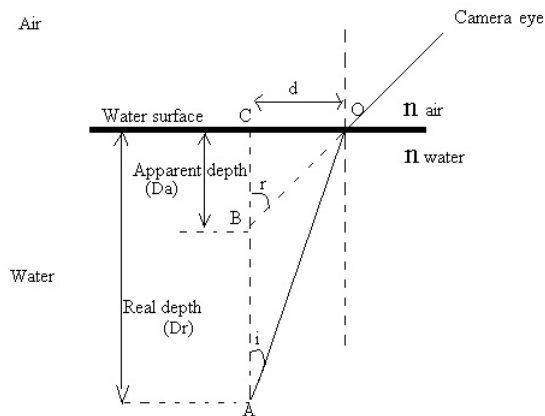


Figure 7.3: Schematic of real and apparent depth

The figure shows the difference between the real and apparent depth of the water-filled pothole. The camera see the pothole depth in the apparent depth because the rays coming from the bottom reaches the camera after refraction. Thus the camera images the depth at a distance called apparent depth ( $Da$ ) from the surface. To estimate the real depth ( $Dr$ ), we need to consider the refractive index of the medium.

Snell's law states that

$$\frac{\eta_{\text{water}}}{\eta_{\text{air}}} = \frac{\sin \theta_i}{\sin \theta_r}, \quad (7.1)$$

where the following notation is used:

$$\begin{aligned} \text{Refractive index of water :} & \quad \eta_{\text{water}} \\ \text{Refractive index of air :} & \quad \eta_{\text{air}} \\ \text{Angle of incidence :} & \quad \theta_i \\ \text{Angle of refraction :} & \quad \theta_r \end{aligned}$$

$$\eta_{\text{water}}/\eta_{\text{air}} = \sin \theta_r/\sin \theta_i \quad (7.2)$$

Refractive index of water is 1.33 and refractive index of air is 1. So,  $\eta_{\text{water}} = \sin \theta_r/\sin \theta_i$

Real depth,

$$Dr = Da * \eta_{\text{pothole}}/\eta_{\text{observer}} \quad (7.3)$$

i.e.,

$$Dr = Da * \eta_{\text{water}}/\eta_{\text{air}} \quad (7.4)$$

As refractive index of air is unity,

$$Dr = Da * \eta_{\text{water}} \quad (7.5)$$

In terms of angle of incidence and angle of refraction

$$Dr = Da * \sin \theta_r/\sin \theta_i \quad (7.6)$$

The apparent depth obtained is 2.18 centimeters. This is multiplied with the refractive index of water to get the real depth of the pothole. By calculating the real depth, the depth of water-filled pothole is changed to 2.83, which is approximately equal to the depth of dry pothole. So by using the equation, we can get the accurate depth of water-filled potholes.

The depth profile of the dry pothole is having continuity than the water-filled pothole. This is because of red light that attenuates in water. For dry pothole detection, red laser can be used. But it will not work good in water-filled potholes. Due to less deep pothole, the images of water-filled

pothole is obtained. But in case of large water-filled potholes, the red laser is not suitable as the red light will be completely absorbed in the surface of water. In order to detect water-filled potholes, a blue laser of 405nm can be used.

## Chapter 8

# Conclusion and future work

The thesis presented two models for the detection of dry and water-filled pothole. The two models work well for detecting potholes and giving warnings. The circuit for the functioning of ultrasonic sensors is fabricated and by using a microcontroller the sensor calculates the distance and depth of the pothole. It gives warnings to the driver in the presence of potholes. The experimental results show that the algorithm works for the detection and warning the driver regarding potholes. It detects the discontinuity and gives the depth of the pothole and warns by displaying 'pothole' on PC.

An array of ultrasonic detectors can be used instead of a single sensor. By using an array of detectors we can get more information about the pothole i.e., we will get the profile of the pothole along with the range and depth. So by using an array we can acquire the 3D image of the pothole. The array means multiple detectors receiving pulses and by adding up of these outputs, we can obtain the profile of the pothole. The reflected signals from different regions can be added up thus obtaining the exact information of the pothole. By using a single sensor, the information of potholes will not be accurate i.e., it can detect any deformation. So to detect the potholes and to image them, an array of detectors need to be used.

It has been shown that the proposed feature extraction algorithm works for the laser module for the detection of water-filled potholes. The experimental results show that the algorithm is highly reliable and accurate in detecting the potholes, obtaining the maximum depth and in generating the depth profile of the pothole.



# Bibliography

- [1] G. Anoosh, S. Raghunandhan, A. Sundar, “ Pothole Detection”, *M-Tech project report, IIT Madras*. 2009-2010.
- [2] Yu. Xinren, E. Salari, “Pavement pothole Detection and Severity Measurement Using Laser Imaging”, *Electro/Information Technology (EIT), IEEE International*, May 2011.
- [3] S. Vijay, “Low Cost FPGA based system for pothole detection on Indian Roads”, *M-Tech Thesis, Indian Institute of Technology*. July-2006.
- [4] C. Mertz, “Continuous Road Damage Detection Using Regular Service Vehicles”, *Proceedings of the ITS World Congress, Carnegie Mellon University*. October, 2011.
- [5] K. Nikhil, “Pavement Crack detection system through localized thresholding”, *M-Tech Thesis, University of Toledo*, December 2009.
- [6] S. Rode, “A Pothole Detection System”, *M-Tech Thesis, Department of Computer Science and Engineering, Indian Institute of Technology, Bombay* 2007.
- [7] S. S. Rode, S. Vijay, P. Goyal, P. Kulkarni, K. Arya, “Pothole Detection and Warning System using Wireless Sensor Networks”, *Embedded Real-Time Systems Laboratory, Indian Institute of Technology Bombay* 2007.
- [8] N. Angelini, M. Gdula, C. Shelvin, JR’. Brache, “Mapping city potholes”, *Project Report, Department of Computer Engineering, Worcester Polytechnic Institute*, April 2006.
- [9] <http://www.sensorzine.com/user-manual-for-ultrasonic-distance-measurement-sensor-4m-rki-1540-503.html>
- [10] Luis Puebla Palma, “Ultrasonic distance measurer” implemented with the MC9RS08KA2 *Freescale semiconductor application note RTAC Americas* 2008.
- [11] <http://www.atmel.com/Images/doc2545.pdf>
- [12] [http://oceansjsu.com/105d/exped briny/13.html](http://oceansjsu.com/105d/exped%20briny/13.html)
- [13] <http://www.engineersgarage.com/embedded/avr-microcontroller-projects/serial-communication-atmega16-usart>
- [14] <http://en.wikipedia.org/wiki/Ultrasound>.

- [15] <http://www.sensormag.com/sensors/acoustic-ultrasound/choosing-ultrasonic-sensor-proximity-or-distance-measurement-825>.
- [16] [http://en.wikipedia.org/wiki/Electromagnetic\\_spectrum](http://en.wikipedia.org/wiki/Electromagnetic_spectrum)
- [17] <http://www.lsbu.ac.uk/water/vibrat.html>
- [18] [http://www.seeedstudio.com/wiki/5mW Laser Module emitter - Red Line](http://www.seeedstudio.com/wiki/5mW_Laser_Module_emitter_-_Red_Line)
- [19] <http://www.enotes.com/topic/Frequency>