

# IoT Platform for Road Surface Analysis Using MEMS Data AI Based Fault Detection System

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## ABSTRACT

The road surface is subject to various types of challenges/problems that can affect its integrity, safety, and overall functionality. The increasing reliance upon Intelligent Transportation Systems (ITS) has provided a new opportunity to use innovative approaches to monitor and address these issues with road infrastructure. To this end, this paper presents an Internet of Things (IoT) platform for the full evaluation of road surfaces utilizing Micro-Electro-Mechanical Systems (MEMS) data. The proposed platform will utilize a network of MEMS sensors located at specific locations (i.e., roadways) to provide real-time data on multiple parameters, such as vibration, temperature, and strain. The IoT platform will be the framework for aggregating and processing the MEMS data. An artificial intelligence (AI)-based fault detection system will be utilized to process and analyze the data collected by the MEMS sensors, detecting anomalies that indicate deterioration of road surface conditions (e.g., potholes/spalling) or other structural defects. Machine learning algorithms will be used to analyze historical databases and train the system to autonomously detect/classify faults with a high degree of accuracy. The fault detection system will utilize a combination of feature extraction, pattern recognition, and anomaly detection methodologies to assess the condition of road surfaces. The implementation of AI will provide two important benefits: (1) increased accuracy of fault detection and (2) the ability to implement predictive maintenance through timely interventions that will reduce the likelihood of further deterioration.

**Keywords:** IoT, MEMS, AI, Road surface analysis, Fault detection, Intelligent Transportation Systems, Predictive maintenance, Anomaly detection.

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## I. INTRODUCTION

There is a critical need for pavement defect detection, specifically in terms of identifying and repairing cracks. If the cracks can be detected quickly and repaired, then the total service life of the road will be increased, resulting in reduced overall maintenance costs to the owner as well as improved safety for motorists. Historically, crack detection was performed using manual surveys of cracks conducted by trained inspectors following the standards set forth by the Federal Highway Administration (FHWA). These methods are time-consuming, labour-intensive, and subject to varying degrees of accuracy. Therefore, with these methods, it is very challenging to establish data accuracy and repeatability, and

there are safety concerns to personnel conducting the manual inspections. [1]. Therefore, these advances will provide a rapid, efficient, and cost-effective option for highway maintenance activities. The mounting of the camera and LIDAR has been calibrated to maintain their relative position to each other using a custom 3D printed mount, which will allow for a standalone measurement device that can be used in various inspection vehicles without requiring recalibration. Consequently, this will help provide consistent performance and ease of use on all platforms. [2]. The advancements made in computer vision (CV) have improved image segmentation functions and in turn, have improved the detection of cracks in structures using image analysis and deep learning segmentation. Both methods will be very useful for the identification of cracks, taking advantage of advances made in the area of computer vision. [3].

Most previous literature in deep clustering methods has focused on exploring classes within datasets that are generalizable and less complex in nature (e.g., MNIST, ImageNet, YFCC100M). The snow-covered road images used in this study, however, are representative of more complex scenes. We used a systems engineering approach to design an automated AI-based framework for annotating the snow-covered road dataset into four distinct categories based upon: (1) Developing system specifications; (2) decomposing the framework into functional modules and finding solutions for all the requirements by completing the following steps (i.e., Data Pre-Processing, Feature Extraction using CAE, Unsupervised Clustering); and (3) applying a deep learning-based classification algorithm to verify the existence of the unknown images found in the dataset [4]. Through a multi-view feature fusion strategy, deep learning-based models will be able to exploit multiple viewpoints of an object to better locate structural characteristics. The ability of DSConv to capture critical features of the target from multiple positions allows for improved model accuracy and performance in identifying complex crack patterns. We also developed a parameter-free attention mechanism, SimAM, to allow the model to focus its attention on critical areas within an image while filtering out background clutter and providing detection of fine and irregular cracks in roadways. Thus, improved detection efficiency is achieved without sacrificing detection speed.

The use of these technologies in unison resulted in a model that performed well in a variety of complex situations and environments, and subsequently gave the solution to the challenges associated with crack detection.[5] The analysis showed that the AR-displayed elements form a visual or cognitive distraction for an operator, depending on what the perceptual form of the graphic element is on the AR display. For Example, in some cases the AR visualisation (for example the “virtual transparent shadow” of where the pedestrian is expected to walk), had a positive effect on the driver’s awareness, and did not detract from his awareness of other objects or elements in the scene. However, using a bounding box to describe the pedestrians caused cognitive overload on the driver because it added excessive visual content to the scene, and degraded attention from the driver on other objects in the scene (which were not highlighted by the bounding box but may have been equally or more important). Therefore while it is clear from the results that AR has potential to improve situational awareness, considerable care must be taken during the design and development of an AR system to avoid creating additional distractions that could reduce the effectiveness of the AR display for assisting the driver.[6] As such, this paper provides value to the reader by demonstrating the significance of the road defect detection issue and the effect of road defects on vehicle damage and human life. This study demonstrates tools to identify road surface defects over time both before and after implementation of single-sensor-based devices or systems that have evolved into multiple-sensordevice systems to automate dataset acquisition. [7] The armature current of the DC motor is controlled by the DC chopper allowing for appropriate speed and torque. In order to perform a power analysis for wind turbines, we first determine

the maximum power produced by the wind turbine by using maximum power points to plot various curve sizes in accordance with changing pitch angles and velocity of wind on the wind turbine. The control system receives data collected from the DC chopper, and sends control voltages to generate control pulses for the DC chopper. The objective of this research project is to develop intelligent IoT wind emulator systems using data acquisition methods. The output of the IoT wind emulator system will also be monitored remotely by using IoT monitoring devices. Additionally, Unlike other researchers who only evaluated their test system at other facilities under controlled conditions-i.e., equivalent to a track facility-and did not evaluate their testing devices in any public roadway setting until now. We however, are providing novel public highway data at greater speeds (wheel velocity) and steering angles than previous studies, while also evaluating unfamiliar environmental scenarios than those seen in previous studies. [8].

## II. RELATED WORK

Detecting pavement defects is important for revenue generation by detecting the best time to repair pavement but is very difficult because it occurs within large backgrounds, low resolution images, and cracks look the same. [1] This paper describes the development of a road crack detection algorithm based on YOLOv- to enhance the Vanillan Net with SE attention modules for improved detection. The original loss function for the bounding box regression was replaced with a weighted loss to produce more balanced results. We have developed a process that is fully automated and is able to locate and repair potholes which will enable reduced reliance upon the use of manual inspection and thus reduce the time for roadway maintenance. We are integrating depth information derived from combining LiDAR (Light Detection and Ranging) and RGB (Red, Green, Blue) camera data so that we can provide a very accurate characterisation of a pothole. WE are using global position through GNSS of a large number of publicly available roadway image datasets of potholes to train the YOLO object detection model used in this work.

This paper presents a new network with the goal of balancing accuracy versus model size; therefore the objective of this work is to increase detection accuracy while minimizing the size requirements of the network. The proposed method consists of incorporating hybrid transformer blocks into C-Nets to enlarge their receptive fields. Additionally, this paper presents a new Adaptive Feature Mapping model to provide the neural network with additional means of learning about, and integrating, various levels of data, including using lower level feature maps for a complete crack detection process. In addition to this goal, this paper will also present an artificial intelligence (AI) based annotation system for a publicly available dataset of snow covered road photographs taken from CCTV footage and other associated time and weather metadata. This data was processed using several data processing methods to provide an automatically generated annotation of each image relative to one of four categories of snow coverage based on snow removal activities. The data was then analyzed through feature learning, using convolutional autoencoders, as well as utilizing

clustering of the images through graph-based clustering, specifically using the Louvain community detection algorithm.

Target detection algorithms, combined with UAVs (unmanned aerial vehicles), can improve road crack detection. Our study utilized RC-YOLO (Robot Control using YOLO), an algorithm for detecting road cracks using UAVs. RC-YOLO consists of a C2f\_DySnakeConv module at layer nine and a SimAM module above the SPPF along with a dyhead attention detection head that fuses three different types of attention mechanisms. Recent developments in sensing and communication technology and IoT could provide opportunities to enhance collaborative situational awareness to detect dangerous driving conditions and exchange information about those driving conditions via cooperative driving methods. Innovative Augmented Reality (AR) visual interfaces such as windshields can now provide a safe and unobstructed way to visualize these new types of data. Damage to and/or defects in a roadway have a significant impact on how well and safely the roadways operate and economically are operating. At present, road conditions can take weeks or months to be fixed by related government agencies after damage is done due to not being aware of it in the first place, (7) We will discuss a review of what is currently being researched and the limitations of the current status or limitations of sensor/calibration of the measurement and classification of road surface conditions is to explain how the findings presented in (8) have been generalized to a larger set of data collected from experimental sites and how to determine how environmental variables and higher speed and greater turning angles affect the performance of the sensor/calibrators and how that affects the performance of classifications made by the sensor/calibrators. As will be discussed in [9] there is a strong correlation between the reduction of friction and the amount of water on a road surface when there is a water film covering the surface and this will be beneficial for all road users (drivers and autonomous systems) to know what the current condition of the road is in regards to the water level on the surface. An example of this would be a capacitive transducer that could be used to measure the amount of water removed from a tire and therefore could help to determine the amount of water on a surface. Previous studies have shown that measuring/identifying water levels using capacitive sensor arrays is an appropriate method, and there are many opportunities for improving classifier results in present and future studies that have used only one classification technique.

The knowledge gained from this project can be used in both ADAS and to provide autonomous vehicle control to improve vehicle safety and performance while meeting the above objectives. In [10], we provide an algorithm that can be used to classify different types of roads based on tire sensor signals from individual vehicles. The reason this is complex is that the measured tire signals are not either linear or stationary over time. Thus, we will be using a combination of time-frequency distributions combined with machine learning techniques to classify different types of roads.

### III. SIGNIFICATION OF THE ARTICLE

This project will create a "road classifier system" for assessing the quality of road infrastructure using real-time

automated algorithms. These algorithms will be developed using innovative AI techniques to learn from data captured using integrated visual and MEMS sensors, creating an autonomous vehicle-based system. The algorithms will run on an electronic module located on the dashboard or vehicle onboard; additional sensors will include devices installed in the vehicle's suspension cavity and a camera capable of transmitting data via Wi-Fi or IoT. Another significant aspect of this project is the generation of brand new datasets of inertial measurements taken from the wheel and road interactions during various road types. This measurement data will come from several different measurement campaigns and in part through data augmentation. Overall, the data can describe a variety of types of roadways; for example, good (nonslippery) paved, unpaved, and poor (cracked or rough). The following are the main contributions of the current paper: When a vehicle moves over a hole in the road, vibrations occur and the movement of the car can be detected with an accelerometer that is being used to measure how severe the hole is. In addition, the accelerometer will give you information from three different directions or axes (x, y and z) and is designed to measure the amount of movement or change in direction of the vehicle at the same time. The amount of vibration detected will be recorded together with where the vehicle is located when the pothole was hit and this data will then be sent to a centralized server for processing. The GPS will track the coordinates of the holes and will be used to create an index of the pothole on a digital map for the user to access through their mobile device.

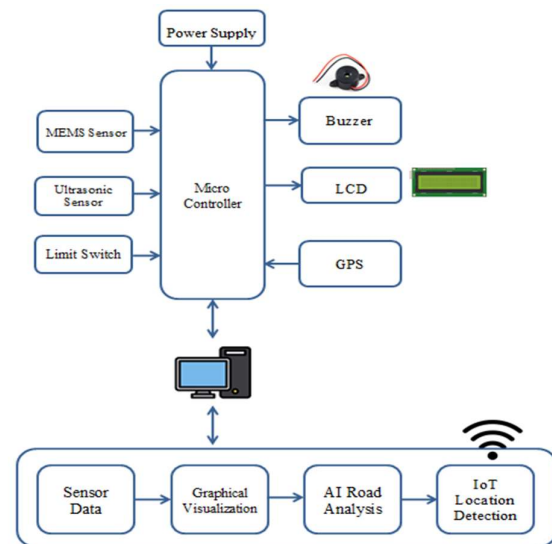


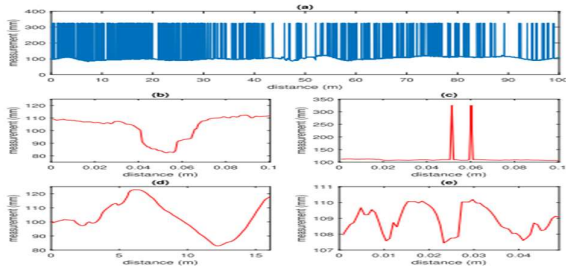
Figure 1 : Proposed Block diagram

## IV. METHODOLOGY

### A. Principle Of Point Laser

The assessment of defective roadways using laser technology has been previously documented. As a laser beam travels down the length of a roadway, it identifies areas where portions of the pavement have settled (i.e. total). A point laser located on the upslope side of the vehicle points to a location on the ground

below it in order to measure the time of flight (ToF) of the laser beam when it returns to the sensor. If the roadway surface is smooth and without defects, then the laser light will be emitted back to the point laser sensor in a uniform manner from a number of different angles. However, because an area of cracked pavement has different reflectivity and many different reflective paths exist between the point laser and the point laser sensor, there will be many different returns from an area of cracked pavement vs. what would be returned from an area of smooth pavement. Therefore, by analyzing how much the return signals deviate from returns produced on a smooth surface, the location of cracks can easily be determined. However, this evaluation is not as simple as it appears due to numerous sources of interference which will degrade the performance of a point laser system.



*B. Accelerometer*

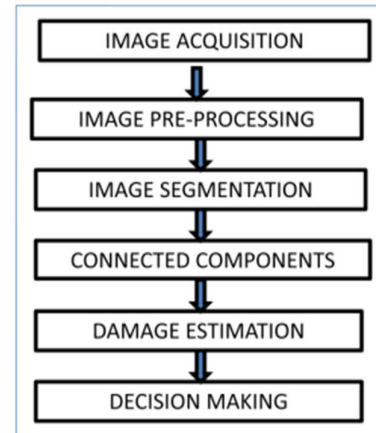
Utilizing accelerometers that are connected to the Internet of Things (IoT), road conditions can be monitored and evaluated using the data captured by an IoT-enabled accelerometer, which measures acceleration and motion of the road surface. The accelerometer data will allow transportation agencies and other road maintenance authorities to identify where road surface quality is deficient and the accelerometer data can help to; identify potholes, cracks, and other types of road surface deterioration; improve efficiencies in maintaining roads by determining when maintenance needs to occur; and ultimately improve the safety of the roadway by creating a proactive approach to maintenance. In addition, using the IoT accelerometer data can enable transportation agencies to develop improved methods of traffic management; provide the basis for scheduling maintenance on roadways; and enhance the overall quality of the vehicle operation for the driver of the vehicle.

*C. Image Processing Methods*

The combination of image processing with Convolutional Neural Networks (CNNs) is a powerful combination for analyzing the roads of a given location. CNNs are used to extract and analyze valuable data from images of different types of roads, which can be captured using mounted cameras on vehicles or drones or through fixed sensors.

With the use of a CNN, a machine learning algorithm can be trained to recognize and classify the different patterns, textures, and anomalies found on a road surface (cracks, potholes, road markings, and debris). The training process for a CNN consists of providing the CNN multiple images of road surfaces, in which the CNN will develop the ability to identify

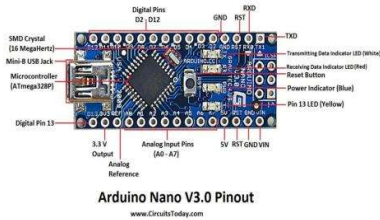
patterns and textures from the various images it is provided. Once a well-trained CNN has been established, it is ready for deployment in real-time analysis.



This tech is very useful for conducting a road surface analysis. It provides a fast, automatic review of the condition of our roads and allows them to be maintained or repaired as needed in a timely manner. Also, it identifies any potential safety hazards which help to improve safety on our roadways. Additionally, the data generated from performing a CNN-based road surface analysis can be combined with other types of transportation management systems to assist with the optimization of traffic flow as well as to provide additional information for use in planning, developing or maintaining infrastructure.

*C. Hardware Description  
Arduino Nano*

The Arduino Nano is similar to the Arduino Duemilanove, but it comes in a different style. The Adobe Nano is equipped with an ATmega328P Microcontroller (same chip as the Arduino UNO). The only major difference between the two is that the Arduino UNO is built as a PDIP (Plastic Dual-In-Line Package) with 30 pins whereas the Arduino Nano is TQFP (plastic quad flat package) with 32 pins (the two extra pins on the Arduino Nano provide the ADC functionality). In addition to the 6 ADC ports provided by the Arduino UNO, the Arduino Nano also provides 8 ADC ports (the latter 2 of which are the additional pins). Another major difference is that the Arduino Nano does not have a DC Power Jack like other Arduino Boards. Rather, the Arduino Nano has a Mini-USB port to provide power for programing and providing Serial Monitoring. The unique feature about the Arduino Nano is that it has a way of determining which power source provides the most power based on electrical potential; therefore the power source selection jumper is rendered useless.



LCD (Liquid Crystal Display)



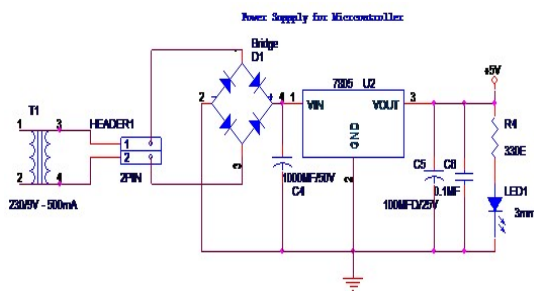
An LCD display is a type of electronic display module used for a variety of applications. The 16 x 2 LCD (a matrix of 16 characters along each line and 2 lines) is quite common and very basic to find in devices/circuits.

In this case, it will display the character of a given line in a 5x7 pixel matrix, with 5 pixels vertically and 7 pixels horizontally.

There are unique registers inside the LCD display, the command register and the data register. The command register will hold the commands to perform various functions by the LCD, while the data register will hold the data, which will eventually appear in the display area associated with each character.

Power Supply

A power supply may also be known as a power supply unit (PSU), or occasionally it may be referred to as a device, machine or system that provides electric or other energy (see below) to one or more output loads or groupings of load (by grouping loads together by type), typically and in most instances, this word refers to the source that provides electric power, less frequently this word has been used to refer to things providing mechanical energy (see below), and only very rarely to anything else in the literature.



Transformer

This small +5V Power Supply circuit is useful for testing/evaluating digital electronics. Wall transformers can be

purchased at any electronics store and supermarket at a low cost, and are typically capable of providing varied output voltages.

Accelerometer

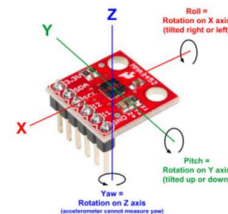
An accelerometer is an important instrument that measures acceleration (linear, rotational and gravitational) in many different types of industries such as engineering, physics, bio-mechanical and consumer electronics. Accelerometers began as relatively large devices, but over time have become smaller, more accurate and more versatile - allowing them to become utilized as components within further types of devices.



Accelerometers work from the basic principle of inertia; they have a mass suspended inside an enclosure (typically either spring mounted or attached to a piezoelectric material). The mass also experiences a force that is equal to the acceleration experienced by the accelerometer, from which you will derive your acceleration measurement from this displacement of the mass relative to the casing.

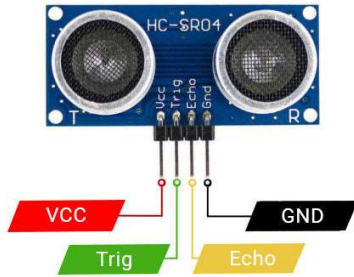
Mems Sensor

In the 1900s, accelerometers best known as the first accelerometer used to determine movement in the earth for purposes of determining if there was an earthquake were large, heavy and not able to measure motion very well. In the later part of that century, through changes in the microfilming process, miniaturized versions of these large accelerometers were now made which had the same use as their larger predecessors but were to be used in greater amounts.



MEMS accelerometer sensors, which are truly miniature; only measuring typically in millimeters. MEMS accelerometer sensors have very accurate and sensitive measurements of acceleration due to their design consisting of a very small proof mass (a mass that you can measure to get an idea how much force is being applied), suspended from four springs with microstructures integrated into a silicon substrate. When you change the motion of the proof mass, the proof mass will produce an electrical signal that can be measured and recorded.

Ultrasonic Sensors are a type of sophisticated electronic device that uses ultrasound (sound waves above human hearing) and provides a variety of applications across multiple industries including the automotive, healthcare, general industry or manufacturing, robotics, and consumer electronics due to its accuracy, reliability and versatility



Ultrasonic Sensors: The three major parts of an ultrasonic sensor include the sensor's transducer, the control circuit and the enclosure (which houses the other parts). The ultrasonic sound waves are used for detecting or measuring distance.

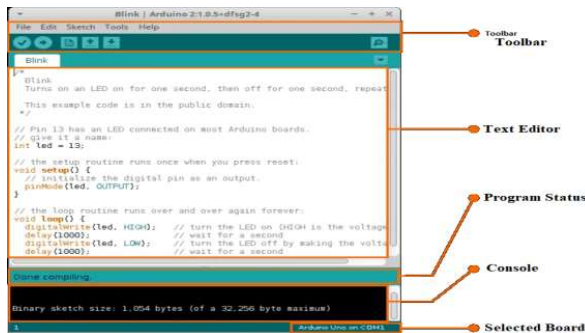
### E. Software

#### Arduino IDE

The Arduino IDE (Integrated Development Environment) is the most popular software tool to program an Arduino board. The Arduino IDE is a free and open source software program. It is available on many different locations.

#### Bootloader

The Bootloader is installed on the ATmega 328 microcontroller so that programming of an ATmega328 can take place from the Arduino development environment via the IDE (Integrated Development Environment). When power is applied to a board or it is reset, an initial bootstrap occurs. When the IDE sends a signal to program the ATmega328, it uses a serial connection to programming via program memory on the dc voltage logic electrical signal level and the baud rates between the IDE and the ATmega328 must match.



#### Python Software:

The programming language known as Python is very complex and allows for the creation of coded programs that function in a computer-readable manner (i.e., execute as code). The original version was created by Guido van Rossum and released to the public in 1991. The goal of Python was to provide

programmers with a way of writing programs in a simpler, more understandable manner. An example of the uniqueness of Python lies in the use of characters and white space to express a programmer's thoughts. Thus, code written in Python can be implemented in several different forms, from a basic script for a small program, to an interpreter or compiler for a larger program. Python's use of dynamic typing and automatic garbage collection enhance the development and usage of applications built with it.

## V. RESULT AND DISCUSSION

In the current project model the Automatic detection of potholes and humps will alert drivers of vehicles reduce the speed and avoid accidents. Well maintained roads form an essential part of the national economy. In our current project we will only require one hub of information; however, in the future we may need a database server. If we have n number of nodes, we would need to create a cloud. The new proposed system is designed to improve user experience through integration of their use. The sensing module system based on Arduino, has been designed & tested to demonstrate successful encounter of vehicles driving on uneven surfaces. Using real-time pothole information, the location of the actual abnormal road condition will be captured and stored in Thing Speak open source data centre. The system is made up of two separate components, hardware and software. The hardware component consists of the supporting hardware including; accelerometer (MEMS), GPS, GSM Module, LCD, buzzer and Power Supply Module. The software component is developed using Arduino IDE. A low energy microcontroller is an Atmega328 Arduino that provides the hardware side of the system. ADXL335 was selected from a variety of accelerometers by the use of their respective 3-axis accelerometer capabilities. Three output pins (X, Y, Z) provide 3-dimension vibration measurements, of which the Z value will be sent directly to the Arduino. An analog to digital conversion will take place inside the Arduino via its built-in ADC (Analog-Digital Converter). A GPS device will provide a method for tracking the location of the system module, where there is a real-time wireless communication between the server and the system.

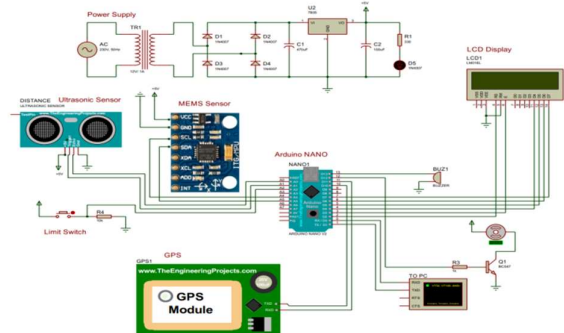


Fig 1.3 Proposed Circuit Diagram

The above computation had been performed and the damage was identified in the image. The results of the damages found were also found in the images below. If the percentage of damaged street pixels was greater than either of the appropriate

rate or threshold then either an error box created, or a prompt created, that would show the user an alternative route in order to provide better travel experience. During this test only a small amount would cause interference but they wouldn't have made a significant impact to the final product, so they were disregarded. Many different sources of images were used for testing and the accuracy was nearly 90% overall. A simple code that gives accurate results faster and better than both by using live feed video or by using prerecorded video.

Parameter	Value[pixels]
Undamaged road pixel	124383
Damaged road pixel	12057
Total road pixel	136440
Result	Continue road

Table : Experiment Results

**VI.CONCLUSION**

The purpose of this project is to automatically detect potholes and speed bumps, and to warn drivers about them in order to slow down their vehicles to avoid accidents. Well-maintained roads are vital to the overall economy of any country, and our project will use one single node in the present time, although there may be a need for a database server in the future. If we add additional nodes, we will create a cloud-based system that can be integrated to enhance the overall user experience. The two-part system consists of an Arduino-based sensing module installed inside the vehicle, which has been tested and designed in the past that drive on bumpy roads, and the real-time location of potholes (and other abnormal road conditions) has been recorded using an open-source ThingSpeak Data Center. The basic design of the two-part system comprises one part with its hardware (supporting hardware components) and the other with its software components (programmed on the Arduino IDE). The hardware section includes an accelerometer (MEMS sensor), GPS receiver (used for tracking the location of where the vehicle is occurring), from the (GSM) Global System for Mobiles (GPRS), an LCD display, a buzzer (for sound output), and a power supply unit. The software side will consist of the Arduino development software. The hardware component of the system is composed of the Arduino Atmega328 low-power microcontroller along with the ADXL335 3-axis accelerometer, which has been part of a wide selection of accelerometers. The ADXL335 has three output pins (X, Y, and Z), and each axis produces readings of vibrations in three dimensions. The value that is available to the arduino will come from its z axis's output pin. The Arduino has a built-in analog to digital converter (ADC), which allows it to convert an analog value into digital value. The GPS will allow the system to be able to track its position in real time, and maintain a wireless connection to the server in real time.

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