# Pothole Tagging System

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***Abstract*—Potholes are not only a source of frustration to drivers but also negatively impact the economy due to damage to vehicles and costly road repairs. Regular and rapid pavement inspection and maintenance is key to preventing pothole formation and growth. To improve the efficiency of maintenance and reduce the cost thereof, a vehicle mounted sensor system is being developed that will automatically detect and analyse potholes. The results will then be packaged together with the Global Positioning System (GPS) coordinates of the pothole for use by technical experts and maintenance schedulers. The system will utilise a Microsoft Kinect and a high-speed USB camera as sensing devices.**

## I. Introduction

Potholes are an irritation, an eyesore and a major cause of damage to motor vehicles. These road surface distresses can also cause accidents when drivers swerve across a road to avoid potholes. Due to these factors potholes have become a serious concern for the South African government, which has launched a new initiative with a budget of R22 billion over three years for the repair of potholes [1].

Potholes are generally caused by the ingress of rain water into the structure of a road [2], but their occurrence can be mitigated by routine road inspection and the sealing of surface cracks. Existing potholes should also be quickly detected and repaired to prevent pothole growth. Finally, it is important to repair potholes in the correct manner to prevent them from forming again.

An automated pavement inspection system attached to a vehicle would improve the efficiency and reduce the cost of a road maintenance program. Data on road surface distresses can be collected by an untrained driver without having to stop the vehicle. The collected data can then be analysed by a technical expert who could then decide the best way in which to repair a road. A maintenance manager can also use the data to determine the most efficient repair schedule. The effects of such a system is that data can be collected more quickly and more regularly and that professional personnel can work in a more time efficient manner.

Various pavement distress inspection systems have been developed, each focusing on different types of surface distresses. The system described in [3] is used for rut measurement and crack detection. The system presents its data in the form of a map of the cracks on a section of road and the measured road profiles. In [4] the texture of a road surface is measured, with the goal being to replace the destructive skid tests normally used to measure texture. Laser ranging is used to measure the elevation size of pavement in [5]. In [6] a number of pavement distress characteristics are measured, namely crack patterns, rut depths and longitudinal profiles in the wheel paths. The latter indicates the roughness of the pavement. The advantage of the defect detection methods discussed is that potholes can be prevented before they are formed. It is still necessary to quickly detect potholes once they already have formed, as potholes can cause damage to vehicles.

There are different approaches to implementing pavement inspection which depend on the choice of sensor used. 2-D Laser scanners have been used in [4] and [5]. The output of two auto-synchronized laser scanners are combined to obtain 3-D data in [3]. In [6] they use a collection of 3-D laser-based optical sensors. This system also records the GPS locations of detected distresses. Ground penetrating radar (GPR) has also been used to evaluate pavements [7] with the advantage that data can be obtained of the sub-surface structure. Laser scanning sensors and GPR are in general very expensive devices. Cameras, as will be used in the proposed system, provide a relatively inexpensive way in which to do pavement inspection, but require the use of complicated algorithms to produce 3-D data. A survey is presented in [8] on various automated distress detection systems that utilise machine vision. In [9] a digital camera is used, while in [10] a structured light approach, utilising both a laser and a line scan camera, is used.

The use of visual data for pavement monitoring facilitates the use of existing image manipulation algorithms and pattern recognition techniques. Multiple types of cracks are both detected and classified in [9]. In [11] another system for crack classification has been developed which utilises a skeleton image of a road section. The system also provides a measure of the severity of the pavement distress. A pothole detection system is presented in [12]. Partial differential equations are used to do the initial segmentation which isolate distress regions. Thereafter the system uses non-linear support vector machines to differentiate between potholes and other types of distresses. Texture comparison is used in [13] to confirm that extracted defect regions are indeed potholes.

## II. SYSTEM OVERVIEW

The goal of the system presented in this paper is to provide a low-cost sensor system which can be mounted onto a vehicle and automatically detect and analyse potholes. The system must also record a photograph, 3-D point cloud data and the location of detected potholes. This recorded data will then be analysed to determine the width and the depth of the pothole. The pothole locations will also be overlaid onto a map of the roads that were scanned using the Google Maps Application Programming Interface (API). The design of the system assumes that the motor vehicle will travel at a maximum speed of 60km/h, the legal limit for residential roads in South Africa.

### A. Kinect

3-D information on pavement structure enables more in-depth analysis and reliable distress detection. As has been mentioned, sensors that were capable of producing 3-D data in the past have been either expensive or had required the implementation of complicated algorithms. With the release of the mass-produced Microsoft Kinect gesture based interface for the XBox 360, an inexpensive 3-D sensing device has become available. A Kinect consists of a normal colour camera, an infrared projector and an infrared receiver. The latter two are used to produce depth information using a structured light method. The projector emits a specific pattern of dots and the depth is determined from the change in position of the dots as measured by the receiver. Both the camera and receiver produce image and depth data at a rate of 30 Hz and at a resolution of 640 by 480. The depth data is produced in the form of a point cloud, which is an array of the 3-D coordinates and the red, green and blue (RGB) colour values for each point. One of the advantages of the Kinect is that there exists a correlation between the pixels on the camera image and the points in the cloud.

### B. High-Speed Camera

If the vehicle is traveling at 60km/h, the Kinect (operating at it's maximum rate) will capture fewer than two point clouds per second. Therefore a high-speed camera will also be used to ensure that enough data is captured. The camera to be used is the DFK22AUC03 universal serial bus (USB) complimentary metal-oxide semiconductor (CMOS) camera manufactured by The Imaging Source. It is capable of between 60 to 150 frames per second. It also has an image resolution of 744 by 480, which is reduced to 320 by 240 at higher frame rates. A M0814-MP2 Megapixel lens will be used in conjunction with the camera, also manufactured by The Imaging Source.

### C. Hardware Layout

Figure 1 illustrates the designed hardware layout for the system. The sensing devices will be housed within a sensor rack mounted onto the exterior of the vehicle. A laptop computer, secured within the interior of vehicle, will be connected to the various sensing devices. A customised Dell M4600 Precision laptop, with 16 GB of RAM and 2.5GHz Intel i7 processor will be used. Such a high performance laptop is needed due to the steep processing and memory requirements imposed by the high rate of data generation from both the high speed camera and the Kinect. The laptop is also outfitted with a 256GB solid state hard drive to facilitate rapid transfer of data. A u-blox 5 evaluation kit (EVK-5H) will be used to provide the GPS coordinates of the vehicle.

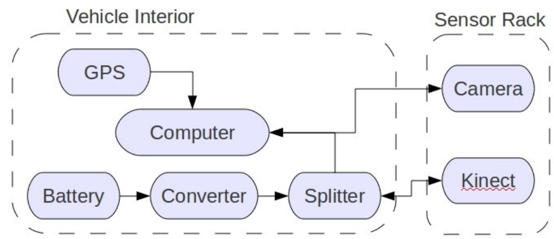


Fig. 1. Hardware layout.

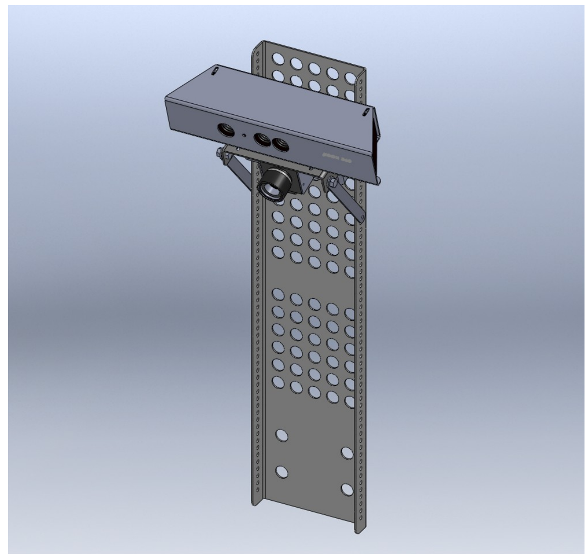

Fig. 2. Design drawing of the sensor rack.

### D. Power Sources

The Kinect requires a 12 V power source to function. A 12 V battery is connected to a DC to DC converter (A Mornsun VRBD-40W). The converter also provides over voltage and short circuit protection. The converter is connected to a splitter cable (sold as part of the Kinect system) which provides a standard USB connection for the laptop and a modified USB socket for the Kinect. The camera is powered through the USB data cable connecting it to the laptop.

### E. Sensor Rack

The purpose of the sensor rack is to provide a secure mounting position for the sensors onto the exterior of a moving vehicle. The platform had to be designed in such a manner that it does not require any modification of the vehicle it is to be attached to. As a vehicle's tow bar provides a reliable and rigid mounting location, as well as an existing

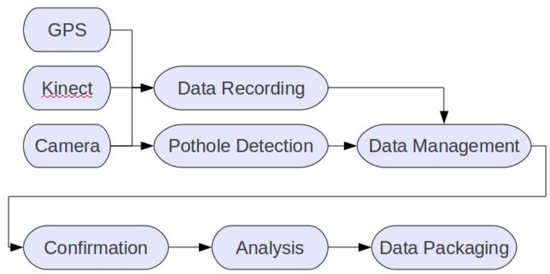


Fig. 3. Flow chart of pothole detection and analysis system.

mounting point, it was decided to locate the platform on the rear of the vehicle secured on the tow bar. The rack has been designed to easily attach in-between the tow bar and the tow-bar mounting plate. The platform also facilitates the cable connections between the sensors and the interior of the vehicle.

As the optimal positioning and viewing angle of the sensors still needs to be determined, it is required that the sensor rack be adjustable. Therefore it has been designed so that the sensor height and angle can be changed, while not compromising on the stability of the structure. In figure 2 an isometric view of the sensor rack can be seen. The sensor rack has a total length of 0.65 m. On a Volkswagen Polo Classic (2007 model), the tow bar is roughly 0.3 m above the ground. This results in a total height variability of between 0.35 to 0.63 m above ground. The platform consists of the following assembled mechanical parts: the main mounting plate, the Kinect enclosure, support bars, the camera plate, a bracket for the camera and a Kinect support plate. The body structure is made out of 304 stainless steel metal plates.

### *F. Software*

The software for the system is based on Robot Operating System (ROS), an open-source meta-operating system developed and maintained by Willow Garage [14]. ROS offers a plethora of drivers for sensor devices (such as for the Kinect and GPS module) and a data transfer structure, which enable faster development of sensor system applications. Furthermore, various useful libraries such as the computer vision library OpenCV and the Point Cloud Library (PCL) have already been integrated into ROS. PCL provides routines for the manipulation, filtering and segmentation of 3-D point clouds.

Figure 3 shows a flow chart indicating the operation of the pothole detection and analysis system. First, sensor data from the GPS, Kinect and high-speed camera are synchronised and temporarily recorded. The high-speed camera data is examined to see whether it contains footage of a pothole. The Pothole Detection function utilises edge detection to find the sharp texture changes between the pothole and the road surface. Only the image data from the high-speed camera is used in this step because of its higher data production rate and the computation time involved in working with point clouds. If a pothole has been detected, the data management routine permanently saves all of the GPS locations, 3-D point clouds and camera images recorded within a certain time interval around the time of detection. If a pothole has not been detected, the recorded data is discarded. The data management routine is vital as the amount of data produced by both the Kinect and the camera can be quite large.

After the data has been stored, the point cloud is investigated to confirm whether a pothole has truly been found. Thereafter, the point cloud is analysed. To do the analysis, the edge of the pothole on the road surface needs to be determined. First, the plane of the road surface is estimated using the random sample consensus (RANSAC) algorithm. The points which do not form part of the plane are therefore the points describing the pothole. The correlation between the Kinect camera image and the point cloud is then used to segment the plane on the camera image. Thereafter contour detection is used to identify the pothole edge. The width of the pothole is defined as the maximum separation between points found on this contour. The depth is determined as the maximum perpendicular distance between the road surface plane and the pothole points. After analysis, all of the calculated information is packaged together with the pothole sensor data for later use.

## III. Early Results

At the time of writing this paper, the project was still in its early stages. Some tests were done to determine the viability of using the Kinect to examine potholes. Image and point cloud recordings were made of various potholes using the Kinect. In figure 4 pixels on a Kinect camera image were manually selected and the distance between the corresponding cloud points was calculated. The measurement made matched the actual pothole width to within half a centimeter. Figure 5 shows the results of a pothole extraction method. The plane was first estimated and the corresponding pixels were made black, as can be seen on the image. A pixel within the pothole was then manually selected. The value shown is the rounded perpendicular distance between the estimated plane and the selected pixel point. This value is also accurate to half a centimeter.

The set of images in figure 6 show the results of the initial pothole detection phase of the system. The high speed camera images were captured from a vehicle moving at 60 km/h. The images on the left show the input video data, while the images on the right show the detected edges. As can be seen, the edges have been detected and the confirmation and analysis phases can now be carried out.

## IV. Conclusion

A vehicle mounted sensor system has been designed which will automatically detect and analyse potholes. This system will now be manufactured, implemented and tested to see


Fig. 4. Pothole width measurement.

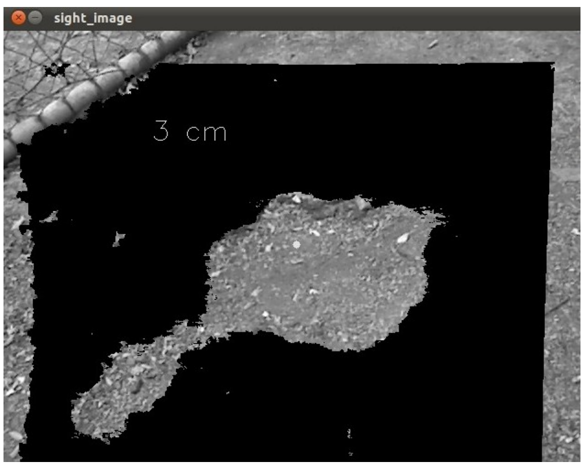


Fig. 5. Plane detection and depth measurement.

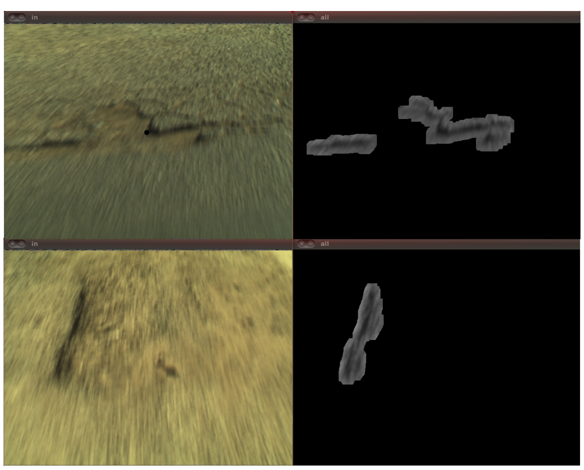

Fig. 6. Image edge detection on video captured from a moving vehicle.

whether it can accurately function at the required vehicle speeds. The benefit of the system is that, once it is operational, the resultant analysis of potholes can help in the scheduling of pavement repair operations with priority given to either larger potholes to prevent damage to vehicles or shallower ones to save on repair costs. The exact manner in which the system will be integrated into existing pavement maintenance programs will be determined at a later stage through interaction with the appropriate parties. The automated nature of the system will also increase the rate of pavement inspection routines, saving time and money. After the project has been completed, the system could be expanded to do rough deflection scanning, rut detection, crack inspection and classification. Furthermore, because the system provides the analysis results in digital format, the system can form the basis of a digital road maintenance system.

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