CONTINUOUS ROAD DAMAGE DETECTION USING REGULAR SERVICE VEHICLES

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ABSTRACT

We outline an affordable system that continuously monitors the road network for surface damage like potholes and cracks. The system consists of a structured light sensor and a camera mounted on vehicles that travel the roads on a regular basis. It makes use of sensors and equipment already present on the vehicle, like GPS on transit buses. The data is collected from many vehicles, aggregated and analyzed at a central location and the assessment results are displayed interactively to facilitate road maintenance operations. We describe in detail the key sensor, the data it collects and the algorithm to detect cracks and potholes.

Keywords: Structured light, road maintenance, pothole detection

INTRODUCTION

Maintenance departments need to regularly assess the quality of the roads in order to properly maintain them. Currently, this is done by yearly inspections or in response to reports from the general public. The inspection is sometimes done by workers walking along the streets and recording the conditions on paper which later is put into a database. In other cases the agency makes use of special vehicles that measure the road surface [1]. Those special vehicles can cost several $100k. In either case the cost of the monitoring is high. It would also be advantageous to continuously monitor the road surface so that damages like potholes can be detected as soon as they occur. Furthermore, detection of precursor signs like cracks will allow the maintenance crews to address problem areas before they develop into serious problems. In general, such a monitoring system will allow a more efficient allocation of maintenance resources. A "pothole patrol" system was proposed in [2]. They use accelerometer readings in cars that traverse the roads in question and look for the tell-tale bumps. This system was not able to detect cracks.

The main challenge for such a system is cost, which includes the price of sensing equipment and the cost of collecting the data. We propose a system with two key features: First, to keep the equipment cost down, we use low cost sensors and already proven equipment. Second, to minimize the cost of collecting road data, we use vehicles that already traverse the road network on a regular basis. In the following sections we will discuss these points and present our prototype system.

SENSOR

For this application we choose a laser line striper, a sensor based on the well-known principle of structured light [3]. A laser sends out a plane of light that intersects with objects which in turn is viewed by a camera (Figure 1).

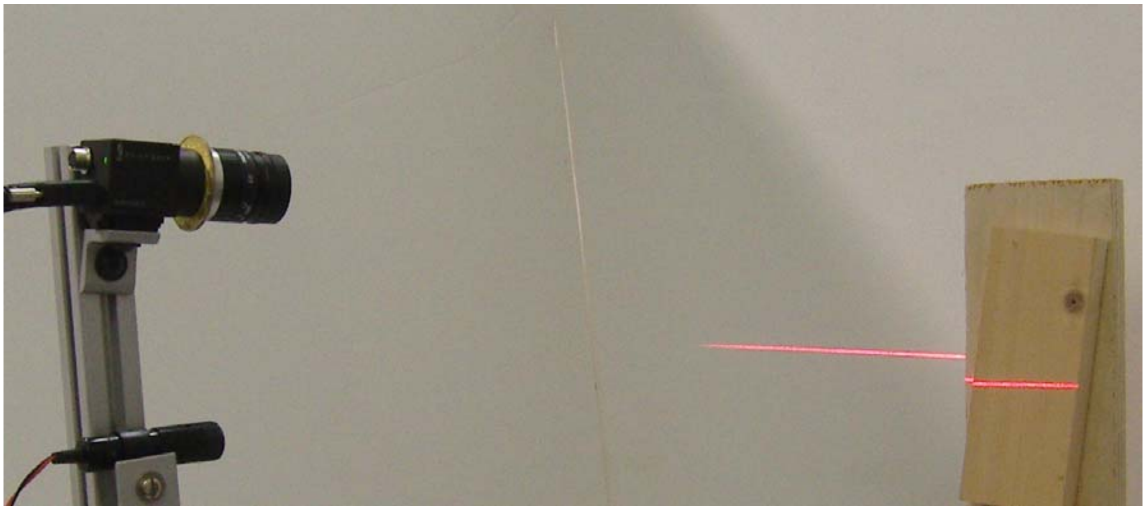


Figure 1 Basic configuration of a laser line striper: A laser (bottom left) sends out a plane of light that intersects with an object (right). The camera is located at a distance from the laser (top left) and views the object.

The camera has a band pass filter to suppress background illumination and in the resulting image the projected laser line stands out (Figure 2 left). The line in the image is transformed into world coordinates via triangulation (Figure 2 right). For each image of the camera one gets one cross section.

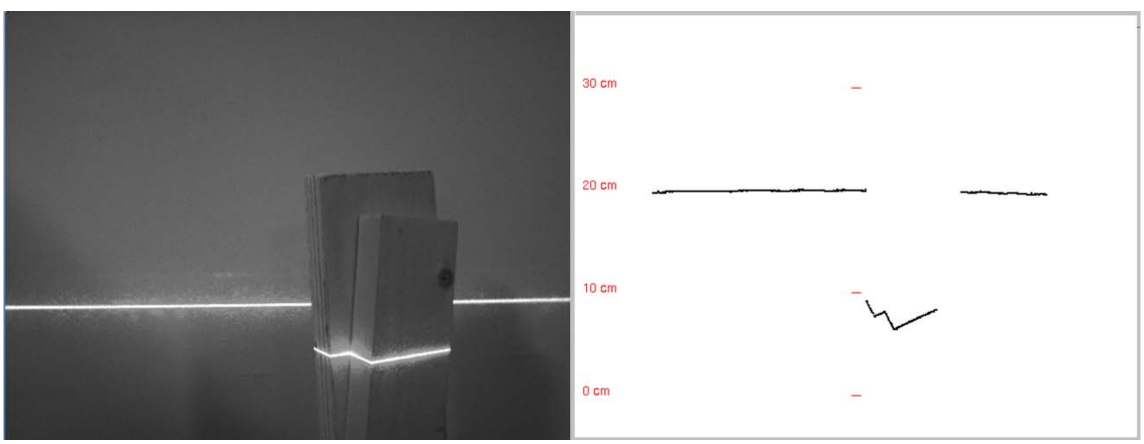


Figure 2 Left: The image seen by the camera in Figure 1. Right: The line transformed into world coordinates.

With such a laser line striper one can acquire high resolution 3D images at distances up to a few meters. An example is shown in Figure 3. A laser line striper was mounted on a pan-tilt-unit and a 3D image of a piece of pavement was created.

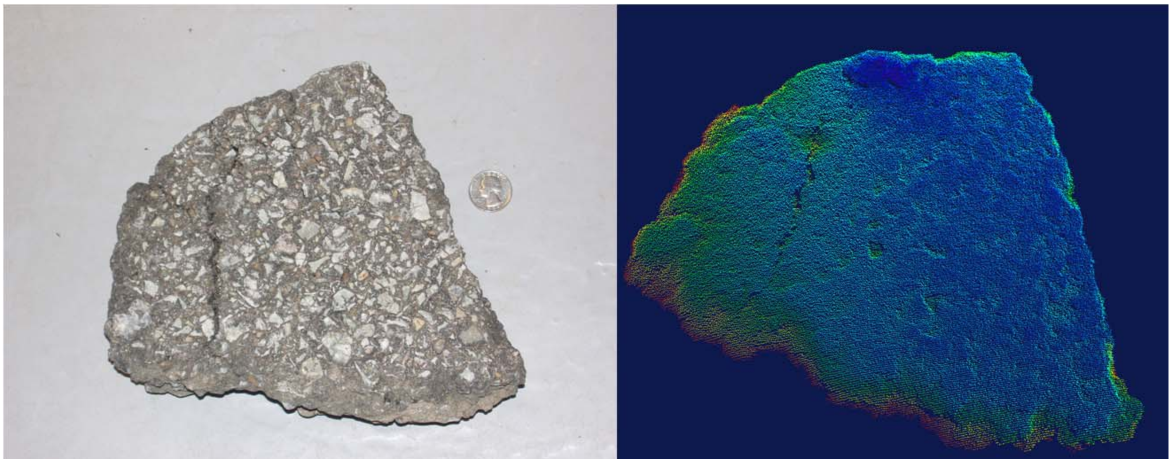


Figure 3 A piece of pavement (left) and its 3D image (right).

The advantages of a laser line striper are cost (around $1000), size and resolution. The system is small enough to be mounted in confined spaces. An example (Figure 4) is the system we installed inside the front bumper of a bus [4]. For the road monitoring project described in this paper we mounted the sensor in front of our test vehicle (Figure 6). For distances up to a few meters the sensor has high resolution, 1 mm resolution at about 1 m is easily achievable. In addition to the laser and camera sensor we installed another camera to record images of the road.

Figure 4 Example of a laser line striper mounted in the front bumper of a transit bus.

SYSTEM OVERVIEW

A key point for the road monitoring system is to use vehicles that traverse the road network on a regular basis (Figure 5). Examples are transit buses that go on their routes several times per day or garbage trucks that drive through all the neighborhoods on a weekly basis.

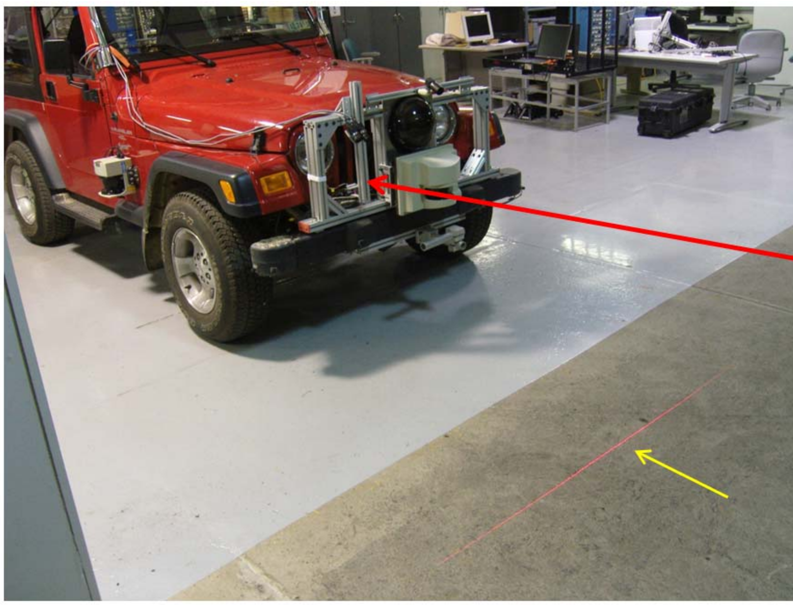
Figure 5 Example of vehicles that regularly traverse city roads.

The system is mounted on these vehicles and 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 we also record the vehicle speed, bearing and its GPS location. The global position is used to put the recorded data in a map. The laser line striper is in a fixed position on the vehicle and the movement of the vehicle allows the sensor to scan the pavement in a push-broom fashion. To produce the 3D image, one needs the speed and orientation of the vehicle. The data is pre-analyzed and summarized on board to reduce its size. At the end of the route the data is downloaded on a server and there in a final analysis the roughness of the road, location of potholes and cracks and any other relevant road metrics are determined. These results are made available to maintenance departments.

To lower cost of the system, one can make use of sensors and infrastructure that is already present. E.g., some buses have GPS installed for their annunciation system and it is common for transit buses to collect engine and other system data and download it at the end of the day; many commercial vehicles have GPS for fleet management purposes and V2I communication over DSRC is anticipated to be widely available in the near future.

TEST SYSTEM

We installed a test system on our Navlab 11 vehicle (Figure 6). The laser line striper was looking at the road in front of the vehicle while at the same time a camera was taking a video. The video was a stream of images at 15 Hz, while the stripe was taken at 120 Hz. At the same time the vehicle state was recorded, it consisted of global position (GPS), velocity, turn rate, acceleration and several other derived dynamic quantities.



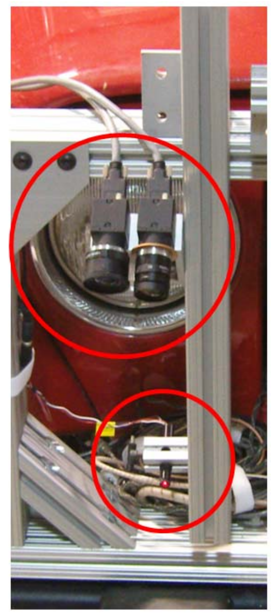


Figure 6 Navlab 11 with road damage detection system. It consists of one camera for video capture and a camera plus laser as a laser line striper. The projected laser line can be seen in front of the vehicle (yellow arrow).

We drove the vehicle over a stretch of road near Carnegie Mellon University where there was some road damage (Figure 7). One data snapshot is shown in Figure 8, it was taken at the location indicated by a yellow pin in Figure 7 (left). The striper and the camera were running independently, but the data was time-stamped and so the data can be matched up with each other.

Figure 7 Left: Bird's-eye view of the test run overlaid on a map. Right: Picture of the road damage at the location indicated by the yellow pin on the left.

The maximum speed of the vehicle was 14.8 m/s. At the time of the data snapshot the speed was 14.3 m/s (32 mph). Combining the vehicle state and several consecutive strips allows one to create a 3D map of the road, this is shown in Figure 8 (right). The cracks and patches of missing road surface can be seen very clearly. In the next section we will describe an algorithm that can detect this damage automatically.

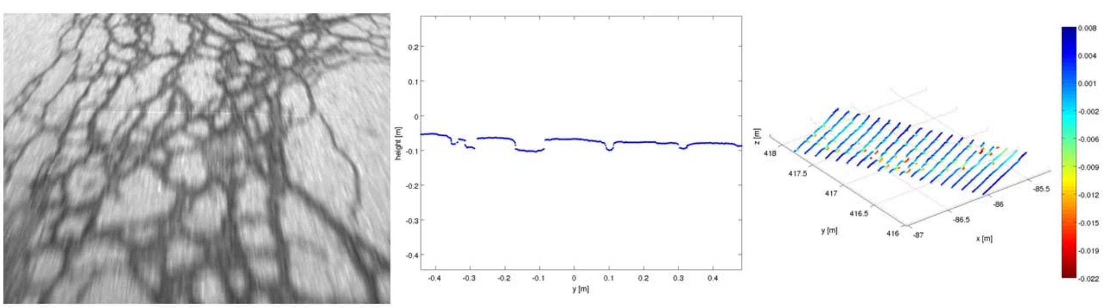


Figure 8 Data snapshot: Left: Image of road damage. Center: Cross section measured by laser line striper. Right: Several cross sections together form a 3D map of the road.

DATA ANALYSIS

We use a step-operator on each cross section to evaluate the unevenness of the road at that location:

$$S = z_n - z_{n+\Delta}$$

Where z_n is the height of the point n of the stripe. In experiments $\Delta=10$ was found to be appropriate.

Next we count the number of points in a stripe where S is above the threshold of 0.015 m. This number is the damage score. In Figure 9 (left) the data points for a stretch of road are shown where the points above the threshold of 0.015 m are marked with red. Also shown are points above a threshold of 0.01 m which indicate areas with smaller cracks. The damage score for this road is displayed in Figure 9 (right). A red arrow indicates the highest score, it is the data snapshot discussed above.

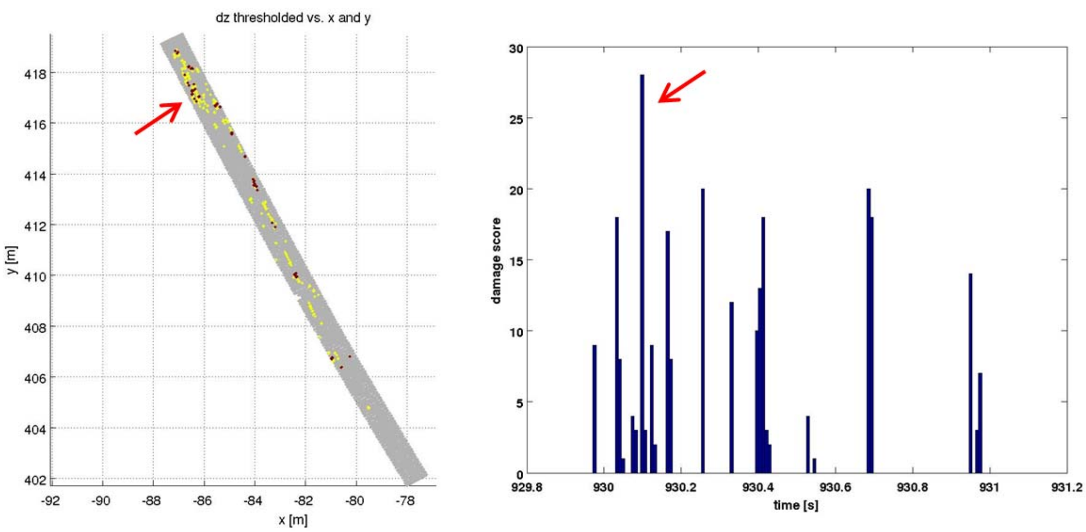


Figure 9 Left: Response of the step-operator on a stretch of road. The red dots are points with a high threshold, yellow are ones with a medium threshold. Right: Damage score for each stripe. The red arrows point to the data snapshot shown in Figure 8.

Notice that the score is calculated for each cross section alone, it is not necessary to know GPS or vehicle state.

RESULTS

By putting thresholds on the damage score one can automatically find areas of significant road damage. Most of the time the classification was correct. In some cases there was noise in the data which caused the score to be high. The grate in Figure 10 also gave a high score.

The damage score described in this paper is meant to distinguish cracks and potholes from a smooth pavement. However, there are many more objects and deformations that can be found in roads, three examples are shown in Figure 10. Two of them are part of the infrastructure, a manhole and a grate. Obviously they are not considered road damage. The third example is an area where the pavement is buckled. These structures can be clearly seen in the 3D maps. We are currently working on algorithms to classify such objects and deformation

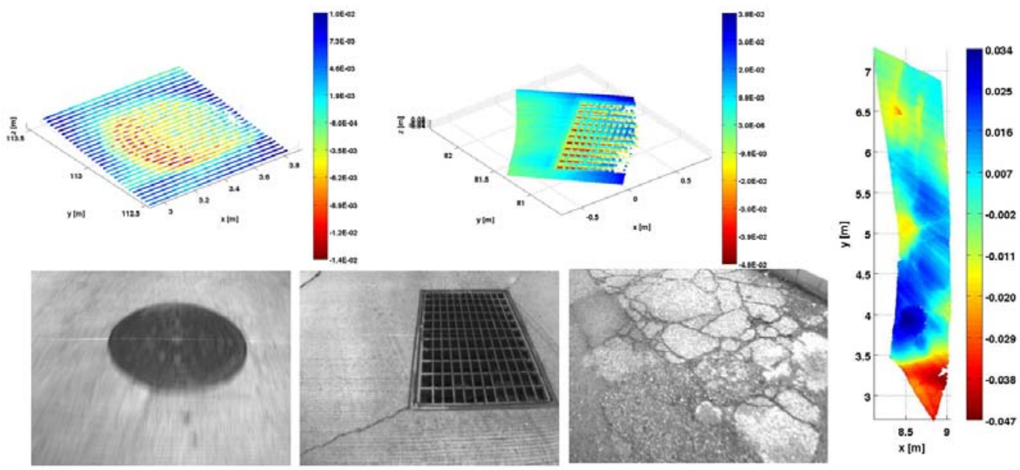


Figure 10 Images and 3D maps of three examples from road surfaces: A manhole, a grate, and buckled pavement.

The areas of damage can be shown on a map and used by maintenance. A display concept is shown in Figure 11 where the user can click on the selected locations and view detailed information about it.

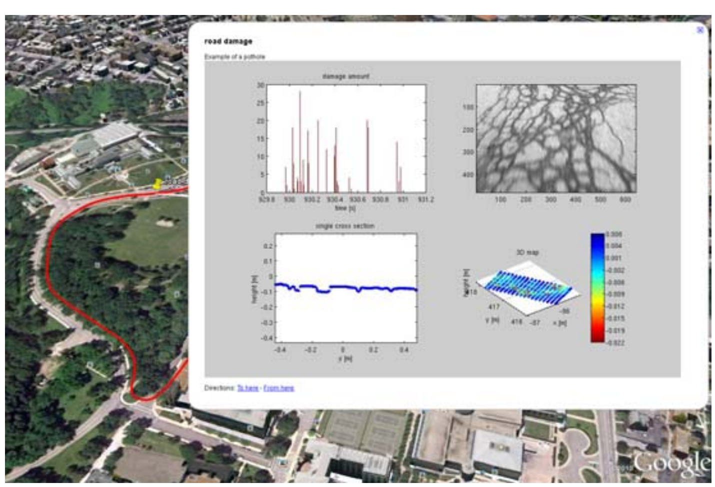


Figure 11 Display concept.

CONCLUSION AND OUTLOOK

We have shown that one can develop a low-cost system that can monitor the quality of the road surface. The laser line striper has the resolution to see cracks and potholes in the road and a straightforward algorithm can automatically detect areas of road damage. The next steps will be to collect data over a longer time period with a vehicle that regularly traverses a route in the city and to develop algorithms that can distinguish between real road damage and other objects like manholes and leaves.

Acknowledgement

This research has been made possible by a grant from Traffic21, a multi-disciplinary research initiative of Carnegie Mellon University [5].

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