Automated Pothole Detection System

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Abstract

Most developing countries in the world have pothole-filled roads mainly because they are unable to allocate adequate funds for road maintenance. Absence of effective systems to monitor road surfaces also contributes to this otherwise preventable situation. A road-surface-monitoring system, which helps to detect the damages to the surface before it gets worse, can bring down the cost of road maintenance significantly. However, most government-funded road authorities in the developing countries are unable to afford such expensive systems. We have come up with a low-cost, road-surface-monitoring method, which employs acceleration sensors mounted on public transport buses, as a viable solution to this problem. According to this method, the sensors record vertical and horizontal accelerations experienced by the vehicle on its route while a GPS device separately logs its corresponding GPS coordinates. The collected data can be then processed to locate potholes along the path traversed earlier by the vehicle. In this paper, we present a technique to analyze and process the acceleration data obtained from the sensors to achieve the aforementioned objective with a reasonable accuracy.

1. Introduction

A developing country undoubtedly needs a network of healthy and travelable roads to meet the demand of everincreasing traffic. However, many countries, such as Sri Lanka, have roads dotted with potholes, but no road monitoring system to watch the road condition before the damage to the surface due to wear and tear becomes very expensive to repair.

There are several advantages of having an effective road surface monitoring system, though they are very expensive. Such a system can identify problem areas early and the relevant authorities can be alerted in time to take preventive measures. Preventive measures always save money. Besides, the studying of the data collected through a monitoring system leads to a better understanding of the road deterioration process, which will come in handy when new road networks are being planned. Although, in the long-run, a monitoring system helps the cost of road maintenance outweigh its initial investment cost, developing countries always look for a low cost apparatus to solve their problem.

We stumbled upon a low cost solution for road surface condition monitoring while designing an environmental pollution monitoring system called BusNet [4]. In BusNet public transport buses carry wireless sensor motes to collect data on environmental pollution; this enables us to measure the pollutant levels in a large area using only a few sensors. In our design the sensor stores the collected data together with the GPS coordinates of the data collection point. Once a bus reaches a regional bus station the collected data are uploaded to a base station over a wireless link. This base station in turn hand over the accumulated data to other buses that travel between regional bus stations so that the data can be routed over the bus network to the main collection point in the central bus station.

The BusNet uses CrossBow MICAz [2] motes and sensor boards. One of the sensor boards that we used for collecting environmental data also has an accelerometer that can measure both the vertical and the horizontal acceleration. We realized that this accelerometer can be used to detect the road surface condition [5]. For example, when a bus goes over a pothole there would be a significant change in the vertical component of the acceleration (and also in the horizontal component due to braking etc.).

The viability of this monitoring system depends on its ability to automate the process of identifying the condition of the road surface (i.e. potholes) by analyzing the acceleration data at hand. In this paper, we present a new and simple technique for automating the pothole detection process.

2. Data collection

As mentioned before the purpose of this experiment is to ascertain whether a vehicle mounted sensor mote can be used to detect potholes.

To gather data for this experiment we fixed a MICAz sensor mote equipped with a CrossBow's MTS310CA sensor board on a vehicle. This sensor board contains an ADXL202E dual axis accelerometer. It has a range of +1g to -1g. The sensor mote was fixed on the vehicle so that one axis (Y) of the dual axis accelerometer is aligned with the vertical direction and the other (X) aligned with an axis that goes from the back to front of the vehicle.

The data gathering apparatus were also carried inside the vehicle. Note that while the BusNet requires a GPS sensor board we have not yet being able to acquire such sensor boards due to export/import restrictions; this restricts us to carry out some of the BusNet related experiment with simulated GPS coordinates. Therefore, for this experiment we used a PDA with GPS capability to get the GPS coordinates while the mote was used to collect the acceleration data.

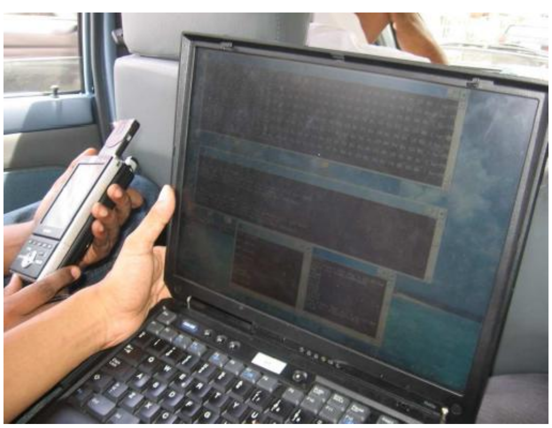

Figure 1: Collecting data.

Figure 2 depicts the block diagram of the data collection and pothole detection process and the Figure 1 is a photo taken at one of the data collection runs.

There are four main components to the data collection setup; The PDA, sensor mote, data logging terminal, and a human operator.

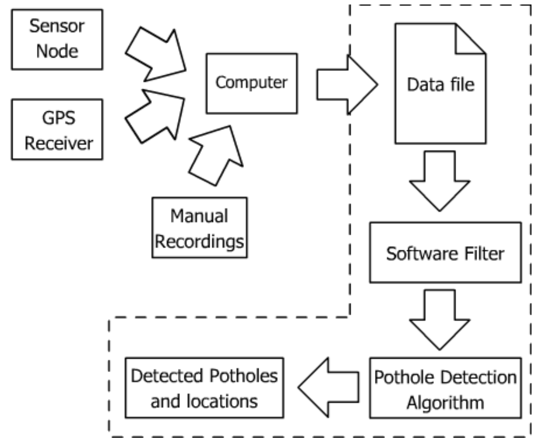

Figure 2: The block diagram of the data collection and the analysis process.

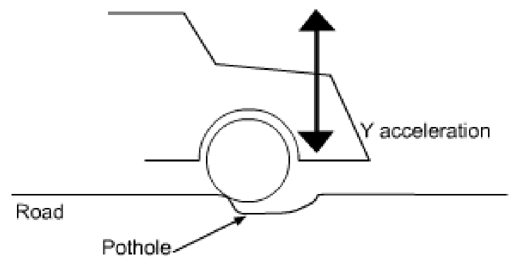

Figure 3: A vehicle going over a pothole.

- As the vehicle travels along the road the sensor collects the vertical (Y) acceleration, and horizontal (X) acceleration of the vehicle, 100 times per second; the sensor collects 100 samples per second.
- Although the sensor captures both Y and X acceleration, only the Y acceleration is used for this experiment because the vertical movement of the vehicle can be directly mapped to the movement when the vehicle falls into a pothole (Figure 3). The horizontal component of the acceleration also changes when a vehicle goes over a pothole, but we limit the scope of this experiment to analyzing only the vertical component of the acceleration.
- For each of these samples, the PDA submits the current GPS coordinates to the computer. So GPS coordinates for each sample will be recorded in the data file.
- In addition to that, for experimental purposes, manual pothole recording needs to be carried out. When the human user feels that the vehicle is going over a pothole, he responds by giving a signal to the data logging terminal. This input is also recorded with the accelerometer readings and the GPS coordinates. Later, it can be verified whether the

detection algorithm actually detects a pothole near that location.

3. Selection of the filtering process

The first phase of the filtering process is to remove the noise caused by the engine vibration and poor shock absorbing quality of the vehicle from the signals recorded during observation. For the purpose of differentiating between the vibrations caused by the potholes and the noise, we assumed that the vibrations are of low frequency and the noise is of higher frequencies. Therefore, by using a law-pass filter, we would be able to refine the signal. The description given below will explain why the Kalman and Chebyshev filters failed at the trials leaving the Butterworth filter the only available option.

The Kalman filter, which is regarded as an adaptive lowpass infinite impulse response digital filter with cut-off frequency depending on the ratio between the process and measurement (or observation) noise, as well as the estimate covariance, assumes that the noise in the signal is normally distributed. However, the Kalman filter is not suitable for our requirement because it needs more details within the signal than that is available in our system. The accelerometer, whose maximum sampling rate is 100Hz, is making our system sensitive only to signals that are less than 50Hz, which is a too low value for the Kalman filter.

The low-pass Chebyshev filter, which can be used to monitor the acceleration of track athletes by mounting sensors on their bodies, has a sharp cut-off slope making it useful in filtering out noise in similar applications such as ours. Nevertheless, there exists a ripple effect within its bandwidth, which gives rise to irregularities in the filtered output in the form of invalid detections (i.e. non-existing potholes).

The Butterworth filter, which is also a low pass filter, has two filter parameters, namely the cut of frequency and the order of the filter, making it functionally very similar to the Chebyshev filter. However, its bandwidth is free from the aforementioned irregularities present in the Chebyshev filter. With the Butterworth filter, we were able to achieve 70% to 80% accuracy in detecting using our system at the trial stages.

4. Pothole Detection

Figure 4 shows a plot of vertical acceleration against the sample number; since samples are taken at regular intervals the X axis also represents the time. The manually detected pothole locations are also marked in the Figure 4. While there are significant variations near the potholes not all such variations indicate potholes; similarly a pothole location is not always associated with a large variation in acceleration in this graph.

The raw data plotted in Figure 4 contains considerable amount of noise. Note that the acceleration values plotted in this graph are un-calibrated readings from the acceleration sensor. One source of the noise is the vibration of the vehicle. We filtered this raw data by sending them through a low pass filter-we used a Butterworth filter for this purpose. The use of the low pass filter is based on the following assumptions.

- The vibration of the vehicle due to the vibration of the engine has a high frequency.
- The variation of the acceleration that occurs when the vehicle goes over a pothole has a lower frequency than the engine vibration.

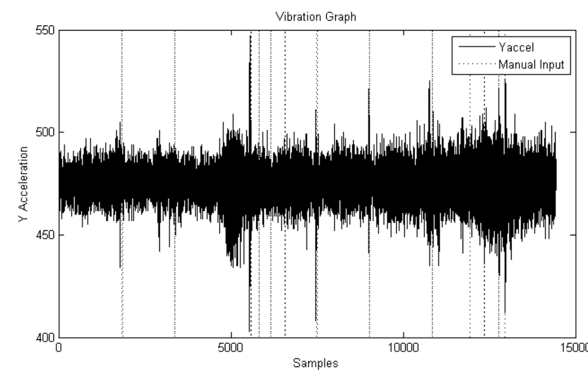

Figure 4: Raw vertical acceleration readings and the manually marked potholes.

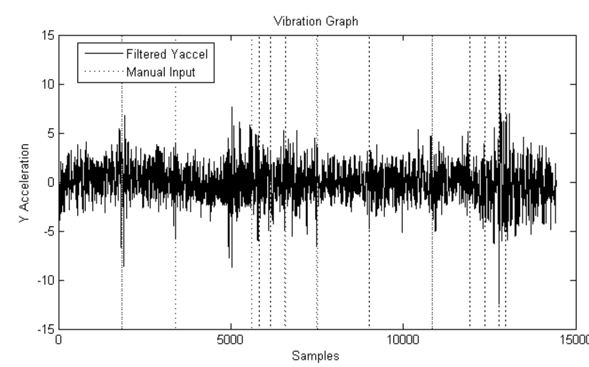

Figure 5: After sending standardized raw data through a low pass filter.

The filtered data set is plotted in Figure 5. This graph again depicts the un-calibrated acceleration readings, but we subtracted the mean value (standardized) to give a better perspective of the variations. This is effective since our experiment is based on relative veriations between acceleration values rather than their absolute values. This graph shows a better correspondence between the variations in the acceleration and the pothole locations.

To extract the pothole locations from the filtered data we use a threshold calculated as follows.

$$threshold = m * std(Y_f)$$

Where $\boldsymbol{Y_f}$ is filtered Y acceleration values for the whole run and m is a constant. ***std*** is the standard deviation. By trial and error we have found that $\boldsymbol{m}$**=2.2** gives good results. Our pothole detection algorithm marks the filtered Y acceleration values above the threshold as indicators of potholes. The potholes detected with this algorithm are marked in the Figure 6 together with the manually marked pothole locations.

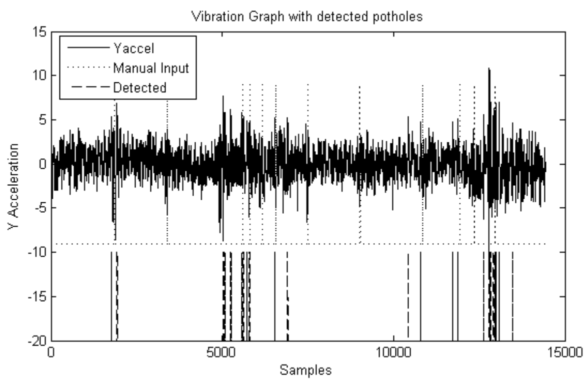

Figure 6: Auto detected potholes.

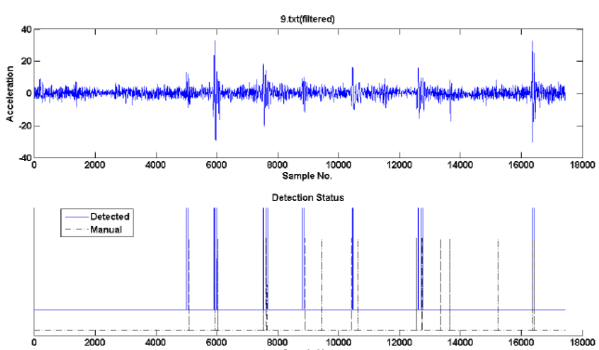

Figure 7: Auto detected potholes on another stretch of road.

The data for the Figure 6 were taken on a particularly bad stretch of road. Figure 7 depicts the filtered acceleration values and the detected potholes for a not so badly damaged stretch of road.

The pothole detection algorithm has identified most of the potholes. However, some auto detected locations do not exactly coincide with the manually marked location. This is mainly due to the reaction time of the operator. The operator most of the times mark the pothole few moments after the vehicle goes over it, but when there are several potholes close by, the operator may miss a pothole.

5. Challenges

While we were able to demonstrate that it is possible to use the acceleration data gathered though a vehicle mounted sensor motes to detect potholes there are several challenges in using this technique in practice.

We found the cut off frequency of the Butterworth filter and the threshold value by trial and error. The success of our technique depends on these values, yet they are highly dependent on the characteristics of the vehicle. For example, it depends on the effectiveness of the suspension system of the vehicle. A good suspension system dampens the effect of the road surface condition on the vehicle and hence it affects the acceleration readings of the sensor mote. Another factor that affects the cut off frequency and the threshold value is the diameter and the condition of the tyres; the impact of a pothole on a vehicle with large tyres is much less than the impact on a vehicle with small tyres.

It is possible to calibrate the cutoff frequency and the threshold value for each vehicle, but the characteristics of vehicles change over time; for example the suspension system may become less effective over time. Therefore, in practice this calibration has to be done time to time.

Chang [1] reports that the accuracy of the accelerometers suffer as the batteries that power them deplete. Therefore, it is important to keep the batteries fully charged throughout the data collection run. One advantage of the BusNet in this regard is that the motes can be powered by the bus’s batteries. However, in this experiment the motes were powered with the regular AA size batteries and therefore there was an impact on the accuracy of the collected acceleration data.

Pothole is an extreme road surface condition. In this experiment we only concentrated on identifying this extreme condition. However, as mentioned before one of the advantages of having a road surface condition monitoring system is that it enables the road maintainers to take actions that prevent such an extreme condition. Therefore, it is essential to be able to detect and identify early signs of deteriorating road surface conditions. These mild conditions are hard to detect since they are not much different from a good road surface.

One limitation of this experiment is that we only used the Y acceleration. However, acceleration along the horizontal axis (X) also can show tell tale signs of deteriorating road surface conditions. For example, a driver inevitably reduces the speed if he detects a pothole and would try to avoid the pothole. This causes a change in the acceleration along the horizontal axis.

We manually marked the potholes in the data gathering run. This is an error prone and subjective procedure. One way to improve this process is to take a video of the road surface and synchronize the frames of the video with the acceleration and GPS data. It is possible to identify the potholes by processing these images. Note that we are not proposing such an apparatus for the road surface monitoring system on BusNet; such an apparatus is only suitable for the experiments that we conduct to establish the viability of using the sensor motes for surface monitoring.

6. Related work

Chang [1] reports an experiment in using sensor motes equipped with accelerometers mounted on a person to track movements. In that experiment he has attempted to deduce the position and the velocity of the test subject from the acceleration data. However, he concludes that it is essential to use a gyroscope to get accurate results. Chang [1] has also experimented in estimating the position of an elevator using an accelerometer and reports an accuracy within a 10% of the actual position.

CarTel [3] is a parallel work to BusNet. CarTel also uses sensor carrying vehicles to collect data. However, CarTel relies on the ad hoc connectivity whereas BusNet uses a relatively stable public transport network for data collection and data transfer. Hull et al. [3] mentions road surface condition monitoring as one of the possible applications that can use CarTel.

7. Conclusions

We discussed above an experiment conducted to ascertain whether potholes can be auto-detected using acceleration data collected from a vehicle-mounted wireless sensor motes. In this preliminary stage, we investigate only the effects of vertical component (Y) of the recorded acceleration. We established that it is indeed possible to identify the potholes, with a very high degree of accuracy, by analyzing only the vertical acceleration readings. Although the technique we used was very simple, the results we obtained were very encouraging.

This research work was only a small, but a necessary, part of a comprehensive project in setting up a sensor network deployed over a public transport system to monitor environmental pollution and road surface condition.

8. Acknowledgement

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