A Mobile Sensor Network Based Road Surface Monitoring System

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***Abstract*—This paper presents a road surface defect identification system based on 3D accelerometers, GPS and video modules deployed on vehicles. The mobile platform architecture and the central data aggregation algorithm are also discussed. Because the mobile system is deployed over a large outdoor area, we also present a solution for the wireless communication coverage problem. Finally, we are highlighting the importance of the gathered information by making it available for the users using a GIS platform.**

***Keywords*—mobile sensor network; event identification; wireless communication; potholes**

I. INTRODUCTION

A well maintained road network is a must for the economic development and the well being of people in any country [1]. Every year, especially after colder periods of time, authorities have to deal with lots of complains regarding the poor condition of the roadways. Many drivers regard potholes as driving hazards and blame them not only for damaging their cars, but even for causing accidents. Bad roads also count for slower, more energy consuming and polluting traffic.

A prime concern of the current transport industry is the provision of sustainable transport through the improvement of efficiency, quality, safety and the reduction of the impact of energy use on the environment [2]. It is estimated that more than 30% of the accidents are caused by environmental conditions [3]. Therefore, in order to achieve a good environmental protection, and to keep a low accident rate, especially in large towns, having a healthy road infrastructure is a major first step forward.

Nowadays, many municipalities rely only on statistical data and on the field visual inspections to assess the condition of the roadways. Invariantly, predictions made using insufficient data are faulty and many clusters of potholes remain unsolved.

Lots of money is spent every year taking corrective measures to recover the quality of the roadways. It would be much cheaper if measures would be taken before road cracks evolve into bigger potholes and the damage inflicted to the passing traffic would be greatly reduced. Early detection is therefore not only a driver's desideratum, but even an economical driven solution.

Having this in mind, automated solutions to identify, localize and categorize the road defects have been tried over the years.

Using different technologies, during the last decades many studies have been conducted in order to find a working solution for automated road condition assessment. In order to perform the specific measuring and categorizing tasks, all solutions have in common a similar architecture based on sensors and a computing unit capable to process the data. In order to be easily deployed wherever it is needed, everything needs to be fit on a vehicle.

The implemented system needs to be practical. Therefore an automated solution needs to work while the vehicle is moving and the speed needs to be inside a practical level (more than 30 km/h), necessary to cover large distances. Using GPS localization and a GIS platform in order to display the results, road monitoring applications could easily be used either by the municipality in order to find its infrastructure priorities or by the drivers who would like to know which roadways are in better condition.

The sensors employed in order to determine the road quality come from a large spectrum of technologies. Some of them are more precise being able to spot any kind of imperfections. Most of these sensors use laser technology and process high amounts of data, being able to recreate the road profile.

In this paper we will discuss a cost driven solution which needs only accelerometers and GPS in order to locate and categorize the road defects. As an extension, video recordings of the pavement can be used either for validation or in order to better assess the pothole magnitude.

With a growing level of accelerometer usage for more diverse devices and technologies, their price dropped and their performance increased during the last decade. This makes them one of the most appealing technologies to be used in system architectures that demand large quantities of devices that collaboratively lead to solving complex problems.

II. RELATED WORK

When it comes to the sensors involved in the monitoring process, a wide range of solutions are to be found. Some of them [4] use accelerometers deployed on vehicles in or measure not only the road surface influence on the vehicle, but also the amount of stress people inside the car feel from going over a rough surface. Other solutions [5] are based on smartphone accelerometers, GPS and wireless connections in order to find a more user friendly approach.

In [6] video images processing is used in order to identify the potholes. This is considered to be a low cost solution, but there are some drawbacks regarding the capacity to discern between different classes of defects and the needed computing power.

A somehow different approach is described in [7] where a combined solution using laser technology and video cameras to detect road defects offers good results at a manageable hardware price. An accurate rut depth measuring system is discussed in [8] using laser technology for and accurate measurement solution.

Two implemented solution for high level road quality assessment are the Canadian road monitoring system ARAN [9] and the ROMDAS [10] system from New Zeeland. Both use a combination of laser, ultrasonic and video sensors to recreate the road profile within very thin margins of error.

ROMDAS uses a Transverse Profile Logger based on an Ultrasonic Measurement System Array for high performance.

All these solutions offer different degrees of practicality and different levels of precision more or less compatible to the standards in use. The main argument against the more exact laser based measuring systems is the high sensor acquisition price and maintenance costs. This would limit the number of vehicles to an unfeasible number compared to the length of the road network in need of monitoring.

Accelerometer based systems are less precise, but their running costs makes them available on a larger scale and therefore usable in a more complex monitoring system.

III. Architecture and Implementation

The proposed solution is based on using 3D accelerometer data in order to assess the magnitude of the asphalt degradation. The mobile platform consists of a local computer, GPS antenna, accelerometer and video capturing equipment (Fig. 1). A data analyzing and pothole identification algorithm is running on the mobile platform.

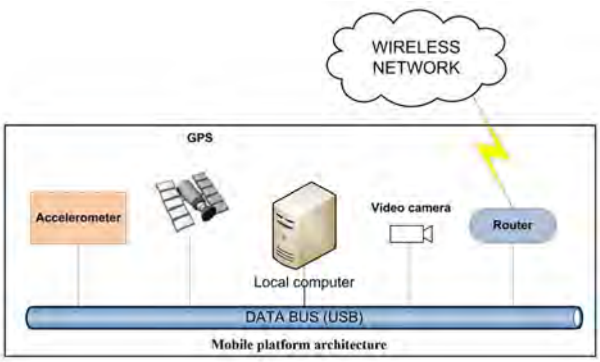

Fig. 1. Mobile platform system architecture

The connection between the mobile platform and the central processing and data aggregation module is provided using a wireless router. The mobile node's modules are interconnected using USB cables. The road defect identification module and the video capture module are both deployed on the surveillance vehicle.

The fact that wireless connections are not available when driving for a longer period of time poses a problem regarding the amount of data we can save on the mobile platform local database. In order to keep sensor data only for a limited period of time and therefore resulting in a smaller database size, an onsite pseudo real time pothole detection algorithm has been developed.

Therefore, the GPS, accelerometer and video data are only stored on the local computer for a limited period of time, enough to run the algorithm and extract the useful data. The processed information is stored in the local database until the data is sent to the central server (Fig. 2).

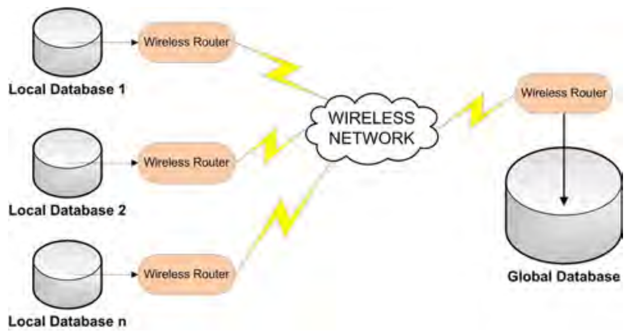

Fig. 2. Wireless communication between the local and the global database

As the entire wireless network consists of many mobile platforms, these need to be connected to the central server by several access points. Providing 100% communication coverage would be infeasible and expensive. A cheaper solution must be implemented. If, for example, the monitoring systems are deployed on the fleet of buses which serve within a certain urban area; it needs to have at least an access point at every end of their respective route. It is important because it allows every mobile platform to connect to the central server often enough in order not to lose data or keep oversized files. Secondary access points are needed, offering the entire network a better level of redundancy (Fig. 3).

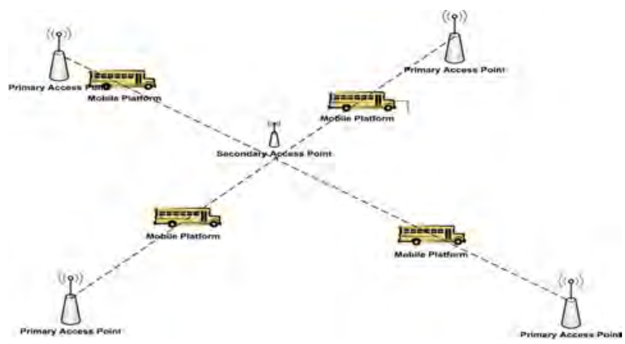

Fig. 3. Primary and secondary access points placement in an urban scenario

The placement of the secondary access points can be chosen such that many different bus lines benefit from the same access point. Being available for only a short period of time, let's say in a bus station, there is a big possibility that just part of the data can be copied during this stage. Therefore, a data transfer acknowledgement algorithm should be implemented in order to reassure that no information would be lost.

The pothole identification algorithm is based on the accelerometer readings. It has the ability to differentiate between a series of events as they are recorded by the onboard accelerometer. It is crucial that no false positives would be presented to the general public as road defects for the entire project success.

The recorded measurements which produce a specific road defect fingerprint are then correlated with the GPS position during the recorded event. By using the timestamp of the recorded data, a framegrabber can provide the associated picture showing the reason why the abnormal values of the accelerometer data are produced.

Therefore, an event is recorded as a series of parameters:

- Location (Longitude and Latitude);
- Timestamp;
- Associated peak value;
- Associated picture.

These parameters are stored in the local computer operating on the mobile platform until an access point is in range and the data is sent to the central server.

After receiving data from the mobile servers, a second layer of computing algorithms is applied. The purpose is to keep the database up-to-date and to discover the false positives within the recorded road defects.

If the integration with a database holding information regarding several known road structures as railway crossings, speed bumpers, etc. is possible, a new level of data processing is available. By this, we can reassess the level of degradation of the entities that are normal part of the road infrastructure or we can exclude them from the pothole determinations (Fig.4).

Fig. 4. Speed bumper (one of the possible infrastructure entities that can be mistaken for a road deffect)

The results are finally shown using a GIS platform (Fig. 5) that allows users to search, categorize and extract statistical data grouped by either geographic criteria or peak levels of recorded acceleration.

The gathered data are biased by the drivers' behaviors which most often are trying to avoid the potholes. This can result in losing a series of road defects because of the employed method which can detect only those anomalies that interact with the vehicles wheels.

Fig. 5. A geographic representation of the found road defects

Although this might be seen as a major drawback, it is not necessarily bad for our monitoring system. After all, we need to detect especially those defects that cannot be easily avoided by careful driving.

For the private users, useful information might be provided using the specific GPS systems which in the future may provide not only directions, but also suggesting the road with less traffic or in better condition. The information can be made available using an internet portal where, by selecting a path or a given area, the locations of the road defects will be shown.

IV. Test Results

The measurements have been conducted on the roads closer to our faculty building. The data include several potholes of different magnitudes as well as some road infrastructure entities like speed bumpers.

We used both a high frequency accelerometer (Shimmer) and the embedded accelerometer from an iPad which also benefits from the advantage of providing already synchronized data with the device GPS location. Both have been deployed in a rigid position close to the car floor. The advantage of this approach resides in the possibility to estimate the comfort level of the people inside the vehicle and also the amount of stress the car body has to endure when going over a road anomaly.

We consider that specific calibration must be conducted for each kind of vehicle in order to have good measurements and data aggregation from different sources to be possible.

A few samples from the collected data during our experimental work are shown in Table I. Accelerations on every axis and the samples respective location are shown together with the recorded speed measured by the embedded GPS module.

TABLE I. COLLECTED DATA

Nr	Lat	Long	Speed (m/s)	Acc_X (g)	Acc_Y (g)	Acc_Z (g)
1	44.43587	26.04889	5.023	-0.077	0.140	-1.146
2	44.43587	26.04889	5.023	-0.062	0.204	-0.992
3	44.43587	26.04889	5.023	-0.036	0.222	-0.936
4	44.43587	26.04889	5.023	-0.047	0.228	-0.952
5	44.43587	26.04889	5.023	-0.041	0.311	-1.06
6	44.43587	26.04889	5.023	-0.052	0.279	-0.972
7	44.43587	26.04889	5.023	-0.084	0.184	-0.846
8	44.43591	26.04893	5.050	-0.153	0.140	-1.149

Data gathered during our tests has been processed using Matlab. Based on our observations, we deduced that many road defects can be described by the lateral accelerations on each of the 3 axis (Fig. 6). Therefore, a speed bumper can be differentiated from a pothole or another kind of road bump because of the symmetrical touch of both wheels in the same time.

Fig. 6. Accelerometer axis orientation and potholes as seen from the interior camera deployed on a vehicle

Usually a pothole has an asymmetrical effect, affecting just the wheels on one side of the car, translating on a lateral acceleration that can be measured.

In Fig. 7 we have some output results of pothole as seen from the 3D accelerometer perspective.

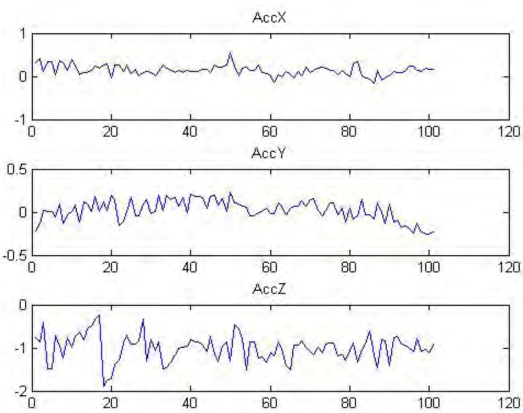

Fig. 7. Pothole accelerometer output

In Fig. 8 we have the output for a speed bumper. Seeing both situations, it is clear that they can be differentiated by the algorithm. Deceleration on the Y axis for both situations because the car is slowing down, but in case of the potholes, the lateral acceleration on the X axis is much higher. In both cases the trigger for an event is based on the high level of the Z axis measured values which grow over a predefined threshold.

The data can be very different from one vehicle to another and also can vary with speed and the angle of approach on which wheel hits the road defect. Previous calibration and careful accelerometer deployment can help obtain better accuracy.

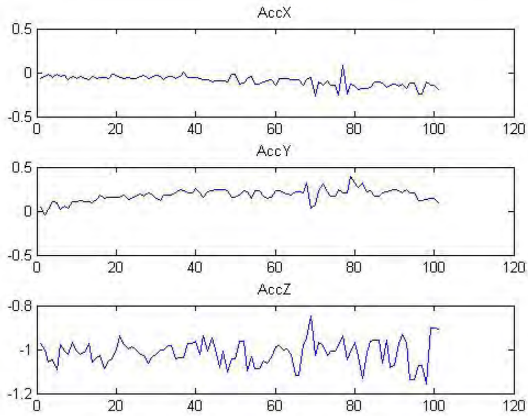

Fig. 8. Speed bumper accelerometer output

As we have previously noticed, the number of false alerts is critical in determining the success of the application. If the number of false positives is too high, people would regard the results as not trustworthy and consequently won't use it. This is one reason why we need another layer of data validation after data aggregation.

By using several measurements of the same event that happened at the same geographical coordinates, we not only validate that a road defect is present, but also find a median value of the accelerations as measured by different vehicles and record a maximum.

If a certain level that is considered to be damaging to the vehicles is exceeded, a higher level of alarm will be associated. If after a while, a certain spot which previously harbored known potholes registers no more alerts, the system will erase the pothole alert on that specific location.

This method can be also used in order to assess the quality of the pavement restoration after conducting maintenance works.

In Table II, a defect clustering sample is depicted. After several measurements grouped on a single GPS recorded location have been stored in the central database, the algorithm on the central server is capable to validate and present the road defect on the map. Associated, the defect would have its maximum recorded magnitude, location (latitude and longitude), the timestamp and the speed of the vehicle (from GPS) when the data have been gathered. A picture of the pothole will also be available if the platforms have an onboard camera in order to validate their results.

TABLE II. RECORDED DEFECTS CLUSTERING

Nr	Timestamp	Latitude	Longitude	Speed (m/s)	Peak magnitude
1	2013-05-07	44.43465	25.98769	12.045	1.45
2	2013-05-09	44.43464	25. 98768	10.674	1.38
3	2013-05-09	44.43465	25. 98767	7.561	1.14
4	2013-05-10	44.43465	25. 98768	9.097	1.41

Data aggregation on the central server also offers the possibility to validate the identified road defects either by means of clustering or by checking them against a predefined map of the known defects such as railway crossings or speed bumpers.

A level of risk can also be associated after several calibration tests in order to comply with the known standards. Usually, standards give the pothole dimensions associated with different risk values because they are adapted to visual inspections of the road surface.

Therefore, we should find a proper correlation between the road defect dimensions and their acceleration signature.

By presenting the road defects using a GIS platform, conclusions regarding the state of the road system can be easily formulated so that preventive measures can be taken as quickly as possible.

A database and a GIS platform also offer the advantage of offering historical data regarding the evolution of the road defect. This information holds a great value because it gives the professionals a good indication about how quick the road surface deteriorates.

The results can be easily correlated, for example, with a database tracking the busiest roads so that a priority system can be associated. For example, if two different roads are considered to be at the same degradation level, the road that is used more often should be first restored.

Other interpretation of the data include road degradation over time and road degradation clustering, so that the best materials that prove to resist the most should be used for further road restoration.

V. CONCLUSIONS

A pothole detection algorithm based on accelerometer gathered data is simple enough to be implemented on a large number of mobile platforms. The bus network which serves inside the city limits or even other volunteering vehicles can be used as a data gathering system.

Information can be processed using a pseudo real time algorithm that enables us to keep only a limited amount of data on the mobile platform computer.

The presented solution can be easily tolerated by its users because it can run for longer periods of time without human intervention.

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