A Pothole Detection System

M. Tech Project Report – II\textsuperscript{nd} stage

Submitted in partial fulfillment of the requirements for the degree of

Master of Technology

by

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2007
Acknowledgments

I would like to thank Prof. Kavi Arya for their invaluable support and guidance. I would also like to thank Prof. Purushottam Kulkarni for constantly encouraging me and compelling me towards the right track. I also want to thank Mr. Sachitanand Malewar and other research staff of Embedded and Real Time Systems Lab for setting up a perfect working environment for the project and providing me with all the needed equipments.

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Abstract

Here we propose design of ‘Pothole detection System’ which assists the driver in avoiding pot-holes on the roads, by giving him prior warnings. Warnings can be like buzzer if the driver is approaching a pothole, or driver may be warned in advanced regarding what road has how many potholes. This system is divided into three subsystems. First is sensing subsystem which senses the potholes encountered by it, about which it did not have the prior information. Then communication subsystem which transfers the information between Wi-Fi access point and mobile node. Access Point broadcasts the data about potholes in its area. When vehicle gets this data vehicle sees if it has sensed any potholes which access point does not have information about; if it is the case then the information about those potholes is transmitted to access point as a feedback. Access Point updates its database with the new entries of potholes. And finally the localization subsystem which reads the data given by Access points and warns the driver regarding the occurrence of pothole.
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Chapter 1

Introduction

1.1 Motivation

With the increase in world’s population, there has been increasing load on the infrastructure. Roads have been flooded with the vehicular traffic. It has become increasingly difficult to manage this traffic. This is the prime motivation behind making a vehicle intelligent enough to aid driver in various aspects.

One of the increasing problems the roads are facing is worsened road conditions. Because of many reasons like rains, oil spills, road accidents or inevitable wear and tear make the road difficult to drive upon. Unexpected hurdles on road may cause more accidents. Also because of the bad road conditions, fuel consumption of the vehicle increases; causing wastage of precious fuel.

Because of these reasons it is very important to get the information of such bad road conditions, Collect this information and distribute it to other vehicles, which in turn can warn the driver. But there are various challenges involved in this. First of all there are various methods to get the information about the road conditions. Then this information must be collected and distributed to all the vehicles that might need this information. Lastly the information must be conveyed in the manner which can be understood and used by driver. We in this project try to design and build such a system. In this system the access point collects the information about the potholes in the vicinity of a wireless access point and distributes to other vehicles using a wireless broadcast. Here 'vicinity' is a user defined term. Ideally the vicinity is every rout till the next access point.

1.2 Problem statement

Pothole detection system is a system that aims at warning the driver about the uneven roads and potholes in its path. We study the different ways in which goal of the system can be achieved. We justify the methods we have chosen in this projects. And then we give details about the working of the different subsystems. The problem statement can be given as follows.

This system consists of two components one is mobile node and other is the access point. Access points responsible for storing the information about potholes in its vicinity, taking the feedback from vehicles, updating the information in repository and broadcasting the information to other vehicles. Whereas Mobile node which is the small
device placed in vehicle is responsible for sensing those potholes which it did not have previous information about, locating and warning the driver about the potholes which it has information about, and giving the data about newly sensed pothole to access point.

The whole scenario works as follows. While deploying the access point we feed in some initial data about potholes to it. Then it keeps on broadcasting the data. Vehicle equipped with the client device catches that data. Now the device has the information about the locations of potholes. The device is responsible for warning the driver about occurrences of pothole. But new potholes may always be formed because of environment or fatigue. So client device also acts as a sensor and finds out the occurrence of newly formed potholes on the road. If it finds out any new potholes it gives data of new pothole to Access point in terms of the feedback. Access points updates this information to its data store and then adds it to the information broadcast.

1.3 Challenges involved

There are various challenges involved in this project.

- Client device must be able to sense the pothole. It will be an added advantage if it can characterize the pothole telling how severe it is.

- Placement of access points is an important factor. It should be in such a way that the data should be distributed to maximum vehicles.

- Communication between access point and client device can have many problems which should be resolved. Some of the problems that communication can face are interference, Low throughput due to large no of client devices, end to end reliability.

- Data representation should be in such a way that the client device should be able to locate and warn the driver about the potholes which it has information about.

In this report we explain the system that has to be built. Chapter 2 explains the overall systems and what are the subsystems involved, different choices for the subsystem. Chapter 3 explains the challenges involved in implementing the selected subsystems. Chapter 4 explains experimental setup, some of the experiments that are performed and some which need to be performed. And finally Chapter 5 gives the summary of the report and Future work.
Chapter 2

Architectural Design

As explained before the System consists of three subsystems: Sensing, Communication, Localization. These three subsystems work independent of each other, but have one center point they revolve around; that is data. Sensing system generates the data; Communication collects, co-ordinates and distributes the data; lastly Localization uses the data and generates information for the driver. The overall design can be given as follows

There are different ways in which these subsystems can realized and implemented. All the ways have there own pluses and minuses. We explain some of the ways In this section and mention some of their pros and cons. We try to choose the best working system and we justify the choice taken.
2.1 Sensing Subsystem

This subsystem is responsible for getting the data. The data in this case would be the data about pothole e.g. location of pothole, the severity of the pothole. There were two methods under consideration for this subsystem one is Vision based and the other is vibration based.

Vision-based method:

This method uses 'Camera' as sensor to scan the road for any potholes. The camera captures the images in real time. These images are applied to image processing algorithms like edge detection. This requires lot of processing time and power. There many design approaches possible. Hardware based methods like use of special Digital Signal Processors or Application Specific Integrated Circuits improve the performance over software based method. But still the response time of the operations required like windowing convolution for the image processing algorithm is still large. This method has one advantage over the other is, it can sense a pothole without experiencing it i.e. Vehicle does not actually has to pass through the pot hole to sense it. Characterization of pothole can be done on the basis of size of the pothole. Some other vision based method for obstacle detection are RADAR[8] but they have little use in pothole detection.

Vibration based method:

This method uses 'Accelerometer' to sense potholes.

Accelerometer: This is a device that measures total specific external force on the sensor. For example if the device is stationary, it will show some reading corresponding to earth's gravitational force. An accelerometer falling freely in the vacuum will show zero reading. The design of the accelerometer is often very simple. The simplest design can be a mass hanging by a thread and some sensor to measure its deflection for original. The device is popularly used to measure vibration or inclination. It is popularly used in iTouch and some cameras to detect inclination and change the view of the display.
The accelerometer device we are using for our project is LIS3L06AL[4] by ST. It can measure acceleration on three perpendicularly placed axis. It can measure acceleration up to 6g. Pothole induced vibrations can generally be measured on the vertical(z) axis readings. We can characterize the pothole on the basis of the magnitude of change in reading of accelerometer.

<table>
<thead>
<tr>
<th>Sensor used</th>
<th>Vision based</th>
<th>Vibration based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response time</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Sensing time</td>
<td>While approaching the pothole</td>
<td>While going through the pothole</td>
</tr>
<tr>
<td>Processing</td>
<td>Complex image processing algorithms</td>
<td>Readings are directly used</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>High because of delicate parts like lens</td>
<td>Low</td>
</tr>
<tr>
<td>Characterization of pothole</td>
<td>Based on the size</td>
<td>Based on the vibrations</td>
</tr>
</tbody>
</table>

Table 1: Comparison between different sensing methods

Here we choose the second method that is Vibrations based approach given the low response time, processing time and maintenance cost of the device.

2.2 Communication Subsystem

This can be said as the backbone of the system. This subsystem collects the data from different vehicles; Co-ordinates the data and broadcasts it to other vehicles. This system uses WiFi infrastructure for communication between Access point and Mobile nodes. There are multiple approaches in which this subsystem can be implemented some of which are as explained below.

Entire Wifi coverage :

This is also a popular approach in several proposed systems which are safety oriented e.g. Vehicle Infrastructure Integration[3]. In this approach access points are deployed on the road so frequently that vehicle will never be out of network coverage. Or at least
Access points are planted at frequent intervals where they are needed for example accident prone areas, dangerous turns.

In our approach we can place access point for the maximum coverage or where the road conditions are especially bad. Access point keeps on broadcasting the position of the pothole in its range. And vehicles can give immediate feedback of new potholes or non-existent potholes which are suggested by Access point. Here access point can also help vehicle in finding the location of pothole. But This approach requires a large initial investment for deploying the access points.

**Public transport as Access point :**

In this approach we use Public transport such as Buses for city or town coverage or ST buses for highway coverage. In this approach Access point itself is moving. This type of approach has been previously used for collecting data from kiosks in rural areas[2].

Conversely in our approach we are using public transport for distributing the data to other vehicles. In this case access point itself is moving, hence we can provide a Sensor device to access point. This will save per private vehicle cost of device by exempting them from sensing application.

Public transport vehicle will sense the potholes on its path and broadcast information about that to the other vehicles passing by. Vehicles equipped with the client device can receive this data. But this approach has several problems. The coverage is not vast. as information about only those potholes are available which are covered by public transport and there may be roads on which the buses don't commute. Also bus only has information about its own route which may or may not be useful for the vehicle as Vehicle can take any path. So vehicle must have some way by which they know which data will be useful for them.

**Hotspot approach :**

Hotspots are traditionally known to provide Internet connections at public places like coffee shops. In those case it is used to provide some service to the public. The same approach is used can be used in our project as follows.

In this approach Access points are deployed at selected places where vehicle concentration is more like Traffic signals, petrol pumps. At these hotspots transaction happens between Access point and the vehicles. This approach can give the entire road coverage. In the sense it can get data from any vehicle having the client device. Hence wherever the vehicles can go; vehicle can generate data for that road. It can give access point corresponding feedback without actually implementing an Access point on those roads. This approach can even be applied locally for some particular area; which has
especially high concentration of potholes. But this approach also imposes some challenges. As access point is not present at the actual place, vehicle has to find its own way; Hence localization is difficult.

<table>
<thead>
<tr>
<th></th>
<th>Entire WiFi coverage</th>
<th>Public transport approach</th>
<th>Hotspot approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment</td>
<td>Deploy access point wherever you want the coverage</td>
<td>Only on the public transport vehicles</td>
<td>At particular location where vehicle density is high</td>
</tr>
<tr>
<td>Coverage</td>
<td>Wherever access points are deployed</td>
<td>Wherever public transport vehicle go</td>
<td>Wherever the vehicle goes</td>
</tr>
<tr>
<td>Cost of access point deployment</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Cost of client device</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Localization</td>
<td>Relatively easy</td>
<td>Difficult</td>
<td>Difficult</td>
</tr>
</tbody>
</table>

Table 2: comparison between communication approaches

For the communication subsystem we choose the third Hotspot approach because of its coverage and flexibility. But because of this localization becomes difficult.

2.3 Localization subsystem

Localization subsystem uses the data given by access point to actually find the location of the pothole and warn the driver about it. As we explained earlier Localization is especially challenging in the situation we selected. Because there is no access point situated near the location of the pothole. So vehicle has to find its own way.

GPS (Global positioning system):

As we all know this is a very popular location finding system. It is also the first and till recently the only global and fully functional location finding system[5]. It is based on the communication with 24 satellite orbiting around the earth. It works as follows.

These 24 satellites are revolving around earth in 6 different paths. Theoretically at any point you need a point to point connection with at least 4 satellites to get your position.
It basically takes 4 measurements to determine 4 parameters x,y,z,t. And then represents in the form understood by the user like latitude/longitude. In real setting it might even require less satellites if one of the parameters is known. For example ships sailing in sea know there altitude to be zero. Also more the satellites you can connect to more accurate location you will get. GPS locations can get as accurate as up to 15 meters.

So in our system data about potholes is stored in terms of x,y,z parameter. Also a long length of a bad road maybe saved as a [(x1,y1,z1),(x2,y2,z2)] which indicate the start and end of a bad road. This data can be used by vehicles directly. As when they get the data from the access point the places where potholes are there can be shown distinctly on the GPS map. According to severity of the pothole or road it can be shown with different brightness. Also when vehicle senses a new pothole it stores the corresponding GPS parameters in its local memory and gives as a feedback to immediate next Access point..

But there are several problem with this technology. First of all it is highly expensive. Not just for maintaining but even the GPS receiver is costly. Another problems with GPS it It needs a clear view of orbiting satellite; so it does not work properly in-doors and mainly in the newly forming urban canyons where it is needed the most. Also it has a high operational cost if it is made to work in real time, as it needs to update its location at real time.
Chapter 3

Pothole Detection System

In last section we made our choice for the subsystems. Now we need to study different aspects are involved in implementing the system. There are many challenges involved in the deployment of this system. These must be answered with the detailed experimentation or simulation. Some of these challenges are as follows

Accelerometer characterization :

As we said before we have used an accelerometer as a vibration sensor. Now there are some issues with the its of characterization as follows.

- Characterization of potholes and roads can be done using the readings of the accelerometer.
- In accelerometer device there is always earth's acceleration 'g' acting on device in vertical direction. Usually it is also subtracted with the offset. But we in our experiments can not do it because in our case it depends on the terrain on which the vehicle is driven. If the vehicle is on the slope this 'g' gets divided in two axis. In this scenario the vibration readings in vertical axis it will read less than actual.

Deployment of the sensor in vehicle :

When the accelerometer is deployed on the vehicle there are many things that should be taken into consideration to get the accurate reading.

- When the accelerometer is deployed in a real vehicle its reading might be biased because of the shock absorption system of the vehicle reduces the effect of the potholes. So the actual readings are also based on how good shock absorption system vehicle has. Or the placement of accelerometer should be such that the effect of shock absorption is minimal.
- Also the different placement of the accelerometer would give different readings. For example we keep device in the boot(at the back of the vehicle) vibrations will be more compared to the front.
- For large vehicle such as Trucks or ST buses; Readings at both front and back might be very different and both maybe important in order to characterize the span the road. So more than one accelerometer are needed for characterization.
Communication Subsystem:

The communication subsystem as said earlier is backbone of the system. It involves communication between vehicle and Access point deployed as hotspot. Firstly broadcast of the hotspot, and then The feedback given by vehicles. These vehicles might be moving, might be stationary(e.g. stopped at signal). Some issues involved in this are

- Throughput of the system depends on speed of the moving vehicle. It has been shown by experimentation that data transferred reduces from average of 58MB at 5mph to 3.8MB at 75mph[1]. This reduction is also because of the protocols that we use in general networking need handshaking which is an extra overhead when wireless network is concerned.

- At any point there maybe large number of vehicle which have some feedback to give. And as the number of vehicle increase the throughput decreases. Hence less and less feedback will reach access point.

- If we use standard CSMA/CA there might be a case where Access point itself gets the medium busy. Because of this the new vehicles(just entering the hotspot range) might not get the data for long time because existing vehicles are giving feedback.

- As the standard communication frequency for WiFi is 2.4GHz There might be interference from many devices in the vicinity such as bluetooth devices, cordless phones in the range.

- End to end reliability is also not provided in broadcast communication, as getting the ACK for data is not possible. In these scenarios transferring the data accurately is difficult. Some significant attempts stating the possible solution have been made, like data fountains[6,7]

Localization:

The localization system that we are using has some problems. It imposes a restriction that, Every vehicle using this system must have a GPS receiver. This increases the overall cost of the system. Hence we have to find some low cost method for locating potholes.
Chapter 4

Experiments

4.1 Experimental set-up

Initial Experiments were done on the Platform called 'Firebird-3'[9].

**Platform used (FireBird-3)**: Firebird is a platform specially made for academic and research purpose in Embedded and Real Time Systems lab. It has various features, some of them which were especially useful for our experiments are explained below

- It has an in-system programming port which can be used to program the ATMEGA128 micro-controller.
- It can communicate to PC via serial port connection.
- It also has optional Wireless radio.
- It has 8 channels to take readings from various sensors. And these sensors can be fitted on platform as and when needed.
- It has LCD which can be programmed to show readings of the various sensor
- It is powered by Li-ion rechargeable battery.

The Accelerometer was used as an extension to this platform. Accelerometer used to give the readings of three axis on 3 of 8 channels which are ADC-1, ADC-2 and ADC-3. LCD is used to display these readings. It also transmits these readings to serial port of the PC. Both of these methods are used as LCDs are easy for debugging purpose and We can collect the data on serial port which can be used for further processing and graph generation.

Our initial experiments were running the Firebird-3 on smooth road, Then running it on moderately and highly uneven roads. For simulating the moderately uneven road we took one sheet and ran the firebird over it with some perforations to the sheet. Also for simulating highly uneven road we placed some computer data cable wires below the sheet. We also ran some experiments road with bumps. Bumps were generated by small pins.
4.2 Details of the experiments performed

**Smooth road with bumps**: On a smooth road we placed some pins to generate the bumps. Then we ran FireBird over such road. And as shown in the graph below we got sudden change or spikes in the readings on at least one of the axis.

![Road with bumps](image1)

**Uneven roads**: For this the FireBird was run on three types of road smooth, moderately uneven road and highly uneven road. The graphs produced are as follows.

![Smooth roads](image2)
Vibration were seen to be increased in terms of the accelerometer reading. Standard deviation of at least one of the Axis was increased significantly when we made the road conditions increasingly worse. Whereas large difference was found between readings of smooth road and moderately uneven roads.

4.3 Experiments to be Performed

Till now all the work has been on the robotic platform 'Firebird-3'. Also we were not able to generate potholes or slopes in lab environment. Hence our next step is to deploy the accelerometer in the vehicle and take the readings. Some of the experiments that are in Queue are as follows.

Characterization of Accelerometer on vehicle:

In the experiments performed till now speed of the platform was limited. The condition largely changes when experiments are performed on actual vehicle. Speed of vehicle is not constant as that of the platform. There are hurdles on the road because of which there is constant breaking. Hence accelerometer may experience different kinds of
vibrations on all the axis. Hence it is more difficult to characterize pothole or an uneven road in the real environment.

**Communication between Access point and vehicles :**

It is very resources and time consuming to perform actual experiments on the large number of vehicles. So we are using simulation for this purpose.

**Simulation of General scenario :** In this experiment with a usual settings. we model the exact drop of throughput with the increase in number of vehicles. We have to model this scenario for different number of stationary and moving vehicles. Speed of the vehicles is also one of the factor which can affect the throughput for a particular vehicle. For example if a vehicle with high speed wants to give feedback. But for the small time it was in the range of accelerometer; it never got free channel. Performance of system in terms of per vehicle feedback and number of vehicle which got the access point broadcast correctly must be measured.

**Use of different channels :** Different channels also can be used for communication in each direction. WiFi can be configured to work in 11 different channels out of which 3 are orthogonal(1, 6, 11). This will even reduce the interference per direction of the system. We can have Access point broadcast on one channel, and vehicle broadcasting on one channel. This will at least ensure that no vehicle is starving for data. On the other hand when all vehicle get data, more vehicle can generate the feedback this will flood the channel used in the direction vehicle to access point further reducing the throughput. These trade-offs must be studied.
Chapter 5

Summary and Future work

Various choices for implementing the System have been studied. These choices were also compared to each other on various criterion. We have specified the High level design choices of the Subsystems and justified the corresponding selections. We did experiments on the platform called Firebird. We were also able to characterize road condition into categories like smooth, moderately uneven and highly uneven from the results of the experiments.

Future work

In future we propose to do more experiments with variety of the scenario.

Our next and immediate step is to use the Accelerometer on real vehicles and measure their response. Apply different scenarios like potholes on the slopes, turns and see how the accelerometer readings can characterize such condition. Along with that in remaining January and February we want to come up with and formalize the alternate solution for the Localization subsystem.

In next months of March and April we perform simulations for given scenarios in Communication subsystem. And we plan to come up with values for the related parameters. For example Loss in throughput because of increase in number of vehicle, Loss in vehicle throughput because of the increase in speed.

In the month of May and June we perform the more experiments regarding the Localization system. If we are not able to come up with alternate solution; Then we will perform the experiments regarding integration of the rest of the system with GPS.
References


