Traffic and Road Condition Monitoring System

M.Tech. Stage 1 Report

by

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Abstract

In this report we look at issues related with designing and developing a traffic and road condition monitoring system for the Indian road network. We survey existing technologies and techniques of traffic estimation and road monitoring. However, these systems do not fulfill the constraints imposed by the road and traffic situation in India. They were developed assuming the road infrastructure of a developed country. The road and traffic scenario in India is very different. In India road conditions are more varied, the traffic is chaotic and unstructured, there is lack of lane discipline, and a wide variety of vehicles. Additional constraints that we impose is that our system should be low cost. It should not require digging up of roads or building overhead structures. Therefore, we need a different method to estimate traffic. For this purpose we introduce a new metric called traffic density. Our system tries to estimate this metric using magnetic sensors coupled with sensor nodes. Unlike other technologies, we do an approximate aggregate traffic analysis. Wireless sensor nodes are used because of their low cost and the flexibility they provide during deployment. We argue that using accelerometers for pothole detection is well suited for our purpose. Our plan is to use accelerometers to not only detect potholes but also quantify them in terms of their severity, size or depth.

**Keywords:** Street traffic estimation, Road condition monitoring, AMR sensors, Sensor Network, Accelerometers.
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1 Introduction

The road network of any city is its lifeline and so monitoring this vital infrastructural resource is important. The problem of traffic jams and congestion are faced by most major cities of the world. For managing traffic, a city’s administration should have both realtime and historical data about the traffic conditions prevailing on the road network. This information can be used for quick reaction measures, such as, changing the timings of traffic lights and advising commuters to take alternative routes through public broadcasts. In the long run, however, this information can be used to plan a better road network by identifying areas of frequent congestion and building alternative routes.

Apart from managing traffic on the roads, maintaining the road infrastructure in good condition is necessary. Municipalities generally have tight budgets. In developing countries like India, funds are even scarce. Hence, what the authorities want to know is where, and to what extent is a road damaged. This would enable them to take preventive measures before further damage occurs or prioritize repair work based on the severity of damage. It is worth noting that damaged roads with several potholes also lead to choking of traffic and cause accidents.

Hence, in such a scenario, a system that monitors and reports the condition of roads and estimates traffic on different road segments would be very useful. Information generated from this system could be integrated with SMS based services that alert users about congestion, automatic traffic light timers, geographic information systems that suggest less congested paths or roads which are less damaged, systems that trigger road maintenance work and analysis tools that help to manage traffic and plan extensions to the road network. There are several challenges in building such a system. These challenges lie in the areas of sensing, signal processing, communication, protocol design, information storage and retrieval. Traffic on the road or condition of the road can only be determined through some sensor. These sensors generate raw values. Appropriate algorithms need to be devised to convert these values into meaningful events. Traffic scenarios change dynamically and the response to congestion must be swift. Therefore, communication protocol for such a system must be near realtime. On the otherhand, the system should be able to estimate if the current congestion is temporary or persistant to trigger some reaction such as changing duration of traffic lights. Traffic monitoring systems generate huge amount of data and systems need to process this into useful information, especially those systems that need historical information to correctly estimate current state of traffic. Road condition and traffic monitoring system also need to be highly scalable.

Considerable amount of work has been done on building parts of such a system. Several projects exist that aim to build a complete road condition and traffic monitoring system. But most of this work has been done keeping requirements and considerations of the developed world in mind. Popular technologies like magnetic loops are expensive to install, require digging up roads and assume laned traffic. Other technologies such as laser based systems require overhead structures and assume some structure in the traffic. Techniques using microwave radars, ultrasonic detectors and infrared detectors need very specialized and sophisticated equipment. Similar is the case for road monitoring techniques. For example, Ground penetrating radar based monitoring techniques need specialized vehicles and expensive equipment. Assumptions that current technologies make do not
match with conditions that exist in a developing country like India. What we plan to pursue is a similar system but with a different set of constraints and assumptions. In the remaining part of this section we discuss our constraints and assumptions for building a road condition and traffic monitoring system and the logic behind them.

The Indian street traffic scenario is quite different from that of the developed world. The road conditions are more varied, the traffic is unstructured, there is lack of lane discipline and numerous type of vehicles. This scenario is challenging for current techniques of traffic estimation that mostly work on freeways or assume structured traffic. Traffic monitoring systems generally try to count, classify or estimate speed of vehicles moving on the road. By determining these parameters they try to deduce the state of traffic on a road segment. This, however, is very difficult in the circumstances discussed above and exiting techniques need to be modified substantially for them to be effective in India.

We believe that a road condition and traffic monitoring system can only be feasible if its cost is low and it provides flexibility in deployment. Hence, there is a need to reduce specialized equipment and reuse existing infrastructure. The system should be unobtrusive and avoid the need of digging up roads or creating additional infrastructure in form of laying wires or making overhead structures. It should be built using cheaply and easily available commercial off the shelf components. A system that can be rapidly deployed in a phased manner, is scalable and minimizes obstruction to traffic during installation is preferable. The cost of operation and maintenance should be low. Day to day operations should involve no human intervention.

1.1 Problem Statement

Our goal is to build a traffic and road monitoring system for intelligent route planning, road usage and maintenance that fulfills the constraints imposed by the Indian scenario. This system should work under varied road conditions, chaotic, dense and unstructured traffic and a large variety of vehicles. It should be cost effect, easy to deploy (no need to dig or build overhead structures) and require minimal maintenance. We should avoid the need for specialized equipment. In order to meet these somewhat conflicting requirements we are willing to be content with system that does an approximate, aggregate traffic analysis and near realtime reporting. We do not want a explicit count or classification of vehicles but rather some information through which we can deduce the state of traffic on a road segment. Hence, we are willing to trade-off accuracy of reporting with ease of deployment. We want to build a road monitoring system that is able to better quantify a road anomaly. Thus, our efforts will be to try find out ways to report severity, intensity or dimensions of a pothole or a damaged road segment.

1.2 Our Contribution

For estimating traffic we introduce a new metric called “traffic density”. So rather than individually detecting and identifying we try estimate this metric. Once we determine this metric we map that to the state of traffic on a road segment. Our contribution will be to relate magnetic sensor
readings to estimate the traffic density metric. For the purpose road monitoring, we hope to contribute by devising a technique that is able to better quantify a pothole encountered in varying road conditions. Existing systems are unable to do this. It should be noted here that, currently, the focus of our work is to resolve the sensing issues with such a system. We believe that the primary challenge of this problem lies on the sensing side.

2 Related Work

2.1 Existing Technologies for Traffic and Road Condition Monitoring

In this section we describe, briefly, some techniques for traffic management and road condition monitoring. We will also see the advantages and disadvantages of each of these technologies. First let’s have a look at current techniques for traffic monitoring.

2.1.1 Magnetic Loops

Magnetic loop is a technology that has been used for vehicle detection and traffic control for the past few decades. These devices are installed inside each traffic lane and act as counters, counting vehicle passing over them. Some variants of the magnetic loop have been used to classify vehicles as well. The loop is a continuous run of wire which is buried inside a traffic lane. The ends of the loop wire are connected through a loop extension cable to the vehicle detector. The detector powers the loop causing a magnetic field in the loop area. The magnetic flux linked with the loop changes whenever a metal object, such as a vehicle, moves over the loop. The detection scheme of loops is based on this principle. The change in flux is sensed by the detector which forces a normally open relay to close. The relay remain closed until the vehicle leaves the loop.

Inductive loops require extensive care during installation or repair. Troubleshooting problems in magnetic loops require costly test equipment or diagnostic software. The inductive loop requires continuous power supply to function. Hence, it is quite evident that magnetic loops being intrusive, expensive to install and maintain do not fulfill our requirements. Also these loops will only be useful in presence of laned traffic.

2.1.2 Camera Based Systems

Camera based systems are able to detect, count and classify vehicles. These systems use video image processors to identify vehicles and their traffic flow parameters by analyzing imagery supplied by video cameras. Images supplied by cameras are digitized and then series of image processing algorithms are applied on them. Information about vehicle passage, presence, speed can be extracted by using various image processing techniques. Though camera based systems are more accurate than loop based systems and do not require lane discipline they have several disadvantages. Their performance is unsatisfactory in foggy conditions of poor visibility. Other environmental conditions such as light reflected from wet pavements and shadows affect the performance of Video image processors. Large vehicles can obscure smaller vehicles. Camera based systems are expensive to install and maintain as they require quite a lot of dedicated hardware and software. Chances of theft are also higher for such systems.
2.1.3 Microwave RADAR

Microwave radars use specially allocated radio frequency for detecting vehicles. In the U.S. 10.525 GHz is allocated for this purpose. There are two types of microwave radar detectors. The first type of microwave radar uses the Doppler principle to detect vehicles. According to the Doppler principle the difference in frequency between the transmitted and received signals is proportional to the speed of the vehicle. So this type of microwave radar first transmits electromagnetic energy at a constant frequency. If the detector senses any shift in the received frequency it deduces that vehicle has passed. On major problem with this type of microwave radar is that it cannot detect stationary vehicles. The second type of microwave radar detector transmits a frequency-modulated continuous wave that varies the transmitted frequency continuously with time. This enables the system to measure the range of the vehicle from the detector. Hence, this type of microwave radar can detect stationary vehicles as well. Speed of the vehicle can be calculated by measuring the time taken by a vehicle to move between two internal markers separated by a known distance. However, even these microwave radar systems have problems like over estimating speed and occupancy values [Var04].

2.1.4 Laser Based Systems

Laser based systems can be used to for counting, classifying and measuring speed of vehicles. Laser based systems offer reliability and durability. Unlike systems based on magnetic loops the installation of these systems does not need any civil engineering work to be done on the floor of the road. Laser detectors, however, need to be installed on a overhead position. Thus, an overhead structure is needed for these systems. Also these systems assume structured traffic on the road which is not the case in India.

2.1.5 Infrared Detectors

Passive infrared detectors do not transmit energy but instead use an energy sensitive photon detector located at the optical focal plane to measure the infrared energy emitted by objects in the
detector’s field of view. Thus, when a vehicle enters the detection region of the device, it produces a change in energy which is sensed by the photon detector. This system can only detect vehicle passage or presence. It cannot provide any information regarding speed of the vehicle. Change in weather conditions such as fog, rain or snow results in performance degradation of these systems.

2.1.6 Ultrasonic Detectors

Ultrasonic sensors use sound waves (above the audible range) to determine the presence or distance of an object. Ultrasonic detectors transmit sound at 25 KHz to 50 KHz. A part of the transmitted energy is reflected back from the road or the vehicle to the receiver. By measuring the time taken for the sound echo to return the distance of an object can be found. The ultrasonic Doppler detector that also measures vehicle speed are much more expensive than the presence detector. This technology is expensive and is sensitive to noise and environmental conditions.

Figure 2: The need of an overhead structure for ultrasonic sensor based traffic monitoring system is evident from this image.

Ultrasonic, infrared, microwave radar detectors and laser based system all assume some form of lane discipline or structured traffic. They are generally suited for expressway and toll booths. But under our constraints they will not suffice. Laser based and radar systems are non-intrusive they do require setting up of additional infrastructure in form of overhead mounting points. These systems along with camera based system lack the flexibility of large scale deployment. All these systems are fairly expensive as they are mostly based on propriety technology and specialized equipment.

2.1.7 Anisotropic Magneto-Resistive (AMR) Magnetic Sensors

AMR sensors are able to sense magnetic fields and are optimized for use within earth’s magnetic field. An AMR sensor comprises of a thin film of Permalloy deposited on silicon wafer as a resistive strip. In the presence of a magnetic field the resistance of this resistive strip changes by 2-3%. The magnetic field is detected by using four of these resistive strips to form a wheatstone bridge. This enables the measurement of direction and magnitude of the magnetic field. AMR sensor based
technique exploit the fact that most road vehicles have considerable amounts of ferrous metals in their bodies. This makes magnetic sensors a good option for detecting vehicles. A vehicle, whether it is stationary or moving, creates a disturbance in the earth's magnetic field which otherwise is uniform over several kilometers. This change in earth's magnetic field is used to detect, classify and estimate the speed of vehicles. The advantage of AMR sensors is that they can be manufactured in bulk at low cost and mounted in commercial IC packages. They are small in size, highly sensitive, immune to noise and reliable. The problem with existing systems using AMR sensors is that they try to explicitly count or classify vehicles. Due to the exponential drop in detection ability of these sensors with distance, they are generally put in the middle of a traffic lane or at the curb. Then they are able to count and classify vehicles in a particular lane. As has been stated several times earlier this assumption will not hold true in Indian circumstances. Counting algorithms based on some sort of thresholding mechanism will degrade under the chaotic, dense and varied traffic conditions in India. Current classification algorithms developed for AMR sensors will not work effectively due to the wide variety of vehicle types, not only cars but large numbers of two wheelers and three wheelers.

Thus, it can be concluded that AMR sensors have cost, flexibility and deployment advantages. However, existing techniques that use AMR sensors cannot be directly used in the Indian traffic scenario. Significant modifications are necessary.

2.1.8 Technologies for Monitoring Road Conditions

Popular technologies for road condition monitoring are summarized below.

Vision based pothole detection schemes have still not matured and work only in simplistic scenarios. It will not be easy to make vision based system work with wide variety of road anomalies and changing visibility conditions.

Ground penetrating radar is a non-destructive evaluation technique for monitoring road conditions. The chief advantage of using ground penetrating radars is that it can detect internal damage in a road before it appears on the surface. However, this technique requires specialized vehicles that need to traverse the entire road network. Also, this technique needs expensive equipment.

Most recent work is now focussed on using accelerometers for pothole detection. Accelerometer is a device which is able to detect acceleration forces both static and dynamic. So the vibrations that occur, when a vehicle encounters a pothole on the road, can be detected by accelerometers mounted on the vehicle. More details in the related work section. We will also be using accelerometers for monitoring road conditions.

2.2 Vehicle Detection and Classification using AMR Magnetic Sensors

[PKT97] and [CW99] describe the properties, construction and working of AMR sensors. Other aspects of AMR sensors for vehicle detection such as orientation of the sensor are explained in [CW99]. It also explains how different vehicles have unique signals on all the three magnetometer axis. This can be used as signature for vehicle classification. The same fact is utilized in [CCD+04]. However, in [CW99] they do not propose any signal processing algorithms for the purpose of clas-
Figure 3: A specialized vehicle with 3D ground penetrating radar mounted on it.

[CCD+04] proposes to use sensor nodes coupled with magnetic sensors along freeways and intersections. A group of nodes is controlled by a more capable node termed as an access point which will be located at road side. The authors use a simple thresholding mechanism and report a detection rate of 99%. For vehicle length and speed estimation they implement a state machine which sets the value of detection flag to 1 when a vehicle is above a sensor. Else it is set to zero. When the value of detection flag changes from 0 to 1 it is called uptime. Similarly, when it changes from 1 to 0 it is called downtime. Ontime is the interval between uptime and downtime. Parameters like headway can be determined by subtracting uptime of a vehicle from the downtime of previous vehicle. Value of ontime can be used to determine average speed of vehicle by using median vehicle length.

Vehicle classification is done by generating a hill pattern from the magnetic sensor samples. The rate of change of consecutive samples is observed. If they increase at a rate faster than a threshold then it is declared to be +1. Similarly, if they decrease at a rate faster than a threshold then it is declared to be -1. This generates the hill pattern which are generated for all three magnetic axis of the sensor. The authors use these three hill pattern as a unique signature for each class of vehicle. They are able to classify vehicles into six categories with 60% accuracy. In the subsequent work [CEV], where they use magnetic length feature, they are able to achieve an accuracy of 82%.

This work is fundamentally different from our system as far sensing requirements are concerned. This is because they try to count and classify vehicles on freeways and intersection by placing sensors on the middle of traffic lanes. However, they do use a wireless sensor network and their communication architecture can be emulated by us. Overall [CCD+04] does give insights into the behavior of magnetic sensors when used to estimate vehicular traffic.

2.3 Other Traffic Estimation Techniques

[YNL07] characterizes unique traffic patterns on road segments. It assumes the presence of a vehicular mobile network or some form of data communication capability. This capability is combined with GPS to generate location time traces. The authors then use several vehicular traces on a par-
ticular road segment to make spatio-temporal traffic plot which minimizes the loss of spatial and temporal traffic information. A threshold based quadrant clustering mechanism is used to identify current traffic condition. The approach of this work is completely different from ours. We do not assume any data communication capabilities or commuter participation. Also traffic in India is varied comprising not only of cars but also three wheelers, two wheelers and other types of vehicles.

[MPR08] assumes the extensive presence of high end (hence expensive) mobile phones with sensors to perform rich sensing. The idea is to opportunistically use mobiles present with commuters as sensors. However, issues like privacy and user participation are still open questions. Though sensing mechanisms are described, but it is not explained as to how all the sensed data will be processed to give useful information. The paper also introduces the concept of triggered sensing where a low power consuming sensor can be used to activate a more power consuming accurate sensor. For example. Traffic estimation is done using cellular localization to trigger GPS sensing. This concept can be adapted in our system where we can use a single magnetic sensor to trigger other magnetic sensors when sensor values remain above a certain threshold for a specific amount of time. Or we can use an acoustic sensor to trigger sensing of AMR magnetic sensors. In this way sensor nodes can conserve energy and get active only during possible onset of congestion.

This approach again is different from ours. It uses mobile phone as its base. It has several open issue to address regarding its deployability in the context of traffic situation in India.

2.4 Pothole Detection using Accelerometers

2.4.1 BusNet

[ZKSS07] proposes to use public transportation network (Bus network) of Sri Lanka to monitor condition of that country’s road infrastructure. The originally Busnet was designed for monitoring the environment i.e. level of various pollutants through sensors deployed on buses. This system has been modified to carry accelerometers attached to sensor nodes (Micaz) in order to detect if the road condition is deteriorating. A GPS receiver is also attached to accurately determine the places where a road is damaged. The authors make the case for this system by saying that for developing countries it is very important to have a monitoring and reporting system for their road infrastructure. With limited funds they must know where exactly to invest and to take preemptive action before the roads get badly damaged. Also historic data generated by this system will be invaluable to planners and researches who can then build better roads and road networks.

Why use buses? It is impractical to deploy sensor nodes on the entire road network. Building a large sensor network is expensive, difficult to maintain and troubleshoot. Having special purpose vehicles may not be a good idea. They incur extra costs and may not give the kind of redundancy that a nationwide bus network can provide. The communication architecture proposed in [ZKSS07] is as follows. Regional bus stations act local data collection centers. The data collected at substations is routed to the main stations over buses themselves. No connectivity is needed between substations and main station. Sensor nodes do not process data but need some sort of threshold to trigger readings.
The system architecture proposed in [ZKSS07] is very similar to what we plan to do. They have used sensor nodes mounted on buses with accelerometers and GPS receivers. We also use a similar system architecture. Localization is an issue we will deal with later. However, their communication network which does not rely on any external infrastructure is an overkill. Expecting some connectivity at substations will make design of the system much simpler and will remove constraints on amount of data that can be sent to the main station. Even a minimal communication infrastructure will do. On the other hand, their idea of exploiting the country’s bus network is something we would want to replicate. [ZKSS07] is system that has been built for a scenario that nearly mirrors ours. Therefore, we hope to build upon this work. This work does not propose any tangible pothole detection and classification algorithms but only a system architecture for road condition monitoring. We, on the contrary, would like to explore if we can use accelerometer traces to characterize road anomalies and try to find out the severity or intensity of a pothole encountered. We want to determine if more than one accelerometers can improve the performance of current pothole detection and classification algorithms. Hence, our focus is on the sensing aspects.

Some problems faced by [ZKSS07] are the following. Drivers of vehicles try to avoid rough patches of roads. Hence, the sensor nodes miss the opportunity to detect these damaged sections of the road. This also means that the potholes reported are tough to avoid and so need urgent repair. Roads traversed by Buses will only be monitored. Interior lanes of a city may remain untouched by such a network. Therefore, it may be a good idea to deploy sensor nodes on taxis or autorickshaw as well.

2.4.2 The Pothole Patrol

The authors of [EGH+08] make arguments similar to BusNet in favor of mounting vibration sensors (accelerometer) on board vehicles together with GPS receivers to opportunistically gather information regarding road conditions. Such a system is cost effective, is able to cover large number of roads and is systematic and reliable. Also there is no need to monitor roads continuously. It is enough to sample a road few times a day.

The system architecture of [EGH+08] is different from [ZKSS07] as they use WiFi and embedded computers which are relatively expensive than sensor nodes. Following is their system architecture. Data from embedded computers attached to taxis is delivered to a central server through opportunistic WiFi connections to open or participating nodes. A reliable delay tolerant mechanism called dpipe is implemented to pass data to the central server. This mechanism uses file based buffers to store data until connectivity becomes available. It then transfers data using TCP and ensures reliability through application level ACKs. The authors found that attaching the accelerometer to the dashboard of the car was both convenient and accurate. The other two places they tried were the windshield of the car and to the embedded PC. They also determined that the standard deviation in the position of an anomaly reported by the GPS was 3.3 meters. The accelerometer was sampled at 380 Hz and the GPS at 1 Hz. Simple linear interpolation was used for the GPS data.

The authors bring out the challenges in Detecting Potholes using accelerometers. There are a number of events that can lead to a pothole being detected even when it is not the case. For
example braking, door closing, swerves. Other road anomalies such as expansion joints or railway tracks that may lead to high energy events but are not potholes. Also every time a pothole is encountered there is variation in the way it shows up on sensor readings. Hence, there is a high chance of false positives which the authors try to reduce through filtering and clustering mechanism.

One of the most interesting contributions of this paper is their filtering mechanism to remove non-pothole events from the accelerometer detections. Potholes are characterized as “high energy” events in the accelerometer readings but one cannot rely on this alone to report potholes. Thus, proper filters need to be put in place to eliminate false positives. The trace which is generated by readings from the GPS and the accelerometer is first segmented into 256 sample windows. Filters are then applied to continuous stream of windows that is generated.

Following are the filters:-

- **High Pass-** Removes low frequency components caused by acceleration, veering etc.
- **Speed-** If the speed is zero or negligible then acceleration events are not considered.
- **Z Peak-** Rejects all peaks in the vertical acceleration signal if its value is less than a threshold.
- **XZ Ratio-** Rejects windows where peak horizontal acceleration within 32 samples from the peak vertical acceleration reading is less than some factor times the peak vertical acceleration.
- **speed vs z ratio-** Rejects the window if peak vertical acceleration is less than some factor times the speed of travel.

The central server then clusters at least “k” events with some margin for accuracy and only then reports a pothole. The tuning parameters of the detector are found by an exhaustive search using hand labeled training data. The accuracy of the detector is improved further using loosely labeled data set where only type and a rough frequency of occurrence of anomalies is known. The authors claim to achieve a 90% accuracy in reported detections (road anomalies which needed repair) during actual deployment on 7 taxis in Boston.

[EGH+08] have used much capable hardware than we have used. We do not have the computation power to use complex filtering mechanism. However, we should be able to implement the above set of filters on sensor nodes. Also our communication protocol will differ from theirs since we use low power sensor nodes with limited communication range. Hence, we intend to combine the system architecture of BusNet with the filtering mechanism of [EGH+08]. This will form the basis of our road condition monitoring system. We plan to be able to characterize potholes encountered by using multiple accelerometers, multiple traces or new algorithms.

### 3 Traffic and Road Condition Monitoring

#### 3.1 Traffic Estimation using AMR Magnetic Sensors and Sensor Nodes

Our approach to the problem at hand is to combine the flexibility of wireless sensor network with the sensing capability of AMR sensors. Wireless sensor networks have several advantages. They
provide flexibility of deployment. Sensor nets are able to cope with harsh environmental conditions, node failures, unattended operation, complex network topology and a large amount of research has been done in this direction. Sensor nodes need very little power for their operation. They are small in size and ubiquitous when deployed. Today different type of sensor nodes from several vendors are cheaply available along with the necessary programming tools. Hence, it is relatively easy to build a traffic monitoring system, using open components, around a network of sensors. The disadvantage with sensor nodes is of limited memory and computational power. So these additional constraints have to be met when we design our traffic estimation system.

As explained earlier AMR sensors are cheap, effective and reliable mechanism for vehicle, detection, classification and speed estimation. They are able to do so by sensing the change in earths magnetic field when a nearby vehicle distorts it. Depending on a vehicle’s ferrous content an AMR sensor can sense it upto 15 meters. However, for practical purposes these sensors are deployed to cover a specific traffic lane as the change in magnetic flux drops at an exponentially rate with distance. Apart from distance, factors like orientation of the detection axis and speed of the vehicle being detected also affect AMR sensor readings. The magnetic distortion caused by vehicle can be modelled as a composite of many magnetic dipoles. Each dipole causes a specific distortion in the earth’s magnetic field. The result is that each vehicle causes a unique distortion depending on where its ferrous content is present. This fact is used by vehicle classification system using AMR sensors. Hence, each vehicle passing by a AMR sensor gives a specific signature. Gradual change in earth’s magnetic field can be handled through analog signal processing or detection algorithm software.

<table>
<thead>
<tr>
<th>Standoff Distance (foot)</th>
<th>Flux Density (milligauss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>270</td>
</tr>
<tr>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Table 1: A typical automotive magnitude (flux density) versus sensor standoff distance. [Hon05b]

AMR sensors like sensor nodes are small in size and have low power requirements. They are small and compact and hence can be easily coupled with sensor nodes to form a vehicular sensing wireless sensor network.

3.1.1 Traffic Density : A New Metric

Conventionally AMR sensors are used to count, classify or estimate speed of vehicles in a particular traffic lane. With chaotic and unstructured traffic present in India, using this approach is infeasible. Therefore, we introduce a new metric called “traffic density” that we will use to quantify the traffic conditions on a road segment. Traffic density can be defined as the percentage of road area occupied by vehicles. The logic behind choosing this metric is that if a high percentage of road area is occupied by vehicles, it can be construed as congestion. Thus, we are doing aggregate traffic
analysis rather than determining parameters like vehicle count and speed. If we can determine traffic density then we can translate that into an estimating traffic on the road.

Figure 4: Traffic Density.

Traffic density metric does have certain deficiencies. For example, on long stretch of a busy road the traffic may be moving yet the road occupancy could be near hundred percent. This cannot be considered as a traffic jam as vehicles are moving at a steady speed. There are approximation involved when we try to estimate traffic density using magnetic sensors. The deflection shown by a magnetic sensor is proportional to the ferrous content in a vehicle. We assume that the ferrous content in a vehicle is proportional to the size of the vehicle and hence the area occupied by it. The key challenge is to reverse map magnetic sensor deflection to traffic density and subsequently to the state of traffic on the road.

Previous work [Duv08] using this approach explored the following aspects of the problem. [Duv08] tried to establish a detection coefficient which related magnetic sensor readings to area of the road occupied. Since the deflection of magnetic sensor varies rapidly with distance, larger vehicles get detected at longer distances than smaller vehicles. Similarly, vehicles near the sensor give more amplitude than the same vehicle at a greater distance. The proposed solution to this problem is to place two sensors at different heights. It was claimed that the difference between the amplitudes of the two was constant for the same vehicle placed at different distances within the detection region. Another interesting property observed was deflection readings were additive for stationary vehicles. Two vehicles were placed near the magnetic sensor at fixed locations. Then they were placed individually at those locations. The deflection for two vehicles was the sum of individual deflections. These experiments were done on static vehicles. Our focus is now to perform
experiments on moving ones. We plan to find traces of moving vehicles at different speeds and distances and see how the traces vary. Our aim is to find some properties in these traces that we can exploit for estimating combined deflection of a group of moving vehicles. We hope to be able to find some sort of function that reverse maps the magnetic sensor readings to traffic density. Then we will be able to test our system in realistic scenarios.

3.2 Road Condition Monitoring using Accelerometers

Accelerometers are low cost, low power, robust sensors that can be easily integrated with ICs. These vibration sensors can be mounted on vehicles (most like public transport buses) to detect road anomalies. Our plan is to use sensor nodes coupled with accelerometers for road condition monitoring. However, there are problems with this approach. The impact of road anomalies on a vehicle and hence its acceleration depends on several parameters that are complex to model. Some of the parameters are speed of the vehicle, driving habits of drivers and characteristics of the vehicle itself like its weight distribution, suspension and size of its tyres. Also we need to distinguish potholes from other road features such as speed breakers and expansion joint.

Though the idea of using accelerometer for detecting potholes is not new, we want to take this concept further. We plan to use accelerometer to able to quantify the nature and intensity of pothole or damaged road encountered. This may involve using multiple accelerometers or comparing traces of same potholes collected from accelerometers mounted on different vehicles. The idea is somehow be able to approximately model the complex interaction that takes places between the vehicle and a pothole and its effect on accelerometer readings. So rather than have just the location of a road anomaly which is the case with current system we would be able to tell more about the nature of the pothole.

It would be worth mentioning here that currently our focus is to deal with sensing issues of both traffic estimation and road condition monitoring. We are not looking at communication, information storage, retrieval and dissemination aspects of the problem now.

3.3 Objectives

Our goal is to design, develop and test under realistic conditions a system built around wireless sensor network that does traffic estimation using AMR sensors and road condition monitoring using accelerometers. The system should satisfy the constraints stated earlier. Traffic density will be estimated using AMR sensor readings which should be mapped to traffic conditions. Our objective here is to find out a technique to this estimation and mapping with reasonable accuracy. Road anomalies will be detected using accelerometers and their nature or intensity determined. We need to find methods and accelerometer configurations to be able to quantify road anomalies more specifically.

4 System Architecture

The system architecture for traffic estimation will consist of wireless sensor nodes and AMR magnetic sensors combined to form a single sensing unit. These units will be mounted on poles present
on both sides of a road segment of interest. We may mount multiple sensing units on a single pole or on consecutive poles to resolve certain sensing issues. Installation of these units will not in anyway obstruct normal flow of traffic. For road condition monitoring a sensing unit will consist of a sensor node connected to to an accelerometer. These sensing units will then be mounted on vehicles (most likely buses). The sensor node will have to store road anomaly events for sometime before they can be off loaded at some data collection point. More than one sensing unit may be mounted on the vehicle to better quantify potholes.

Let us have a look at different hardware and software elements involved in building our system. We will need sensor nodes, AMR sensors and accelerometers to form the core of our traffic and road monitoring system. A brief description of each of these hardware components is given below.

4.1 Sensor Nodes: TelosB

Sensor nodes are small autonomous computing devices. They are generally equipped with a processing unit and one or more sensors. External sensors are interfaced to the sensor node by using analog to digital converters. The signals produced by sensors after sensing the physical phenomena are changed into digital form by these converters. We will be using wireless sensor nodes because of the flexibility of deployment that they provide. Wireless sensor nodes have an inbuilt wireless transceiver for communication. Sensor nodes are mainly battery powered. They can also be supported by scavenging units like solar cells. Sensor nodes have very limited memory and hence external flash memory is used to meet the memory requirements of certain applications.

For our system we will use moteiv’s TelosB sensor node (also called a mote). The TelosB is an ultra low power wireless sensor node with integrated sensors microcontroller, radio and antenna. TelosB is well suited for prototyping, developing and deploying a wide range of sensor application. It is compatible with standards like USB and IEEE 802.15.4 and hence provides seamless interoperability other devices. Another advantage of using TelosB is that it is fully supported by TinyOS which is a popular open source operating system for sensor nodes. The TelosB features the MSP430 microcontroller by Texas Instruments which is an ultra low power 16-bit RISC processor. This processor has extremely low active and sleep current allowing a telosB to run for years on a pair of AA batteries. The MSP430 has 8 external ADC ports and 8 internal...
ADC ports. We will use the external ADCs to read AMR sensor and accelerometer readings. The TelosB module can be plugged into the USB port for programming or communication. The Chipcon CC2420 radio is present on the TelosB for wireless communications. The CC2420 is an IEEE 802.15.4 compliant radio that provides low power operation and reliable communication. The TelosB provides two antenna options. There is internal antenna built into the module and an external SMA connector for connecting to external antennas. If an application requires an external antenna then an SMA connector may be installed and an antenna can be directly connected to TelosB’s SMA female connector.

4.2 AMR Magnetic Sensors: HMC1022

The Honeywell HMC1022 magnetic sensor is a two-axis AMR magnetic sensor designed for earth field magnetic sensing. They are very sensitive solid-state magnetic sensors designed to measure direction and magnitude of Earth's magnetic fields, from tens of micro-gauss to 6 gauss. The 1022 AMR sensors use resistive wheatstone bridges to measure magnetic fields. They only require a supply voltage for the measurement. Once the bridge is energized by the power supply then these sensors are able to convert any incident magnetic field in the sensitive axis directions to a differential voltage output. By using AMR technology these sensors have several advantages over coil based magnetic sensors. The HMC1022 sensors can be used for applications such as Compassing, Navigation Systems, Magnetometry and Current Sensing. [Hon05a]

![Honeywell HMC1022 AMR magnetic sensor](image)

Figure 6: A Honeywell HMC1022 AMR magnetic sensor

4.3 Accelerometers: ADXL203

The ADXL203 is a high precision, low power, dual-axis accelerometers with signal conditioned voltage outputs on a single IC. The output signals are analog voltages proportional to acceleration. ADXL203 can measure acceleration, both static and dynamic, with a full-scale range of 1.7 g. This sensor is made of a surface-micromachined polysilicon structure that is built on top of the silicon wafer. This structure is suspended over the wafer by means of Polysilicon springs which provide resistance against acceleration forces. A differential capacitor is used to measure the deflection of the structure. The differential capacitor consists of independent fixed plates and plates attached to the moving mass. The acceleration faced by the moving mass deflects the beam. This unbalances the differential capacitor resulting in an output amplitude that is proportional to acceleration. [Dev06]
4.4 Operating System

Operating system for sensor nodes have significantly less functionality and capability than general purpose operating systems. This is because of the limited computation power and memory of sensor nodes and their need to conserve energy for prolonged operation. TinyOS is one such operating system that is very popular. It is a free and open source. TinyOS is event driven and component based. This embedded operating system is written in the nesC programming language as a set of cooperating tasks and processes. The nesC programming language is an extension to C designed to embody the structuring concepts and execution model of TinyOS. Programs in nesC are built out of components, which are assembled ("wired") to form whole programs. We are also be writing our application in nesC.

TinyOS has been designed to operate in a constrained environment. It tries to use minimal power and has a small memory foot print. Considering this we chose TinyOS as the operating system for our wireless sensor network to monitor traffic and road conditions. We will be using TinyOS 2.x which is completely redesigned and re-implemented version of the original TinyOS. This was made to fulfill requirements that could not be met because of the inherent design limitations of TinyOS 1.x. [tin]

5 Experimental Evaluation

We did some basic experiments to check the effectiveness of AMR magnetic sensors in detecting moving vehicles when placed beside a road. Our sensing unit comprised of a Telosb mote powered by two AA batteries. One ADC of this mote was connected to an HMC1022 AMR magetic sensor with associated circuitry for signal amplification and stabilization. Thus, we could read the values of one sensitive axis of the magnetic sensor. The HMC1022 was powered by lithium ion batteries which provided the necessary 5.2 Volts. This entire setup was enclosed in a plastic box. The HMC1022 and its associated circuitry was mounted inside the box and fastened by screws. The sensing unit samples the magnetic sensor after fixed interval broadcasts each reading. Another Telosb was used as a base station to collect readings from the sensing unit. This sensor node was attached via a USB connection to a laptop. It transmitted the values received to the laptop where
we stored them. Following were the observations that we made.

Vehicles moving in the center of the road did not show up on magnetic sensors. The width of the road was about 5 meters. Two wheelers could not be detected even if they were only a few feet away from the sensor. We will need more sensitive AMR magnetic sensors to detect smaller vehicles at moderate distances and mid sized vehicles at greater distances. It was observed that speed with which a vehicle moves on the road has an impact on magnetic sensor readings. A large bus moving faster showed a smaller peak value than a pickup moving slower. This can be seen from Figure 8 and Figure 9. The x-axis represents successive samples that were taken from the magnetic sensor. Each sample was taken after a fixed duration of 100 milliseconds. The y-axis represents the magnetic sensor readings in terms of ADC count. This ADC count is directly proportional to the change in magnetic flux observed by the AMR sensor. ADC count can be converted to magnetic flux unit, Gauss, by converting it first into voltage deflection. The voltage deflection can then be mapped to the actual physical unit of magnetic flux which is Gauss. This conversion process is dependent on the specification of a particular AMR magnetic sensor. The other important thing to observe in Figure 8 and Figure 9 is that the width of the peak for a fast moving vehicle is smaller than that of a slow moving one. These experiments were not done in a controlled manner (for example sensor nodes were not at a fixed position). The sensing unit was hand held about two feet above the ground. Hence, the exact distance of a vehicle from a sensor could not be noted but this distance was roughly around one meter. The experiments done till now recorded values of only one axis of the magnetic sensor. We plan to conduct more controlled experiments, varying vehicle types and their distance from the magnetic sensor. This time the sensing unit will be in a fixed position and orientation beside the road. We will record the values of all the three sensitive axis of the magnetic sensor rather than just one. We will then take our setup to a realistic scenario to establish correlation between sensor deflection and traffic density.

Figure 8: Magnetic sensor readings for a bus. The sensitive axis of the sensor is parallel to the ground and perpendicular to the direction of motion of the bus
For road condition monitoring we need to mount sensor nodes with accelerometers on buses and then implement appropriate filters that generate pothole events. Multiple sensing units will be mounted at different places. Then we need to get traces of various tapes of road anomalies. We will then examine pothole traces to see how we can better quantify potholes.

6 Conclusions

In this report the importance of having a traffic and road condition monitoring system was stressed. We discussed the issues related to building a traffic and road condition monitoring system that can be deployed in Indian conditions. A brief survey of current traffic and road condition monitoring technologies was presented. We noted that traditional traffic monitoring systems are built for developed world. In India where traffic conditions are varied, lane discipline is not followed and traffic is unstructured these techniques fail to give expected results. Moreover these systems are expensive to deploy, difficult to install and maintain. Hence, we proposed a different solution using AMR magnetic sensors. Traditional techniques based on AMR sensors count or classify vehicles. This does not work in Indian traffic scenarios. Therefore, we proposed a new metric called traffic density. Our traffic estimation system tries to determine traffic density and map it back to congestion levels on a road segment. Some initial experimental results were presented and architecture of our system stated. For traffic monitoring we intend to use accelerometers because they are cheap and effective. By using accelerometers we want, not only to detect potholes but also quantify them.

7 Future Work

- The immediate task is to interface multiple ADCs (we are experiencing difficulties in this) with inputs from different magnetic axis of the AMR sensor. We plan to conduct more ro-
bust and controlled experiments, varying vehicle types and their distance from the magnetic sensor. This will enable us understand the effect of vehicle size, speed and its distance from sensing unit on the sensor readings. It will help us to determine some correlation between magnetometer values and traffic on the road. This work should be done by mid January.

- We then plan to take our setup to a realistic scenario. Most likely it will be the road outside IIT main gate. We need to collect traces of sensor readings and note the varying state of traffic. Our motive will be to try and find if there is any correlation between traffic density and the magnetometer deflection. It is our intuition that the traffic density may have a stronger correlation with magnetic sensor magnitude than with individual axis readings. Magnitude is the square root of the sum of squares of the readings of each of the three axis of a magnetic sensor. We hope to have this analysis done by the end of January.

- For accelerometers the initial effort will be to collect sample traces of road anomalies and see how they are different from the normal road readings. We will need to mount more than accelerometers on a vehicle and compare their traces for the same pothole event. The idea is to find if using more than one accelerometer helps to better classify or categorize a pothole. This work will be a bit exploratory in nature. We may need to implement some known filtering mechanisms that classify road anomalies as pothole events. Their parameters may need tuning.

- A longterm goal will be to see if acoustic sensors can be used to compliment or fine tune magnetic sensor observation. Traffic estimation using signal processing has been done in [DCTV04]. However, their algorithm’s computational requirements demand the use of a laptop rather than a sensor node. [MPR08] proposes a honk detection algorithm. We may be able to adapt these techniques to perform some estimation correction for our primary sensor which is the AMR magnetic sensor.
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