Scalable Transportation Monitoring using the Smartphone Road Monitoring (SRoM) System

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ABSTRACT

Our quest for ubiquitous Intelligent Transportation Systems (ITS) is simply infeasible over proprietary systems. In a time of abundant smart devices, it is impractical to consider developing competing proprietary monitoring systems to collect information for ITS operation. We argue for utilizing smartphones to present a driver and road monitoring system capable of scaling to the number of drivers without incurring high implementation costs, thus allowing for safer driving conditions and shorter accident response times. We propose the Smartphone Road Monitoring (SRoM) system that is capable of sensing road artifacts such as potholes and slippery roads. The information is collected through crowdsourcing and processed by base stations, giving faster and more accurate responses compared to current systems, to address road safety related events in a timely manner. It is also capable of detecting aberrant driver behavior such as speeding and drifting. SRoM uses both the driver's smartphone and vehicle as sources of information, and allows pedestrians to share media pertaining to each event. The collected data is made available to the public through an interactive map updated with the authenticated events. We implemented a prototype of the system to perform the task of safety monitoring. System evaluation of the prototype shows that the system can be easily implemented in real-life using current technologies at little cost.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols – *Applications;* H.3.4 [**Information Storage and Retrieval**]: Systems and Software – *User profiles and alert services*

General Terms

Management, Measurement, Performance, Human Factors, Verification.

Keywords

Intelligent Transportation Systems; Smartphone sensing; Crowd-sensing; VANets; SRoM; Road safety; Smart cities.

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1. INTRODUCTION

The problem of vehicle overcrowding on roadways is becoming more common around the world. Consequently, expansions were made to networks of roads to accommodate the increasing number of vehicles. However, these changes resulted in an increase in the rate of deterioration of road health, out-pacing current road health monitoring techniques and increasing the number of accidents. The rising tide of Intelligent Transportation Systems (ITS) is growing to address a multiplicity of such challenges.

The significant increase in the number of drivers can be put to use to help address these challenges, through continuous monitoring and reporting of events by the drivers and their vehicles. However, to enlist the help of the public and their vehicles the system must be inexpensive to attract participants. To achieve such a goal we have to repurpose existing hardware available to many drivers that is capable of sensing, processing, and reporting events in real-time.

Current smart devices (e.g., smartphones, tablets, phablets, etc) boast powerful processing capabilities supplemented by a number of sensors available with different degrees of quality and sensitivity. These phones are capable of acquiring information such as current location, direction, speed, and tilt and report this information through multiple access schemes, such as cellular, Wi-Fi, and Bluetooth.

In this paper, we present a client server system that utilizes smartphone technology to monitor both road conditions and driver behavior collected from individual drivers, and to report any anomalies in real-time; thus providing better road conditions and a safer driving experience.

Maintaining traffic and road safety standards is becoming a burden on the current infrastructure due to the increasing number of vehicles on the road. This is manifested in the form of increasing incidents of traffic congestion, collisions, and hazardous road conditions. These problems pose a significant cost for both governments and drivers. The presence of more vehicles on the road in a poorly managed environment also results in more fatal accidents. In Canada alone, 166,725 people were injured during 2011 as a result of traffic collisions, 2,006 of those injured died within one month of the accident [1].

These numbers can be significantly reduced through better monitoring of road conditions and driving behavior. The information collected can help agencies concerned with road safety address issues such as prolonged traffic congestion, slippery roads, potholes, and collisions. This information can also be shared directly and instantaneously with other drivers to avoid problems, such as bad road conditions and collision locations. This allows for safer traffic and better emergency response when needed.

Information dissemination systems for traffic safety exist in a number of countries. The main purpose of such systems is to detect events such as collisions, congestion, and poor road conditions. In general such systems are referred to as Intelligent Transportation Systems (ITS), and are discussed in Section 2. Although they offer a solution to the problem of the increasing volume of vehicles on the road in a timely manner, they require an extensive network of infrastructure that is both costly to install and maintain.

Efficient capturing of information in ITS also requires a form of standardization to be implemented by car manufacturers. However, this process faces many problems due to the long life cycle of current light vehicles which on average is 9 years; moreover, at least 35% of new vehicles are expected to pass the 10 year mark [2], thus making the implementation of such systems an impossibility for rapid deployment. The above reasons make such systems unfit for deployment in many regions of the world that lack the financial support or the time to implement such systems.

In order to address these shortcomings, we propose a system that is inexpensive, requires minimal hardware, and can be rapidly deployed using readily available technology. Our system aims to augment and support ITS technologies already in place.

The objective of this paper is to present a system capable of detecting real-life events, on road conditions, and driver behavior, and report such events to a dedicated server. The system relies on smartphones to act as both the sensing platform and the reporting mechanism, thereby alleviating the need for an infrastructure-based approach. Data gathered from individual vehicles are aggregated to authenticate events based on the frequency of detection, and alert governmental agencies about the event, along with a measured level of urgency. The public is also allowed access to the collected information through an interactive map of recent unaddressed events to help avoid them. Smartphones are utilized in various ways to attain our goals. The system is designed to function without interrupting the driver's focus, and is seamlessly able to detect dangerous road conditions and driving behavior. In case the passenger would wish to contribute actively in the monitoring process, the system also allows for a detailed mode of operation that entails interaction and media collection (e.g., image of road condition).

We propose SRoM; a real-time traffic, road conditions and driver behavior monitoring and archiving system designed and implemented on smartphones. Our contributions are namely:

1) Smartphone sensing with computational offloading to enhance the performance of the monitoring and detecting system.
2) Designing a system that is interoperable and calibrated over the diversity of smartphone brands; i.e. sensors sensitivity.
3) Automated calibration of smartphone built-in sensors customized to the car type and quality of suspension.
4) Designing and implementing a dynamic location prediction scheme to predict the car's current location relative to intermittent GPS readings; to prolong smartphone battery life.

The remainder of this paper is organized as follows. In Section 2 we present the current solutions in the market along with proof of concept solutions found in the literature addressing ITS problems. Section 3 describes the system design, followed by Section 4 which details our prototype implementation. Section 4 details performance metrics and evaluation scenarios carried out on SRoM. Finally, Section 6 concludes the paper and presents our outlook on future work.

2. BACKGROUND AND RELATED WORK

Intelligent Transportation Systems (ITS) span technologies and applications that focus on providing services to improve traffic management and timely dissemination of information among users, governmental agencies, municipalities and other concerned parties for safer, smarter and better utilization of the road networks [3] [4]. ITS information flow is currently restricted between drivers and governmental transportation agencies (driver-ITS), while driver-driver information sharing is limited to social-network based smartphone applications.

Currently ITS information dissemination methods for on-the-road drivers regarding current and upcoming road-related events are often limited to road side information on electric billboards. Extending information dissemination from road side information billboards to a more accessible source of information such as the driver's smartphone, and in vehicle information console, will improve traffic safety and driver road experience. Additionally, collection of real-time road condition data is performed by specialized vehicles of the transportation sector of the government retrofitted with specialized sensors [4]. However, this sort of data collection cannot be relied on as the sole source of information due to their inability to monitor all the transportation networks for real-time problems [5].

Governmental agencies are aware of this limitation; hence arrays of stationary sensors are placed as a solution to counteract the lack of information collected by traditional means. These sensors are set up to monitor roads exhibiting high traffic volume or frequent road problems, thus requiring extensive infrastructure and maintenance to function properly [6].

2.1 Current techniques for traffic and road condition detection in ITS Systems

Currently, there are a number of systems to monitor road and traffic health, process data collected, and provide feedback both to the drivers and the governmental agencies. These systems can be classified into two categories; mobile-based sensing systems and stationary sensing systems. Mobile-based sensing systems comprise of sensors fitted on special purpose vehicles that perform routine road monitoring on the ITS system at different road locations. These systems implement detection methods such as 3D reconstruction, vibration, and smartphone based road monitoring. Stationary sensing systems, on the other hand, rely on stationary sensor nodes installed throughout the ITS system performing continuous monitoring of a single fixed location such as loop detectors, and closed circuit cameras. Both mobile and stationary systems share a number of shortcomings such as the need for extensive infrastructure, high-power requirements, and bulky hardware. Both manned and unmanned aircrafts are used to monitor large stretches of roads with mounted cameras and radars. However such methods incur a large cost to operate and maintain, and fail to provide results in bad weather conditions limiting its usability.

To perform mobile based sensing both land and aerial vehicles are used, these vehicles are retrofitted with sensors, capable of sensing varying aspects of the road to detect anomalies using a number of methods. The 3D surface reconstruction method [7] is a visual type of detection that makes use of either range sensors using lasers, or stereovision algorithms using video cameras. While laser-scanning systems offer real-time detection, they require large devices mounted on the body of the vehicle, frequent maintenance and significant power consumption. This technology is impractical for lightweight passenger vehicles. Comparatively, stereovision-based pothole detection only requires two cameras, and is capable of detecting pothole clusters. However the system also requires complete 3D reconstruction to detect potholes exceeding the computational capabilities of most smartphones.

Smartphones offer better computational capabilities than dedicated systems, lower implementation cost, and no maintenance. However, this approach suffers from power limitations and low accuracy due to placement inside the vehicle. While research efforts showed success, prototypes have required repeated manual adjustments of the sensors' sensitivity to match car type.

To perform stationary based sensing various sensors are used and are placed either inside the pavement or on the sides. These sensors are mainly focused on detecting dangerous driving behavior and traffic congestion of the road, and include loop detectors and exhaustive visual detection (disseminating dedicated vehicles).

2.1.1 ITS systems

The array of sensors mentioned above forms a large network of data collecting nodes, the data collected is then aggregated at a central traffic control center which process the data alerts drivers of potential hazards, and governmental agencies of problem areas that require attention.

In Canada, the first major ITS project is named COMPASS developed by the Ontario Ministry of Transportation (MTO) on January 1991 to manage traffic congestion on urban freeways [12]. The COMPASS system consists of seven major components including vehicle detector stations, closed circuit television cameras, maintenance patrol, traffic operations center, changeable message signs, emergency response agencies, traffic, and road information systems.

The COMPASS system aims to reduce traffic congestion and increase road safety. To achieve this goal the system focuses on enhancing three aspects relating to road safety: (i) decreasing the time latency for detecting and removal of freeway incidents and vehicle breakdowns, (ii) providing live updates to all drivers on the highways regarding delays and traffic conditions, and (iii) addressing peak rush hour traffic flow to avoid deadlocks and prolonged traffic jams through innovative traffic control devices.

Data collecting in COMPASS relies on loop detectors with a minimum of one loop detector per lane. Loop detectors are planted throughout the highway at inter-distance of 500-800m between the sensors. The information is then transmitted to the Traffic Operations Center (TOC) through fiber optic, and coaxial cables. The information is then processed by the Freeway Traffic Management System (FTMS) computer. The data is then sent to electronic signs to inform drivers of upcoming events. The information is also uploaded to a public interactive map which displays information regarding the whole highway for planning purposes. The COMPASS system also uses manual data collection as it relies on maintenance staff patrolling on the highway to call in any incidents they may observe. The system also relies on a network of Closed Circuit Television (CCTV) cameras stationed one kilometer apart along the freeway. The CCTV system is implemented to ensure the accuracy of the data collected from the loop detectors [12].

In the USA, the ITS system nicknamed Clarus, was introduced in 2004 the aim of this system is to monitor and provide near real-time updates regarding adverse weather conditions on surface transportation users by collecting data about both atmospheric and pavement conditions from the environmental sensor stations (ESS), and Automated Vehicle Location (AVL) equipped trucks. The data is then uploaded to an interactive map as well as weather warning service to allow drivers to better plan upcoming trips and alert them of dangerous road conditions.

The current ITS systems do successfully enhance road safety, and lessen traffic congestion. However, these systems are rigid in nature, and incur a large cost when it comes to expansion or upgrading of the hardware used, and are susceptible to bad weather conditions [17]. This makes these systems unfeasible to preexisting road networks, and developing nations [14].

2.2 Smartphones for traffic and road condition detection in ITS Systems

To adapt the sensing of smartphones in a vehicular environment a number of sensors in particular form the main group for usage. These include: global positioning, acceleration in three dimensions, tilt sensing, visual and auditory sensing including ambient light, audio, video, and still pictures. We will detail two pioneering examples in the remainder of this section.

2.2.1 Boston reporting system (Street Bump)

The system was built in collaboration with *Citizapps*, a partnership between Fabio Carrera, a professor at Worcester Polytechnic Institute, and Joshua Thorp and Stephen Guerin of the Santa Fe Complex and the mayoral office of Boston [7]. The system works by utilizing driver's smartphones to monitor potholes in the roads during their in city trips. The data is then collected and sent for analysis to authenticate events based on crowdsourcing, the authenticated locations are posted on the interactive map for the public, and the locations along with the severity of each pothole is sent to road services to address the issues.

2.2.2 Waze

The *Waze* mobile application is an application that uses social networks and built in sensors to share information regarding road condition between drivers within the same vicinity or over social posts made to the social networks [8] [10]. The Waze application also offers augmented road maps with the social reports from multiple users to highlight the busy highway sections and the best routes between the current user location and their destination. The application makes use of the built in GPS sensor to localize the user and ascertain their current vehicular speed. Using that data the application can detect and locate traffic congestion and other similar events. Waze also incorporates active reporting where the users can pick the event type and allow the current GPS location to pinpoint the location of events such as an accident or bad road conditions. While this application's main focus is sensing traffic conditions it makes no attempts to detect the road conditions or driver aberrant behavior using built-in sensors and relies on only active reporting to pinpoint the unique events along the road from hazards and accidents; as with other microphone systems [11].

Inrix is a mobile application [9] that offers an interactive map with road events collected passively from participating smartphones to detect congestion events [13]. It also logs general data such as average speed and location along with time of day to ascertain general traffic behavior and predict traffic jam times to better plan current and future trips.

3. SMARTPHONE BASED ROAD MONITORING (SRoM)

We propose the Smartphone Road Monitoring (SRoM) system that is capable of sensing road artifacts such as potholes and slippery roads. It is also capable of detecting aberrant driver behavior such as speeding and drifting. The SRoM system relies on crowd-sourcing to monitor road health and safe driving conditions. The result is an efficient, low cost system that provides more comprehensive coverage when compared to its predecessor. SRoM combines information from individual drivers, pedestrians, and governmental agencies, and combines this information in real time to locate deteriorating road conditions, or dangerous driving behavior and forward the data to the public and law enforcement agencies to help address these situations as they occur.

3.1 SRoM Architecture

SRoM is designed to meet the following requirements: **Integrated:** Traffic and road conditions are assimilated from various sources including: smartphone, ITS sensors, and local transportation authorities. **Adaptable**: The system is capable of scaling accuracy and functionality based on available hardware. **Human Reporting**: Pedestrians/passengers are able to actively contribute to the system's event stream with more functions available through the system interface. **Context Aware**: data shared with drivers such as alerts are based on their current location and mode of transportation.

SRoM's interactive map has the information collected from the users as well as MTO to better assist viewers in understanding road conditions. The system addresses varying car and smartphone types by applying a calibration phase for new users to adjust the newly registered smartphone vehicle combination to match the preexisting user pool.

The SRoM system is composed of four main components: the end user terminal composed of the smartphone, traffic information supplied by preexisting ITS implementations, SRoM server, and Interactive map. The user terminal collects the majority of information while the ITS supplied information is mainly for scheduled road repair and congestion reports. The user terminal has 2 main modes of operation: (i) pedestrian/passenger mode which uses the smartphone to make active reports of events, and (ii) driver mode, which relies on the smartphone to detect road conditions and abnormal driver behavior. The SRoM server collects the reports from the end users and ITS alerts and combines the data to authenticate events and update the interactive map. Figure 1 describes the overall architecture of the SRoM system.

The end user component of the system consists of two major modes of operation, passive and interactive. Interactive mode is for use by pedestrians/passengers allowing them to report events using the system allowing for better accuracy. In the passive mode the drivers use the built-in smartphone sensors to detect the presence of road deterioration, dangerous driving, or vehicular accidents. The accelerometer is the main sensor used in this mode as the slight variation in the axes translate the events experienced by the vehicle tilting during events such as dipping into pothole, slipping on sleet or driving over exposed gravel areas.

3.2 SRoM Server

The SRoM server is designed with three objectives, namely 1) collecting events from End users and ITS road and weather alerts, 2) track user confidence rating, and 3) push event data to interactive map engine. End users, drivers specifically, create a continuous stream of events. However, due to the diverse nature of vehicles and smartphones used, the server must adjust the confidence rating based on each respective vehicle smartphone combination. The server is supplied with a number attributes associated with each event.

3.3 SRoM System Processes

The SRoM processes consist of the following phases, 1) **Registration phase**: of newly joined smartphones, 2) **Calibration** phase during which auto-calibration of the smartphone is carried out, and 3) **Operation**: consists of two modes: active and passive.

Once a user installs the application and runs it for the first time the system gets a registration request with the smartphone devices unique ID, the server responds with a system assigned ID that is used to report events both passively and actively. The calibration phase is used to normalize the reading of the various smartphones and vehicles combination to ensure more stable readings from the whole participatory user pool.

Once a new user engages the passive mode for the first time the application waits for a stable sensory reading indicating the placement within a cradle (minor noises are ignored). The application requests a training area from the server, the server responds with a list of locations of training dedicated baseline events along with the expected sensory reading. The driver is unaware of any changes in the application the system sets the sensory sensitivity to the lowest threshold preconfigured, while driving. The system keeps the GPS awake and waits to approach a known baseline event. Once the device is in the vicinity of an event

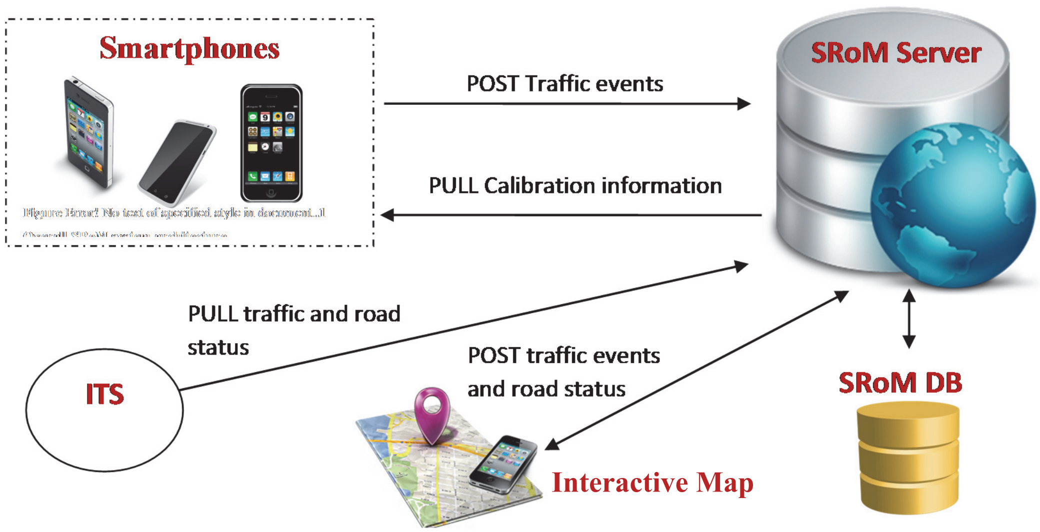

Figure 1 – SRoM System overview

it waits for any sensory input above the normal tries to match them to the supplied sensory data. Based on the comparison the system either passes the calibration incident or a failure is declared. In case of failure, the system adjusts the sensor sensitivity and repeats the process. Once a number of consecutive successes have been registered the last sensory adjustment is saved and the calibration phase's exits and the smartphone device is allowed to start reporting events.

To ensure consistent results along with the smartphone ID the server assigns a confidence rating metric. This metric starts at zero. Once more events are physically checked and authenticated the confidence rating is either elevated or demoted. Compared to a predefined threshold, continuous bad reports by a certain user triggers a recalibration phase and mark the user's vehicle and smartphone as an unacceptable source of reports. After the user passes the recalibration phase, and if he/she continues to report false events, the user is then blacklisted from further use of driver mode for predefined period of time before being allowed to rejoin the system again.

In the operation phase, SRoM allows for active (pedestrian/ passenger) and passive (driver) modes. In active mode the user is actively engage in the reporting of events through the use of the smartphone based form. Driver mode, on the other hand, does not require active participation from the driver. SRoM System Operation is depicted in Figure 2.

3.3.1 Driver Mode

In smartphone mode, dangerous driving detection is mainly for warning purposes because the accuracy and potential for system abuse is high. Once the driver has the smartphone inside the assigned cradle, the SRoM system is activated. State-of-art literature presents several methods of vibration detection to locate potholes and other similar road events [13]. While these schemes provide proof of concept of operation, they fail to provide an answer fitting for a crowdsourcing environment. Existing schemes require distinct manual tuning to achieve accurate results, and fail to adapt to the diversity of the smartphones types, vehicle models and makes and random smartphone placement inside the vehicle.

To address the aforementioned issues, the driver mode had to expand to allow for multiple operating modes to accommodate any smartphone type with differing sensory sampling rate, quality, and current battery charge to discern the proper sensing method to employ. Currently there are three systems predominantly employed in current research and all rely on the accelerometer readings.

Threshold test: In this detection test a threshold is set based on the acceleration amplitude the sensory data is tested once a reading is larger than the predetermined threshold it is identified as a pothole, once the initial threshold is passed a number of tests are required to confirm a positive result to better classify the pothole event as a large pothole or a pothole cluster. In this mode the placement of the smartphone is very important as the orientation of the smartphone with respect to the ground is key. While this test is the simplest and requires rigid placement, it has the lowest computation and power cost when compared to the other tests [15].

Accelerometer deference test: This test is an extension of the threshold test once the threshold test is passed two consecutive readings are taken, the two readings are then compared for the rate of change once the rate of change is large enough signifying an event took place. This test like the previous one has the same drawback requiring the orientation of the smartphone to be upright compared to the ground [16]. However, this test is better than simple threshold test as is capable of detecting pothole clusters, but requires high sampling rate smartphones.

Zero acceleration test: this test looks for a near zero readout in all axis of the accelerometer simultaneously, the orientation of the smartphone is a non-issue in this test allowing for better test results but requires a much higher sampling rate from the smartphone to have good accuracy to detect abrupt events such as potholes.

High-end smartphones employ the three pronged test using all the above tests to ensure high accuracy and lower false positives. However, if the battery drops below certain threshold, the tests are restricted to both Z-DIFF and Z-THRESH. Z-THRESH alone is used once the battery reaches minimum threshold allowable. The system then shuts off pothole detection and only maintains emergency detection.

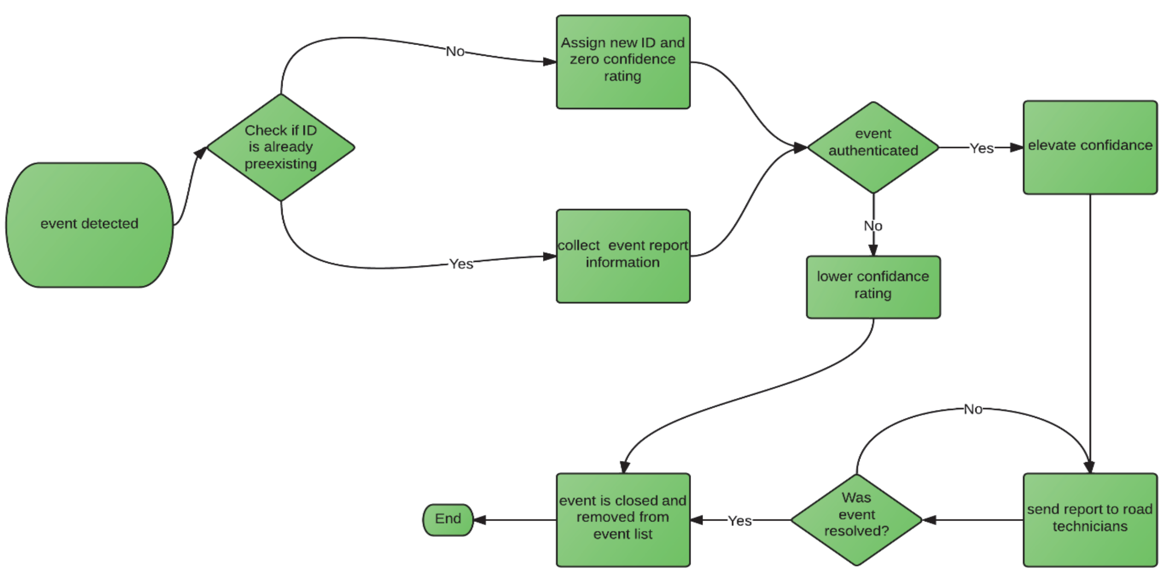

Figure 2 – SRoM Functionality

3.3.2 *Pedestrian/passenger mode*

This mode of operation the application requires human interaction, and offers ease of use in the process of reporting events by the user, thus allowing for a higher number of participants, to accomplish this goal the interface was simplified to shorten the time required to perform a successful report, the interface is comprised of a list of events to choose from after which the user is sent to another screen where they are promoted to either add a video, or picture to their report, or simply share their GPS location alone. The location, event type, and optional media files are then uploaded to the server. Users are registered with the server before getting permission to post reports to ensure accountability the physical address of the phone is used when registering, this allows for black listing repeat offenders, who report false information or attach inappropriate media.

3.4 SRoM Server

Once an event is reported by a driver or a pedestrian/passenger the following processes are performed by the SRoM server:

1. Update related event cluster: Once a number of events occur within a given area a cluster with a unique ID is created and further events of the same type after are amended to the current cluster.

2. Purging old events: Once an event has been flagged as resolved confidence points are distributed to the users involved and the event is then deleted

3. Storing Data: Updated list of users, respective rating, MTO alert areas, and road alerts are stored into the SRoM database.

These processes are event triggered allowing the SRoM server to function without the need for a continuous script constantly performing tasks. The SRoM server consists of a relational database that is used to store all received event data. The database groups each cluster of event confined within a limited space as one event with the location centralized to the one corresponding to the majority of reports.

Reports are weighted by two factors: the quality of smartphone, and time delay until the first successful GPS solicitation after the event. Events pertaining to road condition are held for a period of time based on the severity of the event and the amount of expected traffic on the road this is used to increase the number of reports allowing for better accuracy before sending the location, event type, and severity to road technicians. In the case of emergency events such as accidents the reports are sent immediately to EMS and the police.

3.5 SRoM interactive Map

The interactive map allows users to view the collection of events in their region thus allowing them to better plan their tip and avoid bad road conditions. The interactive map has two modes of operation: heat map and report map. In the heat map mode, the system creates a list of events pertaining to road conditions only and uploads them to the map in clusters marked by circles radiating further for event condensed regions.

This allows users to better judge over all road health in the regions they wish to visit and avoid bad sections of road while traveling. The normal mode has more functions as it allows the users to click events and report events on the map directly by dropping a pin on the location they wish to report. After which the user is solicited for information regarding the event using a pop up page. Users are allowed to view media relating to reported events by clicking preexisting pins generated by active reports and other interactive map users.

4. SRoM PROTOTYPE IMPLEMENTATION

We describe our implementation of SRoM. The goal of the SRoM application is to demonstrate the effectiveness of crowdsourcing for road and traffic monitoring purposes. The prototype implementation involves prototype architecture, prototype interface comprising from a smartphone with Bluetooth and 3G data connectivity, a computer, and a google map engine subscription to test the systems capabilities to detect road artifacts passively, detect hazardous driving, and active reporting.

4.1 Prototype Real World Operation

A SRoM user downloads the application to his smartphone and places the smartphone inside the NFC cradle. The SRoM application starts by requiring the user to swipe left or right from the home screen to choose the form of operation; interactive mode for pedestrians/passengers, or passive mode for drivers. Once the user picks a mode of operation she/he is met by either of the screens shown in Figure 3.

Once a mode has been activated, the server verifies if the current user has an assigned ID or not. If not, new ID is assigned. If the user selects passive (driver) mode, the server solicits the applications for its current location to initialize the training phase. Afterwards, the server responds by providing a list of event locations, which may include bridges, a number of potholes, and other relevant events. If the active mode is selected, the SRoM system verifies that the GPS sensor is on for the sake of correctness of event location reporting.

Figure 3 – SRoM system active and passive home screens

4.2 Interactive map

To simulate the functions of the SRoM system we make use of the Google engine API, as it allowed for the use of heat map and pin map modes. While such use usually requires licensing to use, Google offers free usage to universities and educational institutes.

The map engine is limited in complexity, for the purposes of the project the map is supplied using PHP script an xml page using approved format. The heat map shows cluster location properly, however the radiation is not limited to streets

5. PERFORMANCE EVALUATION AND ANALYSIS

We evaluated the performance of the SRoM system by performing a number of scenarios involving the various modes of operation. The tests measure a number of metrics to show the systems performance in performing its various tasks such as latency time of detection, location accuracy, and detection rate. While the system is setup to handle a multiplicity of events, we emphasize pothole detection. To perform the test scenarios we installed the program on a Samsung galaxy S2 android device. By evaluating the prototypes various functions we aim to show both interactive and passive reporting.

5.1 Performance metrics

Pothole detection rate: We use this metric to evaluate the number of true positives detected by the system versus the number of false reports made by the varying systems modes used.

Detection time latency: We use this metric to evaluate the time lapse between the time the event occurred and the time the system detected and reported the event to the server.

Location accuracy: We use this metric to calculate the overall accuracy of our location when compared to actual coordinates. We have two modes of location detection. The first *GPS reported* and relies on live GPS reading from the Smartphone. The second is *GPS predicted* where the system performs a location prediction based on past GPS readings coupled with sensor data. We use this metric to affirm the rate of error in location when compared to a standing GPS at the same location.

5.2 Experiments and varying scenarios

5.2.1 Pothole Detection

In this scenario we deal with road events detection. The vehicle involved performs a number of laps around a designated area. Initially the pothole locations are collected based on pedestrian/passenger smartphone GPS readings and the types of the potholes were classified into three categories: cluster, large, and small potholes. We report the results of the multiple pothole detection mechanisms used in smartphone mode.

At constant speed, the performance results of the three detection mechanisms under a constant speed are shown in Table 1. As expected, the threshold test being the most simple is the most reliant on accurate sensor sensitivity, while Zero-G shows the best detection rate. As the table shows the three pronged test offers the best accuracy with comparable number of false positives. At variable speeds, performance results of the three detection mechanisms under the three speeds are shown in Figure 4.

Table 1: Pothole Detection Comparison – Constant speed

Type	Total	Threshold	Zero-G	Threshold difference	Three pronged test
Large pothole	6	6	6	6	6
Small pothole	4	2	2	2	4
Pothole cluster	4	1	3	1	3
False positive	-	4	2	1	1
Total	**14**	**9**	**11**	**9**	**13**

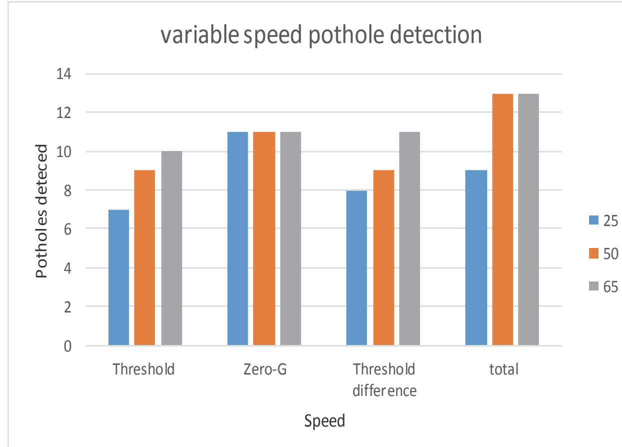

Figure 4 – Pothole Detection Variable Speed

At low speeds the testing mechanism starts to fail, the threshold based test suffering the most loss of accuracy due to its simple approach to detection, while the Zero-G test remains impervious to the low speeds the vehicles are going during event detection.

5.2.2 Location prediction

In this scenario we test the system's ability to predict location in the blind periods between GPS reads, the duration of the test is 2 minutes, the vehicle will perform turns randomly between the start location and end location. While the speed of predictions is adjusted to match the vehicles speed however with lower speeds the ability to detect turns is lowered causing higher error. The performance results of the algorithms under a constant speed are shown in Table 2 as expected, the threshold test being the most simple is the most reliant on accurate sensor sensitivity, while Zero-G shows the best detection rate. As the table shows the three pronged test offers the best accuracy with comparable number of false positives.

Table 2 – Prediction Error Margin

Speed	Lap 1	Lap 2	Lap 3	Lap 4	Lap 5
55	3m	4m	5m	4m	3m
45	4m	5m	5m	6m	5m
25	7m	9m	20m	4m	9m

5.2.3 Accident Detection

The detection of the accidents also depends on using the accelerometer on the driver's SRoM system. Once an accident is detected a timed message is displayed, the user must interact with the message to interrupt incident response procedure. In the case of static GPS readout once the countdown expired, the application immediately sends an email to the preprogramed address with the GPS coordinates and the message that an accident took place.

To mimic the behavior of an accident a class was used to feed pseudo sensory data with both static and continuous GPS readings to ensure correct event response. In our implementation, an alert was issued to the driver in case of an accident to be dismissed, if not dismissed the program sends a distress message to the authorities. In case of a higher event of deceleration the application will forgo the wait time and immediately send a report, this is due to the improbability of a faulty accelerometer reading resulting from human interference.

6. CONCLUSIONS AND FUTURE WORK

In this work we described how SRoM is capable of using smartphones to turn a normal vehicle into a smart vehicle capable of detecting road events and hazardous driving. In the future, SRoM could operate coupled with information from On-Board Diagnostics (OBD) units in cars. The use of OBD-Smartphone assisted systems can help users address car problems and road problems before they become detrimental to the driver's and occupants' health and the vehicle's usability [18].

OBD is normally used for regular maintenance to address specific problems, but OBD can be instrumental to immediately assisting in addressing other issues related to road, traffic, and driving pattern monitoring. Best accuracy can be achieved with the presence of the OBD dongles. OBD dongles are getting cheaper to buy and easier to install for the average user.

SRoM introduced a reactive accident reporting mechanism, and in future work can be improved by adjusting the reporting mechanism to allow for streaming media. This may allow incoming EMS services to locate the event and the extent of the damage via the media stream. It may be beneficial to employ a dedicated line or hotspots along the highway and other problem areas to allow for such a stream to take place since android permissions do not allow for application-generated calls to emergency numbers. The prototype's interface was made in a predefined list of events, but it can be further developed by allowing the user or traffic authorities to update and alter the list content to become better suited for the region. For example, introducing sleet and black ice alerts during the winter and construction alerts during the summer.

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