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Month Year

Candidate's Declaration

I confirm that this dissertation and the work presented in it are my own achievement.

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Abstract:

This dissertation presents RoadSense+, a mobile application that uses smartphone sensors to identify and report potholes on the road in real time. As a smartphone application, RoadSense+ utilizes the accelerometer and GPS features to report pothole locations in real time and with high precision to improve road safety and maintenance. The methodology includes creating a proof of concept employing Agile software development principles and combining sensor data with machine learning algorithms to differentiate potholes from other irregularities on the road. This is supported by field tests that show the ability of the application to detect cases in real time while reporting mechanisms from the community make the system more accurate and reliable. Some of the findings include: It is evident that RoadSense+ enhances the speed and accuracy of pothole reporting more than the conventional approaches. This research suggests a scalable change in the current approach to managing roads in urban areas with more proactive and technological solutions for road maintenance, thereby possibly decreasing the costs of maintenance while increasing road safety in different municipalities.

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1. Critical Evaluation of Existing Technologies and Methods

List of Abbreviations:

1. SVM stands for “Support Vector Machine”
2. ML stands for “Machine Learning”

Chapter 1 Introduction:

1. 1 Overview

While the development of urban infrastructure is a continuous and dynamic process, road maintenance has become one of the most significant challenges affecting the safety, economy, and quality of life of urban populations. Out of all the problems that exist, potholes on roads are not just mere annoyances but are potential dangers that can cause a variety of problems ranging from car breakdowns to accidents. This dissertation proposes RoadSense+, a mobile sensor-based system that can identify and map potholes in real time using the technology available in people's hands to improve road safety dynamically (Gajjar, et al., 2022).

These are surface roughness features, which are usually caused by a combination of factors such as weathering, traffic load, and substandard construction materials among others, and pose a myriad of risks to road users. Apart from inconveniences, potholes pose a threat to the safety of vehicles and their occupants and may lead to accidents, and loss of lives or property. In addition to the direct costs of fixing potholes, there are secondary effects that can be felt in the economy including time lost due to congestion, fuel consumption, and time lost due to productivity losses (Lee, et al., 2023).

In urban areas, traffic congestion is normally higher, and the road network is normally complex, and this explains why potholes are common. In almost every urban centre, new potholes are formed at unstoppable rates due to continuous traffic and severe weather, making them a challenge to municipal authorities responsible for road maintenance (Gajjar, et al., 2022).

1. 2 Rationale

The motivation behind RoadSense+ is driven by enhancing road safety and the impact associated with road maintenance and car damage as a result of potholes. Traditional methods for pothole identification are long and some might be required to use a manual inspection since they cannot meet the increased rate of their formation and reemergence (Faisal, et al., 2019). The project to transit into a more proactive technology-based approach of using mobile sensors to identify, locate, and even remediate the potholes for improved management more effectively and at lower cost. The potholes pose a severe challenge with potential the dangers associated with the users of the road and can cause havoc ranging from damage to vehicles, to causing an accident. They can also conceal traffic signs and road markings, which makes it difficult to make the appropriate decision while driving. Potholes can be dangerous in the following ways: These dangers can be averted through the remediation of the potholes before they bring about severe problems, such as traffic accidents. The potholes also have the impact of weakening the structure of the road network and thus create more potholes and further degradation. Potholes can be fixed before they become a problem, and maintenance can occur before it is needed, thus increasing the life of the roads and decreasing the amount of money that will be needed in the future to repair them (Wu, et al., 2019). The potholes also ruin the sustainable development of cities by bringing about traffic congestion, delays, and wastage of fuel.

The economic effects of the damages that have been brought about as a result of the potholes and their remediation and maintenance costs impact on the monetary losses of people and companies. In its very essence, management of infrastructure in urban areas, infrastructure and pothole detection and maintenance, ranks among the most crucial elements, and in so doing, it provides a catalytic role to improve the quality of human life, their productivity, and potential for cities to be sustainable, consequently fostering economic development and improvement of wellbeing among people (Shravanth et al., 2021).

In general, the importance of pothole management includes an increase in safety experienced on the roadways, a commitment to maintaining the structural quality of infrastructure, and striving for sustainable urban development. It will further include, among to be implemented technologies and strategies, the application of mobile sensors toward the detection of potholes with the aim to reducing the impact of potholes on the quality of life of people living in the cities (Varona et al., 2020).

1. 3 Aim and Objectives

Aim:

To design and build a mobile application called RoadSense+ that uses the sensors of a smartphone to identify and map potholes in real-time.

Objectives:

- To evaluate the capability of smartphone sensors, specifically accelerometers and GPS, to accurately detect and precisely map potholes, ensuring that the functionality of RoadSense+ aligns with the practical needs for real-time road condition monitoring.

- To develop and integrate a community-driven feature within RoadSense+, enabling users to tag and verify the existence of potholes. This feature aims to enhance the reliability of the data collected and improve the responsiveness of the system by fostering user participation and feedback.

1. 4 Outline

This dissertation is structured as follows:

- Chapter 2 presents literature that focuses on the technologies applied in pothole detection and the currently available mobile applications for road condition assessment.
- Chapter 3 provides an overview of the technical design of RoadSense+ and the testing of the prototype.
- Chapter 4 focuses on the RoadSense+ application and its effectiveness in implementation, as well as the results of field tests.
- Chapter 5 describes the findings of the study, and how the proposed mobile sensor approach performs in real-world environment.
- Chapter 6 focuses on the management of the project and the SDLC process that was followed as a cyclical approach.
- Chapter 7 concludes with the results and the direction for further research to enhance RoadSense+ and other similar systems.

Summary of Chapter:

To begin with, the importance of tackling the problem of potholes in urban roads and introducing a new approach based on the RoadSense+ application has been outlined in this chapter. The need to use mobile sensor technology has been explained highlighting the possibility of changing the way roads are maintained through real-time accurate pothole detection. This paper has outlined the following objectives and aims which are expected to play a key role in achieving the intended goals of improving road safety, cutting down the cost of maintenance, and strengthening the public response system. The presented outline of the dissertation structure suggests that the author will elaborate on technological, methodological, and practical aspects of applying a mobile-based solution in urban contexts. This lays the groundwork for a more in-depth analysis of today's technologies, the creation of the RoadSense+ application, and its testing in real-life situations, which will be discussed in the subsequent chapters.

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Chapter 2

2. Literature Review

2. 1 Current Technologies

Such applications deal with technology in a disparate way but tend to be hounded by challenges of getting accurate results and user engagement. The sensors of Street Bump detect the accelerations due to the vibrations of "whoops," which are experienced while roughing out in a street. The system has a real-time reporting system transmitting reports to the municipal authority, but it always falls into the problem of false positives, so the result from it cannot be accurate. However, the detection of potholes depends on critical user participation. The participation does not remain consistent and stationary across different locations, as well as across different user bases. Still, the complexity in machine learning models limits adaptability and scalability into other environments. The promising power of these applications, however, often (Farrahi, et al., 2019).

2. 1. 1 Mobile Applications for Road Condition Monitoring

Sigala et al., 2020 recognise it with the innovation in mobile applications, such as Street Bump, Pothole Patrol, and RoadBotics, among many others, which use smartphone sensors to detect potholes in the course of their travel. It is easily exemplified by the Street Bump application, which uses the accelerometer of the smartphone to collect and report the bumps on the roads that may be an indicator of the presence of potholes. The information in this way gathered is then sent to the city authorities for immediate repair measures. Pothole Patrol is an example of a mobile application using a smartphone's sensors to detect potholes and send a report to the corresponding city authorities. The application uses accelerometers along with GPS to detect potholes and report the problem to the city authorities. At the same time, it poorly distinguishes potholes from other irregularities of the road, for example, speed humps or road cracks. RoadBotics uses machine learning algorithms to provide scanning of the road surfaces and to identify potential risk like potholes. Although it proved to work well in some specific configurations, it suffers from high dependence on the road's condition and sensor reliability (Sigala et al. 2020).

The most significant challenge is related to the detection of potholes because not all the deviations from a flat surface identified by the road sensors on a smartphone are actually potholes. This reduces the credibility of the reported data and makes it necessary that active users are generated by the users themselves in order to justify the need for such applications. Secondly, reports need to be regular, and data need to be consistent too. To sum it up, the success of mobile applications dedicated to monitoring the road condition depends on the correction of the accuracy of detection and rate of utilization issues. For this reason, further improvements should focus on the improved detection algorithms in order to create a better detection of potholes—for a better user experience in order to damp the effect of potholes on road safety and durability of infrastructures (Sigala et al., 2020).

2. 1. 2 Pothole Detection Using Sensor Technology

Thomas et al., 2021 continue to highlight how smartphones are well-built to record such road surfaces with defects, for instance, potholes, by use of sensors like the accelerometer and GPS. They further explain that the accelerometer will register very abrupt changes in data when a vehicle encounters a pothole. These sensors have been incorporated into pothole detection systems because they were originally developed for other applications like navigation and motion tracking, and they are endowed with the functionalities of sensing vibration, motion, and position changes (Thomas et al., 2021).

Examination of Smartphone Sensors:

- The work by Witcher et al. shows how sensor fusion is effective in pothole detection. The paper states that data fusion from the data accelerometers, gyroscopes, and GPS leads to a falsify-proof way of enhancement of the information. Accelerometers are used to determine the acceleration of the smartphone in multiple directions and are used for sensing abrupt changes in velocity and therefore are effective in identifying the presence of potholes on roads. In the case of a car going over a pothole, the accelerometer captures the variance in acceleration that is useful to compute pothole detection (Witcher et al., 2020).
- Gyroscope gives an idea regarding the rotation of the smartphone; it is not used for pothole detection. However, using it in combination with accelerometers helps to gain more information, which boosts the pothole detection algorithm (Witcher et al., 2020).
- Global Positioning System (GPS) can be used to track location and identify detected potholes, which can be accurately reported. For instance, linking the locations of potholes with geographic data and using it in prioritizing the repair work is a form of better allocation of resources to the municipalities (Witcher et al., 2020).

2. 2 Data Processing

2. 2. 1 ML Techniques for Pothole Identification

Nazemi, et al., 2019 explained further the different strategies in training the sensor data patterns to the ML models and subsequently reflecting classification accuracy in road condition. In studying the various algorithms used to detect potholes, the focus has been mainly on Support Vector Machines and Neural Networks. Two of the often-used methods, namely Support Vector Machines and Neural Networks, are different in their approaches to the classification road conditions. Both methods use the same four-step approach where each step follows on from the prior one, although there is often flow-on interaction between the steps in the process (Nazemi et al., 2019).

Machine Learning Algorithms Overview:

- SVM is a supervised learning technique that classifies data points into different classes based on the maximum distance that can be placed between the different class and a hyperplane. Training of SVM on labelled sensor data for pothole detection needed to differentiate between various road conditions using attributes such as acceleration and frequency of events.
- Neural Networks are based on the human brain structure and are comprised of self-regulating nodes called neurons that are stacked in layers. Such networks can learn relatively complex features and data dependencies through training cycles. In pothole detection, data-driven neural networks with large datasets are trained to detect the distinctive sensor data patterns of the pothole (Nazemi et al., 2019).

Methodologies for Training ML Models:

- Feature engineering involves selecting and preprocessing the appropriate sensor data to create features that will aid in pothole detection. Derived features may include acceleration spikes, event duration, and frequency, which are utilized in machine learning algorithms (Kröger, et al., 2019).
- Machine learning models are trained using **labelled** training sets, which are examples of sensor data corresponding to pothole and non-pothole states. Training involves finding the best set of parameters to minimize classification errors, while validation ensures the model's generality to unseen data (Nazemi, et al., 2019).

- Effectiveness of the ML models in pothole detection is measured using performance indicators such as accuracy, precision, recall, and F1-score. These metrics evaluate how well the model can identify potholes, exclude other objects, and assess how many potholes the model misses or falsely detects (Nazemi et al., 2019).

2. 2. 2 Community-Based Reporting Systems

Crofton et al. elaborate on such crowdsourcing mechanisms, including Waze and FixMyStreet, developed to make it possible for citizens to create reports about the issues concerning their roads. One of the research objectives identified within includes a detailed understanding of how effective such systems are in engaging citizens for timely maintenance and points to some of the challenges with data quality and citizen engagement. Such systems provide an opportunity for citizens to share information on road conditions as these occur, thus providing additional routes for the maintenance and planning of infrastructure (Crofton et al., 2019).

Examination of Crowdsourcing Platforms:

Waze is an application that shows the location and helps to find a way in the car; it also allows users to inform other drivers about the problem on the road. Reports that are submitted by users are then compiled and shown in the map interface of the app and can help other motorists and municipal authorities as well (Thomas, et al., 2021). Whereas, FixMyStreet is an online service that allows users to report problems like potholes, non-functional street lamps, and graffiti on streets and other public areas to the concerned council. It is sent to the relevant authorities for action and there is a tracking system that enables users to know the progress of their reports (Crofton et al., 2019).

Effectiveness:

Community-based reporting systems have also been useful in involving people and in the creation of coalitions for change on matters relating to roads. They enable citizens to report potholes and other infrastructure issues for timely repairs, thus improving urban planning (Riaboff, et al., 2020).

Challenges:

The validity of the reports that the users generate is but one of the critical elements that defines the quality of the information that is gathered by such platforms since the supply of reports, which are not correct negatively impacts the process of decision-making and resource allocation.

In this way, the use of ML algorithms could be considered as a powerful tool for pothole detection, and also the patterns available in the sensor data. Community-based reporting systems could be considered a useful approach to draw on the experience and knowledge of citizens in the area of infrastructure maintenance and planning, whereas with those data processing techniques combined, municipalities will be able to enhance recognition of potholes and, therefore, enhance safety as well as sustainability of the urban area. (Crofton et al., 2019).

Table 1: Various technologies and applications related to pothole detection

Technology/Application	Methods Utilized	Criteria for Evaluation	Strengths	Limitations
Street Bump	Accelerometer, GPS	Detection accuracy	Automated detection, real-time reporting	False positives, integration with city systems
Pothole Patrol	Accelerometer, GPS	Detection accuracy	Combined sensor data for better accuracy	Differentiating potholes from other anomalies
Mobile Phone Sensors	Accelerometer, Gyroscope, GPS	Sensor capabilities	High availability, precise location data	Data noise, sensor limitations in different conditions
Data Processing Techniques	Machine Learning Algorithms (SVM, NN)	Data analysis accuracy	Improved classification, feature extraction	Model robustness, diverse driving conditions
Community-Based Reporting	User Reports, Verification Mechanisms	Data reliability	High engagement potential, crowdsourcing	User participation rates, data verification

Conclusion:

The reviewed literature in this work thus far discusses the broad landscape of the current technologies and methodologies involved in pothole detection and community-based reporting systems of road issues. An analysis has been performed that looks at the effectiveness and limitations of mobile applications integrated with smartphone sensors for pothole detection, discussing problems like low user participation and the problem of accuracy.

Moreover, smartphone sensors, accelerometers, gyroscopes, and GPS have been established with the ability to detect road-surcharging imperfections like potholes. Sensor fusion techniques that support the integration of data from multiple sensors enhance the accuracy of detection while filtering out noise and false positives. What was going on in data processing was that machine learning methods, such as support vector machines and neural networks, became very strong tools able to detect potholes, classifying road conditions from patterns in sensor data. A lot of detail was given on the methodologies of training machine learning models and on the validation of their learning performance, including feature engineering and validation.

Community-based reporting systems such as Waze and FixMyStreet were also reviewed to see how they encourage citizens and mobilize collective action in addressing road issues. These platforms have also been found to facilitate timely maintenance and enhance efforts in urban planning while also bringing out data quality issues and challenges in the engagement of users. This literature review broadly brings to light several potentials for such integration: smartphone sensors, machine learning approaches, and community-based reporting systems concerning pothole detection for infrastructure maintenance. The paper also brought out that future research efforts need to focus on how these technologies and methodologies can be mapped toward the creation of sustainable and safe urban environments.

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