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Detection and localization of potholes in roadways using smartphones

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Abstract
A system for the detection and localization of roadway potholes is proposed and is aimed at collecting data on the roadway potholes using the accelerometer, GPS and compass that are embedded into smartphones using the Android operating system. This system has a scalable mobile architecture that contributes to capturing environment information using multiple devices with a large geographic coverage.

Keywords: Geographical Information Systems; Location Based Services; Potholes; Mobile Computing; Mobile Architecture.

Detección y localización de imperfecciones viales utilizando smartphones

Resumen
Un sistema de detección y localización de imperfecciones viales ha sido propuesto con el fin de realizar la recolección de datos de las imperfecciones viales por medio del acelerómetro, GPS y brújula que se encuentran embebidos en los teléfonos inteligentes con sistema operativo Android. Este sistema cuenta con una arquitectura móvil escalable que contribuye a capturar información del entorno desde múltiples dispositivos con una gran cobertura geográfica.

Palabras clave: Sistemas de Información Geográfica; Sistemas Basados en Localización; Imperfecciones Viales; Computación Móvil; Arquitectura móvil.

1. Introduction

With the help of geographic information technologies, it is possible to establish new-strategy based solutions that use information about the condition of roadways. These solutions aim to help people and entities who are responsible for performing preventive as well as corrective maintenance to paved roads through continuous surveillance using their smartphones which are connected to a cartographic server that eases location and quality control of the work done.

Based on this context, we set out the need to build a cheaper system, such as the one we currently use, taking full advantage of the smartphone's sensors and their processing capabilities, which swiftly allow large distances to be reached in a short time. The roadways that have a flow of mass transit were given special priority, such as the ones on which articulated buses carrying more than 150 passengers in just one vehicle circulate.

The limitations we faced when carrying out the project were related to the roadways where the tests were to be performed and the type of mobile devices that were to be used. We did not want the tests to be too expensive as all that was needed was an accelerometer and a GPS. The main objective was to measure potholes on roads.

The following article summarizes the experience of specifying, designing and implementing an information system called RSMS (Roadway State Monitoring System) developed in the city of Bogota, Colombia.

The system collects information on the vehicle's acceleration and the roadway's potholes combined with their geographic and spatial location by using mobile devices that run on Android. The information collected is stored, catalogued according to type of pothole and classified using the scale VIZIR category B [1], which deals with the surface damage of the roadway caused by local factors.

The system is formed by sensors that capture information by using tools such as the accelerometer, compass and GPS. The information is stored on a centralized and georeferenced database that is linked to an app server with web access. The communication between the mobile devices and the server takes place through SOAP (Simple Object Access Protocol) protocol [2].

The analysis processes are undertaken with a geographic information system and a series of information outputs, similar to maps, with the potholes' locations are created, along with a description, their features, closer station and buffer (area of influence) [3] and cluster (markers quantification) [4] analysis.

A roadway corridor approximately 10 kilometers long (6 miles) in Bogota through which there is mass transit was selected for the case study. The suggested architecture presented a number of advantages and made the integration of these devices easier with the Geographic Information System (GIS) and the sensor's added value.

2. State of art

A Geographic Information System (GIS) is "a specific software that allows users to create interactive queries, integrate, analyze and represent in an efficient way any type of geographical information referenced associated to one territory, connecting maps with databases" [5]. GIS systems are widely used as these systems support decisions with information provided by Localized-Based Systems (LBS), which "Is a service that adds value to target locations provided by one localization service. It uses knowledge of a mobile device's location to offer value to mobile subscriber or to a third-party" [6].

Smartphone sensors allow information about daily activities to be detected and recognized [7]. It is important to highlight the sensors' technological development in order to measure accuracy. The main sensors used in this project were the accelerometer, GPS and compass.

The accelerometer is a tri-axial sensor and measures movement, gravity variations, and human movements. As a result of the device's accuracy level, it can detect minimum movements, gravity variations and human movements that can be processed to detect what type of activity is being undertaken [7].

GPS (Global Positioning System) is a circuit that uses the Global Navigation Satellite System (GNSS) to obtain the current position of the sensor with an accuracy of 5 meters or more, depending on the nearest satellites' signal reception. Connection to a Wireless Access Point can improve the accuracy [8].

The compass is a sensor that detects the earth's magnetic field. This sensor locates the terrestrial magnetic north and reads the intensity of magnetic field in micro-teslas. Using this sensor is possible detect the device's direction. Combining the GPS location and compass reading on the roadway, the direction will be associated with the localization to obtain the correct track of the roadway.

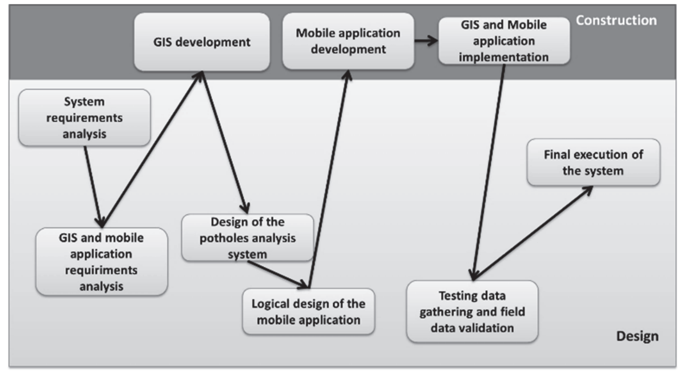

Figure. 1 Saw tooth lifecycle combined with FDD.
Source: Adapted from [5,6]

3. Methodology

The system was developed by applying the saw tooth lifecycle methodology [9], created by Robert Owen and Peter Coad as part of their Feature Driven Development (FDD) [10]. The methodological phases that are part of the development of this project are presented in Fig. 1.

The previously mentioned methodological phases are divided into the design and development of the system according to the combination of features defined in the system requirements analysis. From these features, prototypes are made to validate the conceptualization of the system that is designed from the previously described characteristics and the system is built in a recurring and incremental way [9].

The main reasons that have triggered the use of the Feature Driven Development [10] are the focus on the developer to produce results every two weeks and the ease of looking over the results in a simple way for each one of the functionalities developed without the need to perform big tests.

During the system's design, the web app's established requirements show the user all the detections that were made in a determined geographic area using a map supported by a Location Based System (LBS) [6, 11]. In terms of the information display about the potholes, the system draws influence areas defined by the mass transit system stations and locates them in critical zones according to the recurring detections that are performed via the mobile device. The user can modify the ratio of these areas to observe the affected areas.

In order to limit the responsibilities of the system's functionalities, the following actors were defined:

- Maintenance Manager: this is responsible for displaying the information processed by the system in order to make decisions. This actor can review the information through maps and standard reports to determine the critical roadways. Maps are provided with cluster and buffer analysis to give value information for decisions.
- Data collector: this is responsible for taking the data (location, direction and movement) along the roadway and making different rounds with the mobile device. The mobile device is configured with Android OS and

the mobile application is designed to collect data in the field.

- GIS analyst: is responsible for verifying the information processed by the system that is provided by the data collector. This actor can review the information through maps with buffer analysis, displayed on OpenStreetMaps [12] and Google Maps [13]. In the verification process, the ranking and location of potholes can be modified according to related data.
- Web client: this visualizes the relevant information obtained by the system. This actor can review the information through standard pothole location map and standard report.

The functionalities that are developed as part of the system are:

- Manual capture of data: the data is captured manually over a roadway pothole, and the type of pothole is specified using the mobile device. This functionality is performed by the data collector.
- Automatic data capture: this captures data while the mobile device is on a determined route. It does not specify the pothole type and captures multiple flaws. This functionality is performed by the data collector.
- Cataloguing the possible type of pothole: the flaw is catalogued according the scale given by the category B VIZIR methodology. This functionality is performed by the GIS analyst.
- Analyzing collected information: this is performed by the GIS analyst. The information must be analyzed following the Geographic Information System Methodology.
    - Analyzing information collected using the Buffer method: the information of the measurement is analyzed using Buffer's algorithm with GIS analyst supervision.
    - Analyzing information using clusters: a cluster's algorithm is used with supervision by the GIS analyst.
- Visualizing collected information: visualizing on a map all the information collected by the system during a date rank. This is performed by the web client and the maintenance manager.
- Showing the summary chart of roadway potholes: this is performed by the maintenance manager. It shows a summary of the detected potholes.
- Visualizing possible flaws per station: this shows a map with what has been detected in a determined station. It is performed by the maintenance manager.
- Visualization of flaws per date: this shows on a map the imperfections detected on a specific date. It is performed by the maintenance manager.

The information processing within the system's functionalities is defined in Fig. 2. This shows each one of the stages in which the data is processed; it begins with the capture of the information, analysis of the information, categorization of any type of flaw, storage of the categorization and display of the processed data through maps and reports.

To capture the information manually and automatically, the smartphone must be placed in the bus interior, as is shown in Fig. 3.

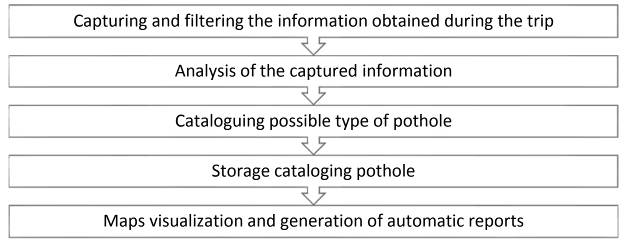

Figure 2. Processing information stages of the potholes' localization and detection system.
Source: The authors.

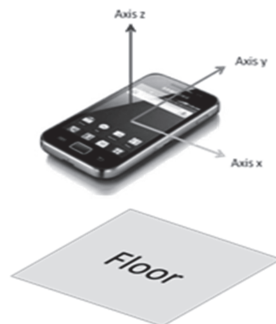

Figure 3. Spatial location of the smartphone to capture information on the roadway potholes.
Source: The authors.

The smartphone must be placed horizontal to the floor so that it is upright (positive axis z) and the phone's head (axis y) is in the direction in which the vehicle is moving.

The data stored in the system relates to the information on the detections of possible roadway potholes that are identified by mobile devices. The potholes are analyzed and classified through the system's functionalities. In terms of pothole detection, the system stores the latitude [degrees], longitude [degrees], GPS accuracy [meters], speed of the vehicle [km/h], accelerometer's acceleration on axis X, Y, Z [m/s2] and compass azimuth [degrees]. The pothole metadata stores the system's date and time, GIS analyst who classifies the pothole is identified, the rating according VIZIR scale (Chart 1), type of pothole (Chart 2) and detections analyzed.

The VIZIR ranking of the B category is used for the functional type potholes and is not related to the structural capacity of the road. [1] This classification is based on the Superficial Deterioration Index which ranks the pothole into three general cases with numerical values from 1 to 7, as is shown in Table 1.

Table 1.
Index of VIZIR Deterioration Surface Methodology [1]

Values	Ranking	Description
1 2	Good	Pothole in fine condition. Requires routine maintenance.
3 4	Fair	Pothole with some structural cracking and deformation. Requires maintenance and medium intensity treatment.
5 6 7	Deficient	Pothole with large amount of cracking and deformation. Requires major work.

Source: Adapted from [1]

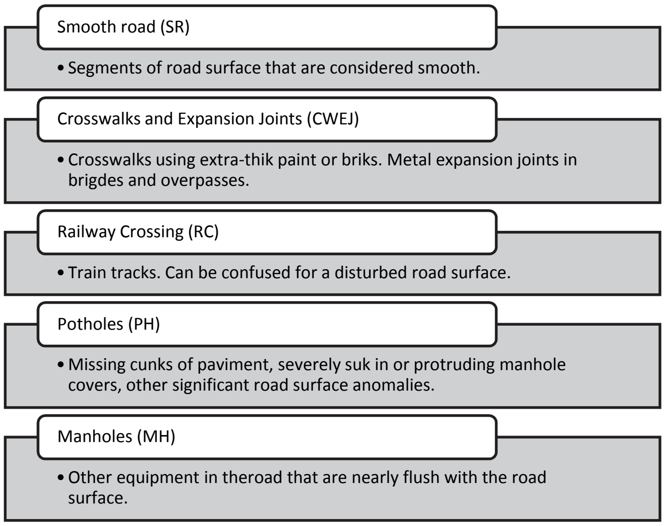

Figure 4. Roadway potholes rankings.
Source: Based on [14-16]

The superficial damage produced by roadway potholes may be caused by different structures located on the road network as well as by local transiting. According The Pothole Patrol [14] that was developed by the MIT, the main types of roadway potholes that should be taken into account during detection and location are ranked in Fig. 4.

From the data collected on pothole detections and ranking, the output displayed by the system to the final user is:

- Summary report of roadway potholes.
- Roadway potholes map (by date).
- Detections map (by date range).
- Buffer analysis map (by date range).
- Cluster analysis map (by date range).
- Roadway potholes map per station.

4. Proposed architecture

The architecture developed for the system is based on the service-oriented architecture for mobile applications [17] and on improvements made to the Information System of Flora and Fauna (ISFFA) [18]. The proposed architecture performs the initial data processing on the mobile device and the web server then performs the processing helped by the Google Location-Based Service using the principles of the Service Oriented Architecture (SOA) [19].

In order to improve the reliability of the data transmission through the mobile network the CarTel project [20] was taken into consideration; this was created by MIT and the Cafnet protocol (Carry and Forward Network) was designed. This protocol helps to maintain the data communication through a network that presenting intermittence and ranges of little coverage, as is shown in Fig. 5.

In order to reduce the impact of mobile device restrictions, there have been some algorithms implemented to the device's software that require low processing, low storage on the main memory and low usage of secondary storage in the disc on system's information. The dispatch of information

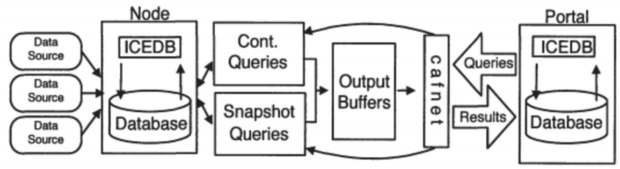

Figure 5. *CarTel* software architecture.
Source: [15]

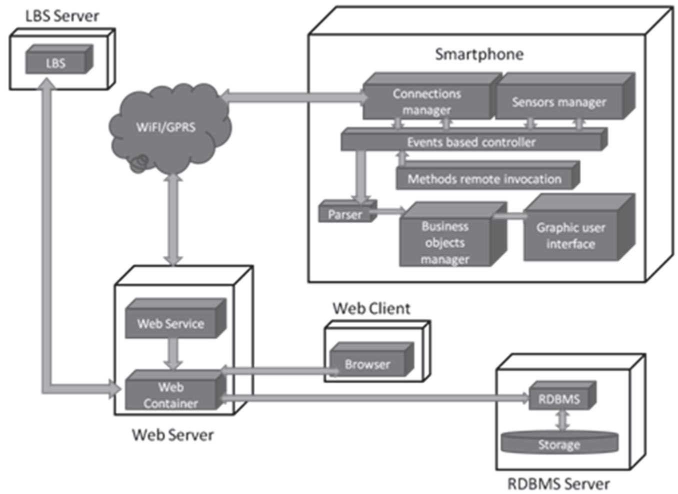

Figure 6. Mobile architecture proposed for the location and detection system of the roadway state.
Source: The authors.

in plain text through messages is created by using the SOAP protocol and XML [2].

The given architecture shown in Fig. 6 focuses mainly on an app for Geographic Information Systems and Location Based Systems. [2]:

In the proposed architecture great emphasis is made on the architectonical design of the mobile app due to the importance that the information capture has through the measuring and acceleration sensors (accelerometer), direction measuring (compass) and location (GPS).

The Sensors Administration component is responsible for collecting all data from the previously mentioned sensors simultaneously and with better accuracy taking into account external conditions. The High-Pass Filter (HPF) [21] has been implemented in this component in order to obtain more significant values and eliminate those that may cause noise and false detections.

5. Results

The system proposes a capture method that is simple and has great coverage compared to other traditional methods and is used in Civil Engineering in the Longitudinal Profile Analyzer (LPA) [22], for example. This requires the use of special equipment that has to be towed with a vehicle moving at a constant speed to make the captures and it also requires additional software and hardware to revise the information analysis. The RSMS (Roadway State Monitoring System)

Figure 7. Segment chosen for the study area and location of the imperfections in the section selected for testing.
Source: The authors.

Table 2.
Characterization of road imperfections located during testing.

#	Latitude	Longitude	VIZIR Score	Closest station	Direction
1	4° 42' 33,329" N	74° 3' 12,272" W	6	Calle 127	South - North
2	4° 41' 50,813" N	74° 3' 1,829" W	4	Pepe Sierra	South - North
3	4° 41' 24,135" N	74° 3' 23,856" W	5	Calle 100	North - South
4	4° 43' 35,867" N	74° 3' 1,829" W	3	Calle 142	South - north

Source: The authors.

carries out the captures only with the sensors located within the smartphone and sends the captured information via mobile network to be processed on the GIS (Geographic Information System).

The chosen study zone was a 10 kilometer (6miles) Phase II roadway corridor belonging to the TransMilenio mass transit transportation system going North-South and South-North, as shown in Fig. 7.

This section was selected due to it having a significant number of potholes throughout the city [23] and also for the type of asphalt used in the construction of phases 1 and 2 (Caracas Avenue and North Motorway.) The asphalt used to construct the roadway chosen is rigid and segmented in tiles divided by transversal joints.

Four roadway potholes which are shown in Table 2 and visualized in Fig. 7 were located and typified in the test.

When the test is performed with data capture on automatic mode the purpose is to examine if the system is capable of detecting the pothole with the data capture on auto

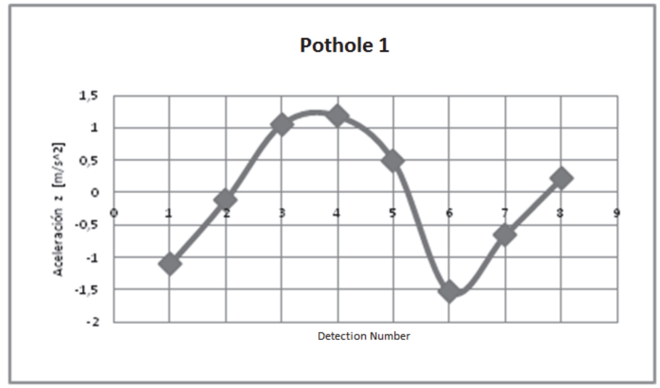

Figure 8. Data capture of pothole 2 during trip 3. Pothole located near to Calle 100 Station, direction North - South.
Source: The authors.

mode. Give the tests conditions, only the false negatives are taken into consideration to evaluate the system´s capacity for detection in the following circumstances: environmental conditions (cloud cover, rain, electromagnetic waves) and the phone location inside the bus. These variables affect the results obtained because the sensors are sensitive to the previously mentioned environmental conditions. [8].

The tests were performed in the best environmental conditions possible: data intake during times of low passenger input, few clouds, sunny days, and the phone located on the window frame on the front part of the bus. Some variables such as additional weight and number of passengers were not taken into account since both of them are hard to control during normal operation of the system.

In order to analyze the detected data, we give an example from the pothole 1 in the round 3. As observed in Fig. 8 there are positive and negative accelerations because of the High-Pass filter effect used to improve the data quality captured by the accelerometer. Pothole 1 has maximum recorded values of 1,24 m/s^2 and minimum values of -1,55 m/s^2. It is possible to perform the detection because of the acceleration variation of 2,79 m/s^2 between the maximum and the minimum values.

The depth ranges of the recorded potholes in the study zones are between 1 and 6 centimeters. These potholes types are frequently found on the road network of TransMilenio phases 1 and 2 [23].

6. Architecture comparison

The most important CarTel contribution is that it uses elements such as the intermittent connectivity through Wi-Fi networks and its own communication protocol in order to obtain information in the environment. These elements allow CarTel to have a wide geographic range in order to obtain information and allow multiple sensors to connect to the system to obtain information from the environment.

In its architecture the system uses a connection to the mobile GPRS network to link the smartphones that are collecting data on roadway conditions from a wide geographic area, as was previously undertaken with the Flora and Fauna (ISFFA) Information System [18]. The use of the mobile network benefits the coverage area and allows connectivity in a wide area of the city through the Connection Manager.

The architecture of the proposed system puts emphasis on the use of protocols and technologies that are nowadays standard in the development of information systems. The SOAP protocol is used for the interoperability between smartphones and web server as it is supported by the great majority of Android devices. This is an advantage as a great variety of smartphones from different manufacturers and OS can be added, providing they are compatible with the SOAP protocol.

Using the proposed architecture in RSMS with a larger number of smartphones and sensors available in the market, it is possible to monitor and obtain information beyond the roadway infrastructure that could lead to the new projects such as the model Internet of Things. This new model states: “Things having identities and virtual personalities using smart interfaces to connect and communicate with social, environmental and user contexts” [24]. Based on this concept it is possible to use an extended variety of sensors to monitoring roadways, vehicular traffic and Intelligent Transport Systems (ITS) that are focused on transportation management and supply chain execution. [25]

The following software and hardware tools were used:

Software: IDE NetBeans 6.9.1, Eclipse Indigo JEE, Android SDK for Windows, MySQL Server for Windows, Google Maps API.

Hardware: Smartphone: Samsung Galaxy Ace

Server: Intel Xeon 2,4 GHz QuadCore, Memory: 4 Gb. Operative System: Ubuntu 10.2, Network interface: 100/1000 Mbps.

7. Conclusions

It has been proved that our design is viable and can help as a reference model in future situations that require interoperability with acceleration, location and direction sensors that are available in mobile devices using a cell phone network.

The use of different devices all from same brand may affect in the accuracy of the sensor’s data capture due to the heterogeneity of the embedded circuits that are located in each one of the models.

The developed system contributed to the test system’s architecture and the data capture through the sensors. Architectural patterns Sensor-Computer-Control and the Android’s operative system architecture for the mobile device, Model-View-Controller for the web client and the Java Enterprise Edition Framework architecture for the app server were chosen for the system design.

The system allows measurements to be made of the roadway’s physical condition and infrastructure using standard commercial hardware, in this case smartphones available on the market. Mobile networks are then used to achieve a wide area range to gather low-cost information using smartphones in comparison to the traditional methods and devices used. The added value is that the information is displayed through the Location Based System [11] and the accelerometer allows access to the information gathered.

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