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Unattended Crowdsensing Method to Monitor the Quality Condition of Dirt Roads

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Abstract—In developing countries, most roads in rural areas are dirt road. They require frequent maintenance since they are affected by erosive events, such as rain or wind, and the transit of heavy-weight trucks and machinery. Early detection of damages on the road condition is a key aspect, since it allows to reduce the maintenance time and cost, and also the limitations for other vehicles to travel through. Most proposals that help address this problem require the explicit participation of drivers, a permanent internet connection, or important instrumentation in vehicles or roads. These constraints limit the suitability of these proposals when applied into developing regions, like Latin America. This paper proposes an alternative method, based on unattended crowdsensing, to determine the quality of dirt roads in rural areas. This method involves the use of a mobile application that complements the road condition surveys carried out by organizations in charge of the road network maintenance, giving them early warnings about road areas that could be requiring maintenance. Drivers can also take advantage of the early warnings while they move through these roads. The method was evaluated using information from a public dataset. Although they are preliminary, the results indicate the proposal is potentially suitable to provide awareness about dirt roads condition to drivers, transportation authority and road maintenance companies.

Keywords—Dirt roads automatic quality assessment, collaborative system, unattended crowdsensing method, roads quality awareness provision.

I. Introduction

AROUND the world, there are many regions where people live in rural areas mainly due to work reasons. In developing countries, people usually move through these areas using a network of dirt roads (or farm tracks), not only to perform their daily activities, but also to transport the farming products to urban areas. The quality of these roads play a key role in regional economies based on production of raw materials.

The quality of dirt roads frequently degrades due to weather conditions (like rains and wind), and the regular transit of vehicles (particularly, trucks and agricultural machinery). The orography of the terrain, particularly in mountainous areas, accelerates the roads degradation process.

In order to keep dirt roads in good conditions, it is mandatory to opportunely detect the need to make them maintenance. Maintenance activities can be quick and inexpensive when addressed in an early stage (i.e., in roads with minor deterioration); however, the maintenance effort increases no-linearly as the road deterioration evolves to severe damage [15]. According to the Geaslin's Inverse-Square rule for deferred maintenance effort: "if a part is known to be failing but operated to failure, the resultant energy required to overcome the breakdown event to the entire organization will be the square of the cost of the primary failure part. If the breakdown event escalates, the energy required to recover from the breakdown will continue to square at each successive level of failure" [5]. Therefore, in this scenario the early detection of roads maintenance needs makes a difference. Particularly, in large rural areas it is necessary to count with a proper mechanism to identify dynamically the spots with major problems and correct them early, trying to guaranteeing the regular transit of vehicles [8].

The personal inspection and monitoring of the road's conditions require to periodically driving along them, looking for eventual fails or damaged areas. This job is frequently performed by professionals and technicians trained in determining the road condition and detect faults before they make visible. This monitoring activity is particularly important in countries with large rural areas, like in Latin America, where the tertiary networks (composed mainly by dirt roads) are large and their maintenance is expensive and time consuming [1]. Moreover, in these countries the budget to perform this activity is usually limited [2]; therefore, the early detection of roads maintenance needs becomes a highly valuable asset.

In order to help monitor the quality of dirt roads and perform early detection of maintenance needs, this paper proposes a method that uses crowdsensing for gathering data of a set of variables, and a pipeline to process such data and determine the probable quality of a road in their several segments. This information can be used to keep informed several actors, like the responsible for the road maintenance, drivers and neighbors (usually farmers) living in the area. The road quality detection method was evaluated using real data from a public dataset, and the obtained results were highly encouraging.

Next section discusses the related works. Section III presents the data gathering and processing methods. This section also shows the feasibility of performing the road quality prediction. Section IV describes the infrastructure required to perform the data gathering and processing. Finally, Section V presents the conclusions and future work.

II. Previous Work

In order to address the problem, it is mandatory to determine the variables to be sensed and the mechanism used to gather such information. Simple technology based

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on regular mobile devices and people acting as human sensors can contribute to deal with this sensing process [4], [12], [14]; particularly, crowdsensing can be used with this purpose. This paradigm involves the participation of people using mobile devices, whom implicitly or explicitly share information to help diagnose, map or forecast the status of processes or objects of interest [4]. Crowdsensing activities can be participatory, opportunistic or a mix of them. In the first case, the users voluntarily and explicitly participate in contributing information [17], and in the second one, the data are sensed, collected and shared automatically by the mobile device without user intervention [4], [6]. Opportunistic crowdsensing tends to make the information provision more robust, given it does not depend on the explicit intervention of the user; however, mixing both approaches is usually recommended. This information gathering approach follows a bottom-up schema, where the data are processed through a hierarchical graph or tree. The sensors, that represent the leaf of the tree, perform direct measures of the variables being monitored, and periodically report such information to interim nodes or stores it in data repositories. The interim nodes, which can also be arranged into a hierarchy, process the information and produce an outcome, e.g., a notification to the participants, or the calculation or forecast of a certain variable.

In the case of diagnosis of road conditions, El-Wakee et al. [3] propose the use of sensors present in high-end cars (like accelerometer and gyroscopes) to determine the condition of streets and urban roads. Such data are collected in the cloud and processed using artificial intelligence techniques. This proposal provides suitable diagnoses when the traffic density is important (like in urban areas); therefore, it is limited to be applied to rural roads networks.

In [13] the authors present an IoT system based on sensors for monitoring urban traffic. The collected data are used to feed a processing unit that performs data mining in order to compute improvements in the road infrastructure. Such a proposal is not focused on identifying damages in roads, and it requires an important instrumentation; therefore, it is recommended for monitoring highways or major traffic infrastructure.

In [16], the authors propose the use of the smartphones movement sensors to detect anomalies in the road. The data provided by these devices are analyzed together with the information available on the type of road surface (e.g., asphalt, tar, gravel or dirt) in order to determine the road condition. Several other papers also propose using the accelerometer and GPS embedded in smartphones as sensors [7], [9], [18]. The idea behind these proposals is to perform crowdsensing to filter and process data related to the road quality condition, and provide a diagnose expressed in some well-known road quality scale.

In the case of [7], this diagnose involves the use of artificial intelligence techniques and also data provided by software applications, like GoogleMaps. In [18], the data are processed in the cloud in two steps; first, by considering the vertical variations detected by the accelerometer, together with the geographic location of the vehicle, and then considering the level of repetition of the measure.

In either case, these systems are limited to determine the quality of dirt roads; for instance, the irregularities in the road may be masked by the suspension system of the vehicles. On the other hand, rural roads are naturally irregular, although this does not indicate that a road is in bad condition; therefore, its quality should be analyzed considering the particular features of that path.

The method proposed in this paper to determine quality of dirt roads is different to the previous ones, as neither accelerometer, inertial sensors or gyroscopes are required. It only uses a basic principle in driving that states that *in a bad condition road vehicles move more slowly*. At this point, it is important to remark that *more slowly* refers to the relative average speed of that vehicle before and after the fragment of the road that is in bad condition.

The participation of drivers in the crowdsensing process involves only to keep running a mobile application (in their smartphone) that uses the GPS information to determine the speed of the vehicle and report it to a cloud service when internet access is available. Moreover, the application provides awareness about the road quality to the drivers in real-time, as a way to motivate its usage.

By considering relative speeds of vehicles to detect areas requiring maintenance, this method becomes independent of the type of vehicle used to sense. In the next section we describe an initial validation of this hypothesis, using real data gathered from three automobiles that traveled on dirt roads in rural areas.

III. Road Quality Assessment Method

The roads networks to be monitored is modeled as series of geo-referenced nodes and edges (i.e., one of more graphs). Each edge, i.e., section of the road, is identified with a unique $path\_id$. Each edge can include several attributes (e.g., wide or type of surface), but mainly a quality attribute that establishes the current status of the path considering their natural features. Drivers using these networks contribute to determine the quality of these paths. Particularly, the drivers use a mobile application, like Waze, that shows the network map, the quality of road ahead and also hotspots. However, the main role of this application is to automatically collect the speed of a vehicle while it transits through the paths, and then report such information to a cloud service when Internet access is available. Thus, it provides geo-referenced information about the actual condition of rural roads. For this it is assumed that variations in the speed of traveling vehicles is an indicator of the road condition.

As there are different kind of vehicles and driving styles, the variations in the speeds are considered with respect to own vehicle. With this normalization, it is not important the actual speed but the relative variations.

The geo-referenced information has a twofold goal: it pinpoints the segment of the road with potential problems, and avoids raising alarms, for instance, if the variation comes from a sharp curve or hill somewhere along the way.

A. Data Processing Pipeline

Using this modeling approach, and also the speeds reported by the mobile application, we designed the pipeline shown in Fig. 1, which is capable to diagnose the quality of each section of the road (i.e., edge of the graph).

The information reported by the mobile application consists on plain text files with the recorded GPS and timestamp data. Speed values are automatically calculated using GPS data and the timestamps related to the recorded positions of the vehicles. These records (labeled as *(a) Driving Speeds and Positions* in Fig. 1) are stored locally in the smartphone and reported in a synchronous or asynchronous way, depending on the internet availability. In both cases, the reporting process is unattended.

When this information arrives to the server (Cloud service), the system calculates the average speed of each vehicle during the travel. Then, for each individual record, it identifies into the graph the road section ($path\_id$) to which it belongs to, and it assigns the corresponding normalized speed value to such a section and record. Every record is then stored in the *Segmented Information Repository* (labeled as (b) in Fig. 1) that is a table in a relational database. The table contains the section identifier, and the normalized speed and timestamp for any record; i.e., for each vehicle that transited through it and made a sensing action in such a road section.

The segmented information is then used by the GIS processing service to determine the quality of each section road. For this, the service selects the new data for a particular road section, and using the normalized speed it determines a quality score in a scale from 1 to 5 (low to high quality condition respectively). This information is used by a notification service to keep informed the drivers through voice messages or explicit queries performed by users of the mobile application. That service also delivers early notifications to the roads authority and the company in charge of the maintenance, indicating the quality of road sections requiring inspection.

This information is also used by the quality prediction model to determine the degradation speed of each road section, and forecast it quality for a week ahead. The model considers weather forecast information as an influential factor since, for instance, in case of heavy rains it accelerates the road deterioration process. Depending on the forecast, the system can deliver early warning messages to the authority and maintenance companies accordingly. Next sections describe the road quality prediction and degradation approaches.

B. Road Quality Prediction Approach

As mentioned before, the prediction of the road quality is based on the hypothesis that variations in driving speed allow identifying potential road sections requiring maintenance. In order to infer the initial validity of this hypothesis, we processed the information speed from the public dataset reported in [10].

The dataset is made up of nine scenarios through which three drivers traveled in different vehicles: Driver 1 (D1) in a VW Saveiro pickup, Driver 2 (D2) in a Fiat Bravo hatchback and Driver 3 (D3) in Fiat Palio hatchback. The dataset includes the position and speed of the vehicles while traveling through several dirt roads, and also the road condition perceived by the driver. The boxplot from Fig. 2 shows the distribution of speeds for each driver considering the road condition. In this analysis, road quality values labeled as "Good-Regular" and "Good" were excluded. As it can be observed, the better the perceived road condition, the higher the average vehicle speed; this trend is the same for the three drivers.

Fig. 3 shows the normalized speeds recorded for each vehicle, as a function of the distance traveled along a path over about two kilometers long. Here it can be seen a correlation between the behavior of the three drivers; particularly, all of them have increased or decreased the vehicle speed on the same sections of the road. Although the speed reduction may be due to the presence of turns or hills, it is up to a human judge to determine if the quality of a road section can be improved or whether it is permanent. Successive measurements of the speed of different drivers along a certain dirt road allows to estimate its quality condition. Furthermore, by recording the evolution of road quality over time, it is possible to identify a deterioration curve.

C. Road Quality Deterioration Approach

A linear model can be used to represent the slope of the declining rate of road quality, as a function of time and weather. Then, having a threshold that is considered as the point at which maintenance tasks are required, it would be possible to anticipate when will this occur. This approach supposes a scheme of continuous improvement for the prediction, since the more data is available, more precise the estimation will be.

Concerning the management of maintenance resources, it is assumed that at each instant there can be many different road sections requiring maintenance equipment (e.g., machinery). Given the transportation of this equipment towards these places usually involves costs, the machinery relocation requires to determine optimal routes to minimize the impact on the maintenance resources. This optimization problem is equivalent to the traveling salesman problem, and it can be addressed using several known approaches.

IV. Architecture of the Supporting System

The proposed method for road quality monitoring requires counting on an IT infrastructure that supports the Internet of People (IoP) paradigm [11], which is an extension of Internet of Things. In IoP, people by means of their mobile devices become sensors or information producers. Then, these data are processed and reported as awareness or information that helps them make decisions.

Fig. 4 presents a layered architecture typically used to illustrate the information flow in IoP-based systems. As expected, the participants in the users and sensing layers are almost the same.

The data obtained from the sensors are uploaded to a data repository in the cloud, and then the data processing services perform the first two processes of the pipeline; i.e., to normalize the vehicle speed and calculate the road

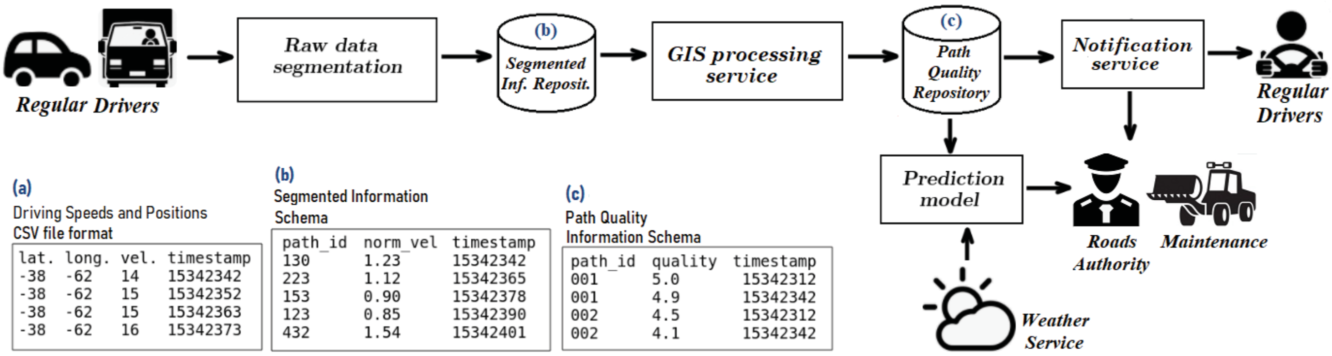

Fig. 1 Data processing pipeline

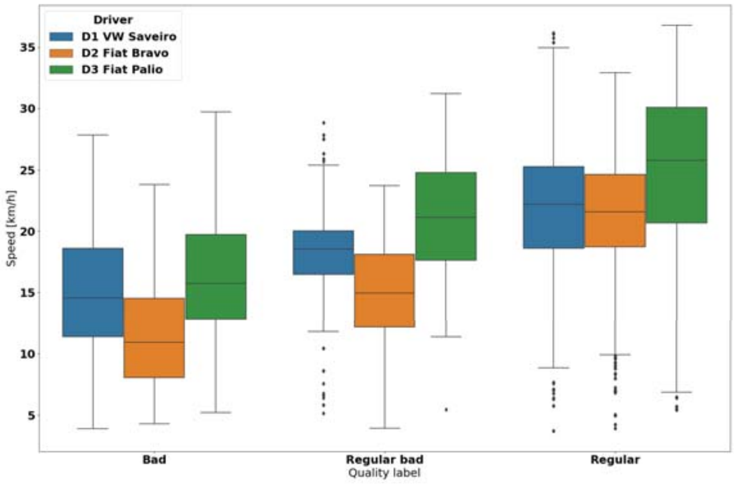

Fig. 2 Boxplot of the speed data distribution for each vehicle

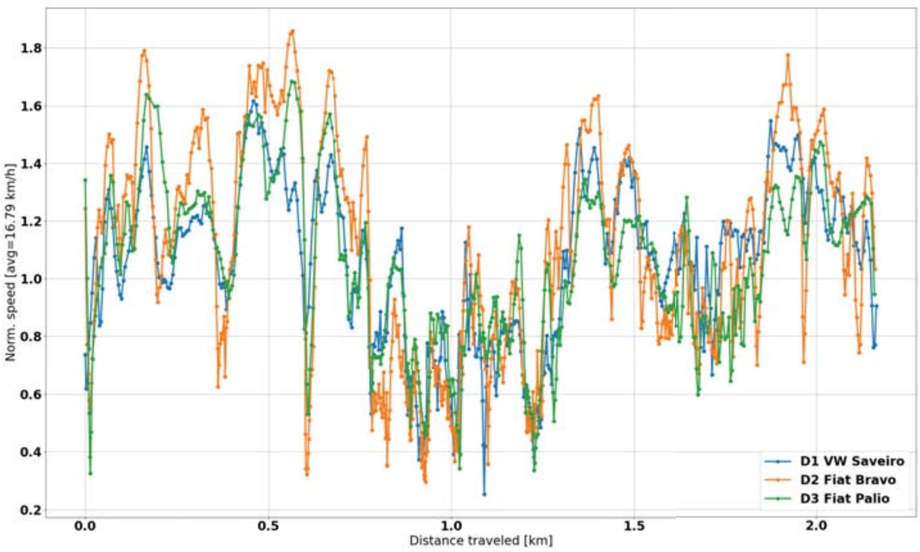

Fig. 3 Normalized speeds of three vehicles traveling through the same dirt road

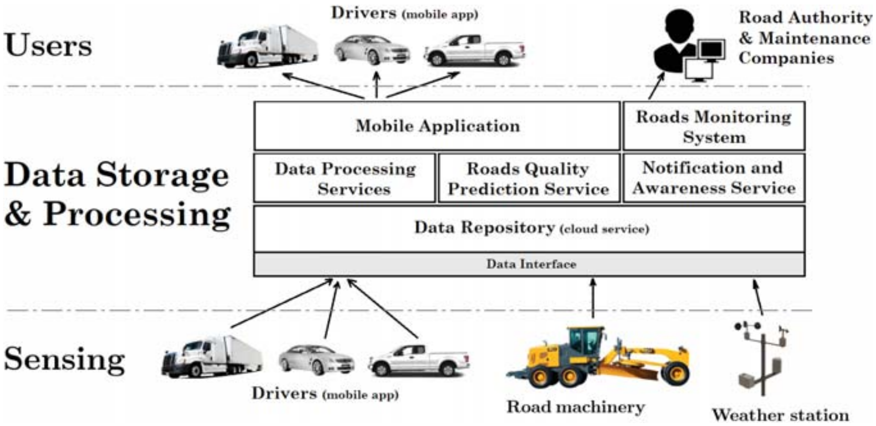

Fig. 4 Internet of People scheme for the proposed system

quality for each section. Using such information the road quality prediction service determines the state of the road and the sections requiring an inspection. The information on the road status is used to make drivers aware about the condition of the road ahead, and also to generate work orders for road maintenance inspectors. Based on this information, maintenance companies can determine the best sequence for road repairs considering the current locations of machinery and the labor priority.

Provided that data loggers (drivers) do not necessarily count on internet access during the travel, the mobile application should operate in offline mode using local information, and synchronize the data with the cloud when it gets internet access. This unattended mechanism prevents the loss of information and provides awareness to the drivers even when they have no communication.

The system architecture is layered and there is a clear separation of concerns among the components in each layer. This provides flexibility and capability of incremental evolution to the system components. Moreover, these components can be implemented using regular technology, which make it affordable particularly for developing countries.

V. Conclusions and Future Work

The roads infrastructure and accessibility constitute key elements for the productivity, economy and wellbeing of citizens. Moving commodities and people across the territory connecting production areas with urban centers, ports, airports and neighbor countries is of major importance. In this context, routes in bad conditions jeopardize the economic and social development of whole regions. This represents a big challenge for countries with large rural areas, like in Latin America, where the traffic network involves mainly dirt roads. Keeping these roads in good conditions requires early detection of maintenance needs, since it allows to reduce time, cost and impact on the civil population. Performing this early detection is a challenge, not only because the quality of dirt roads is affected by several events and decreases quickly, but also because in many sectors of the road there is no communication at all; therefore, it is not easy to use technology to detect and inform maintenance needs.

This paper proposes a method that uses unattended crowdsensing to detect these needs, and thus, to monitor the quality condition of dirt roads and deliver early warnings. The method assumes a basic principle in driving that states that vehicles reduce their speed when transit in sectors in bad conditions. This solution uses a mobile application running in the smartphone of the drivers to detect speed reductions, and also the accumulated data in georeferenced sectors to determine places potentially requiring maintenance.

Unlike other proposals, the use of this method does not require specific sensors (except GPS) and it can be implemented using technology affordable in developing countries. As the system is based on unattended crowdsensing, the cost of the data acquisition is low. Provided that many sectors in rural areas do not have communication coverage, the system should work and collect data even if there is no internet access. The greater the volume of available data, the more accurate and up-to-date the information generated by the system will be.

We used the information of a public dataset to determine the feasibility of utilizing the proposed method in practice, in order to establish the quality condition of dirt roads. Although the results are still preliminary, the method seems to be appropriate and able to be implemented using regular technology. The next steps consider to perform an empirical study using the proposed method.

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