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A mobile application for the crowdsensing of road pavements conditions

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Abstract

Urban environments face significant challenges due to deteriorating road pavements, affecting all transportation modes' safety and comfort. Traditional methods of road assessment are costly and infrequent, but advancements in mobile technology and crowdsensing offer real-time, large-scale data collection solutions. This paper introduces "ShakeSensing", a mobile application that uses Android device sensors to measure vibrations experienced by cyclists and scooter users, providing insights into road quality. The collected data, analyzed to assess road conditions, can benefit both users and municipal authorities, promoting safer and more comfortable travel.

Keywords: road pavement conditions, mobile crowdsensing, sustainability

1 Introduction

Urban environments today face significant challenges due to the deteriorating conditions of road pavements, which affect the safety and comfort of all types of transportation [1, 2]. The integrity of road infrastructure is crucial for ensuring smooth, efficient, and safe travel for commuters, yet many cities struggle with maintaining their roads in good condition [3]. Cracks, potholes, and uneven surfaces are common problems that can significantly impact driving experiences.

With the growing emphasis on sustainable mobility and the urgent need to reduce urban pollution, alternative modes of transport such as bicycles and electric scooters are increasingly being promoted [4, 5]. Governments and local administrations worldwide encourage citizens to switch to these eco-friendly options to combat traffic congestion, reduce greenhouse gas emissions, and improve public health [6, 7]. Bicycles and electric scooters offer numerous benefits, including reduced carbon footprints, lower operating costs, and the promotion of a healthier lifestyle. Additionally, they can contribute to more dynamic and flexible urban mobility solutions, as they can easily navigate through traffic and require less space for parking.

However, adopting these eco-friendly vehicles is often hindered by the poor quality of road surfaces, which can lead to discomfort, safety hazards, and even vehicle damage [8]. In fact, bicycles and electric scooters, being lighter and less stable than cars, are particularly susceptible to the effects of uneven pavements, potholes, and other road imperfections.

The assessment and maintenance of road pavements have traditionally relied on periodic inspections and reports from municipal agencies [9]. While effective to some extent, these methods are limited by their high costs and the infrequency of data collection, which can lead to delays in identifying and addressing road issues. In recent years, advancements in mobile technology and the proliferation of smartphones equipped with various sensors have opened up new possibilities for real-time, large-scale data collection through crowdsensing [10, 11].

Crowdsensing leverages the power of a distributed network of individuals using their mobile devices to collect and share data about their environment [12]. This approach offers a cost-effective and scalable solution to monitor road conditions continuously. By harnessing the sensors embedded in smartphones, such as accelerometers and GPS, it is possible to gather detailed information about road surface quality based on the vibrations experienced during travel.

This paper introduces "ShakeSensing," a mobile application designed to crowdsense road pavement conditions. ShakeSensing utilizes the sensors in Android devices to measure and record the vibrations encountered by users while riding bicycles or electric scooters. The collected data is then analyzed to assess the quality and comfort of the roads, providing valuable insights for both users and municipal authorities.

The remainder of the paper is structured as follows. Section 2 presents some related works, while Section 3 details the design process, from the requirements to the technologies employed. Section 4 details our prototype, and Section 5 describes some preliminary results. Finally, Section 6 presents some final remarks and future works.

2 Background and Related Work

In the context of urban mobility, various situations could benefit from the application of crowdsensing systems. A network of devices capable of taking measurements and reporting data proves to be very useful for activities that require the analysis of a lot of information. An example of the application of Mobile CrowdSensing (MCS) technologies is traffic condition detection. Aggregating data on speed and position from a multitude of devices can enable real-time detection of traffic jams and provide traffic estimates. This type of information is crucial for many activities, such as conducting interventions, planning trips, managing traffic, and building new infrastructure [13]. Another task regards parking availability. Some studies propose using MCS to alleviate one of the major inconveniences of using cars in urban environments, namely, finding available parking spaces. Approaches to this problem are experimental and vary widely, ranging from using the internal magnetometer to determine the presence of parked vehicles [14] to using GPS to determine if one is entering or exiting a parking space (geofencing) [15]. A significantly less explored field is the use of crowdsensing to increase road awareness and safety. In [16], a system using MCS and artificial intelligence is explored to signal accidents, collect data about the incident, and generate reports for authorities. On the other hand, the study presented in [17] proposes leveraging mobile crowdsensing and deep learning to recognize and classify left turns based on their safety to advise drivers.

The scientific literature is rich with studies exploring the use of the crowdsensing paradigm as a tool to evaluate pavement conditions. Some research focuses on the use of dedicated devices for such measurements, as seen in the work by Chen et al. [18]. Their article proposes a solution based on using a common three-axis accelerometer and GPS embedded within vehicles. The project serves as an alternative method to the costly existing measurement systems based on the International Roughness Index (IRI), still producing accurate results at a fraction of the cost.

The Pothole Patrol (P^2) system, proposed by Eriksson et al., leverages GPS and an accelerometer to collect data on vibrations during a vehicle's movement [19]. By implementing a machine learning algorithm, it can identify potholes and other road surface anomalies with high precision. With MiMoSense, Han et al. present an open platform for crowdsensing in the realm of micro-mobility, allowing researchers to use it freely. The system consists of two components: a cloud server to manage collected data and a client that can be installed on Raspberry Pi-based devices equipped with sensors [20].

However, installing specific hardware on vehicles represents an additional step that some MCS solutions aim to eliminate, relying solely on the drivers' smartphones. In [21], Staniek offers a tool called the Road Condition Tool (RCT), which identifies road pavement defects by analyzing movement dynamics. The RCT mobile application collects data regarding position, speed, and acceleration, automatically sending it to the server. By aggregating data from multiple users, this server divides routes into 10-meter segments and calculates road quality indices for each. Staniek also confirms that the analysis of linear accelerations can effectively assess the state of road pavements.

The research by Piao et al. [22] also proposes a pavement condition detection method based on MCS, capable of distinguishing both the presence of substances covering the road surface and its conformation. The approach includes two distinct modules: a clustering one, which groups vehicle travel modes, and a classification one, which classifies the road surface conditions. The results indicate that this approach can achieve up to 90% accuracy and is particularly effective in highlighting the presence of snow or ice on the surface.

Some systems attempt to use smartphone sensors to produce results that are compliant with international standards, such as the International Roughness Index. An example is Roadroid [23], which evaluates pavement quality based on two different indices: Estimated IRI (eIRI) and Calculated IRI (cIRI). The former provides an IRI estimate based on the effective value of the analyzed vibrations. Designed to adapt to three vehicle categories and to compensate for speeds between 20 and 100 km/h, eIRI provides acceptable results with about 80% accuracy. The latter, cIRI, is designed for very specific speed ranges and works effectively at speeds between 60 km/h and 80 km/h, requiring accurate calibration by the operator to ensure reliable results.

Lima et al. [24] highlight how calculating the IRI is a complex and computationally demanding practice, thus proposing a simpler and lighter approach. Their application, named RoadScan, uses an algorithm based on the mean square deviation of accelerations to classify roads based on their quality. This algorithm assigns each road section to one of four available categories: good, normal, poor, and terrible. Despite lacking the precision offered by IRI-based solutions, RoadScan is a useful tool for intuitively determining the general state of a road.

Most articles in the literature studying the application of mobile crowdsensing in the field of road quality focus on the use of cars, not delving into other scenarios, especially those involving the use of bicycles and electric scooters. The study by Cafiso et al. [25] focuses on using light two-wheeled vehicles to analyze and monitor the characteristics of road pavements, evaluating their comfort and safety conditions. The publication highlights some limitations of the IRI system for evaluating urban roads due to their low-speed limits and for vehicles not equipped with suspension systems. The presented results indeed confirmed the lack of correlation between the vibrations perceived using light two-wheeled vehicles and the IRI, emphasizing the need for using other indicators in urban areas where micromobility is encouraged. In [26], authors presented a Mobile Crowdsensing-based navigation system designed specifically for bicycle riders, addressing road surface quality, a key factor for urban mobility and cyclist safety. The system classifies road segments using inertial sensor data from riders' devices, combining supervised and unsupervised learning methods to overcome the impracticality of human labelling.

3 System Design

This Section details the requirements that drove the design and implementation, the system architecture, the database schema, and the main technologies employed.

3.1 Requirements

The mobile application aims to support the data collection of road vibrations by exploiting mobile crowdsensing. Hence, the heart of the app is its ability to record a route and its vibrations, combining localization data with information obtained from the accelerometer, as well as the possibility of showing this data to the user thanks to a map with colored road segments. The other requirements are:

- **User Account Creation and Management**. The application must support the creation of user accounts, allowing users to register with personal information securely. Then, it should provide functionalities for users to manage their accounts, including updating personal details, changing passwords, and managing privacy settings.
- **Route Recording**. The application must allow users to record their routes (referred to within the app as *activities*). During an activity, the app should collect data on vibrations, GPS coordinates, speed, and other relevant metrics.
- **Activity List Display**. Users should be able to view a list of all their recorded activities. For each of them, it should be possible to visualize a summary of the activity, including the date, duration, distance covered, and a brief overview of the vibration data collected.
- **Detailed Activity View**. The application must provide a detailed view of each recorded activity. This view should include a comprehensive breakdown of the data collected, such as a map of the route taken, detailed vibration data, and any noteworthy anomalies detected during the activity.
- **Save Single Location**. Users should have the chance to save a single position, rather than recording an entire route. This feature is useful for pinpointing specific locations of interest, such as a particularly rough patch of pavement.
- **Saved Locations Log**. The application must maintain a log of all saved positions. In this way, users could access this log to review or edit saved locations and view associated data.
- **Various Settings**. The app should include a settings menu where users can customize various aspects of the application. Settings might include preferences for data collection frequency, notifications, data sharing options, and privacy controls.

3.2 System Architecture and Database

The system is based on a classical client-server architecture. A remote server hosts a relational database that stores all the data sensed by users. The server exposes a set of APIs to query such data. The database schema comprises five main entities: users, vehicles, activities, stages, and geopoints. The users table stores the personal information of the participants using the application. A unique user_id identifies each user and has associated details such as email, password, and name. The vehicles table lists the different types of vehicles used during data collection activities. Each vehicle type is uniquely identified by a vehicle_id and described by a vehicle_name. The information about vehicle types is important for understanding the context of the vibration data, as different vehicles can have varying impacts on the collected data due to their unique characteristics and interaction with the pavement. The activities table is the cornerstone of the database, tracking each user session of pavement vibration data collection. It includes a unique activity_id for each session, linking it to the user_id of the participant. The table records the date and time of the activity, the elapsed_time in seconds, the total number of vibrations_count detected, and the total_distance covered. It also notes the vehicle type used, referencing the vehicles table, and an uploaded flag indicating whether the data has been synchronized with the central server. The stages table breaks down each activity into smaller segments, allowing for detailed analysis of different parts of a session. Each stage is associated with an activity through its ID and sequentially ordered using the order column. It records the latitude and longitude at the end of each stage, providing spatial data points within an activity. The table also captures vibration-related metrics such as last_vibrations_count, average acceleration, minimum acceleration, and maximum acceleration for each stage. Finally, the geopoints table captures specific geographical points recorded by users during their activities. Each point is uniquely identified by a geopoint_id and is linked to a user_id to identify who recorded the data. It stores the latitude and longitude of each point, along with the date and time of recording.

3.3 Technologies

The RDBMS employed is MySQL while the server APIs are written in PHP. The application, named ShakeSensing, has been implemented as an Android application, written in Java using Android Studio. The application takes advantage of the following main libraries:

- Play Services Location, the location SDK provided by Google[1].
- OSMDroid, the Open Street Map library for Android[2].
- Material Design for the UI[3].
- Room, for local persistence[4].
- Volley, a library for HTTP for networking[5].
- Gson, a JSON serialization library[6].
- TimeIt, a timer library[7].

4 Our Prototype

When launching the app for the first time, users will be prompted to log in by entering their credentials or registering a new account. To switch from the login module to the registration module, simply swipe the screen to the right or left. Once logged in, the app will display the Home screen, which is the main screen, allowing interaction to navigate to other application components.

Referring to Figure 1, you can identify a Top Bar at the top of the screen, a list containing the various activities performed, a navigation bar (Nav Bar) at the bottom, and a Floating Action Button (FAB) anchored above it. Clicking on the FAB will redirect you to record a new activity while clicking on an item in the list will allow you to view its statistics in more detail. The Nav Bar facilitates navigation between other screens of the application and allows you to move between the Home screen, the screen for saving a location, and the location log. Finally, the gear icon in the corner of the Top Bar opens the settings.

[1] https://play.google.com/sdks/details/com-google-android-gms-play-services-location
[2] https://github.com/osmdroid/osmdroid
[3] https://m3.material.io/
[4] https://developer.android.com/jetpack/androidx/releases/room?hl=it
[5] https://github.com/google/volley
[6] https://github.com/google/gson
[7] https://github.com/yashovardhan99/TimeIt

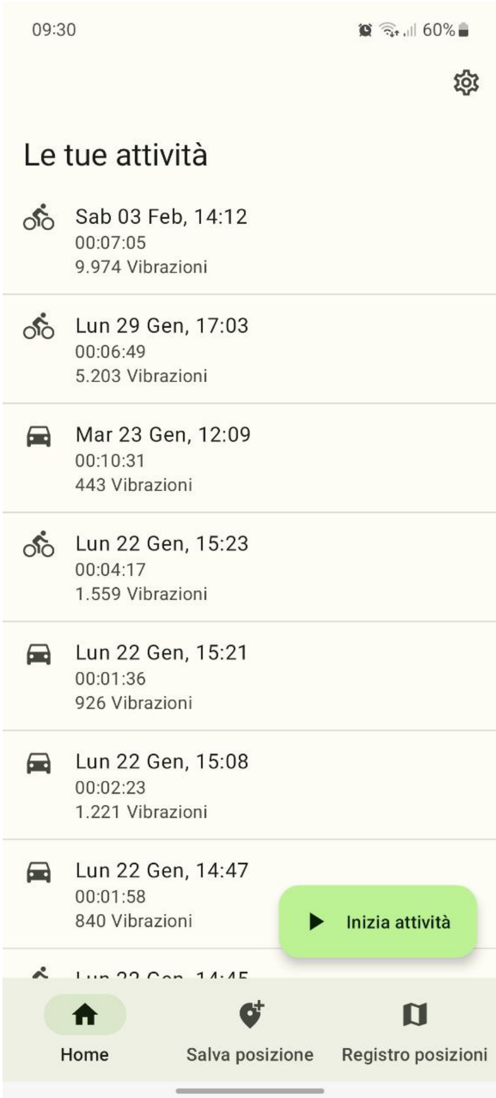

Fig. 1 Our Prototype - Home (in Italian language)

In the screen dedicated to recording an activity (shown in Figure 2), the Top Bar disappears, making room for a map in the upper half of the layout. The structure of this interface is quite simple: pressing the "Start activity" button will start recording the route, while clicking on the vehicle name allows you to select the one you are using. Once tracking has started, the choice of vehicle is locked, and instead of the central button, two smaller buttons will appear to pause or end the recording. Once a route is saved, you can view its information by pressing the corresponding item in the list on the home screen.

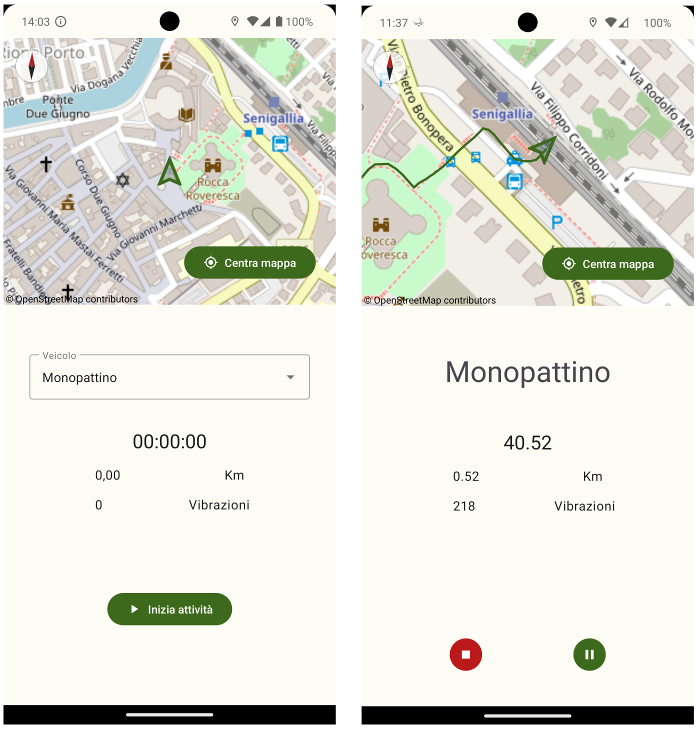

Fig. 2 Our Prototype - Activity (in Italian language)

In the "Activity Details" screen (Figure 3), some statistics about the selected activity are shown, such as the total vibrations or the total distance, as well as a map where the route is divided into numerous colored segments. The color scale ranges from cyan to dark red, and each color is associated with an interval of recorded vibration quantities, thus representing the quality of a particular road segment. In the upper right corner of the map, there are two buttons: the first to choose the chart representation mode (explained in more detail in the next section) and the second to view the legend. Finally, the Top Bar now contains a trash icon to delete the activity.

Moving on to saving a single location, this action has been given a very basic interface, as shown in Figure 4. To obtain and save the location, simply tap the central area of the screen. Subsequently, you can view all the saved locations through the "Location Log". This appears as a screen where the locations are represented both as pins on a map and as items in a list. In the example shown in Figure 4, a location displays an error symbol, and its pin is red, indicating that the upload to the server failed. A cloud icon will also appear on the Top Bar in these cases. If clicked, it will try to load the positions highlighted in red again.

5 User Testing and Discussion

Satisfactory results emerged from the various road tests of the application, demonstrating its effectiveness and reliability. The maps produced by the application accurately

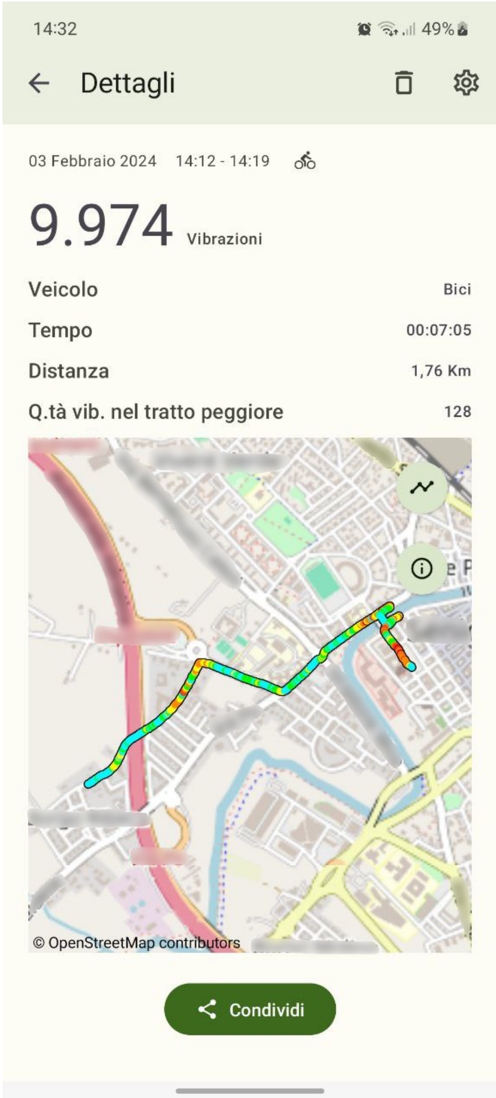

Fig. 3 Our Prototype - Activity Details (in Italian language)

reflect real road conditions, providing valuable insights into the state of the roads. As illustrated in Figure 5, it is possible to distinguish which traits caused more or fewer vibrations. This capability allows for a detailed analysis of road surface quality and the identification of problematic areas that may require maintenance.

However, the project presented has some limitations that need to be acknowledged. For example, the collection of vibration data is influenced by several variables. These variables include the model of the smartphone used for data collection and its placement while driving. If the smartphone is stored in a pocket or a backpack, it tends to detect fewer vibrations compared to when it is mounted on a fixed holder within

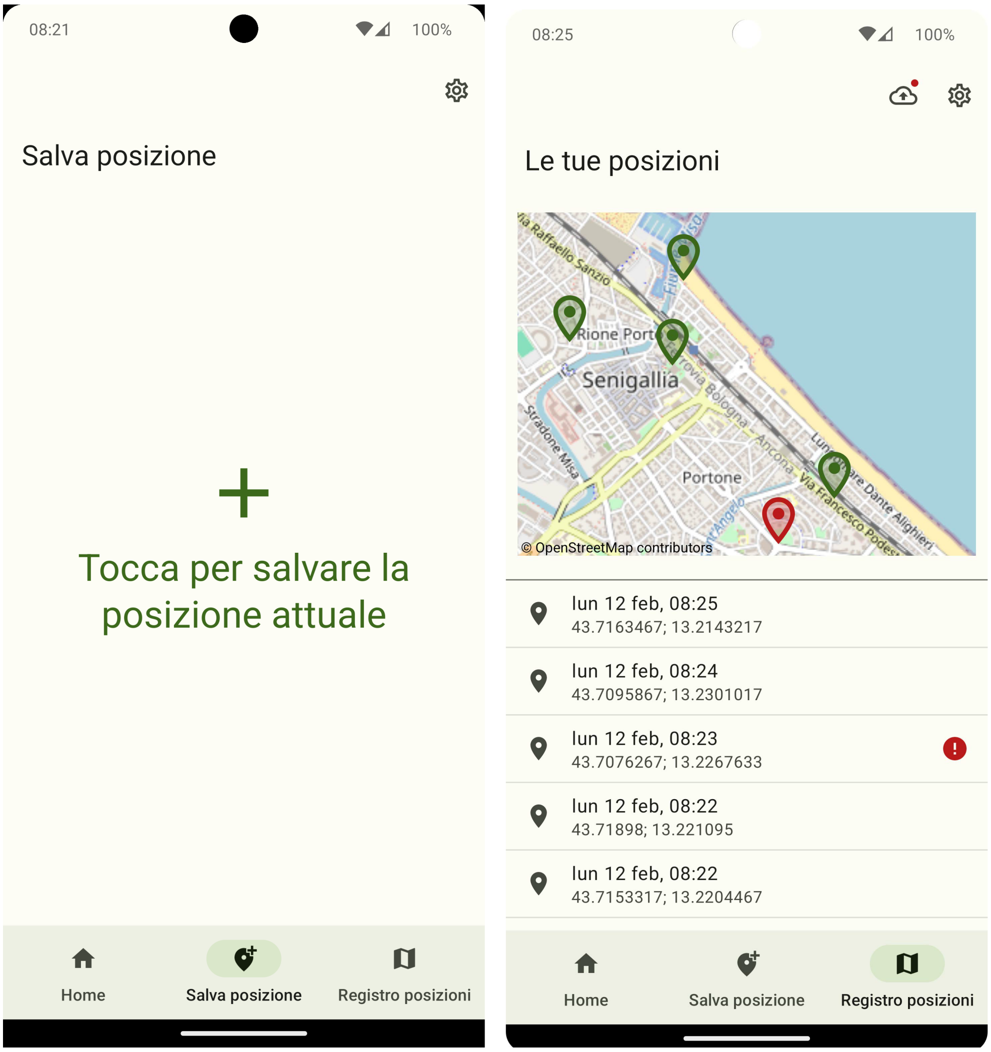

Fig. 4 Our Prototype - Save Single Position (in Italian language)

the vehicle. This data collection method variability can affect the recorded vibrations' accuracy and consistency.

Despite these limitations, this project represents an economical approach to road condition detection. By leveraging readily available technology, such as smartphones, it provides a cost-effective solution for monitoring and assessing road conditions. This approach has the potential to be widely adopted due to its affordability and ease of use.

Looking ahead, there are several possible future developments for this project. One significant enhancement could be the creation of a system that processes the data collected from all users. This system would aim to reconcile the divergences between the different measurements available for the same area. By integrating and analyzing data from multiple sources, it would be possible to create a comprehensive map that accurately represents all the measurements carried out. This map would highlight all the areas where measurements were taken, providing a detailed overview of road conditions across a broader region.

Such advancements would improve the reliability and accuracy of road condition detection, making it a more robust tool for urban planning and maintenance. Overall, the project holds significant promise for enhancing our ability to monitor and maintain road infrastructure in a cost-effective manner.

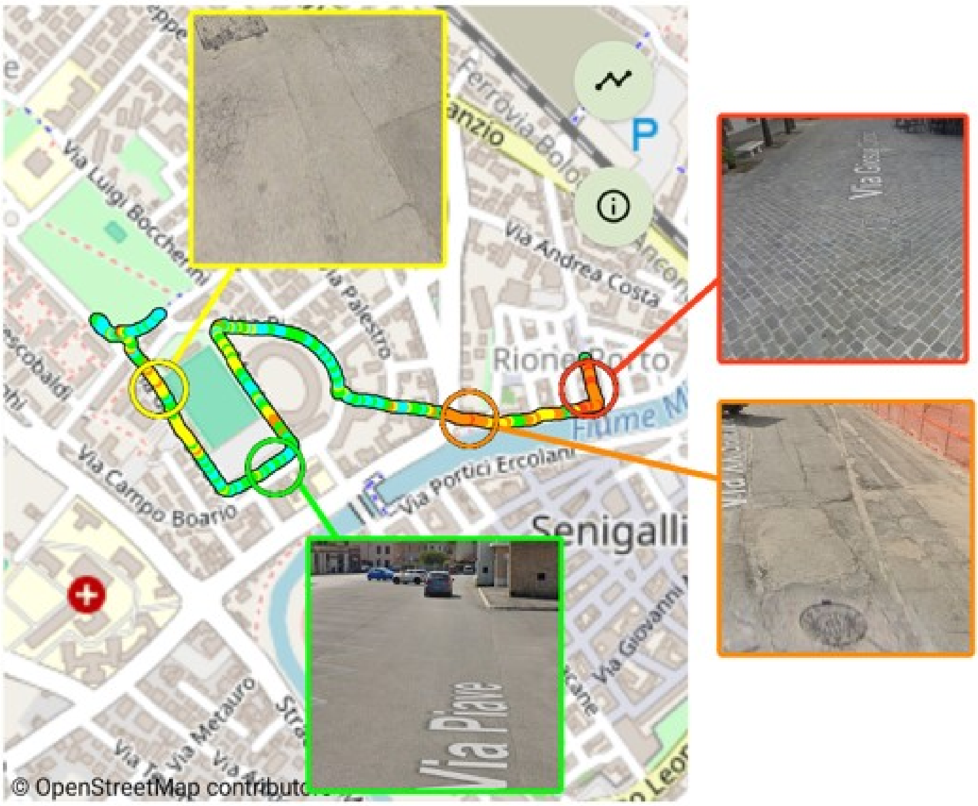

Fig. 5 Data collection examples

6 Conclusion and Future Works

The maps produced by this study reflect real road situations accurately, offering a valuable tool for distinguishing sections of roads with varying levels of comfort. This project represents a potential economical approach to pothole detection and road condition monitoring.

However, there are some limitations to this approach. Data collection is dependent on various factors, such as the smartphone model and its placement during data collection. There are some privacy concerns related to the collection and use of user data. Finally, the personal perception of vibrations can vary, affecting the consistency of the data.

Given these considerations, further developments in this research could involve the creation of a system capable of aggregating and processing data collected from ShakeSensing users. This would enable the production and visualization of interactive maps, providing a service accessible to all through a website or integrated within the application itself. Such advancements would enhance the reliability and utility of the system, offering a comprehensive solution for road condition monitoring. Finally, machine learning could be employed to provide advanced analytics [27, 28].

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