Smartphone Sensor Platform to Study Traffic Conditions and Assess Driving Performance

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***Abstract*—Sensor technology available in smartphones enables the monitoring of mobility patterns, which could be of particular interest for the transportation sector. For example, driving time information can help to determine if a selected path is the most convenient. Moreover, measurements related to the time expended on the road and origin destination matrices can lead to conclusions related to the organization of travel schedules and routes, enhancing reliability and resulting in a shorter total traveling time. Relying on GPS-based Floating Car Data (FCD), we designed a platform to acquire data for the evaluation of traffic conditions and driving performance using mobile phone sensors. Users control the activation of the tracking activity themselves and can benefit from information provided by other users' records. Additional metrics related to the travel time and vehicle's speeds contribute to the assessment of traffic management issues. Conclusions regarding possible applications of the tool are outlined.**

I. INTRODUCTION

Todays smartphones are adhering progressively to sensor technology and they already include equipment that can be applied to recognize and monitor a wide repertoire of activities. Additionally, they contain communication resources and enable the quick deployment of new applications [1]. These applications are of particular interest for the transportation sector, as they provide valuable information regarding the monitoring of mobility patterns [2], [3], [4] that can be used to study driving behavior for road safety purposes. Their cost efficient embedded sensors (i.e. accelerometer, digital compass, gyroscope, GPS, microphone, camera) allow for the collection of pertinent data to gain information related to current traffic situations and is therefore in accord with advanced traffic applications as fostered within the Intelligent Transportation Systems (ITS) research. Based on this information, it is also possible to characterize and classify arterial/freeway systems. Specifically, data related to travel time constitutes an important factor to consider in traffic management, as instrumental for congestion measurement based on the real travelers experience [5] that can be used to improve existing systems [6], [7]. For example, driving time information can help to determine if a selected path is the most convenient. Moreover, measurements related to the time expended on the road can lead to conclusions related to the organization of travel schedules, enhancing reliability through shorter total traveling times. In the planning, transportation, supply and maintenance of goods, this knowledge can positively affect delivery costs, increasing the reliability of delivery and improving the quality of service, but from a global perspective it can also significantly reduce the environmental impact. New forms of traditional traffic detectors offer methods for the acquisition of data that can lead to an improvement of traffic management and control, but even these new technologies present a number of difficulties that must be overcome to effectively utilize the full potential of the ITS concepts. Sensor-equipped mobile phones for the monitoring of traffic conditions overcome these difficulties. They enable capturing not only highway but also minor roads data for extended periods of time, being that the smartphones are deployed without location restrictions. Additionally, the tracking through smartphone devices occurs through a unique process, from the device independent address. Through encryption mechanisms personal information privacy can be guaranteed ensuring an anonymous source of information. The ubiquitous use of smartphones makes them the perfect data acquisition tool for human mobility patterns, including pedestrian information.

This work hinges upon the adoption of the smartphone technology by the traffic community in order to study and characterize traffic and road conditions. For this purpose, relying on GPS-based FCD we have built the Iris geographic information system (GIS)- based platform using the smartphone Android default API for geolocation. The server side of the Iris platform complements the Android Mobile-Sensing System to collect data by storing, pre/postprocessing, analyzing, managing and presenting the results. Additional metrics related to the travel time and vehicle's speeds contribute to the assessment of traffic management issues. The remainder of this paper is organized accordingly: The following section presents related work in the areas of traffic management using similar technologies. Section III presents a description of the application implementation. Section IV describes the methodology followed to acquire and process data for this study as proof of concept. Section V reports on the results of the data evaluation. Finally, Section VI concludes the paper.

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II. RELATED WORK

To achieve an enhancement of traffic management and dissemination of traveler information, both important components of Intelligent Traffic Systems (ITS), reliable and ubiquitous traffic information is required. Therefore, the deployment of different kind of sensors relying on several technologies has been the focus of several works. For example, through a network of stationary sensors, or sensors located in mobile vehicles relying on Bluetooth technology [8], [9] particularly for the collection and use of travel time records for travel mobility metrics in diverse scenarios (i.e. work zones, highways, urban arterials) [10], [11], [12]. Additionally, cooperative traffic information systems based on vehicular ad hoc networks (VANET) exchange sensor information between vehicles via wireless communication, to improve traffic safety and efficiency [13], [14], [15].

Mobility sensors available in smartphones have already been proposed as a source of traffic estimation and therefore, some recent works present traffic related data collected through Global Positioning System (GPS) technology [4], [16], [17].

Moreover several mobile applications have been recently implemented for the monitoring of traffic conditions and record of geographic data [18], [19]. The authors in [20] combined Dynamic Time Warping (DTW) and smartphone based sensor-fusion to classify patterns and styles regarding non-aggressive vs. aggressive driving without external data processing. In a further work the authors in [21] acquired data through sensors located in smartphones to investigate changes in driver behavior patterns compared with patterns of traditional vehicles with combustion engines after having acquired the necessary adjustments needed for driving an electric vehicle.

Some mobile applications include capabilities to monitor driver attention [22], [23], [24] even alerting the driver when a certain behavior has been detected. This has been, exemplified by the application created by the authors in [25]. In the study they analyzed driving patterns collected through mobile phone sensor technology that were compared with typical drunk driving patterns extracted from real driving tests. Also data providers like Google elicit geographical information of a given location in real-time. The GPS-based Waze application relies on contributions from an online community of drivers reporting on traffic conditions that allow the computing of the most convenient navigation routes [26].

We similarly draw on the crowdsourcing practice and adopt in our approach the sensor technology included in mobile phones to develop an application to collect and analyze driving related data. In contrast to the works previously cited, this information is automatically logged by our system. We focus on driver performance metrics and combine several approaches in order to:

- assess driving performance;
- influence drivers' behavior with feedback about unsafe driving actions;
- monitor driving performance improvements to encourage safer driving;
- determine travel times and distances and provide the driver with records related to the selected routes.

System's users control the activation of the tracking activity and can benefit from information provided by other users' records. Similar to the approach presented in the serious games based application to assess the ergonomics of in-vehicle information systems [27], [28], [29] drivers are alerted when speed limits have been surpassed [30].

Our system bases on a client-server approach in order to be able to provide online feedback about unsafe driving actions. To encourage the use of our platform, users that provide us with data additionally benefit from a set of services such as recommendation of alternative route paths, recommendation of driving patterns for a shorter traveling time or for fuel saving reduction. In the next section we describe the system architecture of our Iris tool.

III. SYSTEM ARCHITECTURE

The general context for which we designed the system is depicted in Figure 1. Different means of transportation are regularly used to travel between locations. The smartphones track data related to these travels that is sent to the servers. Therefore, the server cluster provides a parallel computing platform for processing the incoming data. As a consequence our architecture ensures ubiquitous access through the integration of smartphones in the system.

Due to the still limited processing capabilities of some mobile devices, from the server side we guarantee a scalable solution that handles huge amounts of data by paralleling the processing. Regarding the analysis of the system, network traffic and cloud usage on the server side directly affect the performance. As the amount of users increases linearly, the complexity of the algorithms implemented by the data analytic modules increase exponentially. To palliate this effect, the applications implemented in our cloud based on the Service-Oriented Architecture (SOA), with focus on data selection algorithms for data entry and multiple services communicating with each other and connected through graphs.

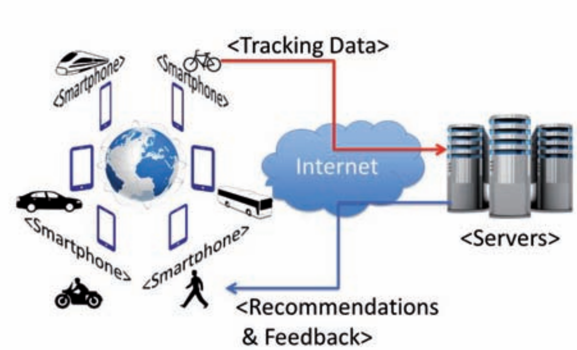

Fig. 1. Overview of the Iris platform designed to capture, store, manipulate, analyze, manage, and present traffic conditions data using smartphone sensors.

We designed the system to analyze the driving performance in terms of speed metrics in real time using mobile phone GPS sensors. The developed application for mobile phones based on the Android operative system (OS) was reliable and non-intrusive, having been previously downloaded and activated by the user for automatic execution on the scheduled days.

A. Server Side

In order to handle large amounts of data in a reasonable time, we aimed for a separate layered structure for each data, processing and visualization process as illustrated in Figure 2. The layers are detailed below.

1) Data Layer: The "Data Layer" hosts multiple databases that store information regarding regular travels or driver behavior. It also synthesizes data persistence and availability. The "Data Sink" element aggregates messages and files from external sources and also performs the preprocessing of the data through message routing previously to its storage in the database. After it, a request to analyze the new data is sent to the processing elements. All the input data is stored in the "Historical Database". Additionally, the "Data Access Layer" (DAL) ensures a uniformed and controlled access to the databases.

2) Processing and Visualization Layers: As the data becomes available, it is processed to extract relevant knowledge. Meta data information is provided to the elements that are responsible for the analysis of the data contained in the "Historical Database". Additionally, several analyzer activation rules contain information related to the specific processing and storage of the data. Figure 2 shows three analyzers with different databases. The stream with the name "Raw Data 1" corresponds to real time data that can be used to detect driving behavior, "Raw Data 2" contains origin destination related data important to infer information relevant to travel times, while "Raw Data 3" contains similar data as Raw Data 1, but instead of being real-time it is logged data that needs to be verified or modified. After the data has been processed and saved in the respective database, the "Visualization Layer" presents information in a meaningful fashion to the user.

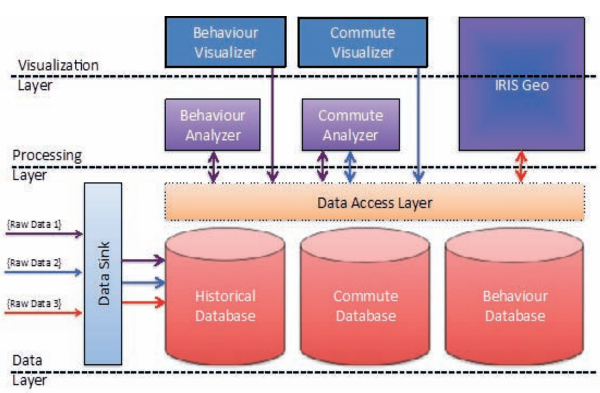

Fig. 2. Layered structure for the data, processing and visualization processes.

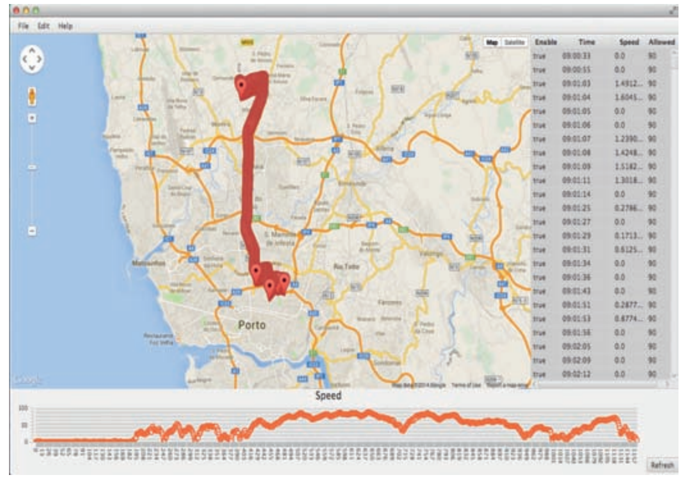

Fig. 3. User interface of the Iris Geo Tool with the different information that can be selected for further processing.

3) Iris Geo Tool: The "Iris Geo" application is a multilayer component of the server framework able to process and visualize data. A screen shot of the "Iris Geo Tool" graphical user interface (GUI) is provided by Figure 3.

It depicts the definition of the maximum velocity allowed on some specific road segments. The GUI is divided in three windows with different information. The window on the right upper side of the interface provides a detailed view of the data that can be selected to edit specific fields. Data rows that are not relevant for a specific analysis can be hidden (i.e. trip ended but data is still being logged). Additionally, GPS tracks are visualized through a map view in the mid window of the interface with pins to signalize the selected rows. The perspective is automatically centered and adjusted for optimal map navigation. The third window on the bottom side of the GUI shows a speed plot that provides a quick overview of the speed behavior from the selected records in the first window. The resulting file from the data set selected can then be exported to the server.

B. Client Side

In this section we describe the structure of the client application. Figure 4 shows the user interface. After the user has been registered into the application, a calendar shows day and time options to enter the schedule to log the data. The application is then automatically activated on the programmed days and times.
The client side of the system architecture is depicted in Figure 5. It is comprised of the following three main elements:

1) Activities: To enable interaction with the user interface, our application performs four specialized activities: "Introduction", "Registration", "Schedule" and "Control". As the user launches the application the "Introduction" activity checks the user's registration state, and the current tracking schedule. If any issue appears, e.g. not registered or no schedule defined, then the activity launches the associated activity "Registration"

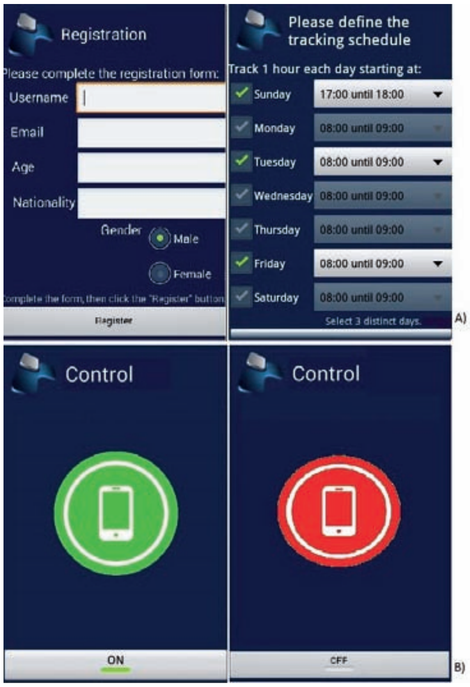

Fig. 4. User interface of the Iris client application. A shows the registration form and the schedule that can be selected for tracking the driving data. B shows the control interface to activate or deactivate the tracking functionality.

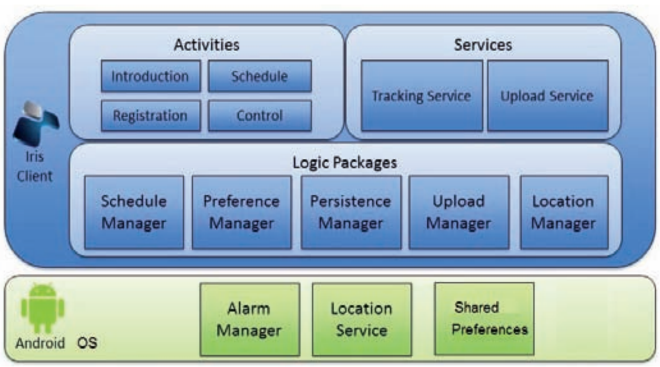

Fig. 5. Client side of the Iris system architecture.

or “Schedule” to handle the issue. When the setup is complete, the “Introduction” activity terminates.

The “Registration” activity, prompts the user with a form to fill in personal data. Once clicked on register button, the data is sent to the server, and the user is registered. The “Schedule” activity allows the user to specify which days the application can automatically track. By default, the application tracks from 8 am to 11 am. The “Control” activity is only available by a notification in form of an icon in the system to provide the user with feedback related to the activation of tracking and whether or not it has occurred. The user can stop the application through this control option when tracking is not desirable (e.g. privacy, battery saving, etc). Figure 4B show the user interface for this option.

2) Services: This element handles automated tasks and facilitates the application management. Specifically, vehicle position tracking over a time window is handled through the “Tracking Service” that interacts with the “Android’s Location Manager” for subscribing updates concerning the device’s location. Tracked data is uploaded after the “Upload Service” has verified connection availability.

3) Logic Packages: The “Logic Packages” contain the application logic and interact with the operating system. This element consists of the following components:

- The “Schedule Manager” is a package designed to perform the operations required to set up a tracking schedule. This component serves as the operation which saves the schedule and also manages the “Android’s Alarm Manager” software component of the Android operating system. In our approach, we use it to control time in the effect of triggering the desired tasks needed in our application. For example, the “Schedule Manager” registers in “Android’s Alarm Manager” a daily alarm at 8 am to verify if the current day is scheduled for tracking and in the affirmative case, proceed in executing the application.
- The “Preference Manager” package stores the application setup configuration. Data concerning registration and the schedule itself are saved persistently using the hash table akin to the Android OS component “Shared Preferences”, to information that is available while the application is installed in the form of key-value pairs without handling file operations (i.e. schedule for tracking and registration data).
- The “Persistence Manager” accesses the Android’s file system, through internal/external storage and proper file initialization, writing, and closing. This ensures the integrity of collected data and allows for the “Upload Service” to detect the new files and upload them.
- The “Upload Manager” is mainly used by the “Upload Service” to manage the network connectivity changes and the files network transfer.
- The “Location Manager” interacts with the Android component “Location Service”, preprocesses the information to the application’s supported format, and sends it to the “Persistence Manager” for storage.

IV. Experimental Setup

In order to demonstrate the feasibility of our approach, we deployed our Iris app through the play store web shop and made available a free version for download.

A. Data acquisition and processing

To verify that our application was behaving in the expected manner we logged encrypted driving data from 3 drivers and a total of 30 trips. No personal data was recorded. The drivers had previously selected which days and times were the most suitable for them. We then stored the data in a database from where it was downloaded for further evaluation. We addressed origin destination matrices calculating the mean point of the 10 first and last coordinate points of the trip. Additionally, speed patterns determined driving behavior. The collected data length allowed for a comparison at every point overlapping similar speed data sections and determining differences in the speed variation. We could determine travel times through the time and location data that was inherent to every device calculating the difference in time between two locations. We started to log the time at the point where the driver exceeded 40 km/h at least 500 m from the origin in order to filter data that was not related to a particular travel. Similarly we set the time where the trip finished at the last point where the driver exceeded 10 km/h at least 500 m from the destination. The system evaluated traffic conditions through the following algorithm: if in a restricted time window (e.g. 5 min) the average of the vehicles was equal or above the speed limit then we considered the traffic congestion to be low. The lower the vehicles velocity, the higher the congestion. This technology allowed us to study and characterize the traffic conditions over selected roads to determine if the selected travel path was the most convenient compared to the fastest suggested routes from Open Street Maps [31].

B. Driving performance assessment

The collected driving related data enabled to assess the driving performance in terms of speed metrics so that drivers could be influenced with feedback about an excessive speed limit. Feedback could be provided to the driver during the trip through an acoustic signal programmed in the smartphone and after a certain trip through the average fuel consumption or time saving selecting a different route.

V. Results

A. Travel time and distance

Results regarding travel times and travel distance showed slight differences based on the real traveler's experience over the suggested routes in Open Street Maps. These differences can be due to a routing algorithm that considers an incomplete or outdated road infrastructure. Figure 6 depicts the results for the second driver.

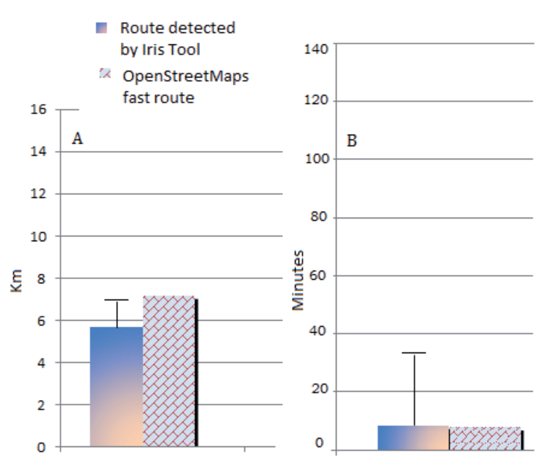

Fig. 6. Travel distance (A) and time (B) logged for the selected roads by driver 2 over the fastest suggested routes from Open Street Maps [31].

B. Driving performance

Figure 7 depicts the results concerning driving performance by driver in terms of speed limit over different travel paths. We analyzed the percentage of the trips per driver that exceeded the speed limit in 10 km/h and more (110-120 km/h). A high variability on the speed behavior could be observed depending

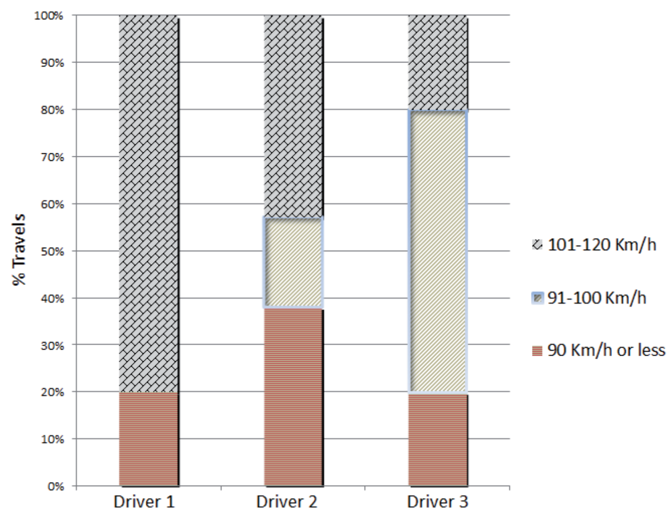

Fig. 7. Driving performance by driver in terms of the speed limits over different travel paths

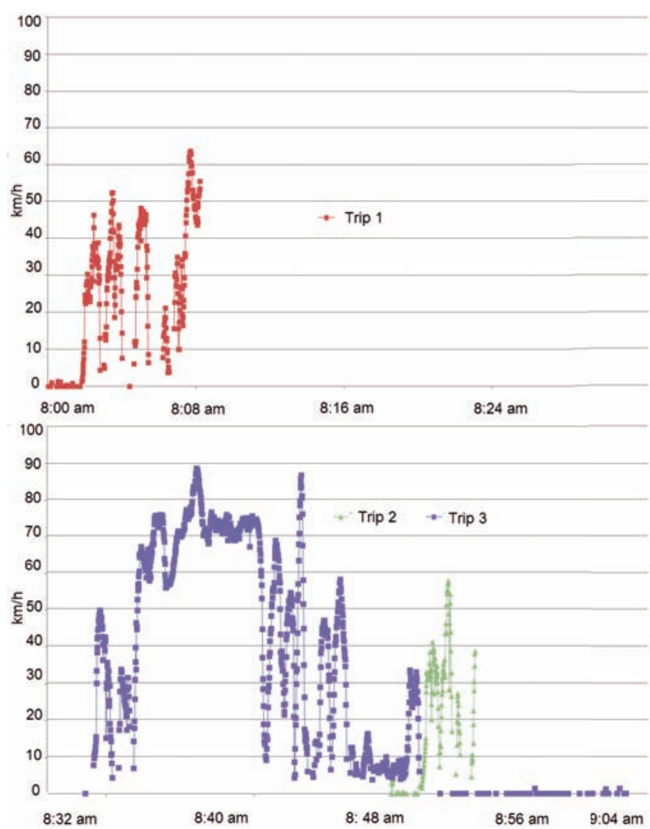

Fig. 8. Velocity over time of 3 trips

on the driver. However, a common thread could be observed in all cases, namely, the percentage of travels where the speed limit was respected, was inferior to 38%. Figure 8 shows the velocity course of three different trips.

VI. CONCLUSION AND FUTURE WORK

In this paper, we proposed the Iris platform to acquire data for the evaluation of traffic conditions and assessment of driving performance using mobile phone GPS. As a proof of concept we showed that data collected by our tool can lead to conclusions related to the organization of travel schedules, enhancing reliability through shorter total traveling times. Particularly, the information related to the selected path compared to suggested routes can be used to improve existing systems. Additionally, the low percentage of travels where the speed limit was respected might be used to provide the driver with feedback about unsafe driving actions so that it can be corrected in future trips. The feedback capabilities of the proposed platform will be presented in future work in which we will increase the sample deploying the tool through the internet and collect and evaluate data from heterogeneous drivers to make driver classification and a better driving assessment and feedback possible.

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