Smartphone-Based Telematics for Usage Based Insurance

Prokopis Vavouranakis, Spyros Panagiotakis, George Mastorakis and Constandinos X. Mavromoustakis

Abstract In this chapter we study and introduce a smartphone-based telematics system for usage-based insurance (UBI). The smartphone has been identified as an enabler for future UBI, replacing the in-vehicle telecommunication hardware devices with a ubiquitous device with a plurality of sensors, means for data processing and wireless communication. We implemented and developed an end-to-end system including a telematics android-based application for client's smartphones and a portal to collect, analyze and record driving patterns and score drivers. Also monitoring driver behavior, recording their driving events (safe and aggressive) and giving feedback of recorded events can enhance driver safety. So we developed an android-based application, which can estimate driving behavior, using data only from the accelerometer sensor or using orientation data of a sensor fusion method. Complementary, we developed a portal, where we can have access to an overall dashboard of all registered drivers. In the portal are presented scores, behaviors, trips reports and routes in maps of all recorded trips. With this way, we help the insurance carriers to assess better the risk of the drivers.

Keywords UBI · Usage based insurance · Driving behavior · Smartphone · Android · Pervasive computing · IoT · Big data

P. Vavouranakis · S. Panagiotakis (✉) · G. Mastorakis
Department of Informatics Engineering, Technological Educational Institute of Crete, 71004 Heraklion, Crete, Greece
e-mail: spanag@teicrete.gr

P. Vavouranakis
e-mail: akisvavour@gmail.com

G. Mastorakis
e-mail: gmastorakis@staff.teicrete.gr

C.X. Mavromoustakis
Department of Computer Science, University of Nicosia, Nicosia, Cyprus
e-mail: mavromoustakis.c@unic.ac.cy

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1 Introduction

Usage-based insurance (UBI) [1] is a type of vehicle insurance whereby the costs are dependent upon type of vehicle used, measured against time, distance, behavior and place.

This differs from traditional insurance, which attempts to differentiate and reward "safe" drivers, giving them lower premiums and/or a no-claims bonus. However, this rewarding is a reflection of history that may do not correspond to the present pattern of driving behavior. This means that it may take a long time before safer (or more reckless) patterns of driving and changes in lifestyle feed the insurance premiums.

The simplest form of usage-based insurance bases the insurance costs simply on the number of miles driven. However, the general concept of pay as you drive includes any scheme where the insurance costs may depend not just on how much you drive but how, where, and when one drives [2].

Pay as you drive (PAYD) means that the insurance premium is calculated dynamically, typically according to the amount driven. There are three types of usage-based insurance:

- Coverage is based on the odometer reading of the vehicle.
- Coverage is based on mileage aggregated from GPS data, or the number of minutes the vehicle is being used as recorded by a vehicle-independent module transmitting data via cellphone or RF technology [3].
- Coverage is based on other data collected from the vehicle, including speed and time-of-day information, historic riskiness of the road, driving actions in addition to distance or time travelled.

The formula can be a simple function of the number of miles driven, or can vary according to the type of driving or the identity of the driver. Once the basic scheme is in place, it is possible to add further details, such as an extra risk premium if someone drives too long without a break, uses their mobile phone while driving, or travels at an excessive speed. Telematics usage-based insurance provides a much more immediate feedback loop to the driver [1] by changing the cost of insurance dynamically with a change of risk. This means drivers have a stronger incentive to adopt safer practices. For example, if a commuter switches to public transport or to working at home, this immediately reduces the risk of rush hour accidents. With usage-based insurance, this reduction would be immediately reflected in the cost of car insurance for that month.

So the proposal for the user is simple. The user has to download an application in his smartphone, open it when he is driving and let his insurance company to monitor his driving behavior: where his vehicle is driven, how fast he drives, how hard he breaks, how hard he corners and so on. In return the insurance will give him a discount on insurance premiums.

The Progressive Insurance [2], the largest insurance company using such methods in the USA, found after analysis of billion of miles and relevant data that key points in driving behavior such as actual miles traveled, braking and time of the day give more than the twice predictabilities compared to tradition variables such as age of the driver, gender, the manufacturer and the model of the insured vehicle. The average discount on insurance premiums for a driver who agrees to record his driving behavior amounts to 10−15 %.

In the future, anyone who does not agree to record his driving behavior may not be required to pay higher insurance premiums, but most companies will not even accept to insure his car. Insurance based on telematics can find great appeal, as no longer requires special devices installed in the car and a simple download of an application in the driver's smartphone is enough. In addition, smartphones are made especially for communication. On the other hand special devices need some kind of transmitter.

Insurance programs based on telematics [2] would mean big changes for road safety. The insurance application on the mobile phone will notify you when you brake too abruptly or run too much, and tame the way you drive. The fact is that people drive more carefully, simply because they know that their driving behavior is recorded. The more expensive insurance premiums act as penalty for recklessness driving behavior.

In this chapter we study and introduce a smartphone-based telematics system for usage-based insurance. The smartphone has been identified as an enabler for future UBI, replacing the vehicle mounted dedicated hardware with a ubiquitous device with a plurality of sensors, means for data processing and wireless communication. In this context we have implemented and developed an end-to-end system including a telematics android-based application for client's smartphones and driving behavior recognition, as well as a portal to collect, analyze and record driving patterns and score the drivers. The rest of the paper is organized as follows: Sect. 2 details in UBI concepts, Sect. 3 presents the methodology for detecting drivers' behavior using smartphone sensors, Sects. 4 and 5 introduce the Native Android Application we have developed for Usage Based Auto Insurance and the e-Platform of a potential Auto UBI System for drivers management, respectively, and, finally, Sect. 6 concludes the chapter.

2 Usage Based Insurance (UBI)

2.1 Definition of UBI

Usage-based insurance (UBI) [2] also known as pay as you drive (PAYD) and pay how you drive (PHYD) and mile-based auto insurance is a type of vehicle insurance whereby the costs are dependent upon type of vehicle used, measured against time, distance, behavior and place.

Usage-Based Insurance is a recent innovation by auto insurers that more closely aligns driving behaviors with premium rates for auto insurance. Mileage and driving behaviors are tracked using odometer readings or in-vehicle telecommunication devices (telematics) that are usually self-installed into a special vehicle port or already integrated in original equipment installed by car manufactures. The basic idea of telematics auto insurance is that a driver's behavior is monitored directly while the person drives. These telematics devices measure a number of elements of interest to underwriters: miles driven; time of day; where the vehicle is driven (GPS); rapid acceleration; hard breaking; hard cornering; and air bag deployment. The level of data collected generally reflects the telematics technology employed and the policyholders' willingness to share personal data.

The insurance company then assesses the data and charges insurance premiums accordingly. For example, a driver who drives long distance at high speed will be charged a higher rate than a driver who drives short distances at slower speeds. With UBI, premiums are collected using a variety of methods, including utilizing the gas pump, debit accounts, direct billing and smart card systems.

The first UBI programs began to surface in the U.S. about a decade ago, when Progressive Insurance Company and General Motors Assurance Company (GMAC) began to offer mileage-linked discounts through combined GPS technology and cellular systems that tracked miles driven. These discounts were (and still are) often combined with ancillary benefits like roadside assistance and vehicle theft recovery. Recent accelerations in technology have increased the effectiveness and cost of using telematics, enabling insurers to capture not just how many miles people drive, but how and when they drive too. The result has been the growth of several UBI variations, including Pay-As-You-Drive (PAYD), Pay-How-You-Drive (PHYD), Pay-As-You-Go, and Distance-Based Insurance.

2.2 Pricing of UBI

The pricing scheme for UBI deviates [2] greatly from that of traditional auto insurance. Traditional auto insurance relies on actuarial studies of aggregated historical data to produce rating factors that include driving record, credit-based insurance score, personal characteristics (age, gender, and marital status), vehicle type, living location, vehicle use, previous claims, liability limits, and deductibles. Premium discounts on traditional auto insurance is usually limited to the bundling of insurance on multiple vehicles or types of insurance, insurance with the same carrier, protection devices (like airbags), driving courses and home to work mileage.

Policyholders tend to think of traditional auto insurance as a fixed cost, assessed annually and usually paid for in lump sums on an annual, semi-annual, or quarterly basis. However, studies show that there is a strong correlation between claim and loss costs and mileage driven, particularly within existing price rating factors (such as class and territory). For this reason, many UBI programs seek to convert the fixed costs associated with mileage driven into variable costs that can be used in conjunction with other rating factors in the premium calculation. UBI has the advantage of utilizing individual and current driving behaviors, rather than relying on aggregated statistics and driving records that are based on past trends and events, making premium pricing more individualized and precise.

2.3 Advantages of UBI

UBI programs offer many advantages [2] to insurers, consumers and society. Linking insurance premiums more closely to actual individual vehicle or fleet performance allows insurers to more accurately price premiums. This increases affordability for lower-risk drivers, many of whom are also lower-income drivers. It also gives consumers the ability to control their premium costs by incenting them to reduce miles driven and adopt safer driving habits. Fewer miles and safer driving also aid in reducing accidents, congestion and vehicle emissions, which benefits society.

The use of telematics helps insurers more accurately estimate accident damages and reduce fraud by enabling them to analyze the driving data (such as hard breaking, speed, and time) during an accident. This additional data can also be used by insurers to refine or differentiate UBI products. Additionally, the ancillary safety benefits offered in conjunction with many telematics-based UBI programs also help to lower accident and vehicle theft related costs by improving accident response time, allowing for stolen vehicles to be tracked and recovered, and monitoring driver safety. Telematics also allow fleets to determine the most efficient routes, saving them costs related to personnel, gas and maintenance.

2.4 Challenges

The practice of tracking mileage and behavior information in UBI programs has raised privacy concerns. As a result, some states have enacted legislation requiring disclosure of tracking practices and devices. Additionally, some insurers limit the data they collect. Although not for everyone, acceptance of information sharing is growing as more mainstream technology devices (such as smartphones, tablets, and GPS devices) and social media networks (such as Facebook and MySpace) enter the market.

Implementing a UBI program, particularly one that utilizes telematics, can be costly and resource intensive to the insurer. UBI programs rely heavily on costly technology to capture and sensitize driving data. Additionally, UBI is an emerging area and thus there is still much uncertainty surrounding the selection and interpretation of driving data and how that data should be integrated into existing or new price structures to maintain profitability. This is particularly important, as the transitioning of lower-risk drivers into UBI programs that offer lower premium could put pressure on overall insurer profitability.

Insurers must also manage regulatory requirements within the states that they do business. Many states require insures to obtain approval for the use of new rating plans. Rate filings usually must include statistical data that supports the proposed new rating structure. Although there are general studies demonstrating the link between mileage and risk, individual driving data and UBI plan specifics are considered proprietary information of the insurer. This can make it difficult for an insurer who does not have past UBI experience. Other requirements that could prevent certain UBI programs include the need for continuous insurance coverage, upfront statement of premium charge, set expiration date, and guaranteed renewability. However, it should be noted that a Georgia Institute of Technology survey of state insurance regulations (2002) found that the majority of states had no regulatory restrictions that would prevent PAYD programs from being implemented.

2.5 Implementations in USA

Metromile. Metromile is a California-based insurance startup funded by New Enterprise Associates, Index Ventures, National General Insurance/Amtrust Financial, and other investors. It offers a driving app and a pay-per-mile insurance product using a device that connects to the OBD-II port of all automobiles built after 1996. Metromile does not use behavioral statistics like type of driving or time of day to price their insurance. They offer consumers a fixed base rate per month plus a per-mile-rate ranging from 2 to 11 cents per mile, taking into account all traditional insurance risk factors. Drivers who drive less than the average (10,000 miles a year) will tend to save. Metromile allows users to opt out of GPS tracking, never sells consumer data to 3rd parties, and does not penalize consumers for behavioral driving habits. Metromile is currently licensed to sell auto insurance in California, Oregon, Washington, Virginia and Illinois (as of July 2015) [4]. More states are expected to roll out shortly.

Progressive. Snapshot is a car insurance program developed by Progressive Insurance in the United States [5]. It is a voluntary, behavior-based insurance program that gives drivers a customized insurance rate based on how, how much, and when their car is driven. Snapshot is currently available in 46 states plus the District of Columbia. Because insurance is regulated at the state level, Snapshot is currently not available in Alaska, California, Hawaii, and North Carolina.

Driving data is transmitted to the company using an on-board telematic device. The device connects to a car's Onboard Diagnostic (OBD-II) port (all automobiles built after 1996 have an OBD-II) and transmits speed, time of day and number of miles the car is driven. Cars that are driven less often, in less risky ways and at less risky times of day can receive large discounts. Progressive has received patents on its methods and systems of implementing usage-based insurance and has licensed these methods and systems to other companies. Progressive has service marks pending on the terms Pay As You Drive and Pay How You Drive.

Allstate. Allstate announced on October 8, 2012 that it has expanded its usage-based auto insurance product, Drive Wise, to four additional states including New York and New Jersey [5]. As of October 2012 Drive Wise is currently available in: Colorado, Michigan, New Jersey, New York, Arizona, Illinois, and Ohio. Allstate's usage-based insurance product, Drive Wise, gets installed into a car's onboard diagnostic port, near the steering column in most cars. Allstate said its usage-based insurance measures things such as mileage, braking, speed, and time of day when a customer is driving. Using that data, Allstate calculates a driving discount for each customer using its telematics technology.

One of the big advantages with Drive Wise is that it can constantly provide feedback to the consumers for as long as they keep the device in the car. Allstate's Drive Wise utilizes data from a monitoring device plugged into a car's onboard diagnostic port. Of the drivers earning a discount, the average savings is nearly 14 % per vehicle. More than 10 % of all new Allstate customers are opting to participate in this coverage.

Liberty Mutual Insurance. Onboard Advisor is a commercial lines pay-how-you-drive, PHYD, or "safety-driven" insurance product by Liberty Mutual Agency Corporation. It offers up to 40 % discount to commercial and private fleets based on how safely they actually drive [1].

National General Insurance. National General Insurance is one of the first and largest auto insurance companies to institute a Pay-As-You-Drive (PAYD) program in the United States back in 2004 [6]. The National General Insurance Low-Mileage Discount is an innovative program offered to OnStar subscribers in 34 states, where those who drive less pay less on their auto insurance. This opt-in program is the first of its kind [7] leveraging state-of-the-art technology using OnStar to allow customers who drive fewer miles to benefit from substantial savings. Eligible active OnStar subscribers sign up to save on their premiums if they drive less than 15,000 miles annually. Subscribers who drive even less than that can save even more (up to 54 %).

Under the program, new National General Insurance customers receive an automatic insurance discount of approximately 26 % upon enrollment [8] (existing OnStar customers receive a discount based on historical mileage). With the subscriber's permission, the odometer reading from his or her monthly OnStar Vehicle Diagnostics report is forwarded to National General Insurance. Based on those readings, the company will decrease the premium using discount tiers corresponding to miles driven.

Information sent from OnStar to National General Insurance pertains solely to mileage, and no additional data is gathered or used for any purpose other than to help manage transportation costs. Customers who drive more than 15,000 miles per year are not penalized and all OnStar customers receive an insurance discount simply for having an active OnStar subscription.

2.6 Future of UBI

UBI is poised for rapid growth in the U.S. According to SMA Research [2], approximately 36 % of all auto insurance carriers are expected to use telematics UBI by 2020. Based on a May 2014 CIPR survey of 47 U.S. state and territory insurance departments, in all but five jurisdictions—California, New Mexico, Puerto Rico, Virgin Islands, and Guam—insurers currently offer telematics UBI policies. In twenty-three states, there are more than five insurance companies active in the telematics UBI market. The CIPR survey is part of a recently released ***CIPR study: "Usage-Based Insurance and Vehicle Telematics: Insurance Market and Regulatory Implications"*** [2], on how technological advances in telematics are driving changes in the insurance market and its impact on insurers.

Telematics-based UBI growth is being propelled by technology advances, which continue to substantially improve the cost, convenience, and effectiveness of using telematics devices. It is through the use of telematics that insurers are able to collect driving data that better enable them to more closely link a driver's individual risk with premium. Through UBI programs, insurers are able to differentiate products, gain competitive advantage, and attract low-risk policyholders. Recognition of the societal benefits and growing consumer acceptance of personal data collection will only serve to further increase demand for telematics-based UBI products in the future.

3 Detecting Driver Behavior Using Smartphone Sensors

There are a lot of applications, which try to detect and analyze the driving behavior of the driver. Many of them have target to stimulate the drive in order to improve his driving style and by this way to achieve lower fuel consumption and to decrease the risk of road accidents [9]. These systems or applications use expensive car-dependent information such as engine power, pedal pressure, wheel position etc. Nowadays the smartphones are already well integrated in our life. Because of that and the various embedded sensors (accelerometer, orientation sensor etc.) in them, the smartphones represent a suitable platform to compute the driving behavior of the driver [10].

We implement a usage based auto-insurance information system, which consists of two elements. The first element is an android-based application for smartphones and tablets, which detects the driver's behavior by analyzing the collected data from device's sensors. For this reason we study various driving detection methods using smartphone's sensor in order to find which method or methods are the best for our implementation. The second element is an e-platform, where someone can have access to all data (trip's information, routes of trips, graphs of sensor's data) of all drivers, of the insurance company.

3.1 Calibration of Device

In order someone to get accurate measurements from a smartphone to evaluate the driving quality, it is required at first to calibrate the position of the device relatively to that of the vehicle [11]. This means virtually rotating the three-axis of the accelerometer sensor of the smartphone to meet the vehicle's orientation (Fig. 1). To do this we need to know all the angles of rotation. To calculate the angles of rotation, we use the atan2 function [12] to measure the angle between two given coordinates.

The calibration is always initiated before monitoring, and is carried out in three steps. The first step of the calibration is to calculate the rotation angles according to the vehicle's level. The second step is to calculate the angle of the driving direction of the vehicle. When these two steps are completed, the final step of the calibration is executed, updating the rotation angles. Figure 1 illustrates the calibration angles.

The first step, explained above, is done while the vehicle is standing still. The angles calculated in the first step are both the roll- and pitch angles. The XY magnitude offset is calculated next. Calculating the average magnitude between the

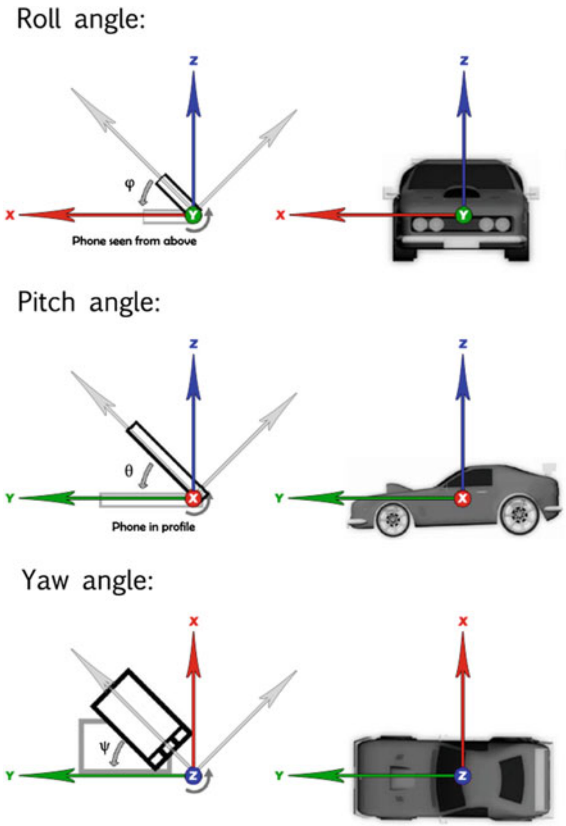


Fig. 1 Illustration of the calibration angles

X and Y-axis does this. This offset is used to check if the vehicle is in motion. If the offset is varying widely, this means that the vehicle is in motion. If the vehicle is in motion at this stage, the first step is restarted and the offset is reset.

When the XY magnitude offset is calculated, we can proceed to the second step; calculating the yaw angle. First we check if the vehicle is in motion by checking if the magnitude of the XY axis (subtracted by the XY offset) is above a certain value. If this is true, we calculate the yaw angle based on this magnitude, and add the angle in an average buffer. This process is repeated until we have enough angles to calculate the average yaw angle. We use the average yaw angle to be certain that it is accurate and valid. If we just set the first calculated angle as the yaw angle, this has got the potential of being invalid.

3.2 Sensor Fusion Orientation Data

Sensor Fusion [13, 14] is the more appropriate method that can be used to determine the orientation of a device. With this method, we combine data from 3 embedded smartphone sensors: the accelerometer, the magnetometer and the gyroscope, in order to get the three orientation angles. The low noise gyroscope data is used only for orientation changes in short time intervals. The accelerometer and magnetometer data is used as support information over long time intervals. With this way we filter out the gyro drift (a slow rotation of the calculated orientation), with the accelerometer/magnetometer data, which do not drift over long time intervals. This process is similar to high pass filtering of the gyroscope data and to low pass filtering of the accelerometer/magnetometer data. Figure 2 illustrates this process.

3.3 Detection Methods

Our algorithm characterizes the behavior of the driver as *Excellent*, *Very Good*, *Good*, *Bad* or *Very Bad* and computes the average speed of the vehicle at the end of every trip.

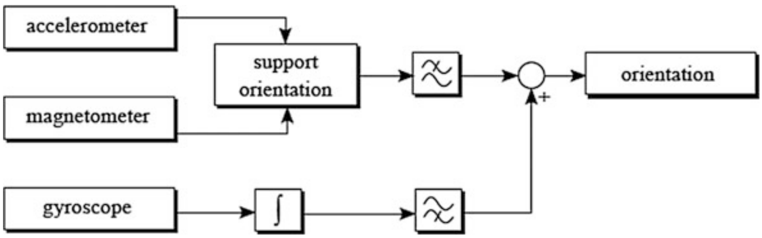


Fig. 2 Flow of the sensor fusion with complementary filter

Our algorithm for the detection of driver behavior uses two types of data. The acceleration output data of the accelerometer sensor and the orientation output data of the sensor fusion method. In the first method we use the three-axis accelerometer sensor in order to record and analyze driver's behavior. In particular, we utilize the x-axis accelerometer data to detect the left/right direction of the vehicle and therefore driving events like safe or sharp turns. For the detection of front/rear direction of vehicle and therefore to measure how the driver accelerates and applies the brakes we utilize the y-axis data. In the second method we use the three-axis orientation output data of sensor fusion. In particular, we use roll data in order to detect the left/right direction of the vehicle. For the detection of front/rear direction of vehicle and therefore to measure how the driver accelerates/decelerates, we utilize pitch data.

Our experience with these two methods shows that the best practice for recognizing driving patterns is the use of accelerometer data. The reason is not that sensor fusion methodology is not accurate or reliable but rather that sensor fusion is not the best option for the detection of sharp turns or sharp lane changes. When we use only the accelerometer, the algorithm detects sharp turns or sharp lane changes faster than when we use the orientation data of sensor fusion method. On the other hand, with sensor fusion the system detects faster the safe/hard accelerations or decelerations of the vehicle than when we use only the acceleration data.

After having chosen the preferred detection method, the algorithm analyzes the behavior of the driver applying specific thresholds over the data collected as he drives [10]. These thresholds have been acquired by testing the data of the detection methods under various driving events and maneuvers. This is the methodology followed in most similar works [10, 15, 16]. With these thresholds (Table 1) we can distinguish and detect 12 driving events: Safe Acceleration, Safe Deceleration, Safe Left Turn, Safe Right Turn, Safe Left Lane Change, Safe Right Lane Change, Hard Acceleration, Hard Deceleration, Sharp Left Turn, Sharp Right Turn, Sharp Left Lane Change and Sharp Right Lane Change.

Every driving event or maneuver, that our system can detect, has a counter. When the algorithm detects that the driver makes one of the already talked maneuvers or driving events, the counter for this type of event is incremented. If the algorithm detects a safe driving event, a counter for this driving event is incremented. When detects a dangerous driving event, then a counter for this event is incremented as well.

When the driver has finished his trip, our algorithm computes the percentage of the penalty for every dangerous driving event. The computed penalties are: hard acceleration penalty, hard deceleration penalty, sharp left turn penalty, sharp right turn penalty, sharp left lane change penalty and sharp right lane change penalty.

The equations for the Hard Acceleration and Hard Deceleration penalties are:

$$HardAccPenalty = \frac{HardAccCounter}{SafeAccCounter + HardAccCounter}$$

Table 1 Thresholds and data Used for the detection of various driving events using accelerometer's data or sensor fusion orientation data

Driving event	Data used (Accelerometer)	Threshold (m/s^2)	Data used (Sensor fusion)	Threshold (rad/s)
Safe Acceleration	Y-axis data	1.3–2.5	Pitch angle	−0.08–0.12
Safe Deceleration	Y-axis data	−1.3–2.5	Pitch angle	0.08–0.12
Safe Left Turn	X-axis data	−1.8–3.0	Roll angle	0.10–0.30
Safe Right Turn	X-axis data	1.8–3.0	Roll angle	−0.10–0.30
Hard Acceleration	Y-axis data	>2.5	Pitch angle	<−0.12
Hard Deceleration	Y-axis data	<−2.5	Pitch angle	>0.12
Sharp Left Turn	X-axis data	<−3.0	Roll angle	>0.30
Sharp Right Turn	X-axis data	>3.0	Roll angle	<−0.30

$$HardDecPenalty = \frac{HardDecCounter}{SafeDecCounter + HardDecCounter}$$

The equations for the Sharp Left Turn and Sharp Right Turn are:

$$SharpLeftTurnPenalty = \frac{SharpLeftTurnCounter}{SafeLeftTurnCounter + SharpLeftTurnCounter}$$

$$SharpRightTurnPenalty = \frac{SharpRightTurnCounter}{SafeRightTurnCounter + SharpRightTurnCounter}$$

The equations for the Sharp Left Lane Change and Sharp Right Lane Change are:

$$SharpLeftLCPenalty = \frac{SharpLeftLCCounter}{SafeLeftLCCounter + SharpLeftLCCounter}$$

$$SharpRightLCPenalty = \frac{SharpRightLCCounter}{SafeRightLCCounter + SharpRightLCCounter}$$

Using the above penalties we can compute the Total Sharp Turn Penalty and the Total Sharp Lane Change Penalty with the following equations:

$$SharpTurnPenalty = SharpLeftTurnPenalty + SharpRightTurnPenalty$$
$$SharpLCPenalty = SharpLeftLCPenalty + SharpRightLCPenalty$$

The equation for the total penalty is:

$$TotalPenalty = HardAccPenalty + HardDecPenalty + HardTurnPenalty + HardLCPenalty$$

Except the penalties at the end of the trip, the algorithm computes the driving score of the driver. The total score depends of the penalties of the dangerous driving events (Total Penalty). The maximum score a user can achieve is ten (10) and the minimum is zero (0).

The equation for the computation of the total score, achieved from the user at the end of the trip is:

$$TotalScore = 10 - TotalPenalty$$

According to the total score (at the end of the trip) of the user, the algorithm characterizes the user for his driving behavior for the current trip. There are various behaviors depending the total score of the user (Table 2). The behavior of the driver at the end of the trip can be *Excellent*, *Very Good*, *Good*, *Bad* or *Very Bad*.

4 Native Android Application for Usage Based Auto Insurance

Putting the above steps in practice, we have developed a native android-based application that can be used by a usage-based insurance company. The application via smartphone's sensors can detect and evaluate the driving behavior of the user for all his trips. All trip data that contains statistics, routes and graphs is saved in smartphone's local memory. Also these data is sent to a company's server, where can be accessed by the employees of the company. The company evaluates the data of all the trips of the user, whose payment to the company is depending to his

Table 2 Driver behavior categories based on the total score of the driver

Driving behavior	Total score
Excellent	Score > 9.75
Very Good	$9 <$ Score ≤ 9.75
Good	$7.5 <$ Score ≤ 9
Bad	$5 <$ Score ≤ 7.5
Very Bad	Score ≤ 5

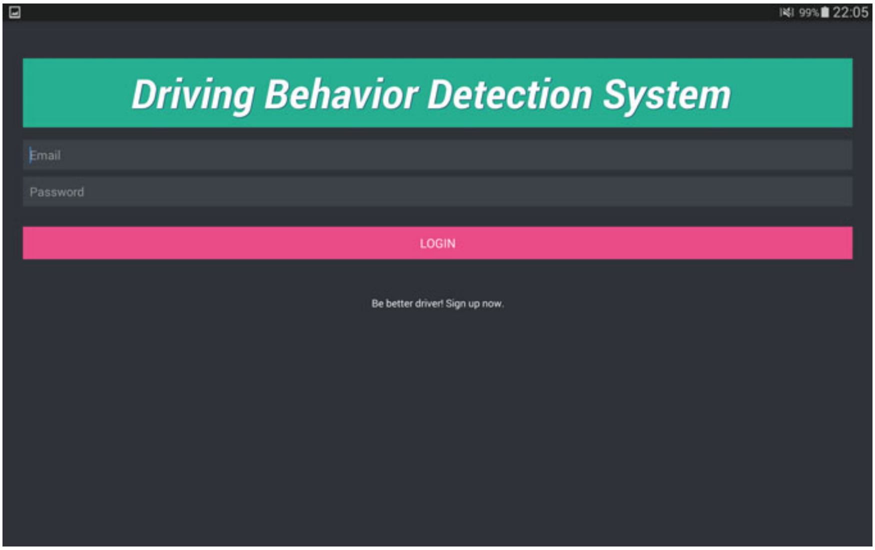


Fig. 3 The login screen of the application

average behavior and to total distance of his trips. In the subsections below we can see how the application works, what data are recorded and how they presented to the user.

4.1 Driver's Login and Registration System

After the user installs and enters the application in his device, the first thing that he sees is a login system (Fig. 3). If the user has already registered in the system, by entering his e-mail and password in the respective fields, he can be entered into the system. If he is not registered in the system, he has to sign up by pressing the "Be better driver! Sign up now" button. In the registration form (Fig. 4) he has to enter the following data: Full name, e-mail, password, address, phone number and the vehicle license plate. When the user completes his registration process he can login successfully in the system.

4.2 Main Menu

When the user is successfully connected, the main menu is presented (Fig. 5) to him. In the main menu there are 4 options. The first option is the "New Trip". We choose this option when we want to start a new trip. The second option is the "My

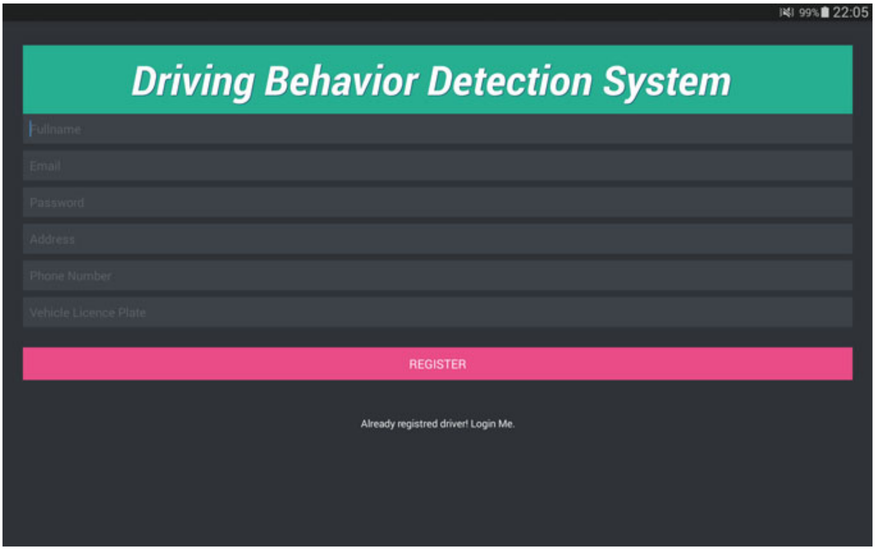


Fig. 4 The registration screen of our application

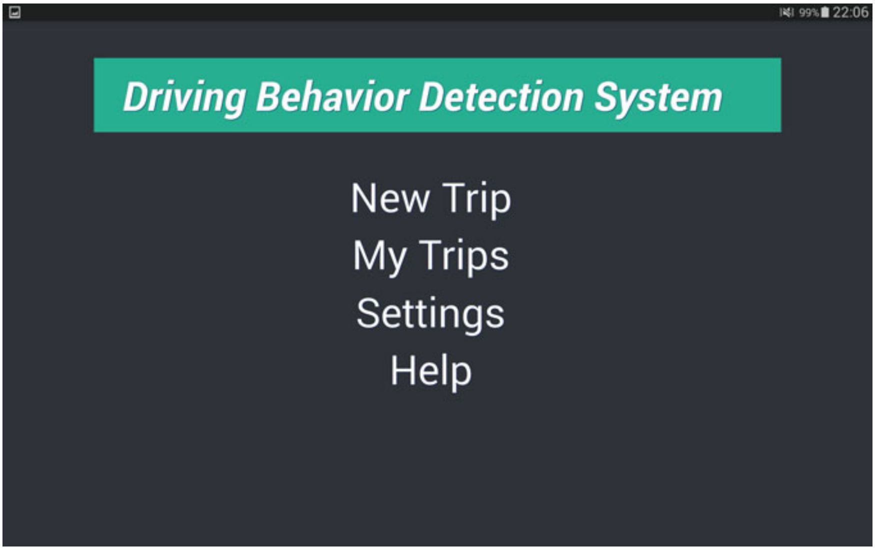


Fig. 5 The main menu of our application

trips" and we choose it when we want to review our trips (routes and statistics). In the third option there are our "Settings" and the last option is "Help" where we can find tutorials and information about how we use the application.

4.3 New Trip

As already motioned above, we choose the “New Trip” option when we want to start a new trip. Before we start driving, the application will tell us to follow some instructions for the calibration of the device (Fig. 6). We set the calibration procedure for the device in order to get accurate readings from the sensors in any fixed orientation of the device inside the vehicle.

During the calibration process the device must be attached in a fixed position and the vehicle must be steel. The whole process takes about 5 s to complete. When the appropriate message is given we can start driving to our destination (Fig. 7).

In the beginning of the process the signal to keep vehicle steel is displayed and in a few seconds “Drive vehicle forward” signal is displayed. When we start driving forward the calibration is completed and the application starts monitoring and detecting our driving behavior until the end of our trip.

The user can select between two options for the presentation of his driving behavior. The first option is the basic option where in the main screen is displayed a “Monitoring Driving Behavior” message (Fig. 8).

When the system detects a safe driving event (maneuver) the main screen color changes to green and the message also changes to the name of the current safe driving event (Fig. 9).

When the system detects a dangerous driving event the color of the main screen changes to yellow color and the message changes to “Attention!” followed by the name of the dangerous event (Fig. 10). For all the dangerous driving events except the attention and the name of the event there is displayed a hint. The hints help drivers to improve their driving behavior and achieve better scores in their trips.

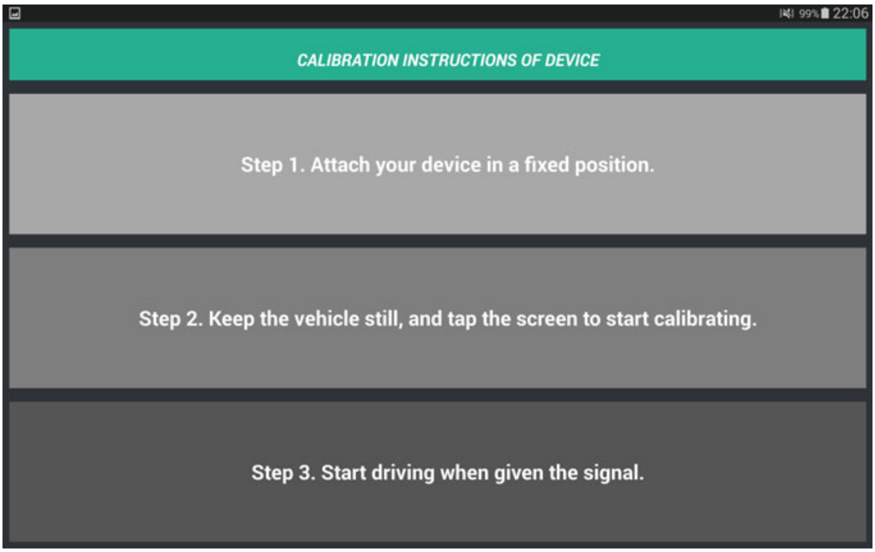


Fig. 6 The calibration instructions screen

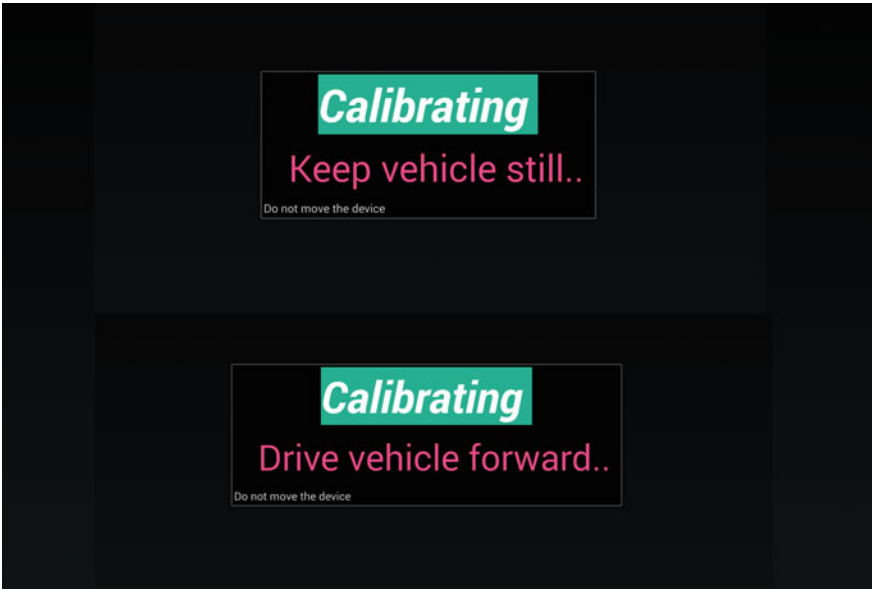


Fig. 7 The given calibration messages as they are presented in our application

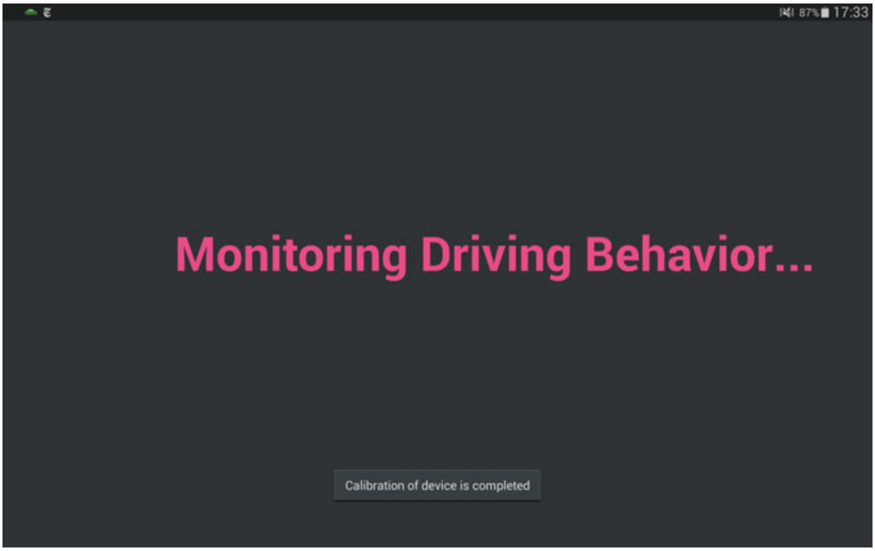


Fig. 8 The basic monitoring option. The system is not detecting anything safe or dangerous driving events

Fig. 9 The system detects a safe deceleration

Fig. 10 The system detects a dangerous Sharp Left Turn

The hints that are displayed are: "try to maintain uniform acceleration" (or deceleration), "try to take left (or right) turn slower" and "try to change the left (or right) lane slower". The attention message and hint is followed by a notification sound.

The second option for displaying the monitoring of the user's driving detection is the Map option (Fig. 10). In this screen option a map is displayed with the car's spot into the map (Fig. 11). When we start driving, our route is outlined in the map. Also, it is displayed with pointers, the starting point of our trip and any bad-driving event (maneuver) that happens.

When the system detects a safe driving event, then a pop up window opens and displays the current safe driving event. In the same way when a dangerous driving event is detected a pop-up window with the name and the hint of the event is displayed for some seconds (Fig. 12). Also, a notification sound is being listened and a pointer in the map with the name of the dangerous driving event is created.

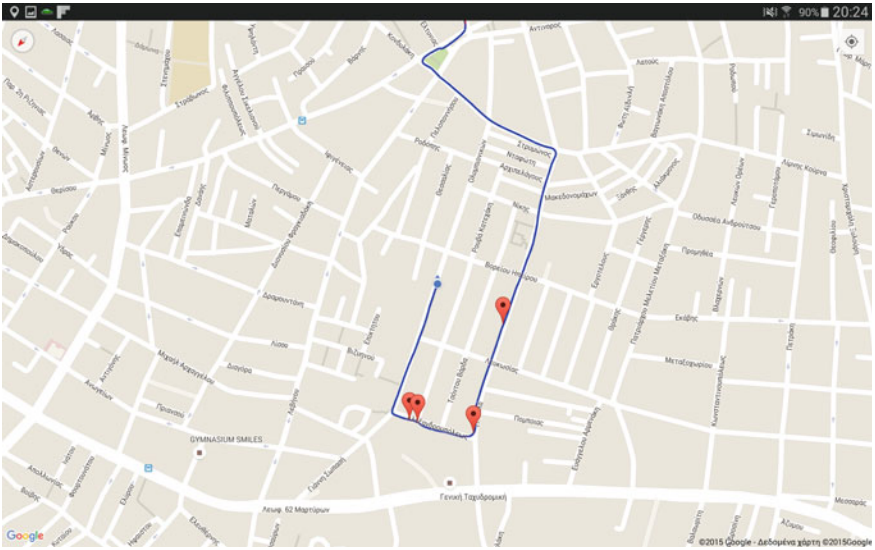


Fig. 11 The map monitoring option of our application

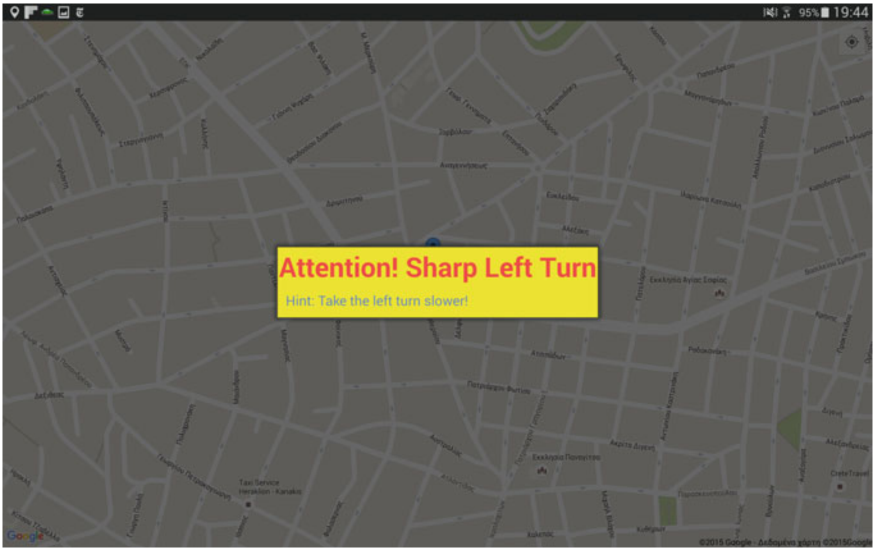


Fig. 12 The system detects a Sharp Left Turn during the map monitoring option

We can alternate between the 2 options for displaying the monitoring of our driving behavior (Basic Monitor to Map Monitor and the opposite) any time we want during the trip by pressing the option button from our device (Fig. 13). When

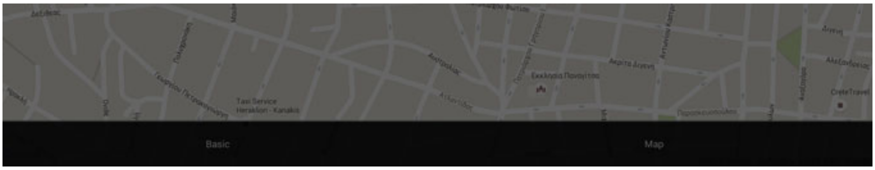


Fig. 13 Option menu, where we can select the monitoring option we prefer

we press the option button, an option menu is displayed in the bottom of our screen and we can choose our choice. When the user finishes his trip, he has to press the back button on his device. Then, the system ends the trip and loads all the statistics, the routes and the graphs.

4.4 Trip's Info

As we mentioned before, by pressing the back button of our device we can finish our trip. After that the system is loading and presenting all information about our trip. All information of the current trip is presented in 3 different tabs.

In the info tab (Fig. 14) are presented some general statistics about the trip like the total distance, the total duration and the average speed. The total duration is the actual duration of the trip. Except the above statistics, there is also presented the percentage of the penalties of dangerous driving events. The presented percentages

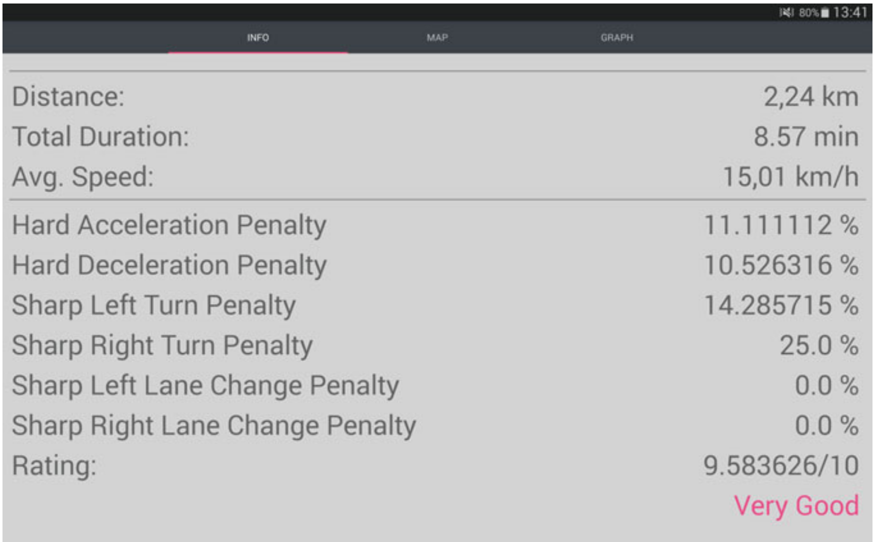


Fig. 14 Info tab screen of our application

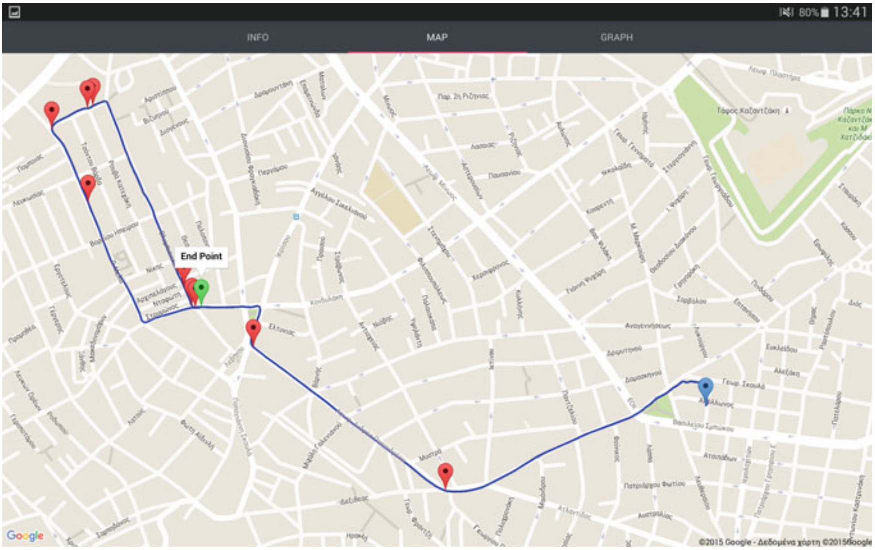


Fig. 15 Map tab screen of our application

of penalties are: Hard Acceleration Penalty, Hard Deceleration Penalty, Sharp Left Turn Penalty, Sharp Right Turn Penalty, Sharp Right Left Lane Change Penalty and Sharp Left Lane Change Penalty. Also is presented the rating (Score—up to 10) and the behavior (Very Bad to Excellent) of the current trip.

The second tab is the map tab (Fig. 15). In the map tab is presented the route of our trip based on Google maps. In the map we can see the starting point of our trip, which is represented by a blue marker and the end point of our trip, which is represented by a light green marker. Also we can see at which point of our route, we are commit a dangerous driving event. All dangerous driving points are represented with a red marker. When we tap in a dangerous driving point it is presented the name of the current event.

The last tab is the graph tab. In the graph tab are presented 3 line charts, the acceleration line chart, the deceleration line chart and the turn line chart (Figs. 16 and 17). We can see one of the 3 charts at the time. If we want to change graph chart we tap on the radio button of the chart we want under the displayed chart.

The x-axis represents the time in milliseconds and the y-axis represents the values of the detection method we have already chosen. These values can be can acceleration values (acceleration detection method—m/s^2) or orientation values (sensor fusion method—rad/s).

The charts are scrollable in the x-axis, which means that by scrolling horizontally we can see the acceleration or orientation values in relation with the time. The displayed x-axed duration is 60 s and as we scroll we can see the next 60 s.

Except the acceleration, deceleration and turn line charts we can see the thresholds lines for each chart. The thresholds line is represented with a red direct

Fig. 16 Deceleration line chart of graph tab screen of our application

Fig. 17 Turn line chart of graph tab screen of our application

line with the threshold value for each event. If there is a value that has exceed the threshold line it means than we have commit a dangerous driving event from the current chart (acceleration, deceleration, turn) at this particular time.

Fig. 18 "My Trip" screen. We can see the list of our trips

4.5 My Trips

In the main menu we can choose the "My Trips" option whenever we want to browse our previous trips (Fig. 18). All the recorded trips are presented in a scrollable list. Each trip is represented with the name "Trip" and an auto increment number, followed by a timestamp, which declares the date and the time that the trip began.

4.6 Settings

In the main menu, the "Settings" option offers the user the chance to set up his preferences (Fig. 19). One of the main settings that the user can change is the standard monitor, which declares the preferred monitoring style. The preferred

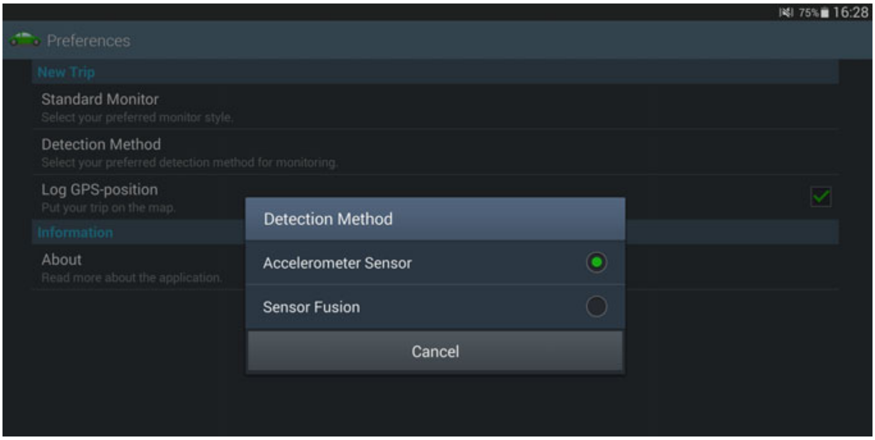


Fig. 19 Select detection method from the settings of our application

monitoring style can be the Basic Monitor and the Map Monitor. The other main setting is the choice of the applicable detection method, which includes the choice of the sensor data, which the system will evaluate in order to detect safe or dangerous driving events and classify the user's driving behavior. The detection method can be one of the accelerometer sensor or the sensor fusion method. Also, we can enable the GPS sensor, if it's not enabled and read more about the application.

5 E-Platform of Auto UBI System

In the context of this research, we have developed a web-based cloud platform that can be used by a usage-based insurance company. The purpose of the platform is to check and evaluate the trip data of the company's drivers (clients).

Via the particular platform an employee of the insurance company can have access to the list and data of all clients by entering the administrator's username and password (Fig. 20).

When a company's employee logs in successfully to the system, he can browse the table with drivers' data (Fig. 21). In this table are presented all data for every driver. The presented data of the driver are: Full name, e-mail, Address, Phone Number and the license plate number of his vehicle.

As we can see in the right side of every row (or driver) of the table, there is a "Select" button. When we want to browse the past trips of a particular driver, we

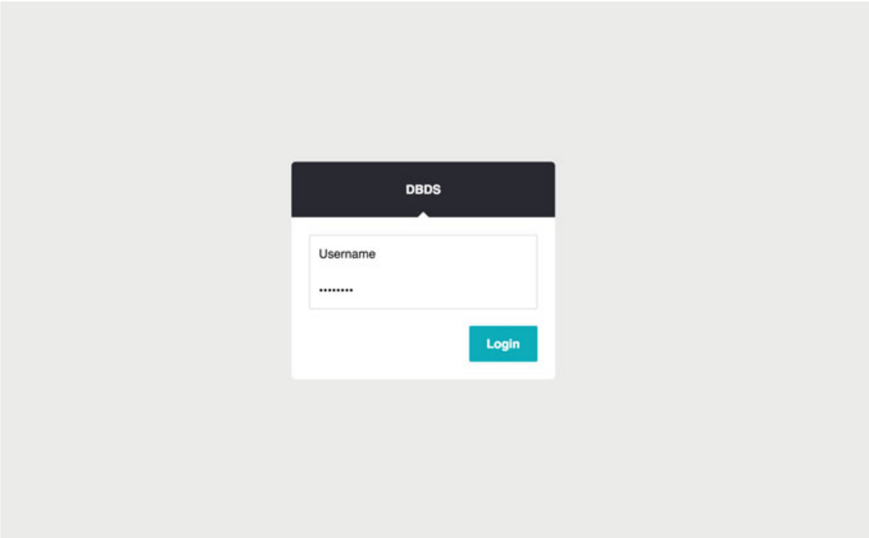
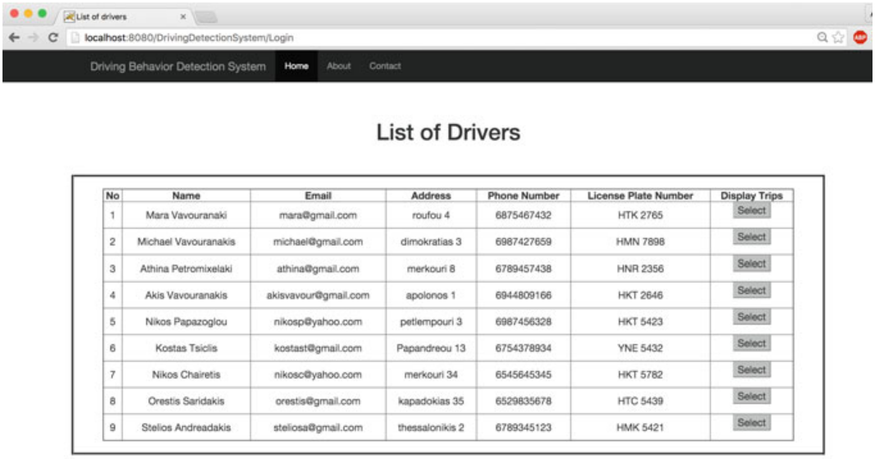


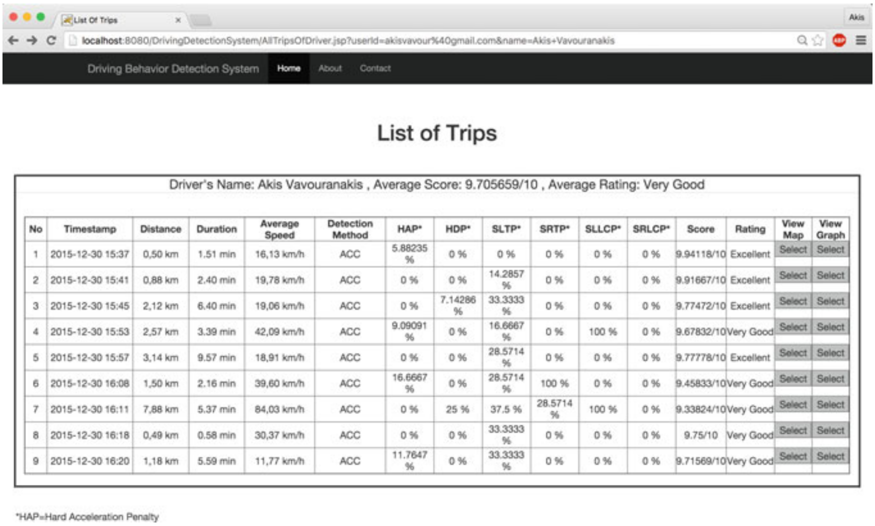
Fig. 20 Login Screen of UBI Portal



List of Drivers

No	Name	Email	Address	Phone Number	License Plate Number	Display Trips
1	Mara Vavouranaki	mara@gmail.com	roufou 4	6875467432	HTK 2765	Select
2	Michael Vavouranakis	michael@gmail.com	dimokratias 3	6987427659	HMN 7898	Select
3	Athina Petromixelaki	athina@gmail.com	merkouri 8	6789457438	HNR 2356	Select
4	Akis Vavouranakis	akisvavour@gmail.com	apolonos 1	6944809166	HKT 2646	Select
5	Nikos Papazoglou	nikosp@yahoo.com	petlempouri 3	6987456328	HKT 5423	Select
6	Kostas Tsiclis	kostast@gmail.com	Papandreou 13	6754378934	YNE 5432	Select
7	Nikos Chairetis	nikosc@yahoo.com	merkouri 34	6545645345	HKT 5782	Select
8	Orestis Saridakis	orestis@gmail.com	kapadokias 35	6529835678	HTC 5439	Select
9	Stelios Andreadakis	steliosa@gmail.com	thessalonikis 2	6789345123	HMK 5421	Select

Fig. 21 List of all registered drivers in the program of UBI company



List of Trips

Driver's Name: Akis Vavouranakis , Average Score: 9.705659/10 , Average Rating: Very Good

No	Timestamp	Distance	Duration	Average Speed	Detection Method	HAP*	HDP*	SLTP*	SRTP*	SLLCP*	SRLCP*	Score	Rating	View Map	View Graph
1	2015-12-30 15:37	0,50 km	1.51 min	16,13 km/h	ACC	5.88235 %	0 %	0 %	0 %	0 %	0 %	9.94118/10	Excellent	Select	Select
2	2015-12-30 15:41	0,88 km	2.40 min	19,78 km/h	ACC	0 %	0 %	14.2857 %	0 %	0 %	0 %	9.91667/10	Excellent	Select	Select
3	2015-12-30 15:45	2,12 km	6.40 min	19,06 km/h	ACC	0 %	7.14286 %	33.3333 %	0 %	0 %	0 %	9.77472/10	Excellent	Select	Select
4	2015-12-30 15:53	2,57 km	3.39 min	42,09 km/h	ACC	9.09091 %	0 %	16.6667 %	0 %	100 %	0 %	9.67832/10	Very Good	Select	Select
5	2015-12-30 15:57	3,14 km	9.57 min	18,91 km/h	ACC	0 %	0 %	28.5714 %	0 %	0 %	0 %	9.77778/10	Excellent	Select	Select
6	2015-12-30 16:08	1,50 km	2.16 min	39,60 km/h	ACC	16.6667 %	0 %	28.5714 %	100 %	0 %	0 %	9.45833/10	Very Good	Select	Select
7	2015-12-30 16:11	7,88 km	5.37 min	84,03 km/h	ACC	0 %	25 %	37.5 %	28.5714 %	100 %	0 %	9.33824/10	Very Good	Select	Select
8	2015-12-30 16:18	0,49 km	0.58 min	30,37 km/h	ACC	0 %	0 %	33.3333 %	0 %	0 %	0 %	9.75/10	Very Good	Select	Select
9	2015-12-30 16:20	1,18 km	5.59 min	11,77 km/h	ACC	11.7647 %	0 %	33.3333 %	0 %	0 %	0 %	9.71569/10	Very Good	Select	Select

*HAP=Hard Acceleration Penalty

Fig. 22 List of trips (and data of trips) of a particular driver

click the "Select" button in the row of the particular driver. For example we click to browse the list of trips of a driver named "Akis Vavouranakis" (Fig. 22).

In the list of trips, we can see the driving history of every driver. In the presented table, every row of the table represents a trip. Lots of data are presented for every trip. The presented general data are: The ***timestamp*** of the trip, which is the date and the starting time of the trip, the ***distance*** of the trip in km, the ***duration*** of the trip, which is the actual duration of the trip (when the vehicle is in motion) and the ***average speed*** of the vehicle (km/h).

Also it is presented the selected from the user detection method (Accelerometer sensor data or Sensor fusion orientation data) and the percentage of penalties of all dangerous driving events. The percentages of penalties of the driving events that are presented are: ***Hard Acceleration Penalty*** (HAP), ***Hard Deceleration Penalty*** (HDP), ***Sharp Left Turn Penalty*** (SLTP), ***Sharp Right Turn Penalty*** (SRTP), ***Sharp Left Lane Change Penalty*** (SLLCP) and the ***Sharp Right Lane Change Penalty*** (SRLCP).

The ***score*** and the ***rating*** of every trip are also presented. The score of every trip is calculated based on the already above mentioned penalties. The max score for every trip is 10. Based on the score the rating (driver's behavior) of every trip is calculated. The rating can be: Very Bad, Bad, Good, Very Good or Excellent.

In the line above the array and its elements, we can see some average data of the driver. First of all, the name of the driver is displayed, which is followed by the ***average score*** and the ***average rating*** of all his trips.

As we can see, in the data table (which contains the list of trips of a particular user), in the last two columns of each row (trip) there are two "select" buttons. By selecting the first one, the route of the trip is displayed in a map (Fig. 23) and by selecting the second the data of the trip are presented in graphs (Figs. 24, 25, and 26). Also a table with the information of the particular trip is presented before the map.

We can see the route of our trip with a blue line. The starting point of our trip is displayed with a blue marker and the end of our trip is displayed with a light green marker. All dangerous driving events are displayed with a red marker. If we tap a

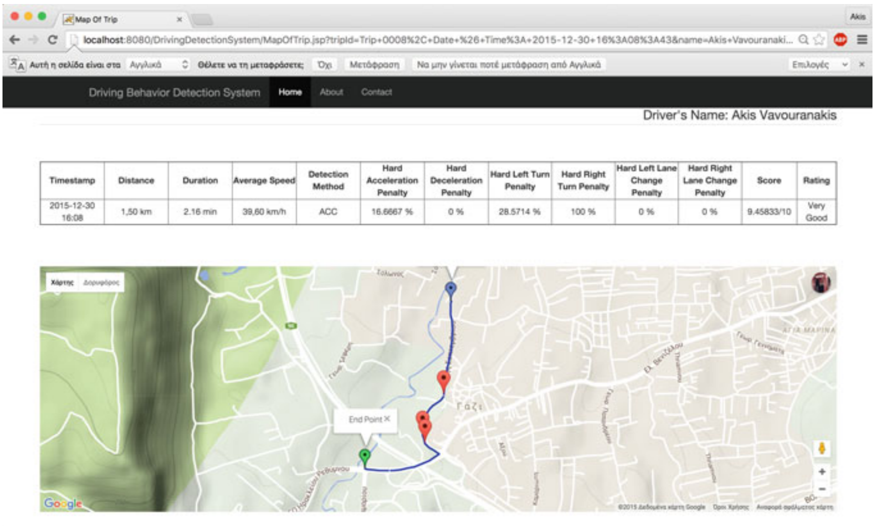


Fig. 23 Map screen of our portal with the route and data of a particular trip

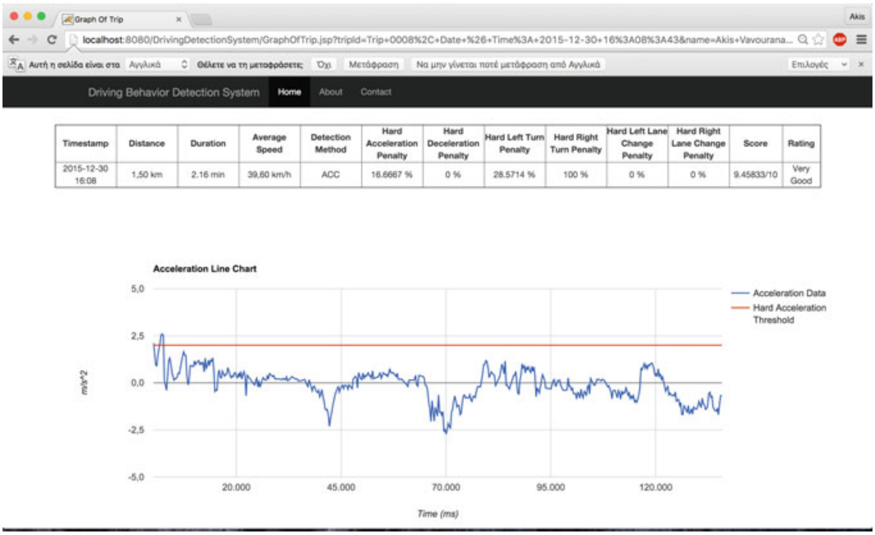


Fig. 24 Acceleration line chart with data of a particular trip

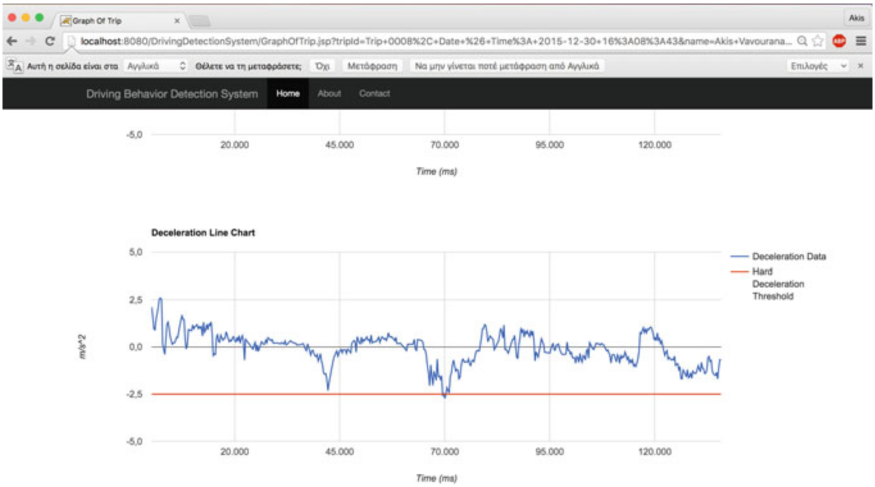


Fig. 25 Deceleration line chart of a particular trip

red marker, the name of the dangerous driving event is displayed. The map is based on Google maps and we can zoom In/Out on it.

By selecting the "View Graph" select button, 3 line charts are presented, the acceleration line chart, the deceleration line chart and the turn line chart. The x-axis represents the time in milliseconds and the y-axis represent the values of the detection

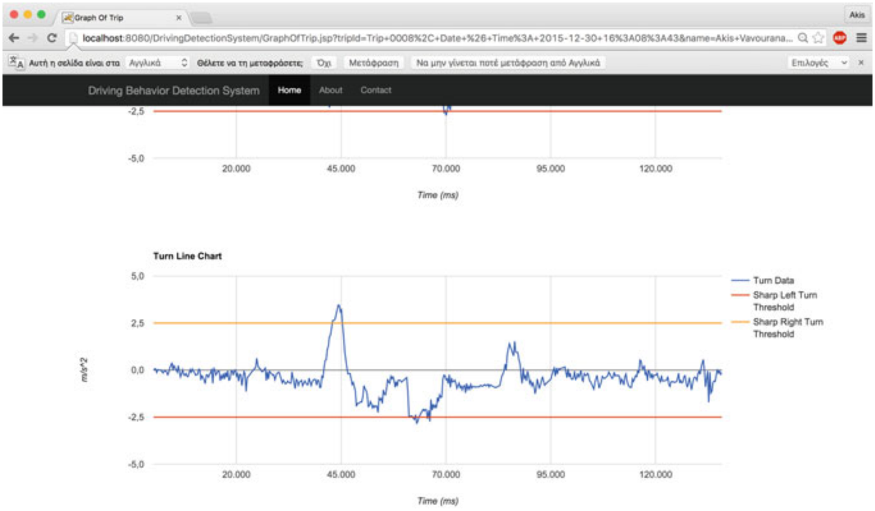


Fig. 26 Turn line chart of a particular trip

method we have already chosen. These values can be acceleration values (acceleration detection method—m/s^2) or orientation values (sensor fusion method—rad/s).

Except of the acceleration, we can see the thresholds lines for each chart for the deceleration and turn line charts. The thresholds line represented with a red direct line with the threshold value for each event. If there is a value that has exceed the threshold line it means than we have commit a dangerous driving event of the current chart (acceleration, deceleration, turn) at this particular time. Also a table with the information of the particular trip is presented before the graphs.

6 Conclusions

This work shows that the user (driver) can benefit from a Usage-Based system; the system rewards the user for being a safe driver and also provides him with feedback on his driving habits, making him a better and safer driver. The device measures various elements of user's driving behavior, safe or hard breaking, safe or sharp accelerating, safe or sharp turns and safe or sharp lane changes. Also, measures the start time of a trip, the duration of the trip and the total travelled distance. Also, for every trip, the user gets a score and a rating, depending on how well he drives. The insurance company has access to all these data (trips data, routes and graphs) of its drivers via the e-platform.

Also, in our work we demonstrated that the user's driving behavior could be estimated based either on acceleration data of the accelerometer sensor or based on orientation data of sensor fusion method. Sensor fusion method combines data from the accelerometer, geomagnetic field sensor and the gyroscope. The driver can choose the detection method from the settings of the application's main menu. We propose to drivers to use the accelerometer-based method as detection method. The reason is not that the sensor fusion method is not accurate or reliable, in total, but rather that sensor fusion is not the best option for the detection of sharp turns or sharp lane changes. When just the accelerometer sensor is used, the algorithm detects sharp turns or sharp lane changes faster than when we use the orientation data of sensor fusion method. On the other hand, when we use the sensor fusion as detection method the system detects faster the safe/hard acceleration or deceleration of the vehicle than when we use only the accelerometer data.

Regardless of the detection method that is used, safety comes first and the system takes into account that sometimes hard deceleration or rapid accelerations or other dangerous driving events are necessary in order to avoid a collision. Hence, our system works to identify a pattern in driving habits so the occasional hard brakes do not have a significant impact (if any) on the potential rating. Thus, the driver's discount depends mostly on his average rating over his trips. So, better rating means highest discount for his insurance.

By using the application and the e-platform of our UBI information system, the drivers and the insurance company have many benefits. Some of them are:

- Social and environmental benefits from more responsible and less unnecessary driving.
- Commercial benefits to the insurance company from better alignment of insurance with actual risk. Improved customer segmentation.
- Potential cost-savings for responsible customers.
- Technology that powers UBI enables other vehicle-to-infrastructure solutions including drive-through payments, emergency road assistance, etc.
- More choice for consumers on type of car insurance available to buy.
- Social benefits from accessibility to affordable insurance for young drivers—rather than paying for irresponsible peers, with this type of insurance young drivers pay for how they drive.
- Higher-risk drivers pay more per use. Thus, they have highest incentive to change driving patterns or get off the roads and leave roads safe.
- For telematics usage-based insurance: Continuous tracking of vehicle location enhances both personal security and vehicle security. The GPS technology could be used to trace the vehicle whereabouts following an accident, breakdown or theft.
- The same GPS technology can often be used to provide other (non insurance) benefits to consumers, e.g. satellite navigation.
- Gamification of the data encourages good driver behavior by comparing with other drivers.

Our system can serve some useful purposes but it has some limitations and drawbacks too. Some of them are:

- The system cannot detect the backward movement of the vehicle. When the user drives backwards, the detected driving events will be wrong. These wrong driving events will affect the score and the rating of the user.
- A limitation of our system has to do with the calibration process of the device. Before we start driving the application will tell us to follow some instructions for the calibration of the device. This process has to be repeated for each new trip and the whole process takes about 5 s to complete.
- Another limitation is when we start the calibration process the car is on a slope. If the car is on a slope during the calibration procedure the reading data will be affected and this will lead to poor results.
- The device has to be in a fixed position during the trip. After the calibration and while monitoring you cannot move the device from its fixed position. If the device moved while monitoring the sensor's output data it will be wrong and the evaluation of the data will not be accurate. In this case the user has to repeat the calibration procedure.
- Some of the low cost Android devices have low quality sensors or processing power. So the readings of the sensor's data are not so accurate and the application slows down due to low processing power.
- All Android devices have in-built the most used sensors like accelerometer and gyroscope. The magnetometer sensor on the other side is not included in all smartphone devices. So, without the magnetometer sensor the user cannot use the Sensor Fusion detection method.

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