From a Traditional Bicycle to a Mobile Sensor in the Cities

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Keywords: Connectivity Platform, Cloud Services, IoT.

Abstract: The present study focuses on the development of a web cloud based connectivity platform to apply in the context of cycling. One of the main challenges in using bicycle as mean of transportation is related to the cyclists safety and risk perception. In response to that problem, we propose an IoT based module, that will be embedded in the bicycle, allowing sensor data collection and real time sending to the connectivity platform. The data will be used to perceive cyclists route choice preferences, give support to stakeholders either in making new policies to promote bike use or to give cyclist suggestions about the most convenient route, depending on his profile. The main objective is to transform a traditional bicycle into a mobile sensor in the city. The connectivity platform will enable several services, so the bicycle can easily be integrated in a free floating bike-sharing environment.

1 INTRODUCTION

The bicycle use as a means of transport is becoming increasingly popular, especially for commuting trips, as it avoids car congestion in large urban centers (Lindsay et al., 2011). For some journeys, it may be the fastest transport, because it allows avoiding long stops due to car traffic. In addition, it is cheap, promotes a reduction in pollutant emissions while contributes to improve user's health (Hsu et al., 2016). However, there are some challenges associated with cycling, being safety a major inherent concern. According to the annual report of the ANSR (National Road Safety Authority), in 2018 there were 17 cyclists who were fatal victims on Portuguese roads, 114 seriously injured, 1984 being the total number of victims that year. There are several reasons for this worrying number, some of them are related to lack of appropriate cycling infrastructure, misbehavior of motor vehicle drivers, among others. In addition, for a cyclist with a lack of knowledge of the surrounding cycling network, it is not easy to choose the most suitable route.

The most reasonable decision for a beginner cyclist is to look for cycle paths or other cycling infrastructures, however, sometimes due to poor planning the built infrastructures are not as safe as desirable. The most common problems are the non-existence of physical separation from motorized traffic, obstacles as lamp posts in the middle of the track, or closure to side parks (Dondi et al., 2011), who may cause hazards, since the track may be obstructed by a parked vehicle opened door.

For the reasons mentioned, more people would consider using bicycle if they could use a bike route planner (Akar and Clifton, 2009), however, the creation of a tool for cyclists requires a great diversity of available data. Firstly, it requires the mapping of infrastructures that influence cyclist safety, such as the existence of bike lanes, infrastructure characteristics (Pucher and Buehler, 2008), slope, route singularities (Menghini et al., 2010) or traffic calming features such as speed bumps (Buehler and Dill, 2016). On the other hand, it requires some extra information, such as the state of traffic or the state of infrastructure such as bicycle lanes. This data is dynamic, since may occur the infrastructure's degradation, thus data should be constantly updated.

This work is divided in six sections. In Section 2, we will address the main motivations and objectives of this work, while, in Section 3, we discuss some related work. In Section 4, the proposed methodology and the created tool are shown in detail. In Section 5 are presented some results, while in Section 6 we conclude our work presenting new steps to accomplish.

Nunes, P., Nicolau, C., Santos, J. and Completo, A.
From a Traditional Bicycle to a Mobile Sensor in the Cities.
DOI: 10.5220/0009349700810088
In *Proceedings of the 6th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2020)*, pages 81-88
ISBN: 978-989-758-419-0

2 OBJECTIVES AND MOTIVATION

The objective of this study is to develop a new tool. It intends to help stakeholders and policy makers to decide the localization of new cycling infrastructures or identify infrastructures that need maintenance. For other hand, it intends to facilitate cyclist's route choices, by joining several useful information in the same tool. The main motivation for this topic is the increasing need for sustainable means of transport, which drives us to the necessity to create policies that protect cyclists, and tools to help them making the best decisions when using the road network. For this purpose, we propose a cloud based platform, web services, as well as an IoT system embedded in the bicycle. It allows the data collection and real time sending to the connectivity platform, thus the data could be analyzed in order to determine cyclists route preferences, pavement quality, detect car drivers misbehavior or places where the car traffic is heavier. With these inputs, policy makers can perceive places where infrastructures need maintenance or optimize new infrastructures location. At the same time, this platform can work as a tool for cyclists, since the data can be used as an input to a bike routing app or to give suggestions to the cyclist as well.

When we think in data collection from bikes, we usually think in bike sharing systems, however, the proposed architecture is designed to be applied in any bicycle, which includes personal bikes or bikes from a bike-sharing system. The cloud services allow almost any bike to be easily integrated in a free floating bike-sharing system, because the IoT module allows the bike to be remotely unlocked.

3 RELATED WORK

Some works related to bike instrumentation, data collection and bike routing have been developed, in this section we discuss some of them.

The concept of IoT has been applied in some studies to collect data from instrumented bicycles. For example, (Grama et al., 2018) proposed an IoT solution with multiple modules that could be replaced according to cyclist needs. The modules have two main features, the measurement of bicycle parameters and the measurement of environmental parameters. Aiming to create a platform to collect and share data about air pollution in urban environment, (Aguiari et al., 2018) also proposed an IoT based module to instrument bicycles.

Since the bike use has become more common, some market solutions have appeared to guarantee an increase of security for bikes against thefts, usually these are designated as smart locks. In this field, there are several solution, as the Linka [1] lock, which has a Bluetooth connectivity, an alarm against thefts and a smart phone app where the user can unlock the bicycle. The Bitlock [2] lock, has the same specs, but with a different design, since it is not attached to the bicycle rear wheel. Lastly, there are locks in the market that act as IoT modules, since they have communication modules who uses the mobile network, for example the BL10 [3] lock has the same features that the other mentioned solutions have, plus a connectivity module, that allows it to send data remotely to a connectivity platform.

The mentioned solutions only tackle a part of the problem that we are trying to solve, there is a lack of a connectivity platform, in which data could be stored and used to determine infrastructures condition. Besides that, the determination of the locations with poor cycling conditions is not straightforward, the data has to be analyzed by models who should be calibrated. In fact, the full potential of data collected by instrumented bicycles is not used. A proof of that is the fact that there have been proposed several works related to bike routing, for example (Song et al., 2014) and (Luxen et al., 2011) that used OpenStreetMaps data to create bike routing solutions, (Singleton and Lewis, 2012) was further and considered accident data in his algorithms, however, we have not knowledge of studies who use real sensor data collected by bicycles to have additional information about cycling network, thus improving the route suggestions quality.

4 METHODOLOGY

To achieve the objectives mentioned, our solution encompasses a cloud based management layer, user and operator interfaces,external web services and an IoT layer which includes a communication module and sensors, as shown in Figure 1. To have real time inputs about the bike and road network status, each bike has embedded sensors and a communication module, which uses the mobile network to send the sensor data in real real time to the management layer, where the information is stored and analyzed.

The proposed solution is projected to be used in several situations, since the on-board device (IoT

[1] https://www.linkalock.com
[2] https://bitlock.com
[3] https://www.jimilab.com

layer) has an actuator to lock or unlock the bike, making it easy to integrate almost any bike in a free floating bike-sharing system. Users and operators can interact with the system using both, web interfaces and mobile apps. It allows operators to control and monitor the system while cyclists can use routing services and remotely monitor their bicycles.

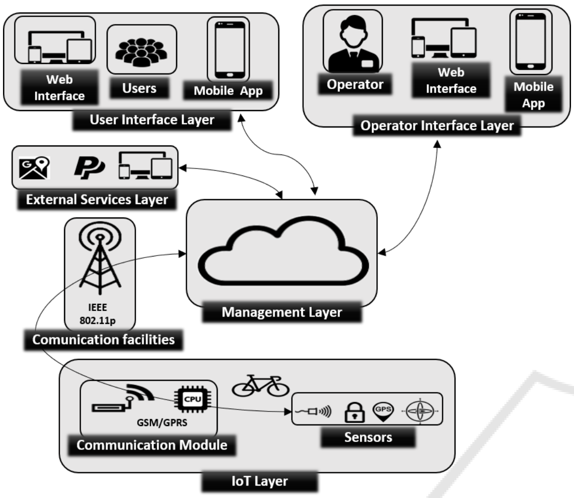

Figure 1: Proposed Solution Schematic.

The cloud based platform is divided in 5 layers, as shown in Figure 2, the user and operator interface, external services, IoT and management layer. In the further subsection, these layers will be discussed in detail.

4.1 IoT Layer

The IoT layer is composed by a GPS (Global Positioning System) to track the bicycle location and speed and sensors as an IMU (Inertial Measurement Unit), to measure accelerations and angular velocities. These features are used to determine the pavement quality, detect bike turns, accidents and vandalism attempts. The distance sensor intends to give some perception about the motor vehicle drivers behavior, namely if they respect the minimum lateral distance when they overtake a bicycle. In order to send the sensor data to data storage unit, the IoT layer has a communication module, which consists of a micro controlled modem that uses the mobile network to access a broker (Management Layer).

The communication between bicycle and cloud based platform (Management Layer) is done through the MQTT (Message Queuing Telemetry Transport) protocol. At a time that all sensor data is read, the modem sends a message to the mosquitto broker containing the following fields:

- GPS Coordinates: Latitude, longitude and altitude.
- GPS Velocity: Instant bike velocity, according to the GPS satellites.
- Angular Velocity: Instant angular velocity over the 3 axis.
- Linear Accelerations: Instant linear acceleration over the 3 axis.
- Lateral Distance: To minimize errors, the following features related to the lateral distance are sent:
  - Instant Distance: Measurement at the sending moment.
  - Average Distance: Average of all measurements, between sendings.
  - Minimum Distance: Minimum measurement between sendings.
  - Maximum Distance: Maximum measurement between sendings.
- Bike state: The smart lock has an embedded contact sensor, thus is sent a boolean containing ”0” if the bike is unlocked or ”1” if it is locked.

The information published on mosquitto broker is then subscribed by a MQTT client application built in python language and sent to a non relational Mongo database (data storage, Management Layer). Lastly, the IoT layer is encompasses a compact smart lock device attached to the bicycle rear wheel, to protect the bicycle against thefts. However, this is not the single purpose of this component, it is built in order to make possible to use almost any bike in a bike-sharing system. This is specially true, if we are talking about a free floating business model, because communication module and the services available in the management layer, make possible to rent a bike, using remote payment systems and unlock it automatically when the system notices that a payment has been made.

4.2 User Interface Layer

The user interface layer is essentially composed by web interfaces and mobile apps. These interfaces may differ, if we are considering a bike owner or a bike-sharing system user. In the first case, the main objective is to allow the cyclist to monitor the sensor data embedded in the bicycle, provide him travel management interfaces in which he can save his trip records containing information about distance, duration, slope during the segments of the trip, wasted calories, among others. In the second use case, it also allow the use of bike-sharing services and remote payment systems, among others. The communication

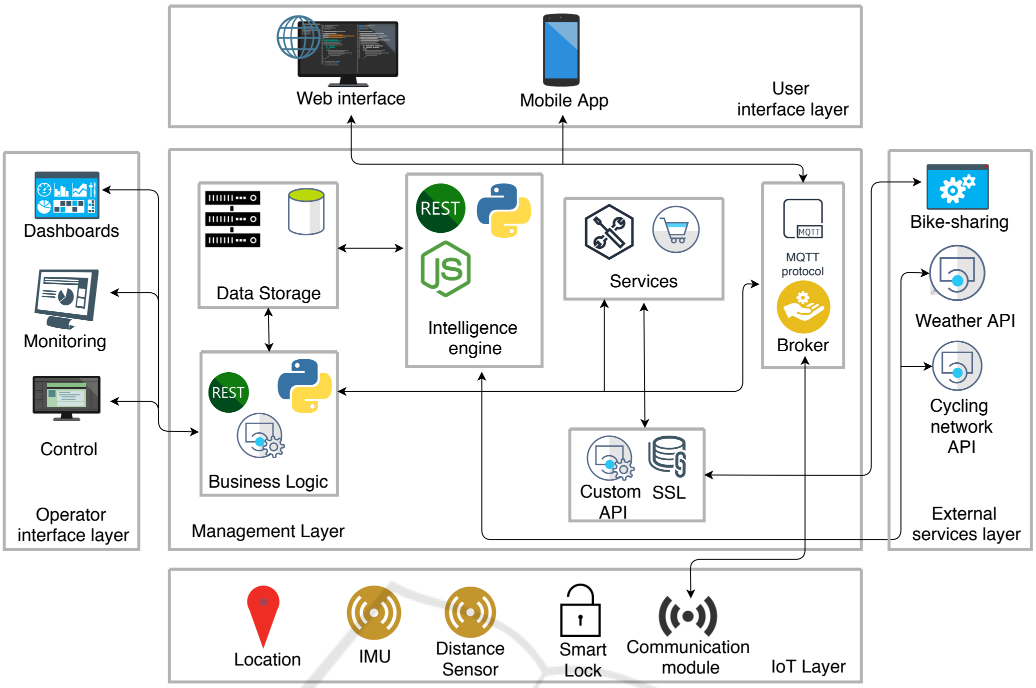

Figure 2: Connectivity Platform Architecture.

between user interfaces and the management layer is made through the MQTT protocol, because it allows easy management of the different service requests.

The main concern of this study is the cyclist safety and bike security, thus the main feature of these interfaces are the routing recommendations, that allow each user to make the best route choice, according to his profile. The user interface also allows the bike monitoring, since it has an embedded IMU (IoT layer), the system can send an alert when the bike is disturbed, and keep it tracked with the GPS module. Lastly, with the smart lock, the user can lock or unlock his bike remotely, using a smart phone app or a web interface instead, making it possible to easily share his vehicle with other people.

4.3 Operator Interface Layer

The operator layer interface intends to be used by the system managers. It allows the creation of metrics and dashboards to follow the work progress and goals achievement. It is important to have tools to handle the system management, to control the platform usage and for monitoring the data sent to databases. These interfaces are web based and use REST (Representational State Transfer) services to communicate with the business logic engine.

This layer can also be used by external mobility services managers. As the proposed solution is intended to be used by bike owners and by bike-sharing business owners or other soft mobility systems, we provide simple interfaces for these entities, thus they can control and monitor their business logic, for example changing or creating taxes or service packages. One problem in some bike-sharing systems is related to vandalism and the bikes misuse, such as inappropriate parking. Since the on-board device (IoT layer) has a GPS, the business owners know where their bikes are, any time, and if they detect misuse, they can impose the appropriate fine to the breaker, since it will be registered in the system.

To handle the integration of different external systems with different business models, we provide customized APIs (Application Programming Interfaces), thus an undetermined number of external systems can be added, with no loss of privacy and quality. We use SSL (Secure Sockets Layer) to guarantee the communication security.

4.4 External Services Layer

The external services layer serves two different purposes. One of them is related to the integration of external mobility systems. As mentioned, the operator interface layer can work as a management interface for external services owners. To integrate these services, we propose customized APIs that allow the access to several services, such as automatic payment systems, user registration platforms, data storage units, among others.

The second purpose of this layer is the communication with external data sources. To create an efficient tool to help cyclists, we need a great variability of data sources. As mentioned, we use data collected from the several bikes as input for routing engines and to make relevant suggestions to cyclists. However, this is not the only data source used, since we use different external APIs to get detailed information about network. In this field we can highlight OpenStreetMaps, because it has very detailed information about the cycling network and cycling infrastructures. Other sources are used to enrich the cyclist knowledge and ensure his safety, as weather services or traffic services, if it they are available. This way, we can provide a great amount of information to the cyclist in a single application.

4.5 Managemet Layer

The management layer is the link between all layers. It comprises several modules that guarantee the correct functionality of the entire platform. In the next subsections, each module will be discussed in detail.

4.5.1 Communication Bus

The communication bus is composed by a mosquitto broker which ensures the connection between the bicycles, management layer and the user. The user assumes a subscriber role, i.e, when he/she uses the payment methods, interact with smart lock or intends to monitor bike trips records or other data, a subscription is made in the broker and it returns a MQTT response, containing the requested data, that have to previously published by the management layer on the broker.

The communication module (IoT layer) has both roles, publisher and subscriber, it publishes the collected data on broker and subscribes bike states and payment records, to ensure that the smart lock only unlocks when the payment is successfully made (on bike-sharing use case).

4.5.2 Customized Integration Module

The customized integration module works as link between external mobility systems and the management layer. We create customized restful APIs for each entity who needs to be integrated into our platform. These APIs, allow the external entities to use services as payment methods, data storage according to personalized business models and other personalized methods that could be relevant. This way, we can include a great diversity of external mobility services and regard the stakeholders interests.

4.5.3 Data Storage

The data storage unit is where the data from different sources is organized and stored. The data sources comprise:

- Sensors(IoT Layer): The data collected by sensors and mentioned in Section 4.1 is stored in a non relational Mongo database.
- Business Model: Each system integrated into the management layer may have his own business model, which comprises users data, payment records, packages and taxes, fleet information as number of bikes, type, among others. In these cases, the database project is directly related to the business model complexity, thus we use both, a NoSQL Mongo databases and SQL SQLite databases.
- External Sources: To create useful tools for cyclists, we collect data from some external sources, as OpenStreetMaps, weather services, among others. In the first case, the information collected is processed and saved in memory, as text file. The real time information, such weather state, is collected and shown to cyclist when requested, but there is no need to store it in memory.

4.5.4 Business Logic

This module is composed by python based applications who publish services on broker. These services can be related to the business logic, for example, payment methods, or it can be a more general service, as a bike routing tool suggestion for cyclists. The last service is designated to any user of our tool, since our main goal is to improve the safety for cyclists and increase the number of bike users.

Lastly, we have restful APIs, based on NodeJS to allow operators to monitor their business in friendly web interfaces. It also enables the creation or the modification of mobility packages or taxes, making the link between the data storage unit and the operators monitoring panels and dashboards.

4.5.5 Intelligence Engine

The intelligence engine is one of the most important pieces in our platform, because the main goal of our solution, that is the creation of a tool to help cyclists and policy makers, is directly related to the intelligence engine.

The first step to build a tool to help cyclists, is to understand their behavior as route users. If we have a plethora of bikes sending GPS coordinates to our databases, we can trace a profile of the user, based on his choices and preferences. However, it is not a simple task, the GPS coordinates can have small inaccuracies due to poor GPS signal, thus a data treatment known as map matching has to be done. To handle this task, we use some python modules.

The IMU measurements are also processed by other parallel python routines, in order to identify places with poor surface condition or obstacles. To achieve this goal, acceleration in 3 axis is measured with a frequency high enough to allow multiple measurements when passing over a road hole. The acceleration measured over the axis that points on Earth gives information about the pavement, while the acceleration over the other two axis and the angular velocities allow to determine if there are road obstacles avoided by cyclist. With this information, machine learning algorithms are calibrated in order to detect locations with the worst pavement condition or infrastructures who need maintenance. This kind of information is an asset, when policy makers need to make decisions, because they can do it in a more conscientious way.

Other use that is given to the IMU data is the vandalism detection, if the bike is locked and a perturbation is detected, the intelligence engine sends an alert to the bike owner by email or SMS. The lateral distance sensor data is used to perceive road links where motor vehicle drivers do not respect the minimum lateral distance when they are overtaking a bicycle. We use python in order to match these information with the OpenStreetMaps data.

Finally, the most important role of the intelligence engine is to create a tool to help cyclists in route choice decisions, improving cycling safety. To achieve that goal, we collect road network data from OpenStreetMaps, throw the API provided by this entity. Then, the data is processed and a cost is associated to each edge, according to metrics shown in literature and improved with the cyclist preference choices determined from the GPS data. This data is complemented with sensor data, i.e., in the edges where poor surface conditions or obstacles in the cyclists way were detected, have an additional cost. The joining of all data sources is used in routing algorithms that provide cyclists an easy way to chose the best route between departure point and destination according to his profile and taking into account his personal preferences.

5 RESULTS AND DISCUSSION

In this section are presented some results, namely some graphs containing data collected by sensors (IoT layer). The sensors were chosen taking into account their utility to determine road conditions, road users behavior and detect obstacles in cycling infrastructures.

Figure 3 shows linear accelerations in the 3 axis, measured by the IMU during a bike trip. In the beginning of the trip, accelerations along the Y and Z axis are near 0 m/s^2 and the acceleration along the X axis is between -10 and -9 m/s^2, which makes sense, considering that the bicycle was stopped and the X axis is aligned with the gravity direction. The trip started at the instant marked with the first rectangle. The acceleration peak in Z axis on that instant, denotes the bike positioning to start the trip.

The second rectangle represents a passage over a bicycle path curb. According to figure 3, this inadequacy is visible by the inverted peak in the X axis. In the third rectangle is visible that the number of peaks in this curve increased. This happen, because there was a change in the road pavement, the cyclist was previously cycling on smooth asphalt and then the pavement changed to cobblestone. The oscillatory peaks in Y and Z axis represent the bike instability, this values, together with the angular velocity data are useful to give information about user behavior, and with a considerable amount of data, obstacles in the road can be detected due to cyclists turns and bike position. The IMU data can also be used to detect accidents or car crashes during the trips. However, to have precise models that detect crashes from data, a calibration with data sets in which occurred accidents or crashes needs to be done.

Figure 4 shows measurements made by the lateral sensor distance who is pointed to the cyclists left. The main goal that led us to use this sensor was the detection of motor vehicles misbehavior, namely, the transgression of the minimum lateral overtaking distance. The lateral distance associated with the GPS coordinates allows to create a list of places and time of the day where most of transgressions occur.

The frequency of data acquisition is much higher than the sending frequency to the databases (management layer), so, in order to not lose measurement peaks and smooth reading errors, we send to the connectivity platform the average of all measurements between sends, the minimum and maximum measurements and the instant measurement. Note that the graph in figure 4 does not show the instant measurements for the test trip, because they are not relevant to the discussion. Figure 4 has two regions that are in-

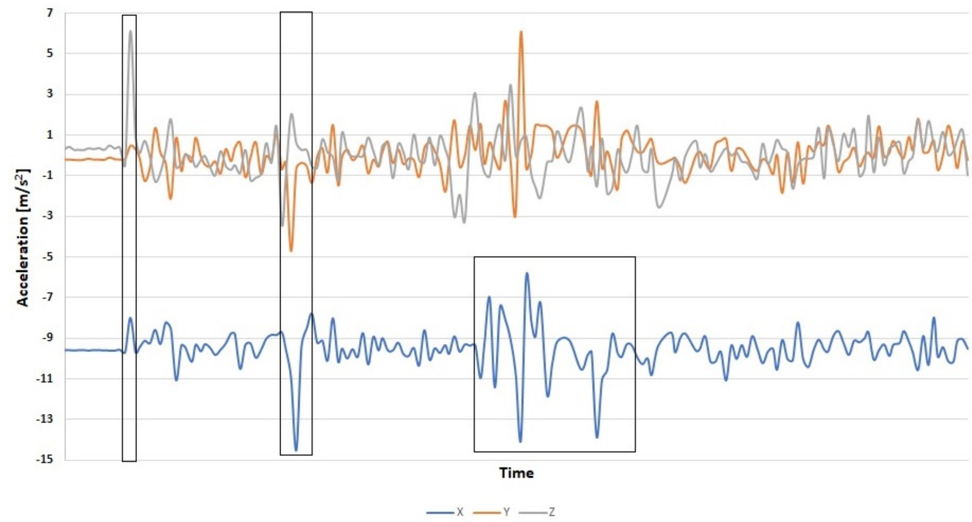

Figure 3: Linear Accelerations (IMU Measurements).

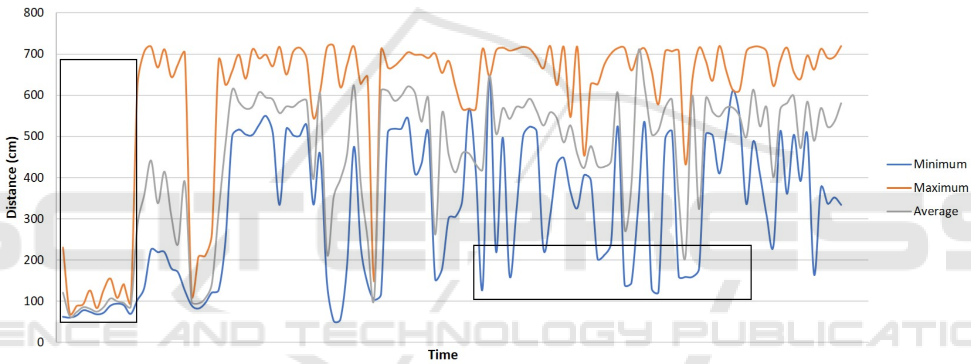

Figure 4: Lateral Distance (Sensor Measurements).

teresting for discussion marked by a vertical and horizontal rectangles. The first one, where the distance values are small, represents a period in which the bike was confined by the surroundings, i.e., the cyclist was passing over a bridge and was confined by it's boundaries. The horizontal rectangle show periods in which real overtakes occurred (as confirmed by tests). Note that the other oscillations and peaks do not represent motor vehicles overtakes, but other obstacles during the trip. The results show that motor vehicles behavior detection from this data is not an easy task, thus, the creation of a mobile interface or embedded button in which the cyclist could mark the places where real overtakes have occurred would facilitate the determination of places where drivers misbehavior occurs.

In figure 5, is shown the proposed routing interface. This service takes into account sensor data and data collected from third party entities, as OpenStreetMaps, to compute algorithms which calculate the best route between two locations, according to one of four criteria: distance, travel time, comfort or safety.

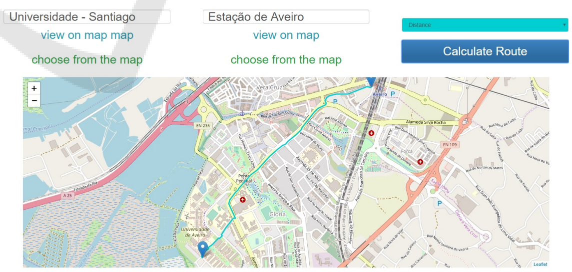

Figure 5: Routing Interface.

In general, the tests made confirm that the IoT layer's components work as expected. We can ensure a reasonable sending frequency to the database. Sometimes there are communication delays that occur due the poor signal coverage in some places, but the system recovers automatically in just few seconds. The laboratory tests with IMU and the distance sensor, showed good measurement accuracy, thus some deviation from expected values, shown in figure 3 only results from the fixation on the bike. The GPS also worked as expected, i.e., the marked points on a map corresponds to the real path taken by the cyclist, with no significant deviations.

6 CONCLUSIONS

This work presents a concept of a connectivity platform and a IoT based solution embedded on bikes. The results showed that the chosen hardware works as expected and the collected data is valuable to determine road features and cyclists behavior. The platform services were tested in laboratory with a bike-sharing system concept.

As future work, we would like to develop the mechanical concept of a smart lock, in order to have the on-board unit (IoT layer) embedded on it. The management layer also needs further developments. The first step will be to test the services as payment or bike renting in a controlled environment, and the resolve some issues that may appear and test it in real environment.

The data collected by sensors proved his importance, with exception to the lateral distance. It is impossible to distinguish real overtakes from confined environments as shown in Section 5, thus it needs the development of a mechanism in which the cyclist could mark real overtakes.

The routing recommendation engine is functional with four criteria, distance, travel time, comfort and safety. However it considers mainly static data from external data sources as OpenStreetMaps. To take more serious conclusions, we need to test the on-board unit (IoT layer) in fleet of bikes, in order to have a significant dataset. It also would give us better insights about cyclists profile and preferences. Our system is prepared to provide the sensor and GPS data through an API, thus third party entities can use it, in order to create their own recommendation systems or to help stakeholders or policy makers making the best decisions.

ACKNOWLEDGEMENTS

POCI-01-0247-FEDER-033769 - ”Ghisallo – Investigação e Desenvolvimento de uma nova solução de comutação urbana, assente num novo conceito de veículo elétrico de próxima geração” – ”Ghisallo - Research and Development of a new urban commuting solution, based on a new concept of a next-generation vehicle”.

UID / EMS / 00481/2019-FCT

CENTRO-01-0145-FEDER-022083

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