IoT Data Collection Concept for a Bike Sharing Platform

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In this paper, a concept of an IoT based solution for a Bike Sharing Platform is presented. The developed platform implements a new layer of instrumentation that allows data collection that could be used for, for instance, route suggesting algorithms, fleet management and distribution, traffic analysis, crashes detection, crashes reconstruction, and driver profiling. All these possibilities are of major interest in today's socioenvironmental context. The use of bicycles and sharing platforms should be promoted and encouraged, but for that to happen, some limitations regarding safety and insufficient user engagement must be overcome. The work developed under this paper aims to mitigate those barriers and provide a functional, innovative, and efficient solution.

1. Motivation

Nowadays, the Smart City concept is becoming increasingly widespread and pursued in major cities around the world. Although a global accepted definition for Smart City does not exist, this concept, generally, represents the objective to improve the usage of the public resources and increase the quality of the services offered to the citizens while reducing the operational costs of the public administrations [1]. The objective to improve the overall city efficiency can be fulfilled by the development and deployment of urban Internet of Things (IoT) based solutions, hence, approaching the realization of the concept of Smart City. IoT represents a communication paradigm that aims to connect everyday objects in a global and ubiquitous network [2]. Consequently, a communication infrastructure such as the one proposed by IoT, may allow the development of innovative and unified services for the citizens while, simultaneously, enabling the exploration of new potential synergies [1]. This type of technologies can help improve the mobility paradigm through, for instance, the enhancement of conventional Bike Sharing Platforms operation by connecting it with other services or adding relevant features such as data collection and real time monitoring. Virtuous and efficient solutions for Bike Sharing Platforms are already established and functioning properly in several developed cities. The importance of this type of systems is undeniable taking in account all the social, environmental, and economic benefits inherent to its use such as, for example, the decrease in pollutant emissions, the promotion of healthy cycling behaviors and traffic reduction. For example, in 2016, Bike Sharing in Shanghai saved 8358 tonnes of petrol and decreased carbon dioxide and nitrogen monoxide emissions by 25240 and 64 tonnes, respectively [3]. Nevertheless, some opportunities that these types of systems offer for improving the overall transports and mobility paradigm are, most of the times, undervalued and unused. Having a fleet of bicycles constantly cruising a city allows the collection of large amounts of data that could be used for enhancing the infrastructure quality, detect collisions and the development of more precise and adapted route suggestion algorithms for cyclists. Also, as mentioned before, the promotion of bicycle usage is extremely relevant in nowadays socioenvironmental context and, with that in mind, the implementation of Bike Sharing platforms, the basis of the solution presented in this paper, should be encouraged and promoted. Therefore, this paper aims to present an environmentally aware solution for a Bike Sharing Platform while also taking advantage of profitable and rich possibilities of implementing data collection technologies on the mobile component of the system.

2. Literature review

Bicycle instrumentation is not a recent technology although, lately, the accessibility to low-cost and good quality sensors allowed the development of distinct and competitive solutions. For instance, other authors considered a low-cost ultrasonic distance sensor attached on a bicycle for monitoring the road surface conditions in the front area of the vehicle [4]. When the system detects bad road surface conditions such as bumps or potholes it notifies the rider via alarm or blinking LED. This way, the rider can easily react, decreasing the speed or avoiding the obstacle. The developed system is particularly useful for helping elderly people in the context of night cycling. Briefly, a microcontroller is used to calculate the real measured distance with the data received from the ultrasonic sensor and then, stores this information in a SD card. Simultaneously, a XBee unit sends all data via a wireless communication to a monitoring PC. The results show that the system can provide useful data about obstacles in front of the bicycle that could be used to notify the user or, alternatively, activate an automatic braking mechanism providing a safer experience.

Other authors developed a method to detect bicycle trail conditions while displaying real-time data on a mobile application [5]. The proposed system uses a GPS unit, two accelerometers, a microprocessor, and a data logger to retrieve, process, save and transmit data in an IoT based solution. The device sends the collect information in two main ways. The first transmits all data (longitude, latitude, and accelerations) to a database through hotspots or other available wireless networks. The second, sends the data directly to the user's smartphone (using the TCP/IP protocol) where it is stored and, simultaneously, sent to the database. Therefore, arises the need to also develop a mobile application to receive and display data from the device. The experimental tests show that the system can help identify damaged infrastructure through the usage of accelerometers as it was intended.

Another piece of research is related with the development of a collaborative bicycle sensing for monitoring urban air quality [6]. A device containing a microcontroller, a GPS receiver, a GPRS module, a Bluetooth unit, a microSD card, and air pollution sensors was developed to allow the collection, saving and transmission of data. The device was mounted on a public bicycle, part of a Bike Sharing platform in Changzhou, China. Data can be directly transmitted to the back-end server using the GPRS modem allowing real-time monitoring or, alternatively, it can be transmitted using a Bluetooth connection to a relay unit (integrated with the bicycle station) while the bicycle is docked. Although the later reduces communication cost and power consumption it makes it impossible to analyse data in real-time. The field experiments indicate that the data collected is linearly correlated to the data retrieved by environmental monitoring stations.

Despite the three mentioned solutions showing good results working individually none of them were developed to function, also, as a Bike Sharing Platform device (only as an additional component). Therefore, the solution presented under this paper represents a single component (to be attached to a bicycle) that allows the filtering and sending, in real time, of all data collected by a group of implemented sensors and, also, to respond accordingly to several commands needed to operate an automatized Bike Sharing Platform. Consequently, it is an innovative solution that combines the needs of two distinct areas (bike sharing and data collecting) in a single low-cost device.

3. Paper Objective

The main objective of this paper is to present an innovative solution for a Bike Sharing Platform by the development of an IoT technology-based device for bicycle instrumentation and all the necessary web platforms to work as interfaces for bicycle payment, renting, monitoring, management and provided data analysis. As mentioned before, the developed platform should, not only function as a conventional one, but also to allow the collection of data during the usage of bicycles. In particular: GPS coordinates, linear velocities, accelerations, angular velocities, and lateral distances to obstacles. All this data should be sent, in real time, to a web server so that it can be stored in a database developed for that purpose. With this implementation all data can be accessed by an administrator or client of the service anytime and anywhere on the planet since the web server and database can be accessed via a TCP-IP connection (internet). Therefore, web media supports to display collected data were also developed (graphs, maps, and tables).

4. Methodology

For the development of the IoT Data Collection Concept for a Bike Sharing Platform the process started by selecting the required hardware for the process. Having the components list established (and hardware assembled) some tests took place to evaluate the stability of communication via TCP-IP connection with the web server (trough GSM/GPRS network). In these preliminary tests, the mobile component was kept immobile until an efficient and stable embedded software on the microcontroller was achieved. Only after that, tests in motion took place. This methodology allowed to separate all possible factors that could, eventually, negatively influence or hamper the communication. Still, the first tests in motion allowed the identification of some problems, such as insufficient GPRS network coverage and message fragmentation. Taking the identified problems in account, the embedded software was constantly upgraded until reaching its final version under which the results provided by the tests presented in this paper were possible. At the same time, web platforms were developed to allow the usage of the system. These were divided into two main branches (since they present distinct objectives) – User's Platform and Administrator's Platform. The first, to be used by clients, should allow one to locate bicycles, pay for credits and unlock available bicycles. The second one, only to be accessed by administrator, must contain functionalities to manage the associated bicycle fleet and, also, analyse all collected data by the mobile component of the system. Both pages were developed using typical web languages and mechanisms such as JavaScript, CSS, PHP and HTML.

5. The developed system

First, it was important to establish the several components of the developed system and, also, the implemented communications architecture. Figure 1 illustrates the main building blocks that, together, form the complete Bike Sharing Platform. First (1) there is the developed mobile device that should be installed on the public bicycles. To allow real-time monitoring of the fleet, all collected data is sent (in real-time) to a web server using the TCP/IP protocol over the GSM/GPRS network. Although this method can be more power-hungry than other alternatives, its versatility is undeniable since it can be implemented, virtually, anywhere where mobile network coverage exists without the need of additional infrastructures. The web server and database (2) represent the static component of the system. They are both needed to receive, interpret, and respond to TCP/IP requests and, also, to store all the collected data in the database. In the same computer where the servers are running, files for the developed web pages are stored. Therefore, the Administrator's Web Page (2.1) allows the monitoring and management of the bicycle fleet and the consultation off all data provided by the mobile device. Finally, the User's Platform (2.2) allows one to sing up, log in, make payments using PayPal and unlock the desired bicycle. Since both websites were developed using web languages and responsive elements they can easily be accessed by devices like computers or smart phones. Notice that, in all communication, data flows in both directions. The mobile device is capable of sending the collected data and also read the state (locked or unlocked) of the bicycle in the database to which it is mounted so that it can lock or unlock it. Similarly, users or administrators can receive information from the database and change it as well.

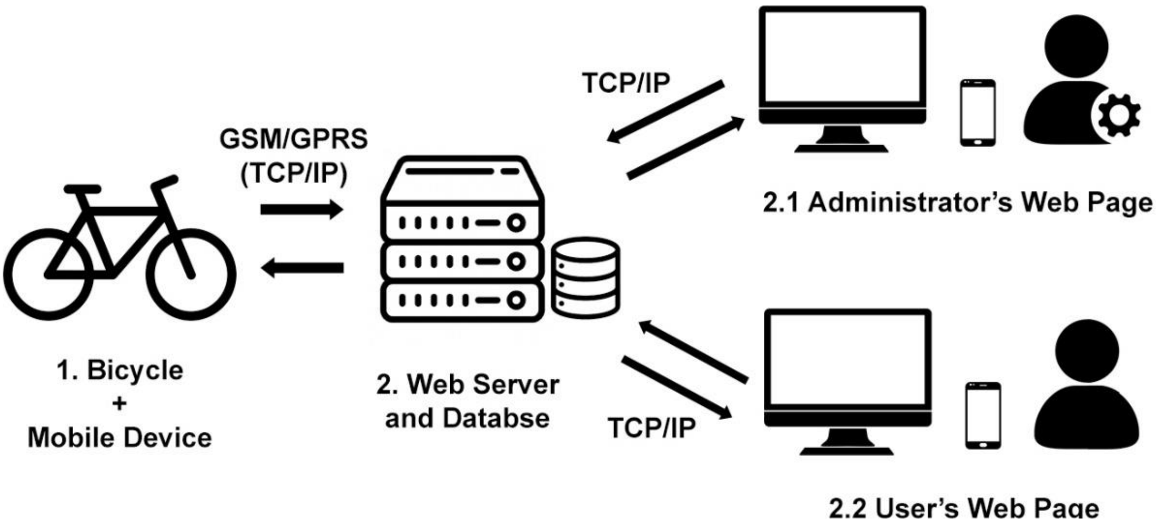


Figure 1 – General communication architecture

Figure 2 illustrates the main components of the developed mobile device and how it communicates with the server. Four data collection units were implemented here: an accelerometer to detect accelerations suffered by the system; a gyroscope to measure angular velocities; a GPS to retrieve latitude, longitude and linear velocities and, finally, an ultrasonic distance sensor to measure distances to obstacles during the route. All four units communicate with a microcontroller where the first data filtering is done. Then, data is sent to a GSM/GPRS modem that, finally, redirects it to the server using the TCP/IP protocol over the mobile network GSM/GPRS.

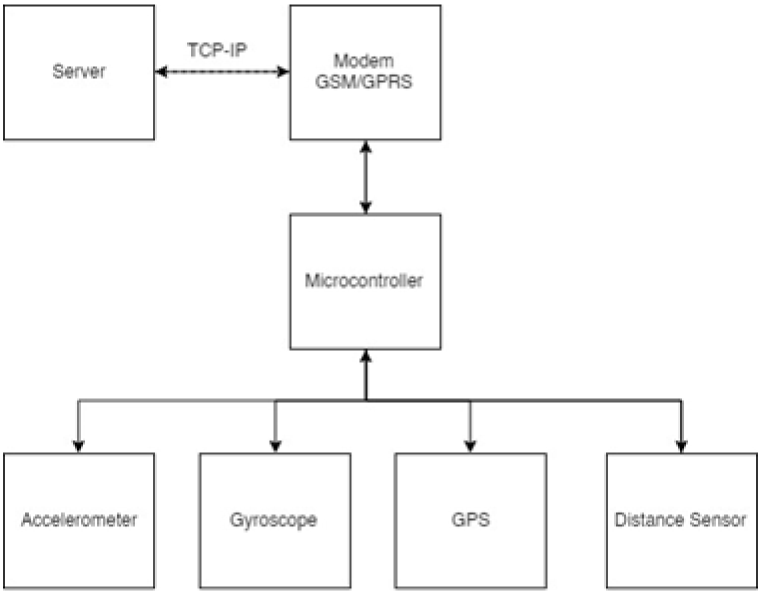


Figure 2 – Communication architecture of the mobile device

After all hardware components were assembled using printed circuit boards, a mounting box was especially developed and produced, using an addictive manufacturing process, to allow the mounting off the mobile device to a bicycle. Figure 3 shows how the system is mounted on the bicycle used for validation tests.

Figure 3 – Mobile device installed on a bicycle

Notice that the distance sensor is pointing to the left of the bicycle. Unlike to what is proposed in [4], this alignment of the sensor should provide readings of overtakings by other vehicles, obstacles, and confined spaces to cycle. These readings are relevant, mainly to understand if there are roads where the minimum limit to overtake a bicycle is constantly neglected. This identification can help the development of more adapted route suggesting algorithms with emphasis on the safety of the overall route.

6. Experimental Tests

Several tests with the mobile component were made to evaluate the quality of results from the sensors and robustness and efficiency of the embedded software in the microcontroller. Nevertheless, only two of the most relevant tests are presented in this paper. Both took place in the city of Aveiro, Portugal. Aveiro presents an excellent topography for bicycle usage. It is, mainly, a plain city which allows easy cycling with low physical efforts. Despite that, repeated degraded road conditions and an evident lack of dedicated bicycle paths negatively impact the usage of this mean of transportation.

Figure 4 a) illustrates the marker placement for the first presented test. Each marker represents a group of measurements of all sensors. Therefore, it is possible to pinpoint the location of all readings in a map (developed using JavaScript, in this case). The test had the total duration of 30 minutes and 43 seconds and, approximately, 7.1 kilometers were travelled. A group of 432 points of data were collected which translates to an average time between database submissions of 4.2 seconds. Having an average time between submissions higher than the established one (4 seconds) is a symptom of delays in communication manly provoked by insufficient network coverage or data fragmentation. This was one of the major concerns during the development of the embedded software. Hence, procedures were implemented to prepare the mobile device to deal with these eventual limitations in the most efficient way as possible. Looking at the results it is clear that the mobile component is capable of maintaining constant or semi-constant submissions to the database during long trips. This validates the platform implemented technology as a real-time monitoring solution for a bicycle fleet. Because of the large quantity of data collected in this test, its correct display and analysis in the present paper would be unclear and inaccurate. Consequently, a shorter test was made to evaluate the congruence of all measurements done by the installed sensors which is presented next.

Figure 4 b) demonstrates the resulting marker placement of test number 2. This route, in particular, was defined taking in account the need to test different types of pavement and infrastructure conditions so that the collected data could be properly evaluated. The test had the duration of 12 minutes and 11 seconds and, nearly, 3.2 kilometers were travelled. A group of 184 points were collected which translates to an average of, approximately, 3.9 seconds between submissions, a value that indicates that no delays were registered between database submissions.

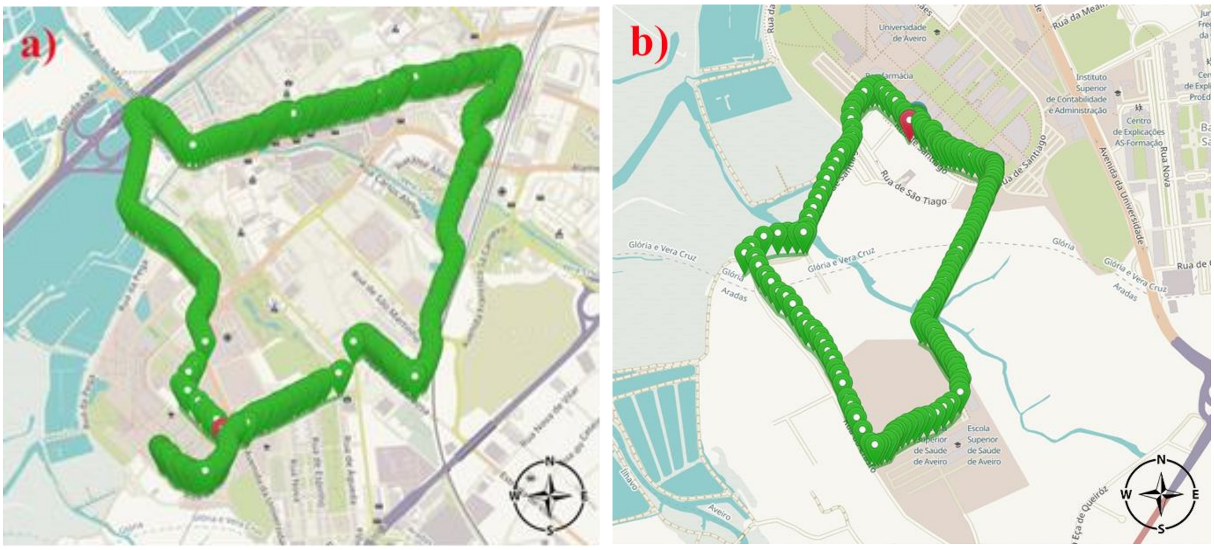
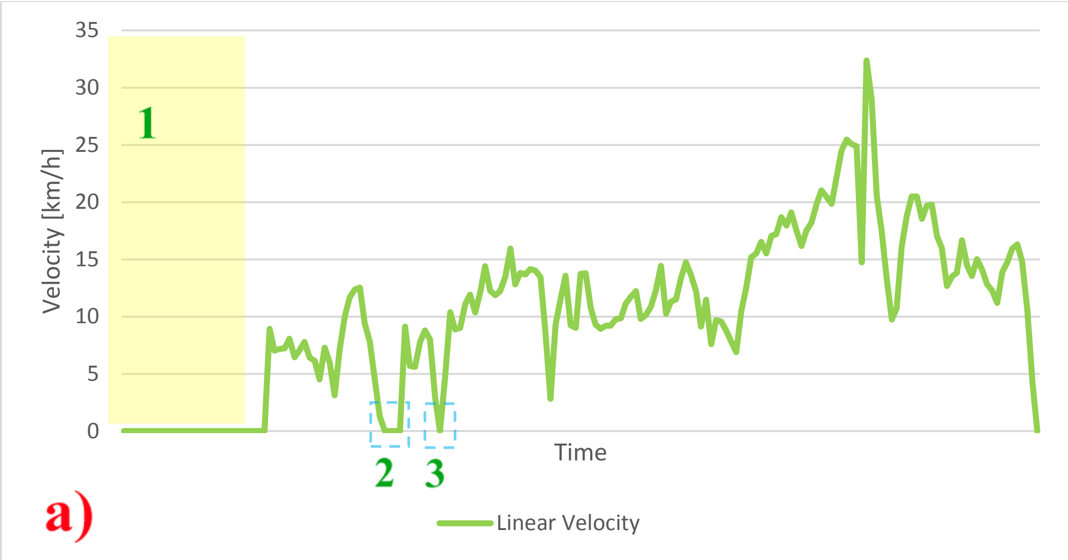


Figure 4 - Marker placement results of presented tests

Figure 5 shows some of the performed measurements by the implemented sensors during the duration of test number 2. Thus, Figure 5 a) represents the collected linear velocities measured by the GPS unit, Figure 5 b) the collected accelerations by the implemented accelerometer, Figure 5 c) the collected angular velocities by the gyroscope and, finally, Figure 5 d) the collected lateral distances to obstacles by the ultrasonic sensor. Because the acquisition frequency is, typically, higher than the server submission frequency average, instant, minimum and maximum measurements related to lateral distances are sent to the database so that no relevant information is lost between submissions. Also, since some of the sensors provide multi-axial readings, it is important to define the overall axes orientation of the system which is represented in Figure 5 b) and c). Accordingly, it is expected, for instance, through reading accelerometer data associated with the x axis, evaluate the road conditions (bumps and potholes).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Velocity [km/h]
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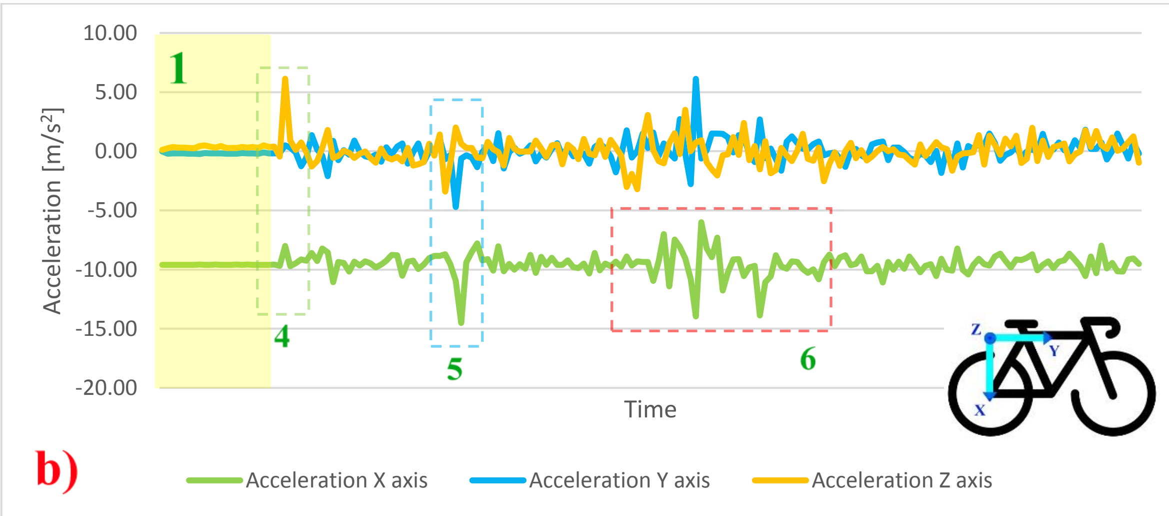
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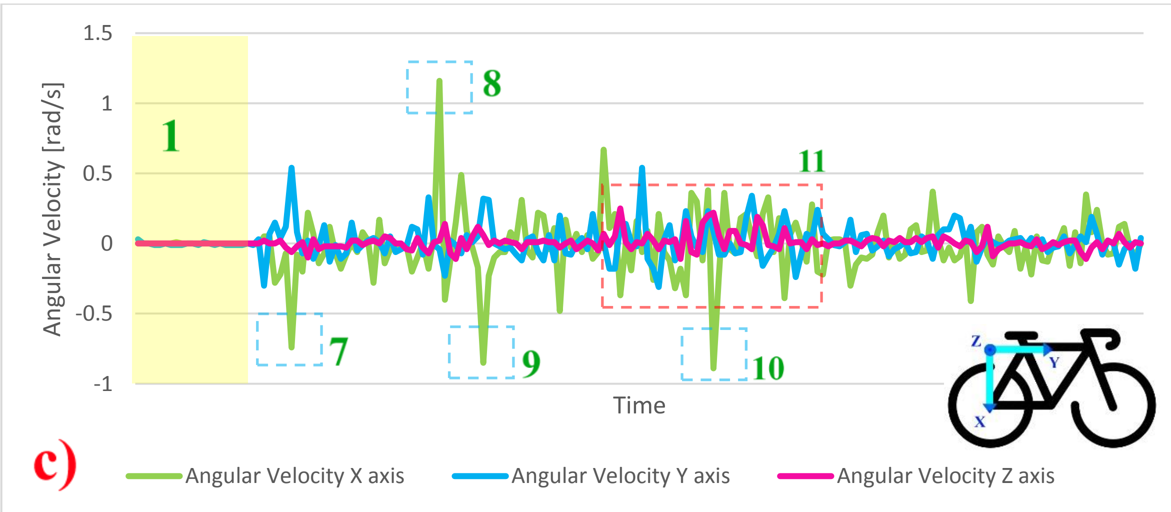
1.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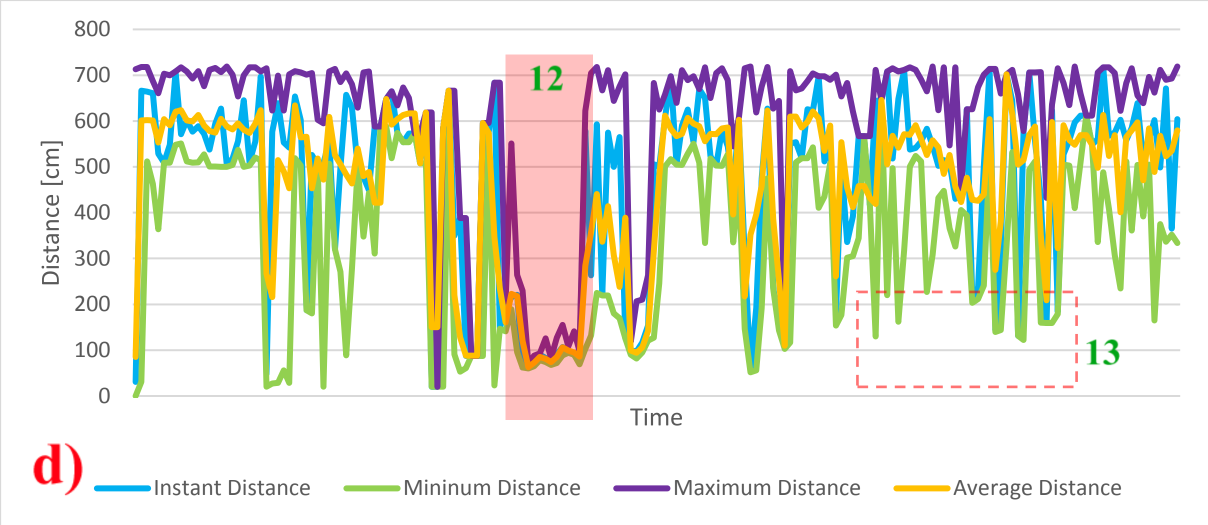

Figure 5 – Collected data from test number 2: a) linear velocity data (GPS measurements) , b) acceleration data (accelerometer measurements), c) angular velocity data (gyroscope measurements), d) lateral distance (distance sensor measurements)

Before proceeding to an individual analysis of each sensor it is important to note a common situation in the first 3 presented graphs (Figure 5 a) to c)). This situation corresponds to the first section of the route where the bicycle was static (marked with a yellow rectangle numbered as 1). Since the system was static the collected data regarding accelerations, angular velocities and linear velocities is predictable and, consequently, can work as a good preliminary indicator of the correct installation of the sensors. First, linear velocities (Figure 5 a)) present a constant value of 0 km/h during this section which correlates with the expected. As for the accelerations (Figure 5 b)), values close to 0 m/s2 for y and z axis and, for the x axis, a value near 9.8 m/s2 (gravitational acceleration) were collected. Despite the proximity of the collected values to the expected ones, it is important to notice the small variances of around 0.2 m/s2. This small departure is, most likely, a consequence of imperfect orientation and mounting of the mobile device on the bicycle. Finally, as for the angular velocities graph (Figure 5 c)) none of the axes show any readings other than 0 m/s, which is a good indicator of the correct installation of the sensor. With a good indication of the correct implementation of the sensors it is now relevant to analyse each graph individually. Firstly, the results of linear velocity during the route (Figure 5 a)) show an evident correlation with the measurements of the velocimeter installed on the bicycle. Although, sometimes, smalls discrepancies of around 3 to 4 km/h to the vehicle real velocity were registered mainly due to the GPS unit limited precision. Anyhow, the stoppages to cross the street are clear (marked with blue rectangles numbered as 2 and 3) and, also, it is easy to pinpoint places that allowed higher velocities which was the main purpose of this measurement.

Secondly, a graph representing the measured accelerations is presented in Figure 5 b). The first major acceleration peak registered occurs right after the start of the test (marked with a green rectangle numbered as 4). Associated with the z axis, the reading it is a consequence of the abrupt reorientation of the bicycle to start the route. Then, another peak, this time inverted, emerges mainly registered on the x axis (orthogonal to the floor plane). The referred measurement occurred right after the passage over a bicycle path curb (marked with a blue rectangle numbered as 5). Both situations illustrate the possibility to identify occasional occurrences during the bicycle usage. Nevertheless, the most important section of collected data is associated with the more abrupt oscillations registered on the x axis, after the middle point of the route (marked with a red rectangle numbered as 6). This was the only section of the test where cycling over Portuguese traditional pavement occurred, while the rest of route, took place over smooth asphalt. The noticeable fluctuations of acceleration, taking in account the rough characteristics of the pavement where the measurements occurred, prove the possibility to, through data analysis, identify surface conditions. As mentioned before, this identification is valuable since it can be used to develop better adapted route suggestion algorithms, pinpoint locations where infrastructure may need improvement or even identify locations where dedicated bicycle paths should be built.

Figure 5 c) illustrates the measured angular velocities along the route. Angular velocities represent the velocity of rotations around the 3 defined axes. Therefore, it is expected to identify curves in the x axis, inclinations of the bicycle in the y axis and jolts due to inconsistent pavement in the z axis. The most evident situations, analyzing the graph, correspond to several positive and negative peaks in the x axis. As expected, all prominent values (marked with blue rectangles numbered from 7 to 10) correspond to curves (positive peaks correlate to right curves and negative peaks to left curves as stated by Figure 4). Looking at the actual values it may become possible to establish a driver profile since aggressiveness can be correlated with curve velocity although, further tests with different cyclist must be done to confirm this hypothesis. Angular velocities in y axis are also a good indicator of cycling infrastructure quality, route safety and driver experience. Abrupt bicycle inclinations are usually associated with an unstable use of the vehicle that could correlate with unexpected obstacles or even insufficient riding experience. Finally, the analysis of collected values in the z axis is also a noticeably relevant one on the evaluation of pavement conditions. Besides providing information related with sporadic bumps or potholes along the route it can also evidence the smoothness of the paving. The most noticeable case of the later is represent, again, by the segment of the route done over Portuguese traditional pavement where higher oscillations are clear (marked with a red rectangle numbered as 11).

Finally, in Figure 5 d), data collected with the ultrasonic distance sensor is represented. Minimum (green), maximum (purple) and average (yellow) curves represent distance readings between submissions to the database while the instant curve (blue) corresponds to the exact reading associated with the latitude and longitude combination of each collected point. From the analysis of the graph presented in Figure 5 d) two main occurrences are particularly relevant (numbered – 12 and 13). The first (12 – red vertical rectangle) correspond to the section of the route where, during the longer period, the characteristics of the surroundings of the bicycle were confined and homogeneous (pedestrian and cycling only bridge). As a result, the collected data shows a constant and similar values for maximum, minimum, average, and instant measured distances during the passage over the bridge. Notice that, although the measured values were not confirmed (with measuring tape) for every obstacle reading along the route, tests under laboratory conditions showed errors of, max, 1 cm when reading distances to obstacles of different materials using the implemented ultrasonic sensor. The second situation that should be noted is identified with a horizontal rectangle and numbered as 13. The evident inverted peaks associated with minimum and instant distance measurements correspond to overtakes done by motor vehicles Accordingly, the possibility to detected moving objects is confirmed. The analysis of this data must be crossed with the geographical coordinates of each reading. Note that, during the route, other inverted peaks can be identified but, only the ones marked in section 13, represent actual overtakes by other vehicles. Therefore, prior general identification of fixed obstacles or street conditions can be helpful to distinguish vehicles from other obstructions. Having said that, the obtained results with the ultrasonic sensor are satisfactory since the main objective of its implementation (the identification of vehicles and other lateral obstacles to the bicycle) was properly achieved.

7. Conclusions and future work

In this paper, an IoT solution for a Bike Sharing Platform was presented. The integration of several sensors in bicycle fleets was proved to be an excellent asset to evaluate several indicators such as bicycle usage, distribution, route obstacles and pavement conditions. All collected data can be, in future works, used to develop route suggesting algorithms, establish an adapted fleet management and distribution and provide important information for traffic analysis, collision detection and collision reconstruction. Therefore, the implementation of similar systems in Bike Sharing Platforms can be a valuable alternative to conventional ones since bicycle instrumentation can help improving the overall safety of the user by providing a more adapted service to each one. The results with the developed mobile device showed that communications through GSM/GPRS network represent a reliable solution for real time monitoring of the bicycle fleet (even with the associated cost). The implemented low-cost sensors collected several amounts of data that represented the travelled routes accordingly with the encountered conditions. The overall developed system totally fulfilled the established objectives proving it to be a functional, effective, efficient and innovative solution by merging the needs for city data with the fact that a Bike Sharing fleet is continuously moving and, therefore, the associated bicycles represent an appropriate target to use as probes.

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