Multi-agent System for the Control and Monitoring of Shared Bicycle Fleets

Luis Méndez(✉), Daniel Hernández, Gabriel Villarrubia, and Juan F. de Paz

Department of Computer Science and Automation, University of Salamanca, Plaza de la Merced, s/n, 37008 Salamanca, Spain
{luismendez,danihiglesias,gvg,fcofds}@usal.es

Abstract. The use of rented bicycles as an alternative means of transport has increased relatively in the last years. This increase sets a challenge to the management of shared bicycle fleets that can now be found in the majority of European cities. The main objective of this work is to design a comprehensive system which will monitor bicycle fleets using low-cost sensors. The system allows for the detection of anomalous situations, detecting possible robberies, vehicle abandonment and use of bicycles in prohibited areas. To this end, the use a multi-agent architecture is proposed for the management of the different hardware devices, for tracking, messaging and alerts that are produced by the system.

Keywords: Intelligent transport systems · Fleet management · e-Bike · PANGEA

1 Introduction

The daily movement of vehicles in cities results in the consumption of 75% of world energy [1] and the emission of 80% of greenhouse gases [2]. The increase in human mobility and transport in urban environments is a great challenge for today's society, as it is one of the main causes of city crowding and logistic and energetic inefficiency, as well as pollution to some extent [3, 4]. To tackle this problem, we need innovative solutions in communication networks, information processing and transport, which would enable us to make a more efficient use of the resources (vehicles, energy, roads, etc.), at the same time, providing free and flexible mobility. The growing idea of intelligent cities implies new challenges and requires new solutions in relation to transport. In the last years, the use of vehicle-sharing systems has spread, one of them being public bicycle services [5, 6], as well as the shared use of cars [7] and motors. "Free" drivers' systems like Uber or; in the goods distribution sector, "flexible" fleets which are formed "on the go" and offer novel systems on the basis of new technological opportunities and dynamic demand [8].

The main goal of this work is to create a geolocation system of bicycle fleets which will allow to calculate the position of different bicycles through low-cost hardware systems. Using the information collected by the system, it will be possible to obtain information about the routes travelled by the different users. This data will provide

J.F. De Paz et al. (eds.), *Ambient Intelligence—Software and Applications—8th International Symposium on Ambient Intelligence (ISAmI 2017)*,
Advances in Intelligent Systems and Computing 615, DOI 10.1007/978-3-319-61118-1_23

knowledge of the most commonly travelled routes by the users, the places visited by the vehicle, performance statistics and areas with least visitor frequency.

The hardware device employed in this work uses GPS technology [9] in combination with a mobile communication system called GPRS [10]. This study will focus on a low-cost device which will be easily installed in the bicycles that are already present on the market. For the management of data and all the events produced in the system, a multi-agent architecture based on the PANGEA [11] platform has been designed, enabling the integration of software agents in hardware devices of low computational capacity, as in the case of the tracking device used.

The rest of this work is organized as follows: Sect. 2 reviews similar works, Sect. 3 explains the architecture and its application in the case study. In Sect. 4 we will present the results and conclusions obtained in the research.

2 Background

The existing types of transport are of great importance in our everyday life, since citizens spend a large part of their lives travelling, both within their own cities and when travelling to other places. The train stations, buses and other vehicles (like cars and bicycles), can be equipped with technology that could provide basic knowledge on how the system can react at each moment. Based on this knowledge, the use of this type of systems in a preventive and effective way, would improve people's daily lives. Additionally, the public transport system can benefit from new technologies, such as the sensor systems, vehicle identification and image processing, which would help achieve a more fluid, efficient and above all, safer transport.

As for vehicle fleet management in urban environments, in the current literature, it is possible to find various works. As in the case of work [12] where the authors present a revision and classification of the intelligent stocking methods for electric vehicles, in accordance to their location. Also, work [13] tackles the problem of bicycle fleet management in the renting systems, analyzing the location of the stations for a more dynamic management; providing high availability to all of the users. Various works also examine this topic, for example in [12, 14] the authors propose different techniques that intend to solve the problem of design, and location of the different stations in the renting and restocking of bicycles in the cities. Other works, such as [15] propose the use of geolocation systems based on GIS for the calculation of potential travel demands to create specific distributions, locate the stations using location assignment models, determine station capacity and define the demand characteristics of the stations.

In the literature we can find numerous works that tackle the problem of integrating software agents in hardware devices of low computational capacity, such as [16]. The work [16] is based on the PANGEA [11] architecture, just like the architecture proposed in this study. This is not the only work where we can find PANGEA, in [17] authors also propose the use of this architecture, integrated in a series of medical sensors for the remote monitoring of patients. Other examples, [18–20] where we can also find the integration of sensors in multi-agent architectures. All these works have in common the use of integrated architectures in hardware systems, however, this has not been applied to real-time tracking systems for vehicle fleets based on low-cost hardware and MAS systems. The following work is proposed after a thorough examination of the present literature and the lack of studies in this particular area.

3 Proposed Tracking System

In this section we present the architecture designed in this work, to track and monitor shared bicycle fleets. We describe the low-cost hardware used and the final system implemented in the development of this work.

A MAS (multi-agent system) architecture system is proposed, based on the PANGEA [11] platform for the tracking and monitoring of shared bicycles in the renting system, implemented in the city. In Fig. 1 we show the designed virtual agent organization.

In the first place, the **Bicycle Tracking System** is formed by the agents: alert, monitoring, coordinator and GPS, embedded in the low-cost hardware system. The agent with the GPS role will be in charge of obtaining data through the GPS antenna. These data reach the coordinator, who is responsible for passing them on to the monitoring agent. If the monitoring agent detects values which are out of the permitted tracking range, he interacts with the alert agent. The alert agent is in charge of sending the incidents to the server which is in charge of its management.

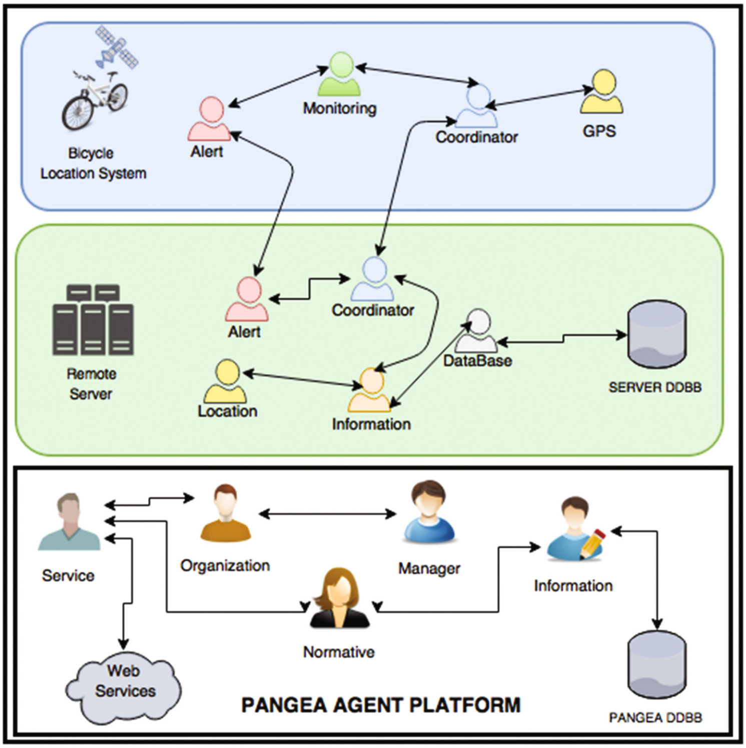

Fig. 1. Virtual organization of the system based on PANGEA platform

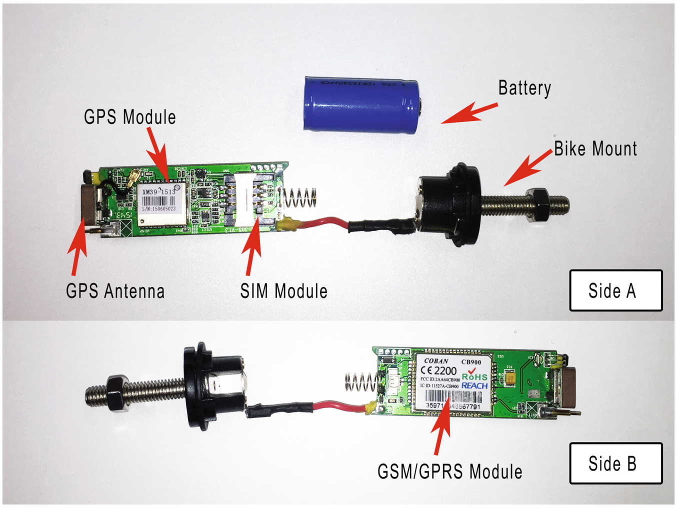

Fig. 2. Bicycle tracker device

The organization **Remote Server** includes the agents: Coordinator, information, alert and database. The agent with the coordinator role is in charge managing information that is received from the tracking device. The agent whose role is information is responsible for regulating the data received and subsequently sending them to the database agent which is in charge of its persistence in the DB. The agent with the alert role is responsible for analyzing the different alerts which are sent form the tracking device. The tracking agent obtains tracking data from the different bicycles, with this information a knowledge base is constructed on user habits, analyzing the repeated locations and frequent routes made. This information is stored again through the database agent in the DB and will be used in future works for system optimization and pattern extraction and statistics on cyclist's behavior in the city.

3.1 Hardware Device

The commercial device used costs less than 30 € and can be installed in any bicycle by placing it in the head tube of the handlebars. In Fig. 2 the device board can be seen, it is composed of the GSM/GPRS communication module, it operates through a telephone line, for that, a SIM card reader module is provided. It has a GPS tracking chip and an antenna with which triangulation data are received. The device also has a compact and light battery of 1400 mg capable of functioning during 6 months and sending data to the central server.

3.2 Final System

An image of the proposed system infrastructure is shown in Fig. 3. Firstly, the GPS device described in the previous section can be seen. It is used to obtain the

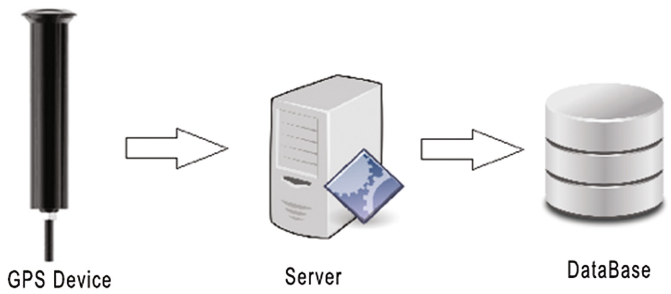

Fig. 3. Diagram of the tracking system

geographical coordinates which are then sent. These data are collected by the central server in which they are received, treated and stored in a database.

The central server identifies each of the devices through their IMEI (International Mobile Station Equipment Identity). This helps to differentiate clearly which bicycle send each tracking message at any time and if the connection has been lost or if the device doesn't have enough battery. The central server also processes all the data in real-time in the search of anomalous values which can indicate some type of problem, such as robberies, vehicle abandonment or if the device is being altered.

4 Results and Conclusions

The main outcome of this research is the multi-agent architecture which is able to communicate with computationally limited devices, such as the autonomous micro-controllers which are connected to low amperage batteries. The use of PANGEA helps save battery as opposed to SOAP type architectures through the use of MQTT protocol.

The device designed in this case study allows for the geolocation of vehicle fleets and its cost is below 30 €, making it a bearable price for the companies in the sector. The information collected from the routes made by the users, enabled us to obtain behavior patterns and information relevant to the owners of the bicycle renting system. As for the administrative user, we can view the km travelled or the condition of each bicycle, so that we know the exact time at which bicycle should go through a checkup.

The tool gives information on the city areas to which the users most often travel. Verification test carried out in the city council can provide information on where more bicycle lanes are needed. In the case of a robbery, the position of the bicycles can always be checked. The end-user of the service can find out which stations have high-bicycles availability and which stations have no bicycles available at a given moment.

Images of the application developed are presented below (Figs. 4, 5, 6 and 7)

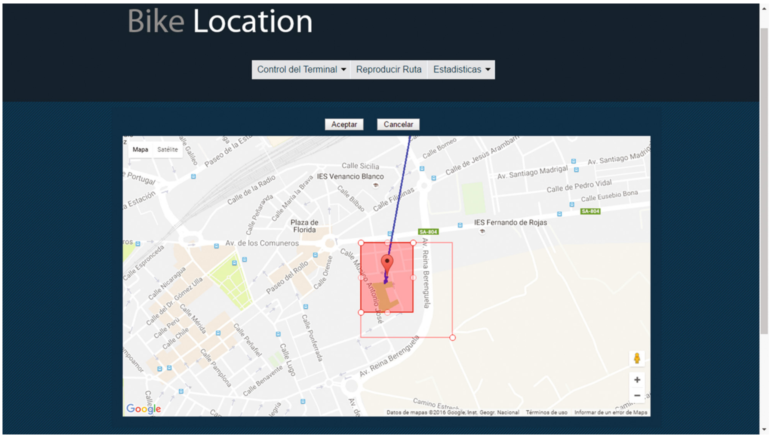

Fig. 4. Geo-boundary configuration to detect robbery and unauthorized use of vehicles

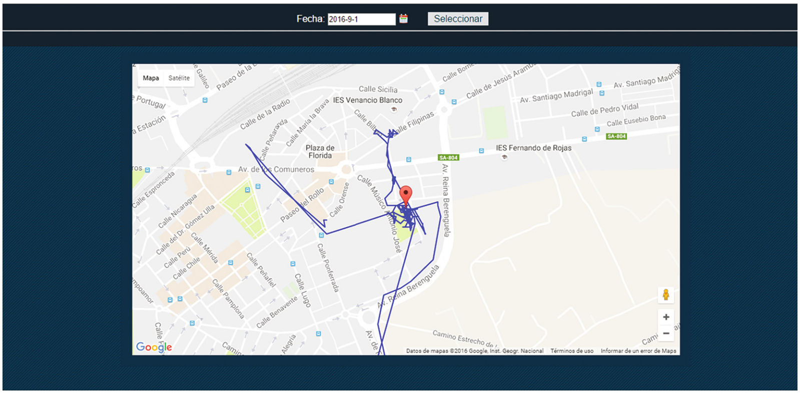

Fig. 5. Retrieved route

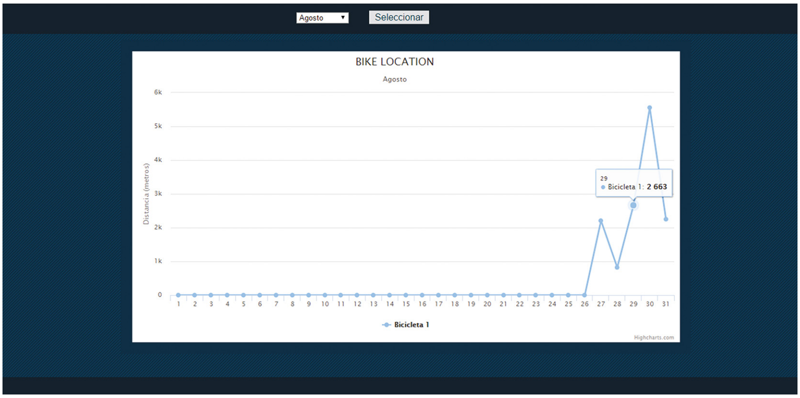

Fig. 6. Distance graph that shows the distances traveled by the user and the total kilometers traveled by the vehicle

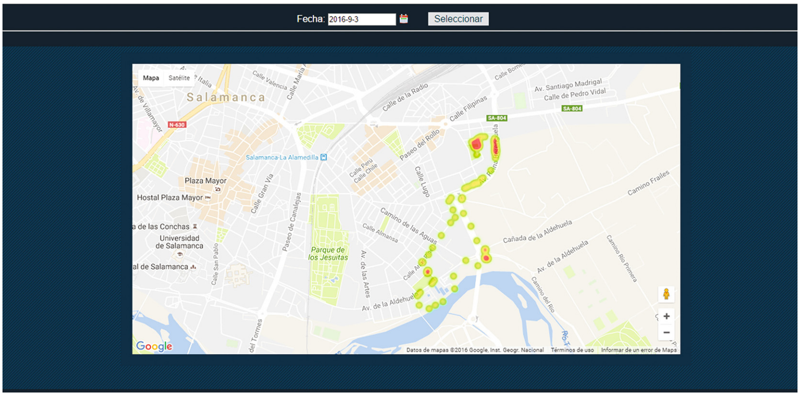

Fig. 7. Heat map indicating the most traveled areas by a vehicle

Acknowledgements. This work was supported by the Spanish Ministry, Ministerio de Economía y Competitividad and FEDER funds. Project. SURF: Intelligent System for integrated and sustainable management of urban fleets TIN2015-65515-C4-3-R.

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