Combined BLE-GNSS Positioning System for Intelligent Guidance and Activity Monitoring of the Visitors to an Archaeological Site.

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Abstract

Location-Based Services (LBS) provided by mobile phones have become an instrument with great potential in cultural environments such as museums or archaeological sites. This paper presents the preliminary results obtained with a real system deployed in the archaeological site of Mértola (Portugal) that, in addition to providing visitors with an intelligent guide service, allows the managers of the environment to obtain information about the behavior of these visitors. The system is based on symbolic positioning using Bluetooth low energy beacons and GNSS positioning data obtained from visitors' cell phones. A specific application for Android devices has been developed to conduct BLE signal detection and establish a bidirectional communication with a central server.

Keywords

Location-Based Services (LBS), Symbolic Positioning, Bluetooth Low Energy (BLE), Activity Monitoring.

1. Introduction

Location-Based Services (LBS) constitute the main reason that has fostered an intense research activity in the field of Local Positioning Systems (LPS). They can be generally defined as information services accessible with mobile devices through the mobile network and utilizing the ability to make use of the mobile device location [1]. These services result from the intersection of three technologies, namely, New Information and Communication Technologies (NICTS), the Internet, and Geographic Information Systems (GIS) with spatial databases [2]. Although LBS share with GIS some common features, such as the handling of data with positional reference and spatial analysis functions, they have different origins and different target user groups, since the former are developed as limited services for large non-professional user groups and must deal with the typical restrictions of the mobile computing environment, like low computational power, small displays or limited battery run time. There is a broad range of different LBS, which can be categorized into a variety of application fields, such as navigation (indoor routing, car park guidance), Emergency (emergency calls, automotive assistance), Advertising (ban-ners, alerts), Billing (road tolling, location sensitive billing), Management (facilities, fleet scheduling), Games (mobiles games, geocatching), Tracking (people/vehicle tracking, product tracking) and Information (shopping guides, tourist guides), among others [3].

The work presented here falls into the last of these categories, and it is a consequence of an attempt to transfer the technological knowledge acquired by our research group in the field of LPS to a particular application: the development of a smartguide for archaeological sites in the Spanish region of Extremadura and the Portuguese region of the Alentejo (The ECLIMUS project

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[4]). This smartguide, intended to replace the popular audio guides should notably enhance the visitors' experience by providing richer multimedia information (text, sound, images, and videos) at no rental cost, and also eliminating any health risk derived from their shared use. Although some smartguides and services alike have been already successfully designed this is, to the authors knowledge, the first work that proposes the development of these services in an archaeological site and, more importantly, with the capability to provide the managers of the environment with information on visitor behavior.

The paper is organized as follows. Section II describes in detail the main components of the proposed system, including BLE beacons, software architecture, detection algorithm and monitoring services. Section III presents some experimental results obtained during the deployment of the system in the archaeological site of Mértola, in Portugal. Finally, the main conclusions of this work and those tasks foreseen in the short term are summarized in section IV.

2. System description

The ECLIMUS smart guide is based on a set of BLE proximity beacons which are strategically deployed in an archeological site to tag different points of interest (POI) for the visitor. These visitors have previously downloaded and installed a free app in their mobile terminals. When activated, this app starts scanning the environment for nearby BLE beacons and sending global positioning data to the central server. A nearby beacon is considered a "Beacon of interest" (BOI) when its received signal strength meets certain criteria that will be described in detail later. The validation of a BOI is shown to the user with a message on the screen of their mobile terminal, and the user decides whether or not to receive the information associated with that BOI by tapping on the message. In the first case, the phone records the time that the user is consulting the information associated with the BOI and sends this information back to the server at the end of this consultation.

2.1. BLE beacons

BLE is a communication protocol designed as an extension of the traditional Bluetooth. It is specifically tailored for short, periodic, and power-efficient communications within the context of the Internet of Things (IoT). Similar to Wi-Fi and standard Bluetooth, BLE also operates in the 2.4 GHz frequency band. The protocol encompasses two types of communication schemes: advertising and connection. In the former, a device periodically broadcasts information that is available to all potential receivers in the environment. Meanwhile, connection mode is reserved for private and direct communication between two devices. BLE transmitters, commonly referred to as beacons, are primarily designed for the advertising mode using use connection scheme only for configuration tasks.

With the widespread adoption of BLE in recent years, lightweight protocols have been developed on top of the BLE specification to organize the format of advertisement information. This information usually corresponds to sensor data, identification codes and URLs directions. The two most well-known protocols are Eddystone and iBeacon frames, developed respectively by Google and Apple to enhance compatibility between their respective systems using BLE.

The BLE beacons used in the ECLIMUS system are the iBKS 105 from Accent Systems [5], which use the Nordic Semiconductors nRF51822 chipset [6]. This device is powered by a single CR2477 button cell battery and is wrapped in a plastic white case. Each beacon can broadcast multiple signals at the same time through different slots. Four slots following Eddystone specification and two with iBeacon, using different transmission powers and advertising periods for each of them. iBKS 105 beacon's settings can be configured using the application provided by the manufacturer or with a custom developed application using its Generic Attribute Profile (GATT) provided in the system's specifications. A picture of the beacon is shown in Figure 1.

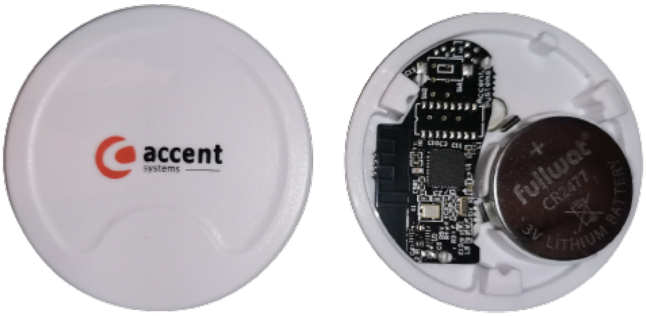


Figure 1: iBKS 105 BLE beacon from Accent System

2.2. Software Architecture

From the highest level, the infrastructure developed to service the application can be seen in Figure 2. This infrastructure presents two perfectly differentiated parts: the server and the app.

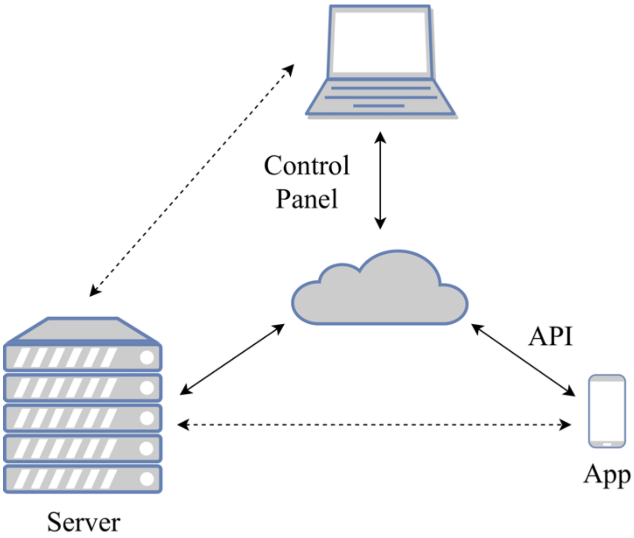
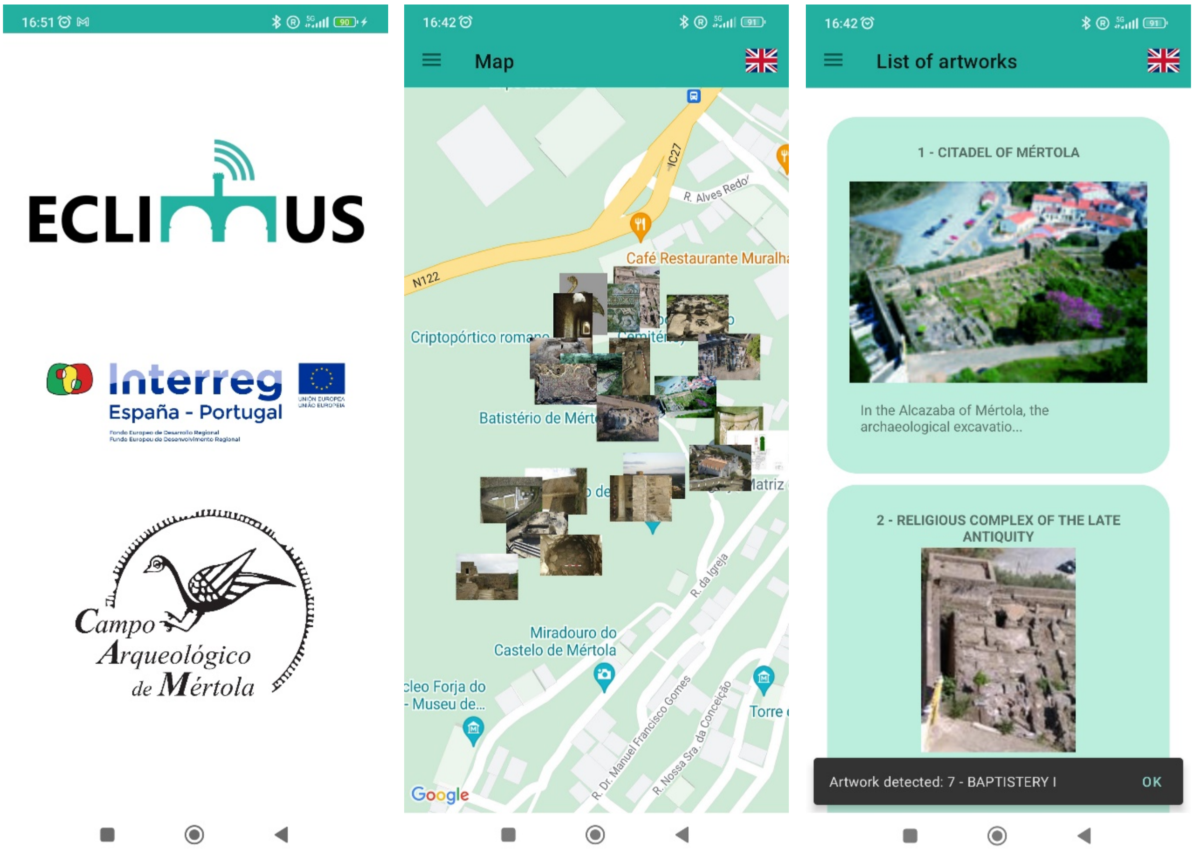


Figure 2: Software architecture

The server provides the app with the data of the different exhibitions in the archaeological site. A REST communication interface [7] is used to obtain the data. A control panel is available for data maintenance and allows museum administrators to see different statistics about the visitors, such as most seen exhibitions, the amount of time spent viewing an exhibition or the GPS trajectory followed by the visitors. Both the server and the application need an Internet connection to work together. The client app appearance can be seen in Figure 3. Its operation is explained below.



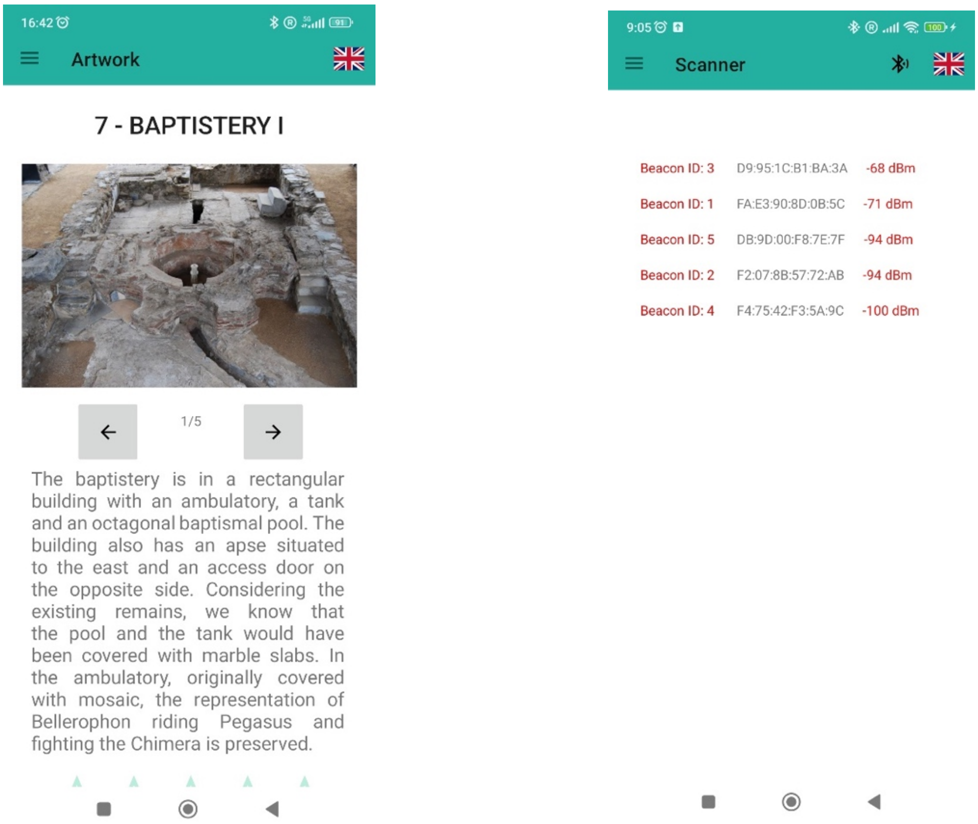
1 - CITADEL OF MÉRTOLA

In the Alcazaba of Mértola, the archaeological excavatio...

2 - RELIGIOUS COMPLEX OF THE LATE ANTIQUITY

Artwork detected: 7 - BAPTISTERY I OK

(a) Splash screen (b) List of exhibitions (map) (c) Searching for BOIs



7 - BAPTISTERY I

1/5

The baptistery is in a rectangular building with an ambulatory, a tank and an octagonal baptismal pool. The building also has an apse situated to the east and an access door on the opposite side. Considering the existing remains, we know that the pool and the tank would have been covered with marble slabs. In the ambulatory, originally covered with mosaic, the representation of Bellerophon riding Pegasus and fighting the Chimera is preserved.

Beacon ID: 3	D9:95:1C:B1:BA:3A	-68 dBm
Beacon ID: 1	FA:E3:90:8D:0B:5C	-71 dBm
Beacon ID: 5	DB:9D:00:F8:7E:7F	-94 dBm
Beacon ID: 2	F2:07:8B:57:72:AB	-94 dBm
Beacon ID: 4	F4:75:42:F3:5A:9C	-100 dBm

(d) Exhibition information (e) Scanner screen

Figure 3: Different screenshots of the end-user version of the ECLIMUS app.

Figure 3a shows the startup screen that appears when the application is executed. At this moment, the server associates an anonymous ID to the user ensuring that all the data collected can never be associated with a person. After a few moments, a new screen appears on the user's phone asking permission for the collection of location background data and informing about the usage of this. When the user accepts or denies the sharing of data, a new screen appears with a list of all the exhibitions allowing the user to access the information associated with each of them at any time, without having to detect the presence of a BOI. This list can be seen over a map (Figure 3b), or as individual items (Figure 3c). In any of these screens, the "BOI search" mode of operation is running in the background scanning BLE beacons in the environment, and when it validates a BOI it displays a detection warning on the screen (Figure 3c). If the user clicks on this notification, they obtain information about the part associated with that BOI (Figure 3d), and the app starts recording the amount of time spent in that screen. The user can rate the exhibition from 1 to 5, and this information is sent to the server together with the view time when this screen is closed. Otherwise, the app continues in search mode. Finally, a "scan" mode of operation (Figure 3e) displays the signal strength (RSS) of all the beacons being detected at a given time. This mode of operation is intended for technicians in charge of deploying and maintaining the system, and is not available in the end-user version of the app.

2.3. BOI detection algorithm

Proximity solutions using BLE for LBS have been extensively explored due to two key factors: a) BLE compatibility with most off-the-shelf smartphones and b) the widespread use of these devices. Proximity detection algorithms with this technology are typically based on the Received Signal Strength (RSS) which measures the signal attenuation using an integer value on a logarithmic scale.

When using BLE for proximity detection, the standard approach is to associate the user position with the position of the beacon with the highest RSS. This approach proves useful when edge or cloud computing options are unavailable since the smartphone must perform all operations. Unfortunately, various factors affect RSS measurements, including attenuation, multipath, and non-line-of-sight effects. These effects increase variability between consecutive RSS measurements and disrupt the before-mentioned logarithmic relationship with distance [8]. Different alternatives have been proposed to tackle this problem. Most notably, using machine learning-based methods [9] to identify proximity or substituting the proximity algorithms with more advanced positioning techniques like multilateration [10] and fingerprinting [11]. However, these solutions require higher computational capabilities and increase the system's complexity. Thus, an optimal proximity detection algorithm must be able to deal with non-line-of-sight effects without having a high computational cost for the device.

In this work, we propose a proximity-based algorithm for RSS measurement based on thresholding the relationship between the beacons with the highest RSS. The detection algorithm is divided into an initialization process and three tasks performed consecutively after each new BLE detection. These stages are 1) measurement list update, 2) time control, and 3) RSS thresholding and redundancy criteria. During the system initialization, four arrays are created, each with a length equal to the number of available beacons (point of interest in the system). These arrays correspond to the list of RSS values, detection timestamps, the list of MAC addresses of each beacon, and a proximity score. The arrays are initialized with null values, except the list with the MAC codes, which content is provided by the server.

When a new beacon is detected, the RSS and timestamp lists are updated by using the index of the corresponding elements in the MAC list that match the MAC address of the newly detected package. Following this update, the timestamp list is compared with the last timestamp added to the list. The score of elements detected more than T_s seconds ago is set to 0 and the corresponding RSS to null. After this correction, the RSS list is sorted and ordered from highest to lowest. Then, the proximity score of the beacon with the highest RSS is incremented by one unit if the following conditions are met:

- The RSS is above a threshold value (Th_1).
- The absolute difference between the first and second RSS in the sorted list is below a second threshold (Th_2).

The proximity score is set to zero if these conditions are not met. Once the proximity score of a beacon reaches a value equal to T_r, it is considered as a valid proximity detection and the algorithm outputs its MAC code to the application.

The parameters of the detection algorithm, Th_1, Th_2, T_s, and T_r, are adjusted based on the specific characteristics of the experimental environment and the configuration of the beacons. Th_1 and Th_2 are determined by the transmission power of the beacons and the desired effective detection area around the Point of Interest (POI). T_s is configured as a function of the beacons' transmission period, and T_r is set as a function of the average noise level of the RSS. By adjusting these parameters, the detection algorithm can be customized to suit the specific requirements of the environment and the desired proximity criteria. The operation of this algorithm is shown in

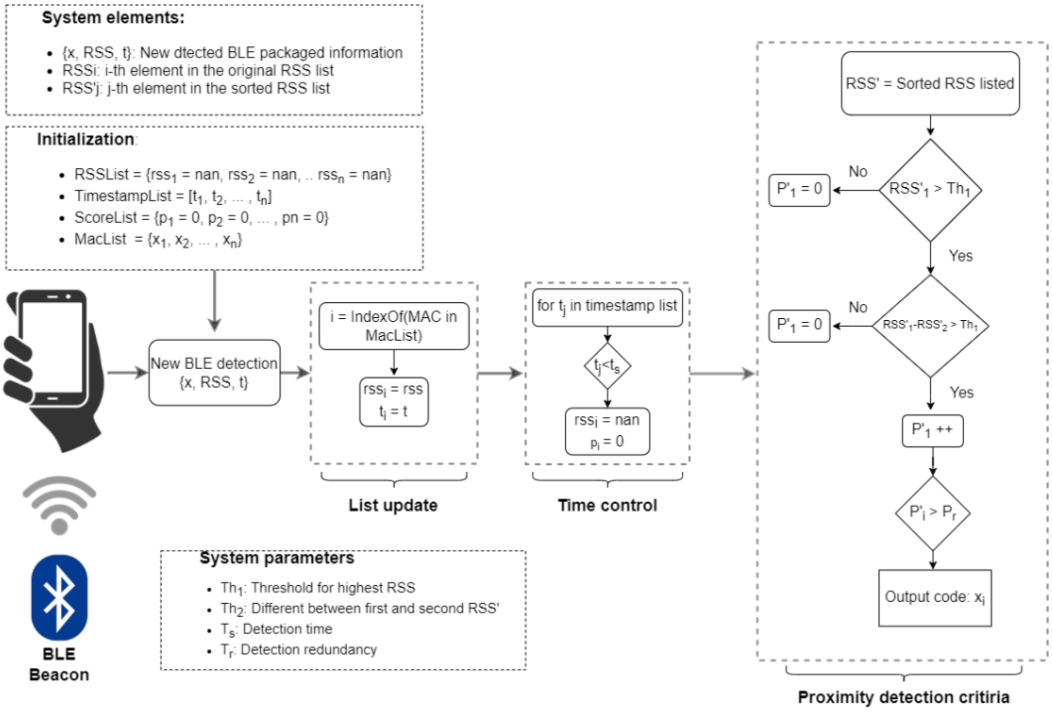


Figure 4: BLE BOI detection algorithm

2.4. Server monitoring services

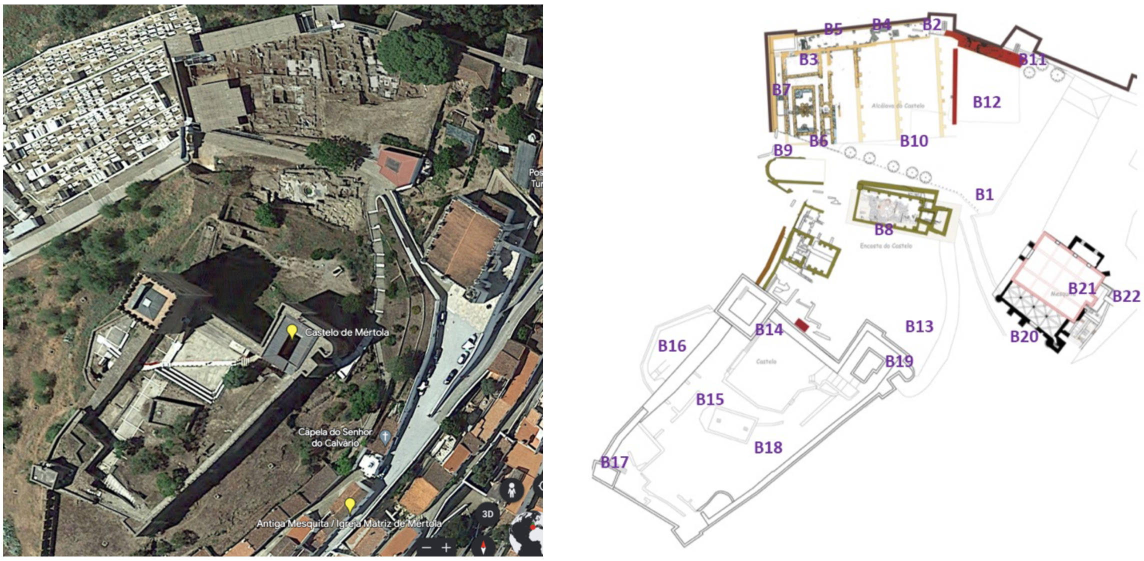
With the permission of the user, the app is constantly collecting location and BLE RSS data in the background and sending them to the server. Besides, information about BOI detections, view times and ratings are also sent to the server. These data are used to provide a set of statistical results that can be accessed by museum administrators at any time in the control panel.

The currently available monitoring services in the control panel are:

- Daily statistics: a table with the exhibitions visited in the selected period. The mean visit time, number of visitors and mean rate is displayed in this table.
- Heatmap: the information of the mean visit time and number of visitors available in the daily statistics is shown in the map of the museum for easier analysis.
- GPS trajectory: the location data collected by the app is filtered by user and its trajectory in the museum is reconstructed and shown in a figure containing the exhibitions' locations.

3. Experimental Results

The system described in the previous section has been deployed in the archaeological site of the city of Mértola, in Portugal, during the last week of May, 2023. This archaeological site has three distinct but close to each other areas, namely the castle, the citadel and the mosque. A total of 22 points of interest have been identified in this environment, each of which has been assigned a BLE beacon. Figure 5 shows a Google Earth image of this archaeological environment together with a map of the environment, where the location of the 22 beacons have been labeled.



(a) (b)

Figure 5: Google Earth image of the archaeological site (a) and map of the environment with the beacons location (b).

Once the system was deployed, its performance was evaluated for one day in order to present some results in this paper. It is important to note that the system will remain installed in the archaeological site throughout the month of June, so that more conclusive results are expected to be available during the conference.

Figure 6 shows information on the number of visitors to each of the 22 POIs, as well as the average time spent by these visitors at each of these points, which is expected to be correlated with their interest in the information presented in that point. The number of visitors to a POI is proportional to the radius of the circle that marks each point, while the average time of the visit is indicated by the color scale on the right of the image. As we can see in this figure, POI #1 (entrance to the citadel) was the most visited one, with a total of 19 visits, while PO1 #14 (the Keep) is the one with the longest average visit time (668 seconds), although this POI was only visited by 3 people. On the other hand, Figure 7 shows the trajectory followed by a particular visitor within the archaeological site This information is shown with circles whose color changes with time according to the time scale on the right of the image. As this figure shows, the app user started his visit at the entrance of the citadel (POI #1), approached the second Baptistery (POI #8), entered the citadel and once there visited the Andalusi quarter (POI #12) and the Andalusi house (POI #11), to stay later at the wall, probably enjoying the magnificent views of the city from there.

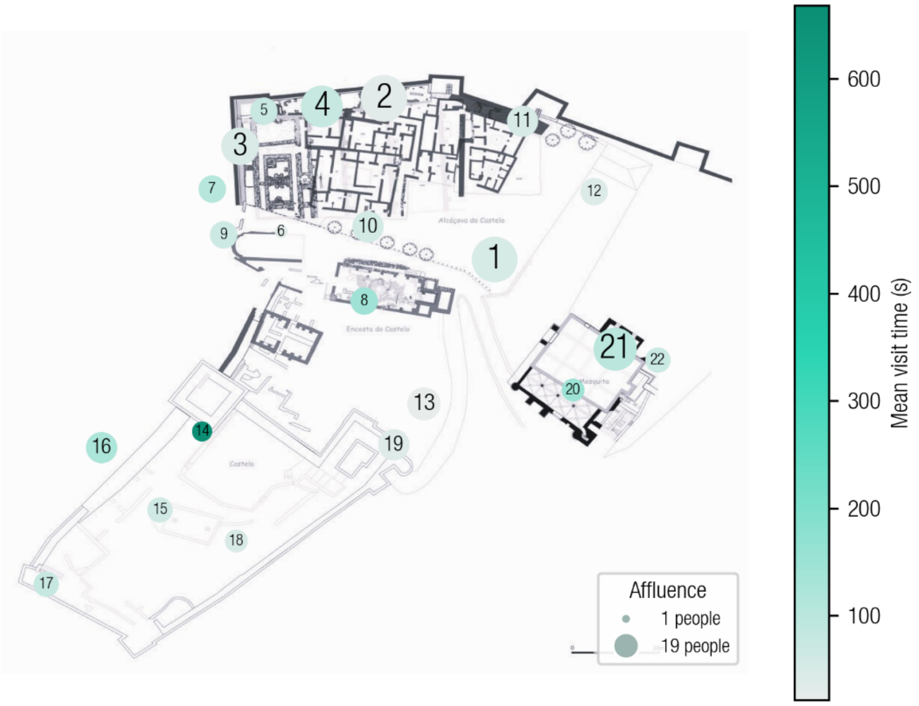


Figure 6: Map of visitors during one day.

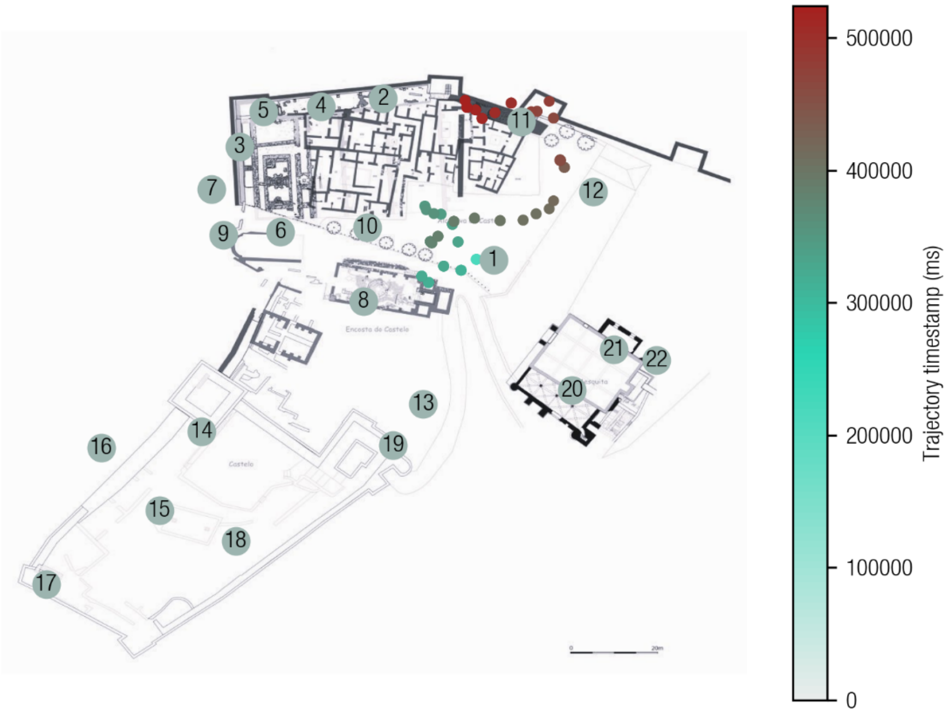


Figure 7: GPS trajectory followed by a particular visitor.

4. Conclusions

This work has presented a combined BLE-GNSS positioning system for intelligent guidance and activity monitoring of the visitors to an archaeological site. The system is based on BLE symbolic positioning to provide the user with useful information related to the nearest point of interest and to determine the number of visits and the average time of visit to each POI. It also gathers the users' GNSS data to analyze their trajectory within the environment. All this information is presented to the managers of the environment through map-based graphs.

The real system has been deployed in the archeological site of Mértola, in Portugal, during the last week of May, 2023 and for this reason only some preliminary results are presented in this work. Since the system will be installed in this site throughout the whole month of June, more realistic and rich results are expected to be presented at the conference.

Acknowledgements

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