Architecture for Museums Location-Based Content Delivery using Augmented Reality and Beacons

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***Abstract*—The digital transformation applied to museum's context is somehow usual nowadays, presenting many benefits to the visitors. However, most of the applications provide static and basic information that is not appealing nor promotes the involvement of the visitor in the tour. This paper proposes an architecture of a location-based content delivery inside a museum, based on a dynamic approach that promotes the visitor to immerse in the tour's story. The solution was created as a response to a real case study for the Foz Côa museum in Portugal. The proposed solution uses beacons, for the indoor location of visitors, and augmented reality for providing contents based on what the user is seeing, following a narrative that captures his attention at all times and providing artifact's details that the naked eye can not see. A comparative study was made to determine the properties and compare two augmented reality tools: Immersal AR and EasyAR. The precision of beacons detection, under different conditions and configurations, was also presented as preliminary results of this work.**

***Index Terms*—Indoor-Location, BLE Beacons, Augmented Reality, Content-Delivery, Museums.**

I. Introduction

Museums have a fundamental role in preserving and transmitting local culture [1]. With the careful preservation of documentation and artifacts, culture can be recorded and remembered regardless of its future. The past can be learnt by everyone and cultural backgrounds can be shared across generations. It is important to promote and develop museums environments where visitors are able to access space information and therefore have a more enriching visiting experience [2]. Several challenges arise in the indoor environment of a museum such as accessing more information of a given artifact, the unavailability of a guide when required or the need of an extra payment for a more individualized experience [3]. It is well-known that visitors often get bored which makes the task of capture the visitor attention a challenge, specially if they are children [4]. Therefore, addressing the different preferences of users during a visit is a challenge for museums. To address this issue, several applications exist that assist museums, by providing guided visiting experiences. However, in most of them, the information provided is static and does not prevent the visiting experience from being boring, except the ones that already use new technologies such as augmented reality. To assure a better experience in the museums, the development of interactive, dynamic and personalized experiences becomes fundamental, combined with augmented reality that provides location-based content in an indoor environment. Involving the visitor in the tour, making him an element creator and contribute with further exposed content is another way to capture his attention. Telling stories about the space itself is yet another way to capture the visitor's attention. The story should be divided by the museum space to maintain the visitors interest by wanting to know the evolution of the story. The story style should also be compatible with the visitor segment (e.g. adult or child).

This paper presents an architecture and preliminary results of an indoor content-delivery solution for the Foz-Coa Museum in Portugal, using augmented reality, beacons and a mobile application. This R&D project emerged with the specific necessity of providing guided visit experiences inside the museum in an interactive and dynamic manner, present specific details of the artifacts and provide guided visits, without the need of a human guide. Towards accomplishing this goal, the project aims to tell a tale along the visit course and engage the visitor's at all moments, making him feel part of the story. The tale intends to be transmitted by a virtual character, using augmented reality.

The main contributions of this paper include a technological architecture proposal for a location based content delivery solution in an indoor environment using Bluetooth beacons, the comparison of two augmented reality technologies and their suitability for the current scenario and a performance analysis of beacon's precision in a set of scenarios that intend to reproduce real life situations that will occur in the museum.

The rest of this paper is organized as follows. Section II presents the revision of related work. Section III introduces some technologies relevant for this study, namely about beacons and augmented reality. Section IV introduces the proposed solution, technological architecture, data model and the mobile application. Section V presents preliminary results regarding beacons precision. Section IV presents the main conclusions of this work.

II. Related work

With the evolution of technology and the constant growth of smartphone usage, the creation of sophisticated and more accurate real-time indoor-location systems became possible.

Cultural domain can benefit from these advances, namely museums.

An example of that is presented in [5] where authors focus on a solution that enhances the user experience in a museum, based on the location information. That location information is obtained from a Bluetooth Low Energy infrastructure installed inside the museum where also several location-aware services can be provided. The content is provided based on the user's position.

In [6], authors present an indoor localization system that enhances the user experience in a museum. The proposed system relies on Bluetooth Low Energy (BLE) beacons proximity and localization capabilities together with a RSS-based technique, which automatically provides the users cultural contents related to the near artworks. This location-system was implemented on an Android application that not only provides content information to the user, but also collects useful analytic, regarding each visit and provides recommendations to the users. The authors concluded that BLE beacons are a promising solution for an interactive smart museum, due to their effectiveness and, as such, should be often used in this contexts.

In [7], a solution based on a special purpose handheld device, with limited storage, is presented. The solution provides the ability to display different types of high-quality multimedia contents, on an interactive screen with high resolution. The solution architecture comprises a server, in which all antiquities database is stored. The moving unit starts by determining its location, sends its coordinates to the database server and then determines the nearest antiquity to the moving unit. In the final phase, the antiquity's multimedia data is sent to the moving unit to be displayed. The location is calculated with the help of Bluetooth Low-Energy beacons for a moderate accuracy, long lifetime, ease of operation and cost effectiveness.

Specific research for understanding patterns of human behavior using real-time location systems is also a focus of the scientific community. In [8], authors investigate behaviours using indoor-location data. They highlight four areas where these systems have an excellent usage: health status monitoring, consumer behaviours, developmental behaviour, and workplace safety/efficiency. The data gathered was categorized into four groups: dwell time, activity level, trajectory and proximity.

In [9], the authors presented an accessibility system that allows visually impaired museum visitors to have a tour around the place. Wi-Fi indoor positioning techniques were used, so that visually impaired visitors could hear relevant audios through an Android app, from their own smartphones, based on their location inside the museum. The system was latter adapted and used to assist the general public during their visits, allowing access to texts, audios and images, always according to the visitant position.

In [10], authors present a solution based on augmented-reality. The solution encompasses an application that reads the deteriorated text of coins and also shows additional information that offers a clear idea of the general meaning of the coinage of the coins. After several studies performed with real visitors, authors concluded that with the help of their app users found it easier to read the information on the coins and see details that the naked eye would never have been able to see. The application made the museum tour more enriching and interesting.

In [11], authors made a study about the tourism sector in Malaysia, more specifically the local culture and history museums, and noticed that the number of visitors were decreasing over the years. Then, they concluded that many museums are now using digital technologies to enrich visitors experience, such as augmented reality because tourists are now becoming more tech related. After performing a study, aimed to examine the impact of augmented reality in museum tours, the authors concluded that with the support of an AR application the sector cloud rise up to 61.2%.

The presented literature demonstrates several works that address single issues but none of them provide a flexible and dynamic solution that addresses all issues in an integrated manner. The work presented in this paper distinguishes itself for being a solution that combines a cyber-physical component with a mobile component and also with augmented reality.

III. Technologies

In the context of the current project, two technologies were tested and validated: beacons and augmented reality. The latter is also used for location purposes through space mapping offered by AR platforms.

A. Beacons

Beacons are small size, low cost and wireless transmitters that can operate with several protocols. [12]. The evaluation tests presented in this work used Estimote Monitoring and the Estimote Telemetry protocols.

Periodically, beacons send their identifier and data packets to nearby devices that support BLE signals, such as smartphones and tablets. This data can be transmitted in a programmable interval, that can vary from 100 milliseconds up to 10 seconds. The broadcasting power can also be adjusted from -40 dBm to 4 dBm. The battery life of each beacon depends on their configuration, the lower interval transmission and the higher broadcasting power. In most of the cases, when the battery runs out it can be easily replaced.

BLE beacons use BLE technology. This technology was designed for applications that doesn't need to transmit large amounts of data and that enable a reduce power consumption and cost. This is a famous technology among the IoT community, due to its low cost and low power requirements.

Beacons have many characteristics that make them one of the best solutions for indoor location systems. First of all, they are small sized, allowing the possibility of being positioned almost everywhere, without being noticed and without disturbing the local environment. Another two important characteristics are the transmission power and the range power, which can both be programmable, according to the system needs. Beacons can reach a range of 60 meters, but this will not only consume a lot of battery but also have a high error ratio. The last characteristic and one of the most important is the Received Signal Strength Indicator (RSSI). This value ranges according to the distance from the beacon and can be used to find the distance between the user device and the beacon.

B. Augmented Reality Technologies

In this section, two augmented reality technologies, **Immersal AR**[1] and **EasyAR**[2], are described and briefly compared.

Although there are several augmented reality tools, these two were chosen and studied because they allow space mapping. This means that spaces can be scanned, in order to provide contents, according to what the user's device is capturing. The mapped space is detected by the AR tools, which offers a means of context location. One of the tools also allows detection of 3D objects.

Immersal AR Commercial Software is expensive and has no feature for 3D object tracking and surface tracking. However, its space recognition is a little better than the EasyAR and makes possible to achieve the following functionalities:

- **Content Placement**: store and move AR objects locally, on the device.
- **Navigation**: create a route system that can guide the user from his location to another.
- **Multiplayer**: enables a multiplayer setup using Unity Networking.

EasyAR Commercial Software is cheaper than the Immersal software and has a large repository of code samples for every single functionality. The EasyAR Sense 4.0 has the following functionalities:

- **Sparse SpatialMap**: to scan the environment and generate sparse 3D point clouds in real time.
- **Dense SpatialMap**: to scan the environment and generate 3D mesh in real time.
- **Motion Tracking**: to track device's position relative to the world.
- **3D Object Tracking**: to recognize and track a 3D object with rich texture in real time.
- **Planar Image Tracking**: to recognize and track planar images in real time.
- **Screen Recording**: highly efficient and simple content recording solution.

Different from Immersal SDK, the EasyAR does not allow to download and have direct access to the generated cloud point maps. A request to the cloud is mandatory in order to used them.

Table I presents a comparison of some of the main features of both software. Both are great for diverse contexts. For this paper solution EasyAR was chosen the because of its low licence price and its additional functionalities.

IV. Proposed Solution

In this section the solution system overview, technological architecture, data model and mobile application are introduced.

[1]Immersal SDK Link: immersal.gitbook.io/archive/v/v1.13/

[2]EasyAR SDK Link: www.easyar.com

	Immersal AR	**EasyAR**
Type	SDK	SDK
Price	Free, Commercial	Free, Commercial
Platform	Android, iOS, Windows, macOS	Android, iOS, Windows, macOS
Geo-Location	yes	no
Unity3D	yes	yes
Cloud recognition	yes	yes
Open CV	yes	no

TABLE I: Immersal AR and EasyAR comparison

A. System overview

Based on the requirements defined by the Foz-Coa museum to deliver content-based information to its visitors, the defined architecture to achieve this purpose is depicted in Figure 1.

Three main components are used in the architecture: 1) a set of wireless BLE Beacons that permanently send a signal; 2) the visitors' smartphones that receive information from the beacons and allow to determinate the room they are in a specific moment and; 3) several **A**ccess **P**oints distributed by the museum rooms, so that every indoor space has internet access, in order to establish a connection with cloud databases and access contents and virtual room maps.

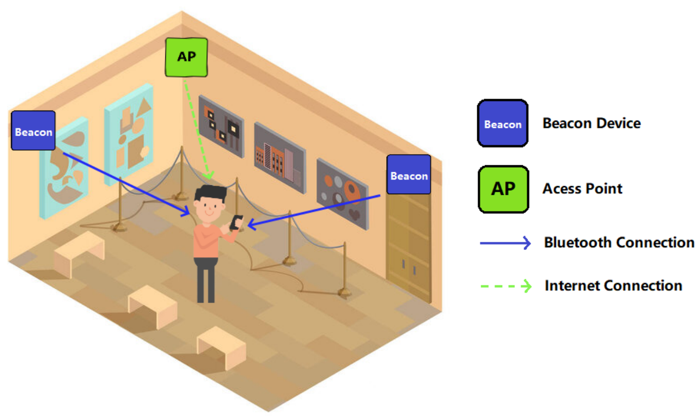

Fig. 1: System Overview.

BLE beacons were chosen due to its low energy consumption and good efficiency in detecting the visitor's room localization. For the correct functioning of the system, in the specific scenario of this museum, two beacons will be placed in each room of the museum: one at the main door entrance and the other inside the room. In case there is more than one door, an additional beacon should be placed.

When a visitor enters in a room of the museum, the signal reception from the beacons make it possible to perceive their location. This is required to access the central data repository, to retrieve the content associated with the room. This content is then shown to the visitor, through the mobile application, and thus enriching the visiting experience. The associated mapped space is also retrieved to allow contextual location for content delivery purposes.

B. Technological architecture

To achieve the system functionality described in the previous section, the technological architecture depicted in Figure 2 was defined.

Inside the museum, beacons are used to locate the visitors' position and obtain the contents and maps of a specific room. It is important to optimize the load of maps and contents; the lesser maps and contents loaded the better application's performance, specially when the museum is quite extensive, that is why two (or more) beacons per room should be used. The visitor position is calculated according to the beacons detected by his device. When only one beacon signal is being received the associated room's contents are loaded. If the device, additionally, captures more signals two scenarios can occur: the additional signal is coming from the other beacon of that room, this means that the user is there; if the additional signal information is coming from other rooms, this means that the visitor is also closed to other rooms, so the contents of that beacon's room are also loaded for a possible case of quick change of rooms.

The contents - that can be images, videos, audios or 3D models - are loaded from a backoffice server, configured and managed by the museum administrators. An API, built in React.js, makes the bridge between the back-office (React.js) and the contents database (MySQL).

In order to ensure that the contents are presented in the correct places a previously scanned map is retrieved and used to correctly place the content in the users field of view, offering a contextual content delivery approach.

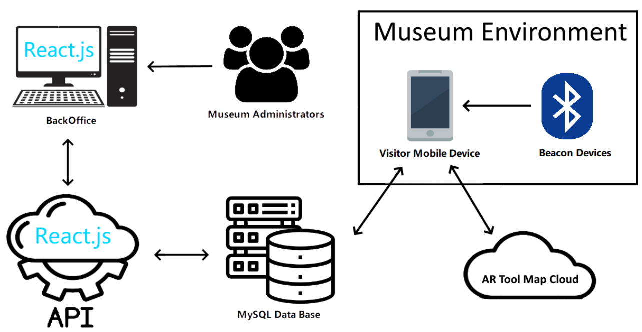

Fig. 2: Overall System Architecture.

C. Data Model

Figure 3 presents the data model used in this solution, which is composed of 9 tables. As previously mentioned, the virtualization of the museum will be divided in rooms. These rooms will have map meshes and beacons associated to them. This means that when a room is created, the system should also provides a mesh of that same room and the group of beacons that will represent that space. The contents are related with the map meshes, because each single mesh will have a set of content animations. These are previously placed in the map meshes coordinate system and presented accordingly to the recognised space. This data and information is all introduced by the administrators in the back-office application.

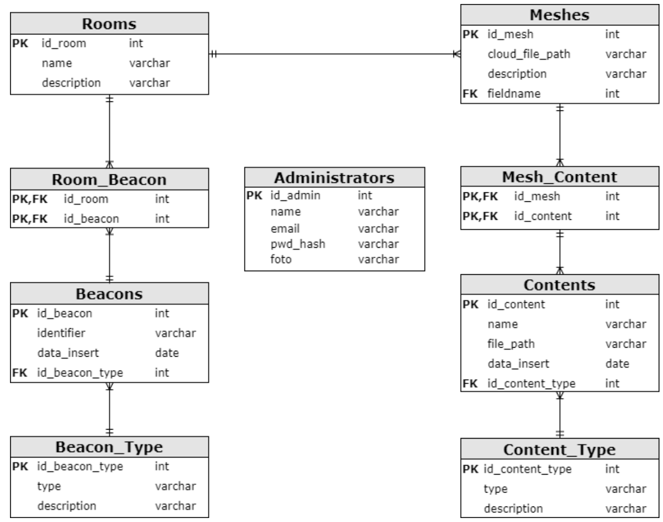

Fig. 3: Database Data Model

D. Mobile application

Figure 4 presents the mobile application workflow. It is composed by the following services and connections:

1) **Receive Beacon Signal Information**: The visitor mobile device, when inside the museum rooms, is constantly listening for beacons signal information. This is the first step needed to move forward.
2) **Determine Room Positioning**: The beacon signal information is processed to determinate the room that the visitor is in. One possible scenario is that only one beacon signal is received by the mobile device, which represent the room the visitor is in. If the device, additionally, captures signal information from other rooms, both spaces will be considered in the next step of the process.
3) **Fetch Map**: After the room position is obtained, a fetch request to the AR Tool Map cloud is made, to obtain the room mesh.
4) **Return Map**: The cloud returns the right room mesh back to the app.
5) **Space Recognition**: Using the AR tool, the space recognition starts with the aim of compare the real-time captured video with the room mesh.
6) **Object Tracking Trigger**: This is another AR tool feature that enables the application to detect a given set of objects in the space. When a certain object is tracked, a trigger is activated to fetch a certain content.
7) **Fetch Local Contents**: A fetch request is made to the content database asking for a specific content.
8) **Return Local Contents**: The database returns the requested content with positioning information.
9) **Contents Presentation**: The obtained content is shown to the visitor in the mobile application.
10) **Beacon Set Changed**: After presenting the contents the system checks if the received beacon signal information has changed. If not, the application continues doing the

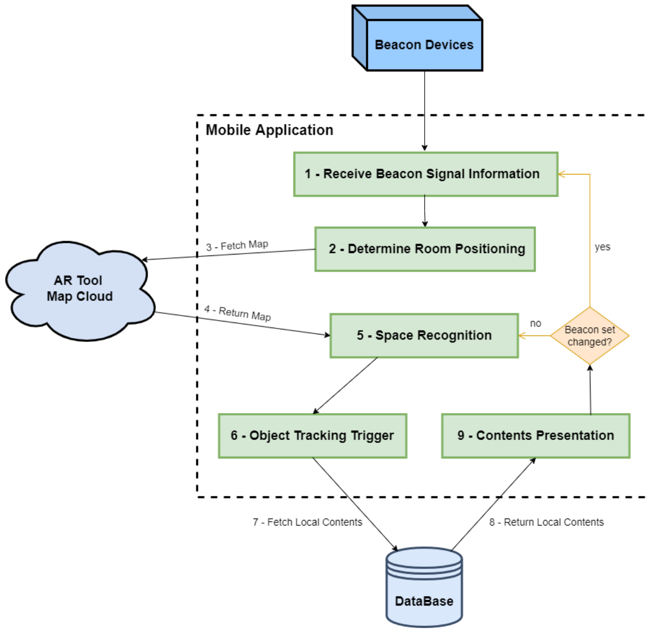

Fig. 4: Mobile application architecture

space recognition and showing contents; If it changes, the room positioning is determined and the loop starts over.

V. PRELIMINARY RESULTS

The tests carried out with the beacons aimed to assess its precision for this particular situation. These detection tests are important in the context of this solution in order to determine the viability of this system when trying to identify the room that the visitor is at. Otherwise, if a indoor location system that is not precise is used, it can lead to many problems like not showing any contents or even show wrong contents to the visitor, creating misinformation.

The tests were made in a laboratory of the Polytechnic Institute of Viana do Castelo. Three sets of experiments were created with different distances between the beacons to evaluate and test the system in different possible environments. For the test, 4 Estimote Proximity Beacons were used and a Xiaomi Mi A2 smartphone. The beacons were configured with an advertising interval of 200 ms and a broadcasting power of 4dBm.

Figure 5 represents the scenario of the test environment along with the beacons disposition. For each set of tests the distance between them varies. The B1, B2, B3 and B4 points represent the exact position of each beacon in the space and P1, P2, P3 points represent the intermediate points between them.

The evaluation consisted in verifying the detection accuracy, in Bx and Py, where x varies from 1 to 4 and y from 1 to 3.An accurate detection is considered when, and only when, the closest beacon is detected and no other one.

The tests were made following the route: B1 - P1 - B2 - P2 - B3 - P3 - B4. Each test series was repeated 20 times. After

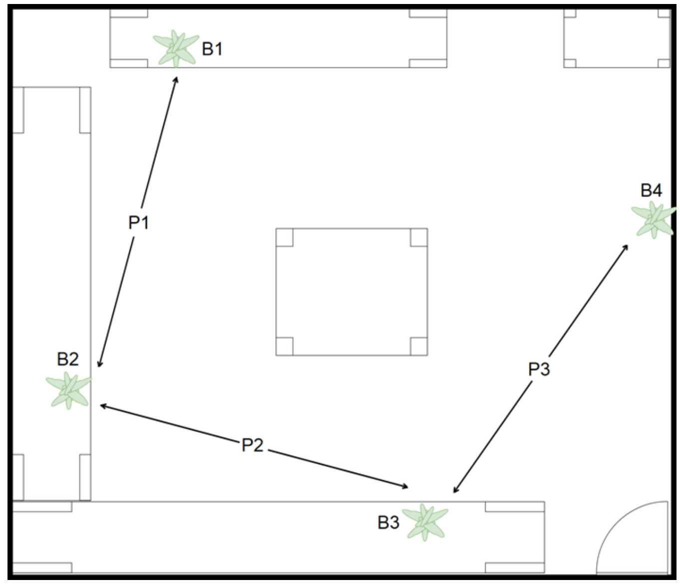

Fig. 5: Test Environment

reaching each evaluation point, and after a 6 second waiting period, the verification is made in order to understand if the correct detection was made.

The first test performed - Test1 - has a distance between beacons of 3 meters and a beacon's range set to 0.5 meters. After the 20 repetitions, the results are the ones presented in table II, with an average precision of **90.71**%.

Distance between Beacons - 3 meters
Beacon's range - 0.5 meters

Point	Correct Detections	Incorrect Detections	Precision
B1	20	0	100%
B2	18	2	90%
B3	19	1	95%
B4	18	2	90%
P1	17	3	85%
P2	18	2	90%
P3	17	3	85%

TABLE II: Test1 - Distance between beacons: 3 meters; Beacon's range: 0.5

The second test - Test2 - used a 2 meters distance between beacons and a beacon's range set to 0.25 meters. After the 20 repetitions the results are presented in the table III. The average precision obtained was **95.71**%.

The third test performed - Test3 - was configured with a distance between beacons of 1 meter and a beacon's range set to 0.25 meters. After the 20 repetitions the results are presented in the table IV. The average precision obtained was **85.71**%.

The test results allow to conclude that beacons are a viable solution for what is intended to be their role in the solution's architecture. The beacons should make it possible to understand the user's location within the museum, i.e., in

Distance between Beacons - 2 meters Beacon's range - 0.25 meters			
Point	**Correct Detections**	**Incorrect Detections**	**Precision**
B1	20	0	100%
B2	18	2	90%
B3	20	0	100%
B4	19	1	95%
P1	20	0	100%
P2	19	1	95%
P3	18	2	90%

TABLE III: Test2 - Distance between beacons: 2 meters; Beacon's range: 0.25

Distance between Beacons - 1 meter Beacon's range - 0.25 meters			
Point	**Correct Detections**	**Incorrect Detections**	**Precision**
B1	18	2	85%
B2	20	0	100%
B3	17	3	85%
B4	18	2	90%
P1	16	4	80%
P2	16	4	80%
P3	15	5	75%

TABLE IV: Test3 - Distance between beacons: 1 meters; Beacon's range: 0.25

which room they are in. The detection accuracy obtained with the beacons, and taking into account the range with which they were configured, allow to conclude that, if the beacons are positioned in specific locations, taking into account the size of each room in the museum, the expected behavior will be possible to be achieved.

VI. CONCLUSIONS

In this paper, an architecture solution for a location-based content delivery in museums was presented, more specifically for the Foz Côa Museum in Portugal.

The technological architecture was presented, as well as the supporting data model and the mobile application. The architecture makes use of beacons for the indoor location of visitors, and augmented reality for providing contents based on what the user is seeing The precision of beacons detection, under different conditions and configurations, was also presented as preliminary results of this work allowing to conclude that this technology will be suitable for identifying the room the visitor is in, and therefore download the associated multimedia content.

The future work involves extending the tests with beacons under different contexts that accurately reproduces the rooms of the museums and also with more recent hardware. Future steps include also to execute tests of 3D object detection using an augmented reality tool. The mobile application will continue to be developed to include the real content delivery of each room of the museum. Finally, real tests in the museum will be carried out to evaluate the overall performance of the system.

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