Utilizing AR and Hybrid Cloud-Edge Platforms for Improving Accessibility in Exhibition Areas

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Abstract. The technological advancements in the areas of mobile and edge computing provide nowadays the required levels of performance to handheld commodity devices to carry out computational intensive tasks which are required for an effective human-computer interaction. This enables advanced Augmented Reality - AR and Computer Vision approaches to operate on edge and mobile devices offering an immersive experience to the users by augmenting the foreground scene without the need of additional and expensive hardware. In this work we demonstrate the capabilities of AR and Computer Vision technologies for object and scene identification when deployed in a hybrid cloud-mobile environment. The prototype addresses the requirements of a real-world usage scenario for improving the accessibility for hearing and mild vision impaired visitors in museums and exhibition areas. This project is part of the implementation of the SignGuide project, an interactive museum guide system for deaf visitors, which can automatically recognize an exhibit, and create an interactive experience including the provision of content in sign language content using an avatar or video. The proposed system introduces a novel Multitenant Cloud AR-based platform and a client library for mobile apps capable of effectively identifying points of interest and creating new opportunities of interactivity between the real and digital worlds.

Keywords: Augmented Reality · Computer Vision · Object Detection · Accessibility

1 Introduction

The mobile device's multitask processing capabilities and graphics hardware facilitate the development of new applications that utilize cutting-edge technologies for interacting both with the users and also the physical world. An application which applies new techniques for acquiring the user's input and improves

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human-computer interaction, can also mitigate the accessibility issues of persons with impairments [3]. To this direction, state-of-the-art Augmented Reality technologies can utilize a commodity mobile device's hardware to offer real-world interaction to the user.

In recent years, it is a primary concern for many museums to enhance the experience of their visitors, and most importantly of those with accessibility issues like the deaf or vision impaired whose senses are limited for interacting with the exhibits and art objects. Visitors with disabilities can utilize helper applications, like AR assistants, to address accessibility issues and improve their visiting experience. Among other factors, AR uses image feature-points to provide localization functionality [18] which in this work is demonstrated in the case of museum exhibit identification and point-of-interest recognition (e.g. sector entrances, next/previous/related exhibits). Visually impaired persons could use the camera of their mobile device (or a mobile device provided by the museum) to automatically guide them in the exhibition while deaf can utilize the exhibit recognition to limit their interaction with the system and instantly get information of the exhibit in their display.

An important factor for exhibition areas and especially museums, is the static equipment required for installing assistive systems, which hinders and disturbs the visiting experience. Mobile guidance systems often require the use of QR codes [9], Bluetooth [19] or other hardware installations. Our solution offers zero interference with the museum area and the exhibits, allowing thus for optimal design of the exhibition for better experiences. There is no need to adapt the exhibition for vision and hearing impaired persons.

This paper introduces a novel Multitenant Cloud AR-based platform which utilizes a mobile commodity device's localization ability to recognize exhibits for increasing accessibility in a museum environment. The proposed system is a part of the SignGuide project, a prototype solution which offers a tour guide and computer-machine communication in sign language for the deaf visitors of the Archeological Museum of Thessaloniki - AMT [11].

The rest of the paper is structured as follows: Sect. 2 highlights past research at the field and introduces the demonstrated background technologies. System architecture, design and implementation are extensively described in Sect. 3, while Sect. 4 demonstrates the operation of the system at the project location. Section 5 presents results from the system's operation and finally, Sect. 6 concludes our work.

2 Scientific Background

2.1 Related Work

The improvement of a museum's accessibility necessitates the integration of new technologies in this area and, thus, the utilization of mobile museum applications. The identification of the main features for the design of a museum application can give insightful thoughts for both museum managers and application developers [16]. Curiosity, Usability, Interaction, Motivation and Satisfaction are components that need to be taken into consideration when developing such applications [1]. Based on the aforementioned factors and the fact that Mobile AR - MAR has proven to be beneficial for the deaf visitors of a museum during their visit, the MAR for the Hearing Impaired Museum visitors' Engagement - MARHIME conceptual model has been introduced [2]. To overcome the difficulties during the tour of visitors in a museum, a system based on AR is introduced to predict the optimal routes in a museum [23].

A different approach for guidance and exhibition presentations is the combination of wearable technologies and AR [22]. The case of the Literary Museum [8] illustrates the user engagement that AR offers, even when the visitors have minimum experience with mobile applications. AR is integrated in different fields of application, as in the development of exergames for remote patient monitoring [13], in nature based solution utilizing AR Cloud Anchor technique with gamification elements [14] or in healthcare education for pharmaceutical substances recognition [12]. From the integration of AR in a museum for school children with zero experience, research concluded that AR increases the interest of the visitors and the gained knowledge [15].

Computer Vision technology, in general, can be implemented in a museum app to collect visitors data and measure their engagement [4]. Other applications conduct state recognition and then object identification to provide the museum visitors an advanced tour [21]. The implementation of multimedia augmented reality information systems that can display 3D models of museum artifacts and provide multimedia content to the visitors [6] increases the overall experience of the exhibition. Moreover, combination of such content with Virtual Reality - VR and AR shows increase of engagement in exhibitions [25]. Many statistical techniques and methods are utilized to measure the impact of the implementation of AR and VR in the museum service model and their results demonstrate they affect the interaction of users with accessibility issues [24].

Part of the developed application that needs to be briefly mentioned, but is not the key contribution of this work, is the binding of a retrieved exhibit with content for the deaf. For a complete interaction between the visitors and the app, deaf users need to perform questions in Sign Language. A crucial problem that needs to be addressed is the monitoring speed of the gesture hands and the hands flexibility [7]. Most techniques for the modeling of sign language are directly dependent on multidimensional data without considering the innate limitations of the human body's physiology or sign language. Deep learning architectures are proposed to reduce the extent of this issue by modeling the information in separate routes [5]. There are general-purpose museum content management systems or static content systems to locate the data required for processing a query. SQL Language is used to extract videos from a library and specifically the most relevant parts that are essential to present the results [10]. Although an Avatar presentation is challenging, as it is related to various facial and hand gestures [17], the virtual character approach of Ada and Grace has been successfully developed at the Boston Science Museum [20]. Various deep learning methods for sign language recognition, the Virtual Avatar and, most importantly, exhibit recognition are utilized in the SignGuide project to achieve human-computer interaction for the deaf.

2.2 Technological Foundation

Augmented Reality. Augmented Reality's biggest advantage -when running on mobile commodity devices- is hardware independence. Most latest generation mobile phones include the sufficient sensors and processors required to run AR, which are: IMU sensors and HD camera. The phone's camera feed can be augmented resulting in displaying 3D content which is seamlessly integrated to the real world. Digital items attached in the foreground scene are referred as AR **Anchors** due to their ability of remaining static at a surface. Such surfaces, that allow Anchor placements and persistence, are referred as AR **Planes**. Any device movement (even change of rooms) will not affect the AR experience as it relies itself on a Simultaneous Localization and Mapping (SLAM) technique. Attaching an Anchor to a Plane requires software that implements SLAM.

Simultaneous Localization and Mapping. SLAM algorithms achieve surrounding area recognition by utilizing camera feed along with data from device IMU sensors. Feature points from certain and dense segments of each camera frame are extracted while the area is steadily scanned. Raw data from IMU sensors (accelerometer, gyroscope) in combination with the feature points create a 3D representation of the foreground scene allowing, thus, the placement of Anchors relevant to these points. Once an Anchor is attached, nearby feature points are captured and included in the Anchor's metadata. A cloud-enabled Anchor identification process utilizes the aforementioned technique to save these feature points in the cloud, for future use. When another device captures the same area, it will recognize, using AI, patterns referring to the pre-captured feature points. If the confidence is high, which means that the area looks the same, a new Anchor will be placed at the exact same spot. This technique requires some computational power resulting, thus, in a limitation of simultaneous Anchor searches, depending on the Cloud Anchor implementation. In our prototype we use the Google Cloud Anchors library which allows 20 simultaneous Anchor retrieval attempts at the same time.

3 Design and Implementation

3.1 System Overview

The proposed system provides advanced user interaction functionalities for creating rich experiences to the users and addressing accessibility issues in exhibition areas and related environments. The system consists of two main elements:

A. ***Multitenant Cloud Platform for AR-based POI Resolution***: a generic AR-based platform which is capable of real-time identification of relevant POIs - Points of Interest in a context-aware manner.

B. ***User Application***: a prototype mobile app which is integrated with the cloud platform to provide the aforementioned functionalities to users in the world scenario of a museum.

The mobile app is classified in the category of museum applications that have as main target to provide additional help and ease the accessibility issues, especially of hearing impaired people. Through the integration with the *Multi-tenant Cloud Platform for AR-based POI Resolution* and the customization of the operational parameters for the particular usage scenario, a set of features for advanced interactivity become available to the User Application.

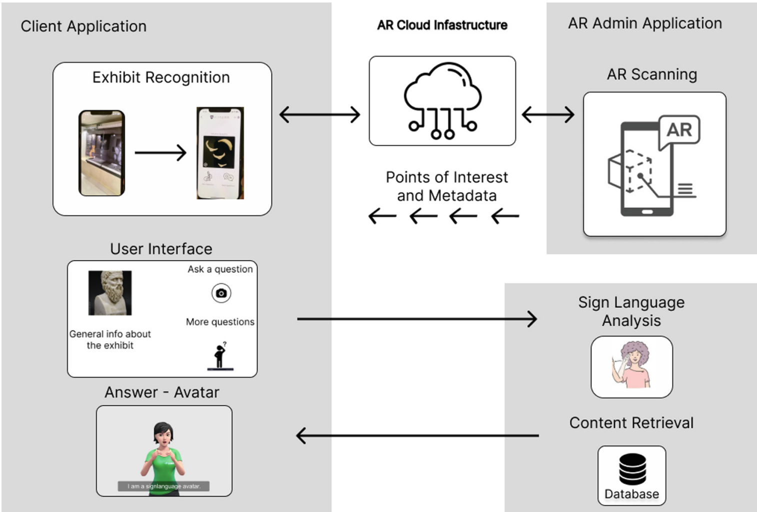


Fig. 1. System Overview and Core Functionalities

Figure 1 presents an overview of the system's design and its core functionalities. The users, as visitors of the exhibition/museum, which are equipped with the app installed in their mobile phones, can open the camera in order to identify exhibits and other points of interest, without the need to use other tools or mechanisms (such as QR codes), and in turn view related rich multimedia for the identified object. The whole process is realized by the AR components which are deployed locally in the app and are configured to identify points of interest in the specific area. The points of interest are preconfigured through the cloud platform for the particular application/scenario and represent specific points in the premises which are considered relevant to the scenario and potentially have interest for the users, such as exhibits, entrances and exits of exhibitions, and other facilities. The real world points of interest, technically defined as anchors, are represented in the digital environment of the mobile app enriched with 3D models, multimedia content and other information providing a unique experience to the users. Besides the metadata attached to each anchor from the cloud platform, additional information for the exhibit is presented within the app. In this scenario, the additional curated content is retrieved from the museum's information systems and consolidated to the digital representation of the POIs. Furthermore, additional services are integrated in the app to provide bi-directional interactivity using sign language in order to facilitate accessibility. The user can ask a unique question in Sign Language which will be analyzed and then, an Avatar will respond using Sign Language.

3.2 Multitenant Cloud Platform for AR-Based POI Resolution

A key advantage of the approach is that the operation of the cloud platform has been decoupled from the client applications in order to operate in a multi-tenant way. Hence, the platform can serve simultaneously multiple client projects adapting however the operational mode to each project for context-aware identification of anchors. The identification process can be further adapted to address dynamically changing needs during runtime based on the user profile, the condition of the area (e.g. highly crowded), interactivity with other participants and other special requirements. This dynamic operation allows for:

- dynamic allocation of the list of POIs to be identified,
- response with different metadata for each POIs based on the request query, and
- consolidation of alternative content to the POI according to the scenario (e.g. guidance of a sole visitor compared to the guidance of a group adolescents).

The integration of the platform with the client projects is performed through a library which is attached to the related client mobile applications during their implementation (see section AR Integration below). This library is responsible for capturing the video stream from the camera of the mobile device and the identification of the POIs by communicating with the cloud platform. The identification is performed in a hybrid fashion as follows:

- The client library makes a request to the cloud platform for a list of anchors to be identified providing contextual information (e.g. building, floor), the recently identified POIs and optionally user related information.
- The platform processes the request and responds with a list of anchors and their visual features.
- The features are used in the client library to identify locally the specific anchor in real-time from the video stream.
- When an anchor is identified, another request is performed to the platform in order to get the respective POI which is associated with the anchor, its metadata and the related content.

It should be noted that an anchor represents a specific spot in the area, which may represent one or more POIs, and according to the usage scenario and the request that will be performed, a different POI may be attached to this

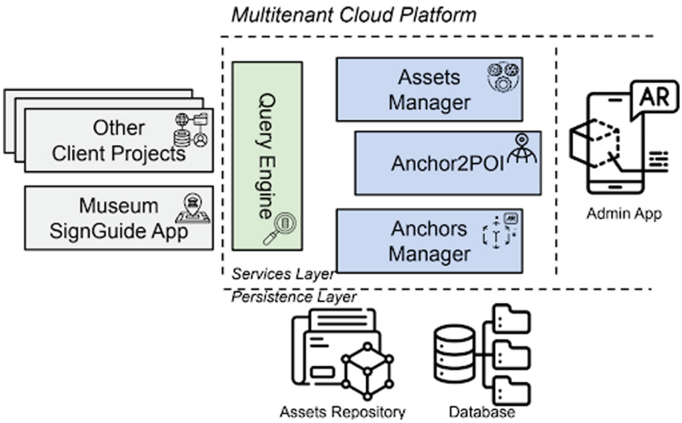


Fig. 2. Cloud Platform Architecture

anchor. Furthermore, the information and the metadata of the POI may also be dynamically produced and updated during runtime. The architecture of the platform is presented in Fig. 2.

In conceptual level, it includes three main elements, a) the *Persistence Layer*, for storing all information regarding anchors and the assets related to them, b) the *Services Layer* where the business logic of the platform is implemented, and c) the *Admin App* for the definition of the anchors. The *Admin App* is used by the managers of the platform and dedicated users (e.g. the museum staff) and its main functionality is the initial identification and definition of the anchors in the area of interest. Through the app which is installed to the managers' mobile device the area is scanned using the camera, and the features of the foreground scene, of the surfaces, and of the objects are recorded in order to place the virtual anchors and store them in the database. The *Anchors Manager* component allows for editing the configuration and the metadata of the anchors as well as their ownership and access parameters so that they are available during runtime only to the specified audience. The *Assets Manager* component undertakes the process for uploading to the system and configuring the assets that will be in turn associated with the POIs. This is carried out through the *Anchor2POI* component where a many-to-many relationship is defined between anchors and POIs. Therefore an anchor may represent different POIs according to the context, or a POI may span across multiple anchors. The *Query Engine* is the interface of the platform towards the client library and is responsible for the analysis of the client requests and for producing the list of anchors and related material (POIs and Assets) which will be used at any time from the mobile app.

3.3 User Application

The user application, through the integration of the client library for communication with the cloud platform, provides several innovative features with the most prominent being the ability to recognize an exhibit of the museum and have instant access to its information. Following the identification of the exhibit, and the presentation of the initial content, a set of questions is displayed, in both text and Sign Language. Furthermore, the user can have a look at photos related to the museum exhibitions or a specific question or answer. All the data is derived from a database of the museum based on the Heurist CMS tool[1].

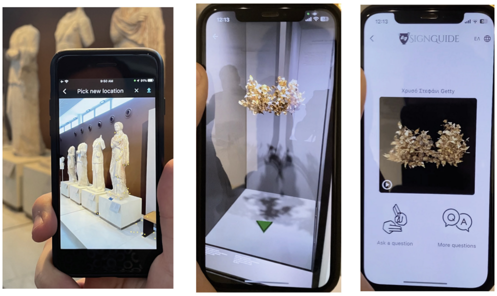
The client library is responsible for performing the exhibit recognition on the mobile device. Once the appropriate button is selected, feed from the camera of the device pops up and indicates the user to point at an exhibit. At the same time in the background, the feature point recognition subsystem has already downloaded the features of the exhibits and continuously checks the current camera feed for patterns. When a frame contains sufficient features matching an anchor, the related POI content is displayed at the spot of the anchor. If the euclidean distance (in meters) between the Anchor and the device is less than 1.5 m, the user is considered to be close to the Anchor, resulting, thus, in the recognition of the corresponding exhibit.

While all AR related functionalities are exclusively integrated to the system by this work, User Application acts also as the front-end of sign language recognition and Virtual Avatar presentation processes. The user can either select one of the predefined questions or ask a question facing at the device's front camera. Answers are generated either in text or in sign language using prerecorded video or Virtual Avatar illustration. Needs to be mentioned, though, that back-end implementations of the aforementioned processes are developed by the other project partners.

4 The System in Practice

The minimization of user-machine interaction needs is achieved through an efficient exhibit recognition subsystem which is trained to recognize the exhibits and POIs of AMT, where the project takes place. A combination of the two Applications, Client Application and AR Admin Application, is required for the system to work properly. First, the area needs to be scanned, using the AR implementation, and the locations of the affected exhibits must be picked. The scanning process requires a clean-of-presence area allowing for optimal feature-point detection at the point of interest. When an exhibit is scanned, an anchor is placed at its location and feature-points along with related metadata are stored to the cloud. Furthermore, such Anchors are linked using a 1–1 relationship with the affected exhibits and their multimedia assets resulting, thus, in the relation between a location and an exhibit.

[1] Heurist CMS tool: https://heuristnetwork.org/.



(a) (b) (c)

Fig. 3. The system in practice

The client-side application aims at improving the accessibility of impaired people while visiting exhibition sites. When the application is launched, a large distinctive button with an appropriate icon is visible at the center of the screen prompting the visitor to open the camera. Immediately the AR subsystem is initialized and the SLAM procedure recognizes the front view. Once an exhibit is visible on the device, and its feature-points are confidently identified, information about this exhibit is retrieved to the application. Due to the possibility of simultaneous recognition of nearby exhibits, the distance between the device and the affected exhibit's location is required to be less than 1.5 m, however alternative configurations can be set in other scenarios and deployments. Figure 3 demonstrates (a) the Anchor scan and POI definition process, (b) exhibit recognition, and (c) successful exhibit information retrieval.

5 Results and Evaluation

The proposed system has been tested at the exhibition of AMT under real usage scenarios with visitors present. Eight museum exhibits have been selected for the test using four different mobile devices: iPhone 12, iPhone SE 2, Galaxy A52s and Galaxy Tab S8 Ultra. Ten tests were performed for each device, for each exhibit, examining the recognition process. Five of the tests searched for the exhibit in its frontal space while five started the procedure at a 45° angle. Table 1 demonstrates average results from 5 tests conducted on each exhibit, with a total of 40 tests, highlighting the time required for each device to successfully detect the exhibit along with a success rate, when searched from the frontal space. Table 2 demonstrates the same number of tests, but exhibits were scanned from a 45° angle.

Results from the tests show that although there is a slight decrease in recognition duration and success rate when scanned from an angle, overall performance of the system is well accepted, considering that there is no reference point (e.g. QR Code) or other identification intervention.

Table 1. Exhibit scanned from the frontal space

Device	Time(s)	Test success rate (out of 5)
iPhone 12	3.39	96% (4.80)
iPhone SE 2020	4.11	94% (4.70)
Samsung Galaxy A52s	4.43	93% (4.66)
Samsung Galaxy Tab S8 Ultra	4.01	95% (4.74)

Table 2. Exhibit scanned from angle

Device	Time(s)	Test success rate (out of 5)
iPhone 12	3.56	95.2% (4.76)
iPhone SE 2020	4.33	93.6% (4.68)
Samsung Galaxy A52s	5.01	94% (4.70)
Samsung Galaxy Tab S8 Ultra	4.21	94.4% (4.72)

6 Conclusion

Mobile commodity devices already achieve satisfactorily results when they are required to run intensive tasks, such as image processing, data transmission and human-computer interaction. These advantages can be utilized to improving the quality-of-life and accessibility of impaired people while at the same time reducing their social exclusion. The general goal of the SignGuide project is to introduce an interactive museum guide platform for the deaf, with capabilities of capturing and responding to sign language, using only mobile devices provided by the museum or owned by the visitor. In this work a prototype AR solution is introduced and integrated to the project, for increasing system accessibility. It is capable of recognizing and interacting with the exhibition area without the need of preinstalled equipment or any sort of intervention. The Cloud Platform for AR-based POI Resolution achieves efficient object detection and object-exhibit correlation using the Services' Layer Query Engine. Run-time tests from the end-user prototype, which runs on both Android and iOS devices, show that even if the exhibition area is partially crowded, or the exhibit is scanned at an angle, the identification is performing well, while at the same time requiring an almost effortless process of training the system. Additional libraries, such as the Unity Framework, can be utilized to further improve the performance of the solution as well as the experience of the users when utilizing the system. Further extensions to the client library and the cloud platform are also foreseen to enhance the accuracy of the system and the time required to identify the POIs even in highly complex and crowded environments.

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