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Enhancing cultural tourism by a mixed reality application for outdoor navigation and information browsing using immersive devices

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Abstract. In this paper a mixed reality application is introduced; this application runs on Microsoft Hololens and has been designed to provide information on a city scale. The application was developed to provide information about historical buildings, thus supporting cultural outdoor tourism. The huge amount of multimedia data stored in the archives of the Italian public broadcaster RAI, is used to enrich the user experience.

A remote application of image and video analysis receives an image flow by the user and identifies known objects framed in the images. The user can select the object (monument/building/artwork) for which augmented contents have to be displayed (video, text audio); the user can interact with these contents by a set of defined gestures. Moreover, if the object of interest is detected and tracked by the mixed reality application, also 3D contents can be overlapped and aligned with the real world.

1. Introduction

Augmented Reality (AR) provides an efficient and intuitive way to visualize computer generated information overlaid and aligned with objects in the real environment. AR technologies have been employed in a broad spectrum of applications: medicine, industry, military, and so on [1][2]. As real and virtual objects can coexist within the same augmented environment, AR solutions have been also used to enhance the user experience in cultural tourism contexts. Many solutions have been presented for indoor [3], where is quite easy to track the user position and light conditions can be controlled. Several museums provide users AR applications that framing well defined images (markers) recognize position and orientation of the user and overlap computer generated assets to the artwork the user is interested in. On the other hand, several challenges have to be tackled for outdoor applications [4]. First of all an accurate tracking of the user is not easy; often GPS-based solutions are provided, but they might be not able to accurately provide both the position and orientation. Moreover, GPS-denied environments should be also considered. The second issue is related to the impossibility to alter the environment by markers or target images. Finally, lighting conditions cannot be controlled.

If the term augmented reality refers to the possibility to overlap computer generated contents to the real environment, the term Mixed Reality (MR) denotes the possibility of the user to interact with these contents.

This paper presents a MR application for outdoor enhancing the user experience during cultural tours. With Mixed Reality, synthetic contents are anchored to some positions in the real space and the user can interact with them. In order to allow the user a full mobility, the Microsoft Hololens has been chosen as a Head Mounted Device (HMD); it is connected by a high-speed and high-throughput network (e.g, 4G/5G cellular networks) to a cloud infrastructure. The application gathers several times per minute images of what the user is watching; in a transparent way, images are sent to the cloud architecture where a visual search engine (MPEG Compact Descriptors for Visual Search - CDVS) is running. In this way, objects of interest framed by the user can be identified; a notification about a recognized object is sent back to the user, that can receive augmented contents about the object.

The application can display both textual information and movies about the framed monument/building/artwork and a semitransparent silhouette of the recognized item can be used to align the user with respect the target, thus enhancing the tracking robustness. When the AR application tracks the object, 3D virtual assets can be overlapped to the target.

The paper is organized as follows: basic concepts behind AR and MR are presented in Section 2 as well as some examples of outdoor augmented reality for tourism, Section 3 details the architecture of the proposed application and Section 4 shows tests and results gathered in the Turin's Archaeological Park.

2. Background

Several attempts of using AR and MR to support outdoor cultural tourism are known in the literature. For instance, Archeoguide [5] where a laptop computer is used to manage computer generated assets and track the scene. In particular, the tracking strategy is based on a set of reference images due to the impossibility to put any special markers onto the historical sites. For each viewpoint there is a set of reference images that are compared with the framed one. When a match is found, the transformation to fit the reference image to the video image is computed. This transformation allows to correctly align and overlap synthetic contents to the real world. A similar approach is also used in [6]. The project Archeoguide has been also extended in order to provide users a powerful mobile device for outdoor AR applications with standard off-the-shelf components [7]. At the date of [7] it was impossible to reach simultaneously the following design goals: intuitiveness, robustness, powerful and lightness. An example of MR application for the cultural heritage in outdoor environment is provided by the PRISMA project, which aim is to design, develop and implement a 3D visualization device based on Augmented Reality technologies [8]. Tourist AR binoculars display augmented contents to the user and the interaction with a pop-up menu allows to switch among different type of contents. Santos et al. proposed a similar approach, focusing on the technologies and approaches needed to enable outdoor mixed reality experiences in the cultural heritage domain [9].

Drawbacks and advantages of Mobile Augmented Reality (MAR) are presented in [10], whereas MAR using smartphones is considered in [11]. Many other examples of application of the MAR paradigm for tourism are known in the literature such as the LIFEPLUS system [12] (which aims to provide a guide for the archaeological site of Pompeii in Italy) and the work presented in [13], which improves the tracking phase on the basis of a combination between computer vision algorithms and device sensors.

Several works have been devoted also to investigate issue related to the expected user

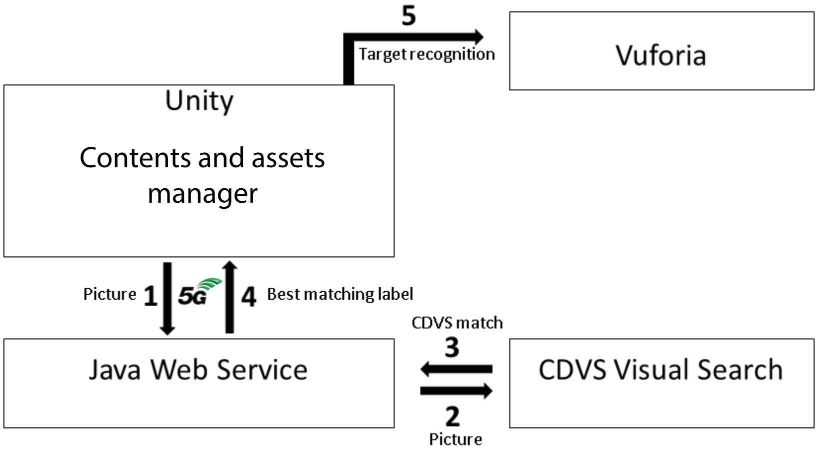

Figure 1. Software architecture and data flow exchange.

experience. For instance, in [14] it comes to light how users are interested in applications that are easy to use and highly customizable, whereas also the emotional point of view is analyzed in [15]: MAR services are expected to offer stimulating and pleasant experiences, such as playfulness, inspiration, liveliness, collectivity and surprise.

3. The proposed MR application

The device chosen for this project has to be a Head Mounted Display (HMD), as this kind of device provides users both an immersive experience and a full mobility. The Microsoft Hololens fulfills the above mentioned characteristics as it is a stand alone device that does not require an external computer for computation.

The detection step is the most important phase for a any AR-based application. After the recognition of a monument/building/art work of interest, information gathered in the RAI archives can be sent to the user. The users have to be able to select the wished kind of information (text, audio, video). Only when the recognized item is correctly tracked, 3D contents can be aligned and overlapped to the real object.

From the hardware point of view, the proposed architecture is very simple. The user wearing the Hololens is connected to the Internet by a high speed network (e.g., 4G/5G). The MR application is running on the glasses and it exchanges data in a bidirectional way with an application of visual content analysis and search running in cloud on a virtual machine (an Azure's node). For this purpose, the MPEG CDVS was integrated as a proof-of-concept. Any other machine learning tool may be seamlessly plugged into the system.

From the software point of view, the architecture is shown in Figure 1. The application is completely developed in Unity (https://unity3d.com/), but it is logically divided in two parts: the first part concerns the connection with the virtual machine and the visual search engine running on it, whereas the second part is in charge to track objects and display correctly aligned 3D models. The first part is composed by 5 different layers: Unity (a game engine) and UWP (Universal Windows Platform - a platform to develop applications for Windows 10, Windows Mobile 10, Xbox One and Hololens) for the application running on the Hololens; Java Web service, the Image recognizer software and Linux for the cloud side. Differently, the second part is composed by three layers Vuforia (https://www.vuforia.com/),a framework for developing AR application, Unity and UWP; all these three layers refer to the application running locally in the HDM.

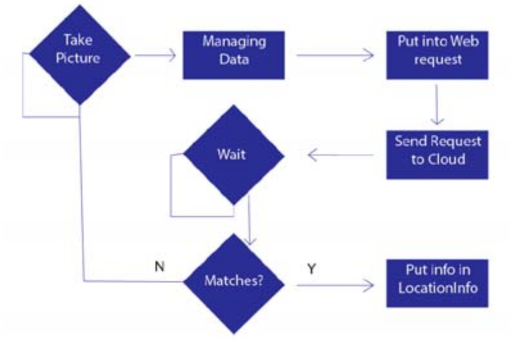

Figure 2. Flowchart of the first scene.

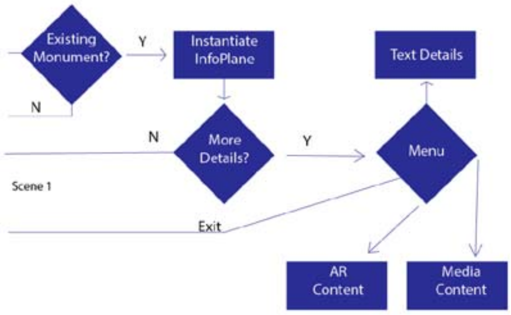

Figure 3. Flowchart of the second scene.

Unity provides many different components ready to use, like AudioSource, VideoPlayer and BoxColliders, but if it is necessary to develop a custom component, e.g., an Internet connection, this can be implemented only with the creation of a Script. Every particular behavior or action of a GameObject must be implemented by a Script. Moreover, in Unity, it is possible to divide the application in some scenes; in this project, there are three scenes: the first one for the cloud visual search, the second one for delivering object details and third one for the augmented contents.

3.1. The first scene

This scene is responsible for taking information from the camera and perform the connection with the cloud. This part is transparent to the user because for the recognition there are only functions that have to manage the application's behaviour. The camera is an important component in order to take the picture for the recognition and it is managed by the Microsoft Hololens SDK. In this scene, as shown in Figure 2, the application takes a picture every some seconds and performs the connection with the cloud while the user is walking freely in a city tour. Every picture is sent to the web service on the cloud that passes the image to the visual search service. CDVS compare the image with its database and return a result. After the computation, the web service get the result from the visual search service and send it to the application on the Hololens. If the result is a valid location, the application stores every important information and prepare the passage to the second scene.

3.2. The second scene

This scene, differently from the first one, provides many visible augmented elements. The application takes the location found and creates a first information hologram about the recognized monument. The plane shows a textual content that describes the recognized item and two buttons: Menu and Exit. If the user is interested to the given monument, he can select the menu button and then the general menu is shown. The menu plane contains 4 buttons that trigger the following actions:

- Details: a new plane is created and it shows particular information about the history of the monument;
- Media Content: a new plane is created and it shows additional multimedia contents such as pictures and movies;
- AR Content: Manager loads the next scene in order to show the virtual reconstruction of the monument;

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The interaction model is a fundamental part for the selection of the contents and it works like a viewfinder: it consist of a cursor, which is controlled by the user gaze, and a gesture recognition module, managed by the Microsoft Hololens SDK. When the user looks at a menu button, he can perform a tap gesture anywhere in the camera range to activate the functionality associated to the targeted item.

3.3. The third scene

At the start of this scene all augmented reality components are initialized adding the Vuforia AR feature to the application. The application take the location info and creates the silhouette related. The user has to align the silhouette to the monument and sees it from the right perspective, this facilitate the vuforia's tracking. When the silhouette is perfectly aligned, the application makes the silhouette invisible and the appropriate 3D model is overlapped to the real monument. If the user move his gaze from the monument, the application loses the tracking, so 3D model is set to invisible and the silhouette appears again. Finally, when the user wants to stop the AR feature and to see the menu again, he has to perform a tap gesture.

3.4. The graphical user interface - GUI

In this application, the selection or interaction with objects is performed through the user's gaze and the "air-tap" gesture; therefore, users aims to something with their eyes and selects it performing a tap. In the first scene, the image recognizer is invisible to the user, so there is not any GUI. When an element is recognized, a GUI appears. InfoPlane is the first panel that the user can see. This is a very simple panel, as shown in Figure 4, with some general information and two buttons to make simpler the user choice. The MenuPlane is a simple panel with four buttons. It is the main menu and from this panel the user can see every available content. The buttons are always big to make them easily selectable. The others two panels are very similar to this, with one or two buttons and the same style.

4. Tests and results

This project aims to enhance tourists' experience during a city tour. Therefore, in order to evaluate a real usage of this application, some tests have been organized at Turin, Italy. Tests are focused on various type of parameters, they have been designed in order to gather both subjective and objective feedbacks. In particular, the usability and the simplicity of use have been the most interesting target of this tests. A questionnaire has been submitted after the test phase and users could rate from 1 (totally disagree) to 5 (totally agree) a set of claims.

Eight testers have been chosen randomly in order to get a representative set of samples. The group of testers is equally composed by women and men, the age ranges between 20 and 50 years, and testers have different knowledge of AR technologies. A half of participants never tried an augmented reality application and some of them have not any familiarity with computers. Testers were all volunteers and their participation was not remunerated.

The location chosen for the tests is the Archaeological Park in Turin [16], and the target monument is the Palatine Towers. This place is impressive, spacious and very popular for tourists. Palatine Towers was the Roman Age city gate, which provided access to the ancient city Julia Augusta Taurinorum. The users had to simulate a normal walking through the Archaeological Park, until the Palatine towers. When they arrived at the monument the application should recognize it and then users could navigate all information as shown in Figure 4. After a starting tutorial about the application, the users were left alone and they had to accomplish the following actions: reading initial information and tap on the menu button, tapping on the Details button and read some additional information, tapping on the Media Content button to see the video content about the monument and tapping on the Augmented Reality button and trying to examine the 3D model of the monument. Moreover, the users had

Figure 4. Initial information after monument recognition.

Figure 5. 3D model overlay of the monument.

to pay attention to some other factors in order to evaluate the usability and visibility of the system: ease to point, visibility, fluency, stability and speed of content switching. Before starting the tests, users were introduced to the pointing system of the Hololens and to the application interface. Furthermore, they were informed about the possibility to move freely in the park by using only their hands to interact with the system. At the end of the tests, the users filled a questionnaire, thus providing their comments about the application.

Before the results analysis, some technical and software limits have to be introduced. One of the most important issue is the limited field of view of Hololens, which is only $30 * 17$ degrees; therefore, the users cannot see large objects when they are too close the framed items. Moreover, the lenses brightness is limited, this makes the contents not really visible when the application is used in very sunny days. Another issue is the unstable tracking of the virtual reconstruction of the monument (see Figure 5). Nowadays, it does not exist a free and stable building recognizer to perform augmentation; furthermore, Vuforia is the only SDK supported by Microsoft to develop applications running on the Hololens. Vuforia recognizes an object by comparing the image framed by the camera with a set of pictures pre-loaded in a database; unfortunately, every light change or object movement with respect the images loaded in the database can compromise both the recognition and the tracking.

4.1. Results analysis

The questionnaire was made of 13 questions, as shown in Table 1, and they are related to different categories in order to have a good panoramic of the application's characteristics. Questions 1-4 discuss the likeability and usability of the application: it's important to know if the user likes to use the system and if he knows what to say or what to do. The next six questions focus on the response accuracy of the system and it's speed. The last three questions have the goal to inquire the usefulness of the application's.

More specifically, the first question concerns the system's usability and investigates the simplicity and the intuitiveness of the application commands. All participants think that the commands are simple and intuitive (see Figure 6). It is also important to know if the users find both the symbol and the text of menus and buttons intuitive or not: the majority of the users positively answered to this question. The following questions involve the fluency (Figure 7), which means the content switch's speed, the objects recognition's speed and the Vuforia's tracking stability.

From the Table 1 it is relevant that the 80% percent of the testers says that the application is quite fluent and the initial recognition is stable and fast. The only concern regards the Vuforia's tracking stability: even if there are many positive answers, the questions regarding the recognition's speed and the model overlapping precision provide an higher number of neutral

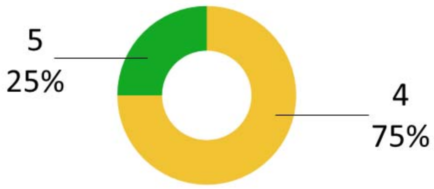

Figure 6. Answers to question 1: "Are commands simple and intuitive?".

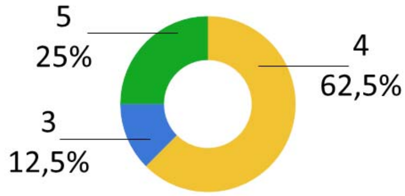

Figure 7. Answers about "Fluency of the application".

Question	**1**	**2**	**3**	**4**	**5**
Are commands simple and intuitive?	0	0	0	6	2
Instructions have been clearly exposed?	0	0	0	3	5
Can you easily come back to the menu?	0	0	0	7	1
Are text and symbology intuitive and clear?	0	0	2	3	3
Is the passage through contents fluid?	0	0	1	5	2
Is starting recognition fast?	0	0	3	1	4
Is 3D model overlay well executed?	0	1	2	2	3
Is the application well realized?	0	0	0	4	4
Is text content clear and visible?	0	0	1	3	4
Are video clips fluid and useful?	0	0	1	4	3
Do you think that read textual information is useful?	0	0	1	3	4
Do you think that see video clips is useful?	0	0	1	4	3
Do you think this application could helps cultural heritage?	0	1	0	2	5

Legend: **1**-Strongly Disagree **2**-Partially Disagree **3**-Neutral **4**-Partially Agree **5**-Strongly Agree

Table 1. Questionnaire's results.

answers. This variety of answers depends on the instability of Vuforia in recognizing images, as environmental conditions can change among tests. However, a noticeable feedback received from the users is that most of them appreciated the application and they think that AR/MR could really help and support the development of the national cultural heritage.

5. Conclusion

This work has been focused on the development of a smart guide able to enhances the experience of tourists during a city tour. The application enhances real monuments with textual and multimedia information; moreover, also an augmentation by 3D models can be provided. Tests show how users appreciate the application both from the usability point of view and from the information content point of view. The application is easy to use and it can really be a valuable tool for outdoor tourism. Indeed, the access to information stored in the RAI's archives is an added value.

On the other hand, several issues have to be tackled in order to move toward a production phase for these kind of tools. There are some hardware limitations that can impact on the user experience (e.g., limited field of view and low visibility in some lighting conditions), but the fast growth of AR technologies promises to limit soon these drawbacks. Another problem is the tracking instability. The fast changes in outdoor lighting conditions strongly limit the use of a image-based tracking. A possible solution could arise by a model-based tracking, which should be much more stable than the image-based one. In this case, a CAD model of the object to be tracked should be available. Finally, the Hololens adoption rate from private citizens could be low and it could limit the diffusion of these applications due to its current cost. However, it is reasonable to believe that, likewise the audio guides usually available in museums, this kind of technology can be made available to the users as a service provided by a private society or even by city tourist offices.

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