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To cite this article: Yasmeen Abdrabou *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **364** 012052

IOP Conf. Series: Materials Science and Engineering **364** (2018) 012052 doi:10.1088/1757-899X/364/1/012052

CHEOPS: Cultural Heritage Enhancement Over Cyber-Physical Systems

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Abstract.

The Internet of Things (Iot) field has been expanding in various domains with cultural heritage being no exception. Nevertheless, cultural heritage sites are still often managed in traditional ways and a prominent gap remains between tour managers and visitors in correctly identifying visitors interest to specific sites and monuments. Previous related works focused on tackling mood detection separately from particular touristic locations which lead to overly generalized assumptions. Accordingly, in this paper, we propose a comprehensive platform named CHEOPS to enhance the touristic experience by detecting the tourists interest in the sites. The proposed platform provides a customized tour through touristic sites by using indoor localization techniques coupled with information about smartphone activity. Accordingly, the visitor is directed to a more interesting location. In addition to interest detection, CHEOPS implements several techniques for interaction with the touristic site such as gaze detection, gesture recognition, and augmented reality. A prototype of the proposed platform is implemented and tested in real scenarios to detect the usability of the system. The output accurately detects the interest of the users, which can then be used to fill the gap between the site manages and the tourists.

1. Introduction

The cultural heritage industry has global renowned importance for many reasons that include national pride and economic value. In fact, the United Nations has recognized in its first resolution on culture and development the economic role of cultural heritage in sustainable development [1]. A study commissioned by Eurostat for cultural heritage [2] states that in certain countries some sites such as the Louvre in PAris and The Colosseum in Rome receive millions of visitors each year, and that trade in cultural heritage goods and services is worth 10s of billions of dollars per year. In addition, the same study states that the cultural heritage sector accounts for 2.9 percent of all employment in Europe. This means that the quality of the services offered in cultural heritage sites can have a significant effect on the experience of the visitors, which is likely to have a pronounced economic impact. Nevertheless, most cultural heritage sites offer traditional services that include static content (for example through audio guides) with minimum interaction. In addition, there is little consideration for the different interests that visitors may have towards the contents of the sites. If these interests are considered, the site tour can be customized accordingly. Furthermore, advanced interaction techniques can be used to engage tourists and provide attractive ways to enhance their experience.

Information and Communication Technology (ICT) can play a role in addressing these challenges. Interaction techniques such as Augmented Reality (AR), eye gaze detection, and gesture recognition can be used to enhance the interactivity with the site and provide a more attractive experience, especially for younger generations. In addition, indoor localization techniques are now inexpensive and mature enough to enable accurate location-based services. Moreover, the proliferation of smartphones can now leverage a wide range of smart services for tourists. Accordingly, we present in this paper a comprehensive platform named CHEOPS (Cultural Heritage Enhancement Over Cyber-Physical) for enhancing the services offered in cultural heritage sites, based on a set of ICT technologies.

2. Related Work

In this section, some pertinent research efforts that study the integration of technology with the world of tourism are explored.

2.1. Augmented Reality in Tourism

Augmented Reality (AR) is the augmentation of a physical world's view with digital content by the use of the camera of a smartphone or a tablet [3]. Some examples of smart tourism systems based on AR include the **Mobile AR system (MARS)** [4]. The prototype registered 3D graphical tour guide information with buildings and artifacts that the visitor sees. Another example,is [5] which used AR to display historical information to the visitors in the form of a 3D model that represents the site. Similarly, **Ancient Egypt ActiveLens** is a newly created AR app ∗ that allows users to see Ancient Egypt through a simulated journey back in time. On the other side, in a collaborative AR scenario such as the one in [6], more than one user can share the same space through virtual objects while they are on the real world.

2.2. Eye Tracking and Pointing Detection in Tourism

Another area of interest to enhance tourism is by using special hardware, such as Eye Trackers. One example of eye tracking-based systems is **Museum Guide 2.0** [7], where the visitors enter the museum putting a wearable eye tracker. Then object detection mechanism runs on the area the tourist is standing in front of and gaze at then it plays a relevant audio file which provides information about the detected object. For pointing detection systems in museums, the mixed-reality system done by C.Malerczyk [8] comes to the foreground. The aim of this system was to allow the museum's visitor to explore the exhibits through interaction and give them the chance to explore some details in the paintings.

2.3. Interest-Based Systems

Interest detection has opened the door for several new applications as it provides much needed enhancements to already available systems to be more personalized to each user. In cultural applications, interest can be detected from the users' activity, specifically their average speed and step count during their visit. Step detection is done via activity tracking using Location-Based Services (LBS), where devices rely on GPS or other WiFi-based techniques [9]. Another prevalent approach is by using sensor fusion through combining accelerometer with gyroscope [10]. Due to researchers' growing interest in this field, several applications and services have been developed utilizing activity recognition and even more specifically step detection in Health [11], Entertainment [12] and Surveillance [13], but none of them was integrated in the tourism field. Thus, the purpose of this research is to enhance the touristic experience by employing the interest detection mechanism in the cultural heritage field aiming to fill the gap between the tourists and the site stakeholders.

∗`https://play.google.com/store/apps/details?id=com.computeam.ww1activelens&hl=en`

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3. CHEOPS Platform

CHEOPS is a comprehensive platform for enhancing the touristic experience inside cultural heritage sites. The platform is based on a set of technologies that are integrated to provide location-aware information services to the visitors. These technologies include Augmented Reality (AR), Computer Vision (CV), eye gaze tracking, and localization, among others.

3.1. Architecture

Figure 1 shows the CHEOPS system architecture, which proposes an e-Tourism system that is based on the visitor's interest detection on the site. The system first determines the interest by detecting the tourists' speed, duration spent in front of every monument, usage statistics of mobile applications and finally, the location of highest interest. Location information is demerited by two methods: using wireless devices such as Bluetooth beacons or by using computer vision to detect the distance from monuments on the site. If visitors are not interested, the system will redirect them to another nearby location and re-checks the interest. If they are interested, then info about the monument/statue will be shown. Displaying the info is supported by two modules: the first one is Augmented Reality(AR) which serves adults and children as well as individual and group visitors. The other module incorporates feature extraction, where the system displays info according to where the visitor is looking and pointing. Finally, the system will redirect the visitor to another area.

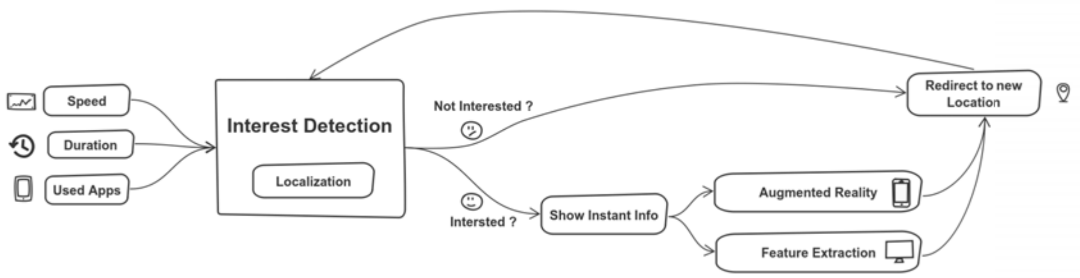

Figure 1. CHEOPS System Architecture

3.2. Interest Detection Methodology and Evaluation

The focus of this module is twofold: detecting the level of interest of the visitors and the level of engagement with the surrounding environment. In order for this system to be effective, the data needs to be easily accessed by the different stakeholders represented by the visitors and the tour guides/managers. The system relies on the visitors usage of their Smartphone to correlate their behavior to their level of interest. More specifically, this is done through two main methods; the first is measuring the users step count and walking speed during a visit. This is compared to the estimated average time it would take a person to visit the site. The second method is through detecting the users Smartphone activity where we correlate a high level of smart phone usage during a visit with a lack of interest in the site. However, the user's camera usage was excluded as it would indicate a higher level of engagement in the visit. After detecting the users' interest level regarding different artifacts, the data is used to redirect them around the site and provide them with information more tuned to their interest. This redirection module is location dependent, and its input detection mechanism is divided into two main parts.

- Motion detection: The system makes use of the Smartphone's accelerometer to record the tri-axial acceleration of the user. The obtained values are filtered to remove the effects of noise, gravity and changes in phone orientation. This is to ensure that only the user's walking speed is being measured without any external interferences. The filtered values can now be used to calculate user's speed, step count and distance traveled.

- Smart phone activity tracking: The system constantly checks the user's smartphone usage during their visit and calculates the percentage of interest. This is done through recording the start time of each application opened while on tour and then measuring the time spent using the application before the user closes it or switches to a different application. The system also tracks when the phone's camera is opened and the number of photos taken at each location.

This input is then sent to the server alongside the user's location, then it analyzes the acquired input in order to infer the user's interest in the surrounding site. First the user's speed, acceleration and time spent idle are examined. The system initially starts with a neutral interest i.e. 50% and according to the visitor‘s speed this value is increased or decreased on a percentage scale (0% - 100%). Here, high speed and acceleration indicate a low level of interest, and accordingly the interest percentage decreases. On the other hand, low speed, deceleration and an increase in time spent idle are all indicators of the user's increasing level of engagement with the site and hence, the interest percentage increases.

Second, we consider durations of application usage where we correlate a long duration of usage with declining interest and vice versa. To be able to adjust the overall interest, the change in percentage of the mobile apps usage is calculated and added or subtracted from the previously mentioned percentage. The camera usage is the only exception to the previous relation, where an increasing number of photos indicates a higher level of engagement in the monument.

An overall level of interest is then calculated from the previously calculated percentages and saved with the corresponding location. This data is later fed to a clustering algorithm (K-Means) that groups locations based on the user's percentage of interest, providing a more informative set of data. K-Means was chosen over other clustering approaches due to its scalability, especially in case of large data sets which is likely in our application. According to the clustering output, the locations with the highest percentages of interest are labeled and ranked for further suggestions to the visitors. These locations are used to redirect the visitors to other places by showing the rank of each location. Figure 2 shows the rankings of some locations. The X-axis represents the locations/halls and the Y-axis represents the percentage of interest. In the following section, we discuss the localization methods used in our platform.

3.2.1. Localization Location tracking is one of the main defining variables in interest detection. In this module, different approaches were tackled to get the user's location.

- Geo-fences
  A *Geofence* represents a virtual border that encompasses a certain location depending on a set radius. This can indicate when a user enters or exits the location using the Global Positioning System (GPS). The GeofencingApi ∗ is used in our system.
- Localization Using Beacons:
  Another technique is to get the visitor's location by using Bluetooth beacons. Once the location has been obtained from the geofences and the Smartphone's Bluetooth is activated, the service starts detecting active beacons in the vicinity and calculates location using triangulation †. This module also supports navigation to a specific location that can be entered by the user. In order to do this, a location map has to be pre-loaded to the module

∗https://developers.google.com/android/reference/com/google/android/gms/location/GeofencingApi/
†http://www.tothenew.com/blog/indoor-positioning-systemtrilateration/

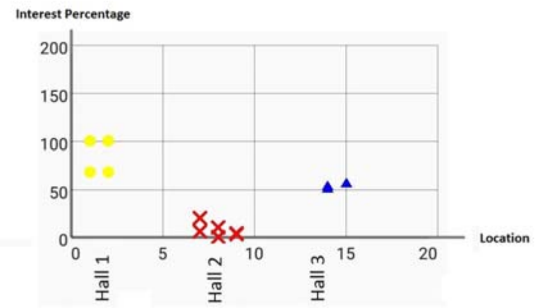

Figure 2. Locations Clustering

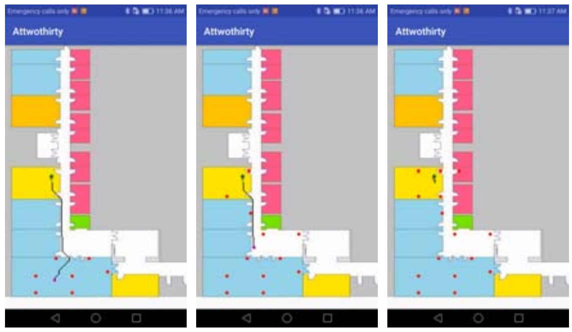

Figure 3. Highlighted location and updated path to destination

as a search space. Then, image processing algorithms are used to convert the image/map to gray scale and filter it to detect the obstacles/walls. Then, Gaussian filters were used along with erosion and dilation to filter the noise and to convert it to a binary image.
After constructing the 2D map, the A* algorithm ∗ was used to get the shortest path. After the user chooses the destination, a green dot is drawn representing the destination point and a line is draw on the map as a guide representing the path. The location of the user and the path is recalculated every 10 seconds and the line path is redrawn as shown in Figure 3.

- Localization Using Computer Vision
  In some cultural heritage sites, it is not possible to install wireless devices. Thus, this module presents an alternative solution for indoor localization using the Smartphone camera with the assistance of Open Computer Vision Library (OpenCV). Since cultural heritage sites are filled with artifacts, the application uses them as marker objects in the database to locate the user along with the real height of the object in meters, the pixel height of the object in the image, and the focal length of the mobile camera. By knowing these attributes and locations of such artifacts, the application would give an estimate to their location using depth calculations. The application uses ORB †, and SIFT ‡ as a feature detection algorithm to match artifacts and then calculates the distance from each artifact in the given image. The module takes into consideration the scaling and rotation factors of the captured artifacts. Afterwards, a modified trilateration algorithm [14] is used given the distances from the artifacts and successfully localizes the user.

Once the system detects a high level of interest in an object, an appropriate interaction technique is used to display proper information. For detailed monuments, eye gaze tracking and finger gesture recognition are used, while we use AR for other monuments.

3.2.2. Augmented Reality (AR) This module leverages the advantages of AR and encapsulates it in all modules mentioned in this section as a real-time interacting tool by displaying historical information of the place to visitors. The proposed AR methodologies differs from one module to another as explained below.

- AR for Adults

∗`http://theory.stanford.edu/~amitp/GameProgramming/AStarComparison.html`
†`http://docs.opencv.org/3.0-beta/doc/py_tutorials/py_feature2d/py_orb/py_orb.html`
‡`http://docs.opencv.org/trunk/da/df5/tutorial_py_sift_intro.html`

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In all AR modules, the user is supposed to point the device camera towards the showcased monuments. On detection of a monument, a button will be rendered on that monument to notify the user. When a button is pressed, an information panel appear presenting historical information about the detected monument. The panel has two options in case the user requires further information: the visitor can get more information either by pressing on the *Wikipedia* button or on *Google Search* button (see Figure 4). The module allows the user to take a picture of that monument and save it by a caption. If there is no info about that monument on the database, the module enables the user to search by image on *Wikipedia* and saves the info with the image for future users on the Vuforia cloud database * .

- AR for Children
  This module is dedicated to serve the particular interaction needs of children, mainly through more attractive interaction techniques and popular culture. Here, 3D cartoon models and animations are used as they are considered the most attractive visualization technique for the target audience. Animations like walking and moving the character's head are added, in addition to voice over audios with the character's tone containing the information given about the statues. The voice over audios, are added to help younger children who may not be able to read the information. Having the information presented in more than one language is an added value to reach more people with different cultures. Figure 5 shows the home page of the application and a screen-shot of the module. The child should first choose the language and then choose the cartoon character. The character chosen narrates the information about the monuments detected within the augmented reality scene. Even though these cartoon characters may not be related to the theme of the project, they are used for their popularity with children. Figure 5 on the right, shows the panel that is displayed with the statue's information displayed. The children can also share their tour and post it on social media.

Figure 4. Detected Targets and Information panel

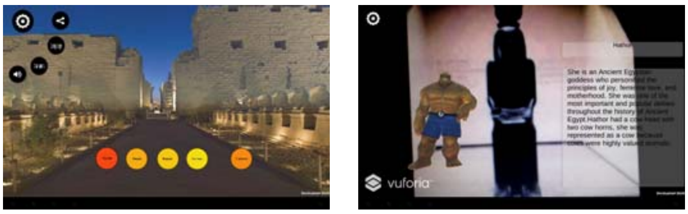

Figure 5. Children module Homepage and 3D Cartoon Models Interface

- Collaborative AR
  This module extends the previous AR modules through collaboration in form of a *Treasure-Hunt* game. Uers play the treasure-hunt game to share with each other the detected monuments. The task of the treasure-hunt team is to detect specific monuments to complete all the letters of a word e.g."LUXOR", and thus be the *winning* team. The game is played simultaneously by different players and the flow is as follows: once a visitor chooses to play the game s/he chooses to join a team e.g.(A), a guide appears on the screen to help the player in finding the monuments that should be detected to get the letter "L", as shown in Figure 6 (a). Once a letter is detected, it appears on the screen of all players joining team (A) (without the need to detect the same monument again) and now it is time to collect the remaining letters. Once any of the users detect a right monument, the letter related to

*https://www.vuforia.com/

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the monument appears to all users as shown in Figure 6 (b). When another visitor decides to play the game and chooses to be in another team e.g. (B), none of the letters will be displayed to this user, who then starts searching for the treasure. When a team completes all the letters of the word "LUXOR", this team wins and the other team loses, the winning team is saved in a *Firebase*∗ database where a message is sent immediately to all users of the winning team informing them that they won and a hard luck message is sent to the losing team as shown in Figure 6 (c) and 6 (d) respectively.

Figure 6. Team A: User 2 detects a monument and wins letter X

3.2.3. Feature Extraction In addition to AR, CHEOPS hosts a set of interaction techniques intended to provide fine-grained information about detailed scenes. Here, the interaction techniques are based mainly on two technologies: eye gaze tracking and finger gesture recognition. The module uses *Tobii EyeX* † for determining the user's eye position and inferring the user's interest. Moreover, it uses *Kinect version 2* (V2) ‡ for detecting the pointing gesture. The module involves taking the inputs from the eye tracker and the gesture from the Kinect and mapping the regions to get the interest area. This area is detected by extending the line of sight and mapping between the detected region from the eye tracker and the pointing region. Finally, the module shows info about the interest region displayed on the user interface. For testing, the painting § shown in Figure 7 (a) is used as a simulation for exhibitions and it is divided into sub regions. The testing scenario is as follows, if the eye tracker and the Kinect detect the same region, it means that this is a correct gesture. However, if they differ, this means that it is a false gesture and the visitor didn't mean to get information about this part.

A pilot study took place on a group of 8 users in Luxor museum to check the system accuracy, usability and to train the interest classifier. We received some comments on the usability of the user interface. However, they was pleased with the system.

4. Conclusion and Future Work

In this paper, we have presented CHEOPS, a comprehensive platform for enhancing services in cultural heritage sites based on ICT technologies. The proposed platform utilizes indoor localization techniques (based on Bluetooth beacons or computer vision) and information about Smartphone activity to detect the level of interest of the visitors, and accordingly provide a customized tour through the sites. In addition, several interaction technologies have been utilized to enable customized information display. Particularly, AR has been used to build interaction

∗https://firebase.google.com/
†https://tobiigaming.com/product/tobii-eyex/
‡https://developer.microsoft.com/en-us/windows/kinect/develop/
§https://goo.gl/YtSX77

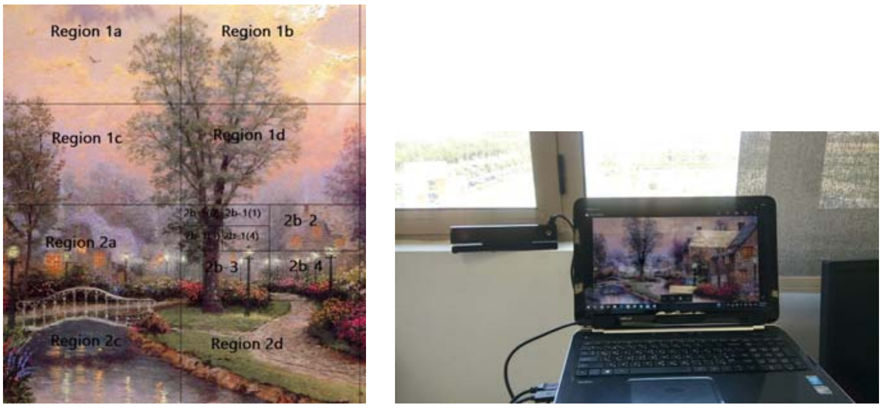

Figure 7. Accuracy Experiment Diagram and Setup

applications for different types of visitors, namely children, groups, and regular visitors. Furthermore, eye gaze detection and finger gesture recognition have implemented to allow fine-grained information display about specific parts of detailed monuments.The functionality of all the developed applications has been verified in realistic scenarios.

Acknowledgments
This work was in collaboration with Luxor Governorate and the ministry of antiquities. The authors would like to acknowledge the contribution of Ahmed Hazem, Safa Ads, Nadine Tarek, Nourhan Wael and Ahmed Elsayed in the implementation and testing phases.

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