Augmented Reality-Based Real-Time Accurate Artifact Management System for Museums

Abstract

In this article, we present an accurate and easy to use augmented reality (AR) application for mobile devices. In addition, we show how to better organize and track artifacts using augmented reality for museum employees using both the mobile device and a 3D graphic model of the museum in a PC server. The AR mobile application can connect to the server, which maintains the status of artifacts including its 3D location and respective room location. The system relies on 3D measurements of the rooms in the museum as well as coordinates of the artifacts and reference markers in the respective rooms. The measured coordinates of the artifacts through the AR mobile application are stored in the server and displayed at the corresponding location of the 3D rendered representation of the room. The mobile application allows museum managers to add, remove, or modify artifacts’ locations simply by touching the desired location on the touch screen showing live video with AR overlay. Therefore, the accuracy of the touch screen-based artifact positioning is very important. The accuracy of the proposed technique is validated by evaluating angular error measurements with respect to horizontal and vertical field of views that are 60° and 47°, respectively. The worst-case angular errors in our test environment exhibited 0.60° for horizontal and 0.29° for vertical, which is calculated to be well within the error due to touch screen sensing accuracy.

1 Introduction

Augmented reality (AR) is becoming more important due to its ability to overlay essential information required by the user in a real-world environment, which is becoming ever more complex. One particular example of the increasing complexity are museums, which have large and increasing collections of artifacts in a limited space. In order to deal with this issue, museums have adopted AR to provide visitors with simplified rich information retrieval.

Museums play an important role in societies, as they have been a source of cultural pride among local communities as well as inspiration for constructive cultural development. Museums try to preserve historical development of cultures in an organized manner. However, as visitors become more diverse and their needs change more rapidly, modern technology is necessary to reorganize exhibits efficiently according to the current needs.
Pervasiveness of technology has provided an opportunity to enable museums to interact with users of all ages in an attractive way. In the early 2000s, personal digital assistants (PDA), interactive information kiosks, and digital screens were introduced to elevate visitors’ interest by providing information tailored to the visitors (Dirk & Heath, 2005). A PDA is used by an individual and provides mobility whereas interactive information kiosks are used by a broader audience but without mobility. Each technology, along with its benefits, has a few shortcomings, such as isolation from peers while using PDA for audio-guided tours and overcrowding due to sparsely placed information kiosks.

Nowadays, the ubiquity of smartphones among all generations has introduced a new paradigm by paving its way in each and every institution, especially museums, to upgrade their spaces and digitize them. Smartphones are equipped with various built-in sensors such as the infrared (IR) sensor, accelerometer, gyrometer, magnetometer, touch screen, and high-resolution cameras. Therefore, amalgamation of technologies in the smartphone provides an opportunity for further technological advancement and penetration into the user’s social space. A report published by NMC Horizon Report in 2015 suggested that museum be mobile friendly and more integrated towards the younger generation. The report stated that “bring your own device (BYOD), games, location-based services, and makerspaces will blend in museum environment by overcoming challenges through digital strategies” (Johnson, Adams Becker, Estrada, & Freeman, 2015).

Museums, focusing on creative tools, are taking a step further to improve the user experience and interact digitally by introducing AR and virtual reality (VR). As mentioned earlier, the aim of museums is to preserve and present cultural heritage; therefore, enabling technologies such as AR and VR have provided a low-cost and a space-saving, as well as a time-effective solution (Styliani, Fotis, Kostas, & Petros, 2009). However, these types of new technologies require museum staff members to be retrained in order to manage them effectively (Johnson, Adams Becker, Estrada, & Freeman, 2015).

### 1.1 Motivation

The galleries, libraries, archives, and museums (GLAM) sector have some limitations, which pose barriers in integrating new technologies within the existing environment. Firstly, in most cases, direct contact with the artifacts is prohibited, especially when they are valuable or fragile in nature (Styliani, Fotis, Kostas, & Petros, 2009). Typically, safe distance barriers or other precautionary measures such as displaying them in glass cases are necessary. Therefore, a solution that provides more intimate interface between artifacts and users is essential. Secondly, printed supplementary information placed beside each artifact overcrowd museums and directly affect their aesthetics. Also, while modifying artifacts’ location, it may lead to space management issues due to the attached supplementary information. An AR system, however, can replace printed supplementary information to overcome issues related to aesthetics and space management. Thirdly, museums contain numerous artifacts and there is a possibility of misplacing or losing track of them. Thus, it is important to have an efficient artifact-tracking management system. This tracking functionality is inherent in AR-based interface. Fourthly, museums are continuously upgrading their artifacts by adding and/or replacing artifacts, which require human resources in keeping updated records in a database. An intelligent database management system using AR can provide a solution to add, modify, and update records of artifacts. Fifthly, museum managers are not experts in computer programming. Thus, they require a simple, understandable, and easy-to-use system with high abstraction of low-level details.

In summary, for GLAM, we need to build a solution that provides a direct user-to-artifact information interface, artifact tracking system, and artifact database management system with maximum abstraction of low-level details. In this article, we propose a solution for GLAMs by developing a mobile AR application for smartphones and a 3D rendering and database-based artifact management system for a PC server. The main contribution is a real-time single touch artifact management using an AR interface, which can send accurate 3D coordinates and artifact ID to the server wirelessly.
The organization of this article is as follows. In Section 2, background of AR systems and their applications, specifically at cultural sites are highlighted. In Section 3, the proposed system and the algorithm of AR enhanced museum (AREM) smartphone application are explained in detail. In Section 4, our system evaluation methodology and results of implementing the AREM application are presented and discussed. Finally, in Section 5, the conclusion is presented along with a proposition for future research.

2 Related Works

The history of AR applications can be traced back to the early 1990s when Boeing replaced manual instructions of airplane assembly by an AR system, HUDSET. In 1996, the Mobile Augmented Reality Systems (MARS) project was initiated by Columbia University that allowed users to experience AR using head-mounts as well as handheld devices with freedom of movement (Feiner et al., n.d.). In 2002, Schmalstieg et al. (2002) developed the Studierstube system, which provided a concept of collaborative AR by employing head-mounted displays or projection screens to combine computer graphics with the user’s view of the real world. Before the invention of smartphones, PDAs were mainly used as display systems for AR application, while high-end servers would handle complex computations (Wagner & Schmalstieg, 2003). With the advent of smartphone technology, the AR application paradigm has completely transformed because smartphones not only provide interactive touch screens for display, but also provide mobility and accessibility that was not possible before. In our literature review, we have presented museum applications using AR and divided them into four categories according to their applications.

Edutainment by enhancing visitor’s experience. One of the primary purposes of museums is to transmit information and impart education about exhibits. However, they also need to personalize and elevate the visitor’s interest in museums, especially for upcoming generations. A study conducted by the Centre for the Future of Museums suggested the necessity for introducing state-of-the-art technologies that are “interactive, immersive and participatory” to increase interest (How Virtual Reality & Augmented Reality Transform Museums, 2017). In recent years, many museums have introduced AR-based systems to achieve the aforementioned goal. The Hirose Tanikawa Narumi Lab has developed an iOS application to exhibit on-site AR by overlaying past scenery onto the present location (Projects | Hirose Tanikawa Narumi Lab, 2013). Likewise, the Netherlands Architecture Institute (2010) launched Powermuseum. The Museum of London has also launched AR applications known as Layar, Urban Augmented Reality (UAR) (n.d.), and Street Museum (n.d.). These allow users to visualize outdoor public spaces along with other attached digital contents, how they once looked in the past, and how they will transform in the future. Museum wearables are another tool that provide an AR experience; however, this requires users to wear a private-eye display and carry a shoulder pack containing a computer for processing IR information received from an IR emitter tag attached to the artifact, which eventually leads to virtual contents displayed beside the artifact (Sparacino, 2002). A project study conducted by the University of Florence is Onna Social House that utilizes natural human gestures to communicate with visitors through an interactive wall by displaying informative content without the use of any wearable or handheld device (Cucchiara & Del Bimbo, 2014). Moreover, another system, Tell_Me_Where, developed by collaboration between the University of Modena and Reggio, is the AR enhancement of the Enzo Ferrari Museum using glass cameras for recognizing their own gestures and smartphones for object recognition to display related details of the exhibited cars (Cucchiara & Del Bimbo, 2014). An AR guidance system was built using computer and separate USB web camera that recognizes a user’s finger pointing towards the marker patterns printed on a distributed pamphlet given beforehand (Ding, 2017). In this system, output is displayed on a computer using 3D models and textural information stored in a database. This system is kind of an AR upgrade of interactive Kiosk, which does not allow users freedom of movement and also requires multiple computers to be placed in the museum at
different locations. Phone Guide is a system with multiple Bluetooth communication devices installed inside a museum for estimating user location and on-device image processing using neural networks (Bruns, Brombach, Zeidler, & Bimber, 2007). Once the user intends to capture a picture, a press button invokes an object recognition algorithm and is completed within 1 second on currently available smartphones. Although Bluetooth grid estimates the position, it does not accurately localize the user coordinates. However, with a museum being divided into various chambers based on Bluetooth IDs, the object search database for recognition is considerably reduced when a user presses the button to take the photo.

**Gamification.** Many museums across the world have introduced AR-based simple, but intriguing, games to involve younger visitors. This feature increases the visitors’ interest while inconspicuously broadening their cultural knowledge. Gamar developed A Gift for Athena, an iOS as well as android-supported AR application, for the British Museum’s Parthenon Gallery in which artifacts are image processed for recognition via smartphone camera. The user is asked to complete simple and fun challenges to learn more about the artifact (Selvam, Yap, Ng, & Ho, 2016; A gift for Athena, n.d.). The Smithsonian National Museum of Natural History launched an iOS-based Skin and Bones application, which covers bones with flesh and displays attached digital contents (Skin and bones—Mobile augmented reality app for the National Museum of Natural History’s Hall of Bones, n.d.). In 2017, Lenovo embedded Tango, an AR-based computing platform providing a feature of placing virtual objects (static, animated, or interactive) onto a real environment without using any specific virtual marker (Peckham, 2018). Tango combines visual and inertial sensors to recreate the room space by recording visual features of the environment and connecting them with inertial sensor data. Moreover, depth perception is used to detect distances, sizes, and surfaces in the room. There are several other features, which enable users to enhance their environment according to their wishes, requiring special training or skill sets.

**Navigation System.** Another application of AR technology is indoor navigation systems around the museum in order to serve multiple purposes such as visitors’ route planning, enhancing the user experience by navigating them through various predesigned or real-time environments user interest-based storytelling, and connecting group members with each other irrespective of their location by sharing interesting content. ARM23 has developed a commercialized mobile platform called Project ARM that provides various features, including an interactive map for touring a museum, scanning the artifacts to get an AR view along with digital contents for explanation, an informative game, and buying souvenirs from shops (New museum AR experience, 2015). Mnemosyne is one of the projects funded by the Regional Government of Tuscany and carried out by the University of Florence, which detects visitors through multiple fixed cameras and through observation; it generates a respective profile for the visitor identifying their most preferred exhibit points, and finally, providing them with a personalized tour of the museum (Cucchiara & Del Bimbo, 2014). An application developed for the Acropolis Museum in Greece takes advantage of AR through personifying the museum tours by profiling the visitors and matching them with already stored profiles (Ioannidis, Balet, & Pandermalis, 2017). Moreover, by evaluating the visitor’s interests, inputs, and positions, the application dynamically reacts to the visitor’s tour by creating personalized storytelling and injecting numerous AR activities such as task completion or games. Unlike other applications, museum curators, rather than IT programmers, design interactive tours. This provides control to museum staff members, who can better cater for visitors’ current needs. The application is based on server-client architecture, where mobile devices are always wirelessly connected to PC servers. Although 3D assets and maps are stored on mobile devices, the majority of computational processes occur through the server, such as personifying the tours and injecting AR activities (Keil et al., 2013; Ioannidis, Balet, & Pandermalis, 2017). In Wang, Lin, Chiang, and Yin (2015), an indoor group mobile navigation system is proposed, employing AR alongside sharing information and group communication. Radio-frequency identification (RFID) tags with unique IDs are worn by users and are detected by RFID detectors at various points,
which enable group members to visualize the navigation space on their respective mobile devices. Moreover, capturing the image of an object leads to object recognition and tracking. Eventually, 3D or multimedia navigation information of an image captured by the mobile device would be presented. However, one important problem was highlighted in this article. If the captured object is not available in the related navigation area due to updates or any other reason, a request to the management system is made to send corresponding multimedia data of the exhibit.

**Artifact Management System.** We have created another category in which AR applications act as an artifact/exhibit management system, which is a perspective that has yet to be explored. There are many systems and applications developed based on AR other than the ones already mentioned, using diverse techniques. However, based on our comprehensive survey, researchers and system application developers have focused mainly on enhancing a visitor’s experience in a museum whereas our work is the first effort that not only enhances a visitor’s experience, but also provides an easy-to-use artifact database management system for the museum staff through AR technology.

3 AR Enhanced Museum

All of the aforementioned applications have mainly focused their primary goals to enhance visitors’ experience; however, the AR technology-driven artifacts management perspective is an area that has not been explored yet. Therefore, we propose an architecture that provides on-site artifact database management through an AR application in real time and off-site through WebGL, which enables a web-based 3D graphics server management system. In addition, an open source database program, MySQL, is used for storing and managing the database of museum artifacts. Based on the measurements stored in database tables, a manager can visualize the real-world room aesthetics and artifacts management in each room by changing the artifacts’ location and wall patterns.

This section explains the proposed system that has been developed to model the real-world museum environment into AR mobile application, which also can be implemented to various indoor scenarios. The developed architecture allows a user to view digital contents such as images, text, audio, and video related to real-world objects by overlaying virtual buttons on top of them through an AREM android application. Finally, the working principle of manager mode is also discussed later in this section.

3.1 Proposed System

3.1.1 Hardware. Our system implements the concept of BYOD as we have opted for optical marker-based tracking using a built-in camera on a smartphone or tablet; thus, we utilize the user’s own smartphones or tablets as a hardware device. For localization and position mapping, built-in inertial sensors including an accelerometer, magnetometer, and gyroscope are used. We opted for a built-in camera and sensors for many reasons. Firstly, it does not incur any additional cost, since smartphones or tablets are pervasive and ubiquitous. Secondly, a built-in feature does not overburden the user to carry separate devices such as webcam, lens, head-mounted-display, etc. Similarly, there are various AR interfaces available such as tangible, collaborative, hybrid AR, and multimodal. In our system, however, we have used smartphone LCD display as an interface between the user and artifacts because of the ubiquity of smartphones/tablets and high processing power available onboard, which is necessary for fast marker recognition. A desktop computer with basic hardware requirements, acting as a server connected to the user via Wi-Fi, is also required for database storage, 3D textures, and room models. In our case, we have successfully implemented the server on both Windows and Linux operating systems.

3.1.2 Software. Our system is developed for indoor systems where GPS is not operable. Therefore, we segregated the museum into large rooms that are differentiated by beacons placed in them. As shown in Figure 1,
when the AREM application is turned on, the device invokes the user to enable Bluetooth for automatically selecting the closest beacon location. For rooms that do not have beacons, manual room selection is necessary. The rooms are 3D modeled beforehand by positioning artifacts with respect to their actual measurements. The geometry of rooms was measured using a laser range finder and the respective dimensions obtained for each room are stored in the respective database file.

This information is prestored in tables created in MySQL database through a web scripting language on the server. When a room is detected or selected, the corresponding database file is read into the application. Then, the user is prompted with a pictorial instruction to move towards the closest visual reference marker (VRM) and capture it within a highlighted area of the live video screen. While measuring the dimensions of a room, the original VRM dimensions and its coordinates with respect to room origin are also measured manually via a laser range finder and stored in the respective room database file. The captured VRM is compared with reference distance measurements and its original dimensions to extract distance and capture angle in relation to the user’s camera. A reference vector from a mobile camera to the VRM is calculated by using values from calculated distance and angle for determining user coordinates with respect to the room’s origin. Finally, vectors to each artifact are calculated by extracting coordinates of artifacts in the room from the database table and virtual buttons are displayed on the mobile screen by overlaying them on respective artifacts. The reference vector is modified as the user scans the room using the camera. This modification is performed utilizing the inertial sensor values. As the vector is modified, the relevant viewable artifacts’ virtual button positions are also modified in real time.

Pressing virtual buttons allow users to interact with the artifacts as each of them has digital contents attached such as image, text, and audio, which are displayed on the screen upon user request. If users want to explore another artifact, they can go back to the AR view of the room. In addition, users can rotate 360 degrees around their position to have a quick scan of the room.

### 3.2 Manage Mode

One of the primary features in our application is Manage Mode. The Manage Mode is designed to add new artifacts in a known room, delete any artifacts, or modify current artifacts to a new position using either an on-site point-and-touch AR-based interface in real time or off-site server based.
In a point-and-touch AR-based interface modification method, when a museum staff person intends to modify any room, for example adding a new artifact, the staff person touches the screen at the desired target point \(P_T\). Since the touch screen environment is 2D, whereas real environment is 3D, a method to accurately calculate the coordinates is developed. This is shown in Figure 2. Initially we assume \(y = 0\) and define the variables:

- \(P_C\) = Pixel value at the screen mid-point
- \(P_T\) = Pixel value on the touch screen for intended artifact at the desired target point
- \(\beta\) = Angle denoting half of the field of view (FOV) of camera
- \(\alpha\) = Angle between \(P_C\) and \(P_T\) \((0 < \alpha < \beta)\)

\(d\) = Focal distance (distance between screen and point of convergence)

Therefore, we can calculate

\[
d \tan \alpha = \frac{P_C P_T}{d}
\]

\[
d \tan \beta = \text{screen width}.
\]

By combining both equations, we can obtain the value of \(\alpha\):

\[
\alpha = \tan^{-1} \left( \frac{P_C P_T}{\text{screen width} \tan \beta} \right).
\]

\(\alpha\) is composed of horizontal and vertical angles, \(\alpha_x\) and \(\alpha_y\). Using the horizontal field of view (FOV) angle will generate \(\alpha_x\), whereas using the vertical FOV angle...
will generate $\alpha_y$. After obtaining values for $\alpha_x$ and $\alpha_y$, we can project the artifact in a respective vector using the corresponding $\alpha$, and thus obtain an intersection point of both vectors onto the wall plane. Finally, the intersection point is the generated coordinates for the new artifact, which are then added into the server database through the touch screen interface without manual measurements. In Figure 3(a), the manager selects the room, which needs to be modified in the application; and captures the image of the visual reference marker shown in Figure 3(b). Thus, the AR view is displayed on the smartphone touch screen. Figure 3(c) shows the camera view with floating virtual buttons on the artifacts after camera calibration.

An alternative way is connecting to a server machine containing MySQL databases through a web-based scripting language. The interactive user interface allows the managers to create their own databases and modify them according to their requirements, as shown in Figures 3(d) and 3(e). Finally, based on the database, each room is 3D modeled using WebGL and visualized through the web hosted by the server. The 3D environment can also be viewed after modification of the database by going to its respective local URL.
Figure 3(f) provides a comparison between before and after changing the database.

### 3.3 Server Management System

We chose the PHP web scripting language environment to interact as a medium to communicate between the smartphone and the MySQL database. Once the PHP-based server is created, it can be accessed from smartphones using static IP address of the server. After taking measurements of the targeted location/rooms, either automatically through touch screen or using physical measurements using a range finder, a MySQL database table is updated by entering data, either through the smartphone application on-site of the artifact or off-site at the server, into the specified fields of the table. In this database, the manager can add, delete, or modify information in any areas of the field through the web interface provided by the PHP environment (Contributors, 2018; Delisle, 2012).

After completing the table in the database, the 3D room model is hosted on the same PHP server. To develop the 3D room model, the WebGL language platform is employed to integrate 3D environment and textures. The data stored in MySQL tables is fetched using an SQL query. The SQL query is embedded in the PHP script, which can be used in HTML5 code. The fetched data are stored in JSON format in a file that is used by the WebGL for constructing the 3D model of a room as shown in Figure 4.

The MySQL database table structure consists of seven attributes, which are shown in Table 1.

In order to register any artifact, all of the aforementioned fields are required. RegTime contains an artifact’s latest entry time stamp linked to the artifact. Wall denotes the unique number representing every wall and table (if any) of a room. 3-axis coordinates are essential for artifact placement in real time as well as the 3D model; therefore, each axis coordinate is stored in its respective field. While measuring dimensions of a museum room and artifacts, a right-handed coordinates system is used. Each artifact is assigned a unique ID that is denoted by Artifact ID. The description is the textual digital contents attached to the artifact and can be viewed in the 3D model space, upon clicking the red button on each artifact, as shown in Figure 5.

### 3.4 Image Processing Unit

The image processing unit performs the task of calculating distance and angle from the VRM. It is comprised of a grayscale-processing algorithm and a feature-matching algorithm. It receives the camera-captured scene that includes a predefined object and stored reference subimages of the VRM. All four images are converted to grayscale for the feature-matching algorithm.

<table>
<thead>
<tr>
<th>Attributes Type</th>
<th>RegTime</th>
<th>Wall</th>
<th>X-coordinate</th>
<th>Y-coordinate</th>
<th>Z-coordinate</th>
<th>Artifact ID</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
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<td>Integer</td>
<td>Float</td>
<td>Float</td>
<td>Float</td>
<td>Integer</td>
<td>Text</td>
</tr>
</tbody>
</table>
to seek the best matching locations of all the reference
subimages.

A predefined room is measured beforehand, including all of the coordinates of artifacts and VRM. The VRM is analyzed with a set of reference subimages to output the relative position vector. To do so, camera calibration is needed to estimate the initial capture pose. Once the relative position is obtained, an absolute coordinate and a view direction of camera are calculated from the known VRM position and its normal vector. Then, vectors are generated from the camera to all artifacts for constructing relative relationships. FOV is utilized along with the vectors to display the buttons on the screen. Each vector points to a unique artifact, and they display virtual buttons on screen if they are inside of the FOV. As the camera rotates, vectors update in real time to follow camera rotation by analyzing inertial sensor values embedded in the phone.

Figure 6(a) illustrates a VRM in the room and the corners that are image processed for angle and distance computations to extract the camera vector. Three reference subimages, as a set, are compared to the captured image through an image-matching algorithm. This same set is used to match varieties of capture distance and capture angle conditions. In Figure 6(b), virtual buttons that are inside of the FOV are overlaid on the screen in reference to the current camera vector and the artifacts’ coordinates stored in the respective MySQL database table.

4 Evaluation and Assessment

The aim of the experiment is to test for the accuracy of the proposed touch-based AR interface in modifying the position of artifacts in Manage Mode. Therefore, we performed an emulation in which an artifact is added by a manager using Manage Mode of the AREM android application in real time. The key
parameter that we want to evaluate is the accuracy of placement of new artifacts through the touch screen in terms of angular deviation from the manager position to the actual artifact position in a real-world environment.

4.1 Method

An accuracy evaluation experiment was performed in a closed room measuring 49.75 m\(^2\) (7.47 m \(\times\) 6.66 m) lit with fluorescent lights. Six dummy artifacts (white A4-sized papers) were placed on different walls of the room and numbered for ease of display. The coordinates of the artifacts were premeasured using a laser range finder and entered into the MySQL database table. An LCD screen was chosen as the VRM for the room as shown in Figure 7(a) and respective coordinates with respect to room dimensions are also measured and inserted into the database file. The device that is used for capturing the VRM and display was an android tablet model having specifications of 8 core processor running at 1.9 GHz with 3 GB of RAM and an 8.4-inch touch screen display. Another three test artifacts (red-colored papers of different sizes) were attached to the walls and respective coordinates were also measured using the laser range finder; however, they were not entered into the database. The measurements of artifacts performed are from the center of the artifact considering it as a point in the database. Finally, actual coordinates of test artifacts were compared to the coordinates calculated in real time through the AREM application. This comparison generated quantitative results to analyze the accuracy of our system.

After setting up the environment, the test room was selected manually and VRM was captured using the application as shown in Figure 7(a). While the application was displaying already-placed artifacts as shown in Figures 7(b), 7(c), and 7(d), we pressed on the touch screen for adding test artifacts (in red color) using the AR view of the application. Corresponding coordinates were generated by first calculating angular measurements with respect to the horizontal as well as vertical FOV. Also, the application asked the manager to input artifact ID and description. Once these descriptions were entered, the SEND button was pressed to transfer
the respective coordinates along with the artifact ID and description to the corresponding MySQL database table wirelessly as shown in Figures 7(e) and 7(f).

### 4.2 Results

In our experiment, 137 empirical readings were performed in which 62 readings were taken for Test Artifact 1; 44 readings were taken for Test Artifact 2; and 31 readings were taken for Test Artifact 3 using Manage Mode of the application. All readings were directly sent and stored in the respective MySQL database table as shown in Figure 7(f). Table 2 shows the measured results compared to the actual measurements.

The blue lines in Figures 8(a) and 8(b) illustrate angular measurements for placing an artifact in real time with respect to pixels on the touch screen, whereas red lines show the respective maximum angular error measurement at any given pixel on the touch screen. Figure 8(a) shows error measurements for $\alpha_x$ which is calculated using horizontal FOV and Figure 8(b) illustrates error measurements for $\alpha_y$ which is calculated using vertical FOV. The tablet used for the experiment had the screen with 141 pixels per centimeter (ppcm) and with a camera that had horizontal FOV = 60° and vertical FOV = 47°. Moreover, angular measurements for any object displayed on the touch screen were calculated based on the target touch finger size, pixel value at the center of the touch screen ($P_C$), object’s pixel value on screen ($P_T$), FOV angle ($\beta$), device’s ppcm, screen size, and display resolution as mentioned in Equation 3.

According to a study conducted by the MIT Touch Lab, the average width of index fingers is 1.6 cm to 2 cm for most adults (Dandekar, Raju, & Srinivasan, 2003). Similarly, we have assumed target touch finger size as $2 \times 1$ cm, which translates to a maximum error variation between 282 ppcm horizontally and 141 ppcm vertically, using the aforementioned device. This error variation is dependent on a smartphone or a tablet’s value of ppcm. Maximum angular errors are shown in the red line in Figures 8(a) and 8(b) for horizontal as well as vertical FOV using angular measurements of $\alpha_x$ and $\alpha_y$ shown in the blue line. The angular measurements are calculated using Equations 1, 2, and 3, whereas angular error measurements are derived by subtracting the subsequent value of angular measurements from the maximum possible error at any given pixel on the touch screen. In our calculations, we have assumed zero error will occur if the center of the user’s finger touches the desired point on the screen.

### 5 Discussion

The presented study investigated the accuracy of artifact modification using a one-touch AR-based interface. We were especially interested in the situation when managers intend to add an artifact through the
The results from our experiments show the accuracy of the calculated 3D coordinates with respect to the touch of a user on the display screen of a smartphone or tablet. From experimental results shown in Table 2, the angular error measured between actual and empirical, a range from $0.03^\circ$ to $0.60^\circ$ for $\alpha_x$ and $0.1^\circ$ to $0.29^\circ$ for $\alpha_y$. As is clear from Figures 8(a) and 8(b), both errors obtained in $\alpha_x$ and $\alpha_y$ are within the range of maximum possible error due to touch sensor accuracy. Also, we conclude that the error in positioning is due to the user’s inaccuracy in touching the desired target location. We have used angular measurements as a criterion of determining accuracy of newly added artifacts during the experiment because it provides independence from distance of the object from the VRM capture point in real time. Moreover, for closer objects, angular error will yield more accurate results, whereas for farther objects, same angular error will yield increased error.
There are a few limitations in our proposed system. Firstly, AREM gives an overview of a room and only provides 360 degrees of rotational view around the original capture position of the VRM for indoor environments. Therefore, the user or manager cannot get closer to artifacts as the AR view is dependent on the user’s initial location. Although the AR view can track rotational movements in all directions, the system does not have the capability of updating the user’s position if the user walks to another location. Secondly, while capturing the VRM, the image processing module processes and finds the corners of the screen in our case. Therefore, the VRM should be carefully selected as it needs to be differentiated from the background environment; otherwise, reference subimages may mismatch and lead to an inaccurate AR view. Thirdly, as we have analyzed, errors due to target touch finger size is a limitation of the system, which is dependent on the user’s touch as to how accurately the touch screen is able to pick up the touched finger center and the view area of the desired location.

In the future, localizing user current location through real-time position calculation through additional cameras attached on the ceiling can be one of the possible solutions to allow additional freedom of movement. It would allow VRM capturing to be performed only once as it is used to calculate only the initial position of the user. If the user’s location can be localized through supplementary cameras, this improved system can allow a constant and continuous AR view for indoor applications, which has yet to be implemented.

6 Conclusion

An AR-enhanced museum management system is designed to achieve better management even to non-technically inclined museum workers and thus improve the users’ experience. Presently, IT has engulfed each and every aspect of human life; therefore, it is also imperative to develop such technologies to connect people with places such as cultural heritage, public libraries, and post offices. In our research, the museum was adopted as a test case scenario in which the AR system is accurate within 0.6 degree of angular error and provides a simple interface for managers in managing artifacts in a museum without requiring any additional resources. In addition, this system enhances the users’ experience and helps them to plan their museum tour in real time by providing a quick scan of the artifacts in a given bounded place. The proposed algorithm can be used in a variety of real-world scenarios such as libraries, department stores, and food courts.

Acknowledgments

This research is supported in part by the Ministry of Culture, Sports and Tourism (MCST) and the Korea Culture & Tourism Institute (KCTI) Research & Development Program 1375026464. It is also supported in part by the Sports Promotion Fund of Seoul Olympic Sports Promotion Foundation from MCST S072014132014.

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