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Augmented Reality Techniques for Museum Environments

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ABSTRACT

Research into indoor exhibition systems associated with the use of augmented reality technologies is very limited. In this paper, we propose an architecture that is capable of generating accurate 3d models using as input only a few photographs and then merging real and virtual information in a seamless way. We have experimentally applied two simple but effective ways of visualising incomplete or broken real objects as they were in their original state by superimposing their missing parts. To enhance the immersion and realism of the simulated environment, the system allows augmented exhibition of other modes of multimedia content such as textual and pictorial information within the 3D world space. Finally, human-computer interaction techniques are implemented to allow users to naturally manipulate the augmented scenarios.

Keywords augmented reality; virtual reality; museum exhibition systems; user interface systems; human computer interaction.

1 INTRODUCTION

In recent years 3D computer graphics interfaces have emerged and their possible benefits have started to be recognised. User interfaces that are more akin to the real 3D world are by definition more intuitive and practical to use. New human computer interaction (HCI) techniques have been developed offering a greater degree of freedom compared with traditional windows style interfaces [1]. On the other hand, augmented reality (AR) offers an interface technology [2] that aims to exploit ways of combining computer-generated information with the real world. Participants in AR environments can interact in a completely natural way unlike with virtual reality technology, which immerses participants in a completely synthetic environment. Although there are still some technological problems that remain unsolved [3] the potential benefits are well presented in [4].

Two of the most important requirements concerning the effectiveness of an AR system relates to the effectiveness of visualization and interaction techniques [5]. The success of an AR exhibition is highly related to the level of realism achieved. In general, there are a few AR applications that do not require a high level of realism, but for some types of exhibition environments (e.g. museums) realistic visualization is a very important aspect. In addition, the end-users (visitors) expect the visualised information to be naturally presented in an instinctive and entertaining manner.

Moreover, all entertainment experiences can be sub-divided into three categories, which represent the areas of multidisciplinary research being conducted in mixed reality [6]: the venue, the content, and the use of artistic convention used for capturing and engaging the imagination through story telling. Furthermore, museums are one of the best places for AR applications [7] because they offer many challenges to AR researchers such as finding novel ways of providing information and offering new consultation methods for archaeological, cultural sites or museums [8].

In this paper, on the first part we present effective ways for generating digital content using as input only digital images. On the second part, we explore the potential of AR interfaces in exhibition environments by complementing the real environment with digital information. To prove the feasibility of our prototype architecture, we have designed two simple but effective ways for visualising incomplete or broken real objects in indoor environments. Potential heritage visitors can make use of the functionality existing in the system to perceive a realistic visualisation as well as interact with the virtual information in a natural manner.

It is worth mentioning that the methodology described in the following sections is not focused for a particular type of exhibition environment and thus can be applied to any type of indoor exhibition (i.e. museums, art galleries, etc). However, one of the most promising type of exhibition environment cover the fields of archaeology and cultural heritage, where incomplete artefacts can be augmented with virtual missing parts in an attempt to represent their original state.

This paper is structured as follows. In the second section, the specification and design goals of this research are illustrated. In the third section, the architecture of our system is presented while on section four we briefly explain how the broken/damaged objects are digitised. In section five, we propose two ways based on AR for complementing real objects with their virtual missing parts. Section six presents ways for interacting with the AR environment as well as changing the visualisation properties in real time. Finally, in section seven we present our conclusions and propose our plans for future research.

2 SPECIFICATION AND DESIGN GOALS

The interactive AR scenarios have been specifically designed to operate under controlled indoor environments, like museums, galleries, exhibition spaces and any other indoor exhibition events. The main requirements of the proposed AR exhibition framework are summarized below:

- The accurate modelling of broken or damaged objects using industry standard tools (i.e. 3ds max) and techniques (i.e. photogrammetry). This process consists of two stages. In the first stage, the aim is to quickly model the real artefacts using a few digital photographs. In the second stage, the 3D representation is refined based on our customized modelling tool (section 5).

- The robust visualisation of the broken or damaged objects using the advantages of AR interfaces technologies, which is achieved by adopting a marker-tracking approach [1] and a previously presented AR Interface Toolkit [5]. Participants can realize the concept and experiences of AR reconstruction, through the use of two augmentation scenarios including partial and complete augmentation (section 6).
- The natural interaction between the end-users and augmented information. Realistic augmentation is achieved by incorporating computer graphics algorithms and tools (i.e. OpenGL API) into the augmented information. Low cost I/O controls such as the keyboard and the mouse are used in order to keep the complexity of the interactions as low as possible and provide an easy way to access additional graphics functionality (section 7).

Based on the above three concerns we have designed and implemented an experimental AR exhibition application whose architecture is presented in detail in the following section.

3 SYSTEM ARCHITECTURE

The three basic stages involved in the architecture of the system (Figure 1) is similar to the ARCO project [9][10] and include: a *content acquisition stage*, a *content generation stage* and a *visualisation stage*. An overview of our architecture is presented in Figure 1.

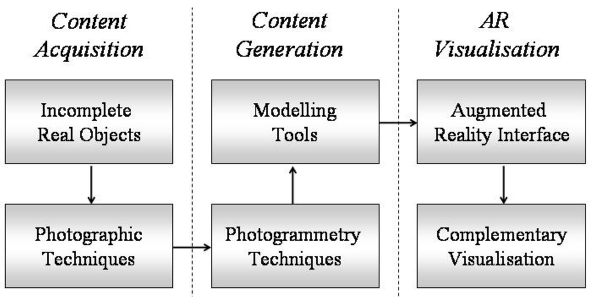

Figure 1. Architecture of the system

In the content acquisition stage, the aim is to collect all the necessary data required for the digitisation and accurately photograph them. Once all information is gathered, professional photographic techniques are employed to capture only a few pictures, which will be used for 3D model generation, and store them in our filing system for further processing.

Further processing depends on the complexity of the object. Simple objects, e.g. an object that clearly has a centre of revolution and is not too complex, can be created directly in the modelling tool using the photographs as a backdrop. Objects that are more complex would use a photogrammetry method, or alternatively laser scanning and texturing from the photographs. Cheap photogrammetry software, e.g. Photomodeller by EOS systems, is also available to process photographs into rough models that may be refined in the modelling tools. The computer-generated model is then stored in the workstation and can be used for the visualization phase (Figure 2).

Finally, in the visualisation stage, the digitised information (i.e. 3D model) is input to the AR Interface Toolkit [5], which fully controls the visualisation scenarios. The digitised information is seamlessly superimposed into the real world in a complementary way. Users can control and examine the AR environment in an intuitive and effective way.

4 OPERATION OF THE SYSTEM

The implementation of the AR visualisation scenarios are based on off-the-self software and hardware components. Currently, a single web camera is used to capture the image of the tabletop environment (more cameras can be used) and a workstation with a flat monitor to visualise the superimposed information. The complete setup comprises of a cy-visor see-through colour HMD, a web camera and the previously presented AR Interface Toolkit [5]. For the model generation stage, to accurately model the shape, a museum focused customized modelling tool is used, this is called the Interactive Model Refinement and Rendering tool (IMRR) which was also developed in the ARCO project [9][10] based on the 3ds max tool. The system's mode of operation starts from a broken real object and finishes with the augmented visualisation is presented in Figure 2.

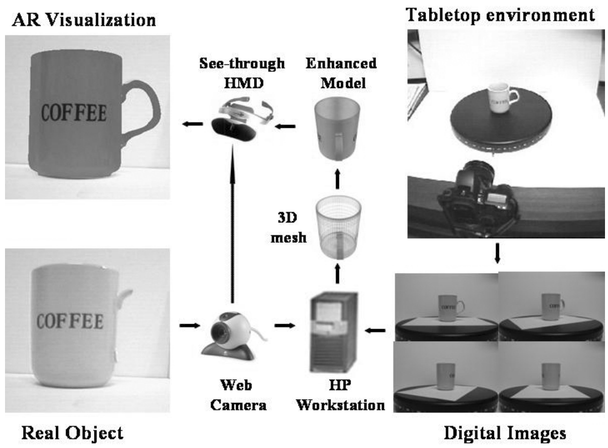

Figure 2. Method of operation [11]

The workflow of the system is as follows. As soon as the application commences, the web camera video scopes the tabletop environment that consists of physical marker cards and broken/damaged real objects (i.e. broken coffee mug). Based on ARToolKit tracking libraries, image processing and computer vision techniques we can accurately calculate the web camera's position and orientation (also known as pose) relative to the physical marker cards [12]. However, the ARToolKit tracking libraries tend to track any black square in the scene making it difficult to correctly perform tracking in a colourful background. To maximize the effectiveness of the system a white background was preferred as a base of our experiments. In addition, the web-camera was calibrated using the well-known Camera Calibration Toolbox for Matlab [13].

Using the pre-existing functionalities of the AR Interface Toolkit, computer-generated information can be first selected and then inserted into the real environment in real time. To increase the realism of the scene, computer graphics techniques based on the OpenGL API such as texturing, lighting, shading, etc. are used. The final visual output can be sent either directly to the user's eyes through the use of the HMD or on a standard monitor (CRT or TFT). The latter offers a greater degree of collaboration but lacks immersitivity.

5 CONTENT ACQUISITION AND GENERATION

The content acquisition and generation is performed as an off-line process and consists of two parts including *shape reconstruction* and *model enhancement*. The photo shooting was done in the research laboratory based on state-of-the-art photo hardware such as a *digital camera* (Canon EOS – D30); a *tripod*; a *turntable*; and *professional lighting equipment*. By keeping the camera in a static position and turning the table for every shot at a specific angle (30 degrees), it was easy and fast to get accurate images of the real object. An overview of our modelling pipeline is illustrated in Figure 3.

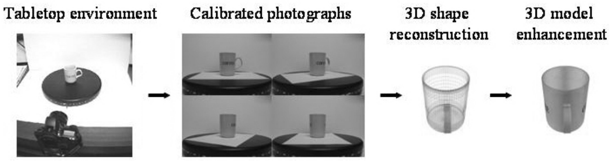

Figure 3. Modelling pipeline

As mentioned above, if the object is simple the IMRR tool can be used to create the virtual object, for more complex object several cheap photogrammetry applications exist [14][15][16]. Thus, the IMMR tool provides a model creation interface to generate simple 3D models from scratch and a model refinement interface to refine more complex 3D models input from external laser scanners and photogrametry systems. As a result, IMRR envisages the concept of creating 3D models using standard shapes to speed up the mesh building process for both refinement and model creation.

For simple model creation the main workflow is as follows:

- Initially, an orthogonal image of the object is imported and set as a background image in a 3ds max view port (shape reconstruction stage);
- Next the silhouette of the object is traced using built in 3ds max functions (shape reconstruction stage);
- The resulting NURBS curve is converted into a 3d representation of the mug base by Lathe function – which spins the curve around 360' and adds surface information to the model (model enhancement stage);
- Finally, the surface is textured using cropped versions of the original images, which are UV mapped onto the object as required (model enhancement stage);

An overview of both methods is illustrated in the following sections.

5.1 Shape reconstruction

Many VR and AR systems utilize Image Based Modelling (IBM) techniques [16][17]. These methods have the advantage that they do not require a very detailed analysis of the characteristics of the real objects. In IBM the objective is use image vision techniques to create a 3D model using as input 2D images. The first step requires the collection of data which will be inputted to the IMRR tool to create an initial representation of 3D models.

The IMRR tool was originally designed for the refinement of more complex virtual artefacts used in the ARCO project but it is also configured to provide a simple user-friendly model generation for inexperienced end-users. The IMRR tool is based on the industry standard 3ds max framework, and in the shape reconstruction stage existing functionality within 3ds max was put together in a simple interface requiring manual operation of this functionality, i.e. NURBS to trace around silhouettes of photographed objects, and so on to 'lathe' the object.

Accuracy of this stage will only be as good as the user can accurately trace around the model silhouette edge and 'infer' shape, etc. This will also depend on how well the user can zoom into the silhouette edge of the photograph if capturing manually—high-resolution photographs are implied with good high definition silhouette edges, so called *shape from silhouette*. This gives a good approximation of the shape of the object, which when textured looks quite reasonable. Of course, if greater accuracy is required all image silhouettes can be traced and result collection NURBS joined and turned into editable meshes. However, once you start to go beyond a certain point manually, it is better to detect the silhouette edges automatically—this can easily be done with a script. The algorithm for such a script is:

1. Prepare high contrast images
2. Load each image
3. For each image
   - Detect silhouette edge
   - Convert to NURB
   - Link each successive NURB and
   - Convert to editable mesh
4. Texture resulting model

And this can be done manually; however, the user may prefer to resort to other photogrammetry software mentioned above or laser scanning to acquire the initial model.

An important step in this algorithm is preparation of the original images both to be able to extract the silhouette and top get good textures. In order to get good contrasting images a contrasting white background was used. Depending on the complexity of the objects a variable number of pictures were carefully taken. The images were taken using a similar approach to those used in the IBM technique of extracting shape from silhouette [18].

The object is placed onto a turntable and in order to make a few images that show all the characteristics of the object. To generate a complete object images of the top and bottom of the object are also important. In this example, the turntable is calibrated to make a turn and stop every 30 degrees. The lens is selected to best suit the object size and show no distortion in the image. The top and the bottom of the object are photographed with the same camera, lighting and lens. for the object in this example, i.e. the coffee mug, was imaged 12 times in total, one for every 30 degrees, with high resolution (2160×1440 pixels)—depending on the complexity of the object texture, more or less images could be taken.

Finally, the digital images were used as input the IMMR tool to start the modelling process and generate a draft 3D representation of the object. The IMRR tool is installed on a HP workstation (equipped with two 2.4GHz Xeon processors and 1024 MB of memory). The resulting 3D model and the collection of 2D images (used for textures) are stored together on the image data store for further enhancement with the IMRR tool.

5.2 Model enhancement

Although IBM methods can provide fast results they also have critical disadvantages. In particular, for applications that require a high degree of realism there is a limited number of methods that can produce very accurate models of real objects [19]. Usually objects, which exhibit some form of geometrical symmetry and have fine detail, are easy to model. On the other hand, often objects acquired through both photogrammetry or laser methods require refinement in a modelling tool due to artefacts on the original object not being captured properly, e.g. outliers need removing, holes need filling, shells need aligning, redundant polygons needed deleting, seams need welding and so on.

To overcome these difficulties the IMRR tool has a refinement interface that is used to refine the generated 3D models.. Its main advantage over other tools is that it provides specific functionality (i.e. zipping or welding meshes, clipping meshes together, capping holes in a mesh, etc) [10] to aid inexperienced users to quickly enhance a 3D model. Other features of the IMRR include a database browser and an exporter and importer for XML files in a standardized format. This XML Data Exchange format (XDE) was used in the ARCO project as an interface mechanism between system components allowing all multimedia data and curatorial metadata associated with a cultural object to packaged and stored in a non-proprietary format.

6 Solutions for exhibition environments

Although there are a some experimental exhibition environments available [10][20] there is no indoor AR system to our knowledge that complements the missing part of broken/damages real objects with virtual ones. One of most obvious approach would suggest placing one (or more marker points) on the surface of the real object so that the camera position can be detected from these points.

Even if this seems a reasonable approach to follow, it is not appropriate for some types of exhibitions because the exhibits (i.e. museum artefacts) can be sometimes fragile or extremely valuable and therefore cannot be touched or moved at all at any point. Another important limitation is that the marker must be always visible so a more generic solution that satisfies any type of exhibition environment is required. To complement the missing real object(s) in an appealing way two simple visualisation methods have been proposed [11]:

- Partial augmentation
- Complete augmentation

For both scenarios a coffee mug was used as a test object to prove the feasibility and the effectiveness of the system. Special attention is given so that participants of our system can feel that the superimposed information is presented as realistic as possible. However, the techniques presented in the following sections can be applied to any type of real object.

6.1 Partial augmentation

In the partial augmentation scenario, a 3D representation of the missing part (broken or damaged) is superimposed in the scene fitting accurately onto the real object. Since the image registration algorithm used is based on ARToolKit tracking libraries, the accuracy heavily relies on the distance between the marker card and the camera. It was experimentally measured that in distances between 1m and 2.5m the registration error increases proportionally with the distance from the marker [21].

To perform accurate registration of the virtual object, a predetermined marker card is positioned at a fixed distance in the environment. In addition, the broken object is positioned at small distance from the marker card (less than 20 centimetres) because this plays a significant role in the registration errors occurred. The smaller the distance between the object and the marker card the lesser the errors produced by the ARToolKit's tracking libraries. An example scenario of partial augmentation is presented in Figure 4.

Figure 4. Partial augmentation scenario [11]

In Figure 4, a real object (a broken coffee mug) is complemented with its missing part (virtual handle) using the functionality provided by the AR Interface Toolkit. To provide more flexibility to the end users, the camera may be located anywhere in the scene as long as it is always in line of sight of the marker cards. This offers the ability to move around the exhibition environment and examine a number of different exhibits.

6.2 Complete augmentation

Partial augmentation scenario is ideal when we want to render a small amount of digital information. For instance for computer generated information that is considerably small in size (i.e. small size 3d meshes) the system's response is fast enough for a real time application. A slightly modified approach overlays a 3D representation of the whole real object on the exhibition environment. This technique has been applied in the past [22] where a complete Greek temple was superimposed on the same location as the ruins of the ancient temple exist. However, this experimental approach was performed in outdoor environments and because of the limitations of current systems the registration errors are considerably large. In addition, users had to carry heavy equipment with them and this raised issues regarding the ease of navigation and safety.

In our prototype system, the complete augmentation operates in a similar manner however vision tracking provides a more robust registration effect. The virtual object accurately overlaps the real object and gives the illusion that the real object does not exist in reality. Also, lighting conditions can be fully controlled and adjusted depending on the requirements of the visualisation scenario. Figure 5 presents an example screenshot where a virtual coffee mug is superimposed in exactly the same spatial location of the real broken coffee mug.

Figure 5. Complete augmentation AR scenario [11]

The proposed complete augmentation solution is very useful on any type of augmented exhibitions and especially in cases where the object must be kept in a fixed position and cannot be touched or moved (i.e. museum exhibition). It is also much easier to overlay the whole virtual mug, than accurately register the virtual handle to the broken real coffee mug. The main disadvantage of this approach is that the final visualisation is heavily based on the quality of the modelling process. In contrast with the partial augmentation, where the amount of virtual information render is small, in complete augmentation realistic rendering is a very important issue (section 6). For the same reasons, complete augmentation might require much more processing and graphics power than the partial augmentation approach.

7 Interactivity and Realism Issues

Natural human-computer interaction and realistic rendering are two of the most important issues in interactive AR environments. In this section, we illustrate the methods and techniques that have been adapted in order to superimpose the digital information as realistically as possible and to interact in a intuitive way. The development of an interactive AR system is different from developing other sorts of interactive system since four distinct aspects have been identified by the literature that can influence a user's interaction within AR systems [23].

Interactions within the augmented reality environment have been carefully designed so that the participants can perform them easily and effectively. Computer generated information can be controlled in a number of different ways such as by using standard I/O devices, or by physical interaction. In all cases, users may provide additional information and special effects using the functionality contained in the Graphical User Interface (GUI) of the AR Interface Toolkit [5].

In a similar way to [1][12] participants of our system can naturally manipulate the marker cards in the environment using their hands, which pre-supposes that the marker cards and the camera are always in line of sight of the camera. This gives the end-user more freedom to interact with the augmented information in an intuitive and natural way. An example of this is presented where the tabletop consists of a broken cup (handle is missing) and a marker card near it. To increase the level of information available to the end-user textual information can be superimposed in the environment in conjunction with partial or complete object augmentation (Figure 6).

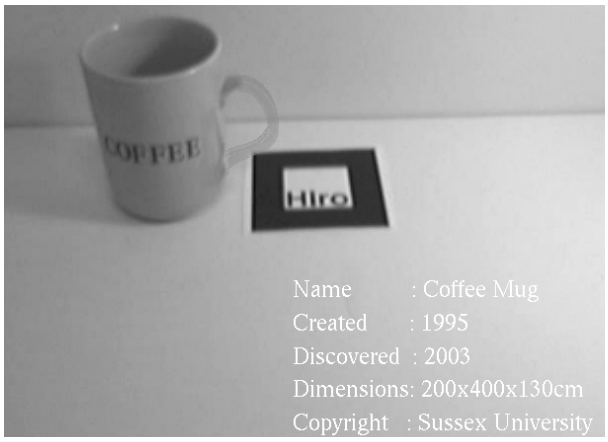

Figure 6. Model and textual augmentation [11]

Figure 6, illustrates how partial augmentation can be combined with descriptive textual augmentation. Both types of digital information (3D model and text) are 'assigned' into the same marker, but in a different way. Specifically, the 3D object is superimposed in three dimensions while the textual information is in two dimensions. The reason for this is because in some cases the graphics can obscure the textual information or vice-versa. So to always have a 'clean' field-of-view, it was decided to place the descriptive textual information on the bottom right part of the visualisation window.

Although usually graphics are sufficient for some forms of visualisations, textual augmentations (or annotations) are important for complicated models [24] that require in depth description. They can provide extra information but they must be of sufficient size so that users can read them. To offer more accessibility to users, a number of options regarding the text augmentation have been implemented including: *resizing of the font size*, *change of colours* and *change of font type* (bitmap, times new roman and Helvetica).

To increase the level of interaction and understanding, users can insert more virtual information anywhere in the working range of operation, by just adding another marker card. Although the second card will decrease the overall frame rate efficiency of the system by approximately 5%, it can provide additional digital information to the users such as images. Another important feature of both partial and complete augmentation scenarios is that they can handle a basic form of occlusions between the augmented information since the relative position of the two cards is calculated in every video-frame. Figure 7 illustrates an example of how a number of 2D images representing the real object can be augmented anywhere in the tabletop environment as well as a complete augmentation of the real cup.

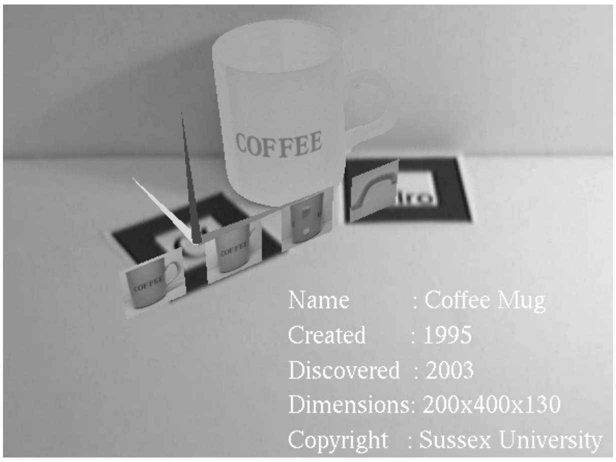

Figure 7. Multiple augmentation scenario [11]

Users can enjoy an interactive experience by moving the virtual object or the marker with the images in respect to six degrees of freedom (DOF). The first three include the position (x, y and z) while the rest the orientation (yaw, pitch and roll). The virtual information can be easily manipulated in the 3D space using the marker cards, the keyboard, the mouse or a combination of all of them [11]. In addition, more sophisticated users (i.e. curators) can alter the visualisation properties of the virtual information in order to make it either look very realistic or the contrary. For exemplar, Figure 8 illustrates a real object (in front) with an artefact (in the back) with a virtual handle having some transparency on it.

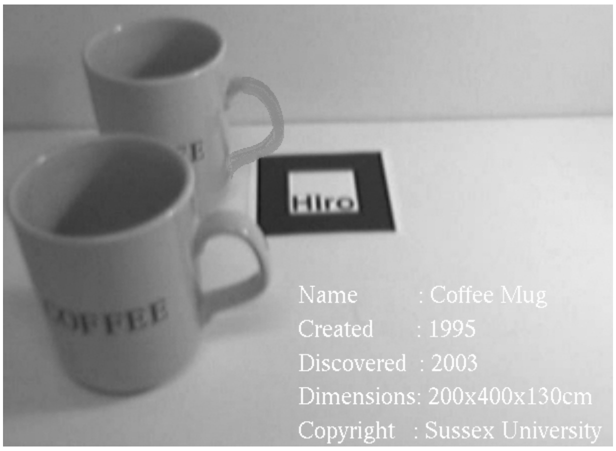

Figure 8. Real handle (front) and virtual handle (back)

The user can manually alter the transparency level and compare it with a real object (Figure 8) in order to achieve the best possible appearance of the virtual model. Apart from the transparency the end-users have the option of changing other significant visualisation effects in real time. Some of the most important include: the colour and material, lighting and shading, the texturing techniques (standard and environmental) as well as other effects (shadows and reflections) [11].

8 DISCUSSIONS AND FUTURE WORK

In this paper, we present our research work carried out in developing two tools for creating cheap and efficient tabletop AR visualisation scenarios for complementing broken or damaged real objects. In the modelling phase we have exploited the customizable nature of 3ds max, which is written using the plug-in philosophy. This exposes all objects in the scene to the plug-in writer and as such it provides a very adaptable solution for dedicated modelling tools. Customised 3D modelling tools can allow inexperienced users to generate easy and fast 3D graphical representations of real objects.

In the AR exhibition scenarios, real objects can be augmented with the previously digitised information that is dependent with the environment. Two simple but effective ways are presented illustrating ways of complementing broken/damaged real objects through AR. To increase the level of interaction and realism other forms of digital information are also superimposed into the environment such as text and pictures. Furthermore, the end-user can interact with the resulted augmentations.

The main disadvantage of the AR system is the poor effectiveness of the tracking algorithms for large distances or in bright lighting conditions. Another flaw occurs only when the user manipulates the marker cards very fast, causing the computer-generated information to disappear from their view. However, for the purpose of this application, the final visualisation is robust at approximately 30 frames per second and in general, there are no other major deficiencies.

Currently we are incorporating haptic devices such as the inertia cube to improve the interaction techniques between the users and the AR environment. Future improvements will automate and improve the modelling phase based on max-script so that our content is generated much faster and more accurately. In the visualisation side, the calibration process and image recognition algorithms will be improved so that the AR system will detect natural parts of 3D features of the real object, i.e. the missing part of the handle in a cup, so that the digital handle can be augmented automatically without the need of markers.

Experimental work performed has proved to be feasible and practical for tabletop augmented exhibitions. The next step is to perform user studies so that we can evaluate the system from a different perspective. Then the whole process will be refined through additional development and instead of test data we will use real archaeological artefacts. Our goal is to apply the proposed framework to museums and other cultural heritage institutions. Finally, we believe that the proposed framework can be adopted by a variety of other applications that require cheap and efficient multimedia augmentation in indoor environments.

Acknowledgements

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