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ReVitAge: Realistic Virtual Heritage Taking Shadows and Sky Illumination into Account

ReVitAge: Realistic Virtual Heritage Taking Shadows and Sky Illumination into Account

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Abstract

Today's modern organizations are striving hard to trace the beginnings of human civilization and maintain cultural heritage throughout the world; as a result the need for an integrative technique materializing this dream is felt more than ever. Realistic historical buildings in outdoor rendering Augmented Reality (AR) systems require sophisticated effects such as shadows, lighting and the ability to reveal the effect of sky dome illumination on virtual as well as real objects. In this project, the sun position and sky colour are simulated using Julian dating and Perez model respectively. The historical buildings are pre-created using LightWave 3D. An AR system is created using a new marker-less camera setting. The sky illumination is exerted on the virtual historical buildings using a Hemicube Radiosity technique. We have tested the proposed method on Portuguese Malacca heritage building (Melaka, Malaysia) in different places to reveal the auto-adjustment of the system in the case of shadow positioning, lighting and the sky's illumination. The final system could be installed on HMD (head mounted display) or in our device called ReVitAge to show the realistic reconstructed virtual heritage buildings, taking the main outdoor illumination components into account. Throughout this method, listed heritage buildings can be revived in the minds of people from different backgrounds who share the same ambitious dream. It is strongly hoped that this idea can make historical buildings a virtual reality; closer to people's hearts.

Keywords: Virtual heritage, realistic augmented reality, augmented reality, outdoor rendering, cultural heritage

1. Introduction

As today's modern organizations are striving very hard to maintain cultural heritage throughout the world and trace the beginnings of the human civilization, the need for an integrative technique materializing this human dream is felt more than ever. Thus, listed heritage buildings can be revived in the minds of people from all walks of life who are interested in this grand dream. Reconstructing virtual heritage buildings can make historical buildings a virtual reality; close to people's heart.

Nowadays, in most historical places and museums, there is a 3D room to show the reconstructed historical objects in virtual environments. However, visiting these objects and buildings in virtual environments suffer from a lack of realism which needs to be addressed.

Augmented Reality (AR) is a technology which is expected to become, without a doubt, a fascinating widespread technology in a multitude of subjects. It has been more than a couple of decades since AR entered computer graphics, and many other fields, to combine real and virtual environments [1] [2] [3][4]. 3D graphics, especially augmented reality, may be used to create a bridge between modern civilization and the past that future generations may forget.

Virtual Heritage in AR is an interactive computer based technology which can be used to achieve visual reconstruction, aiding scholars and educators of traditional entities such as buildings, artefacts and culture [5][6][4][7]. This technology preserves delicate historical buildings from natural disasters and vandalism [8][9]. For producing a virtual heritage, there are seven design principles which must be taken into account including high geometric accuracy, high automation level capture of all details, low cost, photorealism, flexibility, portability, and model size efficiency [10].

Augmented Reality makes virtual heritage interactive and more realistic due to the reconstruction of original buildings among real environment objects. Generating a virtual building in real environments enables the user to interact with traditional buildings while recovering some of the ruined parts which will help increase the reality of the ancient culture. Modern users can be connected to the ancient culture and traditional customs through our proposed virtual heritage in augmented reality systems.

The SIGGRAPH reports that Augmented Reality is one of four attractive topics and they encourage more submissions due to diversity challenges[11]. Augmented reality has been employed in different areas such as training aid for surgery [12, 13], maintenance and repair [14], annotation [15], robot path planning [16], entertainment [17, 18], surgery [19], military aircraft navigation [20], targeting [21] and cultural heritage purposes[22].

There is a diverse range of historical buildings in the world and most of them have been ruined partially, some even completely. Reconstructing these cultural heritages not only helps getting in touch with the past, but also enhances the appeal for tourists [23].

According to the European Commission's report [24][25] "Computing hardware and software have advanced to a point where it is possible to construct and view models using personal computers." We have taken this further and created a simple device to visit historical buildings through our personal computers.

In this study, we attempted to create a realistic real-time mixed environment. We placed virtual heritage in real environments, taking the sun position and sky illumination into account, with respect to shadows from a given time, date and location. The mixed environments are observed through a simple device named ReVitAge (Realistic Virtual heritAge). ReVitAge controls the orientation of augmented buildings in two different directions; vertical and horizontal. ReVitAge is proposed to overcome the main issue of most marker-less techniques, which are not robust enough.

3D modelling is widely used in Virtual Environments (VEs) and Augmented Reality (AR) which is an integration of virtual environments and Real Environments (REs). An AR-system incorporates more real objects and fewer virtual ones, with the real objects taking a dominant role over the virtual. Furthermore, if a real object is set within a virtual environment, the system is called Augmented Virtuality (AV). In this case, most of the system elements are virtual. Figure 1 illustrates these concepts.

In general, Mixed Reality (MR) can be characterised by the integration of virtual and real objects, real-time interaction and 3D registration.

In addition to the inclusion of some virtual objects within the real en-

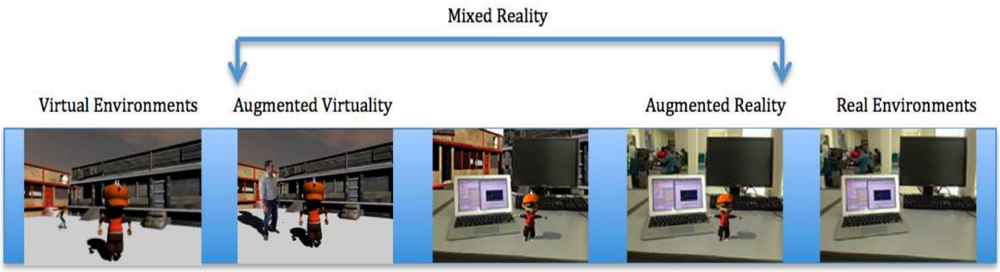

Figure 1: Taxonomy of Mixed Reality systems

vironments, augmented reality makes it possible to remove or hide some objects. This is known as Diminished Reality.

Virtual Heritage in AR is a realistic interactive virtual historical building showcased in real environments. The virtual building can be placed in the same place as the original building or in any other site. Visitors can observe the virtual building and its shadows, and the interaction of sky illumination with the virtual building, with respect to the sun position at the specific location, date, and time, making it more realistic.

2. Motivation

Virtual Heritage is a new technology for preserving traditional cultures in modern civilization. Hakim et al. [10] introduced some of these motivations. Documenting historic buildings and objects regardless of any unexpected events, preparing educational history resources, reconstructing ruined historic monuments, visualizing scenes from viewpoints impossible in the real world due to size or accessibility issues, interacting with objects without risk of damage, and providing cheap virtual tourism and virtual museum exhibits.

In general, the main goal of this study is to give users the ability to visit a reconstructed, previously ruined, traditional building or object with no damaged parts. Eliminating travel expenses is the other reason for focusing on virtual heritage. An AR-based heritage technology offers visitors a taste of novelties from the past and the opportunity to experience a specific time or place, long forgotten.

Visiting many different historical places in one single real location is also another advantage of this project. Observing enormous buildings in a small place, such as a classroom, can be considered another benefit of this project.

Finally, this paper is provided to highlight the principle improvement of generating realistic virtual heritage in real environments.

3. Related Work

There are many works being done in virtual reality heritage, which are not using AR systems, such as Virtual Hagia Sophia [26], Virtual Campeche [27], The Virtual Pompeii project [28], 3D reconstruction [29][30], Xanthi city [23], Ancient Malacca Project [31], Iberian Art Museum [4] and Virtual exhibition [32]. These kind of virtual heritage projects however are not as effective as virtual heritage in augmented reality due to a lack of interactivity.

Augmented reality, or even augmented virtuality, enhances the realism and attracts visitors to the heritage building. Interaction between real environments and virtual buildings is the main reason to focus on virtual heritage in augmented reality systems.

Kolivand and Sunar [33] focused on creating realistic virtual objects in augmented reality. In these studies, the researchers worked on sky colour and semi-soft shadows with respect to the position of the sun, considering different locations, dates, and times. The final results were validated by comparing the similarities and differences of produced images and real environments. The highlighted parts in real and virtual environments were also compared to show the features of the technique and validate it. Similar to the techniques used by Xing et al. [34, 35] and Liu et al. [36, 37] , they compared the results with the colour of real sky and the effect of the sky colour on real objects.

Papagiannakis et al.[38] is one of the oldest works, which presents augmented virtual humans in real environments in the case of off-line rendering. In this project, virtual humans, animals and plants are augmented in a real scenario of ancient Pompeii. The virtual humans are supported with face expression, speech and clothes which are simulated in real time. In 2005, and 2006 they extended their work to an innovative revival of life in ancient fresco painting [39][40]. Lack of realism and interaction between real and virtual objects is the main issue in this project.

ARCHEOGUIDE [41][42] is a project which reconstructs Ancient Olympic Games in Greece. In this project, visitors are able to choose one of the predefined tours to guide the visitor through the site.

Mourkoussis et al. [43] worked on projects called ARICH (Augmented Reality in Cultural Heritage) and ARCO (Augmented Representation of Cultural Objects) which focused on indoor rendering of virtual heritage. In these projects, virtual museums are constructed to cover the limitation of real museums e.g. reconstructing dishes, planes and tools.

Ruiz et al. [44] present a virtual heritage of archaeological Maya Cities for reconstructing Calakmul's archaeological site in augmented reality. This project aims to construct the virtual Calakmul and to reduce the cost of traveling through a deep tropical jungle for almost 5 hours. There are no shadows or realistic effects in this project.

Fritz, et al. [45] cooperated with a tourism application and presented an AR virtual heritage called PRISMA, known as the tourist binoculars. Using this integration, users can observe interactive multimodal information about a traditional building. The mounted binocular camera captured the data, which is sent to the processing unit resulting in an augmented stream, and included graphical data.

Valtolina [46] prepared a platform to integrate real and virtual environments to immerse users into a virtual environment, creating the illusion of being a real scene. In this platform, the user must be placed in front of a large apparatus with a pair of stereo glasses to make it feel like they are being placed in a virtual environment.

Virtual Asuka (VA) [47] is a project in AR which applied shadow mapping and used image-based algorithms for shadow detection and recasting with a spherical vision camera.

Mortara et al.[48] teach cultural heritage using a proposed serious game which highlights educational objectives throughout. The main difference between Mortara et al.'s game and previous attempts, such as that presented by Falk Anderson et al. [49], is the focus on application aspects. It also analyses the complex relations between genre, context of use, technological solutions and learning effectiveness rather than simply a technical perspective.

Virtual Asuka is an AR project where shadow mapping is applied and image based algorithms for shadow detection and recasting are employed with a spherical vision camera [50]. First, shadow regions are detected using camera sensitivity. Then, by applying the illumination invariant constraint and employing the energy minimization method, the shadow regions are picked up and used to recast shadow onto the virtual object with the spherical vision camera. Recasting the shadow regions on the virtual objects forms the main part of this algorithm. Since the foreground depth and height is estimated using the spherical vision camera the shadow maps are applied on the non-flat surfaces using a simple formula. The algorithm can be used for static objects and the camera must be fixed in the MR. The main issue with this algorithm is the inability to use dynamic cameras which would allow viewers movement in the virtual world.

One of the latest projects in culture heritage is Agata which is presented by Soler et al. [51]. They proposed a specialized software for professionals in culture heritage to document related work in 3D. A key novelty of Agata is the ability to interact with these documents and annotate them in a different raster directly. Storing the manipulated models in a standard format makes it easy for them to be used in different software. Kolivand et al. [52] provided this ability through LivePhantom which reconstructs a 3D model and allows users to annotate vector graphic information and export it with different standard formats.

Considering global illumination as the indirect component of lighting in AR systems is presented effectively in [53] but a lack of realism in outdoor virtual heritage leaves the issue open yet. Madsen et al. [54] presented a geometrical technique to cast volume shadows on virtual objects in real environments but without taking the effect of the sky illumination into account. Debevec et al. [55] considered sky illumination in filming in non-real-time rendering. In addition, marker-less based techniques are not usually robust enough for outdoor environments due to the long distance between the AR camera and the targets. AR using ReVitAge is robust and can be used for any distance.

The ultimate goal of this research is to prepare a realistic real-time virtual heritage in real environments using a marker-less camera setting taking the sky illumination and shadows into account with respect to the sun position from a given location, date and time.

This research paper covers three main contributions in knowledge. A systematic real-time environment is presented to trace the sun position and consequently the sky colour and shadow positioning. A new algorithm is presented to generate semi-soft shadows as it is required for outdoor rendering. An accurate 3D model of Portuguese Malacca is reconstructed with details to make the AR system realistic. Integration of the 3D model in markerless AR system is the technique ultimate achievement of this research.

4. Methods and Materials

The current issues of virtual heritage in augmented reality can be categorized in four sections, namely; registration, reconstruction, rendering, position or orientation tracking.

4.1. Registration

Registration refers to the accurate alignment of augmented objects with real environments. AR systems with no precise registration are listed as unsuccessful mixed environments due to faulty output results. There are some tracking technologies which offer high enough accuracy but none of them can be used for outdoor AR rendering [56] [41] [42] [5].

The marker-less camera setting has been considered to eliminate markers which reduce the reality of the environments as well as the robustness of AR systems. ReVitAge is a simple device with a simple design. At the prototype stage, we created the device using a USB ball mouse and an elastic band. The rubber band connects the scrolling part of the mouse and a plastic pipe, which is the stand of the AR camera (Figure 2). Changing the camera's view rotates the camera's stand, hence moving the elastic band causes the mouse to scroll. The orientation setting is employed by mouse movements. Through this simple device, we change the orientation of the building by changing the camera view. The technique can be extended for up and down directions as well as left and right.

4.2. Reconstruction

Reconstruction refers to constructing the virtual objects in such a way as to replicate the original building. During this stage, 3D modelling plays a significant role. The appearance of virtual objects on an appropriate model that covers accurate enough details is necessary. These objects must be matched with the original ones so the visitors may be able to see them at the background of live videos. Paying attention to semi-soft shadows is also a main part of the reconstruction. Shadows are generated in real-time with respect to the sun position in a specific location, date and time. Finally, exerting the effect of sky illumination on the virtual building during daytime is the last part of making the realistic virtual heritage in AR systems.

4.2.1. 3D Modelling

In this research two different types of 3D models have been employed OBJ data and FBX. The prototype is implemented in C++ OpenGL and C# Unity 3D separately. In the case of OpenGL, the OBJ data is used without textures. The terrain is constructed based on a mathematical formula, which collects height input data from a PNG file. The PNG file is constructed using

Figure 2: ReVitAge device

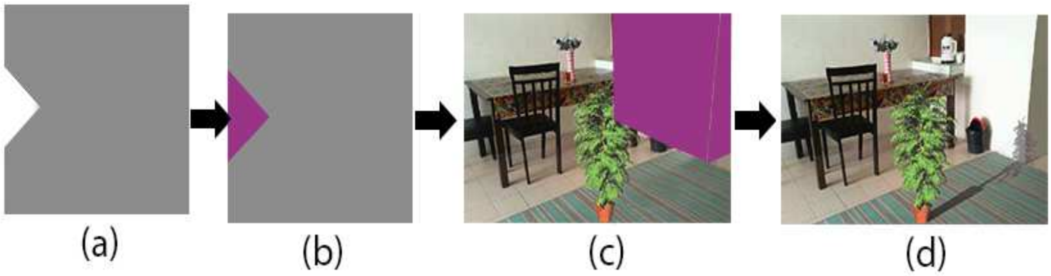

Figure 3: Terrain generation based on PNG file

a grayscale mode. Black colour drags it down from the horizon and white colour shifts it up from the horizon. The grey colour exactly matches the horizon or the flat parts of the terrain. Figure 3 shows the process of this terrain generation. Most of the PNG file is grey, which will be a flat surface. The white parts will be the maximum height, which has been set in advance. The white part of (a) will be the purple colour in (b) and is considered as the virtual walls, which can be seen in (c). The virtual walls are transparent in AR mode so as not to obstruct the real walls. Then virtual shadows are applied on the virtual walls but can be seen on the real ones.

In the case of Unity 3D, FXB data with texture mapping is used. There is no limitation for 3D data. FXB is employed for animation purposes and OBJ data is used for static modelling. The terrain is constructed in real-time rendering and in the transparent mode, keeping the Matte Shadow in mind. The matte shadow technique creates a terrain which can receive shadows in transparency mode.

For the modelling of the building, LightWave 3D is used. Figure 4 shows step by step generation of the virtual Portuguese Malacca using LightWave 3D.

4.2.2. Shadows

One other contribution of this research is implementing a new shadow generation technique to cast semi-soft shadows based on shadow mapping. Semi-soft shadows are the principle factor in making the virtual objects realistic in outdoor environments as the sun is far from the objects occluding it. The improved shadow algorithm for generating semi-soft shadows with respect to the sun position is called SS-SpL (Semi-Soft Shadow SpLine) [57]. The results can be seen in Figure 5 where a comparison is provided with

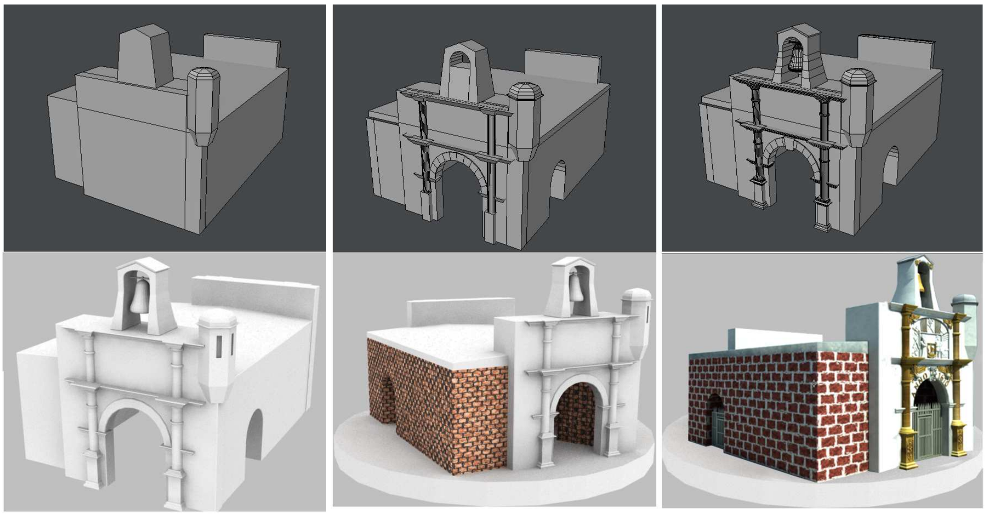

Figure 4: Step by step generating of the Portuguese Malacca using LightWave 3D

other widely used techniques in Figure 6.

Algorithm 1 SS-Sp Shadow algorithm

1: $Capture\ the\ environment\ from\ light\ point\ of\ view\ and\ save\ it\ in\ the\ depth\ buffer$
2: $Capture\ the\ environment\ again\ from\ camera\ point\ of\ view$
3: $Recognize\ the\ shadow\ parts\ by\ comparing\ the\ two\ captured\ data$
4: $Apply\ the\ quadratic\ Sp - Line\ on\ the\ silhouette\ of\ the\ shadows$

More details about Sp-Line approximation has been achieved in [57]. The results illustrate suitability of this technique for shadows in outdoor rendering such as virtual heritage.

4.2.3. Sky colour modelling

Dome generation and controlling the sun position in specific locations, dates and times are the main materials for sky modelling in real-time rendering. This section is presented to construct a sky model which will be used for the sky illumination resources. For more details about the sky colour generation, readers can refer to [61] and [62].

Modelling the sky is the first step for sky colour rendering. The use of a virtual dome is appropriate for sky modelling to employ Perez model. A

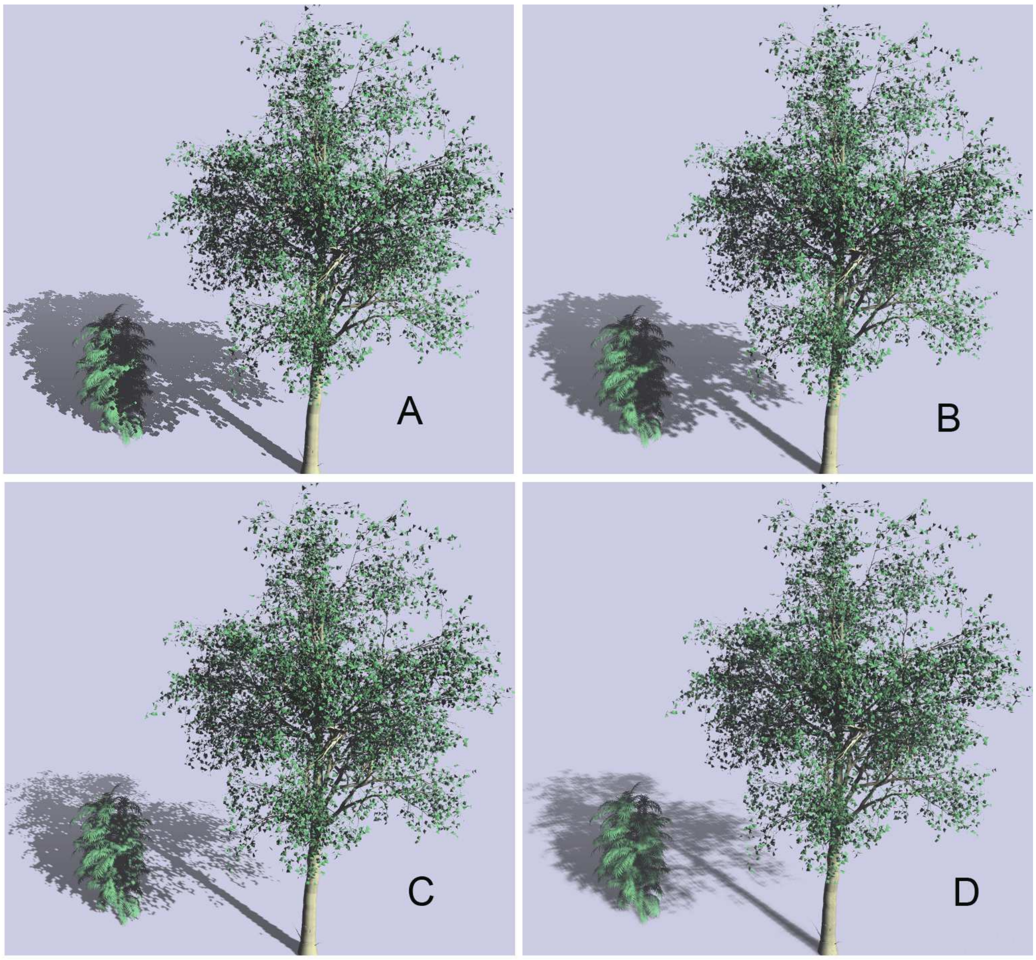

Figure 5: A comparison between shadows technique, A: Shadow maps [58], B: PCF (Percentage Closer Filtering) [59], C: CSMs (Cascade Shadow Maps)[60], D: SS-Sp

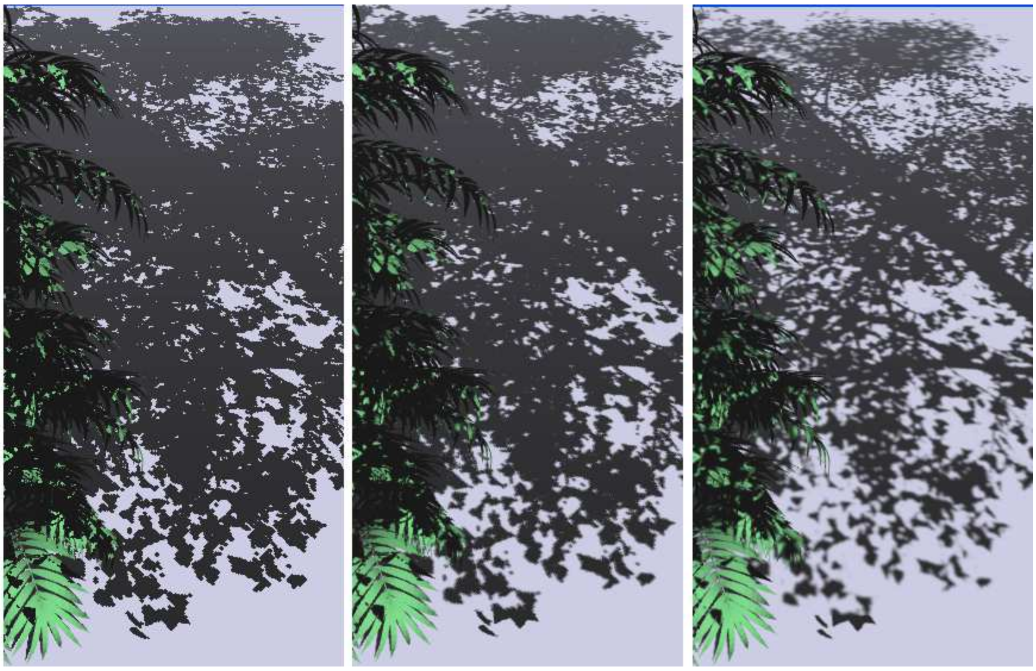

Figure 6: left: Shadow maps [58], centre: PCF (Percentage Closer Filtering) [59],right:SS-Sp shadows

dome is like a hemisphere, in which the view point is located inside. Dome generation has also been undertaken in more detail by [61].

The zenith and the azimuth supply enough data to calculate the position of the sun regardless of time or place. The location, described in terms of longitude and latitude, the date, and the time are required to calculate the specific zenith and azimuth. Solar time using Julian dating can be calculated by:

$$t = t_s + 0.17\sin(\frac{4\pi(J-180)}{373}) - 0.129\sin(\frac{2\pi(J-8)}{355}) + 12\frac{SM-L}{\pi} \tag{1}$$

t: Solar time
t_s: Standard time
J: Julian date
SM: Standard meridian
L: Longitude
The time is calculated in decimal hours and degrees in radians. The solar declination is calculated as follows:

$$\delta = 0.4093 sin(\frac{2\pi(J-8)}{368}) \tag{2}$$

Having calculated zenith (θ_s) and azimuth (φ_s) the sun's position can be obtained using the formulae (3) and (4).

$$\theta_s = \frac{\pi}{2} - sin^{-1}(sinl sin\delta - cosl cos\delta cos\frac{\pi t}{12}) \tag{3}$$

$$\varphi_s = tan^{-1}(\frac{-cos\delta sin\frac{\pi t}{12}}{cosl sin\delta - sinl cos\delta cos\frac{\pi t}{12}}) \tag{4}$$

Where l is latitude.

After generating the dome, assigning the colour of each patch with respect to the sun position, location, date and time is the main task completed in this section. For more details readers can refer to [61] and [62].

The CIE standard allows a colour to be classified as a numeric triple (X, Y, Z). All the CIE-based colour spaces are derived from the fundamental XYZ space [63]. Yxy space is a space that determines the XYZ values in terms of x and y chromaticity co-ordinates. To convert XYZ space into Yxy co-ordinates to get the results for RGB systems, readers can refer to [61].

The following model is convenient for illuminating (θ_p, γ_p) arbitrary points of the sky dome with respect to the sun position. It uses the CIE standard and could be used for a wide range of atmospheric conditions. Luminance of point $(\theta_p, \gamma_p)$is calculated using the following formulae ((5) and (6)). The results of sky colour generation is presented in Figure 7.

$$L(\theta_p, \gamma_p) = (1 + Ae^{\frac{B}{\cos\theta_p}})(1 + Ce^{D\gamma_p} + E\cos^2\gamma_p) \tag{5}$$

where

$$\gamma_p = cos^{-1}(sin\theta_s sin\theta_p cos(\varphi_p - \varphi_s) + cos\theta_s cos\theta_p) \tag{6}$$

A: Darkening or brightening of the horizon
B: Luminance gradient near the horizon
C: Relative intensity of circumsolar region
D: Width of the circumsolar region
E: Relative backscattered light received at the earth surface

4.2.4. Outdoor AR Integration

This section discusses how the integration of the main components in outdoor virtual heritage has been done, in which the virtual and real worlds are integrated to produce realistic virtual heritage in augmented reality systems. The principal idea discussed in this section is the creation of virtual heritage buildings and their shadows, in a real environment, and the interaction between sky colour and the buildings, as well as the interaction between real sky colour and real environments.

The virtual building was modelled using LightWave 3D in advance. Sky dome is created as a semi-sphere in mathematical form. For generating traditional objects our suggestion is using *Qp* [64]. The model is placed into the scene using two different engines; ARToolkit [65] and Metaio [66] separately. A virtual point light source has to be placed into the scene, but it must be placed in the same position as the sun. The virtual light source follows the real sun's path. Semi-soft shadows are generated based on the improved shadow algorithm which was discussed earlier. Shadows of the virtual objects are generated in the direction of the real shadows by using Julian dating formulas in (1)-(6). The next step is to restore the intensity of the sky by setting the location, date and time. To reveal the interaction between

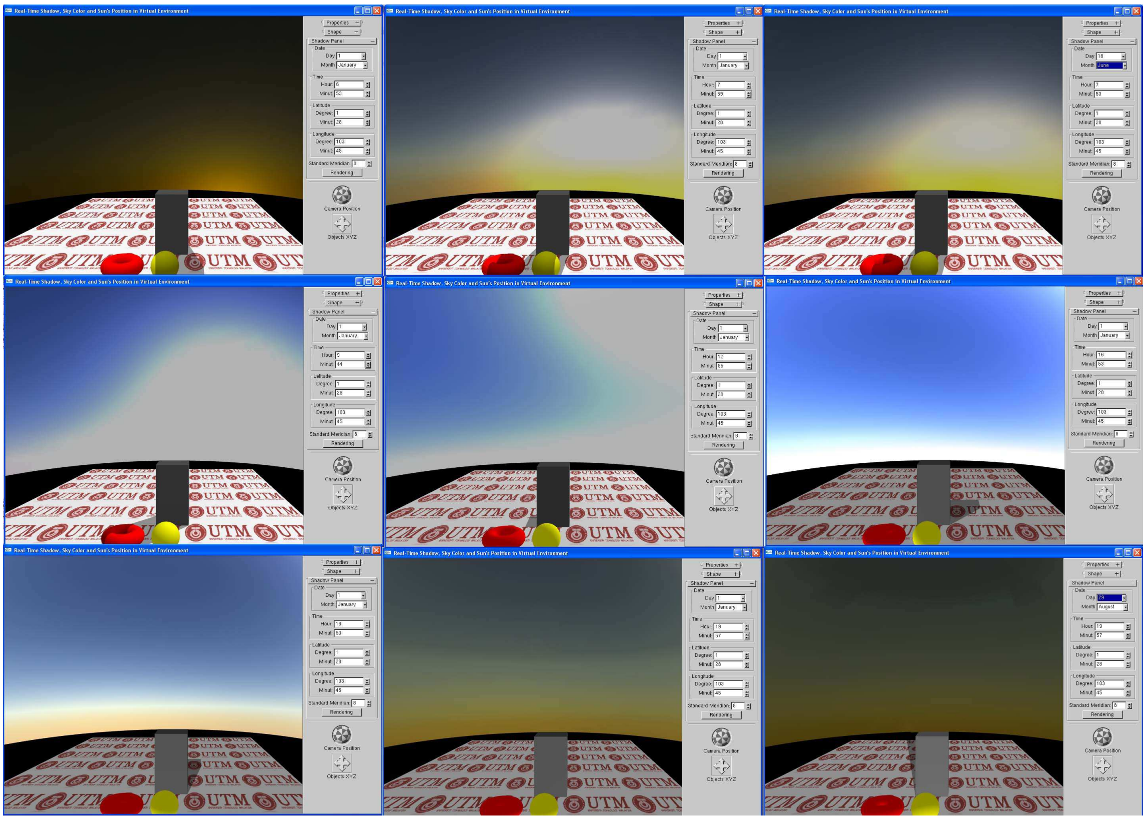

Figure 7: Sky colour in specific location, date an time (Universiti Teknologi Malaysia)

outdoor illumination and virtual buildings, a hemicube radiosity technique is employed [67].

The animation of virtual objects is straightforward in the augmented environment using a setting file in Unity 3D game engine.

As mentioned earlier, Julian dating is used to trace the sun position. Perez sky model is applied to generate sky colour. By combining these two methods, sky colour with respect to the sun position is constructed. The 3D building and 3D animated objects are loaded in the real scene with respect to the provided location. In this step an outdoor virtual heritage system is constructed. Setting location, date and time; and applying Hemicube radiosity [67] in the virtual heritage environment, completes the final result that is realistic virtual heritage in augmented reality systems.

4.3. Animation

Realistic animation is the last contribution of this research which has been taken into account in order to create realistic virtual heritage in AR systems. Applying some animated objects which are controllable using keyboard and a setting INI file, makes the AR system as realistic as possible.

People who are walking and wearing traditional clothes, which are illustrated in Figure 2, makes the environments more appealing and places the visitor in the olden days. Walking, thinking and praying are some of the common behaviours which have been taken into account in this research project. Some of the actions can be seen in Figure 8.

5. Results and Discussions

There are many ruined historical buildings around the world which this project reconstructs in an AR system. In this case study, Portuguese Malacca in Melaka city of Malaysia is reconstructed through the ReVitAge.

All virtual components, including the sun position, sky colour, dome illumination, shadows and receiving the energy of a virtual sky dome on an augmented virtual Portuguese Malacca, are successfully implemented.

Figure 9 (left) is Portuguese Malacca, after three and a half centuries, which is captured at 13:15 in April 1^{st} 2014 at Melaka Malaysia. Figure 9 (right) is part of the building which is modelled in a 3D environment.

Figure 8: Animating characters with Malaysian traditional cloths

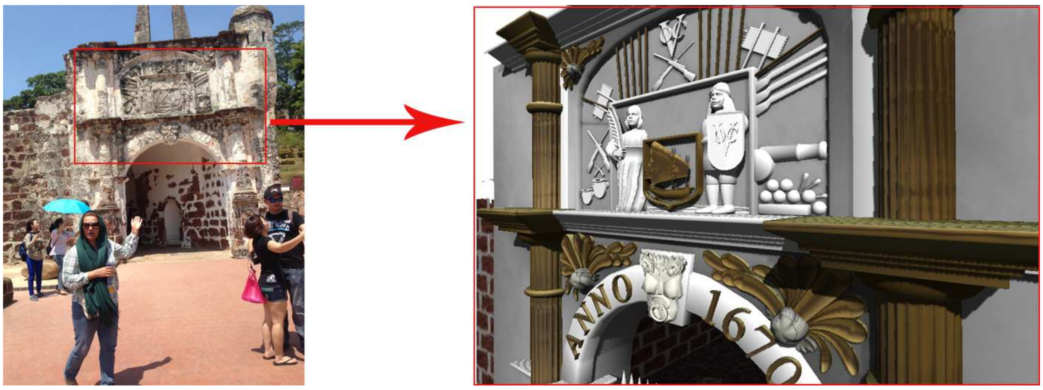

Figure 9: left: Original broken historical building of Portuguese Malacca in Melaka, Malaysia, right: reconstructed building in a 3D environment

Figure 10 shows a real environment in Universiti Teknologi Malaysia captured when the sky was yellowish, while Figure 10 (right) is the scene with an augmented building. The virtual dome illumination is exerted on the building as well as the whole environment. When the real objects are darker, due to the real sky illumination, virtual objects also follow the effect of real sky colour using the proposed technique.

Figure 10: Realistic reconstructed Portuguese Malacca building in Universiti Teknologi Malaysia. Left original view, right AR view

Figure 11 is captured in the evening of 09 Aug, 2017 in Grown Street Park, Liverpool where the research is completed. However, the sky does not gloom yellowish in twilights but the shining effect looks realistic in both the real environment and the virtual one. In Figure 11 (left), the sun is located on the left hand side of the camera. Comparing the real human?s shadow and virtual human?s shadow reveals that the orientation of shadows is accurate enough to make the outdoor AR realistic. This can be seen on the right hand figure as well.

Figure 11: Realistic reconstructed Portuguese Malacca building in Grown Street Park, Liverpool UK

Figure 12 is captured on 10 of Aug, 2017 in Princes Park, Liverpool, when the sky looks bright and blueish. The real objects are lighter, compared to the time in Figure 11, due to the real sky colour changes. In this case, the virtual building's shadows are replicating the real environment's shadows. The shadow positioning is successfully aligned with the real light orientation. In Figure 12, the two left scenes are in the same location at almost the same time but with different camera movements. Virtual character animation is also inserted to make the scene more realistic. The character can be controlled using a keyboard and mouse.

Figure 12: Realistic reconstructed Portuguese Malacca building in Princes park, Liverpool, UK

ReVitAge can also be used for simulating a new building before starting the real construction. When a building is going to be built, a simulated building in the exact place can be augmented. Observing the simulated building in the real environment from different points of view, with the exact dimensions and orientation, can give the feedback required before construction. Many issues will arise after the construction of a new building, however observing different sides of a simulated building in the same place, which can be compared with other buildings, provides feedback in advance. This feedback is not only free, but also eliminates charges which may occur in the case of any construction failure. The main advantage of ReVitAge is observing realistic, virtual buildings in real environments with the sun position, shadows and the effect of sky illumination on them.

6. Conclusion and Future Work

3D digital reconstruction of historical buildings has been an attractive topic, which will be made interactive by mixing reconstructed objects and real environments using augmented reality. Many academic research laboratories and companies are involved with creating attractive virtual heritage, but not enough work has been done in the aspect of realism, which we have focused on in this study.

In this paper, a realistic virtual building is augmented in real environments to be observed live through an AR camera. To augment a realistic building some of the main outdoor components, such as the sun position, shadows, sky illumination and virtual traditional animated characters, are augmented in real environments at the place of real historical buildings, or any desired locations, in different times of the day and different days of the year. Here, we have presented some new ideas in the case of virtual heritage. First and foremost is modelling the 3D model of Portuguese Malacca. A systematic real-time system to trace the sun position, using Julian dating and sky colour modelling using Perez sky model, is presented to create outdoor illumination. A semi-soft shadow algorithm is applied to support the realism of outdoor augmented reality systems. Marker-less AR is presented using a simple camera set-up system.

Our future work is to employ the presented work on Microsoft HoloLens, in addition to preparing an application which can be installed on smart phones. A different marker-less technique is required for both cases but will make it portable and easier for everyone who likes to visit historical places in his/her location.

We hope, through this research, that cultural heritage buildings can be maintained and traces of human civilization can be revived in the minds of people from all walks of life. Observing a realistic reconstructed heritage building, which replicates what had originally existed, can bring historical buildings closer to people's hearts.

Apart from visiting the realistic reconstructed historical building in place of the original ruined one, which might be highly enjoyable and more beneficial for whoever is interested in cultural heritage, observing different parts of a virtual traditional building from anywhere in the world also reduces the costs of travelling. We also hope this product could be used for students to visit different historical monuments, while simply sitting in their classrooms, and to become more familiar with our past as a civilization.

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