SHADOW AND SKY COLOR RENDERING TECHNIQUE IN AUGMENTED REALITY ENVIRONMENTS

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To my wife who is the apple of my eyes

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Hoshang Kolivand, Skudai Malaysia

ABSTRACT

Realistic rendering technique of outdoor Augmented Reality (AR) has been an attractive topic since last two decades due to the large number of publications in computer graphics. Realistic virtual objects in outdoor rendering AR systems require sophisticated effects such as shadows, daylight and interaction between skycolor and virtual as well as real objects. A few realistic rendering techniques have been proposed to overcome this issue most of which are related to non real-time rendering. However, this problem still persists especially in outdoor rendering. This research proposed a new technique to achieve realistic real-time outdoor rendering taking into account the interaction between sky color and objects in AR systems with respect to shadows in any specific location, date and time. This approach involved four main phases, which cover different outdoor AR rendering requirements. In the first phase, sky color was generated with respect to the sun position. The second phase involved the shadow generation algorithm which is called Hybrid Shadow Mapping (HSM). During this phase some improvements in shadow volume and projection shadow are employed. The third phase started with the introduction of a coherent formula for the sun position and shadows in any specific location, date and time. The coherent formula aims to find the shadow positioning automatically. This phase also addressed the interaction between sky color and objects in virtual environments. Finally, a technique to integrate sky color and shadows through the effects of sky color on virtual objects in the AR system is proposed. The experimental results reveal that the proposed technique has significantly improved the realism of real-time outdoor AR rendering thus solving the problem of realistic AR systems.

ABSTRAK

Teknik penjanaan imej realistik bagi Augmentasi Realiti (AR) telah menjadi satu topik yang menarik kerana bilangan penerbitan yang banyak dalam bidang grafik komputer sejak dua dekad yang lalu. Dalam sistem penjanaan imej AR di persekitaran luaran, kesan yang terperinci seperti bayang-bayang, cahaya dan kesan interaksi antara warna langit dengan objek maya serta objek sebenar diperlukan. Terdapat beberapa teknik penjanaan imej realistik telah dicadangkan sebagai penyelesaian kepada isu yang kebanyakannya berkaitan dengan penjanaan imej bukan masa nyata. Walau bagaimanapun masalah ini masih belum diselesaikan sepenuhnya, terutamanya dalam proses penjanaan imej bagi persekitaran luaran. Penyelidikan ini mencadangkan satu teknik baharu untuk mencapai hasil imej realistik dalam masa nyata dengan mengambil kira kesan interaksi antara warna langit dengan objek dalam sistem AR persekitaran luaran yang melibatkan bayang-bayang bagi sebarang lokasi, tarikh dan masa yang khusus. Pendekatan ini melibatkan empat fasa utama yang meliputi beberapa keperluan dalam penjanaan imej AR bagi persekitaran luaran. Dalam fasa pertama warna langit telah dihasilkan dengan merujuk kedudukan matahari. Fasa kedua melibatkan penjanaan algoritma yang dinamakan sebagai Hybrid Shadow Mapping (HSM). Dalam fasa ini beberapa penambahbaikan dalam teknik bayang-bayang, iaitu isipadu bayang-bayang dan bayang-bayang unjuran dilaksanakan. Fasa ketiga dimulakan dengan memperkenalkan formula koheren bagi kedudukan matahari dan bayang-bayang pada sebarang lokasi, tarikh dan masa. Formula koheren bertujuan untuk menentukan kedudukan bayang-bayang secara automatik. Fasa ini juga menekankan interaksi antara warna langit dengan objek dalam persekitaran maya. Akhirnya, satu teknik pengintegrasian warna langit dengan bayang-bayang menggunakan kesan warna langit pada objek maya dalam sistem AR telah dicadangkan. Hasil eksperimen mendapati bahawa teknik yang dicadangkan telah meningkatkan realisme penjanaan AR persekitaran luaran dalam masa nyata. Kesimpulannya, teknik ini telah berjaya meningkatkan kesan realistik pada sistem AR.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PC	–	Personal Computer
GUI	–	Graphic User Interface
FPS	–	Frame Per Second
PCF	–	Percentage-Closer Filtering
VSSM	–	Variance Soft Shadow Mapping
GIS	–	Geographic Information System
LVSM	–	layered Variance Shadow Maps
VSM	–	Variance Shadow Mapping
CSM	–	Cascaded Shadow Maps
EESD	–	Extended Edge Silhouette Detection
HSM	–	Hybrid Shadow Maps
SH	–	Spherical Harmonics
PRT	–	Precomputed Radiance Transfer
3D	–	Three Dimension
GMT	–	Greenwich Mean Time
VE	–	Virtual Environment
AR	–	Augmented Reality
MR	–	Mixed Reality
RCC	–	Radiosity Caster Culling
	–	

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Rendering atmospheric phenomena are known to have had their base in the fields of atmospheric optics and meteorology. Nevertheless, practical computer graphics applications have been limited by the complexity of the associated rendering problems. The techniques for rendering outdoor scenes are different from those of their indoor counterparts as the sun and the sky color are the main resources for consistent illumination of outdoor rendering environments (Klassen, 1987; Kaneda *et al.*, 1991; Sunar *et al.*, 2003; Dobashi *et al.*, 2002).

Over the last two decades, Augmented Reality (AR) or in general, Mixed Reality (MR) has been one of the most attractive topics in computer graphics making researchers interested in achieving good results in this field (Azuma, 1997; Jacobs *et al.*, 2005; Madsen and Nielsen, 2008). In AR, realism can be achieved through entering shadows as well as inducing interaction between objects (Jensen *et al.*, 2009; Liu *et al.*, 2010; Xing *et al.*, 2012; Madsen and Lal, 2013).

In general, realistic augmented reality has been a critical point in computer graphics before the turn of 21^{st} century (Azuma, 1997). In this research, to produce a realistic virtual object in real outdoor environments, the sun position, sky color, shadows and interaction between sky color and objects are taken into account. Figure

1.1 represents the research area. The final focus area is shown as well as all open issues in AR.

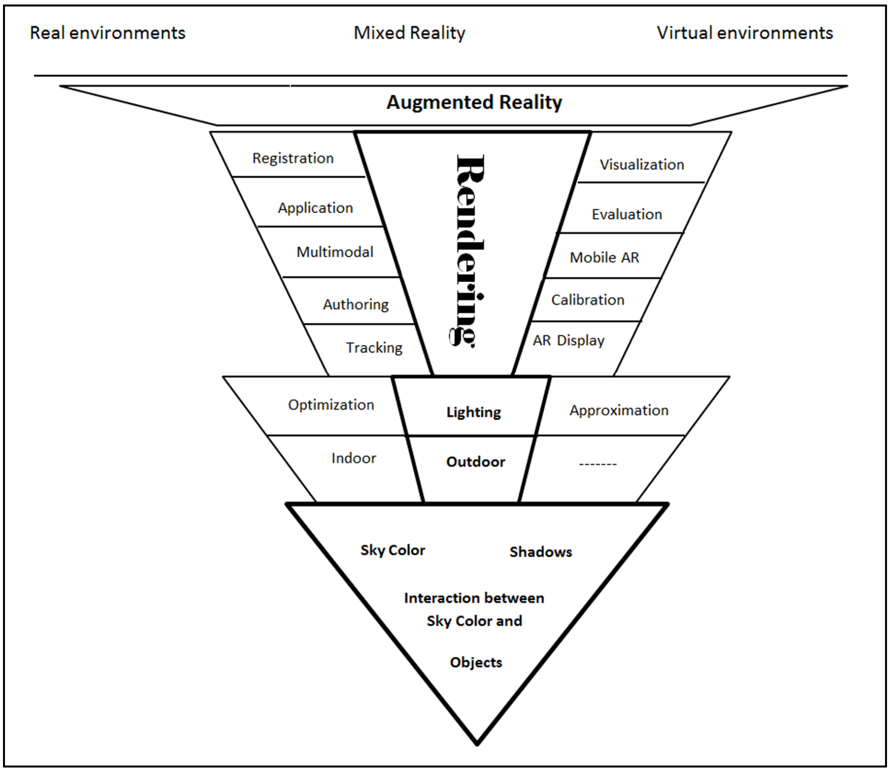

Figure 1.1: Research focus area

Studies about sky color and shadows are the main resources for outdoor components using grammars with sets of rules. Rendering outdoor components is studied for visualization of natural scenes in different contexts: animators, ecosystem simulations, video games, design architectures and flight simulators (Klassen, 1987; Sunar *et al.*, 2003).

Sky illumination on virtual objects is the most significant factor in outdoor rendering not only in virtual environments but also in augmented reality systems (Kaneda *et al.*, 1991; Tadamura *et al.*, 1993; Gibson *et al.*, 2003; Feng, 2008; Xing *et al.*, 2011, 2012; Feng, 2008; Yeoh and Zhou, 2009; Aittala, 2010; Kim, 2010; Xing *et al.*, 2012).

The principle of calculating the sun position has long been known. The ancient Egyptians were able to calculate the sun position many years ago by digging a large hole inside a pyramid; just once a year, on the king's birthday, the sun would shine on the grave of their king (Perl and Weihs, 1990; Nawar *et al.*, 2007). The practical use of the sun position in computer graphics applications is one of the outdoor rendering concerns.

Daylight is combination of all direct and indirect light from the sun, sky color and diffusion of other object especially the earth. In other words, daylight includes direct sunlight, diffused sky radiation, and both of these reflected from the earth and terrestrial objects. Intensity of skylight or sky luminance are not uniform and depend on the clarity of the sky (Nishita and Nakamaei, 1986).

The sun and the sky are the main resources of natural illumination. The sun is a light source simulating the effect of sunlight and can be used to show how the shadows cast by a structure affect the surrounding area. The angle of the light from the sun is controlled by location, date and time. The skylight is the most important outdoor illumination to render the scene realistic (Dobashi *et al.*, 1996).

Most real-time rendering has focused on indoor rendering but the real ability of computer graphics can be demonstrated in outdoor rendering taking the sky illumination into account (Preetham *et al.*, 1999; Rönnberg, 2004). It is because, the sky usually illuminates a point from almost all directions. A realistic sky scene will greatly improve the reality of the outdoor virtual environment (Wang, 2007). Generating sky color as a background for each outdoor scene is essential factor to make it realistic. Displaying the sky has become critical, as many buildings are designed, so that the sky or a surrounding scene is reflected in the building windows (Dobashi *et al.*, 1997).

Rendering realistic outdoor environments in real-time has always been a crucial problem in computer graphics especially in game engines. In real life, natural scenes include a huge number of small and big objects which are difficult to model and take long time to render. This also requires a substantial amount of memory. Overcoming this problem has been an attractive topic and challenging many researchers since later in the previous century.

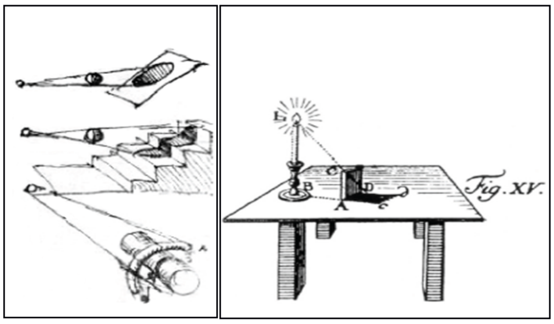

Figure 1.2: Left: Study of shadows by Leonardo da Vinci (1490), Right: Shadow construction by Lambert (1774)

In computer games, shadows make gamers feel a sense of playing in the real world resulting in maximum pleasure. Games without shadows are not pleasurable to gamers. Nowadays, gamers taste virtuality and their imaginations constantly demand more and more realism. To create realistic environments, shadows are very important as they reveal information about the distances between objects in the entire scene. It is a major factor of 3D graphics, but unfortunately it is expensive in the case of rendering time in virtual, let alone in augmented reality environments. Shadows are one of the most significant aspects in virtual and augmented reality environments both for the spectator to detect distance relationships between objects, and to reveal the complexity of objects resulting in more realistic environments. Leonardo Da Vinci (Figure 1.2 (left)) was the first to focus on painting and static images take shadows into account (Vinci, 1490). There are some materials by Lambert who worked on shadows, specifically the geometry underlying the shadow receiver (Figure 1.2(right)) (Lambert, 1774).

Shadows help realise the relative distance of objects in a scene. Without shadows and shadow casters, it is difficult to comprehend the real size of objects when

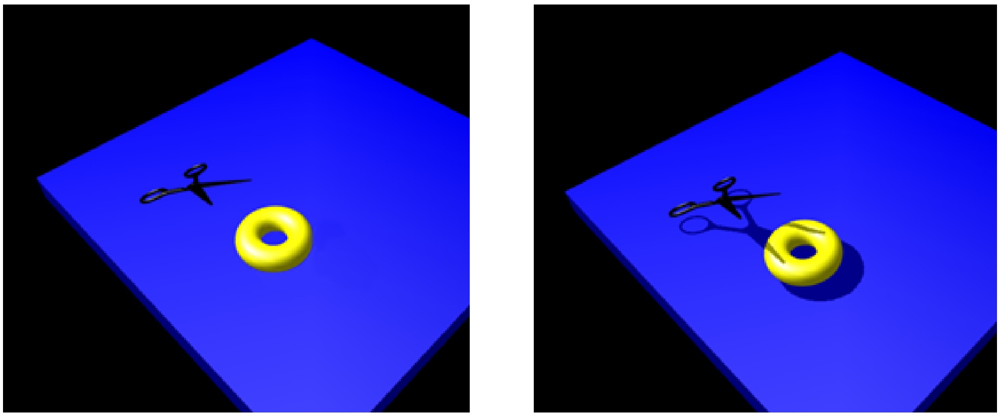

Figure 1.3: Comparison between a scene without shadows and with shadows to realise distance and size of objects

compared with other objects which are located far away. For example, in Figure1.3, on the left, the distance and size of the objects are not clear but on the right of the Figure 1.3, it is obvious that scissors are above the plane, and torus is on the plane. Another advantage is that shadows help the viewer realise the geometry of a complex object which includes huge number of polygon. In Figure 1.4 (left), it is not clear what the curve is. However, the number of tines in the fork is clear on the right of the picture.

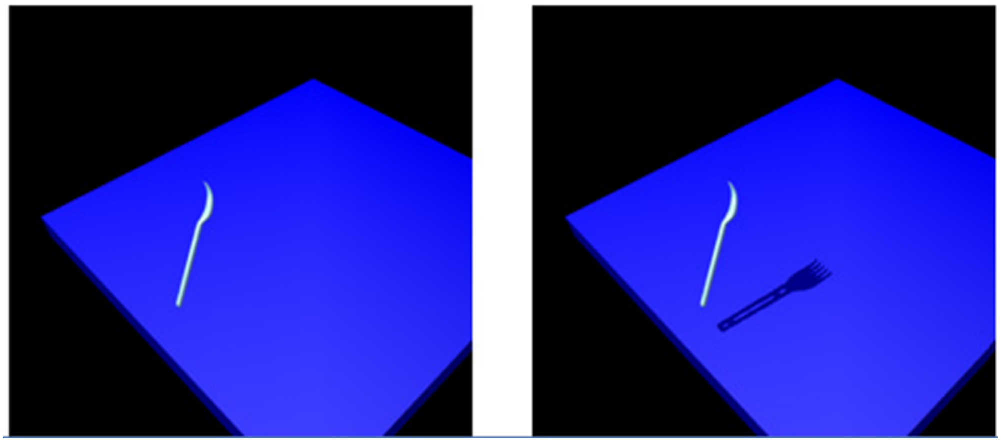

Figure 1.4: Comparison between a scene without shadows and with shadows to realise the geometry of complex object

Another significant effect making the outdoor scene more realistic is the interaction between sky color and objects. The method is followed through exerting sky color energy on virtual objects. The interaction between sky color and virtual objects in AR systems could be the latest state-of-the-art to make the AR system more realistic at the time of writing the present thesis (Liu *et al.*, 2009, 2010; Xing *et al.*, 2011, 2012, 2013).

To sum up, the significant factors in realistic outdoor AR rendering include the sun position, sky color, shadows and interaction between objects. Sky color and shadow generation are expensive for rendering individual cases let alone their integration. Thus, they require more improvements not only in the case of rendering time but also in the case of realism. In this research, an attempt is made to reduce the rendering time through some improvements on shadow generation algorithms and radiosity technique, and enhance realism by applying shadows and the effect of sky color on virtual objects in augmented reality environments.

1.2 Problem Background

More than 30 years has passed since the first computer game was invented (3D Monster Maze 1981); many prominent researchers have spent much time to improve the quality of virtual environments and make the virtual scenes realistic similar to what meets the eyes. Nowadays, large companies, e.g. NVIDIA, Maya and 3D Studio Max spend exorbitant amounts on improving the quality of various fields of computer games. Although speed is crucial in real-time applications, visual quality is also a very significant factor (Boulanger, 2008; Feng, 2008; Kim, 2010; Xing *et al.*, 2011, 2012).

As the DreamWorks Animation CTO Ed Leonard reported, Shrek 1 used 5 million CPU rendering hours, Shrek 2 used 10 million CPU render hours, Shrek 3 used 20 million CPU rendering hours, and Bee Movie needed 23 million CPU rendering hours which are too long, a real-time technique will be in order to reduce the CPU render time. Real-time rendering is the best technique to avoid long CPU rendering hours not only in the case of virtual environments but also augmented reality systems.

In general, poverty and unfair division of revenue are highly interconnected. In computer graphics also, for a desirable result, an enhancement in quality will produce a lower reduction in Frame Per Second (FPS). Therefore, any enhancement in quality is considered undesirable for rapid reduction in FPS and vice versa. However, in some development techniques there is a trade-off between FPS and quality. Introducing a compromise technique to enhance the quality which remains FPS could be a desirable achievement for the current research.

In real-time rendering, realism can be achieved only by combination of sophisticated modellings such as daylight, reflection, absorption and shadows (Jansen and Chalmers, 1993). Most real-time rendering has focused on indoor rendering due to the complexity of outdoor rendering especially in augmented reality environments (Preetham *et al.*, 1999; Rönnberg, 2004). All these motivate us to focus on sky color and shadows in outdoor AR rendering systems to enhance the realism and reduce rendering time. Outdoor rendering components such as the sun position, sky color, shadows and interaction between sky color and objects in augmented reality environments, implementation of related objects, and their relationship form some of the topics in the approach adopted in the present research.

Outdoor rendering is a very extensive topic in video games. The main problem when dealing with outdoor scenes is the visual realism of shadows and the sky color (Rönnberg, 2004). The effects of shadows cast from objects due to sunlight; and skylight is extremely important for any outdoor scenes. The fact that shadows move over time and shadows are often soft is due to the entire sphere of influence around a point contributing to the illumination. The illumination at the point is very important to have realistic outdoor scenes (Kaneda *et al.*, 1991).

Many algorithms are proposed for shadow generation. Shadow volumes and shadow maps are classical real-time shadow techniques. Shadow volumes are accurate enough but they are geometrically-based and require extensive calculations. Although shadow volumes are established in the gaming industry, they have two expensive phases; updating volume rendering passes, and silhouette detection to recognize the outline of occluders (Raskar and Cohen, 1999; Assarsson and Akenine-Moller, 2003; Jung *et al.*, 2004; Billeter *et al.*, 2010). Silhouette detection requires a novel algorithm or an improvement on existing algorithm to reduce the rendering time in shadow volumes.

In the case of shadow volumes, recognizing the outline of objects can be effective in rendering speed of the algorithm. Silhouette detection is essential in determining the outline of the object as it reduces the cost of rendering. Silhouette detection is an important phase in all visual effects. To generate shadows, silhouette detection plays a crucial step in detecting occluder boundaries (Raskar and Cohen, 1999; Assarsson and Akenine-Moller, 2003; Chen *et al.*, 2011).

Richards *et al.* (1987) was the first researcher who focused on silhouette detection interpreting the silhouette of objects. Saito and Takahashi (1990) improved the silhouette detection using G-buffer. Hertzmann (1999) proposed a technique for recognizing silhouette of irregular objects using Z-buffer. Simultaneously, Raskar and Cohen (1999) by changing the front faces and back faces of a polygon object presented a new technique for silhouette detection. Jung *et al.* (2004) improved the algorithm by proposing a technique using spatial coherence and frame coherence. Fawad *et al.* (2009) combined Canny (1986) method, Markosian *et al.* (1997) method and method of Markosian and Adviser-Hughes (2000) to introduce a fast silhouette detection for shadow volume generation but still extensive calculations were needed.

Contrary to shadow volumes, shadow maps are image-based and easy to be implemented. Shadow maps are proposed by Williams (1978) which are a milestone in shadow generation time-line. Although shadow maps are more widely used than shadow volumes due to less expensive rendering, they suffer from aliasing. Aliasing is a crucial problem of shadow maps (Williams, 1978; Reeves *et al.*, 1987; Woo *et al.*, 1990; Lokovic and Veach, 2000; Lauritzen and McCool, 2008; Eisemann *et al.*, 2009, 2011; Scherzer *et al.*, 2011). Improvement of these categories of shadow generation algorithms is another contribution of the present research.

Reeves *et al.* (1987) proposed a new technique to reduce aliasing by filtering the algorithm which they called percentage-closer filtering (PCF). This algorithm, by filtering the depth map with interpolation of binary data, attempts to produce monotonic data in the outline of shadows. This method involves binary data. Lokovic and Veach (2000) proposed a technique entitled deep shadow maps to reduce aliasing. Unlike traditional shadow maps which store one depth for each pixel, deep shadow maps store fractional visibility functions that represent the visibility through a given pixel at all different depth levels. Fernando *et al.* (2001) tried to resolve shadow maps aliasing using the technique of synchronizing the pixel size in two viewpoints. This is accomplished by storing the shadow maps in a hierarchical structure instead of the normal flat two-dimensional view.

Stamminger *et al.* (2002) proposed Perspective Shadow Maps (PSMs) to reduce aliasing. They implemented PSMs in normalized device coordinate space. PSMs reduce aliasing and create almost sharp outlines. This idea provides almost good resolution for near objects and decreases resolution as the viewer moves away from the viewpoint. Donnelly and Lauritzen (2006) proposed an algorithm entitled Variance Shadow Maps (VSMs) based on traditional shadow mapping to reduce aliasing. In this algorithm, instead of storing a single depth value (z-value), they store mean and squared values for depths distribution. Dimitrov (2007) proposed a technique to create semi-soft shadows, based on shadow mapping entitled Cascaded Shadow Maps (CSMs). Cascaded shadow maps try to reduce aliasing by z-partitioning. Lauritzen and McCool (2008) proposed an algorithm which could solve both VSMs problems. They called the algorithm Layered Variance Shadow Maps (LVSMs). LVSMs divide depth shadow into layers but reduce the texture precise.

Yang *et al.* (2010) improved variance shadow maps and published their paper entitled Variance Soft Shadow Mapping(VSSM). VSSM is based on PCF and exploits recent advances in VSMs. VSSM could render high quality soft shadow faster than PCSS. They presented some other ideas on variance soft shadow mapping for rendering plausible soft shadow in real-time. Variance soft shadow mapping is based on the theoretical framework of percentage-closer soft shadows. Their new formulation allowed efficient computation of blocker distances, a common bottleneck of percentage-closer soft shadows.

Bittner *et al.* (2011) proposed a technique to cull parts of shadow caster which do not contribute to shadows. The method uses a mask to cull the shadow casters using a hierarchical occlusion culling. They proposed different masks to cull the shadow casters and calculated the cost for each. They claimed the technique achieves 3x-10x speedup for rendering a wide scene like a city and 1.5x-2x speedup for rendering an actual game scene.

In the case of augmented reality, realistic virtual objects in outdoor rendering environments require state-of-the-art effects such as consideration of shadows, daylight, reflection and absorption (Jansen and Chalmers, 1993; Madsen and Lal, 2011). Shadows are one of the significant factors enhancing the realism of augmented reality outdoor rendering which have been examined for more than fifteen years (Azuma, 1997; Naemura *et al.*, 2002; Debevec, 2004). Many researchers studied how the shadows in augmented reality environments can be applied and improved (Madsen *et al.*, 2003; Haller *et al.*, 2003; Gibson *et al.*, 2003; Jacobs *et al.*, 2005; Madsen and Nielsen, 2008; Madsen and Lal, 2013). Enhancement of shadows while considering light is another aspect making objects more realistic in outdoor AR rendering but they are still distinguishable with the real ones (Yan, 2008; Nowrouzezahrai *et al.*, 2011; Aittala, 2010; Madsen and Lal, 2011; Figueiredo *et al.*, 2012; Knecht *et al.*, 2012). An interaction between sky color and virtual objects during daytime is the last contribution of current research to enhance the quality of outdoor augmented reality environments.

Haller *et al.* (2003) applied shadow volumes to create shadows in augmented reality with the main issue which is silhouette detection. Jacobs *et al.* (2005) simulated

2011). Low FPS is due to more complexity of outdoor environments. Most complexity comes from geometry, lighting and shadows (Boulanger, 2008; Bittner *et al.*, 2011). The geometry is because of too much detail in outdoor environments. Lighting computation is caused by higher levels of light reflection over all visible objects in the scene. Complexity of shadow generation is caused by projection of all visible objects from light point of view to the shadow receivers. To overcome this complexity, much research has been conducted on this challenging problem (Reeves *et al.*, 1987; Assarsson and Akenine-Moller, 2003; Jung *et al.*, 2004; Boulanger, 2008; Billeter *et al.*, 2010; Liang *et al.*, 2011). Rendering a scene with full ecosystems or large environment is a difficult task because of the level of geometry and complexity that was mentioned before. The lowest frame per second happens when the scene is wide as is the case in outdoor environments. This requires more improvement to render a large scene realistic. Thus, approximations giving the most visually convincing results at the lowest possible cost are required (Wyman, 2004; Zhang *et al.*, 2007; Boulanger, 2008; Nguyen *et al.*, 2010; Liang *et al.*, 2011).

In the case of shadow generation, shadow volumes need to be improved in the silhouette detection phase which is the most expensive part of the algorithms (Crow, 1977; Assarsson and Akenine-Moller, 2003; Jung *et al.*, 2004; Billeter *et al.*, 2010). Shadow maps require an improvement in aliasing which is their critical problem (Williams, 1978; Reeves *et al.*, 1987; Woo *et al.*, 1990; Lokovic and Veach, 2000; Lauritzen and McCool, 2008; Eisemann *et al.*, 2009; Scherzer *et al.*, 2011).

Shadows play an important role and are an essential factor for a 3D impression of a scene to achieve a realistic augmented reality result, (Naemura *et al.*, 2002; Debevec, 2004). Simulating shadows in augmented reality for a virtual object in real scenes is difficult especially when the approximate geometric details about the real scene and the light source are known (Jacobs *et al.*, 2005).

Nakamae *et al.* (1986) is an early work on illumination in augmented reality to merge virtual objects into real images. Liu *et al.* (2009) by estimating the light source for outdoor scene images improving the Nakamae's method. They produced shadows for virtual objects but there is no interaction between sky color and objects.

Direct and indirect illumination on virtual objects in augmented reality systems is an open question in current augmented reality environments due to researchers' focus on consistent illumination (Gibson *et al.*, 2003; Hughes *et al.*, 2004; Steinicke *et al.*, 2005; Feng, 2008; Jensen *et al.*, 2009; Xing *et al.*, 2011, 2012; Madsen and Lal, 2013). In addition to shadowing, interaction between real and virtual objects is a more important aspect to enhance the realism of virtual objects in augmented reality (Feng, 2008; Yeoh and Zhou, 2009; Aittala, 2010; Kim, 2010; Xing *et al.*, 2012), and the main outdoor objects is the sky. Outdoor rendering in augmented reality is more complicated due to the unpredictable illumination changes with respect to sky color (Lu *et al.*, 2010).

Increasing the rendering speed is still the challenging problem facing augmented reality as important as realistic (Liu *et al.*, 2009; Xing *et al.*, 2012). To have an interaction between sky color and objects taking shadows into account, a fast shadow technique is required as much as an improvement on radiosity technique to share the energy between outdoor objects.

In summary, to avoid the CPU rendering time, real-time techniques are required. The main factors in realistic outdoor AR environments are the sun position, sky color, shadows and interaction between sky color and objects. A few techniques are employed to enhance the realism of AR systems but most have focused on indoor or non real-time rendering. A new shadow algorithm without aliasing and a technique for applying the integration of the main mentioned factors are required to enhance the realism of outdoor AR systems.

1.3 Problem Statement

The most sophisticated components in outdoor rendering are shadows and lighting (Jansen and Chalmers, 1993; Preetham *et al.*, 1999; Rönnberg, 2004; Boulanger, 2008). In general, lighting refers to global illumination and interaction between objects where the main object in the outdoor environment is the sky (Kaneda *et al.*, 1991; Tadamura *et al.*, 1993; Nishita *et al.*, 1996; Tamura *et al.*, 2005; Boulanger, 2008; Arief *et al.*, 2012; Madsen and Lal, 2013; Xing *et al.*, 2013). Shadows refer to the dark portions and halftones which include all different categories such as hard, soft or even soft outline shadows and self shadowing.

However, registration and tracking are two of the main issues in building effective AR systems (Madsen and Laursen, 2007), generating realistic virtual objects in augmented reality environments that are indistinguishable from real ones is still an open issue (Yan, 2008; Liu *et al.*, 2009; Sheng *et al.*, 2010; Krevelen and Poelman, 2010; Xing *et al.*, 2012; Madsen and Lal, 2013). An interaction between objects in augmented reality can be used to improve realism (Rönnberg, 2004; Liu *et al.*, 2010; Xing *et al.*, 2012; Madsen and Lal, 2013; Xing *et al.*, 2013; Zhang *et al.*, 2013).

Realistic rendering of virtual objects in outdoor environments which makes the objects indistinguishable from real ones is the most difficult task in augmented reality environments (Madsen and Laursen, 2007). For outdoor rendering, sky effect is the first and most important factor to be taken into account for generating a realistic environment (Kaneda *et al.*, 1991; Tadamura *et al.*, 1993). Therefore, realistic outdoor rendering augmented reality could be achieved by applying the effect of sky color on virtual objects as well as real objects.

Liu *et al.* (2009, 2010); Xing *et al.* (2011), Xing *et al.* (2012, 2013) and Zhang *et al.* (2013) proposed an outdoor image, taking sunlight and skylight into account but for live videos. They aimed to apply the interaction between sky color and objects in real-time rendering which is the most salient feature the present research is going to address.

Lack of real-time outdoor rendering environments in sufficient realism (Boulanger, 2008), encouraged the researcher to apply a convenient technique to integrate the main outdoor AR components by considering sky color and shadows with respect to sun position in any specific location, date and time.

1.4 Research Aim

The aim of this research is to propose a technique to achieve realistic real-time outdoor rendering taking into account the interaction between sky color and objects in augmented reality environments with respect to shadows and the interaction in any specific location, date and time.

1.5 Research Objectives

To achieve this aim, the following objectives need to be followed:

1. To propose a new shadow algorithm for increasing the realism and reducing the rendering time
2. To introduce a new mathematical formula to calculate the shadows with respect to the sun position in any specific location, date and time
3. To enhance outdoor AR environments by applying a new technique for integrating sky color, shadows and interaction between sky color and virtual objects in AR

systems

1.6 Justification

This research has prepared three improved algorithms and a new technique to integrate outdoor components in AR systems. Two algorithms are related to shadow generation and the other one is in radiosity. The algorithms address some problems facing game makers. Animators are the main audience who can use the algorithms to create outdoor environments in virtual and augmented reality. The new algorithm in shadow generation can be used for game makers to construct shadows in both virtual and augmented reality environments with high frame per second and high enough quality in realism. In the case of shadow generation, the results obtained from this research are poised to become a basis for the much needed industrial standard in computer graphics. They address the issue of image and geometry-based shadow generation. It is also believed to have a significant effect and impact on the rendering time and realism.

In the case of the final integrating technique, three groups form the audience. The first group are animators and game developers. The second group is the physics and arts teachers. Building designers and architectures form the third group who can use the final prototype.

Virtual Heritage is a relevant subject which can benefit largely from the results of interaction between sky color and objects with respect to the sun position in any specific location, date and time to reveal realistic heritage in real environments (Noh *et al.*, 2009). Interaction between the sky and objects in virtual and augmented reality environments could make the scenes appear more realistic for game programmers.

Physics teachers, also, can use the application in some cases. The effect of sun position on shadows and measurement of direction and length of shadows are from among the low-level uses of this integration. At an intermediate level, investigation of Perez model and the effect of sun position on sky color in different locations, dates and times can be useful for students to reveal God's miraculous creation, the solar system. Observation of the interaction between the sky color and objects in virtual and augmented reality environments could form a professional discussion topic for physics and arts students.

Finally, to recognize the best direction of building in cold or warm areas and to save the energy, building design industry can use the final software. Specification of the best building direction in any specific location is an important factor. In cold places, a building needs to be situated where shadows lie in the back of the building; in warm places, building should be located in the position where shadows lie in front of the building. This is a simple way to save the free blessing which God presented to us. It is hoped that this will be of enormous help to all groups.

1.7 Research Contributions

- The shadow generation algorithms is one of the contributions to keep maintain the trade-off between FPS and quality of results. An algorithm for silhouette detection based on geometrical techniques for shadow volume generation and a hybrid shadow maps algorithm based on shadow mapping are the first contributions of this research. In the case of shadow volumes an improvement on silhouette detection increases the FPS. The hybrid shadow mapping not only enhances the quality of shadows but also increases the FPS.
- The mathematical formula introduced to calculate the shadows with respect to sun position in any specific location, date and time is another contribution of the

present research. This coherent formula could make outdoor rendering as easy as indoor rendering. Outdoor rendering using a coherent formula eliminated the need for shadow positioning during daytime.

- The main contribution of this research is to propose a new technique for rendering the shadows and sky color to reveal the interaction between sky color and objects in the AR system. The prototype takes into account the outdoor components such as sky color and shadows with respect to the sun position in augmented reality environments to make the interaction between sky color and objects appear. The improved algorithm for radiosity technique to share the sky color energy and to improve the trade-off also needs to be mentioned in this regard.

1.8 Research Scope and Limitations

The shadow generation algorithms can be used for opaque objects as well as previous algorithms which are a requirement for outdoor AR systems. The occluders are opaque, thus light penetrable objects such as semi-transparent are excluded. In the case of shadow volumes, the algorithm is newly-designed for silhouette detection. In the case of hybrid shadow maps, the algorithm could improve both FPS and the quality of shadows. The algorithm is implemented with OBJ, PLY and RAW data. The shadow generation techniques exclude complicate objects such as hair, fur and smoke. However, hybrid shadow maps could be implemented for complex objects such as grass and trees in augmented reality systems.

The coherence mathematics formula covers shadows with the respect to the sun position. The formula works for the daytime in any specific location, date and time. The sky color is created based on Perez model which is an accurate technique. The sky color excludes scattering and other phenomena.

The interaction is applied for both virtual environments and augmented reality environments. Two classes of sky color generation are employed to reveal the outdoor-element interaction; virtual sky model and real sky model. The software does not take into account other atmospheric phenomena such as rainbows, halos, glories and coronas.

The AR system considered multimarker and markerless as well as single marker. In some parts of the research multimarker is used to show different virtual objects in real scenes when the distance between camera and virtual objects is not so long. In the case of wide outdoor environments markerless AR is applied because detecting the far marker is not rebuts and capturing a far scene including near marker does not lead to more realism. In the case of markerless AR, the location and direction of virtual objects could be handled using keyboard and mouse or a configuration INIfile.

1.9 Thesis Organisation

Chapter 1, includes the statement of the thesis. It starts with the introduction and then problem background. Next comes problem statement, aim and objectives followed by the scope and limitation which are described clearly. The structure of thesis is outlined at the end of the chapter.

Chapter 2, provides an in-depth literature review of all the three major areas; the sun position and sky color generation in computer graphics, shadow generation and augmented reality systems. Emphasis is laid on the various contributions and limitations of the proposed algorithms and techniques in all three relevant areas.

Chapter 3, presents the research methodology in four phases. Phase 1 investigates the sun position and the sky color and the implementation of sky color with respect to the sun position, viewer's location, date and time using Perez model. Phase 2 examines shadows and the implementation of different types of shadow algorithms. The proposed coherent formula for sun position and shadows will be implemented in phase 3. The last part of phase 3 takes up construction of an outdoor virtual environment and implementation of the interaction in virtual environments(VE). Phase 4 is allocated to augmented reality and applying the interaction in AR; then testing and evaluating of the results.

Chapter 4, discusses the realisation of the first and second objectives of this research. It starts with implementing the sun position and sky color. Then redefinition of shadow parameters and implementation of the improved and proposed shadow algorithms are employed in this chapter. Shadow volumes and shadow maps are implemented separately. Two new algorithms are proposed. EESD (Extended Edge Silhouette Detection)improves the shadow volume algorithms and HSM (Hybrid Shadow Maps) reduces rendering time and enhances the realism of shadows. Integrating sky color and shadows, an outdoor rendering environment is provided in the third section. The environment is produced in two different cases; geometrical and image-based. The chapter ends with the introduction of the coherent formula which meets the second objective.

Chapter 5, presents the interaction between sky color and objects in both VE and AR. This chapter introduces an improved algorithm on radiosity which is required for meeting the last objective. The final technique to integrate the outdoor AR environments is presented in the last part of this chapter.

Chapter 6, presents results emanating from the application of the three algorithms. Testing, evaluation and validation of the all contributions are employed in this chapter. The shadow generation techniques are tested separately. The sky color with respect to the sun position is the section which evaluates the results of the generated sky color in the virtual and augmented reality environments. The last part of this chapter is testing and evaluation of the proposed technique. Comparing the real scenes and the results obtained from the technique in the same location, date and time in both virtual and augmented reality environments, the final goal is tested and evaluated.

Chapter 7, concludes the thesis. The thesis ends with a conclusion and suggestions for further research which may provide directions in which future researchers of outdoor rendering and augmented reality may proceed.

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