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CROWD AND ACOUSTICAL MODELLING IN DIGITAL CULTURAL HERITAGE

LIM CHEN KIM

UNIVERSITI SAINS MALAYSIA

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CROWD AND ACOUSTICAL MODELLING IN DIGITAL CULTURAL HERITAGE

by

LIM CHEN KIM

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AERO	Adaptive Elastic Roadmaps
AI	Artificial Intelligence
%ALCons	Percentage Articulation Loss of Consonants
App	Application
CAHRISMA	Conservation of the Acoustical Heritage by the Revival and Identification of Sinan's Mosque's Acoustics
CG	Computer Graphics
CPU	Central Processing Unit
DSLR	Digital Single Lens Reflex
DTM	Digital Terrain Model
EA	Experimental Analysis
EAU	East Anglia University
ERATO	Identification, Evaluation and Revival of the Acoustical Heritage of Ancient Theatres and Odea
ERC	European Research Council
FIFO	First In First Out
FMM	Fuzzy Mathematical Model

FoV Field of View

FSM Finite State Machine

GPU Graphics Processing Unit

GS Geometry Shaders

GUI Graphical User Interface

HBRs Human Behavior Representations

HRTFs Head Related Transfer Functions

HSV Hue Saturation Value

IBR Image Based Rendering

IDE Integrated Development Environment

IK Inverse Kinematics

ILD Interaural Level Differences

iOS iPhone Operating System

Is Incentive Value of Success

ISO International Organisation for Standardisation

ITD Interaural Time Differences

JFIF JPEG File Interchange Format

JPEG Joint Photographic Experts Group

JUPEM Jabatan Ukur dan Pemetaan Negara

LOD Level of Details

MLSSA Maximum Length Sequence System Analyser

MMS Multimedia Messaging Service

MOV Movie

Ms Motivation's Intensity of The Agent who Wants to Win Success

MVC Model-View-Control

ODEON Oscar Deutsch Entertains Our Nation

PHT Penang Heritage Trust

PNG Portable Network Graphics

Ps Possibility of the Successful Completion of Task

QTVR QuickTime Virtual Reality

RDT Range Detection Technique

RGB Red Green Blue

ROI Regions of Interest

ROV Recursive Speed Obstacles

Rt Reverberation Time

RTS Reactive Taboo Search

RVO Reciprocal Velocity Obstacles

SDK Software Development Kit

SMIL Synchronised Multimedia Integration Language

SPL Sound Pressure Level

STI	Speech Transmission Index
TDW	Tiled Display Wall
TIN	Triangulated Irregular Network
Ts	Success of Target Tendency
UJF	Universite Joseph Fourier
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UX	User Experience
VGH	Viking Ghost Hunt
VHD++	Very High Definition
VR	Virtual Reality
XML	Extensible Markup Language

LIST OF SYMBOLS

α	alpha
$^\circ$	degree
δ	delta
lim	limit
π	pi
$\sum$	summation of all
θ	angle in radians

PEMODELAN KUMPULAN RAMAI DAN AKUSTIK DALAM WARISAN BUDAYA DIGITAL

ABSTRAK

Istilah warisan secara meluas merujuk kepada kajian kegiatan manusia pada masa lampau dan pengkisahan budayanya dan memayakan warisan bermaksud merealisasikan kandungan warisan secara digital. Apabila mencuba untuk memahami sesebuah tapak warisan budaya, cabaran yang wujud termasuklah pengguna merasakan bahawa mereka tidak mampu untuk menghubung kait ke masa lampau dan menghayati keadaan masa kini kerana maklumat sejarah sesebuah tapak warisan biasanya tidak mencukupi. Oleh itu, objektif utama penyelidikan ini adalah untuk membawa kehidupan ke dalam warisan budaya digital dan ini memerlukan penggabungan audio dan maklumat visual sekeliling, dan orang ramai pada masa kini dan juga pada masa lampau. Dalam penyelidikan ini, membawa kehidupan kini yang merangkumi kumpulan ramai dan audio sekeliling dalam pemandangan panorama, dan membawa kehidupan lampau yang merangkumi tingkah laku sosial kumpulan ramai heterogen yang berlaku di sebuah pelabuhan perdagangan lama. Bagi pembinaan pemandangan panorama, kajian ini mencadangkan sebuah skim yang cepat dan cekap untuk menjana panorama pada platform bergerak. Kaedah ini menyimpan imej yang terhad dalam tatasusunan untuk menjana pemandangan panaroma 360° dari pelbagai sudut yang berbeza dari sesebuah tapak warisan. Selain itu, model warisan akustik digabungkan ke dalam pemandangan panorama 360° pada platform mudah alih sebagai salah satu unsur untuk membawa kehidupan masa kini ke dalam warisan budaya digital. Model yang dicadangkan termasuklah modulasi ciri-ciri bunyi dalam zon azimuth pelbagai panorama yang seimbang melalui interaksi pelbagai gerak isyarat pengguna. Pemodelan kumpulan ramai dalam pandangan panorama merupakan percubaan pertama dalam menambah maklumat

tambahan iaitu kumpulan ramai dalam tapak warisan di dalam pemandangan panaroma. Akhir sekali, untuk membawa kehidupan lampau ke dalam warisan budaya digital, simulasi kumpulan ramai mikroskopik digunakan untuk kes kompleks pelabuhan perdagangan pelbagai etnik, yang melibatkan pola tingkah laku yang berbeza melalui kaedah simulasi kumpulan ramai heterogen. Dalam simulasi ini, kaedah kawalan peringkat tinggi, keadaan-mesin berhierarki dan model pembentukan kumpulan diperkenalkan melalui formalisme interaksi antara etnik. Keputusan penilaian dan pengesahan menunjukkan bahawa skim, model dan kaedah yang dicadangkan adalah cekap, berkesan dan berjaya digunakan di George Town, Malaysia.

CROWD AND ACOUSTICAL MODELLING IN DIGITAL CULTURAL HERITAGE

ABSTRACT

The broad term of heritage refers to the study of human activity in the past and its cultural narratives and to virtualize heritage means to actualize the heritage content digitally. When attempting to understand a particular cultural heritage site, the challenge here is that user feels that they are not able to connect to the past and appreciate the presence due to insufficient historical information of the heritage sites. Therefore, the main objective of this research is to bring lives into digital cultural heritage and it would need the inclusions of the audio and visual information of the surroundings and the people in the present as well as in the past. In this research, bringing present life into digital cultural heritage includes the crowd and surrounding audio in panoramic view, and bringing past life includes social behaviours of heterogeneous crowd transpired in an old trading port. With respect to the construction of panoramic view, this research proposed a rapid and efficient scheme for generating panoramic view on mobile platform. The method stores finite images in an array to generate a 360° panoramic view from different angles of the heritage sites. Besides, an acoustical heritage model is incorporated into 360° panoramic view on mobile platform as one of the elements to bring the present life into digital cultural heritage. The model includes modulations of sound properties within various balanced panorama's azimuthal zones through user's multi-gesture interaction. Crowd modelling within panoramic view is the first attempt in adding extra information i.e. crowd to the heritage sites in panoramic view. Finally, to bring the past life into digital cultural heritage, microscopic crowd simulation is applied to the complex case of a multi-ethnic trading port, involving different behavioral patterns through a heterogeneous crowd simulation method. In the

simulation, a high-level control method, hierarchical state-machine and group formation model are introduced through inter-ethnic interactions formalism. The results of the evaluation and validation have shown that the proposed schemes, models and methods are efficient, effective and have successfully been deployed in George Town, Malaysia.

CHAPTER 1

INTRODUCTION

In this research, two types of life would be brought into digital cultural heritage, namely the present life and the past life. With rapid advancement of technology, people can roam around the virtual world through the aid of the Internet. One of these advances is a photographic technique called panoramic view where the images are captured with elongated field of view using specialised software or equipments. One of the best ways to construct the environment of the present life in digital cultural heritage is through panoramic view. In a virtual tour application, several photographs of the heritage sites are stitched together to produce a 360° panoramic view. Mobile phone is one of the simplest devices encountered everyday. In order to easily share a visit with others, mobile platform offers high accessibility of the digital contents in a more popular style. By using panoramic view on mobile platform, user can keep on updating the present visual information like an archive. Archiving own experiences in this way offers the possibility for users to follow their own interests and create highly personalised visits of present digital contents, which can grow and change over time. So, the virtual tour allows the user to roam around by giving an immersion in the space almost as if the user is in the actual heritage site. However, it is computationally expensive for mobile platform to store enormous number of panoramic images. Therefore, a scheme for efficient and rapid generation of panoramic view is essential in order to give adequate information of a heritage site of the present life.

Many digital representations of objects and buildings fail in at least one aspect of their presentation because they lack elementary contextual information (MacDonald and Honsinger, 2006). For example, at present, acoustical heritage in 360° panoramic view is not available.

Therefore, panoramic view may offer new possibilities for interpretation of dynamic surroundings through sound. Acoustical heritage which is the science of sound is designed to absorb and control a sound. Realising that sound has a very rich potential for user interaction, digital preservation of the acoustical heritage in 360° panoramic view is necessary in order to enhance user's experience about the cultural surroundings.

Beside having acoustical heritage in 360° panoramic view, other digital collections such as images or Two Dimensional (2D) simulations may also increase the freedom of movement and capacity of understanding of the users by at least another degree. However, people or crowd in panoramic views are static since they are captured together with the environment. Thus, the content or crowd is fixed and unlike the actual physical environment. In order to strengthen contextual information in the 360° panoramic view, dynamic crowd modelling is vital to augment the user's perception and interpretation of the present life in the digital cultural heritage sites.

Although the present life through panoramic view will become the past life in the future, past life in digital cultural heritage needs to be reconstructed using Three Dimensional (3D) view since it is not possible to construct panoramic view of the past life as the content of the heritage is not normally available. Besides, 3D view is also not possible to be done on restricted capability mobile platform. In the simulation and rendering of 3D past life such as a virtual museum, bringing life is more challenging as it lacks narration for cultured learners. A virtual museum provides searchable and browsable content for virtual learning and remote visit of the ancient heritage site is possible. The problem with reconstruction of past life is that the documents are usually not properly preserved and the younger generation is not interested in learning cultural heritage if it is not captivating enough. In order to cultivate the interest of the user on a heritage site, there is a need to model past life in such a way that the social behaviours are reasonably displayed.

In spite of the increasing opportunities for easy and affordable travel, many visitors struggle to enjoy the present cultural heritage and the living memories of our collective past through one visit (MacDonald and Honsinger, 2006). Therefore, this research allows the users to remotely access and see the living assets would open doors to higher level of acceptance of digital cultural heritage.

1.1 Digital Cultural Heritage

Heritage is defined as our legacy inherited from the past, our traditions that we practice today, or our immaterial possessions that we are passing on to the next generations (Russell, 2010). On the other hand, digital cultural heritage which is a relatively new discipline, shares and expands the objectives of traditional cultural heritage, and aims to preserve the past and possibly increase public awareness and interpretation of cultural heritage. Digital cultural heritage is also called virtual heritage when it deals with three-dimensional synthetic recreation of real environments (MacDonald and Honsinger, 2006). In other words, virtual heritage is one of the computer technologies that creates explicit visual representation of a structure erected to commemorate monuments, artifacts and cultural buildings (Stone and Ojika, 2000). In the present society, people live in two distinct worlds which are the real world and the virtual world. The advancement of Virtual Reality (VR) becomes crucial in multidisciplinary areas such as simulation for education, entertainment, medical application and gaming (Noh et al., 2009). With digital cultural heritage, people can have an overall imagination of the heritage sites although they might have not visited some of the places before. Virtual heritage has also become a platform for improving the learning process of certain events and historical elements for use in educational field (Jianhai and McDonough, 2009).

1.2 Cultural Heritage Sites

The World Heritage List includes 981 cultural or natural heritage places considered as having outstanding universal value (UNESCO and Convention, 2013). This list includes 759 cultural, 193 natural and 29 mixed properties in 160 states parties and was ratified by 190 states in September 2012. In this research, an attempt is made to recreate complex lively scenes for one of these historical places. In 7 July 2008, George Town and Melaka which were jointly declared as the historic cities of the Straits of Malacca in Malaysia were included in United Nations Educational, Scientific and Cultural Organisation (UNESCO)'s prestigious World Heritage Listing. In the last 500 years or so, George Town has been well known for their multi-cultural trading activities. The city as well as other major port cities in East and Southeast Asia were very much influenced by traders from all over the world and the conquest of the Europeans' power. With a combination of Malay, Chinese, Indian and other cultures, in particular under the British colonial influences, different architectures, religions, dialects, costumes, cuisines, festivities and lifestyles have been established in the historic city. The heritage zone of George Town included in the UNESCO World Heritage Listing covers a 109.38 hectares site on the north-east coast of Penang Island consisting of the core zone and the buffer zone which surrounds the core zone which is as large as 150.04 hectares. This zone is chosen as a point of reference for this research in bringing the present life into digital cultural heritage.

The trading port at Weld Quay which is also in the heritage zone of George Town is chosen as a point of reference for reconstruction of past life in digital cultural heritage in this research because it served as a meeting point, in the 19th century, for several types of population of very different origins and cultures. Weld Quay was the earliest trading port during the colonial era in this part of Malaysia. It was very famous for its strategic location which is on the largest island encountered on the trading sea-route in the region. Over the years, the exchange of human values and the mixture of cultures among many races living in this part of the city have

been well preserved. These make the port a unique and outstanding cultural area. However, with Penang being one of the topmost tourist destinations, Weld Quay now plays a leading role in the nation's tourism industry: the old trading port has been transformed into a terminal for international cruise vessels and a marina. In order to construct the terminal and the marina, a number of captivating monuments and beautiful houses were demolished. Initiatives on virtual preservation and reconstruction of this site, in an effort to preserve, protect, and understand its specific cultural heritage and historical importance were relatively few.

1.3 Panoramic View

Panoramic view is a widely used technique to present digital cultural heritage since it gives a sense of immersion in the scene. There are several representations of panoramas such as spherical, cubical and cylindrical panoramas as illustrated in Figure 1.1. Spherical and cubical panoramas can be viewed from any directions from a current fixed position. Both of these panoramas offer the users a 720° view that is a full view in both horizontal and vertical directions. However, spherical and cubical panoramas are difficult to capture compared to cylindrical panoramas since spherical and cubical panoramas also contain the top view image and bottom view image. For cylindrical panorama, the observer's view in the vertical direction is limited but they offer a full 360° horizontal view. Yet, cylindrical panoramas fulfill the requirement in most virtual reality applications. Furthermore, the image format for cylindrical panorama can be saved as a normal photo format such as Joint Photographic Experts Group (JPEG) and Portable Network Graphics (PNG). Therefore, cylindrical panoramas can fit most applications and reduce problems of format incompatibility with software devices. Besides, cylindrical panorama can also be unrolled into a planar image as shown in Figure 1.2.

Digital cultural heritage applications combine real and virtual objects. So, cylindrical panorama is one of the most suitable techniques to be adopted in developing digital cultural

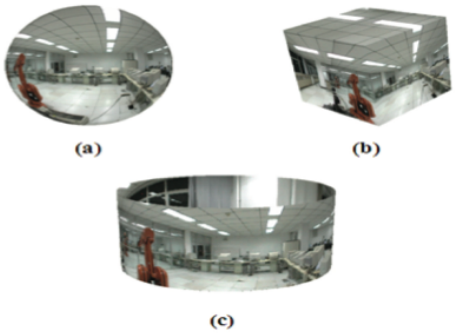

Figure 1.1: Representations for Panoramas (a) spherical (b) cubical (c) cylindrical (Ying et al., 2009).

Figure 1.2: An Example of a Cylindrical Panoramic Image (Ying et al., 2009).

heritage applications because it is possible for the users to navigate a 360° horizontal walk-through (Ying et al., 2009). Within 360° panoramic view, users can now experience the heritage sites rather than merely looking at the photographs or reading the historical articles. Debacle Software's Pano lets users create panoramic images from sequence of individual images using an iPhone camera (Ebling, 2010). Nonetheless, there is still a need for a scheme for efficient and rapid generation of panoramic view in digital cultural heritage in particular on mobile platform.

1.4 Acoustical Heritage

Several research works have been carried out on acoustical perspective mostly with the aim of adding sensorial audio experience to the users. One of them is the case study of Ocarina (Wang, 2009) which is an electronic music piece that acts as a musical instrument which has virtual keys that is similar to an ancient flutelike instrument. In another work, LaDiDa (Ebling, 2010) is an effective reverse karaoke application that enables users to generate appropriate background music to accompany voice recording by correcting the pitch and tune by keyframing. Robosonic (Luz et al., 2009) allows modulation of two sound characteristics that are the pitch

and loudness in real-time. Previous acoustical solutions have been investigated to enable high quality results, but this is not available in generating user's immersive experience in digital heritage application on mobile device. Therefore, there is a need for acoustical heritage model that can modulate various sound characteristics in 360° panoramic view on mobile platform.

1.5 Crowd Modelling and Simulation

Crowd of people can be an impressive spectacle and are often employed effectively by graphics productions to convey occasion and grandeur. Although posing a unique set of challenges, bringing crowds into the 360° high quality panoramic view can greatly enhance the perceived realism of a virtual heritage environment. However, current attempts such as IT Crowd [1] commonly fall short of increasing user-expectations since the sense of immersion is quickly dispelled when crowd simulation ceases to appear dynamic, realistic and distinct. Moreover, there is no reported work on dynamic crowd simulation in panoramic view. With the data and the photography collected in this research, it is also possible to include crowd simulation of the virtual heritage ultimately in panoramic view in order to bring lives into the historical sites which portray the cultural activities, trends and traditions. Therefore there is a need for modelling dynamic crowd in 360° panoramic view.

Crowd simulation has been widely used in many applications domains such as urban planning, emergency training and evacuation, simulation of epic battles and traffic engineering. Crowd simulation has also already been used to animate historical cities such as Rome (Thalmann and Musse, 2007a) and Nicosia (Dikaiakou et al., 2011). They are based on microscopic crowd simulation which avoids the labourious process of individually animating characters; they behave according to a simulation model. The simulation model is also based on the principle which states that the global-microscopic-behaviour of a crowd emerges from the local

[1] http://www.panoptics.co.uk/gallery/it-crowd/main-set

interactions between individuals: how each of them influences others and how these interactions are combined. It is thus a relevant approach to re-create populations in historical places, especially for frequently visited sites. Performing this specific simulation brings a number of difficulties. For example in simulating an old trading port such as Weld Quay, in George Town, Penang, Malaysia, several ethnic groups with distinct behaviours such as Indian, Malay, Chinese, and British colonists co-exist in this environment. There exist several crowd simulation methods that involve two distinct groups through the different levels of autonomy such as ViCrowd model (Musse and Thalmann, 2001) and pursuit and evasion model (Rodriguez et al., 2011). However, in bringing the past life into digital cultural heritage, there is a need to have heterogeneous crowd simulation involving several distinct ethnic groups.

In the task of digitally giving life to ancient or past populations, it is believed that the main objective should be to re-create the general atmosphere of the place. The distribution of individual activities, the interactions between agents and their surroundings, and the global motion that emerges from everyone's actions creates this atmosphere. Although little information may be available on how the population of these ancient or historical sites looked like and on the general impression that emerged from it, there are hardly any precise descriptions of the individual activities and of social interactions between people of the past. Since social behaviours vary from each individual to each population, a mechanism to adjust and adapt the parameters of each agents and each ethnic group in real-time is needed. One of the works in crowd simulation that involves high-level control in a synthetic-vision based steering approach is introduced by Ondřej et al. (2010). In order to drive the changes of goal and behaviour, for each virtual agent from the multi-ethnic or multi-group interactions taking place around it, there is a need for a high-level controller which runs an action selection mechanism.

Modelling of the interactions between these diverse populations needs to have each of the population group to be associated with a set of possible states which corresponds to specific

behaviours. The changes of states are triggered by global or local interactions between populations. The global and local interactions are then used to decide the next event in daily life of the virtual agent. To enable tracking of what has been done by an individual agent in a simulation cycle, hierarchical state machine is used in the microscopic crowd simulation. This approach allows the activities that have been carried out by a specific agent belonging to a population to be re-tracked. This re-tracking is good for understanding the lifestyle of each ethnic group or group of people which can be different from other ethnicity. This work is also partially inspired by the research in crowd simulation for interactive virtual environments and VR training systems (Ulicny and Thalmann, 2001). There is a need to re-create past life from this perspective: let the global atmosphere emerge from a detailed modelling of individual activities and interactions between people using hierarchical state machine.

As the heterogeneous population of say an old trading port of Weld Quay in George Town is highly diverse in ethnicity, culture, language, and religion, the interaction model of these populations demonstrates the social activities in a specific environment. For instance, the trading activities include interactions such as escorting the clients, daily greetings with different social classes in the population or even supervising the work of their workers. One of the good solutions to establish these interactions is to support more complex behaviours like various kinds of group formations. There exist some works on modelling such group formation, namely the automated generation of freestyle group formation through user input (Gu and Deng, 2013) and the spectral-based group formation control (Takahashi et al., 2009). However, these works are based on keyframing and the simulation needs a flexible and automatic reformation and dispersion of group members in real-time based on their interactions. Therefore, there is a need to is to adopt a bottom-up approach based on a microscopic crowd simulation technique to model the group formation realistically and find a reasonable way of handling different kind of group formations.

1.6 Motivation

Digital cultural heritage is a way to inculcate the public on cherishing and restoring historic buildings, and understanding the activities of the heritage in which the old and new co-exist. Therefore, there is a need to provide useful visual information and sensibility about the digital cultural heritage together with both present and past lives in a more pedagogic way in order to enhance user's immersive experience. Panoramic view can contribute to both conservation of historical sites while displaying enough information for the user to perform their visit remotely through mobile devices. Besides, having the panoramic view to show the digital cultural heritage environment, sound and people can be crucial in bringing life into digital cultural heritage.

While the past is being conserved manually through diverse media such as postcards, guide books and documentaries, crowd simulation and rendering can provide representations of the site, structure, viewpoints and details of the activities in the past. There is also a need to model past life to show the younger generation about the narratives that have transpired in a cultural heritage site such as an ancient trading port as most of the historical documents are not well preserved. By culminating this research through the environment, sound and peoples, the public is able to obtain a holistic view of the evolving nature of the past and the present lives of digital cultural heritage.

1.7 Problem Statement

One of the best way to reconstruct digitally the cultural heritage environment is through panoramic view. The panoramic view is important for virtual tourism as the user can keep on updating the archives of the present life of cultural heritage and it allows the user to gain a clear vision around historical monuments. However, it is computationally expensive on mobile platform to generate 360° cylindrical panoramic views (Au and Liang, 2012). There exist a few image

stitching tools for stitching images into a panoramic view such as Adobe Photoshop CS5 [2], PTGui Pro [3] and Panoweaver 7.0 [4] but the referred image stitching tools are not available for mobile platform. Therefore, the challenge is to propose a scheme for efficient and rapid generation of panoramic view on mobile platform.

The most popular way to preserve the audio surroundings of a heritage site is through computer simulation of acoustical heritage (Yuksel et al., 2005);(Karabiber, 2000). However, the existing works are for non-mobile platform and not done within panoramic view. For this research, the challenge here is to incorporate acoustical model of 360° panoramic view on the limited capabilities of the mobile device.

There exist some works on showing crowd within the 360° panoramic view such as IT Crowd [5]. However, the crowd displayed in the panoramic view is mainly the image captured with the environment and is therefore static. As crowd should be dynamic in actual environment, just like in real life, the challenge here is to model dynamic crowd within 360° panoramic view.

Reconstructing past life is to portray the history or things that are no longer there and thus a 3D view is important for such reconstruction. In most of the research involving reconstruction of heritage sites, the digital cities are modelled without any inhabitants such as in Milanese Palace [6], Italy by C. García-Lasuén (2009) and George Town [7], Penang by C. Eugene (2011) and virtual Greece [8], House of the Vine [9], Rome and ancient Egypt [10]. This make the users getting the impression of visiting deserted environment and cannot learn anything about the way

[2] http://www.photoshop.com/products/photoshop
[3] http://www.ptgui.com
[4] http://www.easypano.com/panorama-software-pw7.html
[5] http://www.panoptics.co.uk/gallery/it-crowd/main-set
[6] https://www.youtube.com/watch?v=184VvVrizZY
[7] https://www.youtube.com/watch?v=nTnnWEDKhUU
[8] https://www.youtube.com/watch?v=rW3RdNC0qfc
[9] https://www.youtube.com/watch?v=W4eF1tw8_nU
[10] https://www.youtube.com/watch?v=6M1hZ-AOc0I

the place was used in the past for daily activities. There are also research done on reconstructing digital cities with crowd modelling but the crowd are treated homogeneously such as in Angkor Wat [11], Cambodia (Chandler, 2012), Roman Odeon in Aphrodisias, Turkey (Ciechomski et al., 2005), virtual Pompeii (Maïm et al., 2007), Babylone 3D [12] and virtual Imam in Hagia Sophia Ottoman Mosque (Papagiannakis et al., 2003). Therefore, the next challenge is to enhance digital reconstruction of historical sites with animated populations, illustrating ancient or past life in these historical places with heterogenous crowd.

In the simulation of past life such as a trading port, various kinds of social interactions between the heterogeneous populations are triggered by the changes of state. Each population is associated with a set of possible states which corresponds to specific steering behaviours. One of the good approach is through microscopic crowd simulation. However, simulating the diverse populations and changing their behaviours in real-time are still open issues. Therefore, the challenge here is to provide a high-level controller where the parameters of the agent can be adjusted and re-adapt into the simulation in real-time. One of the main advantages of having a high-level control is that the heterogeneity of crowd can be improved with the tuning of agents' parameters.

Even though the heterogeneous crowd simulation is based on microscopic approaches, the simulation is also driven by some global descriptions. For instance, in Thalmann and Musse (2007a), users can directly describe which social status is expected for people in specific places. This is expressed through a semantic description of the city. The characters selected their goals based on this semantic. Their behaviours are locally influenced by this semantic too. Meanwhile in their work, the interactions between characters are the same, whatever the place, and whatever their social status and these can only be applied to non-heterogeneous crowd. So,

[11] http://ngm.nationalgeographic.com/2009/07/angkor/angkor-animation
[12] https://www.youtube.com/watch?v=_EPc6Gn9-zs

in this research the challenge is to devise a mechanism to re-track activities and interactions in the simulation cycle to understand the lifestyles of different populations within heterogeneous crowd.

In bringing past life into digital cultural heritage, the behaviour of each population in a heterogeneous crowd is highly dependent on the predefined social rules. The social rules in the past involves the superiority and military constraints where there exist some complex behaviours in a group. One of the challenges here is to model the group formation specifically in leader-following behaviours while respecting the personal space between the leaders and the followers. Besides, reasonable number of followers also poses a problem in simulating microscopic crowd simulation as realistically as possible.

1.8 Research Questions

1. Bringing present life into digital cultural heritage:
    - How to lower computational cost and effort in generating 360° cylindrical panoramic view for low-end mobile device?
    - How to raise the audio realism of a digital cultural heritage environment on mobile platform and 360° panoramic view?
    - How to tackle behaviours of autonomous units of crowd simulated on a limited capacity of processing power on mobile device and 360° panoramic view?
2. Bringing past life into digital cultural heritage:
    - How to model a simulation with high density and heterogeneous crowds in real-time that are all interacting between the groups naturally and simultaneously in a largely populated dynamic environment based on social rules and based on past environment?

- How to adjust the agents' parameters and adapt the change of parameters into local and global interactions that drives the change of goals in real-time?
- How to re-track the history of the activities and interactions of each individual agents and each ethnic group or group of people?
- How to re-organise group formation as realistic as possible with reasonable number of followers based on the predefined social rules of past life such as in a trading port?

1.9 Objectives

The overall goal of this research is to digitally construct, and reconstruct cultural heritage sites and bring the past and present lives into digital cultural heritage by establishing a framework that allows the user to view digital cultural heritage. Therefore the objectives are as follows:

1. To develop a scheme for efficient and rapid generation of panoramic view of cultural heritage environment
2. To model an acoustical model of audio surroundings and crowd modelling in 360° panoramic view in order to enhance the immersion and emotional engagement of the present life of cultural heritage sites
3. To extend crowd simulation model to heterogeneous crowd interaction and provide high-level control from interactions between different groups
4. To model a mechanism to re-track activities of each agent and model various types of group formations among the agents in heterogeneous crowd simulation in order to bring past life into digital cultural heritage environment

1.10 Contributions

This thesis comes up with the following contributions:

1. A scheme for efficient and rapid generation of panoramic views on multiple mobile platforms without having to use an intermediate software to convert the image file format.

2. An acoustical model for sound manipulation on a mobile device through the rendering of imaginary sound that gives a psychoacoustic effect of the heritage sites within 360° panoramic view.

3. A dynamic crowd model within 360° panoramic view on mobile devices.

4. A crowd simulation method for heterogeneous crowd of a past life in cultural heritage with four distinct populations.

5. A high level controller for changing parameters of each agent and group, a hierarchical state machine for retracking individual agents and interactions and a group formation model for reorganising the formation of group based on social behaviours of the heterogeneous crowd simulation method.

1.11 Scope and Limitations of the Research

As mobile devices are becoming more dominant, mobile applications can be a key point in disseminating prior information of the heritage sites to global virtual tourist. So in this research, the present life will be restrained within the wide usage of mobile applications. Besides, as a proof of concept, the proposed methods will be applied in all cases to the heritage zone of George Town, Penang. In term of simulating the crowd of past life, although visual documents depicting past life of this trading port in general were not disregarded, the crowd is simulated mainly based on the rudimentary knowledge about the groups of people of different ethnici-

ties, cultures, languages, and religions interacting there in the past for trading purposes: The different groups of people include British colonists, Malay, Indian, and Chinese. Besides, reconstruction of past life needs 3D simulation and rendering. However, in this research, the 3D simulation on mobile platform is beyond the scope. Furthermore, it is almost impossible to construct panoramic view of past life in cultural heritage. The reconstruction of past life on mobile platform has to be ported through Unity3D iOS Pro, Android Pro, BlackBerry 10 Pro or Windows Phone 8 Pro.

1.12 Benefits of the Research

A combination of digital archiving of images and audio through panoramic view to bring the present life and computer graphics technology through crowd simulation to bring the past life will help in preserving cultural heritage sites and objects by taking the heritage sites and its relics into the virtual world. With such research, the original masterpieces and sites will be preserved and protected from subsequent destructive human influence, and at the same time it will cultivate the concept of edutainment through virtual tour and virtual museum to reach out to the "global virtual tourists". This application is also a good choice to advertise our famous tourism information because of the increasing difficulties in maintaining and circulating our long-forgotten cultural heritage sites to the world. However, this application is not limited to tourism. We could take this advantage to attract visitors by providing them useful information about traditional cuisines, costumes, trades and crafts with acceptable 360° panoramic view on the mobile platform. On the other hand, this research is also beneficial for physical reconstruction of cultural heritage sites for digital compilations.

1.13 Research Approach

The first stage of this research is to investigate the previous work related to the objectives of this research. These include literatures on panoramic view, acoustical heritage and crowd modelling. Some data on a selected cultural heritage environment of the past and present are then collected. Besides, the surrounding sounds are also recorded and the various types of social behaviours are explored. Then, the research work starts off with rendering of digital cultural heritage environment by coming up with a scheme for efficient and rapid generation of 360° of panoramic view.

The next stage is the pre-processing of the audio data collections using third party audio cropping software. The procedure is then carried on to modulating the sound properties using the proposed method. The aim of this step is to model a psychoacoustic effect through user interactions in a digital cultural heritage application. A practical implementation of acoustical heritage is introduced on mobile platform that allows the user to experience panoramic view of various heritage sites, accompanied by its background sounds of different frequencies and loudness.

Panoramic views without the inclusion of dynamic crowd is not satisfactory and dull. A solution is needed to overcome the problem of modelling crowd on limited capabilities of hardware support of mobile platform in order to allow the panoramic view to stand out in a more magnificent and dazzling manners. So, this stage is to model crowd and animate them based on accumulation buffer within 360° panoramic view.

Next, the research focuses on building a simulation platform with adapting parameters for global and local interactions among various populations by incorporating Reynolds' (Reynolds, 1987);(Reynolds, 1999) and Helbing's Models (Helbing and Molnár, 1995). This research concentrates on believable production of scenes and not about scientifically correct crowd simu-

lation. Besides, in the interaction model, the behaviours are scripted with social-cultural rules while the communications are animated. Global events trigger the changes of local and global behaviours of the virtual characters. The microscopic crowd simulation includes the simulation of heterogeneous crowd, the high-level controller, the hierarchical state-machine and group formation model in order to demonstrate the complex interactions among different ethnic groups or groups of people.

Finally, in each of the stages, this research includes the evaluation and validation of the schemes, models and methods proposed in this research.

1.14 Organisation of the Thesis

The rest of this thesis is organised as follows:

- Chapter 2 reviews the background of panoramic view, acoustical heritage and crowd modelling and simulation. Panoramic view is discussed based on two categories: (1) the methods used to generate the view and (2) the problems in panoramic view. Acoustical heritage is reviewed based on simulation of sound in virtual heritage and other application. Crowd modelling and simulation are discussed by comparing simulation of digital cultural heritage environment with simulation with the existence of crowd. The schemes are discussed and other shortcomings and drawbacks are also reviewed and presented in this chapter.

- Chapter 3 gives an overview of the methodology by describing the step-by-step constructions of the present and past lives, which include the scheme for efficient and rapid generation of 360° panoramic view, acoustical modulations in 360° panoramic view and crowd modelling in 360° panoramic view for construction of present life, and crowd simulation and rendering for the reconstruction of the past in digital cultural heritage

environment.

- Chapter 4 presents the details on bringing the present life of digital cultural heritage. This chapter also presents and analyses the proposed methods, schemes and models.
- Chapter 5 presents the detail on bringing the past life of digital cultural heritage. The chapter focuses on the execution based on the proposed methods, schemes and models.
- Chapter 6 presents the experimental analysis, evaluation and validation in detail based on the proposed schemes, models and methods in this research.
- Chapter 7 concludes the thesis and presents future work for this research. This chapter revisits the objectives and the contributions of this thesis and discusses some open area for further research.

CHAPTER 2

LITERATURE REVIEW

This chapter focuses on background of panoramic view, the application of acoustical heritage and the theoretical ideas about crowd modelling and simulation. This chapter also emphasizes on the fundamentals and applications of crowd simulation and rendering. The section on crowd modelling and simulation is further subdivided into (1) Crowd modelling and simulation in general (2) Crowd in virtual heritage (3) Crowd behaviour (4) Crowd movement and animation (5) Crowd rendering and (6) Crowd evaluation.

2.1 Panoramic View

Panorama was first introduced in the 1880s by Robert, B. and his son, Barker, H. A. (Fan et al., 2008). Apple Incorporation has developed a well known QuickTime Virtual Reality (QTVR) on the early Apple computers in 1995 which allows users to travel virtually and interactively through panoramic views (Chen, 1995). Basically, panoramic view is a wide-angle view of representation of a physical space in photograph either in cylindrical, spherical, or cubical. Spherical panoramic view used 360×360 degrees roaming in both horizontally and vertically, while cubical panoramic view consists of six source images. In general, spherical panoramic view employs non-symmetrical sampling and leads to serious distortion when approaching to its two poles while for cubical panoramic view it is rather difficult to acquire a cubical panoramic view and stitch the six images into a cubical panorama. In addition, cubical panorama suffers from non-symmetrical sampling and distorting problems at the borderlines and corners of cube. Cylindrical panoramic view is a good choice because of its easiness of capturing panoramic images and good visual effects during roaming.

In the recent years, Fan et al. (2008) developed a technique which combine the panorama roaming and stereoscopic display. Panorama roaming is a technique which captures a single panoramic image with one camera at a single viewpoint, while stereoscopic panorama roaming requires a pair of stereoscopic images captures at two different viewpoints, which each should be a pupil distance away from other. In addition, Peleg and Ben-Ezra (1999) proposed a technique that produced stereoscopic pair from one source panorama captured by a single camera instead of regular usage of at least two cameras. Although this technique is good, there are two obvious limitations. One of them is the fixed focal length that makes the user having less adjustment flexibility and the result is worse when the users are staring at a viewpoint with zero parallax. Parallax is the difference in the apparent position of an object that is viewed by two different lines of sight. The viewpoint is at zero parallax when the two views of an object are exactly superimposed on top of one another. The second limitation is the need to process one panorama in order to double up the panoramas. This processing technique is not suitable for real time rendering. The rendering time determines the speed of image combinations and how effective the users can roam around the virtual environment. Furthermore, Bourke (2006) proposed a toe-in technique for capturing a pair of stereoscopic panoramas with zero parallax by using two rotating cameras. This method controls the parallax between two stereoscopic panoramas efficiently and permits zero parallax at a limited distance. However, this method also has a weakness. There is an unexpected heavy image load in practical development when camera needs to be rotated 5° per stereoscopic panorama in order to capture one panorama image.

Beside the technique of stereoscopic in panoramic view, Ying et al. (2009) proposed a method to achieve the continuous walkthrough between the two adjacent panoramas. Basically, Ying et al. (2009) took the images in sampling points of the transition path, then the coefficients of the image transformations among these images are estimated directly from these

images. Finally, the images in the non-sampling points are synthesized from those images in the sampling points by using image transformation techniques.

Furthermore, Kwiatek and Woolner (2009) created high resolution panoramas by integrating these panoramas into virtual reality. In order to create high resolution panoramas, they also used Digital Single Lens Reflex (DSLR) camera and a panoramic head, and basic 3D models of the interior view of the building were generated in Autodesk Image Modeler software. They exported the 3D files to 3D StudioMax in order to generate a photorealistic visualization of the interior of the building. The sequence of spherical images is imported to QuickTime Pro in order to generate movie (Movie (MOV)) files using H.264 codec which is compatible with Lucid Viewer or suitable for displaying on a 360° screen. Moreover, the 360° images are taken in both still and video motion as a preparation for an interactive storytelling following a story design. To display actors in the spherical panoramas, chroma keying technique is used. In another method, Hirayu et al. (2000) constructed a virtual reality of a heritage site by starting with making models of the building, and then capturing aerial photographs for colour images using a helicopter. They also compressed the file of the images collected before constructing the building in 3D.

2.1.1 Discussion on Panoramic View

There are various techniques in generating panoramic views such as cylindrical, spherical, and cubical. In general, one main limitation in panoramic view is the problem of distortion and the complexity of the steps to construct the panoramic view. This would certainly caused delay and inefficiency in generating the panoramic view. Therefore it would be better for this research to explore the possibility of coming up with a rapid and efficient scheme by redefining the steps to construct the panoramic view and solve partially the problems of distortion.

On the other hand, various types of image-stitching tool such as Adobe Photoshop CS5, PTGuiPro and Panoweaver 7.0 can be found and utilised in the domain of digital heritage. Adobe Photoshop is a raster graphics editor developed and published by Adobe Systems for Windows and OSX. It can edit and compose the raster images in multiple layers and it can also support masks, alpha compositing and several colour models such as RGB, CMYK, Lab colour space, spot colour and duotone. In addition to raster graphics, it has limited abilities to edit or render text, vector graphics, 3D graphics and video. PTGuiPro is a panoramic stitching software for Windows and Mac OSX developed by Graphical User Interface for Panorama Tools which includes 1) PTGui can stitch multiple rows of images and 2) PTGUI can create 360° cylindrical panoramas, 'flat' partial panoramas and spherical 360 x 180° panoramas. Panoweaver 7.0 is one of the most popular photo stitching software and Flash panorama publisher. It is able to stitch still images into full 360° or partial cylindrical panorama. In addition, it also allows the output to be published into Flash or HTML 5 or QTVR.

In constructing a panoramic view, the individual images that make up the view have to be combined by using Adobe Photoshop. In order to view the panoramic view, the 'Cubic-Converter' software is used to convert the view into the cubic format of Apple Inc.'s QTVR movie. QTVR is a real-time walk-through system in which the image file format is only meant for the Macintosh platform. However, as the proposed work is implemented on iPhone 1 iOS version 3.1.3, there is a need to find an alternative method of producing panoramic views since QTVR is not supported on this platform. Therefore, the proposed rapid and efficient scheme is used and the detail will be given in Chapter 4.

Nowadays, Apple iPhone which is a mobile phone provides a handy and an attractive Graphical User Interface (GUI). iPhone is also equipped with an audio line-out that allows sound to flow through an external device. Besides, iPhone has a built-in microphone that has a relatively flat pitch response (Krome and Erdol, 2009). Furthermore, mobile technology is also

Figure 2.1: Normal Photo of Kapitan Keling Mosque.

Figure 2.2: Cylindrical Panorama of Kapitan Keling Mosque.

becoming more popular in the digital cultural heritage sector since the 360° panoramic view has been effectively used as a travelling aid for tourists. With the iPhone development kit (iOS Developer Program), creation of 360° panoramic view and accompaniment of the background sounds and the illustration of the peoples can be optimized and thus, this application also has some potential commercial merits.

2.2 Acoustical Heritage

Acoustical heritage is a science of sound which is designed to give virtual perception in digital heritage environment. In this research, the type of sound concentrates on the existing external audio of the surroundings of the heritage sites. The following subsections aimed to review some works done for acoustical heritage and other applications with acoustical considerations in order to overcome the challenge of incorporating acoustical heritage in 360° panoramic view.

2.2.1 Acoustical Heritage in General

Papagiannakis et al. (2003) proposed a virtual reality technique to illustrate a complexity curbing and complexity hiding based framework for real-time interactive and immersive character based on religious ceremony in the Hagia Sophia Ottoman Mosque, Turkey as shown in Fig-