EVALUATING MULTI-SENSORS DATA FOR THE DEVELOPMENT OF THREE-DIMENSIONAL PHOTO REALISTIC MODEL OF ARCHAEOLOGICAL SITE DOCUMENTATION

NURUL SHAHIDA BINTI SULAIMAN

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Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia

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Dedication

From the bottom of my heart,
I would like to dedicate this thesis especially to
my beloved mother, Norizan Binti Osman, my father, Sulaiman Bin Simat
and both of my siblings. They became the strength and the remedy for me
every time obstacles struck me off.
In addition, this thesis is also dedicated to my soul mate,
Mohd Hafiz Shafiq bin Hamdan who has supported me in many aspects.
Thank you for all your encouragement and undefeated courage
that brought me till this stage of victory.

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ABSTRACT

Stimulated by the highly demand on three-dimensional (3D) photo-realistic model of archaeological remains, a method which can rapidly record the remains meticulously has become a crucial requirement. Conventional method seems to be impractical to fulfil the demand because the output is in two-dimensional, destructive method, require bigger storage and a lot of manpower. Hence, this study was carried out in order to develop method for integrating multi-sensors data with the aim of producing 3D photo-realistic model of archaeological remains. Besides that, it is also intended to determine the reliability of Leica ScanStation C10 Terrestrial Laser Scanner in generating accurate geometric model of the monument. Based on the results obtained, the integration of ScanStation C10 and images data is capable in providing a 3D photo-realistic model of Bukit Batu Pahat shrine where feature mapping accuracy shown that the model is 90.56 percent similar with the real object. Additionally, the geometrical accuracy of the model generated by ScanStation C10 data is very convincing which is ±4 millimetres. Besides that, NextEngine scanner had produced an outstanding photo-realistic model of the artefact where feature mapping analysis shown that the artefact models are 88.89 percent similar with the real artefact while ±0.02 millimetres for geometric mapping accuracy. Visualization of the models in 3D environment is effective and fascinating. Instead of conducting virtual measurement and texture analysis, archaeologists can use the visualization as a bridge to share archaeological remains with the public. In a nutshell, the goals of this research have successfully achieved where a 3D photo- realistic model of Bukit Batu Pahat archaeological remains were generated from multi-sensors data and possess good geometric accuracy.

ABSTRAK

Terdorong oleh permintaan yang tinggi terhadap model foto-realistik tiga-dimensi (3D) bagi tinggalan arkeologi, satu kaedah yang boleh merekod tinggalan tersebut dengan teliti telah menjadi suatu kehendak yang penting. Kaedah konvensional tampak kurang praktikal untuk memenuhi kehendak tersebut kerana hasilnya di dalam dua dimensi, bersifat merosak, memerlukan ruang simpanan yang besar dan tenaga kerja yang ramai. Oleh itu, kajian ini dilakukan bagi membangunkan kaedah untuk menggabungkan data beberapa penderia dengan tujuan menghasilkan model foto-realistik 3D tinggalan arkeologi. Selain itu, ia juga bertujuan untuk menentukan kebolehbergantungan Leica ScanStation C10 Pengimbas Laser Mukabumi di dalam menghasilkan model geometri monumen yang tepat. Berdasarkan keputusan yang diperolehi, integrasi data ScanStation C10 dan imej berupaya untuk menghasilkan model 3D foto-realistik bagi candi Bukit Batu Pahat di mana ketepatan pemetaan sifat menunjukkan model itu adalah 90.56 peratus sama dengan objek sebenar. Selain itu, ketepatan geometri bagi model yang dihasilkan oleh ScanStation C10 adalah sangat meyakinkan iaitu ±4 milimeter. Di samping itu, penderia NextEngine telah menghasilkan model foto-realistik di mana ketepatan pemetaan sifat menunjukkan model artifak itu adalah 88.89 peratus sama dengan artifak sebenar manakala ±0.02 milimeter bagi ketepatan geometri. Visualisasi model-model dalam persekitaran 3D adalah berkesan dan mempesonakan. Di samping melakukan pengukuran maya dan analisis tekstur, ahli arkeologi boleh menggunakan visualisasi tersebut sebagai penghubung untuk berkongsi tinggalan arkeologi bersama orang awam. Kesimpulannya, matlamat-matlamat penyelidikan ini berjaya dicapai di mana model 3D foto-realistik bagi tinggalan arkeologi Bukit Batu Pahat dihasilkan daripada pelbagai data penderia dan mempunyai ketepatan geometri yang baik.

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LIST OF ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
4D	four-dimensional
BC	Before century
DEM	Digital Elevation Model
GPR	Ground Penetrating Radar
GPS	Global Positioning Systems
HD	High Definition
HDS	High Definition Surveying
IMU	Initial Measurement Unit
LiDAR	Light Detection and Ranging
m	metre
mm	millimetres
RMS	Root Mean Square
UiTM	Universiti Teknologi Mara

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The purpose of this introductory chapter is to provide and highlight the main ideas of this research. Initially, some definitions and concepts related to this study are briefly explained. Several current issues are exposed to know the importance of carrying out this research. The aim and objectives of this research are also pointed out in this chapter. Besides that, scope of the research is outlined in the next section to emphasize the research's limitation. Finally, the contributions of this research and thesis organization are clarified at the end of this chapter.

1.2 Research Background

Within this section, basic introduction related to this research such as the concept of this research, information about the study area, instrument used for data acquisition and software utilized during data processing stage are discussed.

1.2.1 Research Concept

Archaeology is a scientific study, which carried out in order to re-create the events of the past and reconstruct the lifestyle of prehistoric people and their culture through the study of artefacts, monuments and other remains left behind (Saskatchewan Archaeological Society, 2010). According to Kipfer (2000), the features or remains belongs to ancient people are surveyed, excavated and record systematically in order to unveil the history of the past, to study the cultural process and reconstruct the lifestyle of the ancient people. There are several ways of finding the remains i.e. accidentally found during farming or construction, excavation at the predicted site and by using geophysical technique to detect things lie beneath the ground.

In order to interpret the life of people from the past, all the remains found either monuments or artefacts must be precisely documented in the form of analytical and critical reports, illustrated with drawings and photographs (Haddad and Akasheh, 2005). After excavation process is finished, archaeologist will draw a plan that represents the result of the excavation with a complete detail of measurements, soil and artefacts or monument found (**Figure 1.1**). Rationally, bigger archaeology site requires longer time to be drawn manually. A proper documentation with sufficient information will be the basis for various treatment activities, including research, interpretation, preservation, reconstruction, stabilization and data recovery (Stanco *et al.*, 2011).

According to Diaz-Andreu *et al.* (2005), traditional techniques is not sufficient enough to give the degree of detail and accuracy needed by researchers and conservators especially when recording and documenting a monument with inscriptions carved on the wall. Additionally, the quality of conventional recording often depends on the qualification, interest or condition of the documenting archaeologist. There is no precise scale used during the drawing process and thus measurement cannot be directly conducted thorough the picture.

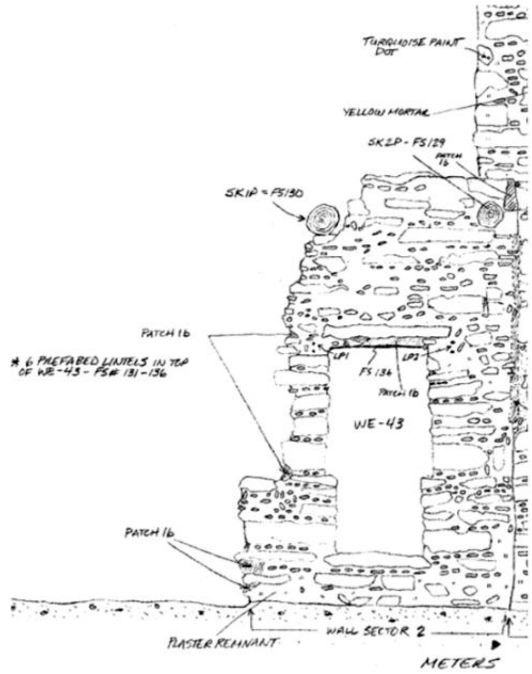

Figure 1.1: Field drawing and notes made by archaeologist (Patel, 2009)

Documentation, conservation and restoration of archaeological sites requires accurate spatial information such as geometric of the structure, shapes of remaining walls, physical extent of erode surfaces, thickness of walls, dimensions of features and so forth (Miri and Varshosaz, 2005). Additionally, instead of requesting spatial information of the structure or the artefact, there is a strong demand for photo-realistic three-dimensional (3D) models of archaeological monument and artefacts (Aguilera and Lahoz, 2006). Ergincan *et al.* (2010) stated that advanced Geomatic technologies offer rapid, accurate and detailed documentation solutions on the physical characteristics of artefacts and archaeology sites (**Section 3.2**).

Prompted by the high demand on fast, accurate and detailed digital documentation of archaeological sites, the role of Geomatic field has becoming seriously important in archaeology discipline at the present time (Campana *et al.*, 2008). Therefore, methods for acquiring spatial data as well as texture of the archaeological findings are indeed necessary. As mentioned by Campana *et al.* (2009), in order to document archaeological findings, it is crucial to utilize Geomatic techniques because the techniques are capable in representing correctly all peculiarities of the investigated object.

Due to the complexity of some structures and the lack of a single tool in giving satisfactory results in all measuring conditions, Geomatic tools are integrated to get precise photo realistic model of archaeology site (Gonzo *et al.*, 2007). Hence, this research is carried out to develop method for generating photo realistic 3D model with required geometric accuracy of Bukit Batu Pahat shrine and its artefacts by the means of multi-sensors data integration. Global Positioning System (GPS), total station and Leica ScanStation C10 were used to record spatial data of the shrine. Due to the low quality of the coloured point cloud provided by the scanner, a digital camera, Nikon D300s is used to capture photos of the shrine for texturing purpose. The integration results are presented in term of accuracy and quality of the model.

1.2.2 Study Site and Data Specification

Previously in 1840s, Colonel James Low, of the East India Company, detected an undoubted relic of Hindu colony in Kedah thus starting an investigation (Tourism Malaysia, 2008). Other people continued his effort in 1920s, 1930s and 1936. Eventually, the ruins of the temple, which believed to have been built during the 11th century, was reconstructed in 1960 at its original location with the help from Universiti Malaya and the Angkor Wat Conservation Centre in Cambodia. Bukit Batu Pahat shrine is considered as Malaysia's version of Angkor Wat in Cambodia.

Bukit Batu Pahat shrine is known as Site 8 and it was found by Quaritch-Wales on 1936 to 1937 (Mohd Supian, 2011). The shrine is made by granite block, obtained from the nearby river, Merbok River. It has vimana and mandapa structure articulate with each other. Additionally, the structure has 40 pillar bases located at vimana and 30 pillar bases mandapa (Tourism Malaysia, 2008). A research by Alastair Lamb on 1959 to 1960 shows that this monument has religious influence in its design where the shrine once had rooftop made of palm leaves (Mohd Supian, 2011).

Bujang Valley is situated in Kedah, a state located at the north part of Peninsular Malaysia (**Figure 1.2**). Numerous shrines were found scattered in Bujang Valley. The unique architecture and design of every shrine has made the structure an important asset for Malaysia. The most prevalent shrine in Bujang Valley is Bukit Batu Pahat shrine (**Figure 1.3**). Bukit Batu Pahat is the largest shrine in the area and it is made of stones obtained from the river nearby. Of all the shrines, this monument is preserved on the exact place where it was found. Since this shrine is worth to preserved for generations to come, this structure is chosen to be scanned in this research and finally photo-realistic 3D model of the shrine is generated.

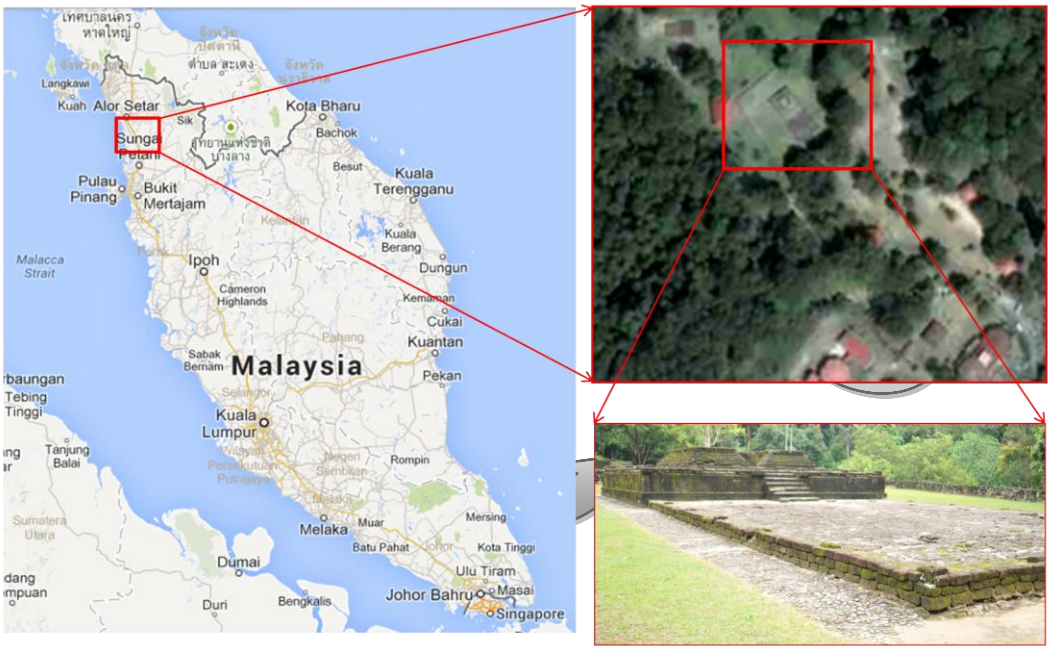

Figure 1.2: Location of the study area; Bukit Batu Pahat shrine in Bujang Valley

Figure 1.3: Place of worship for Hindu religion, Bukit Batu Pahat shrine is the largest shrine among other shrines in Bujang Valley

The archaeological area is approximately 48 x 40 metres and contains hundreds of religious artefacts. Various types of artefacts can be found during excavating the archaeological site. In Malaysia, the artefacts can be in the form of utensil, ancient water container, ornament, beads, keris and even skulls. Since the research area is located in Bujang Valley; which previously a well-known entrepot and ancient civilization, numerous kinds of artefacts from China, Britain and Netherland can be found there. However, in this research, artefacts related to Bukit Batu Pahat shrine are chosen as the study objects. The artefacts were stored in Bujang Valley Archaeological Museum. Artefacts chosen include a bronze container, silver piece of Hindu demigod, gold coin, Dutch bowl and kitchen stoneware (**Figure 1.4**).

Figure 1.4: Selected artefacts from Bukit Batu Pahat Shrine

1.2.3 Instruments and Software

Fundamentally, two archaeological work phases are included in this research; site survey and archaeological site mapping. Site survey is a process of locating the site relative to the real world. Global Positioning System (GPS) was used to acquire coordinate of the archaeological site. Besides that, a total station was used to conduct control survey for covering the archaeological site area. The coordinates data gained from this phase is integrated with point cloud data generated by the terrestrial laser scanner. Hence, every point cloud scanned will have their own coordinates respective to the real world.

There are two types of archaeological findings documented in archaeological site documentation phase; the monument and the artefacts found during excavating the site. Different sizes between the two objects require different types of laser scanner. In order to generate highly accurate geometric and photo-realistic model, several Geomatic sensors are used to record spatial data and texture data of the shrine. A terrestrial laser scanner, Leica ScanStation C10 is used to acquire spatial information of the shrine. Using a built-in camera in the scanner, a low resolution images of the monument are captured. In order to achieve photo-realistic model of the monument, high resolution images are taken using Nikon D300s digital camera and integrated with laser data.

On the other hand, a close-range laser scanner, Next Engine laser scanner was used to scan the artefacts belongs to Bukit Batu Pahat shrine. The scanner is operated based on triangulation principal. Thus, it allowed smaller objects to be scanned precisely together with the peculiarities, cracks and the texture. The scanner consists of a built-in camera, a rotary table and clipper, which can be used during scanning unstable artefacts. **Table 1.1** shows the instruments used in this research and suitable software to process the data generated from each sensors.

Table 1.1: Geomatic sensors and data processing software used in this study

Archaeology Work Phases	**Geomatic Tools**	**Data Processing Software**
Site Survey	 Global Positioning System (GPS)  Total Station Leica TCR307	• Data from total station is calculated manually
Archaeological Site Documentation	 Terrestrial Laser Scanner Leica ScanStation C10  Digital Camera (Nikon DSLR D300s)	• Cyclone software to process data from Leica ScanStation C10 • 3D Reshaper 7.1 to generate 3D model from the point cloud
	 Close-range Laser Scanner (NextEngine)	• ScanStudio HD 1.2.0 to process data from Next Engine laser scanner

The final outputs of this research are 3D photo-realistic model of Bukit Batu Pahat shrine and the artefacts found during excavating the site. In order to make the visualization interesting and effective where virtual analysis can be carried out, the output is presented in the form of 3D interactive visualization. 3DReshaper Viewer is used as a medium for data dissemination in this research. This software is capable of visualizing 3D models in various format such as .pts, . xyz, .msh, .dxf and .obj. The environment in 3DReshaper Viewer allows the objects to be viewed in orthographic and perspective view. Indeed, measurement onto the 3D models is available where a customizable report is generated based on the measurements made.

1.3 Problem Statements of the Research

In this contemporary era, there is a high demand in documenting cultural heritage objects such as artefacts, sculptures and buildings (Boehler and Marbs, 2004). Moreover, as stated by Müller *et al.*(2004), people are looking forward for a high levels of detail and photo-realistic 3D model of archaeological findings. This is because an integration of detailed model with photo-realistic rendering can express the impression of reality that can never be achieved via single sensor. Besides that, realism and accuracy of the final 3D model are the important characteristics which archaeologists, historians, and museum practitioners strive to achieve and that the general public comes to expect (Roussou and Drettakis, 2003).

A nearly realistic 3D model is a model that has geometry and texture that almost the same with the original object and this model is useful in many applications such as in digital conservation, restoration, virtual reality applications, 3D repositories and web geographic systems (Remondino *et al.,* 2008). Even though there is an alternative using computer graphic technique to provide textured 3D model, the output are sometimes being oversimplified yet neglecting the purpose to perpetuate the original appearance. On the other hand, there are two methods to generate 3D photo-realistic model as pointed out by Pavlidis *et al.* (2007); active method (i.e. terrestrial laser scanning) and passive method (i.e. photogrammetry).

Recently, people started to integrate laser and photogrammetry data to manipulate the intrinsic abilities of each method (Stumpfel *et al.*, 2003). Laser scanner can swiftly collects 3D measurements data (Lerma *et al.*, 2010) but it cannot provide high resolution images. Thus, generating photo-realistic 3D model via the method itself is impossible. Conversely, photogrammetry managed to overcome the problem but having high resolution images without fine geometric details, the model will exhibit flat-looking and silhouettes that can easily detected (El-Hakim *et al.*, 2008). Hence, laser data and photogrammetry fusion is indeed the best solution as the methods has traits that complement one another (Guarnieri *et al.,* 2004).

A textured 3D geometric model is a highly desirable rather than the object representation since it gives full geometric dimension and allows unrestricted interactive visualisation with variety of lighting conditions (El-Hakim *et al.*, 2008). Furthermore, the lack of geometric element can makes the model become unacceptable for documentation and reconstruction purpose (El-Hakim *et al.*, 2004). According to Shu and Kwok (2009) laser scanner is the most suitable method to capture relatively accurate geometric details. Nonetheless, the edges cannot be well defined as one cannot be sure whether the laser hits exactly at the edge of the object or not (Koch and Kaehler, 2009).

In this research, a terrestrial laser scanner, Leica Scan Station C10 is used to scan a shrine which made of rock with rough surfaces and finally yield a high accuracy geometric model of the monument. A typical problem when generating a geometrical model is the edges of the model and therefore, Grussenmeyer *et al.*, (2012) suggested that photogrammetry is the best complementary method for edge detecting. On the contrary, Boehler *et al.* (2003) pointed out that the essential object feature such as corner points or edges are not directly obtained; it must be extract from the point clouds. Hence, instead of using photogrammetry, data from the scanner itself can be used to overcome the problem. By increasing the scanning resolution, the point density will increase thus providing more points at the edge of an object. Hence, the edge detection process is easier when more points are available.

The aim of archaeological documentation is to make information accessible to other users (Böhler, 2005) especially to interested parties such as archaeologists, researches and students. In recent times, the idea of 3D virtual archaeology which is a navigation of exploring archaeological sites in space and time without physically travelling there seems to be a spectacular idea. According to Pujol (2004), virtual archaeology can fulfil archaeologists demand such as a precise reproduction of archaeological record, flexible database and provide scientific tools for data interpretation. Nevertheless, Gillings (2000) revealed that the representation of scenes, objects and sites of the past in virtual archaeology environment are relentless seeking for the elusive grail of photorealism and even more faithful simulation.

3D virtual archaeology has becoming a crucial need in every country. However, majority of online virtual archaeologies present information in two dimensional (2D) (Chapman *et al.*, 2011). Additionally, Bujang Valley is still using digital images as a medium for virtual archaeology (Jabatan Muzium Malaysia, 2011). The aim of virtual archaeology is to make the data in a comprehensive manner which has academic integrity rather than simple aesthetic appeal (Chapman *et al.*, 2011). Therefore, a virtual archaeology which can benefit scholars by providing access to the collections in 3D photo realistic with geometric dimension, allows object analysis and interpretation of the site is essential in this modern day.

Figure 1.5 shows the existing web based for Bujang Valley Archaeological Museum that is still using 2D digital images for data dissemination. There is no scale or measurement can be conducted on the findings. In photo gallery site, the only feature provided is caption for the pictures, explanation, zooming function and image provider. A 2D presentation for this place cannot be used to create 3D virtual archaeology for Bujang Valley. Hence, the results obtained from this research are displayed interactively in a desktop-based environment by providing photo-realistic model visualization, mesh model and measurement tools for each of the artefacts and monument of belongs to Bukit Batu Pahat archaeological site.

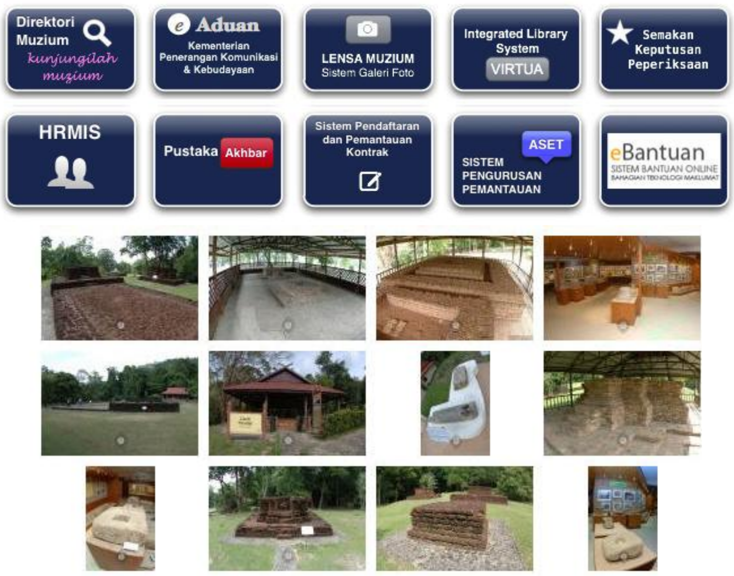

Figure 1.5: Bujang Valley Archaeological Museum website (Jabatan Muzium Malaysia, 2011)

1.4 Research Aim

The aim of this research is to produce three-dimensional (3D) photo-realistic model with required geometric accuracy of archaeological monument and artefacts via multi-sensors data integration.

1.5 Research Objectives

Three objectives are designed in order to successfully achieve the research aim. The objectives are listed as follow:-

a) To evaluate methods for integrating multi-sensors data with the aim of producing three-dimensional photo realistic models of archaeological monument and artefacts.

b) To determine the geometrical accuracy of the archaeological monument model generated independently via terrestrial laser scanner, Leica Scan Station C10.

c) To present the 3D models of archaeological remains in an interactive and simple desktop based display for virtual analysis and effective data dissemination.

1.6 Research Questions

At the end of this research, this research is able to answer the following questions:-

a) What kind of suitable methods to be used to generate 3D photo-realistic model of monument and artefacts?
b) How to integrate different types of sensors data to get 3D photo-realistic model of a monument?
c) By manipulating the resolution of scanning, how effective and reliable can the laser scanner be to produce a model with required geometric accuracy?
d) Why is so important to document a 3D model with photo-realistic appearance and geometric measurements?
e) What is the suitable platform to share the 3D model so that the information is accessible by the citizen, researchers and historians?

1.7 Scope of the Research

This section discussed about the extents or scopes exist in this research. The restrictions occur due to several reasons such as budget constraint, area of interest and final output requirement. Initially, this research is only focusing on two phases of archaeology work which are site survey and archaeological site documentation. Site survey is a process where the location of the archaeological site is observes using any positioning method where in this case Global Positioning System (GPS) is applied. Nonetheless, due to instrument unavailability, a team from other institution was asked to observe two control points using static observation method. Thus, the coordinate value is used in this research to georeference the point cloud model.

Besides that, this research is only aim to document the remains that has been found without involving with the process of excavation. Thus, there is no information about the excavation grid or the pit level where the artefacts found. One monument is chosen as a study area and the artefacts found during excavating the site are scanned. The multi-sensors data integration is mostly focusing on the monument documentation. Basically, coordinate data, photogrammetry images and laser data of the monument are fused. On the other hand, only a close range laser scanner is used to scan the artefacts.

In the visualization part, only 3D surface models and the 3D photo-realistic models are display instead of point cloud and wireframe. Accuracy for each model is referred to a standard required by archaeologists. Feature mapping analysis was conducted by comparing digital 3D model with correspondence images to evaluate texture quality of 3D photo-realistic model. Additionally, geometric mapping accuracy was carried out by comparing virtual measurement of the 3D models with on-site measurement using measurement tape.

1.8 Significance of the Research

Archaeology in Malaysia had started since 1863 yet the popularity of this discipline in Malaysia still at a low level (Yunus, 2004). Due to rapid development in this country, archaeologists are often forced to excavate and document the findings within a limited time especially when the area involved building construction. The documentation of the remains found during the excavation work must be as detailed and accurate as possible because the excavated sites will no longer available once the excavation is finished as features are often destroyed during investigations (Southport Group, 2011). Hence, by implementing several sensors and integrate them with Geomatic knowledge, a rapid generation of digital 3D photo-realistic model for archaeological sites in Malaysia is no longer impossible to achieve.

Preservation of archaeological sites will bring significant contribution to the country especially in tourism activities. Systematic management and preservation of archaeological sites will increase tourism activities because activities will act as an economics sources for a country. Currently, the lost of archaeological cultural heritage is faster than it can be documented. Major disasters, which caused the vanishing of archaeological heritage site, are human and natural disasters (Letellier *et al.*, 2007). Human trigger off wars, uncontrolled development and recklessly build squatters. Concurrently, archaeology sites are facing enormous natural disasters, such as air pollution, acid rain, flood and earthquake.

By implementing laser scanning technology in recording archaeological monument, the geometrical dimension of the structure can be extracted. Thus, using the information given, the structure can be digitally reconstruct if it is destroy by natural disaster and no longer available to be visited. A sustainable development can be achieved in which human needs are fulfil while preserving the environment so that both development and ancient remains are enjoyed not only in the present, but also for generations to come. Besides that, by visualizing 3D photo-realistic model of the remains in an interactive environment, it will initiate a new way of data dissemination that is more effective and interesting. Archaeologists and researchers can conduct virtual measurements and share their findings without having to be in-contact with the object.

While heritage sites are major tourists' attractions in worldwide, Bujang Valley in Malaysia on the other hand is not popular among the tourist community for its heritage sites. Due to the need of development as well as the urgency of other pressing priorities, Malaysia is unaware of its rich culture heritage sites. Collecting archaeological data via integration of Geomatic tools can yield a 3D photo-realistic model of the archaeology monuments and artefacts. Hence, the model can be displayed in an interactive virtual 3D environment and publish in the internet as a medium for tourism attraction in Malaysia. It will bring an enthusiastic feeling for those who watch virtual reality of archaeological site in Malaysia even though they are far away from Malaysia.

1.9 Thesis Organization

This thesis consists of six chapters. **Chapter 1** clarifies the main ideas comprised in this research including the concept, description of the study area and also instruments and software that used to perform this research. Some explanations to justify the important of carrying out this research are also being discussed in **Section 1.3**. The aim and objectives of this research are pointed out in **Section 1.4** and **Section 1.5**. Besides that, scope of the research is outlined in the **Section 1.6** to emphasize the research's limitation. Finally, the contributions of this research are explained at the end of this chapter.

Chapter 2 and **Chapter 3** are mainly about reviewing and explaining the basic concept, conventional and current trend in archaeological documentation. Basically, the definitions of common terms used in archaeology field, theory in archaeological documentation, existing and current method used for documenting archaeological remains are described in the second chapter. Additionally, the third chapter explained about the role of several sensors that have been successfully applied in archaeological field. The utilization of every sensor to record different types of archaeological remains is discussed in term of advantages and disadvantages of the sensor.

Chapter 4 describes the methodology used to carry out this research. It started with a flowchart to clarify the process of data acquisition, data processing and visualization. **Section 4.4** and **Section 4.5** is about collecting the data for monument and artefact, which mentioned separately in different sub-section. After that, **Section 4.6** is established to explain about the data processing for monument modelling. The section contained three types of data processing; point cloud processing, point cloud modelling and photo-realistic generation. **Section 4.7** discussed about artefacts data processing. The process of rendering and displaying the 3D models is explained in the **Section 4.8**.

Chapter 5 is where the results are discussed and analysed critically. **Section 5.2** is discussing about the result for creating control of the archaeological site and georeferencing the point cloud. The accuracy for traversing also being analyzed. This is followed by the results and analysis of Bukit Batu Pahat shrine models. The section is divided into two sub-sections; (1) results and analysis of the point cloud model, (2) results and analysis of the photo-realistic model which explained about data integration results and data quality assessment. Finally, evaluation for the visualization is discussed in the last sub-chapter. **Chapter 6** is the final chapter in this thesis that generally conclude what the research has achieved, problems faced also some recommendations for future research.

1.10 Summary

Generally, this chapter is focusing on explaining overall idea of this research. Even though various Geomatic tools have been widely used in archaeology discipline, Malaysian archaeology is differ. Geomatic only applied in the preliminary work phase such as doing a site survey of the archaeological area using electronic distance measurement (EDM), total station and theodolite. In order to move along with current trend and demand, this research is conducted using several sensors by applying Geomatic knowledge for documenting archaeological site that is Bukit Batu Pahat shrine in Bujang Valley, Malaysia. The introduction of laser scanning technique in collecting archaeology data can be a booster towards rapid exploration of new archaeology sites in Malaysia. Laser scanning technique that used in capturing archaeological data are more practical, less complex to handle and provide metrically accurate data which is highly significant for architectural, historical and other scientific research as well as for conservation and restoration purposes (Ruther, 2002). It is time to do some innovation in Malaysian archaeological field. Everything left by our ancestors finally can contribute to the world civilization history.