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3D DOCUMENTATION AND PRESERVATION OF HISTORICAL MONUMENT USING TERRESTRIAL LASER SCANNING

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Abstract

The digital preservation of historical monuments using advanced 3D measurement technologies becomes a potential and efficient tool for mapping solution. In addition to traditional methods such as simple hand measurement and tacheometry, 3D terrestrial laser scanning is rapidly becoming one of the most commonly used techniques due to its completeness, accuracy and fastness characteristics. This paper evaluates the capability of terrestrial laser scanning technology for documenting the historical monument facade data in 3D environment. Then this is followed by the generating of 3D visualization model based on registered colourized point clouds. In this project, the FARO Photon Laser Scanner 120/20 system was used to record the geometry data of the historical monument. In order to capture the colour information of the geometric object, a Nikon DSLR digital camera was integrated with the FARO System. Our technological approach provides the ability to generate 3D coloured visualization model of the historical monument with the automatic colourized process. The attachment of RGB value from the detailed high resolution digital images onto the 3D point clouds data was completed using FARO Scene software. In this way, the 3D model can be visualized in much more photorealistic way. The case study is the A'Famosa Fortress, Porta de Santiago, one of the world heritage monuments in Melaka, Malaysia declared as UNESCO World Heritage Sites in 2008. The data fusion of TLS and digital photogrammetry is presented and explained in detail in order to produce a photorealistic model in 3D environment. Then, a 3D virtual fly through animation of A'Famosa Fortress was created based on millions of colourized point clouds.

Keywords: *3D Terrestrial Laser Scanning, Photogrammetry, Colourized Point Cloud, 3D Coloured Visualization Model, Historical Monument*

1.0 INTRODUCTION AND RESEARCH AIMS

It is well known that the preservation of cultural heritage can helps to educate younger generation through the history event happened. Furthermore, historical monument is something inherited from ancestor, what we live with today, and what we pass on to the future generation (Prentice, 1993). They give us most sophisticate techniques, knowledge and people's life styles in each period of human history. Thus, efforts to study and visualize the historical monument or sites have been of high priority. Conserving historical monument is an important issue due to its high historic value. These object is subject to erosion, vandalism, and as long-lived artefacts, they have gone through many phases of construction, damage and repair. It is important to measure and model a historical monument with relatively high accuracy. Due to the complexity of these structures, 3D visualizing and modelling of these structures is time consuming and difficult, usually involving much processing effort. To achieve this approach, the advent of new digital 3D terrestrial laser scanning technique is applied to reduce the time of visualize a 3D historical monument model using automatic method. The application of 3D laser scanning for reconstruction and conservation of heritage buildings, monument or archaeological sites is generally accepted by survey community due to its completeness, accuracy, and fastness characteristic (Sgrenzaroli, 2005).

In recent years, the use of 3D terrestrial laser scanning (TLS) seem to be increasing as its effectiveness in recording and documenting cultural heritage is widely documented. This is due to its capability to provide users with better spatial information of structure in complex 3D scenes in a rather short period of time. The 3D coloured point clouds data produced by the laser scanner can be used to give a realistic impression of a monument or structure for users to interactively navigate the viewpoint around it, viewing it from all the angles and position desired. TLS technique provides higher efficiency in data collection especially useful in unreachable place as it gives complex and detail 3D point cloud data in a matter of minutes.

Many related works have proved that terrestrial laser scanner was a powerful tool towards the recording of objects and sites for heritage preservation purposes, scientific research and built environment applications. One of the sample of research work carried out by Ruther et al (2009) had discussed that using a precise and realistic 3D model of the heritage site can insist to both the aesthetic and practical implications of restoration and conservation work in the future. Thus, digital documentation of cultural heritage is very important as a digital reference and record for future generations and refurbishment due to present information remain in paper and photo format. Traditional 3D modelling tools are often insufficient for cultural heritage applications because of the shape complexity and high accuracy required, whereas 3D laser scanning technique is capably accurate to capture high details of the shape (Fontana et al., 2002).

In this study, we demonstrate the practical use of 3D TLS in documentation of heritage monument. The terrestrial laser scanner system used for this project is a phase shift based laser scanner, FARO Photon 120/20. This system was mounted with the Nikon SLR D300s digital camera to capture the high resolution images of the geometric model. This project evaluates the capability of FARO terrestrial laser scanner system for capturing high detailed heritage geometric data. Moreover, we present the combining of 3D point clouds measured by TLS with the RGB information yield by photogrammetry technique. Lastly, the 3D coloured visualization model of A'Famosa fortress was produced using FARO Scene and a virtual flythrough animation based on registered RGB point clouds was rendered using Pointools Edit Pro.

2.0 BACKGROUND OF TECHNOLOGY AND RELATED WORK

Digital photogrammetry and laser scanning are the most two common techniques used for the data acquisition of heritage digital models. Digital photogrammetry techniques for object capturing are already well established (Remondinho and El-Hakim, 2006). Image-based technique has a simple data acquisition procedure but it has the limitation on capturing complex surface. In contrast, laser scanning technique does not bother with the surface shape (Boehler and Marbs, 2004). It also accomplishes the needs of high density of data, speed of capturing and accuracy in different field (Biosca and Lerma, 2008). Unfortunately, the laser ray cannot identify the colour of the measured surface. As the result, the obtained 3D point clouds from the laser scanner are colourless. Thus, in most cases, a proper combination of both laser scanning and photogrammetry technique able to produce better 3D textured model when the characteristics of the study area are complex and with large dimensions (Remondino and Campana, 2007).

According to (EL-Hakim et al, 2002), the generation of detailed 3D models of heritage buildings and artefacts have to accomplish some specifications and requirements in term of geometric accuracy and level of details. In order to get an accurate 3D point cloud data of the whole object surface there are two factors that need to be concerned such as distance accuracy and space resolution of the laser scanner (Boehler and Marbs, 2005). There is also a research discussing about the quality of the intensity value and a feasible influence on distance measurement using laser scanner (Pfeifer et al, 2007).
The latest developments in sensor technology, laser scanning, offers a new efficient data collection method for measuring an objects. The use of TLS for cultural heritage recording and documentation is becoming increasingly popular (Yastikli, 2007). Since the development of the first generation of terrestrial laser scanner in 1999, laser scanning technology undergoes continued phase of product development, growth and expansion into many areas of survey (Bellian et al., 2005). In the review research study conducted by Xiao et al (2007) from Wuhan University, the use of terrestrial laser scanners for architectural surveying is a promising technique to produce 3D measurable models and efficient in documentation of historical heritage.

A plenty of cultural heritage projects used TLS technique for data capturing such as the Digital Michelangelo Project (Levoy et al, 2000), the acquisition of Michelangelo's Pietà in Florence (Bernardini et al, 2002), and the acquisition of a portion of the Coliseum in Rome (Gaiani et al, 2000). Besides, the 3D resconstruction of Petra, Jordan was carried out by Alshawabkeh (2005) using terrestrial laser scanner, GS100 manufactured by Mensi. Furthermore, recent research work emphasizes on the capability and reliability of scanning sensor to record paintings, artefacts, and archaeological sites by member of the National Research Council of Canada. In recent years, many researchers have combined both photogrammetry and TLS in different ways (Yastikli, 2007; Grussenmeyer et al, 2008; Al-kheder et al, 2009; Cabrelles et al, 2009; Lerma et al, 2010). Laser scanning technology also improves the efficiency and quality of construction projects as described by Arayici (2007).

3.0 METHODOLOGY

3.1 Site Description

A'Famosa ("The Famous" in Portuguese) is a fortress located in Melaka, Malaysia which is granted the status of World Heritage Site by UNESCO in 2008 (see **Figure 1**). It is one of the oldest surviving remnants of European architecture in Asia (see **Figure 2**). Once as part of a mighty fortress, this tiny gate known as Porta de Santiago, one of the four main gates of the famous Portuguese fortress. The fortress consisted of long ramparts and four major towers. One was a four-story keep, while the others held an ammunition storage room, the residence of the captain, and officers' quarters. This structure was built by the Portuguese in the year 1511 under the command of Alfonso de Albuquerque, after the Portuguese invaded Melaka. It was intended to fence off the attack from Sultan Mahmud of the Melaka Sultanate Era and the continuous attack from Acheh and Johor empires (Godinho de Eredia, 1997).

The A' Famosa fortress with 3 meters thick walls and a 40 meters watchtower had played a major role in protecting the Portuguese from their enemies. It was also the most well-known and symbolic fortress that the Portuguese had ever built. The Portuguese believed that Malacca would become an important port linking Portugal to the spice trade from China. In 1641, Dutch was successfully drove the Portuguese out of Melaka and took over the fort. As a result, the A'Famosa was renovated and rebuilt by Dutch in 1670, which explains the logo "ANNO 1670" inscribed on the gate's arch. Above the arch is a bas-relief logo of the Dutch East India Company.

The fortress changed hands again in the early 19th century when the Dutch pass over to the British to prevent Melaka from falling into the hands of Napoleon's expansionist France. When British took over Melaka from the hand of the Dutch, Captain William Farquhar of the English East India Company decided to demolish the fort in 1795. This nearly happened, but Sir Stanford Raffles (the founder of Singapore) and Lord Minto persuaded the English to let the residents remain and also prevented the total destruction of the fort by convincing the English to let one gate remain for history's sake. As a result, A' Famosa fortress was not totally destroyed. However, three out of the four main portals were demolished by the blast. The only one remaining historical monument was the portal facing Bukit Cina, and that is the Porta de Santiago (A'Famosa Melaka, 2010).

According to (Izani et al, 2009a, b, c) A Famosa is an important historical relic that should be preserved and documented for future reconstruction in digital medium. The research conducted by Izani et al, 2009 used traditional 3D modeling process based on the existing 2D drawings and existing evidences on location to reconstruct A'Famosa. As the physical remains of the fortress is very minimal, the process of reconstruct the fortress is a big challenge. In this way, TLS is an essential tool to assist the preservation and conservation work of A'Famosa.

Figure 1: Location of A'Famosa in Melaka, Malaysia

Figure 2: Entrance to A'Famosa

3.2 Planning and Data Collection

The TLS data acquisition at the A'Famosa was carried out with the phase-shift based scanner, FARO Photon 120/20. The data capturing procedure was executed in two steps, laser scanning and photographing (see **Figure 3**). The geometry and the intensity of facade data were captured by the terrestrial laser scanner while the RGB values of the geometric object were captured by a high resolution digital camera. The A'Famosa had very complex features for its inner and outer shape. Hence, an appropriate scanning positions need to be established to capture the full coverage of the façade data.

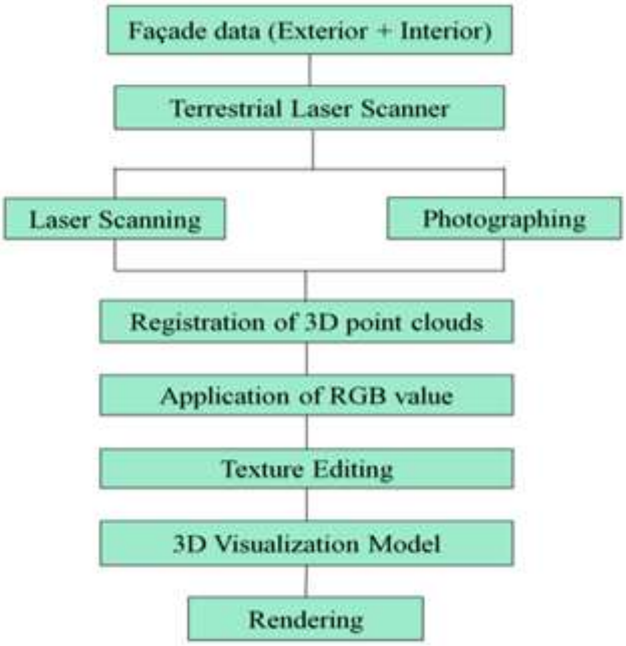

Figure 3: Details of approach

3.2.1 3D Laser Scanning

The survey of the interior and exterior walls of A'Famosa was performed with FARO Photon Laser Scanner 120/20 system (see **Figure 4**), which uses laser, safety class 3R and capable of capturing up to 976,000 points per second. The maximum captured range for this scanner is 153 meters with low ambient light on 90 percent reflective surface. This system is based on phase shift measuring principle and it provides a larger field of view of 360 degrees in horizontal direction and 320 degrees in vertical direction with 0.009 degrees accuracy, and allows the collection of full panoramic views. The systematic distance error was ± 2 millimetres at 25 meters depending on the reflectivity from white to dark grey.

Figure 4: FARO Photon 120 integrated with Nikon DSLR 300s

After scanner measuring the façade of A'Famosa, all the recorded digital data would directly stored in the controlling laptop by using the FARO Scene software. Then, the laser scanner only continued with image acquisition process. The well-known integrated digital camera would take 10 photos at each scan station to provide a panorama view of the surrounding. The data capturing procedure was shown in **Figure 5**.

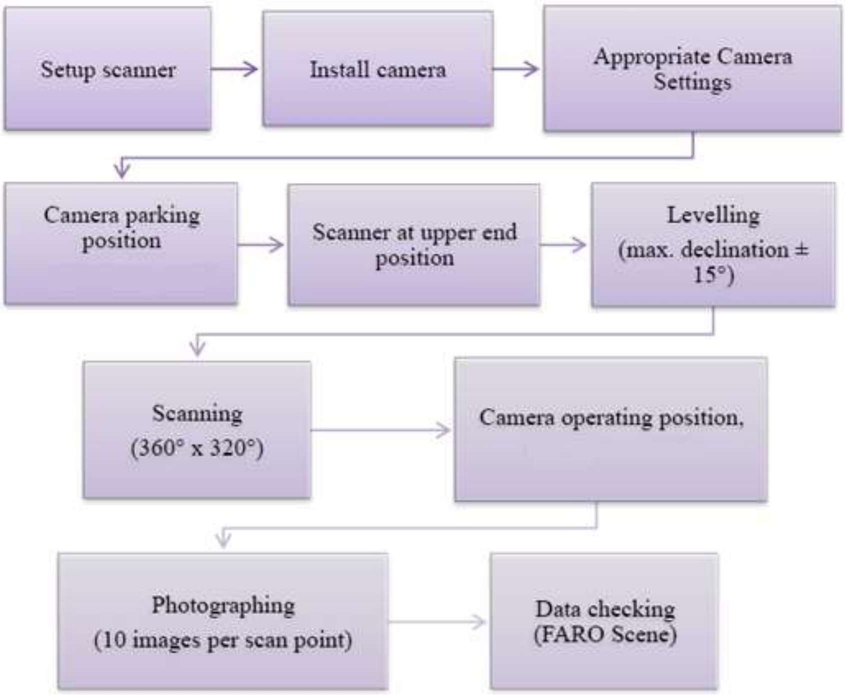

Figure 5: Procedure on data capturing

For this project, the resolution of 1/5 was chosen for scanning. The expected scan time and file size were depend on the resolution, noise compression, and scan range chosen. The higher the degree of resolution selected the result on scan time and file size would longer and bigger. The maximum tolerance declination range for the instrument was ±15 degrees. Hence, the levelling of the laser scanner is crucial to ensure the good quality data capturing.

There were 10 captured scans to cover the whole A'Famosa structure (see **Figure 6**). There were more than 20 artificial spheres (act as control point) placed around the 3D space. The placing of the spheres must meet the requirement of minimum 3 corresponding points in two different stations. This necessity was needed to smooth the post processing work. Besides, the numbers of total scan station depends on the size and complexity of the structure. Hence, appropriate scan station needs to be established for better coverage to cover all the details of the monument.

The distribution of the artificial sphere has to be fairly located at a distance around 1.5 meters to 7 meters from the scanner to obtain a good geometry network. The distribution of the spheres plays an important role in registration stage in processing procedure. The spheres need to set in a position that could be seen and corresponded between two scan stations which require minimum 3 corresponding target. **Figure 7** shows the position of the camera during scanning and image acquisition.

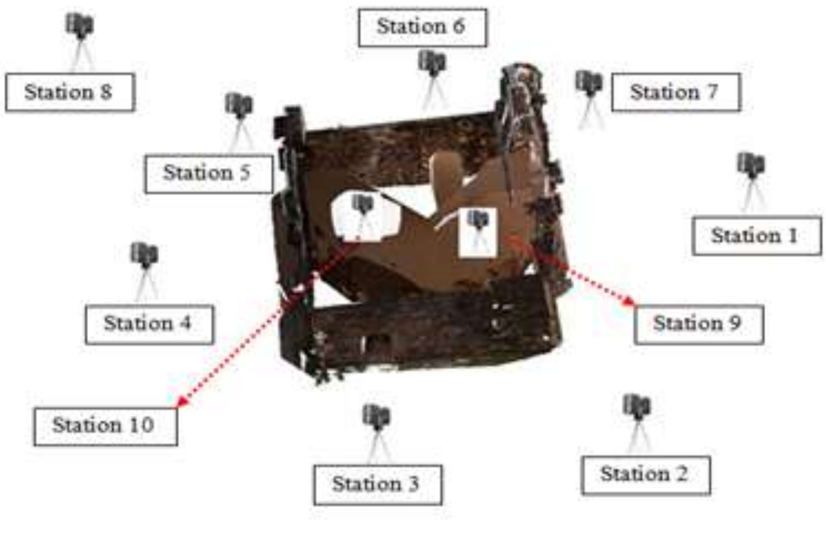

Figure 6: Layout plan for laser scanning

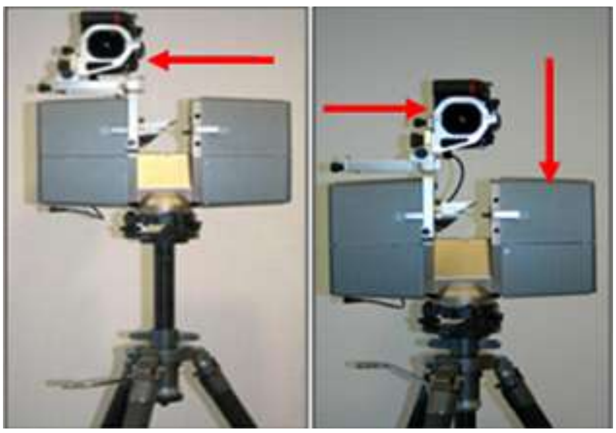

Figure 7: Position of the camera when scanning (left) and photographing (right).

3.2.2 Image Acquisition

A professional digital camera Nikon DSLR 300s (see **Figure 8**) was used to capture high resolution digital images of the A'Famosa. This is a 12.3 megapixel DX-format camera with a 15.8 x 23.6 millimeters CMOS sensor size. For this project, an AF DX Fisheye-NIKKOR was attached to the camera for an ultra-wide picture of 180 degrees. The focal length was 10.5 millimeters, equivalent to 16 millimeters focal length on a 35 millimeters format size. About 100 images were acquired for the total of 10 scanned point clouds at the focus distance, while the images resolution was set at the highest level (4288 x 2848 pixels) in order to capture better quality textures.

Figure 8: Nikon DSLR 300s and AF DX Fisheye-NIKKOR

The camera position was parked at the same position as the laser beam transmitted by the scanner. The assumption would be from every single images captured it is same to every scene being scanned from the view of scanner. This camera captured 10 images per scan station but cannot have full coverage in vertical field of view as compared to the scanner. So, the choosing of sufficient scan position was the important issue. The operation of the photographing was controlled by the scanner software. Once the scanner has finished the scanning, the scanner would turn backward. During images capturing, it stop several time and take a picture on each stop. Instantly, the picture were automatically transferred to the controlling computer and put into the scan file. Although the mounted camera approach satisfied the requirement of colour information, but it still has some limitations. First, the high resolution quality was obtained at the best lighting conditions for the image which may not be at the same position of the laser scanner due to its horizontal shift. Second, the vertical field of view from the attached camera is limited compared to the laser scanner vertical field of that covers until 320°. Third, whenever the surface of scanned object was too near to the scanner, false angle colouring might occur. So, extra care must be taken to ensure good exposure by selecting the most appropriate scan position.

3.3 Point Cloud Processing

Figure 9 shows the flow of the point cloud processing stage. This involves the basic checking of data, removal of bad point cloud caused by blocking object or false returns. FARO Scene was used to mesh the point clouds. The registration involved point clouds from a total of 10 scans location covered the whole A'Famosa structure with clockwise direction. There were 8 scans positions at the exterior part and 2 scans in the interior part of the A'Famosa (see **Figure 10**). These point clouds have to be registered into one coordinate system in order to achieve a complete visualization model of A'Famosa. Millions of measurement have been taken and contain several of noise and errors. Before starting to mesh the point clouds, data filtering process need to be done to correct or remove the selected scan point from the raw data. This was determined by the selection criteria. The filters differ according to which method they identify an inaccurate scan point and which counter measure was then taken. The details of combining TLS and photogrammetry data can be summarised in **Figure 11**.

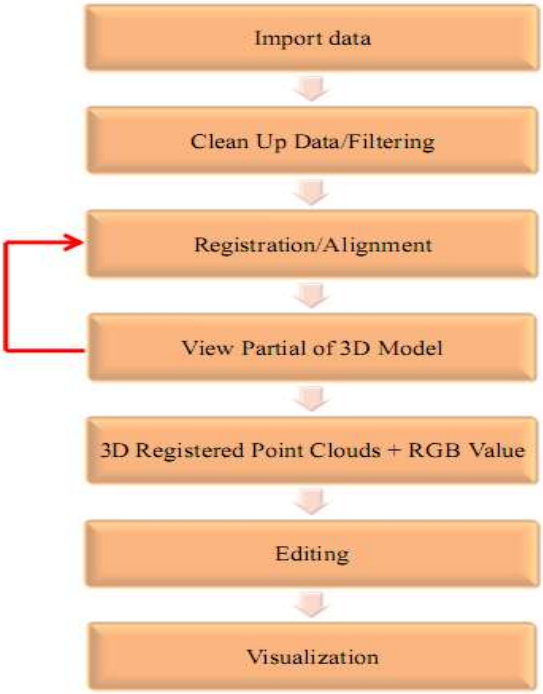

Figure 9: Point Cloud Processing Flowchart

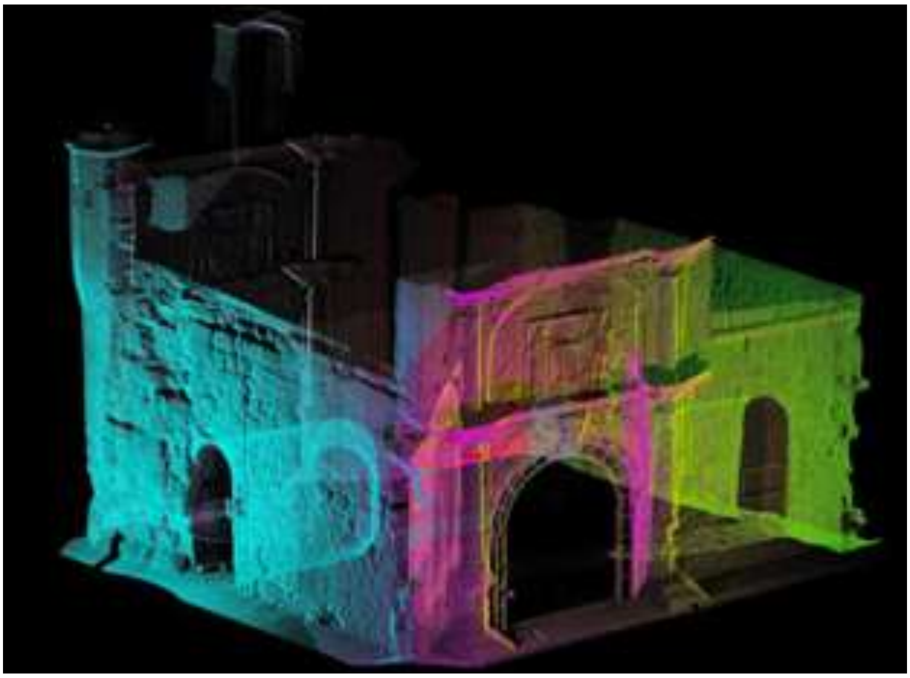

Figure 10: 3D view of point cloud captured at A'Famosa

3.3.1 Registration of 3D Point Cloud

The FARO Scene software was used to register the range data (10 scans, 38 million points see **Figure 11a**) and produce a 3D visualization model based on registered colourized point clouds The registration of all scans were performed pair by pair by means of minimum 3 control points required to match two different datasets in one common coordinate system (see **Figure 11b**). Before starting to mesh the point clouds, data filtering process need to be done to correct or remove the selected scan point from the raw data. If a geometric object has an active target fit, the overall quality of the fit with the object was symbolized by a traffic light. Green means that all the quality criteria were met. Amber shows that at least one quality criterion was somewhat compromised and red means that at least one criterion was seriously compromised. This might due to bad matching of control point between two different scanning epochs. Once the scan registration was completed, a partial 3D model view of the A'Famosa was loaded in 3D form to check whether the two scans were correctly registered.

3.3.2 Application of RGB Value

The colour information from the high resolution digital images would be fused with the 3D registered point clouds after the geometric object had correctly meshed (see **Figure 11c**). In order to attach the RGB value of digital, some prerequisites have to be matched. First, the digital picture has to be free of any distortions caused by the lens (see **Figure 11d**). Especially wide-angle lenses tend to cause so called barrel distortion, which caused a straight line does not appear straight but bend. Second, the position, orientation, and zoom factor of the camera have to be known. For this project, colourizing using scanner based pictures was applied to gain a 3D coloured visualization model (see **Figure 11e**). All the pictures were done with the well known camera (Nikon DSLR) of the scanner, and they were under control of the scanner. Hence, all above mentioned prerequisites were met. Once the colourize scan registration was completed, in order to obtain a simplified 3D coloured visualization model, a data reduction was applied to reduce the memory usage and to speed up the loading process when visualizing the whole 3D merged surface of A'Famosa. Besides, texture editing would be done to remove the noise and smooth the model.

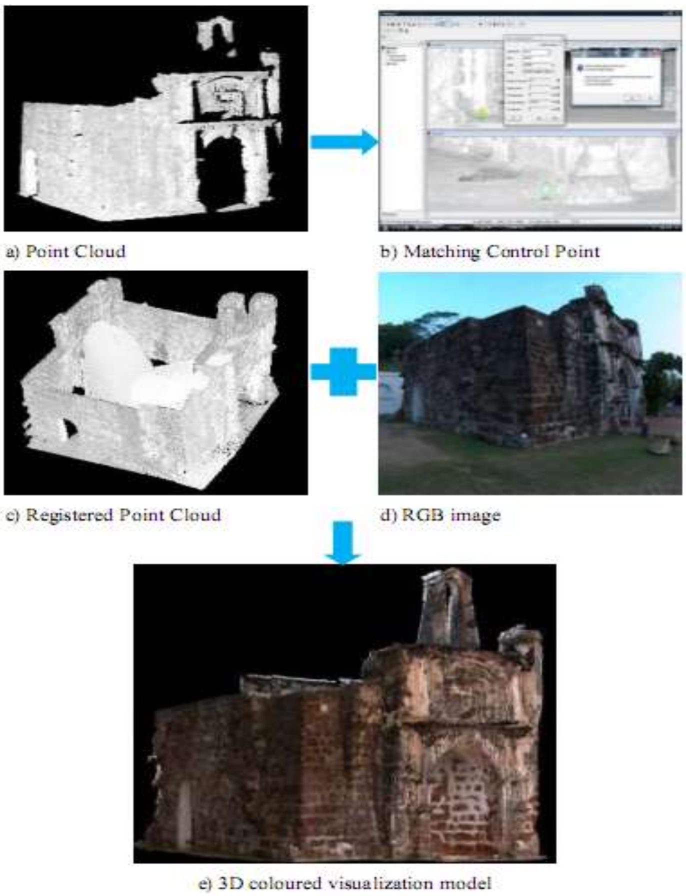

Figure 11: Summary of steps combining TLS and photogrammetry data

3.3.3 Rendering of A'Famosa Fortress

Pointools Edit was used to create the walkthrough animation and followed by rendering of animation of the complete 3D registered colourized model (see **Figure 12**). The Animation Wizard was chosen to set up an animation. Animation Wizard provides a quick and easy way to set up an animation. There were two types of animation mode available which is Fly Through and Orbit. In this project, the Fly Through mode was selected to create a short fly-through type video clip in .avi format. Firstly, the point cloud data was imported into the software and then the camera position was entered along the path. This procedure could be done by moving the camera into the next position which essential to be visualized and click Enter. This step was repeated by setting as many positions as needed to have a complete virtual scene of the visualization model.

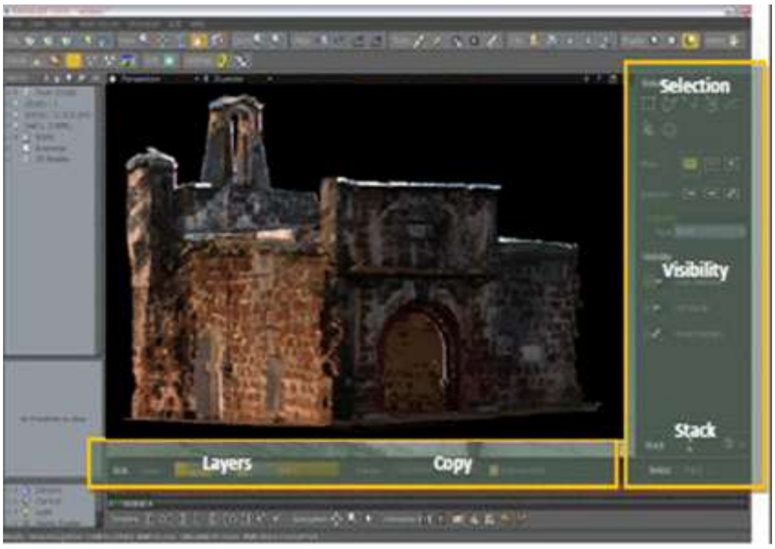

Figure 12: Rendering of 3D A'Famosa animation in Pointool Edit Pro

4.0 RESULTS AND ANALYSIS

The completed 3D coloured visualization model was shown in **Figure 13**. In this project, each of the scans used approximately 10 minutes to complete the scanning and image capturing. The onsite scanning basically was done in 2 hours excluded the onsite planning before the data observation starts. Quality of visualised 3D coloured model greatly dependent on how well the FARO Photon 120 system integrated with the photographing device. In the contents of historical monument visualisation, texture mapping have been the most troublesome issue concerned. The wrong interpretation of colour details happened when the RGB information from the images fused on the wrong point clouds.

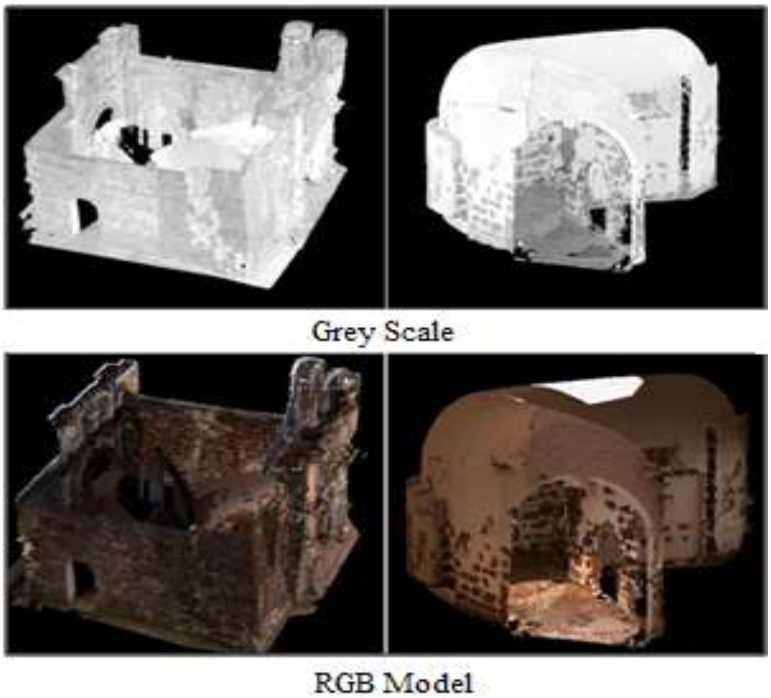

Figure 13: Complete registered 8 exterior scans (left) and 2 interior scans (right)

The comparison of visualization model generated by laser scanning technique and close-range photogrammetry (CRP) technique would be presented in **Figure 14** and **Figure 15**. The software used for both methods were Faro Scene and Photomodeler Scanner. The comparison was done visually to both of the models produced as the aims to give users an informative virtual experience on the historical monument. It was found that the output from close range photogrammetry approach was not as detail as it was compare to the model formed by using terrestrial laser scanner.

The 3D point clouds generated by close-range photogrammetry method were not as dense as terrestrial laser scanner. In term of data capturing process, terrestrial laser scanner required more time compared with image based method. But for post-processing process, close range photogrammetry required much more time in order to generate a complete simple visualised model as shown in **Figure 14**. On the other hand, the 3D colourised model generated through TLS method was fast and effective. Laser scanning technique gave better 3D visualization model and accuracy if compared with close-range photogrammetry. Unfortunately, this technique had some limitation on displaying the façade data at the edge and the line features of the heritage building as proven by other researchers.

What’s more, some measurement was made to the 3D colourized model in FARO Scene using the measuring tool to validate the result created giving comparative accuracy in real space object such as the main entrance and side entrance (see **Figure 16**). The tape measurement value was used as the standard for evaluation purposes. The results of the comparison between terrestrial laser scanner and close range photogrammetry would be presented in **Table 1**.

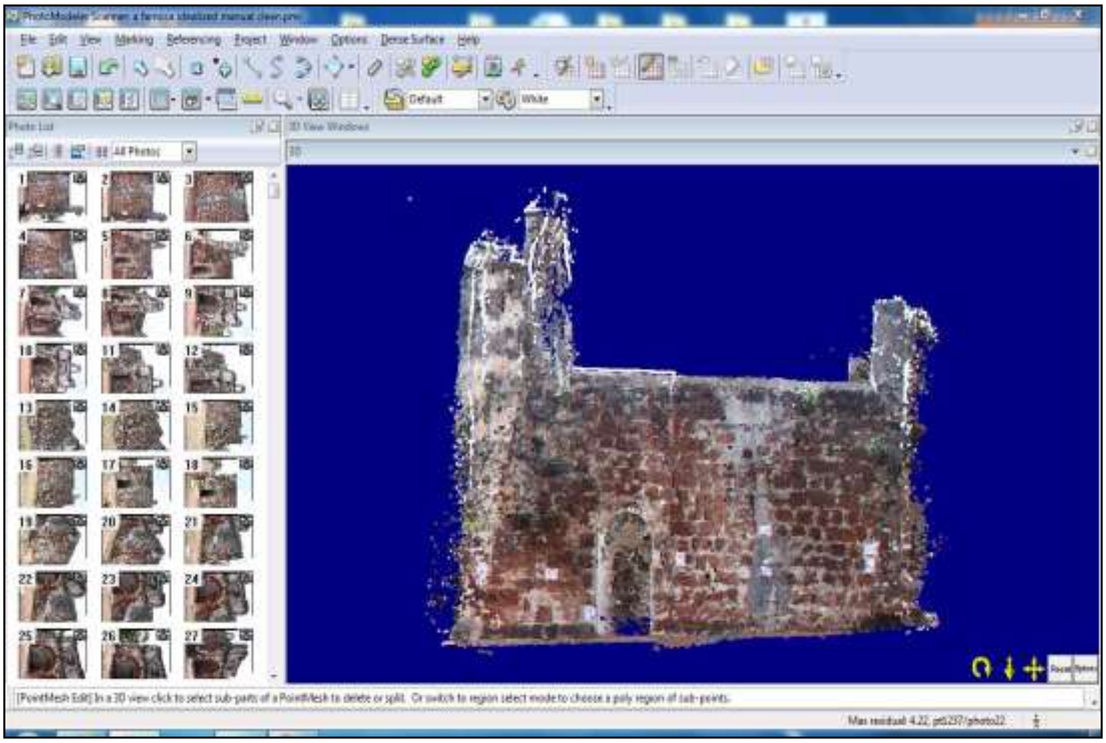

Figure 14: 3D visualised model using Photogrammetry-Based Dense Stereo Matching (Ng, 2010)

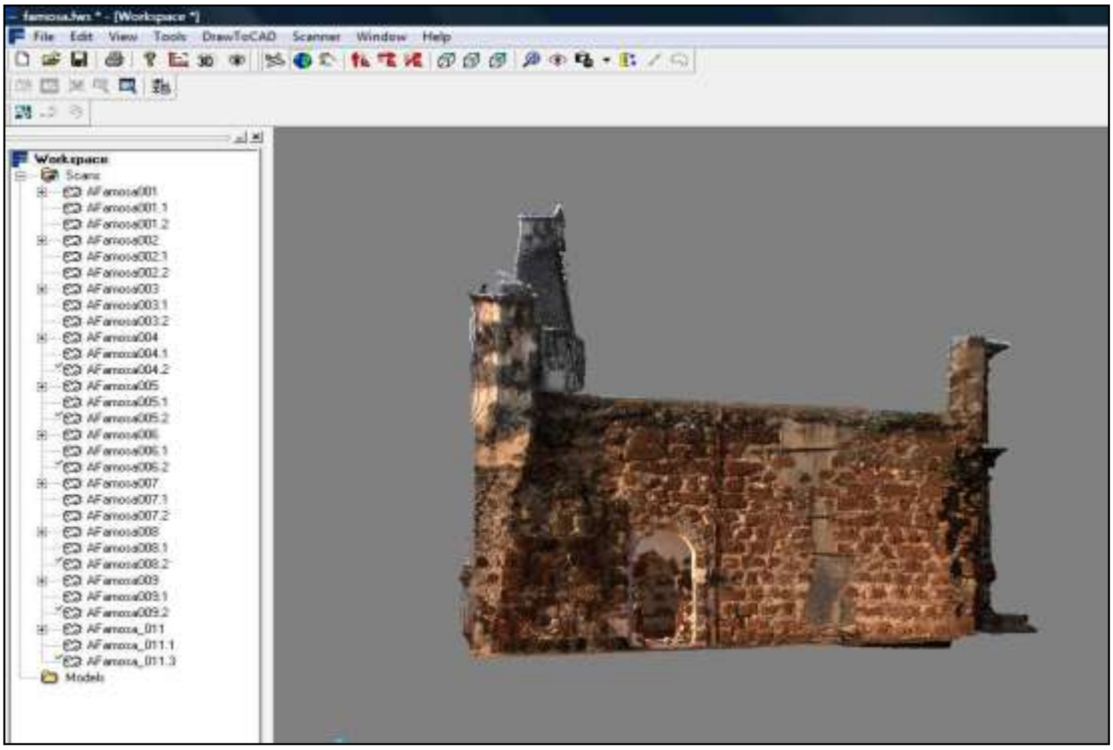

Figure 15: 3D visualised model using Terrestrial Laser Scanning

Figure 16: Measurement at different part of A'Famosa fortress

Table 1: Comparison between CRP and TLS with measuring tape

	Method A CRP (Ng, 2010)	Method B Measuring Tape	Method C TLS	Differences	
				A vs B (%)	B vs C (%)
Main Entrance	3.285 m	3.317 m	3.306 m	0.965	0.332
Site Door (Left)	1.257 m	1.245 m	1.249 m	0.964	0.321
Site Door (Right)	1.159 m	1.172 m	1.168 m	1.109	0.341

From **Table 1**, the measurement obtained was sufficient to prove that the laser scanning method was accurate and sufficient to produced reliable virtual detailed 3D visualized model which target object consists of complex feature or facade. The accuracy of laser scanning was very close to the value from the measurement tape. The difference was at centimetres level.

Moreover, there were several problems encountered during the registration and colourizing of the point clouds data such as the system was run out of memory to process the data because of very dense point clouds, false colouring due to the algorithm in the software, error on loading and visualizing the registered scans data. These problems could be solved using data reduction approach, which the redundant data or additional point cloud were eliminated to allow the users work easily and faster on registration and colourizing process. The false colourizing issue could be minimised by manually adjust the picture's angle. In order to visualize the complete registered 3D coloured model in 3D form, the corresponding of the scans point as control on the desired surface would be selected and stored in a new folder to compress the numbers of scan points.

5.0 CONCLUSION REMARKS

At the end of this project, the combination of TLS and photogrammetry ensures a well solution for generate a high quality of photorealistic model and this benefits can provide a well-documentation for preserving complex heritage sites. 3D coloured visualization model of A'Famosa was produced as a final product of this study. The Audio Video Interleave (.avi) format video gave user a virtual walkthrough scene of the historical monument. Terrestrial laser scanning is proven as a very effective technology for capturing 3D geometry data of cultural heritage. The capability of terrestrial laser scanner has been documented widely especially FARO Photon Laser Scanner due to its fastest capturing speed, high accuracy and high resolution features among the modern terrestrial laser scanner. The needs for wide application of point cloud data are growing, and the development of 3D visual contents using the data is more and more important. Hence, a better understanding of users with this technology or technique for the various possible applications is a big challenge as it worth the investment with vast improvement in terms of quality and accuracy of data and cost effectiveness.

It is recommended that this project can be further towards the modelling of heritage monument using TLS data. The digital 3D model of the monument can helps in future preservation work such as reconstruction and renovation. It is beneficial to have this real 3D environment model to act as the guideline to responsible authority as reference for better documentation planning and tourism purposes. In this study, the rooftop part of the A'Famosa was not fully implemented as it is inaccessible using Terrestrial Laser Scanner. In term of level of details defined by CityGML standards, it can be upgraded to higher detailed model, LoD 4 which covered both interior and exterior and also the rooftop of it. In order to have a complete detailed 3D model of a historical building, a well proper combination of close-range photogrammetry and laser scanning method can be applied in high quality 3D recordings of heritage documentation.

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