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Preservation of cultural heritage: 3D modelling of traditional Pinas boat using multi-source photogrammetry method

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***Abstract*—In East Coast of Malaysia, there are local people that mastered in traditional sailboat building. They built using the indigenous technique without proper plans with hull first and frames later. This uniqueness of production needs to record with the help of current technology through Photogrammetry, before the traditional boats are damaged or in some cases completely destroyed. Therefore, in this paper, a hybrid multi-technique approach is proposed for maritime heritage preservation and, as case study, the 3D modelling of a 25-cm-long scale model of a famous historic Portuguese Indian Armada, the "Flor de la Mar", will be act as a sample before applying this technique to the real size junk rigged schooners Pinas, "SABAR". The survey is placed in a wider project aiming to document raw 3D representations of real-life object and then converting them into Augmented Reality (AR) to realize the virtual maritime museum of Terengganu Malaysia, for making it available to a wider public and also preserving its cultural heritage. Preliminary results are presented and discussed, highlighting relevant aspects that emerged during the experiment.**

Keywords—Augmented Reality (AR), Photogrammetry, 3D model, maritime

I. INTRODUCTION

Malaysian famous sailboat named Pinas, made by the local ship builder in eastern Peninsular Malaysia, Terengganu has been sustained for years since 1910 [1]. They developed the wooden boat with unique techniques without a plan by building first the hull and fitting the frames later. This traditional boat crafting technique and skills will soon be perished as the young generation does not find it interesting. In addition, the Chengal woods to build the boats also are currently high costs and limited as the Chengal tree is hardly been seen in the forest, because of deforestation. In this regard, it is important to preserve the designs as they are among country's heritages. The preservation work was mostly done through many methods; among them are documentation in books or manuscript (picture and text), video (in the case of cultural information : song, dance, or even documentary) and replication of the artifact [2], [3]. So, what is done to preserve this historic ship? Well, of course many researchers and companies around the globe has done various methods [3] and techniques [4] in order to reserve their historic monuments including ships. Most of them used laser scanning and photogrammetry in order to reconstruct the historic monument or object by collecting and processing the obtained 3D data.

In this study, photogrammetry method is used to generate 3D models at low cost by using only a smartphone. The targeted object will be the 25-cm-long scale model famous historic ship, "Flor de la Mar" before applying this technique on site. This method requires high spec computer for processing the 3D models. The most common used software for this method is Photoscan, Reality Capture, Alice vision, FlowEngine, Regard3D and Agisoft Metashape. Some of them are free open-source software solutions, which base their technologies on the core image processing libraries. The Reality Capture software gives better result output and fast meshing compilation compared with others [5], but this software is a paid licence where it provides limited access to some features for free users. While, for free open-source software, Agisoft Metashape is among the best, as it generates good output results with higher accuracy [5]. Therefore, in this paper, Agisoft Metashape is selected to build the 3D model of "Flor de la Mar" and making this model available to be viewed in AR by using Unity.

II. THE BOAT HISTORY AND BUILDING PROCESS

In Terengganu, traditional boats are famous for its building techniques and art designs. The uniqueness of wood carving on the boat attracts people from over the world to come and study. The creation of various craft products have its own meaning, where the designs are taken from the figure of birds, flora-fauna and shadow puppets character ('kulit wayang') [6]. Some of the design such as dragon head called 'naga' and stork bird built at the bowsprit as a figurehead. The people believe that it can avoid any bad spirit during sailing [7]. Then, when Islam came to the island, the wood craft changes into plant and flower arts.

The beautiful wood carving creates harmony environment to the sailor when set sail to the sea. Sometime, the strong waves during bad weather can cause lethal damage to the boat that could lead to shipwreck and kill all the crews onboard. That is why Terengganu boat builder made different types of boats which are Bedar, Sekoci, Payang and Pinas that focus on specific task. Bedar boat comes from the word "besar" in Malay language where it means big boat. This boat is used to carry merchandise from other states and transport people from one place to another. The big boat has high durability that is potential to sail out through the wide sea. While, Sekoci and Payang boats are used for fishermen to catch fishes as the boats are smaller than Bedar. These boats cannot sustain too long against big waves, because the structure of the hull is small and does not have waterline for water benchmarking. Lastly, Pinas boat which is the largest boat built at Terengganu than Bedar. This Pinas boat only used for deep sea navigation to distant ports as a transportation and goods exchange.

For this study, famous Pinas boat was chosen among the others for documentation process, as Pinas is no longer seen at the coast area in Terengganu. The Pinas boat named SABAR has been docked at the museum of Terengganu will be our boat reference. The boat was built by the generations of Hasni Che Ali, the famous boat builder that lived at Pulau Duyong, Terengganu. These craftsmen do not require plans or blueprints in building the boat. They used their experience and knowledge from try and error that passed down from generations to generations, while produce intricate designs with great precision and details. The survival methods from sailing experience make them more creative in building the boat even without basic knowledge of Archimedes principle [1]. These remarkable skills have earned international recognition by German sailor, Christoph Swoboda who bought the Pinas boat and named it as Rainbow Dragon 2 ("Naga Pelangi 2") which is the second boat that he bought from Hasni.

The work of making the boat begins with the laying of the keel followed stem and sternpost. These measurements are carefully made, leads by the craftsman with the help of his employees in order to maintain the quality of the results and also his reputation. Most craftsman will follow some simple formula as shown in the Figure 1, that has been inherited for generations for obtaining the boat's shape. This formula is considered efficient by the boat builder in terms of load, speed, and wood consumption.

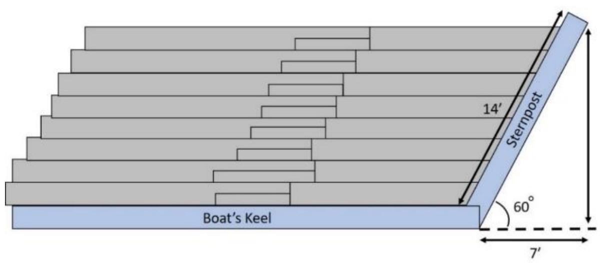

Figure 1: Simple right-angled triangle formula

Then, the sternpost and the keel are combined together using massive bronze bolt with the knee support. The first plank which is the garboard strake will be heated up first for bending process before fitting with the keel. At the same time, the craftsman marks the position of the dowels which joined the plank to the keel together, where the dowels were produced manually. These dowels made from a square cut piece of hard wood that firmly driven through a hole and thereby turn into a round dowel. The fitting process was added with the Gelam skin that seam with the dowels that taken from the Gelam tree to keep the boat dry for years. Then, the craftsman hammered the planks to meet the hundreds of dowels into the keel.

The craftsmen create two plywood frames at the middle of the boat to indicate the intended shape of the hull. The frames were fitted later into the finished half. The plank was tucked onto plank by means of the wooden dowels creating a hull, as if it were made in one casting shape. Next, constructing the ballast keel, where generally the boat does not carry external ballast, the boat itself is their ballast. In order to get more space inside the boat's belly, the ballast was built at the outside of the keel. On top of that, the center of gravity shifts downward resulting in an increase of the momentum to resist the lateral forces on the sail. The ballast will be held by the bronze bolts. Then, the molten lead will be poured into the casting mold by attaching the molten pans using Philip pipe. The pipe was being heated constantly until the molten leads are filled entirely into the lid.

Then, the craftsmen build the stern potion of the rubbing strake where this part protects the hull from chafe when going alongside a wharf. They used 15 thousand of silicon bronze countersunk screws hold the hull planks to the frames. The countersunk screws outside the hull were filled with white color waterproof epoxy putty as for sealing holes. While, the inside bolts were sealed with green protective paint for long lasting. The partition panels are fashioned in the style of the Malay wooden houses where all the wood works were hand crafted from solid wood. The companionway to enter the main cabin with galley, char table dick and cabin roof painted white because they were epoxy coated for waterproofing reasons.

After a lot of sanding process to the hull, priming coat of white paint is applied. This paint is water resistance that can sustain for years when set sail to the sea. Then, the craftsmen installing the bronze rudder fitting onto the sternpost before putting the rudder in place. Lastly, the boat is painted again for the second coating as to remove any previous painted defects. White color has been chosen for the hull by Christoph Swoboda, the buyer from Germany, as it looks clean and nice. The boat was then waiting for the painted to dry off and ready to be pulled out to the sea. The 2 masts and a bowsprit will be mounted onto the boat after it was safely moved to the water. The big mast called "Layar Agong" will be mounted at the middle of the boat. While, the other mast called "Layar Topan" will be at the front which the sail will be connected to the bowsprit using strong rope.

III. 3D MODEL PRESERVATION USING SMARTPHONE

Pinas was a great boat that made from Chengal wood which has extreme strength and hardness that highly flexible, but it cannot sustain forever at the museum. Therefore, Photogrammetry method was approached to document the boat into 3D virtual models, since it offers a powerful tool for conducting in-depth analyses, reverse engineering and creating database.

Digital photogrammetry is a technique to obtain 3D model by overlapping the captured images in measuring the size, shape and 3D geometric position of an object. The principle of operation is based on the assigned point located on the images. The points connection needs to be at least two images that could create the 3D object coordinates. The 3D model quality improvement could be made by increasing the intersection numbers of assigned points. These process has been proven by the researchers in reconstructing a 3D historic building using Reality Capture software [8].

The camera position method for photo capturing has been studied by the researcher, where the arrangement of the photos effect the construction of the 3D model [9]. The camera position is dependent on the size and shape of the object. In addition, camera selection also makes the 3D model differ from others, as camera has its own pixels and focal length that can be adjusted. The Figure 2.21 and Figure 2.22 show that the camera is repeatedly captured the images at a different angle and orientation according to the size of the object. These 2 techniques has been clarified by the observers that image capturing style are variant, where the camera flow-path are differ for every type of object [3]. A proper flow-path will come out with a good 3D model result because the back-bone software will create link-points estimation between the images according to its sorting flow in constructing 3D model.

For ground photo capturing is quite easy to handle as the object can be captured by using standard camera such as Nicon, Go Pro and even smart phone [10]. But, for a large object such as Pinas boat, need an aerial photographing to capture the boat's topmasts. Therefore, some researchers have done their studies on reconstructing a historical building by deploying a drone as a medium device to capture a large object [11]. This method can be applied on the Pinas boat because the masts are way up high for the ground method to capture. In addition, the construction accuracy of the 3D model will be improved, if the ground and aerial methods are combined together [11] as the images covered all side of the Pinas boat. Then, all the images captured will be process into structure from motion (SfM) software such as Reality Capture, Agisoft Metashape, and others. These software are popular among the researcher as it easy to deploy.

IV. COMPUTER VISION PHOTOGRAMMETRY METHOD

Computer vision photogrammetry is one of the 3D scanning method that can be done to recreate a 3D object by capturing photos. Most leading Computer Vision systems are characterized by Structure-from-Motion (SfM) imaging techniques that utilize feature-detection algorithms to automatically match and align overlapping multi-image datasets. Features matched in three or more images are located in a 3D coordinate system according to the principle of intersecting rays, in the process determining camera location and generating a sparse point cloud. After image alignment, additional features may be detected more efficiently by utilizing the known locations and orientations of the images in order to generate a dense point cloud. By interpolating between points to create polygons, a 3D mesh is created. After completion of the SfM process, the model may be further enhanced by generating a texture from the imagery and draping it over the mesh [12].

Over the past decade, Computer Vision photogrammetry software has become widely available across a broad range of open-source and commercial packages. While users should be cautious using the automated algorithms hidden within "black box" software packages [13], systematic test indicate that contemporary Computer Vision models are comparable to those produced with terrestrial laser scanners, and are sufficiently accurate for cultural heritage documentation [2]. Furthermore, the researchers [14], found that photogrammetric measurements of models created using Agisoft Photoscan which is a popular SfM software package also used in this study were accurate when compared to conventional measurements. However, in both studies, shorter measurements were found to be less consistent, possibly as a result of human error during conventional recording. Using currently available technology, it is now feasible to create accurate and detailed 3D models of cultural resources using relatively inexpensive camera systems and accessible off-the-shelf photogrammetry software [14].

In this experiment, smart phone Honor 9 Lite with 2 MP embedded depth sensor and 26mm focal length are used to take the pictures, and using stated SfM software, which is Agisoft Photoscan to generate pictures into 3D model. Even though the researchers have used the software in earlier 2014, the software still popular in 2020 because the software has been updated to the latest version as the hidden algorithms has been upgraded with more accurate pictures orientation results. There are other paid SfM software such as Reality Capture that has better back algorithm with more accurate and faster with less post-processing work in creating 3D object. Therefore, in this study both Agisoft and Reality capture software have been tested to gain better accuracy in term of dimensions.

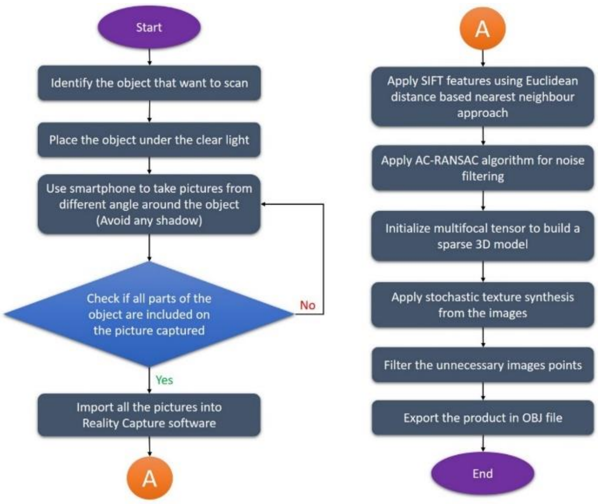

Figure 2: The scanning process flowchart using photogrammetry method

According to the flowchart, the process is straightforward that easy to follow and understand the steps.

The process is simple because the software has done all the steps for the user. During the process, algorithms in the software do the calculation, where it calculates the point localization for each image, images orientation, depth images and blur pictures filtering to create a precise 3D model of the object on the pictures. The researcher [15], went through these processes to reconstruct a 3D parts using photogrammetry method and reconstruct in SOLIDWORKS for applications in industry.

In depth, computer vision photogrammetry process flow starts with capturing the object's pictures. In order to generate a smooth surface 3D model, the object must be secured from any additional light disturbance and very low contrast light because will reduce the accuracy during calculation process [16]. Then, scale-invariant feature transform (SIFT) is applied on the software system for extracting from multiple view images that can be used to perform reliable matching between different views of an object. The SIFT, image descriptor, is a method for detecting interest points from grey-level to color image at which the local gradient directions of image intensities are observed with the intention that this descriptor should be used for matching corresponding interest points between different images.

Figure 3: Image acquisition of the ship model captured at different angle

In this configuration, first method of SIFT is by applying assignment orientation method in each Figure. This method allows the system create gradient lines on the pictures and labeled the directions based on feature point localization from image's pixels. Each pixel has its own neighbor which includes above, below, left and right. The equation of Pythagorean Theorem is used to identify the slop and angle of the line.

$$m(x,y) = \sqrt{\left(L(x+1,y) - L(x-1,y)\right)^2 + \left(L(x,y+1) - L(x,y-1)\right)^2}$$

$$\theta(x,y) = \operatorname{atan2}\left(L(x,y+1) - L(x,y-1), L(x+1,y) - L(x-1,y)\right)$$

- The center pixels will become the reference to obtain the value;
- Right neighbor (x+1), Left neighbor (x-1), Upper neighbor (y+1), and Below neighbor (y-1).
- The symbol (L) is the pixel color, (m) is gradient, and Theta is the angle obtained in degree.

This method was proven by [17], where the algorithm used to practice for image matching and object recognition. From the formula above, it creates a local gradient directions of image intensities from its neighbourhood around each of the interest point, with the intention that this descriptor should be used for matching corresponding interest points between different images. Therefore, during photo capturing, the object captured must be at least 60 percent overlap with the previous picture to obtain minimum 3 pictures can be matched at different orientation. Along with that, an appropriate contrast and camera focus should also be considered.

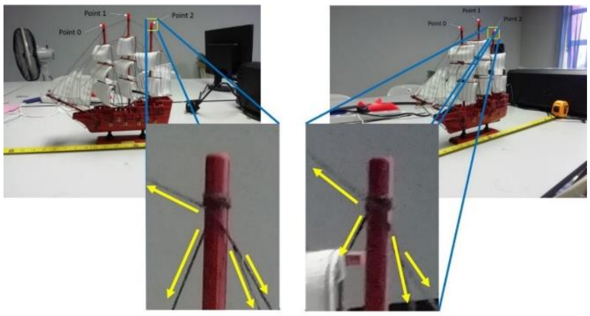

Figure 4: Ship model focuses on point 2, where the captured pictures are different in distance and angle of view by using the same device

In the Figure 4 shows that there are 3 points that pinned on the images for matching process. All the points have been assigned accordingly at the top of each mast because all the pictures taken includes the topmasts, but at different positions. This will be easy for the software to estimate the locations and orientations of the camera with a higher precision. The main constant variable during the picture capturing is the focal length (f) which is the zooming features. The camera has been set to normal state without changing the focal length while photographing. Both of the taken picture above shows the same image quality but when focus on the selected point, it becomes blur. This is because, the distance of the object from the camera are differ among the pictures. The blur images create a different pixel values which contribute to distance finding between camera and the object. While the SIFT method can obtain the camera orientation. Then, the pictures will match each other with the obtain result and recalculate the position and angle of orientation with the targeted object by applying point distribution method to create a 3D point clouds.

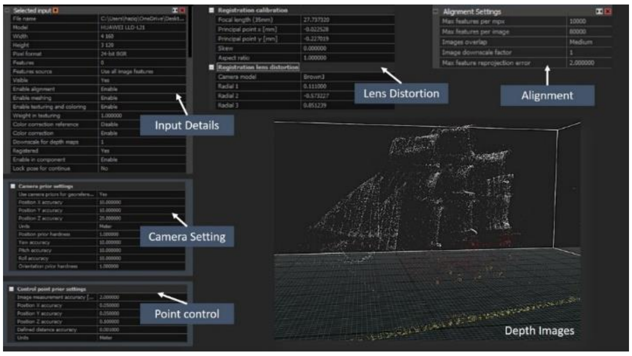

Figure 5: Depth image setup layout using Reality Capture software

The Figure 5 shows the point cloud view in 3D space after alignment process. The input details feature has been automatically updated according to the type of camera used. It is the same goes with the camera setting, where the data written is obtained over the internet automatically. Some of the researcher want to limit the point cloud by using control point settings to avoid laptop crash or hanging because of too much data and space used. While, the focal length is constant at approximate 27mm auto setup according to the camera spec. When all the data has been setup correctly, the point cloud will undergo meshing process followed by the texture projection to construct a proper 3D model. These processes take a longer time depending on the laptop spec. The processes have been done using laptop with high spec which are intel core i7, plus NVIDIA GEFORCE GTX 860M graphic card.

Lastly, the finished 3D model will be measured by using measurement tools from the software to get the dimensions, and transfer the data to CATIA software in generating the 2D blueprint. Unfortunately, the dimensions obtained maybe slightly inaccurate due to the camera calibration process. Therefore, the researcher [18] setup markers and targets to get accurate feature recognition and measurement calibration which many other research studies and company used. But it is not mandatory to have markers on the object. It also can be replaced with other things with known dimensions near the interest object such as measuring tape. From the Figure 3.13 shows the location of measuring tape located besides the ship model has been setup before photo captured. This will act as markers for measurement calibration process.

V. RESULTS

In this section, the replica ship model Flor de la Mar has been created by applying the same method as before, which is photogrammetry. The process starts with capturing photos of the model and transfer the images into the SfM software. The model has been placed under direct light to avoid any dark area as been explained before at chapter three. This will give sharp images during photographing and basically to prevent the compilation error during process.

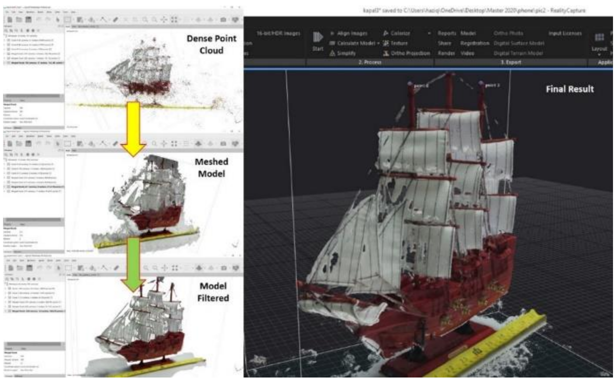

Figure 6: 3D ship model result from the alignment of the images and post-processing

In order to obtain the above result, 202 photos have been taken at every angle of the ship model to make sure all side of the model has been registered into images. In addition, the photographing pattern also need to consider as it affects the alignment process in the software. For this model, the image acquisition method in circular pattern has been applied in anti-clockwise direction based on the scale of the object. This method is not applied to all object. It depends on the size of the object that need to be captured. Therefore, for this model, it is suitable to develop 3D model using this configuration.

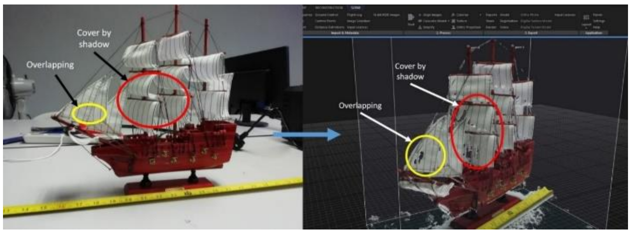

Figure 7: The defects occurred after completing the process

During observation, there are some holes on the 3D model that mostly at the staysail and mainsail of the ship. This occurred because of overlapping of the sails and covered by its own shadow as shown in the Figure 4.6. Therefore, this defect can be solved by pre-processing by using image editor to remove the shadow from the sails or add more external light during photographing.

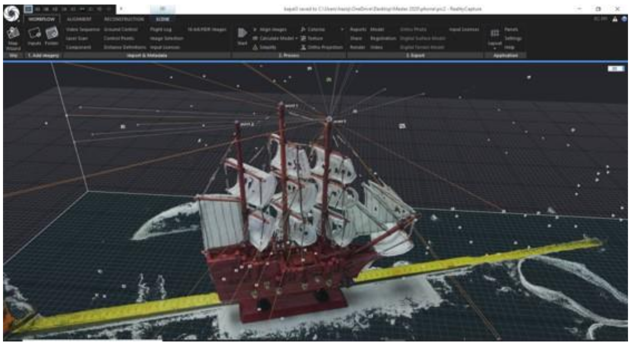

Figure 8: The images alignment focused on point 0

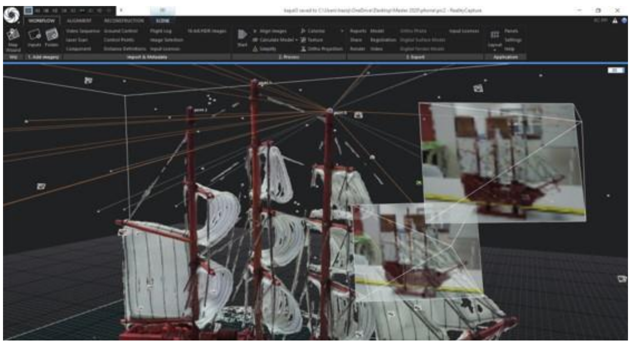

Figure 9: The system re-arranges the images according to the assigned point

The Figures show that the output process for images alignment that focuses on the point of interest (POI) that has been pointed. There are 3 total assigned points located at the topmasts, and each image that has same criteria will align based on the POI. The more the images aligned, the greater the output model result. While, the distance and the orientation of the images to the object has been calculated by the software according to the camera details such as focal length, and pixels.

A. Comparison (Reality Capture Vs Agisoft Metashape)

Figure 10: The images align according to the location of the captured photos

For the model of “Flor de la Mar”, 148 images were captured in the static position on top of the table at three camera heights. The images were brought into the two different processing programs which are Reality Capture and Agisoft Metashape software. Overall, the fastest total time spent processing is Reality Capture compared with Metashape. Metashape took an average total processing time of 154min with high accuracy setting. This model needs to be manually aligned as automatic alignment failed. Therefore, 8 points markers were assigned on the images to reduce the calculation errors during alignment process. While in Reality Capture, the total processing time took an average of 74min with the same accuracy setting with only 3 points markers were assigned on the top masts of the model. The output result shows that Reality Capture created more details and less open holes than the model on Metashape.

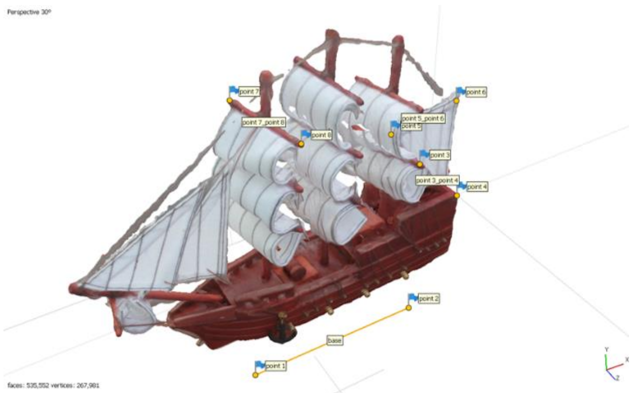

Figure 11: Located points mark on the 3D model

Though Reality Capture has the fastest processing time and quality output, it needs a paid license to export the model and create measurements. While, Metashape is an open-source for everyone to access and it is free to use. Therefore, Metashape were chosen for model measuring and confidence tests. Confidence model is the estimating performance of a population parameter at a certain area on the created 3D model. The color bar indicator on the left side as shown in figure 15, indicates the estimating performance area in percentage (%). The greater the percentage values, the higher the accuracy to become true model.

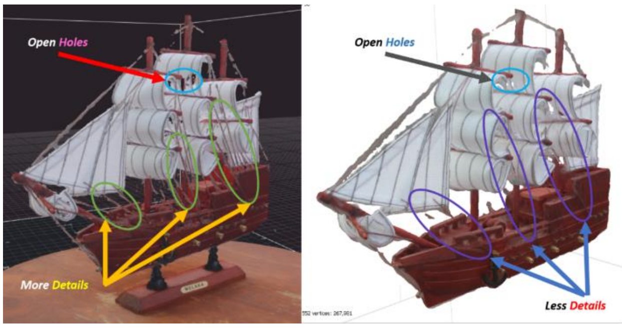

Figure 12: The comparison output result between Reality Capture (left) and Metashape (right)

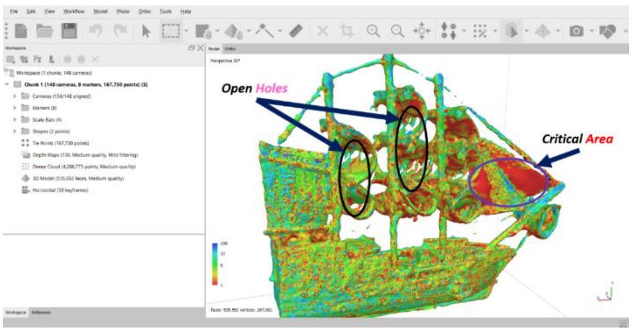

Figure 13: The performance percentage output model

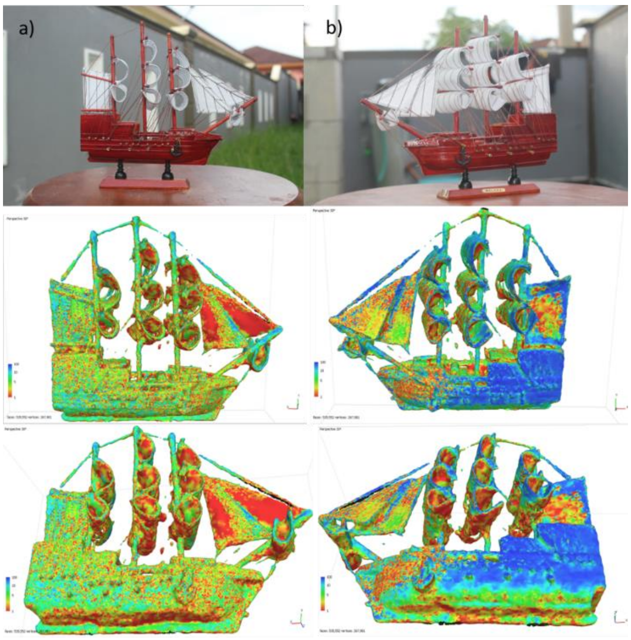

Figure 14: a) Image captured at starboard side of the ship b) Image captured at port side of the ship

The blue shaded color on the model represents the ideal value, which is about 95% exact measurements between the real object and the 3D model. While, the red shaded color is highly estimation measurement error with the percentage of only 1% to become true model. Most of the red shaded color are on the right side of the model and at the bottom of the sailcloth. This may due to the excessive light and shadow during the caption [19]. The images taken in the evening at the open space area, where the sunlight is hidden against the clouds. Therefore, during the photographing process, there are some surface areas are blocked and cover with shadows that could lead to estimation errors. In addition, the thin white sailcloth may become transparent during the caption as the light pass through the sailcloth. The transparent object will reduce the percentage of accuracy drastically during images alignment, as the system's algorithm initially estimates with wrong values [19]. Therefore, to reduce the percentage errors, points markers were used to help the system to identify the positions, orientations and depth of the model in the images.

B. Model measurement precision

Once the pictures alignment has been finalized, a polygonal model (structured data) is generated followed by texture in order to produce the best digital representation of the surveyed model. The produced model needs some editing, cleaning, and repairing process to close holes, fix incorrect faces and non-manifold parts before presenting the model into virtual platform. These repairing parts will be covered on another paper, as this research focuses on obtaining high accuracy by using low-cost hardware and software that can be applied on real-size Pinas. Therefore, the 3D model dimensions need to be assigned and compared in order to justify that this method can be used for documentation.

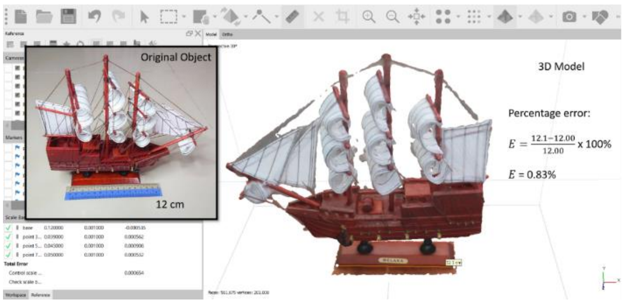

Figure 15: Calculation of percentage error for the base holder length

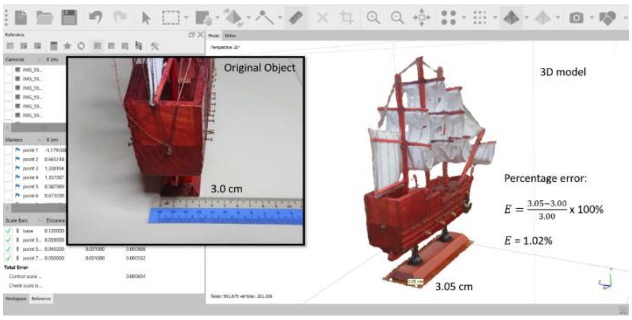

Figure 16: Calculation of percentage error for the base width

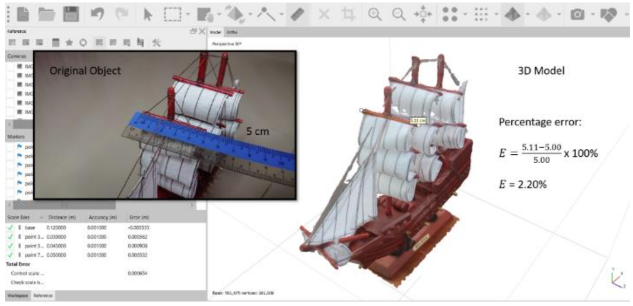

Figure 17: Calculation of percentage error for the sailcloth holder length nearer the topmast

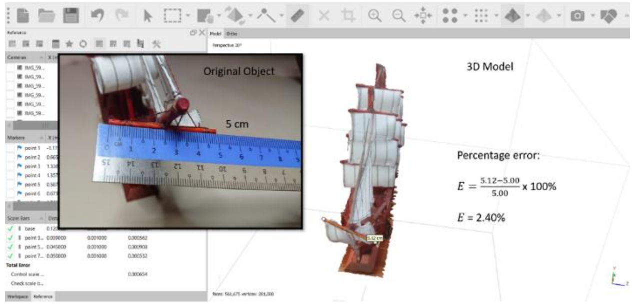

Figure 18: Calculation of percentage error for the bowsprit that holds the sailcloth length

This process starts by importing some known dimension values of the real object into the Metashape software to initialize the model's size ratio to 1:1. The length of the ship's holder will act as a reference by assigning the actual length value into the created scale bar in the software. The actual length of the holder has been measured by a ruler, where the value shown is 12 cm. On the other hand, the holder for the 3D model shows 12.1 cm value, where the percentage error is less than 1%. Next, the width of the actual value is 3.0 cm, while the model's width value shown is 3.05cm. The percentage error increases to 1.02% from 0.83%. It seems that the width of the model has higher error value than the model's length. Then, the sailcloth holder nearer the topmast also has been measured, and the original length is 5 cm, while the model's value is 5.11 cm, where the length error is about 2.20% from the actual length. Lastly, the highest error that has been measured is 2.40% at the bowsprit that holds the sailcloth, where the original length is 5 cm, while the model's length shows 5.12 cm. In conclusion, Metashape software has the ability to scale the model into original size, which is 1:1 scalar with the precision of 97% successful rate for this model. Therefore, this method is very suitable to use for the real-size Pinas that is approximately 9 m length, 3 m width, and 12 m height.

C. AR development

Augmented Reality technologies offer practical ways to enhance the sense of reality by combining the real and virtual objects into a real environment. The previous 3D model can be exported into this AR environment which can be used to increase the motivation, and participation of people while performing learning activities at the museum.

This type of technology is useful as it only requires minimal spaces, and always keep this national treasure safe from damage without monthly maintenance.

There are many platforms that can be used to visualize the 3D model into virtual platform in real world. Some of the company such as Unity has the plugin feature to use AR environment, which is Vuforia package. Vuforia is a free license AR interfaces that useful for those who want to develop AR application. The Vuforia detects QR-codes, images, and 3D object as a medium access to project the 3D model. This method is used in this project because it can be easily displayed the 3D model in AR mode by using smartphone or desktop PCs.

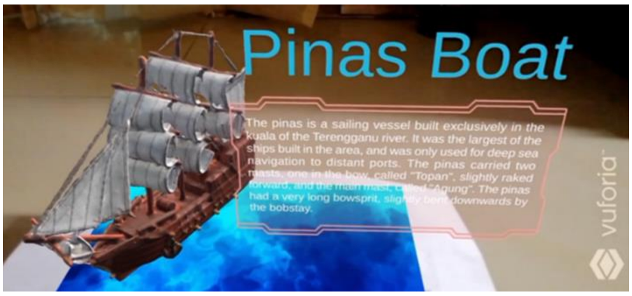

Figure 19: Screenshot of the 3D model ship in AR platform using smartphone

In Unity, the 3D model has been edited by adding some information to the model, and add some water effects to make it more attractive. Then, this model is exported into APK file application for android user. This application uses image detector by using phone's camera to initialize the model location in real world. The model will show up on the targeted image, when the camera is focus on the image. This method is simple and interesting, as it visualizes the invisible that hide on a piece of an image.

VI. CONCLUSION

Current stage development of the 3D model ship has met the requirements of getting the 3D model as well as the dimensions. The model of Flor de la Mar ship will be able to act as successful sample for the next scan which is SABAR, the Pinas. The current method was able to provide accurate dimensions and develop the 3D model view with good quality texture which is considered significant information to make a blueprint. However, there are parts that are under consideration to further study. One of the ongoing efforts is to study the design of Pinas inner frame where it is closed tightly by glue and wooden dowels. It is hard to identify the length and the quantity of the fitting frames used inside the Pinas just by looking the body frame. Therefore, if there are no solutions to solve the problem, the inner frame will be considered as one solid frame. Currently, the inner frame is still in searching process to solve the problem. While the other process such as 3D model making has been successfully achieved. For the AR system, it will make a good learning tools for the visitors to study more on the Pinas as well as attracting them to the museum.

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