UNIVERSITI TEKNOLOGI MARA

PRESERVATION OF CULTURAL HERITAGE: A COMPARISON STUDY OF 3D MODELING BETWEEN LASER SCANNING, DEPTH IMAGE AND PHOTOGRAMMETRY METHODS

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MSc

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Thesis submitted in fulfillment
of the requirements for the degree of
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CONFIRMATION BY PANEL OF EXAMINERS

I certify that a Panel of Examiners has met on 20 December 2022 to conduct the final examination of Mohamad Haziq bin Ahmad Yusri on his **Master of Science** thesis entitled "Preservation of cultural heritage: A comparison study of 3D modeling between laser scanning, depth image and photogrammetry methods" in accordance with Universiti Teknologi MARA Act 1976 (Akta 173). The Panel of Examiner recommends that the student be awarded the relevant degree. The Panel of Examiners was as follows:

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AUTHOR'S DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Teknologi MARA. It is original and is the results of my own work, unless otherwise indicated or acknowledged as referenced work. This thesis has not been submitted to any other academic institution or non-academic institution for any degree or qualification.

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ABSTRACT

Preservation of historic structures is of paramount importance to avoid the loss of Malaysia's architectural heritage. This study proposes a multi-technique approach for capturing and documenting historical legacy, focusing on the creation of three-dimensional (3D) model representations of physical artefacts and the utilization of orthographic projection to document design. The study employs three primary techniques, namely laser, depth imaging, and photogrammetry, to create a three-dimensional object, followed by a comparative evaluation of their effectiveness. To evaluate the techniques, a case study is conducted, utilizing a 25cm scale model of the historical Portuguese Indian Armada ship "Flor de la Mar" as a sample for 3D model record development. The outcomes indicate that photogrammetry is the most effective technique in terms of accuracy, precision, and visualization, while laser scanning and depth imaging produce less precise point cloud data. The photogrammetry method attains 97.6% accuracy in terms of dimensions and shapes. Based on the results, this promising technology can be employed to document data blueprints for the actual measurements of classic ships.

Keywords: *historical preservation, 3D scanning, laser scanning, depth imaging, photogrammetry*

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Abbreviations

LiDAR	Light detection and ranging
ROS	Robot operating system
SFM	Structure from motion
1D	1 Dimension
2D	2 Dimension
3D	3 Dimension
RGB-D	Red, green, blue, depth usually for camera
CMM	Coordinate measurement machine
TOF	Time of flight
IMU	Inertial measurement unit
UI	User interface
OS	Operating system
IR	Infrared
SDK	Software development kit
ICP	Iterative closest point
AR	Augmented Reality
VR	Virtual Reality
LMT	Laser measuring tool

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Preservation refers to the act of maintaining and safeguarding objects or non-objects for future reference. This study aims to investigate the most effective method for preserving historic maritime buildings, specifically traditional boats. The research outlined in this thesis involves conducting experiments on a scale model of a traditional boat in the form of a three-dimensional (3D) model.

This section provides an overview of the study, beginning with a discussion of the importance of preserving traditional boats in our country. It then presents the problem statements, research objectives, and research questions that guided the study. Additionally, this chapter outlines the limitations of the study and the significance of its findings. The discussion in this chapter concludes with a summary of the key points presented.

1.2 Research Background

Since the 19th century, Malaysia has been a developing nation (Ahmad et al., 2013), and the technological revolution is crucial for its future growth. As technology advances, traditional building methods are becoming forgotten.

In East Peninsular Malaysia, Terengganu, the development of distinctive traditional sailing ships was a significant event (Latif et al., 2015). These ships were wind-powered vessels made of Chengal wood, which were built by Malay craftsmen such as Hasni Che Ali on Pulau Duyung. The Pinas, Payang, Bedar, Sekoci, and Kolek are some of the traditional ships built by him and bear his name as a testament to his skills as a designer and maker. It is worth noting that many of these ships were built without the aid of blueprints or designs. In 1955, a Malay ship, Pinas, was even featured on a British postage stamp (Ahmad et al., 2013). The Malays have been building this type of watercraft out of Chengal wood since the 19th century, and it is an important part of Malay maritime culture. One of the more experienced craftsmen in Terengganu was Hasni Che Ali, who lived on Pulau Duyung. Many of the traditional ships he created, such as the Pinas, Payang, Bedar, Sekoci, and Kolek, bear his name as a testament to his skill as a designer and maker. These shipwrights build sailboats from the bottom up, without the aid of any blueprints or designs. Crafting traditional vessels requires patience, specialized woodworking skills, and a lack of interest among the younger generation. Therefore, it is crucial to preserve antique sailing vessels because they represent the culture of the people of Terengganu. Currently, Laser Measuring Tools (LMTs) and Measuring Tapes (MTs) are the most commonly used technologies for measuring structural elements.

Generally, the preservation of cultural heritage entails safeguarding the artifacts and traditions of a community from factors that may alter or weaken them. Typical instances of cultural heritage preservation include the refurbishment of historic edifices, the transmission of ancient skills, and the documentation of folk tales. UNESCO, on the other hand, defines cultural heritage as "the legacy of physical artifacts and intangible qualities of a group or civilization that are inherited from past generations, maintained in the present, and bequeathed to future generations for their benefit". The following points outline the scopes of preservation:

- Monuments: Architectural works, monumental sculptures and paintings, structures or elements of an archaeological nature, inscriptions, cave dwellings, and combinations of features that hold outstanding universal value from the perspectives of history, art, or science.
- Groups of buildings: Separate or interconnected buildings that, due to their architecture, homogeneity, or location in the landscape, are of exceptional universal value from the standpoints of history, art, or science.
- Sites: Man-made works, natural features, and combinations of both, including archaeological sites, that possess outstanding universal value from the viewpoints of history, aesthetics, ethnology, or anthropology.

In regard to heritage preservation, the most frequently employed techniques comprise of documentation in books or manuscripts, videography (for cultural information such as music, dance, or films), and the replication of artifacts. In recent times, the field of three-dimensional architectural heritage reproduction has emerged as an exciting and demanding academic area. For instance, a 3D reconstruction of a historical building can be accessed online by people worldwide. In fact, this is not a novel concept that hasn't been explored and experimented with previously.

Through the literature review, various strategies have been developed for Three-dimensional preservation tasks. In general, the 3D information about a historic structure can be gathered using a combination of laser scanning, depth imaging, and photogrammetry. Laser Range Scanner called Light Detection and Ranging (LiDAR) sensor that uses light in the form of pulse laser to measure distance. Over the past years, LiDAR has been used in robotics sector to avoid obstacles within a pre-determined range. (Sui & Lin, 2020) design an autonomous household cleaning robot using low-cost 2D LiDAR in a Robot Operating System (ROS) environment. The LiDAR collects surrounding data while the cleaning robot moves throughout the entire room and later construct a two-dimensional (2D) map. Interestingly, LiDAR is also capable in creating a three-dimensional (3D) mapping by making fine adjustments to the 2D model. For instance, (Queralta et al., 2019) used a multiple rotating 2D LiDAR to produce a 3D world visualization using ROS environment while (Lercari et al., 2018) developed a 3D perception system robot using a single 2D LiDAR. Meanwhile, depth Image uses Kinect which packed with an RGB camera, a depth sensor, and four microphone arrays for better motion capture capabilities, and help it recognize a user's facial features and movements. The Kinect camera collects colour and 3D depth photographs at 30 frames per second, resulting in a cloud of colour and depth images based on an infrared pattern on the scene. It can scan both human motion and depth images. (Siv et al., 2018) used Kinect Version 2 to rebuild a 3D human face and applied the Poisson surface approach to reduce noise. The scanning region focuses primarily on the subject's face, and the distance between the Kinect's console and the person is designated between 500mm and 700mm. When the Poisson surface method is employed, the outcome shows a smoother surface of the 3D reconstructed face when compared to the surface generated without the Poisson method.

The final technique involves utilizing photogrammetry to create a three-dimensional model to measure the dimensions of traditional sailing vessels. (Apollonio et al., 2021) employed a photogrammetry-based approach to construct a 3D representation of museum assets. The authors proposed a combination of mobile equipment-based acquisition and real-time rendering. To achieve photogrammetry, two independent devices and four distinct targets were employed for calibration. During this experiment, two devices were used - the iPhone X and Nikon DS200. Four distinct objects were analyzed for their quality and accuracy: the Marsili Bust, Heracles, Horn d'Arturo's Globe, and Porcupine Fish Artifacts. The photographic results obtained from the iPhone X (smartphone camera) met industry standards for superior image quality within a streamlined photogrammetric procedure and were essentially identical to those obtained from the Nikon DS200 (SLR camera). Previous studies indicated that these techniques could be effective for scanning a specific object. However, while reliable and accurate scanning technologies are not yet available, their application for scanning a specific object is still in the experimental stage. (Ahmad et al., 2013, 2013; Latif et al., 2015).

This thesis focuses on the archiving of traditional ships as digital data and aims to establish a digital blueprint that can guide future initiatives. In the initial phase of the inquiry, all three scanning technologies will be evaluated to determine the most effective method for scanning ancient sailing vessels. To develop a measurement standard, a real-world case study will be designed, and a 25-centimeter-long wooden replica of the famous Portuguese Indian Armada, the "Flor de la Mar," will be employed as a sample. Using the scanning methods mentioned above, the experiment will be conducted to obtain precise measurements of structural members. Finally, the scanned sailboat will be converted into a digital 3D model using the program 3D Modeler.

1.3 Problem Statements

Traditional boats are facing a threat of extinction due to several factors such as the increase in raw material prices, illegal logging, aggressive deforestation, and fewer workers wanting to be traditional boat builders. The preservation of traditional boats is of utmost importance to ensure their survival for future generations. This study aims to address this problem by preserving a scale model of a traditional boat in 3D data form. The study compares the output results of three different methods, which are the laser method, depth imaging method, and photogrammetry method. The primary objective is to develop a high-accuracy 3D model of the traditional boat that can serve as a guide for future initiatives. This will be achieved by evaluating the effectiveness of the different scanning technologies and developing a measurement standard.

1.4 Research Objectives

The main objective of this research is to create a digital archive of traditional ships using 3D scanning techniques and to establish a digital blueprint for future initiatives. To achieve this, the following specific objectives have been identified:

1. To explore and identify affordable 3D scanning technology and software that can be used to accurately capture tangible cultural heritage.

2. To compare the dimensions of the 3D model generated from scanning with those of the real model, and to evaluate the accuracy and precision of the scanning process.

3. To demonstrate the suitability of the 3D scanning approach for documentation and preservation of traditional ships as tangible cultural heritage.

1.5 Research Questions

The following research questions were constructed based on the research problem:

a) What are the best affordable devices and software to obtain high accuracy and precision 3D model?
b) What are the pros and cons from these three methods: laser scanning, depth imaging, and photogrammetry?
c) Is it possible to replicate the model into 3D data with high level of details by using those three methods?
d) Is it possible to document the digital data only by 3D scanning?

1.6 Significance of the Study

This study is significant in several ways. Firstly, it addresses the urgent need to preserve traditional ships, which are becoming increasingly scarce due to a variety of factors, such as deforestation and declining interest in traditional boat building. By archiving traditional ships as digital data and establishing a digital blueprint, this study ensures that these cultural artifacts can be preserved for future generations.

Secondly, this study employs cost-effective technology and software to provide high-precision measurements of traditional ship models. This approach can be used to document other types of relics or artifacts, contributing to the broader field of cultural heritage preservation.

Thirdly, this study utilizes advanced augmented reality technology to create interactive interfaces that can generate interest among younger generations. This approach has the potential to increase public engagement with cultural heritage and promote its preservation.

Lastly, this study creates a draft plan of the ship model in orthographic view, which can serve as a reference for future preservation efforts. The data gathered from the 3D scanning approach can be stored digitally and accessed from anywhere, making it an accessible resource for researchers, preservationists, and the general public.

Overall, this study presents a promising possibility for the preservation of historical buildings and cultural artifacts, contributing to the conservation of our nation's heritage.

1.7 Limitations of the Study

While this study provides valuable insights into the effectiveness of various scanning methods for preserving traditional ship models, there are some limitations to consider. Firstly, the experiment was conducted solely on a replica model, which may not be representative of the intricacies and variations present in actual historical ships. Additionally, the scanning process only captured the outer surface visible to the naked eye, which may not provide a comprehensive understanding of the ship's structure. Furthermore, the study did not delve into the black box formula behind the post-processing software, which may impact the accuracy of the resulting 3D model. The comparison between methods was based solely on output results and techniques used, without considering other factors that could affect the quality of the model. Lastly, the documentation of the 3D model was presented only in orthographic view and through augmented reality technology, which may limit the accessibility of the data to those without access to AR devices.

1.8 Conclusion

This study provides insights into the best approach for preserving traditional boats, which are facing extinction due to several factors such as the high cost of raw materials and the scarcity of skilled workers. By utilizing three 3D scanning methods, this study compares and evaluates their precision, accuracy, and cost-effectiveness. Although the scanning process only covers the outer surface of the model, the results demonstrate the potential for this approach to be applied to larger and more complex structures. Additionally, the use of augmented reality technology allows for the creation of interactive and engaging interfaces that may pique the interest of younger generations. While the study has limitations, such as only using a replica model and not studying the black box formula behind the software's post-processing, it provides a valuable contribution to the preservation of tangible cultural heritage. In future research, more sophisticated techniques could be explored, and the potential to apply the approach to other types of relics and artifacts could be investigated.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter delves into the importance of preserving cultural heritage and explores several methods used by researchers to achieve this. It begins by defining tangible and intangible cultural heritage and providing examples of previous research studies that have used laser scanning, depth imaging, photogrammetry, and other methods to preserve historical values across the world. The chapter then delves into the details of each method. Laser scanning is discussed, including the various types of laser scanning, such as 1-dimensional (1D), 2-dimensional (2D), and 3-dimensional (3D). The chapter also highlights previous studies that have used these methods to obtain 3D models. The chapter then covers the depth imaging method, which focuses on using Kinect sensors. It highlights three different Kinect versions: Xbox 360 Kinect, Xbox One Kinect, and Azure Kinect sensor, to obtain 3D models. Next, photogrammetry is discussed, which focuses on both ground and aerial scanning techniques, and captures objects depending on their size. Finally, the chapter reviews the use of augmented reality (AR) in cultural heritage preservation. The chapter concludes by summarizing the importance of cultural heritage preservation and the potential of these methods to achieve this goal.

2.2 Type of preservation

2.2.1 Introduction

In this section, we will examine the two categories of national cultural heritage: tangible and intangible. Tangible cultural heritage refers to physical objects, structures, and places that have cultural significance and historical value. This includes things such as buildings, monuments, artifacts, and archaeological sites. Intangible cultural heritage, on the other hand, encompasses traditions, customs, beliefs, and practices that are passed down from generation to generation. Examples of intangible cultural heritage include music, dance, storytelling, festivals, and traditional knowledge.

Preserving national cultural heritage is crucial as it not only provides a link to the past but also helps to shape our collective identity and sense of belonging. Cultural heritage reflects the values, beliefs, and practices of a society, and preserving it ensures that these are not lost over time. This is particularly important in a world where globalization and modernization have resulted in the erosion of many traditional cultures and practices.

As researchers, our task is to find ways to document and preserve these cultural heritage objects, structures, and practices so that they can be passed down to future generations. By doing so, we can ensure that our cultural heritage is not lost and that it continues to be a source of pride and inspiration for our communities.

2.2.2 Preservation for tangible cultural heritage

The historical buildings and monument are the places of attraction to the researchers for doing their studies. The researcher (Li & Nan, 2021) in their study, they explore the urban area and make a study on preserving the urban tower St. John by using laser scanning and digital photogrammetry. While (Condorelli & Rinaudo, 2019) used photogrammetry and machine learning to document the cultural heritage. They combined the data in the form of videos to create a 3D model. Then, (Ghandali et al., 2019) take the chance by replicating the artifacts by using 3D printing technology after obtaining the 3D model. The purpose of replicating is to protect the original artifacts from any type of damages. In addition, the replica model can be used for display and future study.(Zahraa Sameer & Fanar M. Abed, 2020) used the method of reverse engineering techniques to conserve and restore the artifacts by using 3D laser scanning. Followed by (Wilson et al., 2022), where the researchers using the same concept which is laser scanning and 3D printing in preserving the Roman tablet artefact. This method needs higher accuracy detection to detect the Roman word written on the tablet before it disappears. Therefore, the researchers using high precision laser scanner to collect all the data. Meanwhile, (Gomes et al., 2018) using red-green-blue depth (RGB-D) cameras for 3D reconstruction by extracting from the images captured. Lastly, (De Paolis et al., 2022) presented the works of 3D model using virtual reality platform to enhance the inaccessible historical artifacts by the society. Therefore, this method allows historians and architects to explore the artifacts or monuments in virtual world as they were in the past and make them easy to study the evolution of technology.

2.2.3 Preservation for intangible cultural heritage

The researchers from Greece, (Grammalidis et al., 2016) introduced i-Treasure where a collection of rare intangible cultural heritage that contains video, audio, motion capture, depth, and ultrasound data. They used Xbox 360 Kinect to record the depth position and locations for each dancer, the movement, timing, and pose are all captured and stored in the database. The methods are the same as (Hou et al., 2022) study, where they digitalize the data of intangible cultural heritage such as storytelling and experiences. They used edutainment method in the digital realm which they documented the historic culture into the game. In addition, they presented the data in virtual space that makes more interactive in digital story telling. (Mah et al., 2019) and (Selmanović et al., 2020) also developed the virtual space presentation to give the people opportunity to be there and feels the environment of cultural heritage. In the study by (Selmanović et al., 2020) stated that most of the participants using the virtual reality (VR) headset are women compared with men. Most of them are enjoyed the view and obtained some experience from VR device. The researchers (Tan et al., 2020) created learning the intangible cultural heritage through augmented reality (AR) experiences. The people can have their own virtual tour guide by using AR technology. This will give more space and leisure time for the user to enjoy learning the intangible cultural heritage seeing the virtual dancing and singing moves and play in the real life.

2.2.4 Conclusion

In conclusion, tangible and intangible cultural heritage have many ways and methods to document and preserve them. We have seen that most researchers used laser scanning, depth imaging, and photogrammetry in duplicating the artifacts and cultures. They stored the data on the internet where everyone can easily access the web to learn more about the artifacts or cultures. Moreover, they are researchers used virtual technology to enhance the artifacts and cultures into a better learning process to make it easier to understand. Therefore, this study is categorized under tangible cultural heritage where the aim is to preserve the traditional boat by documentation into a 3D model. Eventually, the research is about to identify the best method to preserve the traditional boat by experimenting on the scale model using three different methods which are laser scanning, depth imaging, and photogrammetry that has been used by previous studies.

2.3 Laser scanning method

2.3.1 Introduction

In previous section, we have talked about type of preservation and has concluded that this study is a tangible type in cultural heritage study. The aim is to document the scale model. They are three methods that we can used to extract the 3D data from the actual object which are laser scanning, depth imaging, and photogrammetry. In this section, we will look at the laser scanning method to preserve the cultural heritage. There are three different types of laser scanning which are 1-dimensional (1D), 2-dimensional (2D), and 3-dimensional (3D) laser scanning. We will go through each of them in this section. Then, we will look at the capability of the sensor in two different environment which are indoor and outdoor area. After that, we will look at the components and devices that can read the laser sensor. Lastly, we will look at the main system that control the whole system which is the robot operating system (ROS). Then, we end up this section with conclusion.

2.3.2 Characteristics of light detection and ranging (LiDAR)

LiDAR shortform for light detection and ranging, is the famous laser device to obtain high precision data either in 1-dimensional (1D), 2-dimensional (2D), or 3-dimensional (3D). This LiDAR technology using time of flight (ToF) concept. ToF is the reflection of the emitting rays from the device scanner that will provide information about the object. In addition, the time that elapses between emission and detection yields the distance to the object since the speed of the laser light is precisely known (Xu et al., 2013). The standard measurement device, conventional coordinate measurement machine (CMM) has been widely utilized in industrial standard because of their high precision contact sensor (Isa & Lazoglu, 2017). This sensor is expensive and slow due to the higher scanning per frame with their laser in obtaining very precise data.

Figure 2.1 The lists of 3D scanner available at the market

The scanned data were recorded to visualize the model in a 3D virtual environment. This data will process by using specific software in developing dense 3D point clouds that roughly visualize the 3D model. Some researchers (Queralta et al., 2019) developed a system using a cheaper LiDAR sensor for 3D field mapping by attaching it to the drone as aerial laser scanning. This method is suitable for scanning the traditional boat where the height is approximately about 10m from the keel to the topmast. But this aerial 3D scanning method is hard to control as it needs an extra supporting sensor such as GPS and IMU which locates the position and orientation of the drone before scanning process. The data accuracy depends on the quality of the LiDAR sensors (Xu et al., 2013) as the sunlight wave frequency will disturb the LiDAR detection when applying the scanning process outside the building. Therefore, noise tolerant is applied to the data imager in obtaining clearer 3D image as well as 3D model (Fassi et al., 2013).

The simple way to create the 3D model is by developing our own 3D scanner platform which is much cheaper than buying the 3D scanner itself. We can setup our own algorithm that can manipulate the laser sensor data from 2D coordinate points into 3D coordinate to form a point cloud. 3D scanning the static object is not a new method for developer or researchers. They have their own method and design to extract the model into 3D point cloud using laser scanner. In this project, we aim to scan the scale model using 2D LiDAR sensor to obtain 3D point cloud data of the model structure. The idea is the same as the researcher named M.R. Shahrin where he and their team members developed the simple 3D scanner using 2D LiDAR and two servos that operate the 2D LiDAR in a spherical domain (Norzam et al., 2019). This method needed multiple sweep scan from various locations to create complete 3D model point cloud. Other researchers, et al. K. L. NG and his team developed using the same principle which mapped the surrounding area using 2D LiDAR and 1 servo motor only (Sui & Lin, 2020). These two researchers using low-cost devices which is Arduino Uno as the microcontroller to scan their model and plot the points in real time processing. Least square deviation point was used by M. R. Shahrin for the calibration method to allocate the points into 3D data space. Due to the certain noise from the reflection of light in the data collections, some of the data obtained are not accurate (Sui & Lin, 2020). This can be confronted by using advanced 3D laser scanner which is expensive. Therefore, in this study, industry grade of 2D LiDAR (A2M8) is used in the experiment to obtain and allocate the points into point cloud. Meanwhile, the hardware used is raspberry pi 4B 8GB RAM to read the sensor data and plot them on the 3D cartesian plane in Linux environment.

2.3.3 Different between 1D, 2D, and 3D laser scanner

Laser scanner technology is used to perform remote mapping of an area by transmit the laser to the surrounding. The laser projected to the object with the speed of light and bounced back to the sensor to measure the distance during the flight. This phenomenon called as time of flight (ToF), which measure the time taken of the light speed. This can be easily calculated as the speed of light is a constant value. Knowing the position and orientation of the sensor, the XYZ coordinate of the reflective surface can be calculated. By repeating this process continuously, the collected data points build up a complex ‘map’ made up of combining all the data points together. This discussion has been stated before where LiDAR sensor is under the laser scanner family. There are three category of LiDAR sensor which are 1D, 2D, and 3D LiDAR. A 1D LiDAR sensor is a static laser beam that measure the distance between sensor and the obstacle on one dimension as a single point-and-shoot distance measurement. For a 2D LiDAR sensor, a laser beam is projected on a spin movement and collect the horizontal distance to the targets to obtain the data on X and Y coordinate. While a 3D LiDAR sensor has several laser beams projected on the vertical axis to obtain the data on X, Y, and Z coordinate. Each laser beams have an angle delta with other beams. Therefore, in order to duplicate a 3D model, we have to ensure that the data also must be in 3D coordinate. 1D LiDAR is basically one dimension data which has only one coordinate position that could be X, Y, or Z coordinate. To obtain a 3D data the 1D LiDAR needs to combine with additional devices such as servos, or stepper motors to rotate the 1D LiDAR in 360-degree rotation. (Isa & Lazoglu, 2017) developed small 3D scanner using 1D LiDAR by adding another stepper motor to move the 1D LiDAR upward, downward, left, and right position. (Furukawa et al., 2018) created a flying laser sensor using 1D-LiDAR which they control the light travel by using reflection of mirror. These two researchers successfully developed high precision 3D scanner using only 1D LiDAR. This conclude that even 1D LiDAR can create a 3D model by adding supporting devices such as stepper motors and servos.

For 2D LiDAR, the data scanned in 2 dimension which contained only 2 coordinates. So, by using the same principle as 1D LiDAR, we can add another servo motor or stepper motor to obtain another angle to form a complete 3D coordinate. (J. Sun et al., 2016) created a 3D scanner using 2D LiDAR which combine with one stepper motor to get the 3D laser point cloud data. The data obtained in 3D point cloud with no visible colour. (Rehman et al., 2019) using 2D LiDAR sensor to scan the cubic box while moving around it. They combine with the inertial measurement unit (IMU) sensor to locate the position of the 2D-LiDAR. Then, the data is combined with the 2D-LiDAR sensor to form a 3D point cloud. For this 2D LiDAR sensor need another hardware device such as stepper motor, servo or IMU to complete the 3D coordinate. Therefore, instead 1D LiDAR need another 2 additional devices, 2D LiDAR only need another 1 additional device to complete the scanning.

Lastly, 3D LiDAR is a common sensor that has been used to scan any model perfectly into 3D model. They usually combined with the camera to obtain the colour of the object. (Gong et al., 2013) used 3D Velodyne LiDAR to scan the surrounding area. They add camera for colour reference and combine with the data gathered from the 3D LiDAR to form textured 3D model. (Skabek & Kowalski, n.d.) used the 3D LiDAR to rebuild the cultural heritage object into 3D model. The same principle goes to (Parfenov et al., 2022) where they reconstruct the damaged and destroyed cultural heritages into 3D model for repairing and documenting. This 3D LiDAR technology has gone better and better until nearly perfection that also can be used in industry studied by (Rao R et al., 2018) because of its precession. In the marketplace, 3D LiDAR is the most expensive sensor compared with 1D LiDAR and 2D LiDAR sensors due to its high precision. Therefore, 3D LiDAR is the best sensor to scan or replicate the cultural heritage structure with high precision. But due to the aim of this study is by focusing on affordable 3D scanning method, we used 2D LiDAR and additional device such as stepper motor to obtain the 3D model.

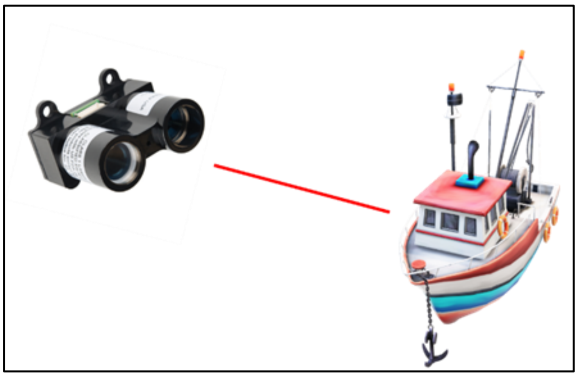

Figure 2.2 1D LiDAR projection beam

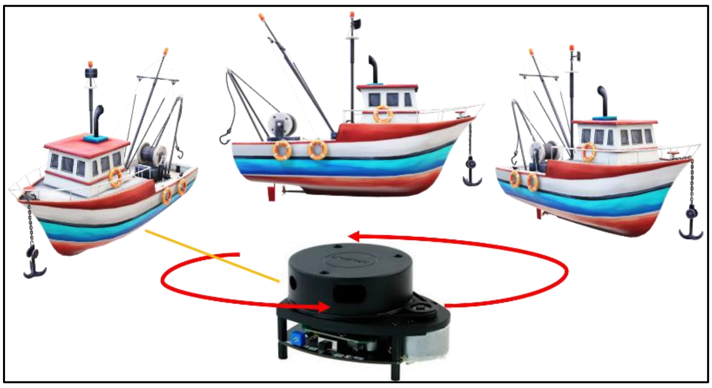

Figure 2.3 2D LiDAR projection beam

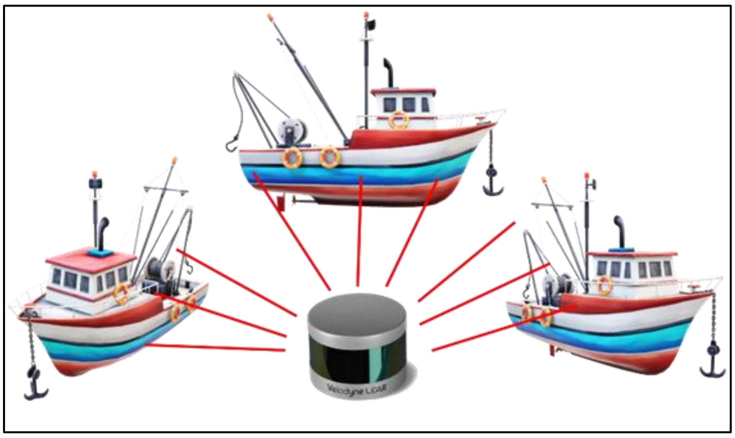

Figure 2.4 3D LiDAR projection beam

2.3.4 Indoor and Outdoor laser sensor

A laser beam for each LiDAR sensor emit with different wavelengths depends on the type of sensor. Some wavelengths have a higher potential that can harm the human eye and damage the retina. Therefore, the industries have limited the wavelength to use for certain job. These are the LiDAR wavelengths used in certain situations:

- Infrared wavelengths are in the range of 1500 to 2000 nm and are usually used for meteorology or Doppler LiDAR in scientific use.
- Near-infrared wavelengths are in the range of 850 to 940 nm and are usually used for terrestrial mapping.
- Blue-red wavelengths are in the range of 500 to 750 nm and are usually used for bathymetry sector.
- Ultraviolet wavelengths are in the range of 250 nm and below and are commonly used in the meteorological sector.

According to these wavelengths, only a few of the LiDAR sensors can be used outdoor because of the present of sunlight. All the LiDAR that complies to this technology standards can be used indoor. The following factors need to be considered when choosing the LiDAR sensor:

- The laser wavelength
- The ambient light resistance (in Lux)
- The type of surface
- The environmental noise resistance ability
- The operating range temperature
- The electromagnetic considerations

The A2M8 LiDAR sensor is used in this experiment where its wavelength is in the range of 775 nm to 795 nm. This sensor is ‘Class 1’ laser safety standard that uses a low power infrared laser as its light source which emits the light in a very short time frame. This to ensure the safety uses for human and pet because the experiment is conducted indoor. This LiDAR transmit modulated laser which can effectively avoid the interference from ambient light during ranging scanning process. Therefore, this

LiDAR capable to operate in all environments indoor and outdoor (without sunlight) excellently.

Most importantly, the scanned object must solid and opaque surfaces. If the model is transparent or translucent surfaces, the light will pass through the surfaces and providing a false data. Other than that, the noise from environment (rain and snow) also can affect the laser data. Therefore, this experiment is conducted in control environment without any other noise interferences.

Other than a secure noiseless environment, the suitable of the laser distance range also need to consider scanning the model. In this experiment, a historical ship model with a scale of 1/6000 is used to scan the model into 3D data. While, for our A2M8 LiDAR sensor can transmit to a distance laser range from 0.15 to 8.00 meter with angular range of 0 to 360 degrees full rotation. Therefore, it is suitable to use this type of LiDAR for scanning the model ship in close environment.

2.3.5 3D scanning interface for LiDAR sensor

To develop a 3D scanner from the LiDAR sensor, we need to have user interface (UI) to control and manage all the data obtained in X, Y, and Z coordinate from the laser. This high-speed LiDAR can take 4000 times per second with a scanning rate of 400 samples per scan. Therefore, the interface, controller, and communication protocol must be able to keep up with the data rate measurement in order not to lose any data information during scanning.

Raspberry pi 4B 8GB RAM microcontroller is used to collect and process the incoming data from the LiDAR. The processor for Raspberry pi 4B is using Broadcom BCM2711 with quad-core Cortex-A72 (ARM v8) 1.5GHz processing power. With this processor, it is very compatible to read all the incoming data from the sample frequency of 4000Hz LiDAR sensor. In conclusion, the two-way communication speed between the LiDAR and the Raspberry pi must have the same speed to process and plot the data accurately.

Next, we move on the software interface that visualize the data in 3D point cloud environment. The base operating system (OS) used in the Raspberry pi 4B is Raspberry Pi OS called as Raspbian OS. This operating system has the same environment as Linux OS which is more suitable for programmer and developer. This operating system is not the same as Windows OS which focus on gaming with high graphic resolutions. This

Raspbian OS mainly operates using command prompt and coding to automate any system that has been programmed. In addition, the Raspbian OS environment operate with less power consumption and less memory space to run the program. This gives benefits to the system as the memory focuses only on collecting and processing data from the LiDAR sensor. Therefore, Raspbian OS is suitable for this experiment to maintain the consistency for the efficiency of the data collection to create the 3D point cloud model in 3D space environment.

2.3.6 Robot operating system (ROS) platform

The two-way communication between LiDAR and microcontroller are linked together via robot operating system (ROS) protocol. ROS is an open-source solution which is a set of software libraries and tools design to help the creation of robot applications. ROS provides high-level functionality for asynchronous and synchronous calls, centralized database of data, and robot configuration system. It also provides a range of features standard to an operating system such as hardware abstraction, contention management, and process management. This includes LiDAR operation with simplify data abstraction based on peer-to-peer architecture in ROS environment. The LiDAR A2M8 featured is ROS compatible that enables to dialogue directly with any other devices, synchronously or asynchronously as required. In addition, ROS is language-neutral where the developer can program the robot with any programming languages such as C++, python, C#, etc. The communication between two devices can be done even using different set of language. The developer of LiDAR A2M8 provides the codes in C++ in their main website to use it in ROS environment. The code is executable using ROS platform and able to retrieve the LiDAR data during scanning.

The obtained data is then plotted on simultaneous localization and mapping (SLAM) platform which included in the ROS libraries. This SLAM will generate 3D point cloud simultaneously during scanning process. The LiDAR A2M8 rotates at a frequency of 10Hz with 400 samples per scan and each sample is plotted on the 3D coordinate in SLAM asynchronously. This is a very powerful features for any kind of 2D and 3D mapping especially in robotics. With these tools and libraries, the robot can manoeuvre automatically around while avoiding any obstacles easily. Plus, it can map the path during moving until the robot reached the destination. The recorded map can be in 2D, or 3D depends on the type of LiDAR sensor. Therefore, in our case, we used these tools and libraries to scan the scale ship model into 3D point cloud.

The A2M8 LiDAR sensor is a 2D laser scanner which can obtain only 2 axis which is X and Y axis only. The result will be in flat 2D point cloud in 3D spaces. Therefore, the researcher K. L. NG and his team attached another 1 servo motor to the LiDAR in obtaining another axis which is Z axis to create a 3D form (Queralta et al., 2019). While, M.R. Shahrin and his team develop 3D point cloud using 1D LiDAR with addition of another 2 servo motors to create 3D points coordinate (Norzam et al., 2019). The 1D LiDAR provide 1 axis and another 2 servo motors provide another 2 axes to form complete 3D coordinate. Therefore, for this experiment, the LiDAR A2M8 is combined with 1 stepper motor to create another 1 axis to form 3D point clouds data.

2.3.7 Conclusion

In conclusion, laser scanning method has been discovered by a lot of previous studies where they have been used different types of laser sensors starting from 1D-LiDAR sensor, 2D LiDAR sensor and 3D LiDAR sensor. Their purpose is the same which is to preserve the object or artifact for documentation and further studies. The previous studies show to us that it is possible to build 3D scanner from 2D LiDAR sensor. Therefore, for this study we used affordable 2D LiDAR sensor with the combination of stepper motor to form a 3D scanner. The details of construction for 3D scanner will be explained details in the next chapter.

2.4 Depth imaging method

2.4.1 Introduction

In this method, the study focused on details about the capability of the Kinect sensor to scan the scale model. Kinect is a compact sensor that have been embedded from other sensor such as IR emitter, colour sensor, IR depth sensor, tilt motor, microphone array etc. There are three version of Kinects that have been developed by Microsoft which are Xbox 360 Kinect, Xbox One Kinect, and Azure Kinect sensor. According to the previous study, this technology made by Microsoft is capable to turn the Kinect sensor into a 3D scanner. To obtain a precise and accurate 3D model, this study has reviewed several previous studies that using Kinect sensor on the object. In the last of this section will be a conclusion from these three different Kinect with the final decision of choosing the best and affordable depth sensor.

2.4.2 Depth scanning using Xbox 360 Kinect

Firstly, we will take a deeper look at Xbox 360 Kinect. This type of Kinect sensor has been made for the Xbox 360 gaming console to free up the use of a hand controller while playing the game. This first advanced technology made by Microsoft in 2005 creates enthusiasts for the researcher globally to study more in this technology. Therefore, Microsoft developed the software development kit (SDK) for the researchers to study this Kinect for further development or improvement in their research study. The interest has become more popular among the researchers as the Kinect Xbox 360 consists of a combination of several sensors, which are a colour sensor, infrared depth sensor and motion sensor. These sensors embedded in the Kinect make it easier to handle and conduct any experiment using Kinect sensor. However, the camera resolution for this Kinect is up to 640 x 480 of depth image that will limits the smoothness and vividness to obtain quality texture 3D model.

The researchers mostly conduct their experiment using Kinect sensor to reconstruct the object into 3D model. For example, (Q. Sun et al., 2012) used the Kinect sensor to replicate the shape and texture of a person's face. From their study, the Kinect is successfully replicate the face with texture and shape in 3D model. Eventually, the study contained too many noises that created blur texture colour with uneven surface for the face. While (Pang et al., 2015) conduct the same experiment using Kinect sensor but rather than scanning only the human face, they scan the whole body. The study shows that a few holes appeared on the triangulation (surface area) on the body. In this study, the face is not recognisable and has less details compared with the previous study. The researcher, (Sabale & Vaidya, 2016) mentioned in their study that the further the camera for the Kinect sensor from the object, the higher the absolute mean percentage error (AMPE) will be. From this statement, the face is not recognisable maybe because of the Kinect is too far away from the body that lost some data information to construct the 3D model. In addition, (Teng Wang et al., 2015) in their study highlighted that the shadow and water marks are detected as noises that can cause an illumination to the Kinect sensor. (Doumanoglou et al., 2013) supported the statement by stating in their study that this Kinect version is imperfect 3D scanner with noisy data for real-time 3D reconstruction device. But they stated that, even this device is imperfection, this Kinect is capable to do the 3D scanning with affordable solutions. To increase the details for the 3D model, (Imaromkul et al., 2018) found the solution to this problem by implementing post-processing using iterative closest point (ICP) algorithm to reduce the unwanted points by using the alignment of colour markers on the object. They have achieved reconstructing the 3D model with small average error that less than 1%. In conclusion, Xbox 360 Kinect is imperfect device to 3D scan the model, but it can be improved more by applying markers on the model to reconstruct the model correctly.

2.4.3 Depth scanning using Xbox One Kinect

We have studied that the previous Xbox 360 Kinect is capable to scan and reconstruct the object into 3D model. Then, in 2010, Microsoft company produced another version of Kinect which is Xbox One Kinect an upgraded version from Xbox 360 Kinect sensor. Xbox One Kinect has features of higher resolution camera with 1920 x 1080 pixels and time of flight (ToF) depth sensor with 512 x 424 pixels that can run up to 30 frame per second (FPS). The major upgrade for Xbox One Kinect is the depth sensor. Previous Kinect using structured light scanning to obtain the data. While, for the Xbox One Kinect sensor using ToF depth measurement technology that has wider range of visual angle, faster data acquisition, better data fidelity and higher colour resolution. Therefore, we will review the Xbox One Kinect sensor from several previous study.

The researcher (Gomes et al., 2018) explored the Xbox One Kinect for 3D reconstruction of cultural heritage. In their quantitative studied, they evaluated the quality of the 3D model by using root mean square error (RMSE) and found that the error is 3.01%. The result obtained is highly satisfied because of the correct colour tone with smooth surface area due to post-processing by clearing the noises. While (Shen et al., 2017) reported in their study that the highest relative error obtained is 3.3% with high resolution texture. According to (Hauenstein et al., 2019) also that if the object is transparent, the 3D model cannot be built due to the illumination effects and tend to be inaccurate. This illumination effect is mutual enemy to Kinect sensor as the Kinect using camera and depth sensor to recreate the 3D model. Other researchers (Jing et al., 2018) reconstruct the underground tunnel using Xbox One Kinect sensor. In their study, they constructed the 3D model using Kinect for windows software development kit

(SDK). They found that not enough light in the area also can cause inaccuracy when reconstructing the 3D model. That is why, (Shen et al., 2017) conduct their experiment study indoor to control the amount of light. To increase the reconstruction accuracy and processes of 3D model, (Yang et al., 2015) and (Liu & Li, 2018) used multi–Xbox One Kinects technique rather than just using single Kinect. The analysis studied by (Samir et al., 2015) and (Teng et al., 2021) shows that the Xbox One Kinect overcomes the shortage of Xbox 360 Kinect as it supports complex model and massive point cloud with higher accuracy due to the wider angle of capture and pixel resolutions. For complex model, the need of post-processing is essential as there will be a lot of noises on the 3D model. (He et al., 2018) applied depth map denoising to remove the noise. Then, they applied the same concept used by (Imaromkul et al., 2018) which is iterative closest point (ICP) algorithm to clean up the noises and smoothen up the surface area of the 3D model. Therefore, we can use this affordable Xbox One Kinect sensor to 3D scan our scale model as it shape is complex and small.

2.4.4 Depth scanning using Azure Kinect

Lastly, we have latest device which is Azure Kinect sensor. The Microsoft company released a new and compact device, Azure Kinect in March 2020. This Azure Kinect is mainly for the developer to create AI powered application either by 3D scanning or for others uses. But, in our case, we focused on 3D scanning. We have learnt about the previous Kinects: Xbox 360 Kinect and Xbox One Kinect that these two Kinect are affordable and scannable to recreate the object into 3D model. The Azure Kinect has notable performance improvement over its predecessors in term of the resolution of RGB camera and the resolution for depth camera mode. The camera type OV12A10 12-Megapixel complementary metal oxide semiconductor (CMOS) sensor embedded in the Azure Kinect can capture up to 3840 x 2160 resolution with 30 frame rates per second (FPS). In addition, Azure Kinect integrate with 1-Megapixel time of flight (ToF) depth sensor with wide field of view that can operate up to 3 meters. With this improvement, some of the researchers studied to reconstruct the 3D model using Azure Kinect sensor.

(Delasse et al., 2022) studied the Azure Kinect performance in reconstructing the 3D model in control environment. The result obtained from their study shows some improvement in term of resolution compared with the other predecessors. On the other hand, the data obtained by the Azure Kinect sensor still affected with a phenomenon of flying pixels and multipath interference same as the Xbox One Kinect. Plus, (Delasse et al., 2022) stated that the Azure Kinect feels warm when running the 3D scanning process. In addition, the performance of the colour camera is weak when operate in a dark room stated by (Teng et al., 2021) but come out great when operate with constant light source. (Teng et al., 2021) using filtering method to eliminate the floating-point clouds. Through multiple iterations, the data can be obtained with high (Kurillo et al., 2022) stated in their study that systematic spatial error for Azure Kinect has extended to a higher accuracy measurement compared with Xbox One Kinect sensor and supported by (Fol et al., 2022). To conclude, Azure Kinect has overcome the previous predecessors in term of size, weight, camera resolution, accuracy, and power management. But the Azure Kinect relatively long warm-up time with at least 40 to 50 minutes stated by (Tölgyessy et al., 2021) and also have multipath and flying pixel phenomenon issues. Overall, this latest Azure Kinect device is great, but the price is much higher than the predecessors and has increase double accuracy compared with Xbox One Kinect sensor.

2.4.5 Conclusion

In conclusion, these three Kinects sensor: Xbox 360 Kinect, Xbox One Kinect and Azure Kinect are capable to reconstruct the object into 3D mesh model. The different between them are the accuracy, and precision for each scanning. Xbox 360 Kinect has very low resolution compared with the other two which is not suitable to our study that need to scan the scale model with complex texture. Then, for Xbox One Kinect and Azure Kinect are suitable to use for this study. Unfortunately, Azure Kinect cannot be tested due to unavailability of the device. On the day of the experiment, the country in Malaysia has been locked down due to the pandemic Covid 19. Therefore, this study for this method is focused using only Xbox One Kinect to reconstruct the scale model into 3D mesh.

2.5 Photogrammetry method

2.5.1 Introduction

For the last method, we focused on the possibility and methods used by previous studies in using photogrammetry methods. This method like a real magic because by only capturing photos of the object, we can obtain a 3D model. This is what we called as computer vision technology where we utilize the algorithm to extract all the depth data from the photos to form 3D model. Therefore, in this section, we will go through the photographing methods and software used by the previous study to generate a 3D model from 2D photos. Then, in the last section, will have a conclusion that conclude the overall research studies in preserving the cultural heritage using photogrammetry method.

2.5.2 Application of photogrammetry

Photogrammetry has been used seen decades ago for object reconstruction that mainly used in preserving cultural heritage. This method can be applied on any type of objects even the design has a complex shape, or the object is big or small. The photogrammetry method captures all the view into a 2D photos that include colour texture. In addition, this method can used to identify the distance or length of the object precisely (Jiang et al., 2008) by applying post-processing. NASA using their space camera to construct topological map for their own analysis such as predicting earthquake, and tsunami. Topological map also can be used to explore the world of unknown which may conceal the historical area. This data can also be an archaeological exploration to the archaeologist to study and explore the undiscovered area. (Pacheco-Ruiz et al., 2018) using the photogrammetry technique to discover the underwater archaeological region area. By using this method, (Virtanen et al., 2020) used this method to create an interactive dense point cloud in their game engine. This will have a realistic live of scenery in the game where we can feel the realistic touch of the object or artifacts when playing the game. Furthermore, the game industry enhances the interaction method by uploading the game interface into virtual space so it will look more realistic. (Selmanović et al., 2020) presented their research using virtual reality interface to attract more people to learn about history.

2.5.3 2D to 3D photogrammetry process

In this section, we will look at the process from 2D photos turn into 3D model by using photogrammetry method. As we all know that photogrammetry is one of the methods to get 3D model data. The process of photogrammetry is by overlapping the photos together by 80 percent from the previous photos. The operation principle is based on the assigned point located on the photos. The 3D model quality improvement could be made by increasing the intersection numbers of assigned points. This process has been proven by the researchers in reconstructing a 3D historic building using Reality Capture software (Calin et al., 2015).

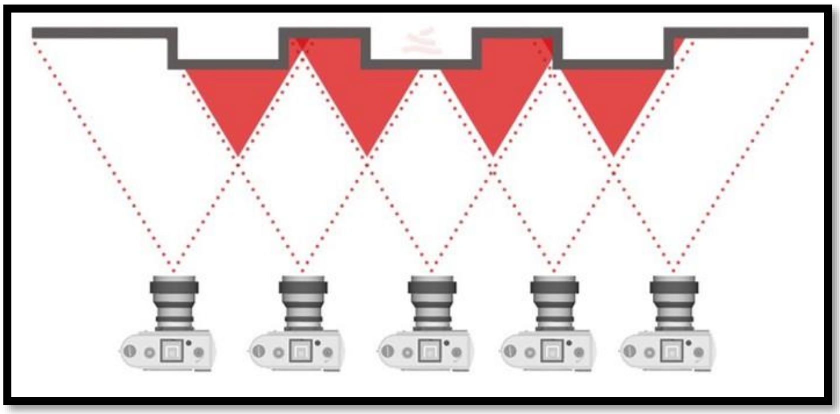

Figure 2.5 Image capturing method for large object (Jiang et al., 2008)

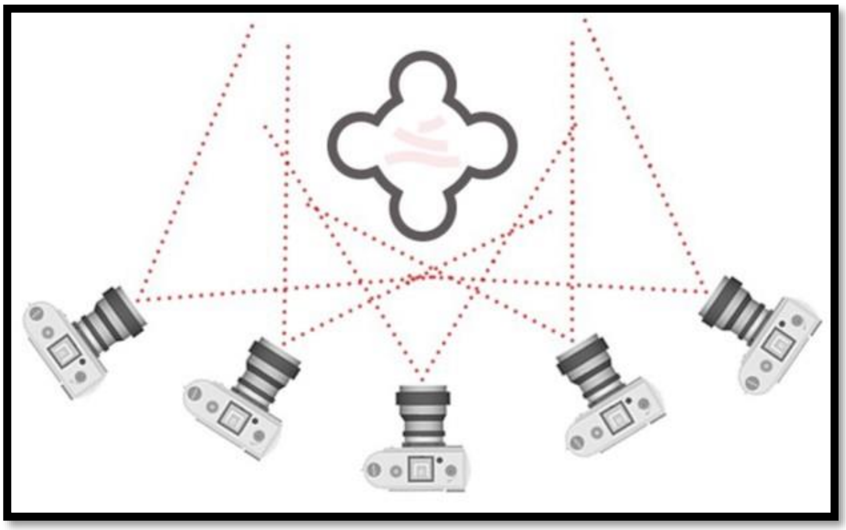

Figure 2.6 Image capturing method for small object (Jiang et al., 2008)

The position of the camera will be the first step to develop a 3D model. In this method, the photo capturing has been studied by the researcher, where the arrangement of the photos affects the construction of the 3D model (Pacheco-Ruiz et al., 2018). The camera position strategy depends on the size and shape of the object. In addition, the selection of digital camera also essential because the sharper the camera, the better the output result. This is due to the camera pixels and the focal length control. Digital single lens reflex (DSLR) camera and smartphone camera have their own pixels and focal length. Therefore, **Figure 2.5** and **Figure 2.6** show that the camera is repeatedly captured the images at different angles and orientations according to the size of the object. These 2 techniques have been clarified by the observers that image capturing styles are variant, where the camera flow-path are differed for every type of object (Apollonio et al., 2021). 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 the 3D model.

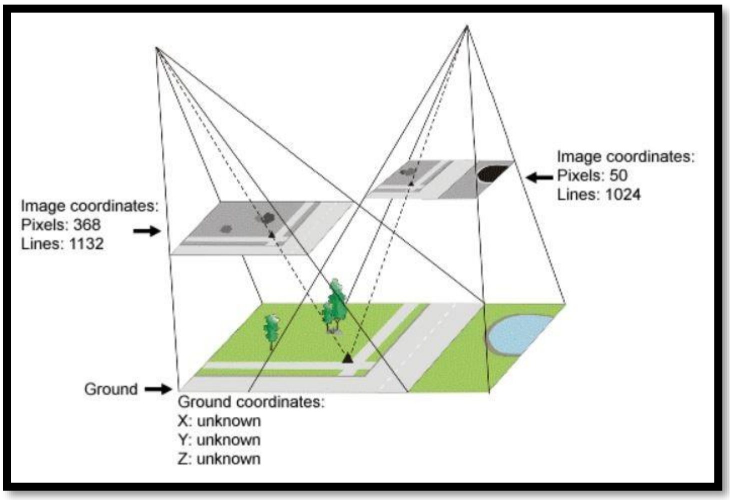

Figure 2.7 Aerial photogrammetry method (Colomina & Molina, 2014)

Ground photo capturing is quite easy to handle as the object can be captured by using a standard camera such as Nikon, Go Pro, and even a smartphone (Gaiani et al., 2017). But a large object such as real size traditional ship, needs an aerial photograph to capture the ship'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 (Condorelli & Rinaudo, 2019). This method can be applied on the traditional ship 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 (Condorelli & Rinaudo, 2019) as the images covered all sides of the traditional ship. Then, all the images captured will be processed using structure from motion (SfM) software such as Reality Capture, Agisoft Metashape, and others. This software is popular among researchers as it is easy to deploy. Therefore, in this research we used Reality capture and Agisoft Metashape software to generate the 3D model. Both results will then have compared each other in chapter 4 to identify which is the best.

2.5.4 Conclusion

In conclusion, photogrammetry method is the simplest way to obtain the 3D data by only taking several photos and import the photos into the SFM software. Then, the photos undergo several processes start with photo alignment, dense cloud, meshing and lastly texturing. Both SFM software mentioned (Reality capture and Agisoft Metashape) used the same workflow to generate the 3D model. Lastly, the 3D model undergoes cleaning process which need to remove the floating-point cloud. Compared with other methods, photogrammetry only focuses on the post-processing to obtain the best output 3D model. This method does not need any additional devices to create a 3D model. We just need a smartphone or DSLR camera to take photos. Most researchers used high resolution DSLR camera to take a shot and combine it with laser sensor to increase the accuracy. On the other hand, this study focused on comparing the output result from 3 different method. The best 3D model among these 3 will be chosen to present in virtual platform which we will look in the next section.

2.6 Augmented Reality (AR) technology

2.6.1 Introduction

In the new era of technology, we have a lot of teaching and learning medium that can be used to learn anything. In this section, we focused on virtual environment. Previously, we have gone through all the techniques and methods used by the researchers to conserve and document the cultural heritage for tangible and intangible values. There are researchers have presented their study using virtual medium such as virtual reality and augmented reality recently. They used this medium to do the storytelling and also as a game entertainment for more attraction to the society. Therefore, for this last section, we will focus on the software and methods that the previous studies used to create the virtual platform.

2.6.2 Software and methods of study

The revolution of technology nowadays gives the developer or creator accessibility to display their works everywhere around the world by posting them into the internet. Since the introduction of the internet, the number of people who have access to it has steadily increased. So, the people who interested with their works can search the internet and view the model in 2D screen. Although everyone can view them, the presentation is still bulky and not attractive enough to attract people especially young generation to view and study about historical information. Therefore, augmented reality, AR is the alternative way to enhance the attraction for the young generation to learn and understand the importance of history.

This AR application best suit to be used at the museum where all the artefacts stored. Most places around the world such as Turkey, Japan, German, US, UK etc. have implemented the virtual visualization using AR in their country and can be viewed using smartphone (Mohammed-Amin et al., 2012). Smartphone is the intelligent gadget that capable in combining the 3D model with the real world together to form an augmented display. This display creates an interactive model where the person can control the rotation, position, and even the size of the model using only a bare hand (Kyriakou & Hermon, 2019). Plus, extra material also can be displayed in AR mode such as information, video, photos, and audio to describe the model. These materials can be combined with AR to create a real environment or situation when describing the artefacts or models (Alyousify & Mstafa, 2022). Hence, by using augmented reality, people may study course material in a more engaging and understandable way.

Augmented reality, AR is not dedicated only for museum. AR also can be applied on tourism, entertainment, robotics, IoT and education system. Lately, AR games are popular among young generations and getting better since 2016 where the first Pokémon Go AR game released. The rise of mobile AR within the next 19 days after the game released had reached a recorded of 50 million users played the game as it can be downloaded on the app store or google play store for free (Garzón, 2021). The number of players keep increasing until today. After that, there are a lot of AR games published to entertain the player by using the same concept as Pokémon Go.

The evolution of AR from hardware-based AR to application-based AR and currently to smart glasses Web-based AR makes the contents more attractive and more understandable. AR in education also creates high impact to the learning process as the student nowadays are born in a digital-centric world. They are digital natives that speak and interpret the language of technology fluently. In addition, student can get a deeper understanding of the principles being taught by teacher. With augmented reality, learning in a classroom setting may become more exciting. Researcher D. Roopa from India has built an interactive AR study using image recognition and tracking to visualize and animate the AC generator using mobile AR (Roopa et al., 2021). He created a 3D animations of armature rotation with electron particle movements trough out the circuit. The researcher used Unity and Vuforia software to develop the AR app. The app contains a mesh collider component from Unity library to create an animation of the electrons flow.

Other researcher from Russia named Aleksandra Pauls developed an augmented reality, AR to display the calligraphic object in interactive way with animation (Pauls & Karsakov, 2021). The AR app does not need a marker or object image to activate the 3D calligraphic model. This method is suitable used at any places where the user can learn whenever or wherever they want without worrying to bring along marker. In contrary, Ahmed L ALYOUSIFY from Iraq developed an AR children book to assist the children in learning of Turkish alphabets (Alyousify & Mstafa, 2022). His method requires image markers from the book to visualize the 3D alphabets and 3D model in AR. He used the same software which are Unity software and Vuforia engine to develop the AR app. The used of marker images need a cloud database so that the images are recognizable as markers when using the AR app.

2.6.3 Conclusion

In conclusion, Unity software and Vuforia engine is suitable to use to develop the AR app for android smartphone. The opportunities provided by the AR technologies offer practical ways for the researcher in integrating the digital objects with real-world assets simultaneously (Özdemir, 2017). Plus, everyone nowadays has access to the smartphone especially young generation that loves to update their smartphone with the latest model on the market. Therefore, we can utilize the smartphone to get more attraction within young generation with a new visualizing technique to display the historical 3D scanned vessel using AR.

2.7 Summary

In summary, there are various methods and devices available for obtaining high-quality 3D models with precise meshing. These methods involve 3D scanning to extract point clouds from real objects, which can be achieved using sensors such as LiDAR, Kinect, or camera devices. The size and location of the object should be considered, as larger objects can be harder to scan. This study proposes three methods for extracting a traditional vessel into digital 3D data, including laser scanning, Kinect scanning, and photogrammetry. Each method is explained in detail, along with the software used for creating the 3D model. The resulting 3D models are displayed in augmented reality (AR) using Unity software and AR core library. This study provides a detailed analysis of the proposed methods to preserve traditional boats and attract younger generations to learn from traditional boatbuilders.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This section provides a comprehensive description of the experimental setup and methods employed to acquire the 3D model of the traditional vessel.

The laser scanning method utilized a laser sensor that emitted a laser beam to measure the distance between the sensor and the object. The sensor consisted of a transmitter that emitted the laser beam and a receiver that detected the incoming laser. The data obtained was transformed into a point cloud and plotted into a 3D Cartesian plane to form a 3D point cloud. A step-by-step configuration for the laser scanning method, including a list of hardware and software used, is presented in **Figure 3.1**.

The second method employed the Kinect sensor, which used a projector to project light onto the object while a depth camera sensor detected the depth of the real model to obtain distance data. The Kinect SDK extension library was used to operate the Kinect sensor on a laptop or PC, and the data acquired was manipulated, stored, and displayed on a 3D virtual environment provided by Microsoft. The experimental setup for the depth imaging method is depicted in **Figure 3.2**, along with the necessary steps and procedures to acquire the best 3D model.

Lastly, the photogrammetry method utilized a camera to capture multiple images that were processed using software such as Reality Capture and Agisoft Metashape to create a 3D point cloud. The software packages were used to generate the 3D model from 2D pictures. The hardware setup for photogrammetry was straightforward, requiring only a camera, such as a smartphone or DSLR camera, to capture the necessary images. **Figure 3.3** shows the overall process flow for the photogrammetry method.

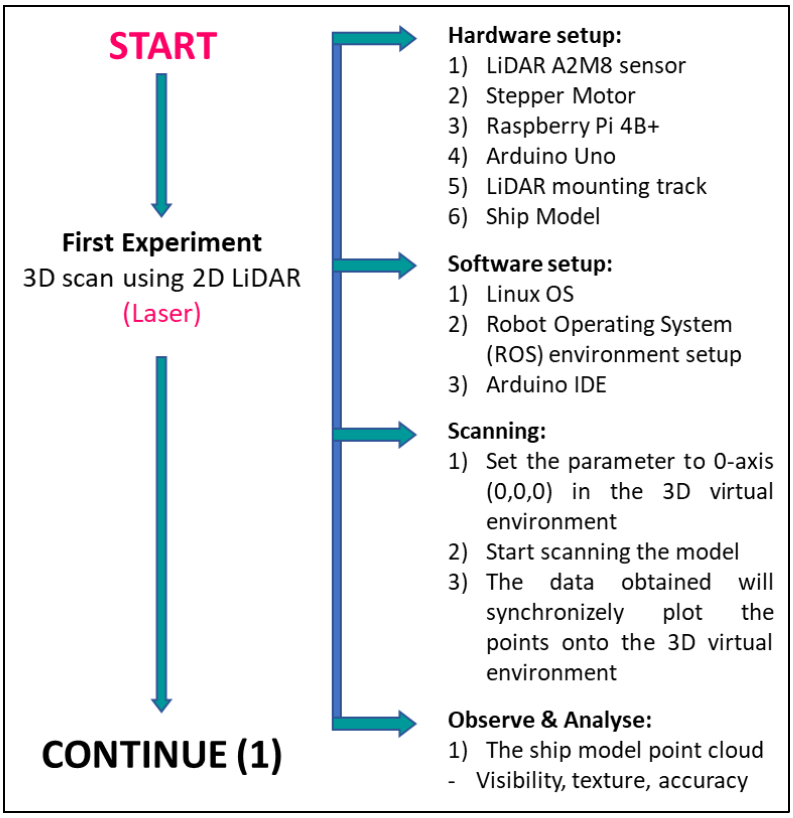

Figure 3.1 Flowchart of Laser Scanning processes.

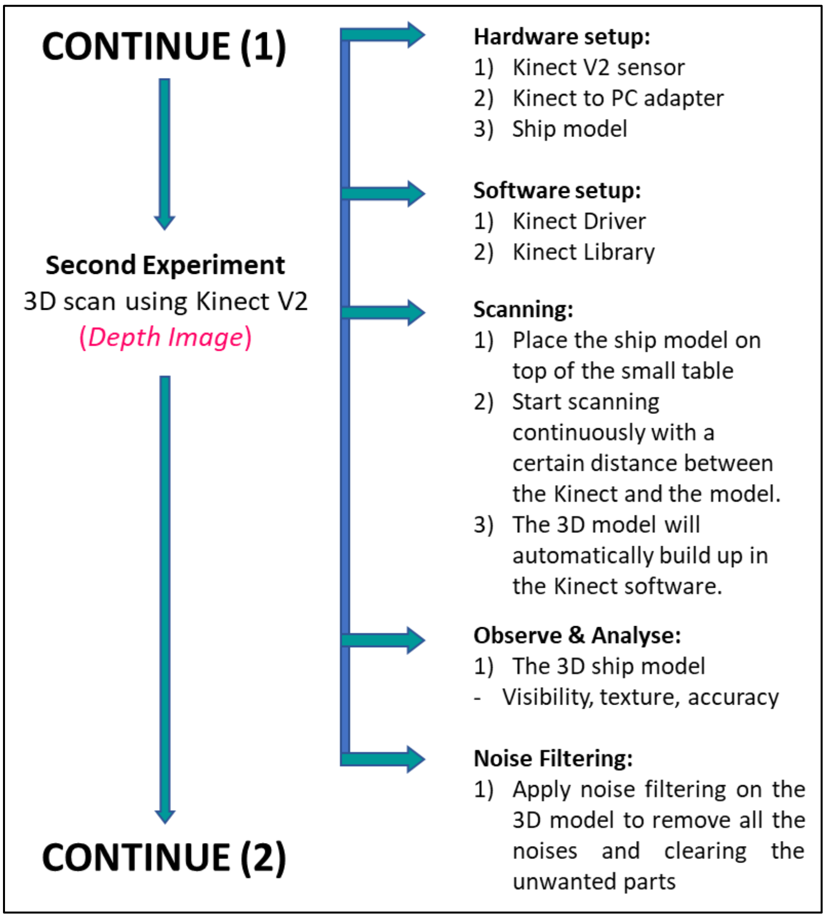

Figure 3.2 Flowchart of Depth Image processes.

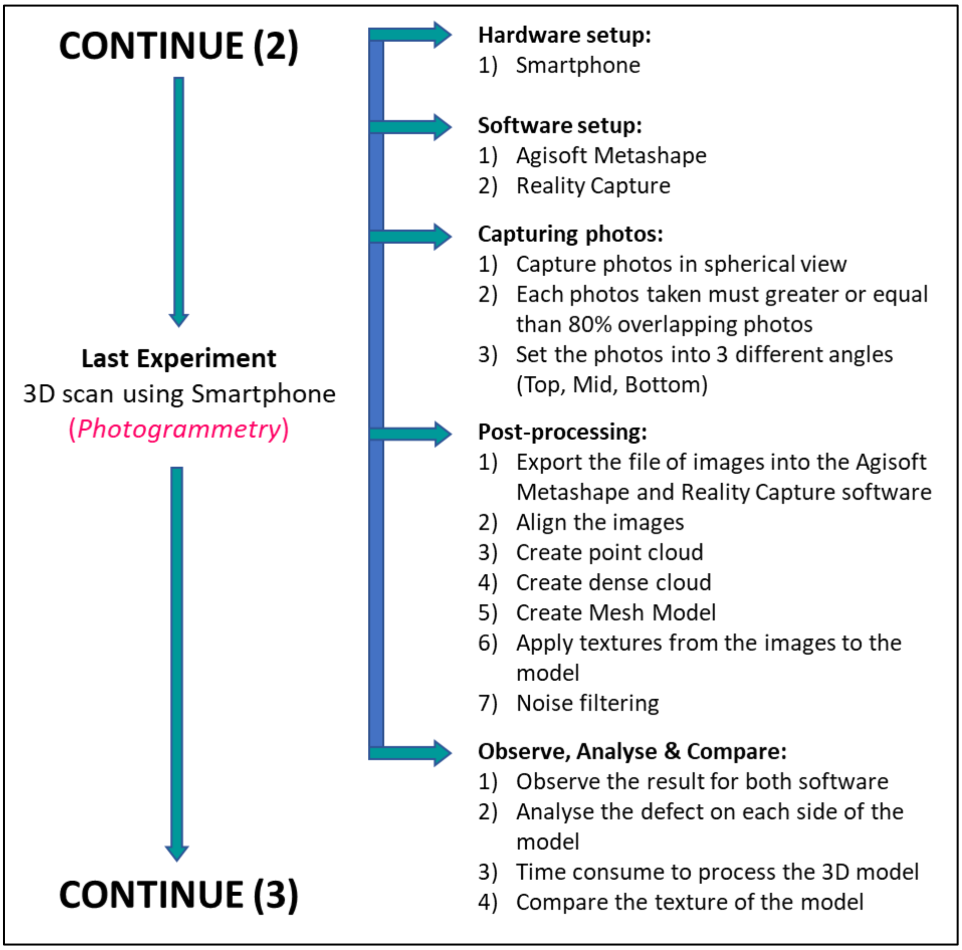

Figure 3.3 Flowchart of Photogrammetry processes.

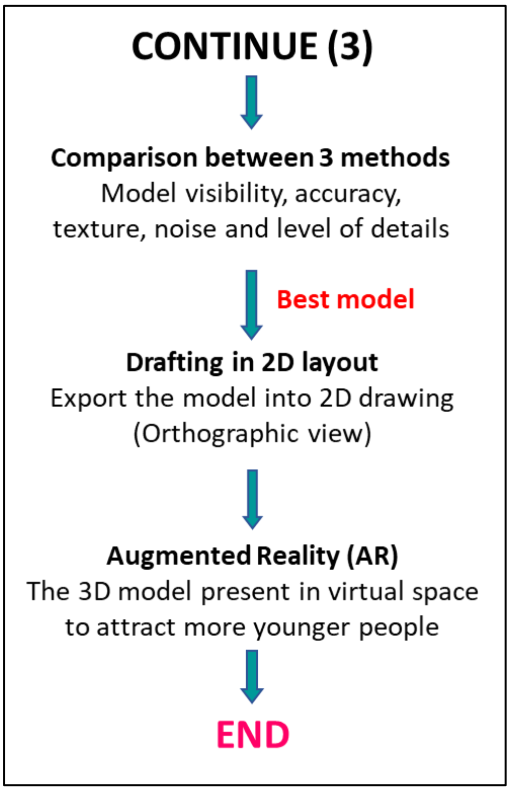

Figure 3.4 Flowchart of comparison study.

After acquiring the 3D models using the three methods, the models were compared in terms of visibility, accuracy, texture, noise, and level of detail, as depicted in **Figure 3.4**.

3.2 First Method: Laser scanning method

In this section, we will discuss the laser scanning method used in the experiment and the setup details. The setup consisted of both hardware and software components.

3.2.1 Hardware setup

The hardware setup included a master unit and a servant unit. The master unit was a Raspberry Pi 4B+ that controlled and processed all the data in a single device. It collected data from the LiDAR A2M8 sensor and compiled it into a point cloud. The servant unit was an Arduino Uno that followed all the commands coming from the master unit.

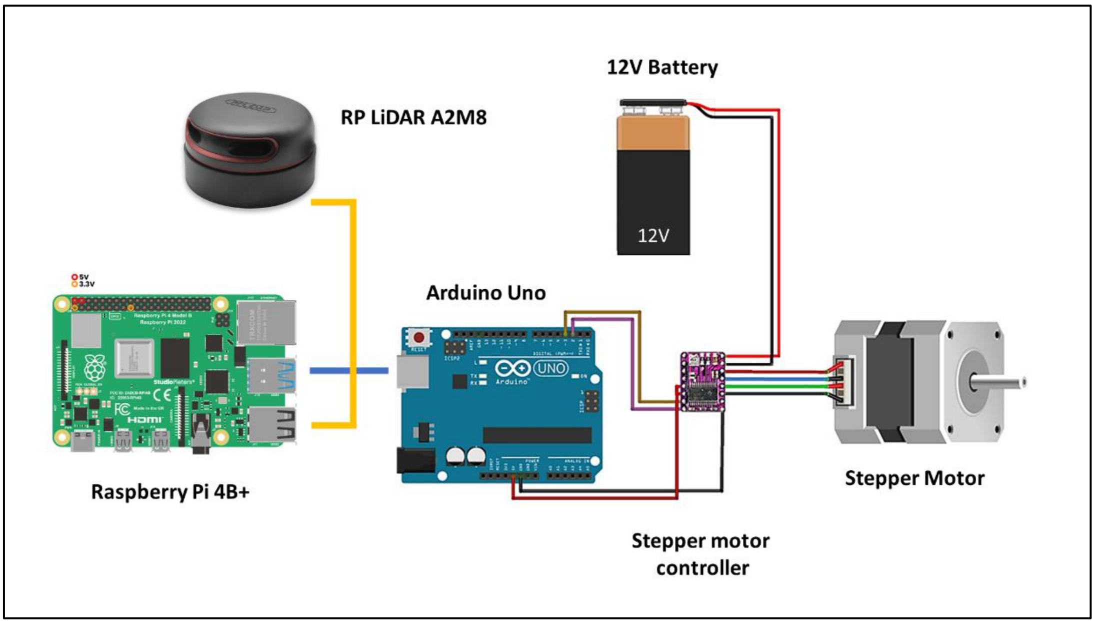

Figure 3.5 Connection circuit for the laser scanning method

The LiDAR A2M8 sensor used time of flight (ToF) laser beams to get position data for each angle in one complete rotation. It could detect objects up to 16 meters away from the sensor and was positioned approximately 50 cm from the ship model. The LiDAR rotated at a default setting that allowed it to take up to 8000 samples per second. The data recorded by the LiDAR was filed into X, Y, and Z coordinates and saved in the Raspberry Pi as illustrated in **Figure 3.5.**

The setup also included a stepper motor and mounting track as shown in **Figure 3.6** and **Figure 3.7**. The stepper motor, a Nema17, was controlled by the Arduino Uno and powered by a 12V power supply connected to a motor driver. The stepper motor moved the slider back and forth during scanning the model, while the LiDAR A2M8 was mounted on the track slider. The mounting track was designed using Catia and TinkerCad software, using two PVC pipes with a length of 105 cm, 3D printed parts holder for both ends, and a LiDAR mount. The LiDAR was mounted vertically on the tracker.

Overall, this hardware setup allowed for the accurate scanning of the ship model and the collection of precise data for further analysis. The complete setup is shown in **Figure 3.8.** The details of the software used in the setup will be discussed later in next sub-section.

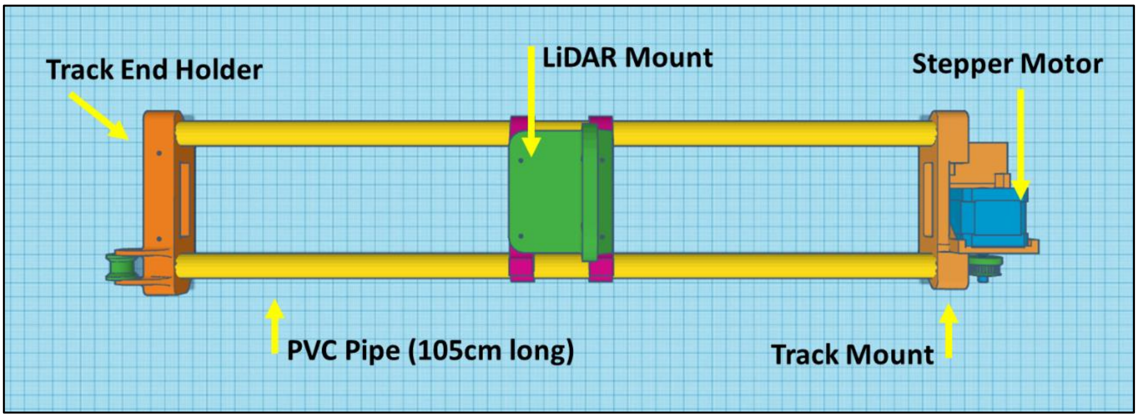

Figure 3.6 The design of the mounting track

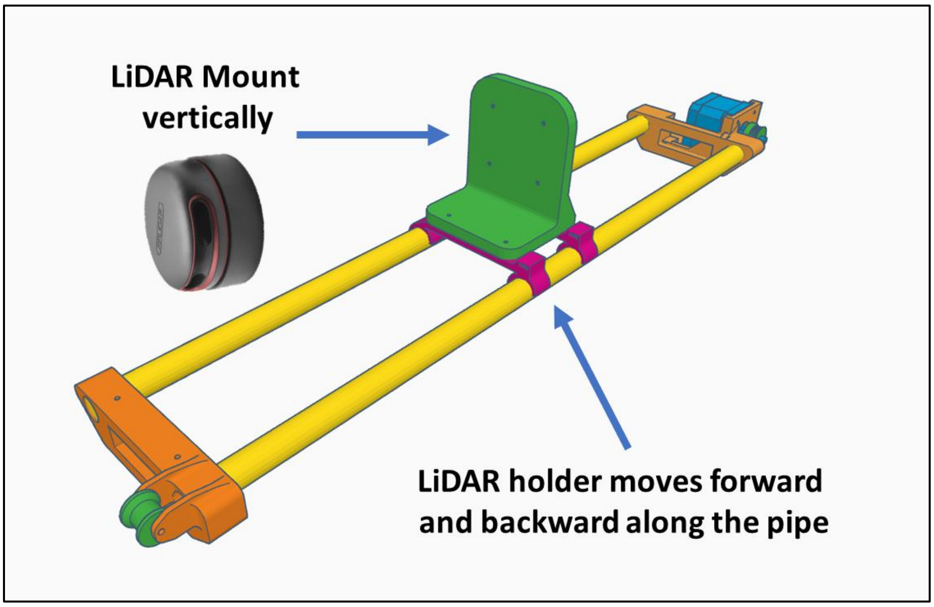

Figure 3.7 The position of the LiDAR A2M8 setup

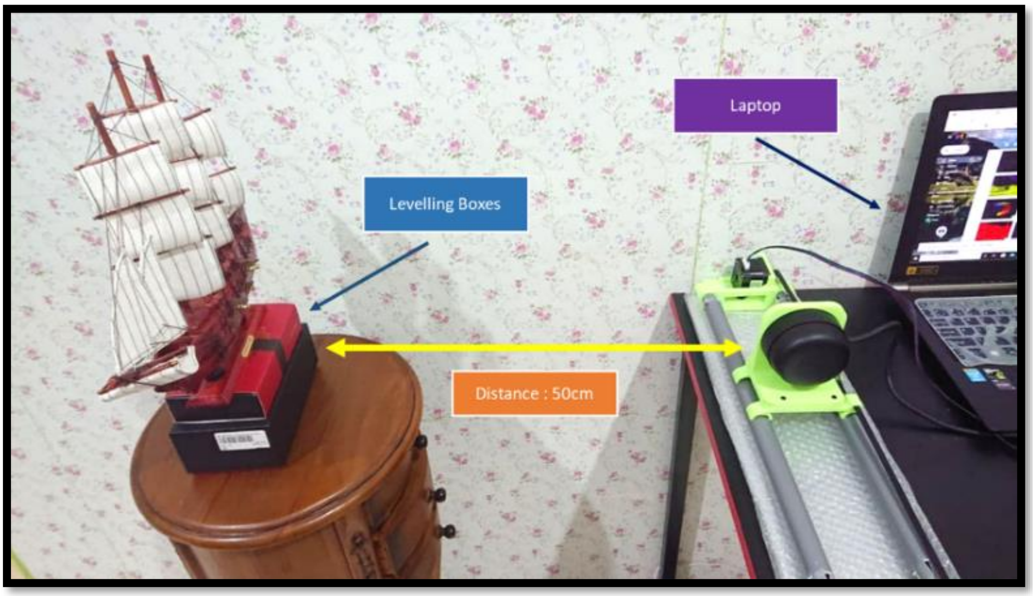

Figure 3.8 The position of the LiDAR A2M8 sensor with the ship model

3.2.2 Software setup

For software setup, we used Linux OS for the master unit control, specifically the Raspberry Pi 4B+. Linux is an open-source operating system that facilitates communication between hardware and software. In this study, we utilized Ubuntu, which is also open-source and provides customizable code. Additionally, Ubuntu incorporates AppArmor, which enhances system security by restricting program behavior. Compared to Windows, Ubuntu is more lightweight, and can run on less than

1GB of RAM in the Raspberry Pi 4B+. The official Ubuntu website offers a free download, and the Raspberry Pi official website offers a tailored version that can be downloaded to meet specific needs.

To process data and plot it into 3D virtual space, we used the Robotic Operating System (ROS). ROS is a powerful, open-source meta operating system that facilitates communication between hardware devices, such as Arduino, LiDAR sensors, and stepper motors. ROS provides a two-way communication infrastructure between devices, allowing data from sensors to be allocated into a single file compilation. The ROS visualization (RViz) widget can then be used to plot this data into a 3D virtual environment. The ROS software can be downloaded for free from the official website, but it may take some time to install, as it requires numerous repositories and dependencies. The ROS Melodic Morenia version with Ubuntu 18.04 was used for this study.

The Arduino Integrated Development Environment (IDE) software is necessary for programming the Arduino Uno device. The Arduino communicates with the Raspberry Pi 4B+ via serial port communication protocol and subscribes to the assigned topic to control the speed and rotation angle of the stepper motor. The speed and rotation of the stepper motor depend on the data collected by the LiDAR sensor. In this study, we set the speed of the stepper motor to 1 step per LiDAR rotation to scan the ship model smoothly and collect a large amount of data to form a point cloud.

Overall, this software setup as depicted in **Figure 3.9** enables efficient data collection and plotting in a 3D virtual environment. The Raspberry Pi 4B+ with Ubuntu and ROS, along with the Arduino Uno device and RP LiDAR sensor, create a powerful system for gathering and analysing data.

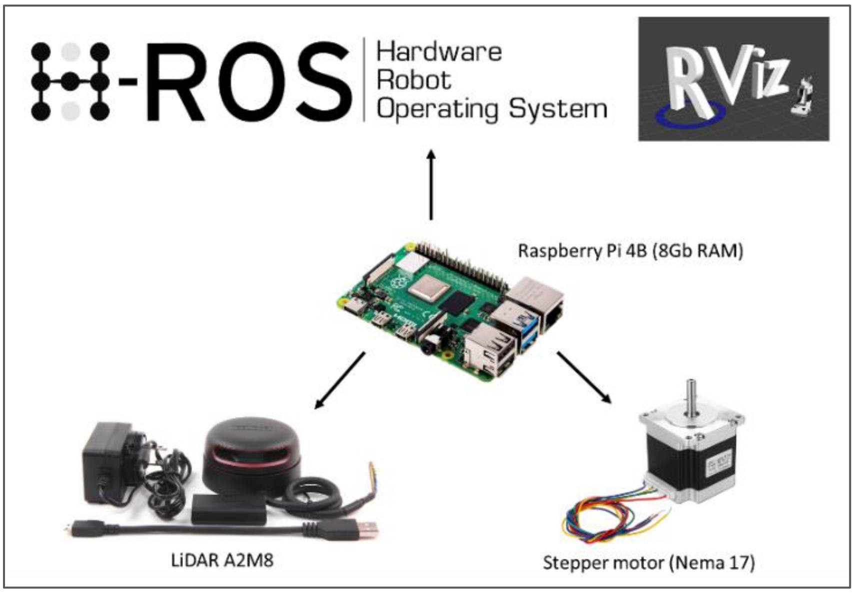

Figure 3.9 All the process are done in ROS environment.

3.2.3 Scanning process

After completing the hardware and software setup, we can examine the system's functionality. Figure 17 illustrates the LiDAR A2M8 sensor rotating along the Y-axis to conduct a continuous 360-degree scan of the surrounding area and collect data in a 2D plane consisting of X and Z axes. However, to create a 3D point cloud, we need to incorporate a stepper motor that moves the LiDAR along the Y-axis, enabling the collection of Y-axis data. By combining the X, Y, and Z axes, we can generate a 3D representation, as depicted in Figure 17. We utilize a straightforward formula to plot each point from the collected data into a 3D virtual space in ROS visualization (RViz).

$$x = cos\, \alpha\, .\, d \tag{1.1}$$

$$y = linear\ incremental\ by\ 5mm \tag{1.2}$$

$$z = sin\, \alpha\, .\, d \tag{1.3}$$

After collecting the data from the LiDAR and stepper motor, each point in the 3D virtual space is represented by its X, Y, and Z coordinates. These points, collectively known as a point cloud, are plotted in real-time as the LiDAR and stepper motor scan the surrounding environment. The resulting point cloud provides a comprehensive representation of the scanned area, and its visualization is discussed in detail in the following chapter.

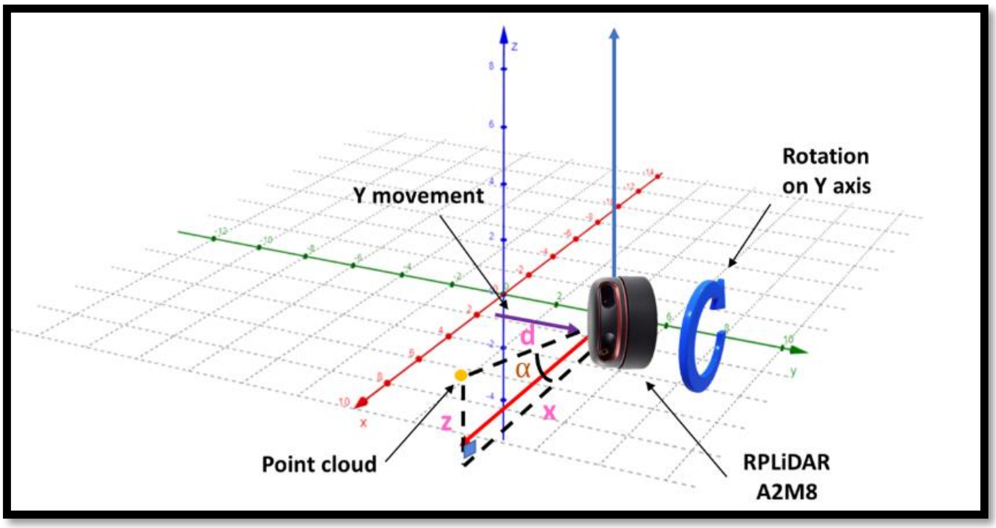

Figure 3.10 How the points plotted onto the RViz platform.

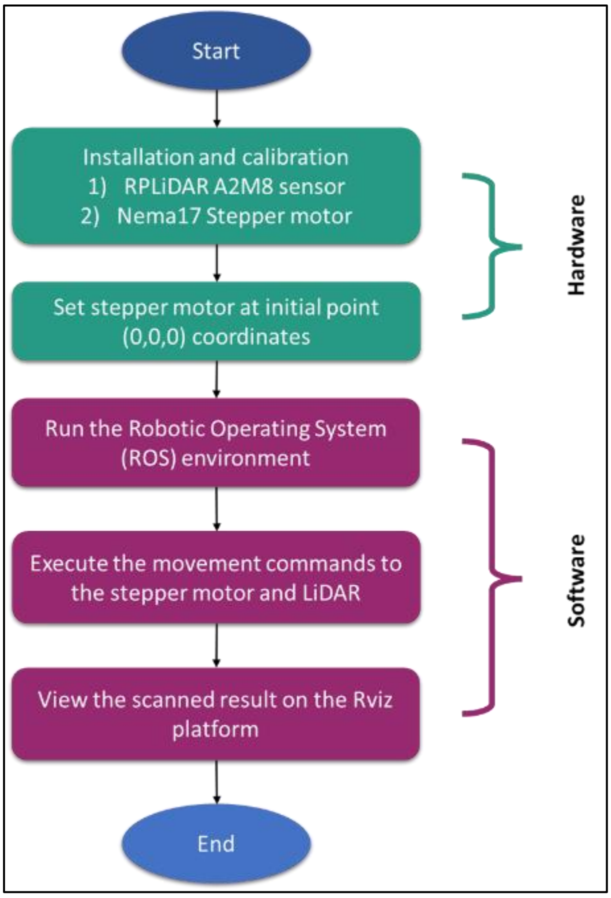

Figure 3.11 Simple flowchart for overall process

3.3 Second Method: Depth Imaging method

3.3.1 Hardware setup

In the second method, we utilized the depth imaging technique by employing an X-box Kinect sensor as depicted in **Figure 3.12** to scan the ship model. The Kinect sensor is designed to interact with video game characters using the player's movements. However, its depth camera sensor makes it useful for 3D scanning applications.

Figure 3.12 Kinect X-box One sensor

3.3.2 Software setup

To set up the software for 3D scanning with the Kinect sensor, we used Windows 10 as the operating system. To access the features of the Kinect sensor, we needed to download and install several tools. Firstly, we installed Microsoft Visual Studio version 2010 or higher, which included .NET Framework 4 or higher for the main frame. This allowed us to use 3D visualization on the laptop. Secondly, we installed the Kinect for Windows Software Development Kit (SDK), which provides developers with access to features such as body gesture recognition, voice recognition, and 3D scanning. This SDK includes application programming interfaces (APIs) that allow users to reprogram the given features using programming languages such as C and C++. We used this toolkit to scan the ship model and conduct our analysis.

3.3.3 Scanning process

In the 3D scanning process, the Kinect sensor is moved around the ship model while facing it to capture the entire hull and generate a 3D model in the Windows toolkit. Two methods can be used in the Windows developer toolkit for 3D scanning: scanning by colour, which generates a 3D model with colour texture only, and Kinect Fusion Explorer, which includes add-on features such as capture colour, pause integration, mirror depth, mesh format, near mode, maximum and minimum depth threshold, voxel resolution, and maximum integration weight. These features are useful for calibrating the Kinect sensor before and after the scanning process. However, running Kinect Fusion Explorer requires DirectX 11 software for graphics cards to run real-time 3D construction.

To scan the ship model, there are several steps that must be followed. First, initialize the location and orientation of the Kinect sensor. The Kinect has a 6-axis inertial measurement unit (IMU) sensor that can read both a 3-axis accelerometer and 3-axis gyroscope. With this sensor, the Kinect can recognize its position in 3D space and update data when the Kinect moves or rotates. This sets the initial coordinate for the Kinect's position. Next, move the Kinect sensor slowly around the ship model to capture all the depth data. The Kinect takes time to process all the data at once in real-time, so it is important to avoid redundant scanning to prevent overlap of captured data that could affect the shape of the scanned model. If there is too much overlapping data, errors may occur, and the scanning process will stop. Errors can also occur if the user moves the Kinect sensor too fast or there is too much light during scanning, interfering with the scanning process. Therefore, it is essential to take note of all these errors to ensure that the data captured is valid and accurate.

Once the scanning process is completed, the captured data can be viewed in the Windows Developer Toolkit in the form of a 3D model, which will be discussed in Chapter 4. It is important to note that the scanning process requires high memory usage to generate the 3D model, so patience is necessary when moving the Kinect sensor around the ship model.

3.4 Third Method: Photogrammetry method

3.4.1 Hardware setup

The photogrammetry method involves using a smartphone camera to capture a series of photos of the ship model, which are then processed to create a 3D model. In this experiment, we used an Honor 9 Lite smartphone, which has a 2-megapixel back camera with an inbuilt depth sensor. To ensure accurate alignment of the photos during post-processing, the camera's zooming feature was set to a fixed value of 26mm focal length.

One of the most critical aspects of photogrammetry is lighting. The lighting conditions during photo capture can significantly affect the color texture of the resulting 3D model and, consequently, the accuracy of the alignment. To address this, we placed the ship model in an open outdoor space under clear skies to ensure adequate lighting and minimize color variations.

To capture the photos, we took them from multiple angles, including the front, back, top, and bottom, to ensure that all parts of the ship model were adequately captured. We also took care to capture the photos systematically, ensuring that there was sufficient overlap between adjacent photos to enable accurate alignment during post-processing.

After capturing the photos, we used specialized photogrammetry software to process them and generate the 3D model. The software uses advanced algorithms to analyze the photos, identify common points between them, and triangulate their positions in 3D space. The resulting 3D model can then be viewed and analyzed using a variety of tools and applications.

3.4.2 Software setup

In this experiment, we used a Honor 9 Lite smartphone, which features a 2 Megapixel back camera with an inbuilt depth sensor. During the photo shoot, the camera settings were adjusted to ensure a fixed focal length of 26mm, which helps to prevent photo alignment errors during post-processing. Lighting conditions were also carefully considered to minimize variations in color and texture across the model.

For software setup, we used a Windows 10 laptop to process the photos and create the 3D model. To do this, we employed two software programs: Agisoft Metashape and Reality Capture. Both of these programs are widely used in the industry and offer a range of features for compiling photos into a 3D model, including point cloud generation and meshing.

Once the 3D model is generated, we used Blender software to refine the mesh surfaces and remove any unnecessary areas or excessive point cloud. This step is important to ensure that the final 3D model is accurate and visually appealing.

3.4.3 Scanning process

Figure 3.13 Anticlockwise globing path (AGP) technique

For the photogrammetry method, it is important to note that this technique involves taking a large number of photographs of the ship model from various angles, which will then be used to create a 3D model. The quality of the resulting model will depend on several factors, including the camera used, the lighting conditions during photography, and the software used for processing the photos. during the photographing process, it is important to ensure that the photos are overlapping each other correctly to achieve a high level of accuracy during the alignment process. In this experiment, the "anticlockwise globing path (AGP)" technique (as illustrated in **Figure 3.13**) is used to take photos of the model. This technique is divided into three phases of taking photos: top, middle, and bottom in an anti-clockwise direction. Each photo must overlap the previous one by at least 80%, and all the photos are compiled together into one file for the next process. By following these techniques and paying attention to detail, we can create a highly accurate and detailed 3D model of the ship.

Once we have taken all the required photos, the next step is to align them using software like Agisoft Metashape or Reality Capture. This process is critical as it helps to ensure that the resulting 3D model is accurate and free from errors.

To begin, we import all the photos into the software and create a new file called a “chunk”. This chunk serves as a compilation of all the photos and is essential for combining different parts of the ship model. We can divide the ship model into four parts, namely the top, bottom, front, and back, and create separate chunks for each part. This approach ensures that the software can process each chunk more efficiently and accurately, resulting in a better 3D model.

Once we have created the chunks, the software aligns the photos using various techniques, such as feature matching and depth maps. The alignment process involves identifying common points between the photos and then adjusting their positions to create an accurate 3D representation. This process can take some time, depending on the number of photos and the complexity of the ship model.

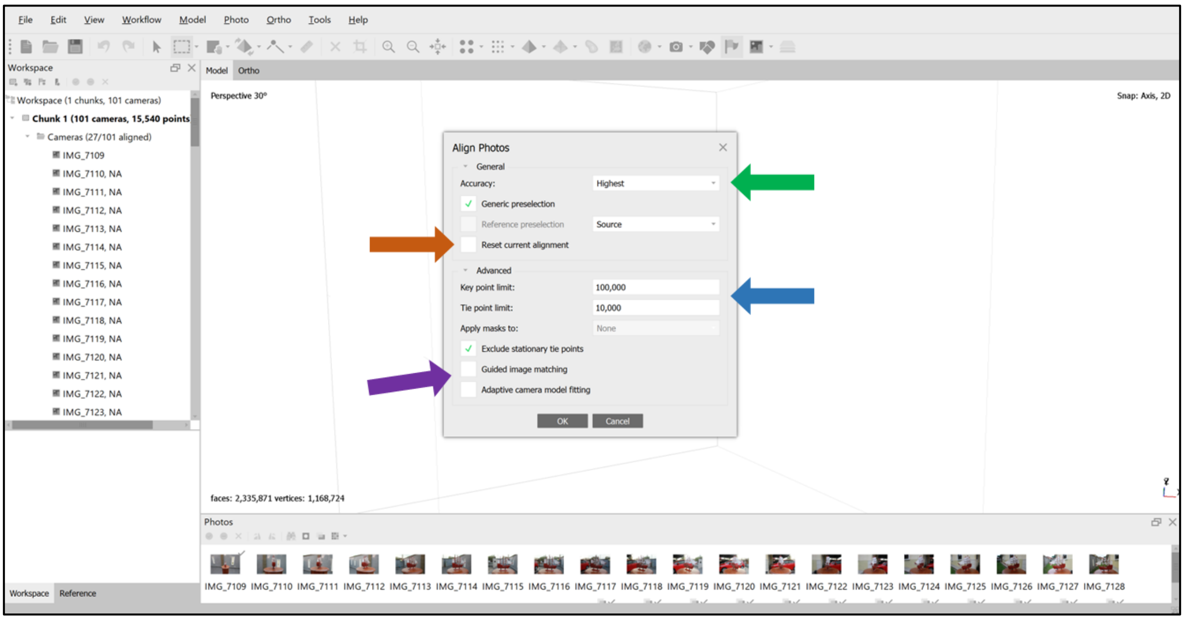

Figure 3.14 Align photos setting area.

During the alignment process, it's essential to ensure that the photos are overlapping correctly to provide accurate alignment points (see **Figure 3.14**). It's also important to check the software settings and adjust them as required to ensure optimal results. Once the alignment is complete, the software creates a dense point cloud that represents the ship model's shape and geometry as illustrated in **Figure 3.15**.

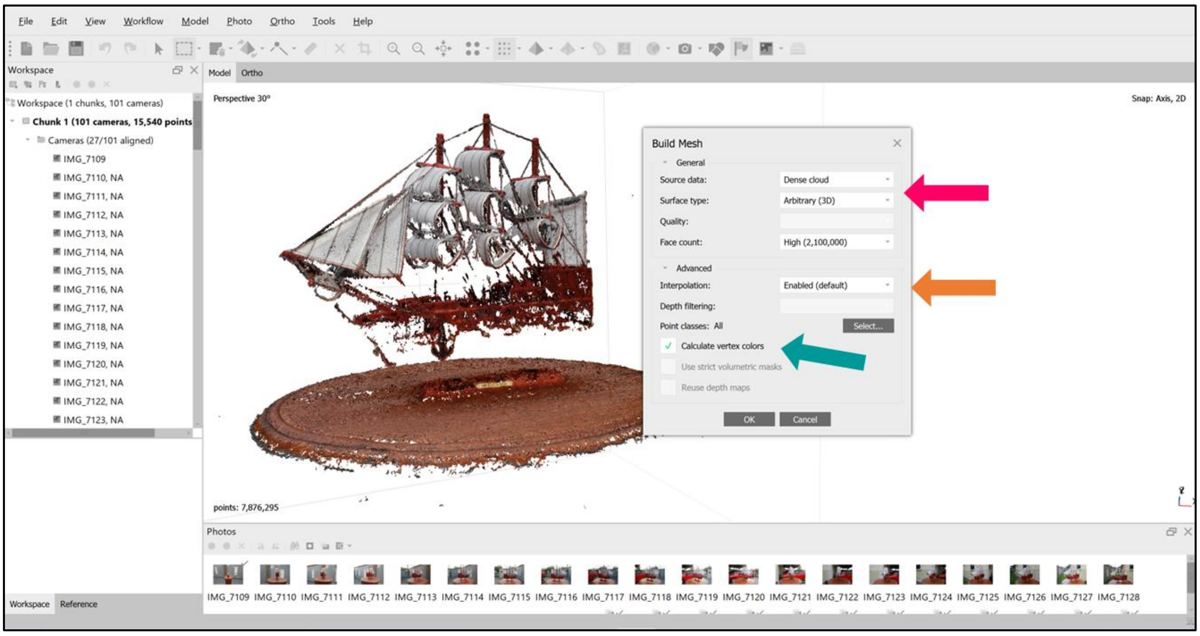

Figure 3.15 Dense point cloud of generated model.

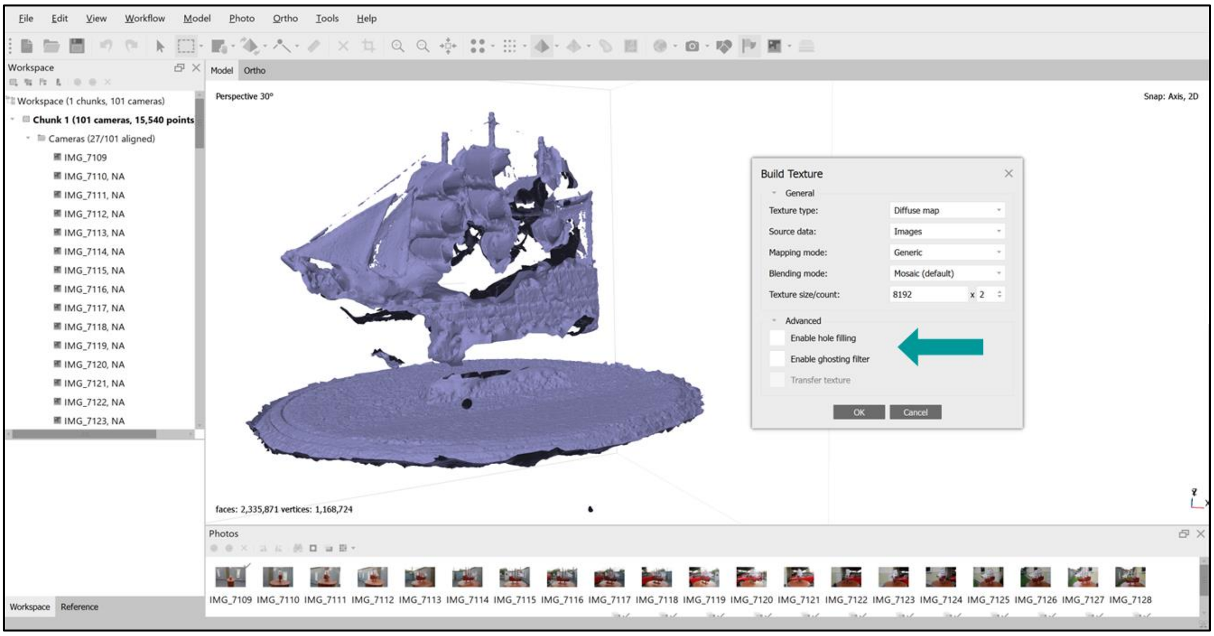

Figure 3.16 The texture build setting

In order to create a smoother surface and visualize the 3D model, we need to build a mesh on the point clouds that connect all the points together. This can be achieved by using the meshing process, which uses the previous dense cloud as source data and sets the surface type to Arbitrary (3D). To ensure a higher quality surface, we set the face count to High (2.1 million faces) and enable interpolation calculation and vertex colour calculation for advanced settings.

Once the mesh is created, the user can see that the point clouds have combined to create a surface area, although there may still be holes in the model. We can fix these later by combining all the chunks together. We then set the model texture using the diffuse map texture type and the images or photos as source data, which extracts all the textures from the photos into the 3D model. We set the mapping mode to generic and the blending mode to mosaic, with a texture size of 8192 and count of 2 to set the texture quality onto the 3D model. For advanced settings, we enable hole filling and ghost filter to avoid texturing errors.

After completing the model with texture, there may still be some noise around the model. To clean up the noises and smoothen the mesh surface, we export the model in object (OBJ) file format and use Blender software to reconstruct the mesh and improve the surface projection. Blender is an open-source software that can effectively clean up the noises from the textured model and provide a better surface projection.

3.5 Mesh smoothing using Blender

In Blender software, we can effectively examine and manipulate the geometric pattern of the mesh model. It is crucial to check the overall areas of the mesh to ensure that there are no overlapping meshing and extra point clouds on the surface, as it can significantly reduce the accuracy of the model.

After importing the mesh model into Blender, we need to decimate the mesh to make it easier to examine. Blender provides a modifier tool that can automatically decimate the face count while reducing and collapsing sharp edges of the mesh, as shown in **Figure 3.17**. However, it's important to keep in mind that collapsing too many edges at once can lead to shape distortion, resulting in the loss of the 3D model's fine details. Therefore, we need to be careful while using the decimation tool and choose the appropriate decimation option, such as planar decimation, which can effectively remove redundant meshes from the model while reducing the face count.

In addition to mesh decimation, Blender also provides mesh deformation tools that can rearrange the mesh into a better deformation mesh while lowering the face count without affecting the object's fine features. As a result, the mesh may have a tidy, well-organized structure with a high-resolution texture composition.

By using Blender's decimation and deformation tools effectively, we can optimize the mesh model and improve its accuracy while retaining its fine details.

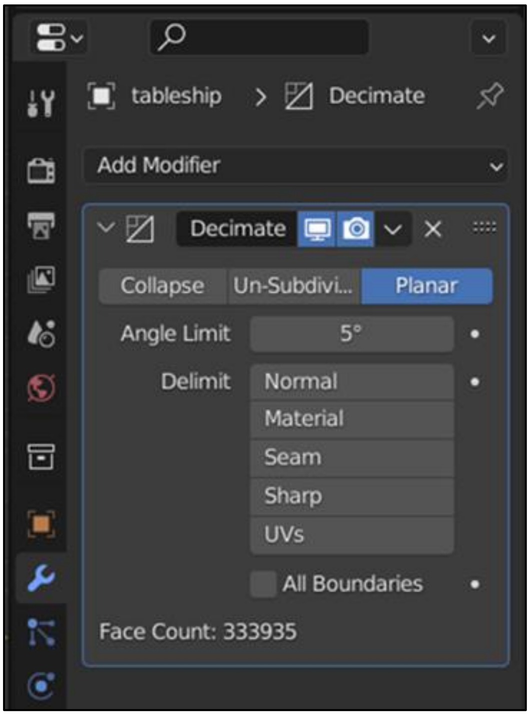

Figure 3.17 Mesh decimation tools in Blender software

3.6 Converting 3D model into 2D drawing

To transform 3D objects into 2D technical drawings, we need to export the 3D models into 3D Computer-Aided Design (CAD) software. In this step, we are using Computer-Aided Three-dimensional Interactive Application (CATIA) software to complete the procedure (see **Figure 3.18**). As mentioned earlier, Blender software provides the ability to export a 3D model into several file formats, such as STL, OBJ, FBX, GLB, and more. Similarly, CATIA software supports several readable file formats, including CAD, STL, OBJ, and others. For this study, we are exporting the mesh model as an STL file and importing it into CATIA.

The conversion process in CATIA software is straightforward, as it can automatically convert the 3D model into an orthographic projection that previews the top, right side, and front views of the model. The isometric projection can also be included in the drawing as a reference to 3D models. To avoid measurement redundancy, we carefully select the key dimensions after projecting the technical drawing's dimensions onto each side of the projection view. The drawing's final product will serve as the basis for this investigation.

By exporting the 3D model into CATIA software and creating the technical drawing, we can effectively communicate the design's intent and specifications with precision and clarity. The technical drawing can be used for manufacturing, documentation, and quality control purposes.

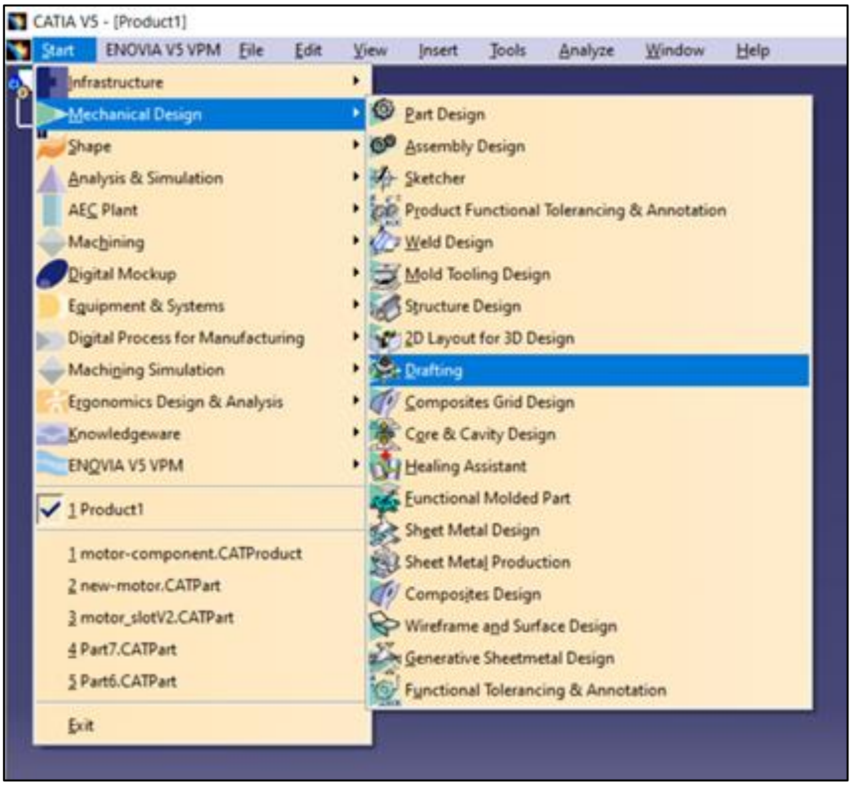

Figure 3.18 Converting the 3D model into 2D drawing using drafting tool in CATIA.

3.7 Augmented reality (AR) display platform

Preservation is crucial for ensuring the long-term accessibility of historical record data. In this study, Augmented Reality (AR) is the best option for preserving and managing the 3D model, as it offers digital preservation capabilities beyond a simple blueprint. AR applications enable user-interaction and integration with the real world, providing an engaging and context-rich experience for the audience. There are two alternatives for developing AR applications: one that requires a specific device, such as Android OS, and another that is WebAR-based and does not require any specific device.

In this case, WebAR is the most suitable approach. To develop WebAR-based applications, we used open-source programming languages such as A-Frame JavaScript or ARjs to control and manage the 3D model on the website and turn it into an interactive AR experience. Although there are other options available, A-Frame is a free license and easy to use, even for those with little knowledge of Java programming language. Our 3D model is saved in STL, GLB, and OBJ file formats, which can be easily imported into the A-Frame programming architecture using just a few lines of code. Moreover, the 3D model can be animated, such as rotating, bouncing, linear movement, adding background music, etc. A-Frame libraries offer various features that can be used to make our model more interactive and attractive to the audience.

3.8 Conclusion

In summary, this chapter discussed the successful deployment of three methods for 3D scanning: laser scanning, depth imaging, and photogrammetry. These methods were sorted according to the hardware setup, software setup, and scanning process, with laser scanning being the most complex. This method required several devices, including microcontrollers, a stepper motor, a 3D printed rack design, and a LiDAR sensor. Additionally, the software setup was also complex, requiring an operating system and a virtual 3D environment robot operating system. In contrast, depth imaging only required an Xbox One Kinect sensor and Kinect to PC adapter, with simple software setup. Photogrammetry only requires a smartphone, with shooting techniques for capturing photos, and two software interfaces, Agisoft Metashape and Reality Capture. After completing the setup, the 3D model needs to be cleaned to remove any noises, and can be displayed as a 2D drawing or in an AR platform. Overall, each method has its own advantages and limitations, but they all have the potential to provide high-quality 3D models for various applications.

CHAPTER FOUR
DATA ANALYSIS AND DISCUSSION

4.1 Introduction

In the previous chapter, we discussed the various steps involved in scanning our ship model using three different methods: laser scanning, depth imaging, and photogrammetry. Each method provides a unique approach to capturing 3D data and has its own advantages and limitations.

Laser scanning involves using a laser sensor and software to produce a 3D point cloud. By combining a LiDAR sensor and stepper motor, we can obtain a single 3D coordinate (X, Y, Z) for each point. The data points are plotted in texture colour on a 3D virtual environment, such as RViz, with the texture colours representing the distance from the base point.

Depth imaging, on the other hand, requires only one device, the Xbox Kinect sensor, to scan the scale model and produce a 3D model. The Kinect is simple to set up and can be used as a handheld scanner to capture the shape and texture of the model for future analysis. The resulting data is presented in 3D form, including meshes and textures from the actual scale model.

Lastly, photogrammetry involves planning a path during photographing to capture the perfect angle and position for a suitable mesh structure. This method is especially useful for our scaled model as we only require a smartphone to take photos and a few pieces of software to construct a 3D model. We will examine the results of using Metashape software and Reality Capture software in this chapter.

4.2 Result of laser scanning method

Let us look at the result in the first method, which is laser scanning. The laser beam emits from the LiDAR sensor and collect all the distance data for each degree of rotation. The combination of data from LiDAR sensor and the movement of stepper motor creates a 3D form coordinate that can be plot in 3D virtual space. All the data is stored in the Raspberry Pi in the form of 3D coordinate data (X, Y, Z). By using RViz tool in ROS environment, the data can be clearly seen in the form of point cloud. As a result, the point cloud appearance looks alike as the scale model as shown in **Figure 4.1** and **Figure 4.2**.

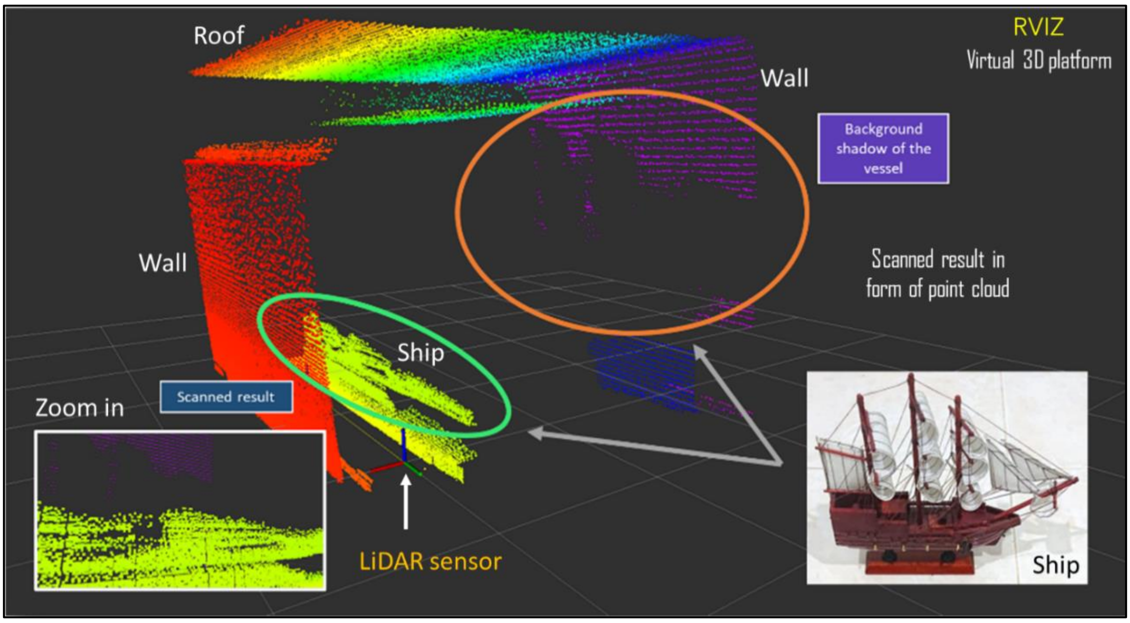

Figure 4.1 A view of 3D point cloud result using RViz tools.

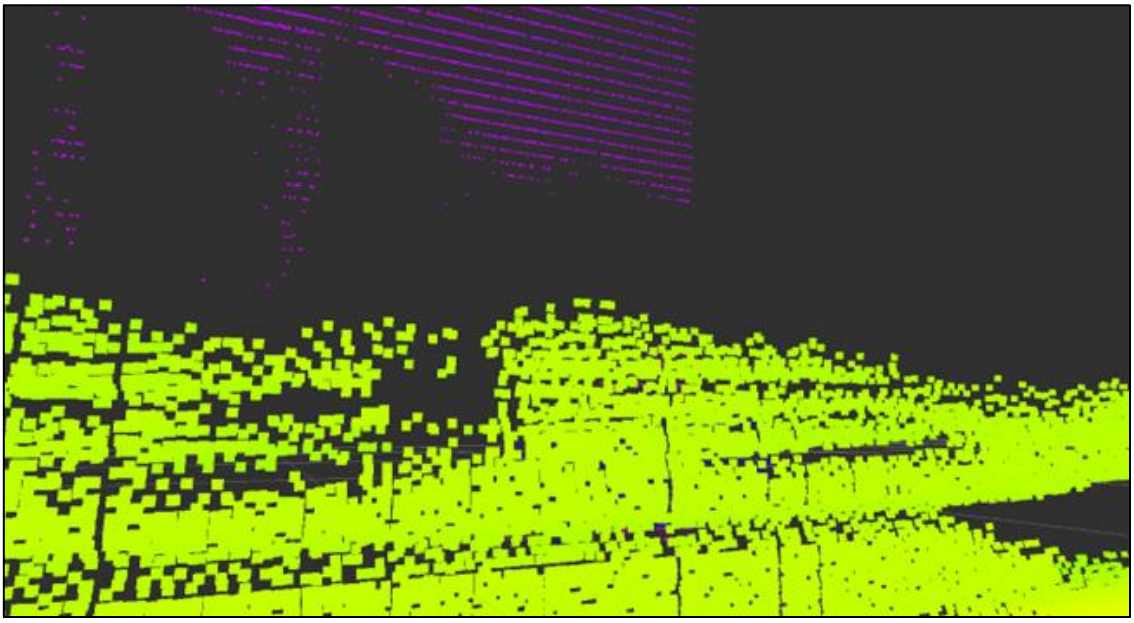

Figure 4.2 A closer look for the scale model point cloud

The color variation in the point cloud represents the distance from the LiDAR sensor. The point cloud includes walls and roofs, but not the floor. The red point cloud represents the closest obstacle to the RP-LiDAR during scanning, which is the wall. The point cloud for the sailing vessel is greenish yellow. In **Figure 4.1** and **Figure 4.2**, the violet point cloud resembles the sailing vessel from the greenish-yellow point cloud. However, when compared with a real object, the result is not very good, as the appearance is not clear and does not closely resemble our target for obtaining a 3D model from the point cloud.

Ongoing experiments are being conducted to identify the problem and its presentation. One issue is that the position of the LiDAR sensor and the model are not aligned, meaning the sensor is higher than the model. Additionally, the model is a scaled version of an actual ship, so some parts are not touched by the laser and are therefore missed. The size of the laser and the object may also be problematic, as the sensor may detect some parts of the model while missing others. Laser deflection can also affect the point cloud output. The model is not a regular design and has poles, platforms, and wire ropes, which can cause the laser to skip over small objects. The RP-LiDAR can handle only 8000 samples per rotation at a rotation speed of 5Hz, with a specified angle resolution of 0.9 degrees for each scan, so some parts of the model may be skipped. Therefore, although the accuracy is great, this method is not suitable for our scale model in this study.

4.3 Result of depth image method

The next experimental study employs the depth imaging method using an X-box Kinect depth camera sensor for 3D scanning. The X-box Kinect sensor is a widely used game controller for the Xbox console that includes a built-in camera capable of capturing depth images for game control environments. This capability can also be utilized for 3D scanning purposes by capturing depth images of objects, which is why we used the X-box Kinect sensor to scan the scale model for this study.

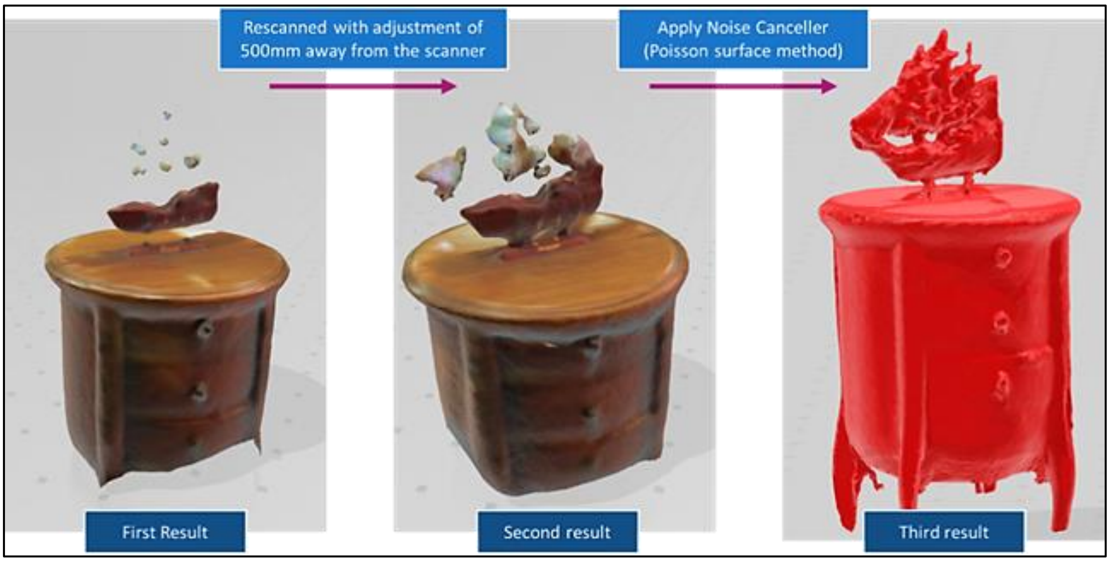

Figure 4.3 Workflow overview for the 3D scan using X-box Kinect sensor.

Figure 4.3 shows the sample scale model placed on a small round table, being scanned using the X-box Kinect sensor. The first scanning result with an 800mm distance parameter between the Kinect sensor and the scale model showed only the hull and a few cloudy sails visible on top of the round table. The hull appeared to be hovering above the table with white clouds representing the white sail for the scale model. However, the round table was clearly visible with good texture and shape. Therefore, we made an adjustment to the distance limit for the second scan.

In the second scan, the Kinect sensor was moved closer to the model, about 500mm away from the scale model, and provided a better view of the hull with additional details of the sails. However, the sails appeared to be floating above the hull, which was undesirable. To reduce the noise during scanning, we applied a noise canceller provided by Microsoft tools.

Finally, we thoroughly re-examined the model and applied the noise canceller to form a clearer 3D model. The result showed the visible hull, sails, and the shape of the scale model interacting with each other. However, the tool focused only on the shape of the model, neglecting their texture and colour, resulting in a grumpy and uneven surface. We used Blender software to smoothen the surfaces.

The 3D model produced by the Kinect sensor was much better than the previous method. However, the quality, accuracy, and precision details of the 3D object were weak and can hardly be used for reconstructing a 3D model of a physical object. This outcome may be due to the small size of the scale model, making it challenging for the device to capture the overall details.

4.4 Result of photogrammetry method

Photo capturing was an essential first step in this study. To ensure accurate results, we positioned the scale model under clear light to minimize dark areas on its surface. We captured 202 photos from various angles to ensure complete coverage of the model. We also carefully planned the photographic technique to maximize the output result during the photo alignment process. For this scale model, we used an anticlockwise circular pattern image acquisition approach. The result is shown in **Figure 4.4.**

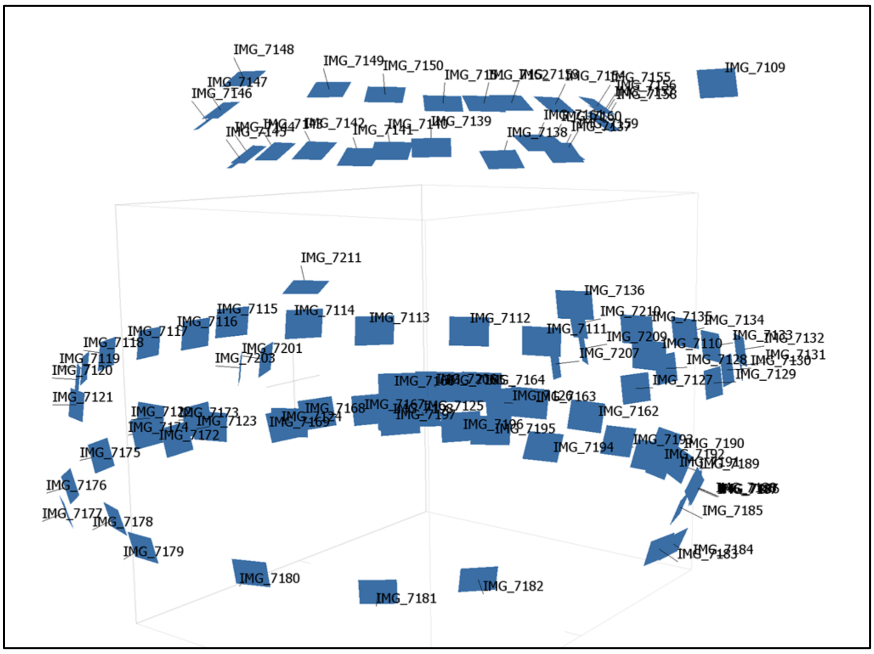

Figure 4.4 Photos alignment result using anticlockwise globing path (AGP) technique.

Each of the photos are labelled with numbers that identifies the photos sequences during photographing. During the photographing, we have separated the photos into three capturing phase which are the top phase, middle phase, and the bottom phase. The top phase is used to capture the top area of the scale model that cover the sail and the top mast. Then, the second phase for scale model middle area which cover the body hull and the inner deck. Lastly, the third phase is captured for the bottom area under the hull and under the sail to cover the blind spot area during photographing.

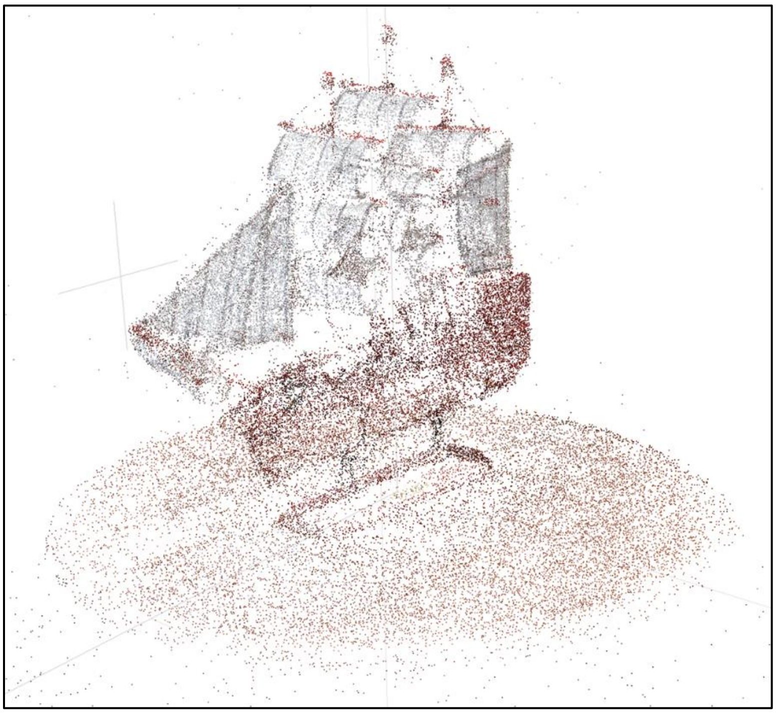

Figure 4.5 Build dense cloud from the aligned photos.

Next, we go through the next process which is the dense clouding. **Figure 4.5** shows the output result for our dense cloud where it clearly seen same as the shape of the scale model. In addition, the points are assigned with coordinates and textures which is benefits to us for measuring the 3D model later. The points texture is used for the texturing process where it will combine all the texture together into one whole texture.

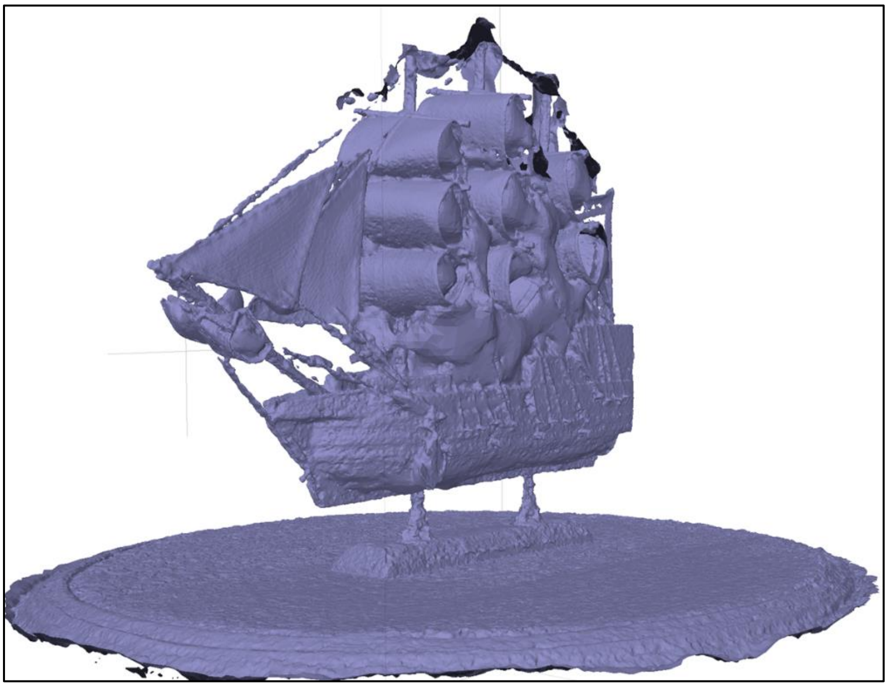

Figure 4.6 Meshing result from the dense cloud.

After the dense clouding process is complete, the next step is to create a solid 3D model by meshing all the points together. This is achieved by connecting the points and forming a surface area that covers all the points surrounding them. The software automatically calculates and finds the nearest points to form a mesh. In this phase, the texture is ignored as the main objective is to construct the surface area from the point cloud. The resulting mesh is shown in **Figure 4.6** without any texture assigned to it. This allows us to inspect the mesh area before texturing it.

However, the output of the 3D model is frequently impacted by noise and inaccuracies in the point cloud. Certain point clouds may contain redundant and inaccurate meshes, resulting in uneven surfaces on the model. Additionally, some areas may have incorrect meshing, especially in the sail cloth area. Therefore, it is necessary to remesh the model or clean up the noise later in other software.

Figure 4.7 Texture the mesh model using texture tools.

The next step in the process is to texture the meshes, as shown in **Figure 4.7**. This involves using the previous data from the point texture and combining them into a texture mesh. The resulting 3D model is then colored accordingly, just like the actual scale model. The brightness of the colour depends on the lighting conditions during the capture of the scale model. The denser the points in a certain area, the clearer the texture that will be assigned to the 3D model.

However, upon closer inspection of the model surface, there may be holes and gaps in certain areas due to a lack of point cloud coverage. To address this issue, we need to generate more dense point clouds by either repeating the dense clouding process or realigning the photos to obtain an optimal point cloud in that area. This will ensure that the 3D model is complete and accurate, with no missing areas or gaps.

Figure 4.8 Clean the textured model with smooth surfaces.

Lastly, we apply a smoothing surface to the textured model to obtain a clean and polished 3D model, as shown in **Figure 4.8**. The resulting output is magnificent, with the 3D model looking exactly like the scale model. The brown and white colours, along with the strip lines texture on the 3D model, are the same as the original scale model. Additionally, the hull of the 3D model displays its detailed properties, such as the cannons, strip lines, ropes, and deck area. The round mini table also has a very clean surface with a wood texture captured by the camera.

However, upon closer inspection of the top of the masts, there may be some noise in a greyish color near them. This noise is caused by the small size ropes that hang from one mast to the other mast. During point clouding, the software detected these ropes as the nearest point cloud and combined them together to form an undesirable-looking model. Therefore, the last step is to clean up all the meshes from incorrect meshing by using Blender software. This will ensure that the 3D model is clean and accurate, with no unwanted noise or artifacts.

4.4.1 Analysis of Model Confidence Level: Actual Model vs. 3D Digital Model

Before proceeding to the next stage, it is important to analyze the specifics of the model. As shown in **Figure 4.9**, a comparison of the physical model and the mesh model is presented, with the physical model on the right (starboard) side and the mesh model on the left (port) at the same locations but in different angles. The shaded blue area of the model represents the ideal measurement, which is 95% agreement between the actual object's dimensions and the 3D model. However, the model's right side and the bottom of the sailcloth are colored in reddish tones, indicating a deviation from the ideal measurement. This could be a result of the excessive use of light and shadow during the photography process. The photos were taken in the afternoon in an open area where the sun was shielded by clouds, causing some surface portions to be obstructed and covered in shadows, leading to inaccuracies in estimating the dimensions. Additionally, the thin white sailcloth could become transparent due to light passing through it, leading to incorrect initial estimates by the system's algorithm during image alignment. To address this issue, point markers were used on the model to assist the system in identifying the locations, orientations, and texture of the model in the photos, resulting in reduced percentage errors.

Figure 4.10 shows the combination of confidence color levels, including red, blue, and green colors assigned to various areas of the model. The red color indicates the highest error of accuracy compared to blue and green areas, while green color has a higher accuracy rate of 90% when compared to the actual photos. The software assigns these colors based on auto-calculation that differentiates the model's accuracy from the actual scale model using all the photos. When we split the confidence level into two sections, namely the green and red sections, it is evident from **Figures 4.12** and **4.13** that the red area has a higher concentration of errors compared to the green area. The red confidence color mostly corresponds to redundant surfaces detected by the software. However, it is important to note that the confidence level is just an estimation from the imported photos, and the model needs to be reverified to ensure that it has the same shape and texture as the actual scale model. This is crucial to obtain the perfect confidence level for the evaluation process.

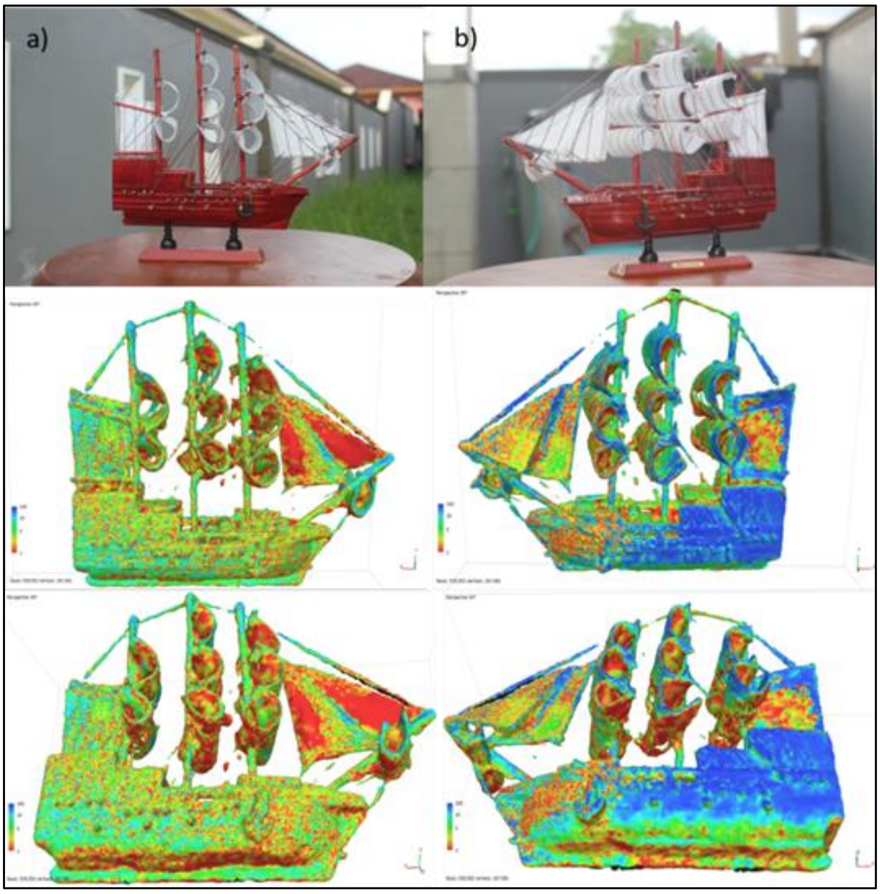

Figure 4.9 A comparison of the photogrammetric point cloud and mesh model coloured according to absolute deviation in percentage, a) starboard side b) port side.

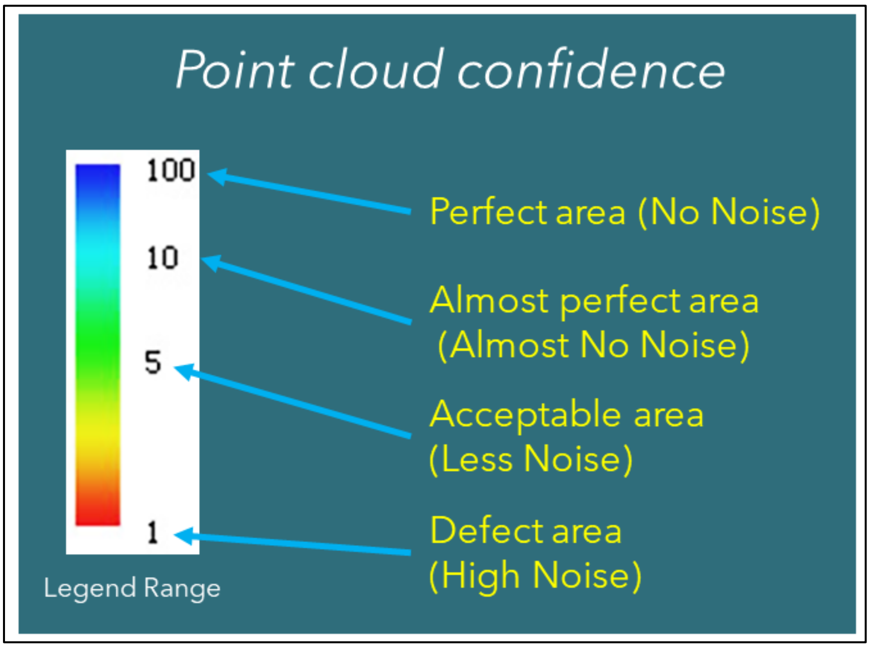

Figure 4.10 The confidence level colour chart in the range of 1 to 100

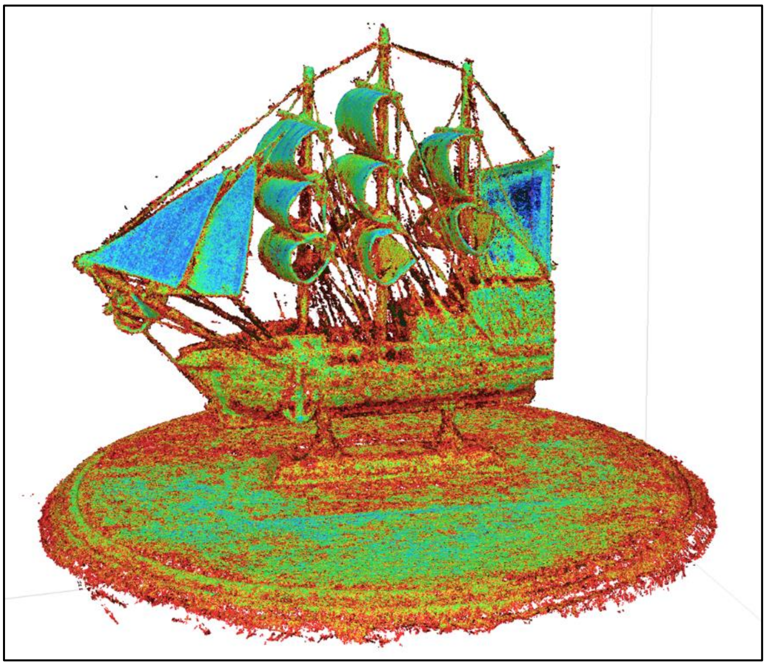

Figure 4.11 The overall confidence level for 3D model

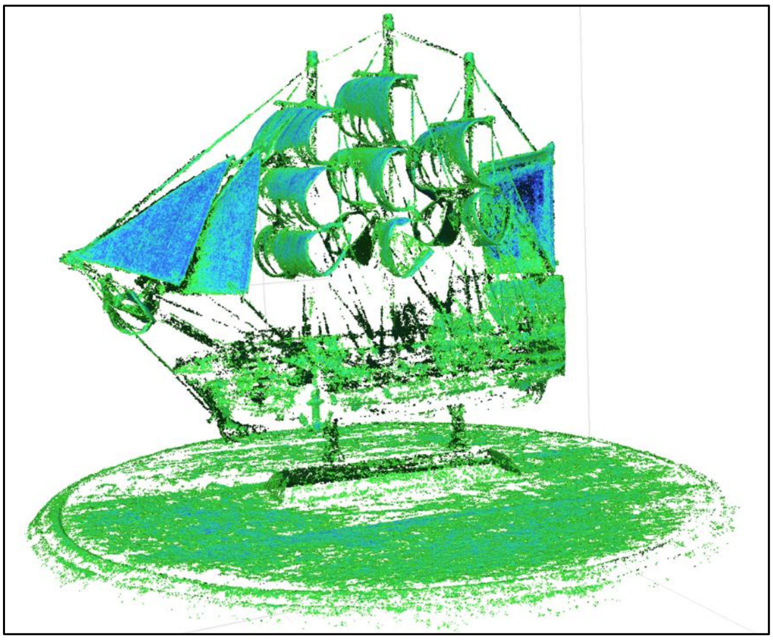

Figure 4.12 The 3D model with high precision level area detected by the software.

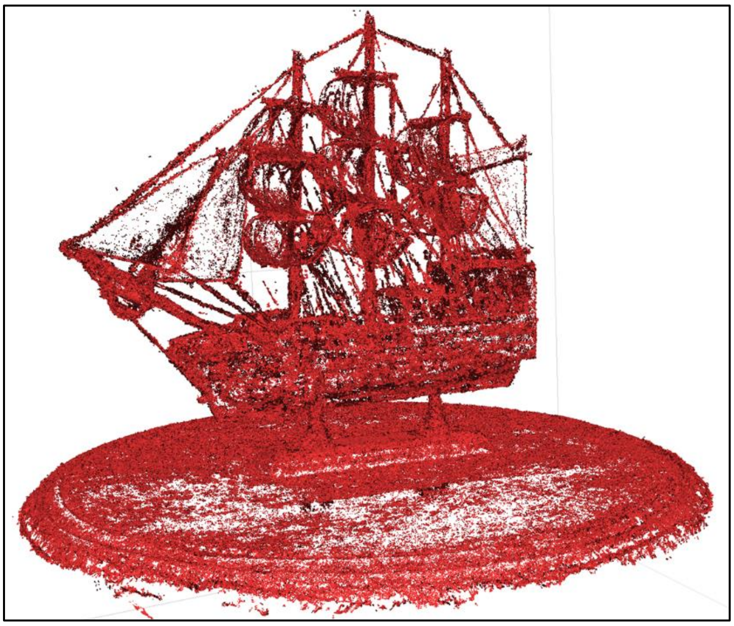

Figure 4.13 The 3D model with very low precision area detected by the software.

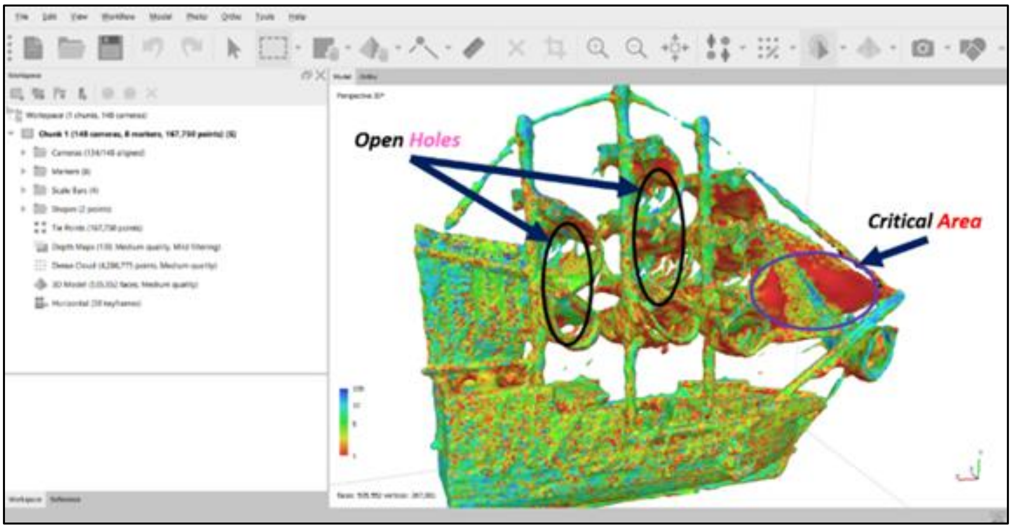

Figure 4.14 The critical and open holes on the mast area.

4.4.2 Model measurement precision

The precision of the 3D model is a critical aspect of documenting cultural heritage using affordable technology and software. After completing the photo alignment and creating an organized polygonal model with texture, it is necessary to perform editing, cleaning, and repair work to ensure accuracy. The model's dimensions must then be evaluated and compared to the real object to demonstrate the approach's suitability for documentation. The study's results, presented in **Figures 4.15** to **4.19** and

Table 4.1, focus on the comparison of the 3D model's precision to the real object.

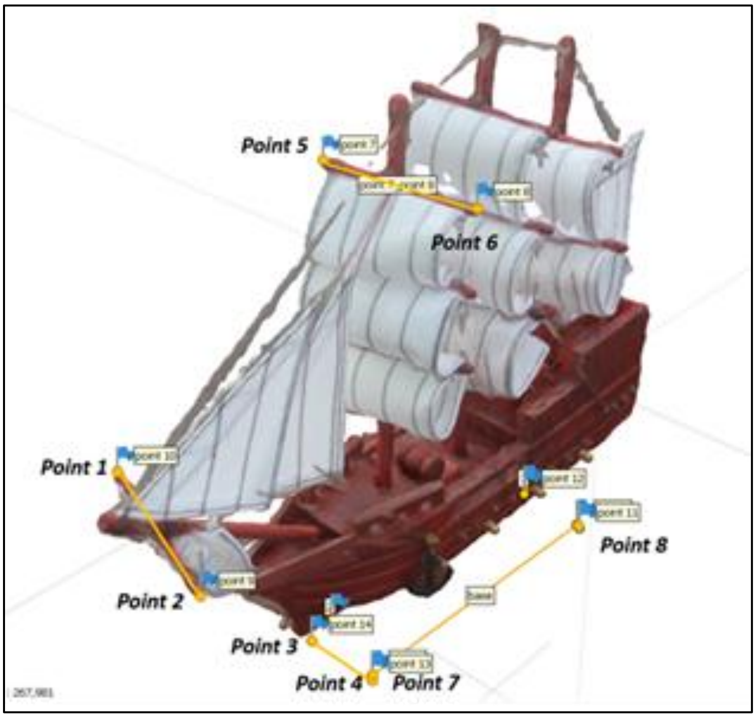

Figure 4.15 Marked points on the 3D model for precision analysis.

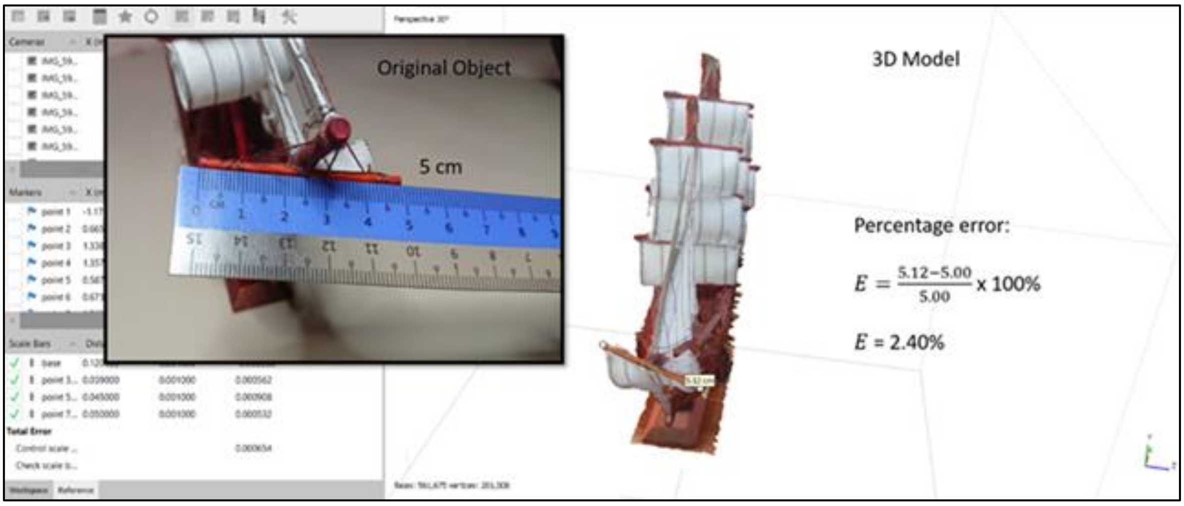

Figure 4.16 Percentage error for front sail holder

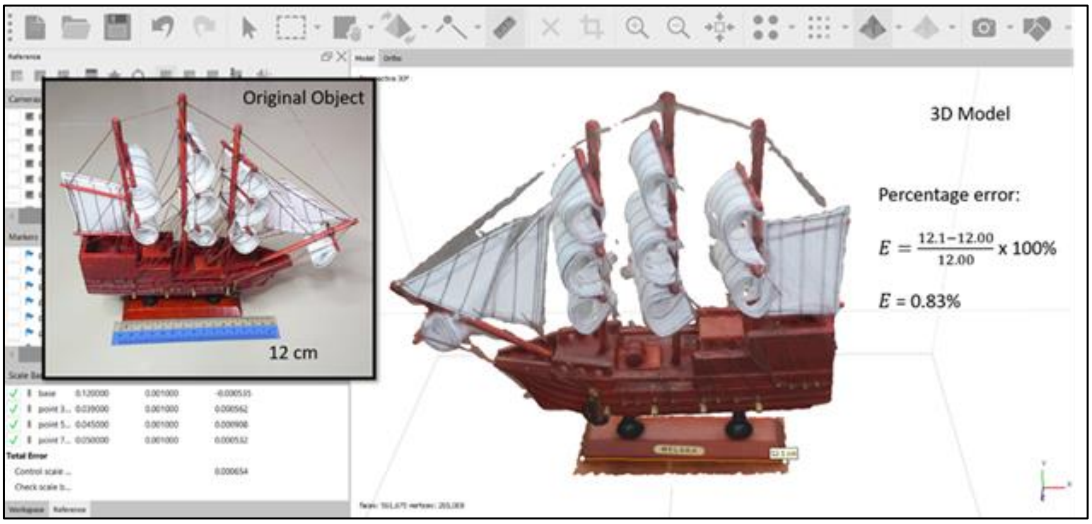

Figure 4.17 Percentage error for base holder length

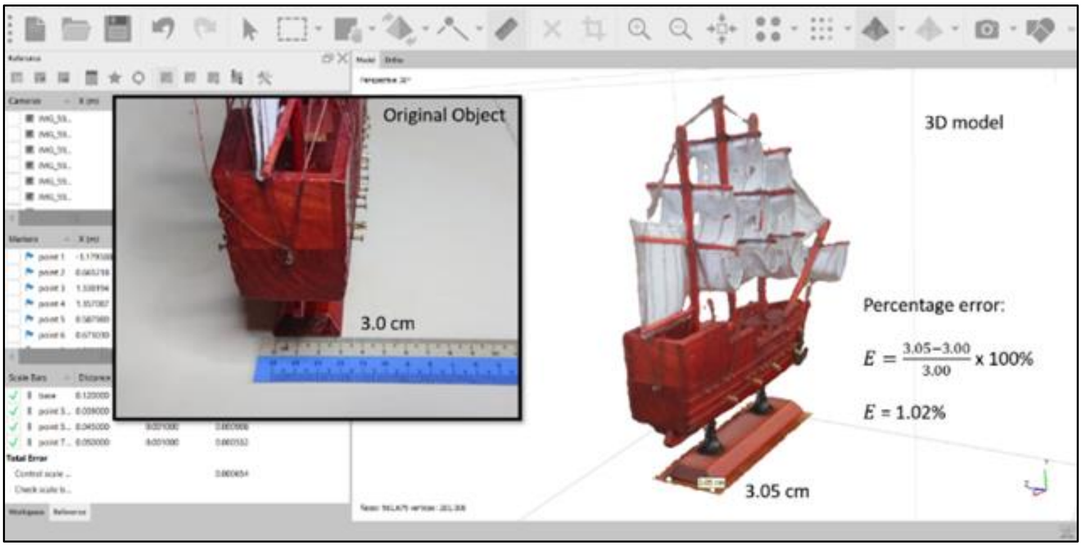

Figure 4.18 Percentage error for base width

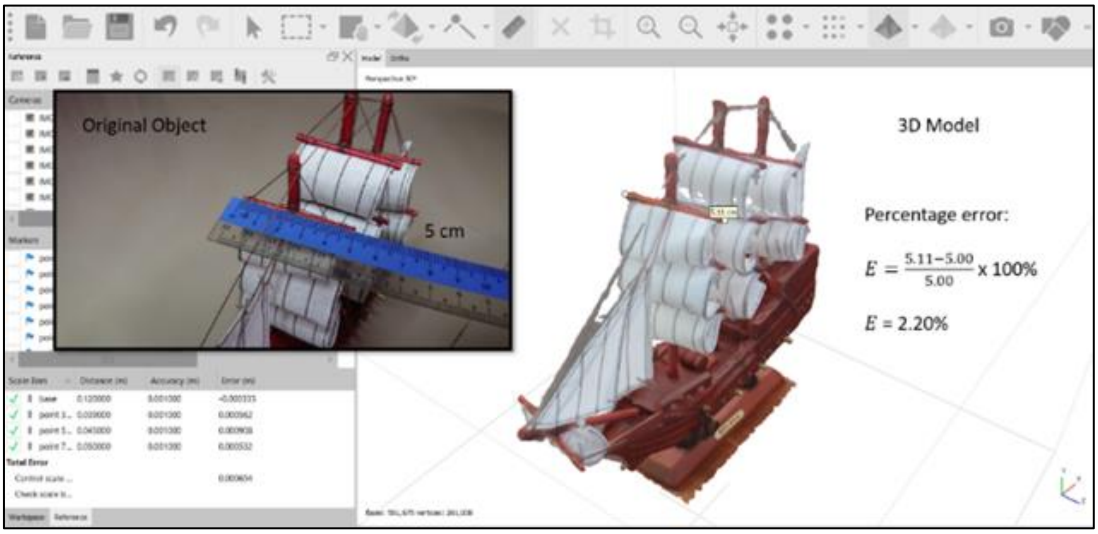

Figure 4.19 Percentage error for the foremast sail holder width

To facilitate the assessment of the precision of the reconstructed 3D model, specific regions have been highlighted in **Figure 4.15**. These regions offer potential points of investigation for precision, including the length of the Sailcloth holder (**pt. 1** to **pt. 2**), the width of the base (**pt. 3** to **pt. 4**), the length of the bowsprit (**pt. 5** to **pt. 6**), and the length of the base (**pt. 7** to **pt. 8**).

Table 4.1

Percentage error between physical and 3D reconstructed models

Part	Actual Dimension	Model Dimension	% Error
Sailcloth holder length	5.00cm	5.11cm	2.20
Bowsprit length	5.00cm	5.12cm	2.40
Base length	12.00cm	12.10cm	0.83
Base Width	3.00cm	3.05cm	1.02

Table 4.1 presents summary information on the percentage error of selected regions in the physical and 3D reconstructed models, as shown in **Figures 4.16** and **4.17**. To ensure a 1:1 size ratio of the model, known dimension data from the real object is imported into the Metashape program. The ship's holder length is used as a reference by entering the real length value into the established scale bar in the software. The physical model's true length is measured using a ruler, and the result is compared to the 3D model's length. The 3D model holder is 12.1 cm, with an error of less than 1%. The width of the physical model is 3.0 cm, while the 3D model's width is 3.05 cm, with an

error of 1.02%. The sailcloth holder near the topmast is also measured, with the physical model's length at 5 cm and the 3D model's length at 5.11 cm, with an error of 2.20%. The highest error measured is 2.40% at the bowsprit that holds the sailcloth, with the physical model's length at 5 cm and the 3D model's length at 5.12 cm. The overall precision of the model is calculated by subtracting the perfect precision from the highest error measured. The Metashape software has a 97% successful rate in scaling the model to the original size of the Pinas, which is approximately 9 m in length, 3 m in width, and 12 m in height.

4.4.3 SFM software performance: Reality Capture vs. Agisoft Metashape

This study involved the use of two different software platforms, Reality Capture and Agisoft Metashape, to create a 3D model of "Flor de la Mar" from 202 recorded photos. The performance of the two software platforms was compared in terms of processing speed and output quality. The results show that Reality Capture outperforms Metashape in both aspects. With identical settings and installations, Reality Capture takes only about an hour to complete all the necessary processes, while Metashape takes nearly three hours. Additionally, Reality Capture delivers a higher quality output with more details and fewer open holes than Metashape, as depicted in **Figure 4.20.**

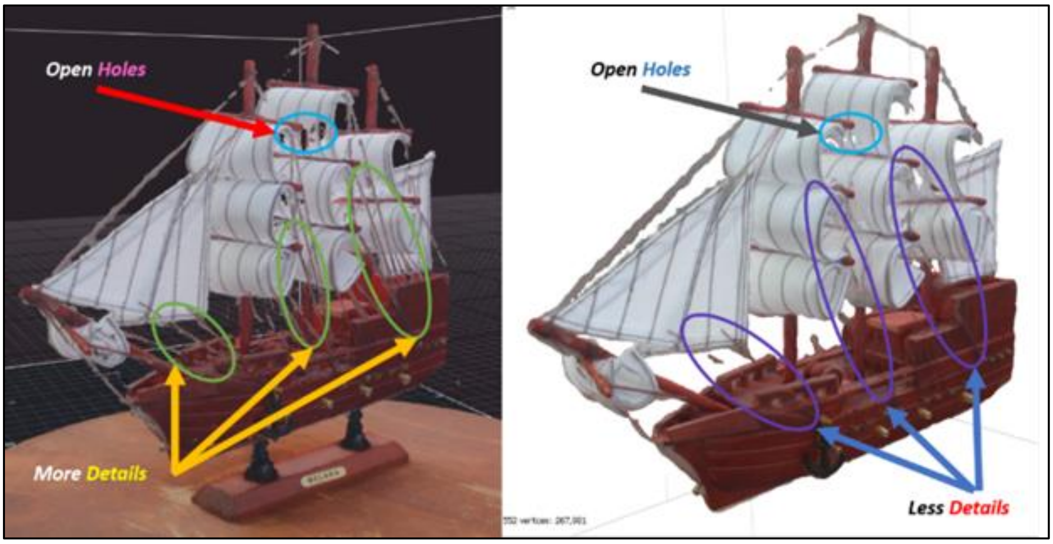

Figure 4.20 The comparison output result between Reality Capture (left) and Metashape (right) software.

4.5 The comparison between three methods

All the experiments were aimed at extracting 3D data from the scale model using different techniques, devices, and software. In the first experiment, a LiDAR sensor was used to emit laser to the object and collect all the data that collided with the laser. The output was displayed in the virtual environment RViz area, showing only the point clouds without texture of the scale model. In the second experiment, a single X-Box Kinect sensor was used to obtain a 3D solid shape with blurred surface details. The texture was removed from the 3D model when applying the noise canceller. However, the last experiment using photogrammetry with a smartphone and software resulted in the best outcome in terms of shape, texture, noise, and accuracy, exceeding the laser and depth imaging methods. The photogrammetry method is also easy to set up, and the result has the same figure as the actual scale model. Thus, the photogrammetry result was chosen for 2D drafting and deploying in a virtual world. All the results obtained from each method are shown in **Figures 4.21** and **4.22**.

Figure 4.21 The comparison study between laser, depth image, and photogrammetry

Figure 4.22 The comparison in shape, texture, noise, accuracy, and setup

4.6 Conversion from 3D model into orthographic projection.

The chosen outcome from the previous experiment is being used to create an orthographic projection for simple documentation purposes. The photogrammetry method is selected over other methods for this purpose due to its realistic 3D model that is the same size, colour, texture, and shape as the actual scale model. Creating a 2D projection from the 3D model allows for a clear top, front, and side view. As a result, this outcome is being utilized to map the 3D model onto a 2D draft plan using CATIA software. The result is illustrated in **Figure 4.23**.

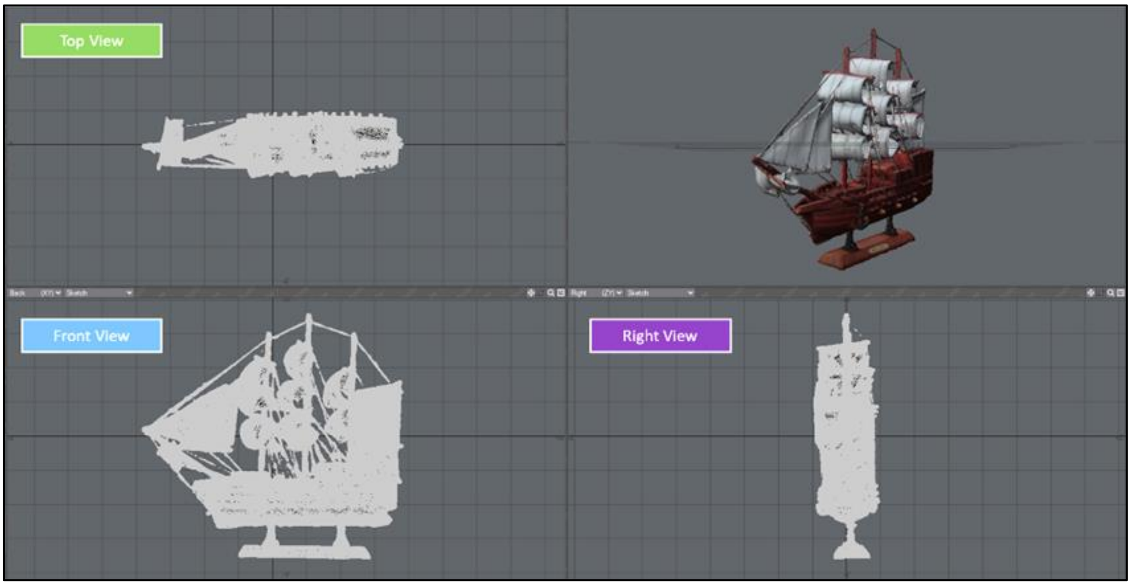

Figure 4.23 The orthographic projection result for the 3D model

4.7 Presentation in Augmented Reality (AR)

The final phase of the project involves merging virtual and real elements to create an augmented reality (AR) experience that enhances the feeling of reality. The 3D model generated in the previous phase can be imported into an AR setting, providing an engaging and immersive educational experience for visitors to the museum. AR technology offers numerous advantages, such as being space-efficient and protecting the valuable national asset from harm without the need for regular upkeep.

There are several platforms available for viewing 3D models in the real-world using AR, including web-based and mobile applications. Web AR, which is often used for educational purposes, requires the use of another media such as a QR code or photograph to launch the AR content. For example, Animonsta Studio created an AR card game based on the popular Malaysian animation BoBoiBoy, where scanning the QR code on the card reveals the anime's AR character. On the other hand, AR apps require downloading the AR Apk files to our smartphone to play the AR content. While the AR app may require some space on the device, it is often used for game deployment.

The use of Augmented Reality (AR) in mobile games such as Ingress and Pokémon Go has become a popular phenomenon around the world. The AR platform has allowed game developers to create engaging and innovative games that cater to a wide range of audiences, including Pokémon enthusiasts. These games are primarily played on the AR App interface for Android and iOS smartphones, and revenue is generated through in-game purchases. Depending on the nature of the information we want to convey to the public, both AR platforms offer unique advantages.

For this project, we have utilized both AR platforms to share information with the public. We first designed using Web AR for ease of access, incorporating a QR-code scanner to link to the AR content. By scanning the land marker, the 3D model will emerge, which is programmed using javascript as detailed in Chapter 3. **Figure 4.24** contains the image that users need to scan to access the online application shown in **Figure 4.25**.

Figure 4.24 Web AR deployment for the scale ship model

Then, we used Unity, a game development program, to create an AR app. The business has developed an AR plugin feature for use in the Vuforia package's AR environment. Vuforia is a free AR platform that is helpful for people who want to create AR applications, as it can recognize QR codes, images, geo-locations, and 3D objects as a medium access to project the 3D model in augmented reality.

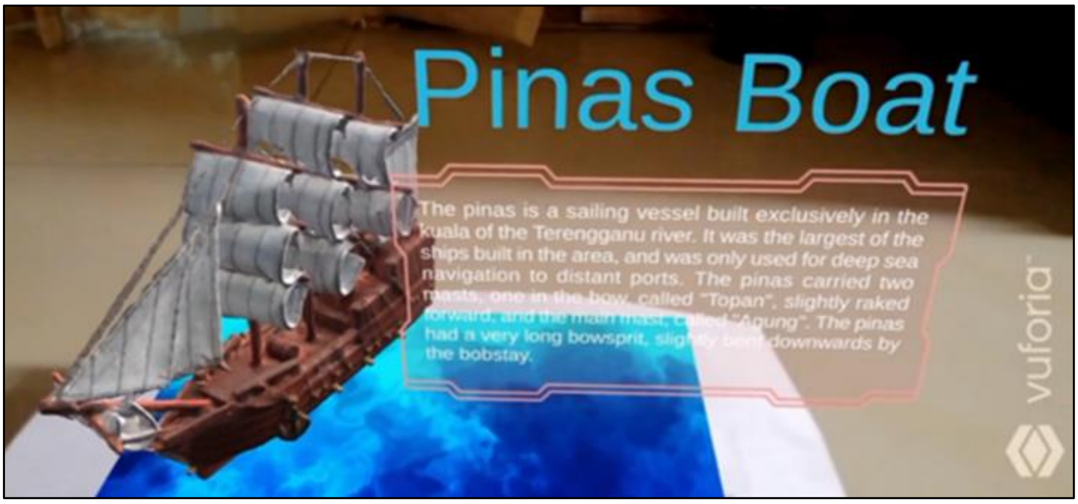

Figure 4.25 Screenshot of the 3D model ship in AR mode using smartphone.

We further enhanced the 3D model in Unity by adding information and water effects to make it more appealing. The model was then exported into an Android APK application. This application uses an image detector that leverages the phone's camera to populate the model location in the real world. When the camera focuses on the desired image, the model appears there. This technique is simple yet fascinating as it visualizes the invisible elements that hide on a portion of an image.

4.7 Conclusion

In this chapter, a comparative research study was conducted using a qualitative approach with an analysis method to evaluate different 3D scanning methods for creating accurate and high-quality 3D models. The results indicate that photogrammetry is the most efficient method in terms of accuracy, texture quality, and productivity compared to laser and depth imaging methods. The study found that using a 2D LiDAR sensor combined with a stepper motor is not recommended due to the mismatch of the data with the actual model. The Xbox One Kinect used for depth imaging was found to be highly sensitive to movement and distance during scanning, leading to decreased accuracy at greater distances. On the other hand, photogrammetry only requires a smartphone camera and an SFM software for image processing, making it a simple and cost-effective solution for creating 3D models.

For this study, two different software applications, Reality Capture and Agisoft Metashape, were utilized to create the 3D models. The results indicate that Reality Capture has a faster processing time and better meshing process compared to Agisoft

Metashape, but both produced clean 3D models with high-quality textures. Finally, the best 3D model was used to create an augmented reality (AR) display and 2D documentation. Overall, the findings of this study suggest that photogrammetry is a superior method for creating high-quality 3D models, and Reality Capture is a recommended software for efficient and accurate processing.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

4.8 Introduction

This chapter provides a comprehensive overview of the study in three main sections. Firstly, a summary of the research methods used, including laser scanning, depth imaging, and photogrammetry, is presented. Secondly, recommendations for 3D scanning of both the scale model and actual scale are provided to improve the accuracy and texture quality of the resulting 3D models. Finally, the chapter concludes with a summary of the entire research and its findings, highlighting the superiority of photogrammetry over other methods in terms of accuracy, texture quality, and productivity.

4.9 Research Summary

This study aimed to compare the accuracy and effectiveness of three different approaches for creating three-dimensional (3D) models: laser scanning, depth camera, and photogrammetry. The findings indicate that laser scanning is the least preferred method as it only produces point clouds and cannot construct 3D models. The 3D model generated using depth camera method is rudimentary with limited surface details and some warped sections. The photogrammetry approach is the most effective with precise dimensions and high-quality 3D texture. The success of this method has important implications for preserving national heritage in augmented reality environments and for future form design blueprints.

In terms of software, the post-processing photogrammetry software Reality Capture outperforms Agisoft Metashape in both processing speed and output quality. Testing with a scale model showed that Reality Capture can scale models back to their original size with 97.6% accuracy. The research findings provide valuable insights into the most effective approach for creating 3D models and suggest that photogrammetry is a promising technique for future applications in augmented reality and other fields.

4.10 Suggestions and Recommendations

The researcher gives several recommendations in this study for future study in the same topic and field. The suggestions related to the 3D scanning the scale model are explained as follows:

4.10.1 Recommendation for laser scanning method

The researcher suggests that in this method, the setup of laser scanning need to be modified due to the inaccuracy from the obtained result. The data shows a bunch of point cloud plotted are not aligned with the actual situation. This is maybe because of the inaccuracy design setup where in this study, the researcher used only 2D LiDAR sensor to obtain the 3D data coordinate. The researcher combines the 2D LiDAR sensor with a stepper motor to obtain the 3D coordinate data. During the scanning process, the scanning data from the LiDAR sensor is not tally with the movement of stepper motor that cause the data is inaccurate during plotting the data. Therefore, the researcher suggests that to modify the design by changing the stepper motor or by swapping the 2D LiDAR sensor into 3D LiDAR sensor in order to obtain precise data.

4.10.2 Recommendation for depth imaging method

In the second method, the researcher recommends upgrading to the latest version of the Kinect sensor, which is the Azure Kinect sensor, as it offers improved features and functionality compared to the X-box Kinect sensor used in this study. The Azure Kinect sensor is specifically designed for project-based applications, including those involving artificial intelligence devices such as service robots and automation. In contrast, the X-box Kinect sensor was primarily developed for X-box console games and requires an additional adapter to run on a laptop, which may not be compatible with all laptops. Additionally, the Azure Kinect sensor can be easily detected by most laptops without any additional supporting devices, and it is much smaller and easier to carry than the X-box Kinect sensor.

Furthermore, the internal hardware of the Azure Kinect sensor has been significantly improved compared to the X-box Kinect sensor, featuring a 1-megapixel depth camera and a 12-megapixel RGB camera that can capture sharper images with higher resolutions. Therefore, for future experiments involving either scale models or actual size objects, the Azure Kinect sensor should be used instead of the X-box Kinect sensor. This would ensure that the resulting 3D models have improved accuracy and detail, as well as facilitating better integration with artificial intelligence devices and other project-based applications.

4.10.3 Recommendation for photogrammetry method

To improve the texture quality of the 3D model, it is recommended to use a DSLR camera instead of a smartphone camera. Although the accuracy of the model obtained using a smartphone camera is high, using a DSLR camera can enhance the texture quality. In the case of a full-size traditional ship, a drone camera can be used to capture high places such as the top mast, hull, sailcloth, and figurehead. However, for the scale model used in this study, a smartphone camera was sufficient to obtain a highly precise 3D model. In future studies, the use of a DSLR camera or DJI drone camera can be considered to capture higher and further places, which can further improve the quality of the 3D model.

4.11 Conclusion

The study demonstrates that photogrammetry is an effective approach for creating accurate and high-quality 3D models with excellent texture. Laser scanning and depth imaging methods were found to be less preferable due to limitations in accuracy and surface detail. Reality Capture was identified as the best software option, with faster processing time and superior output quality compared to Agisoft Metashape.

The 3D model created using the proposed approach can aid in preserving national heritages in an augmented reality environment and provide a more realistic approach to developing future form design blueprints. In future studies, full-size ships such as SABAR and Pinas ship will be used to further verify the suggested strategy. Additional research efforts will focus on the inner structure of traditional Pinas ships, which will require further investigation to identify the length and quantity of fitting frames used.

Overall, the proposed approach has the potential to serve as a useful educational tool for visitors and draw them to museums. By providing accurate dimensions and high-quality 3D models, the approach can aid in the preservation of cultural heritage and contribute to future form design.

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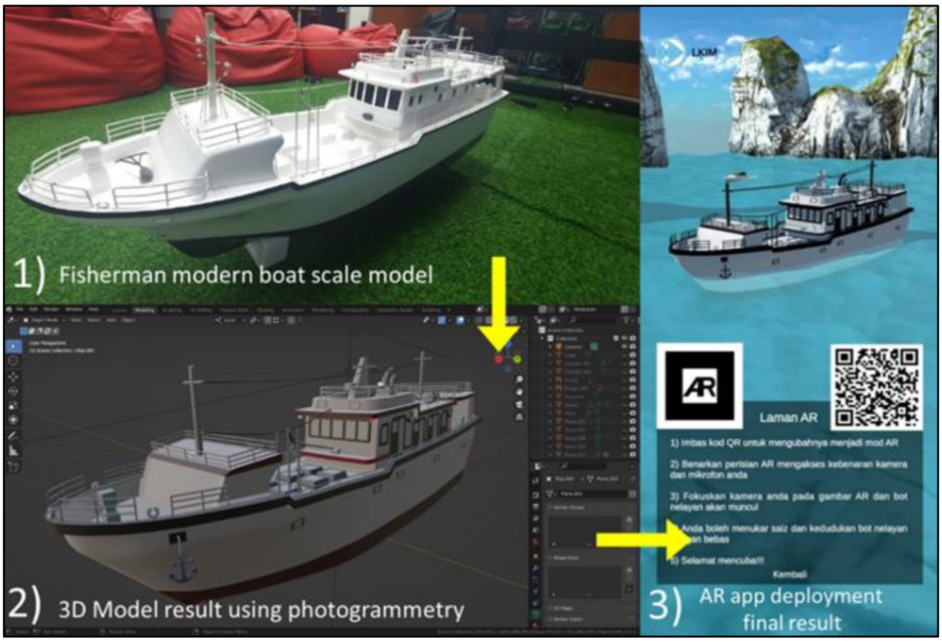
APPENDICES

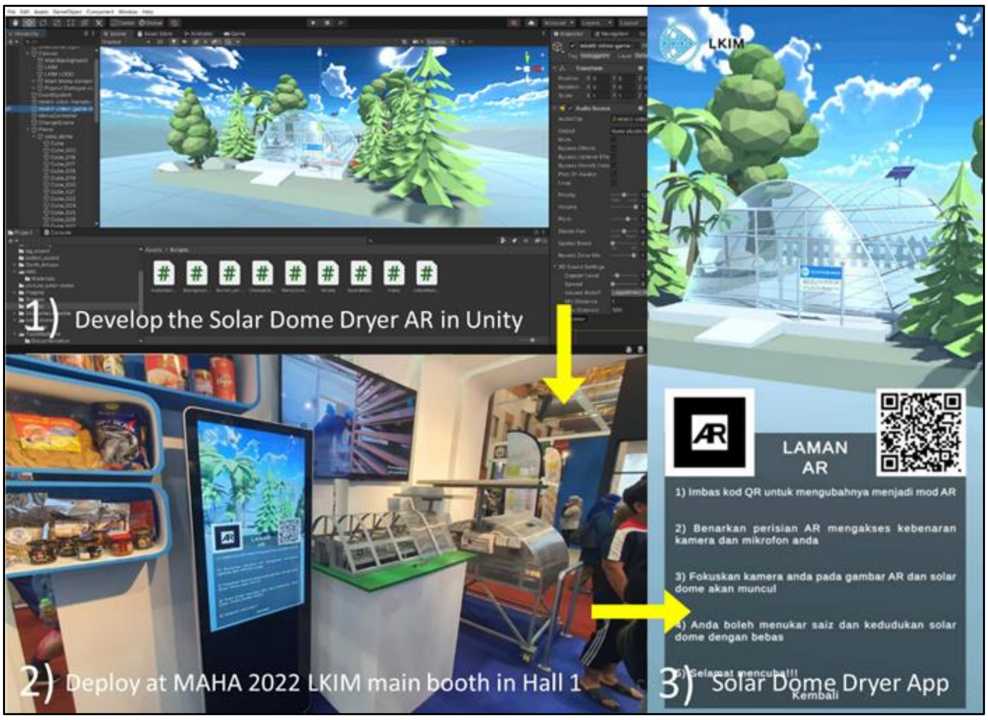
APPENDIX 1

This section highlights some of the successes of the suggested strategy. The first is the digitalization of a contemporary fishing vessel from Lembaga Kemajuan Ikan Malaysia (LKIM). Figures below show the finished product for mobile apps that were shown at the Malaysia Agriculture, Horticulture, and Agro-Tourism (MAHA) Exhibition 2022, which was held at MAEPS in Serdang from August 4 to August 14, 2022. The second on is Solar Dome Dryer which was showcased in MAHA 2022 as illustrated in the figures.



LKIM project: AR app deployment for Fisherman modern boat

APPENDIX 2



LKIM project: AR app deployment for Solar Dome Dryer App

AUTHOR’S PROFILE

Mohamad Haziq Ahmad Yusri obtained a Bachelor of Mechanical Engineering (Hons.) in 2020 from University Teknologi MARA (UiTM), Shah Alam, Selangor. His major is in C++ and C# programming and 3D design. During his study, he was very committed to developing robots and joining the robotic club until he was assigned to be president. After retirement, he continues studying for a master’s degree in the same course. Currently, he is working with SEA-IC to develop Augmented Reality (AR) interface for the engineering education system. He aims to develop a virtual education system to enhance the understanding of the engineering module.

List of Publication:

Ahmad Yusri, M. H., Johan, M. A., & Ramli, M. H. M. (2022). Preservation of Cultural Heritage: A Comparison Study of 3D Modelling between Laser Scanning, Depth Image and Photogrammetry Methods. *Journal of Mechanical Engineering*, *19*(2), 125–145. https://doi.org/10.24191/jmeche.v19i2.19768