Research Article

Mini-C Arm Rotational Camera Station for Supporting Reverse Engineering Technique

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Abstract
By knowing the significant factors and controlling in scanning-surface acquisition, the alternative method has been introduced and it will be able to reduce the surface reconstruction time by 20–30% while controlling the 3D CAD model quality that will benefit greatly in surface fitting and rapid prototyping process. The working environment (light intensity) and other important factors (object sizes, reference gap, surface coating, and the number of images for non-scanning method as well as degree of capturing) were studied in this research for supporting the design phase of developed equipment called *Mini C-Arm Rotary Camera Station (RCS)*. The tips for adjusting camera conditions on the RCS are presented to avoid the errors occurred during surface acquisition. The obtained results could be applied for assisting the 3D laser scanner to capture small details of the object's surfaces. The design and components of this developed equipment are the key components which need to be identified and analyzed for obtaining the good 3D model.

Keywords: Reverse engineering, Non-scanning, Surface reconstruction, C-arm imaging acquisition, Rotary camera station

1 Introduction

In traditional manufacturing, engineers use the engineering drawing as their guide to produce the parts by manufacturing process such as trimming, drilling, facing, or casting [1]. However, there is time when engineering drawing or CAD (Computer-Aided Design) drawing is not available; then traditional manufacturing process will not be applicable. That is where the new manufacturing technique: Reverse Engineering-steps in. "Reverse Engineering" (RE) is used to summarize the process of reconstructing an already existing object [1].

Reverse Engineering is now widely used in numerous applications, such as manufacturing, industrial design, and jewelry design and reproduction. With RE, the design engineer starts with the final product and works through the design process in the opposite direction to arrive at the product design specification. RE can be separated into three simple steps: *Data acquisition, Surface reconstruction and Surface fitting* [2]. The first step, data acquisition, is the most important and in the past, the object can be measured by traditional method, such as Vernier caliper, ruler and measuring tape which was the fastest measuring method during that period. Then after some years, coordinate measuring machine, or CMM, has been introduced contact acquisition method. It provides high accuracy; however, it requires long process time [3].

In this research, for fast acquisition of the small objects, the 3D laser scanner has been applied as the reference acquisition device to detect the geometric shapes quickly; however, some details of the surface cannot be captured and revealed. The assumptions

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were raised and concerned about the limitations of the scanner, setting up equipment/environment, complicate steps required, and the light condition. It would be great if the other technique which is available, easy-to-access or user-friendly function, and widely used in everyday life can be asked for assisting this scanning technique to obtain clean and clear virtual model. Imaging acquisition techniques (i.e., non-scanning) have been introduced for detecting and capturing geometric shapes quickly with simple image taken [4], and these techniques show the popular trends to apply rotary platform and camera-based devices as the key components. The benefits obtained from easy-to-access imaging device might improve the quality of the final model where the number of inspections and maintenance cost can be reduced [4]. The uncontrolled hand-shaking can be reduced or eliminated during imaging activity since the function of rotary table and mini curvature arm can enable pan/tilt motion control of a phone camera with less human labor required. This activity and technique allows the users place the object on the rotary table, and as the table rotates, the digital/phone camera captures a sequence of images easily with the camera optic axis having an angle varied between 5 to 10 degrees or more to help obtaining clearer details and shape. However, a perspective distortion may exist on the captured images because the angle between the camera and a surface is not orthogonal. These distorted images might lead to the lack of 3D shape and size. In order to improve the quality of the input images, the technique called 2D projective transformation (Homography) might be applied for transforming the image plane to be the world plane [5]. These have led to our research to design an alternative imaging equipment where everyone can spend short period of time to capture and detect geometric shapes from different views while maintaining clear images.

2 Research Background

Data acquisition process is the most important process since it defines all the details and shapes of the existing objects. Hence, 3D laser scanning method and image registration method help to obtain 3D CAD model in short amount of time with acceptable measurement. It can also edit the object surface. Using these processes will allow 3D CAD model to be constructed directly from its original object. Collecting dimensions on an object is not an easy task, especially that with curvature surfaces, undercuts, or complex shapes [6].

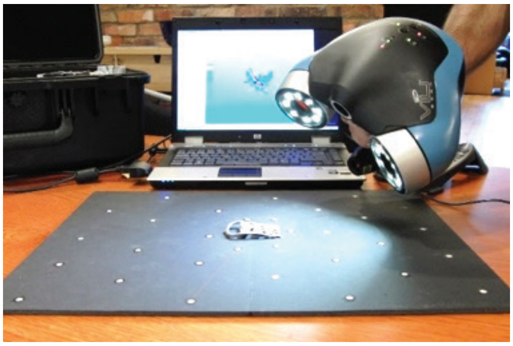


Figure 1: 3D Laser Scanner [7].

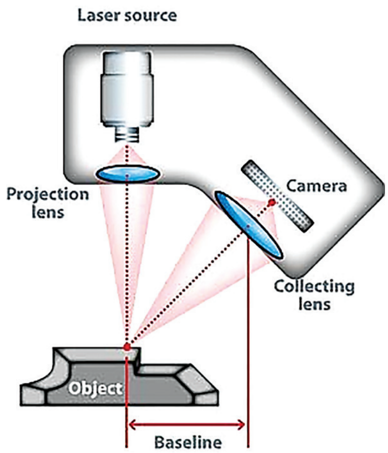


Figure 2: Laser Triangulation 3D scanner [9].

2.1 *3D laser scanning technique*

Laser scanning method is widely used across the industries. The 3D laser scanning by projecting the laser beams on the surface and reflect back to the capturing camera (using the reflection and triangulation theory) as shown in Figure 1. A 3D laser scanner is a device that analyses a real-world object or environment to collect data on its shape and possibly its appearance. The collected data can then be used to construct digital three-dimensional models. There are several limitations in this kind of objects that can be digitized. Triangulation based 3D laser scanners are also active scanners that use laser light to probe the environment (Figure 2).

With respect to time-of-flight 3D laser scanner, the triangulation laser shines a laser on the subject and exploits a camera to look for the location of the laser dot. Depending on how far away the laser strikes a surface, the laser dot appears at different places in the camera's field of view. This technique is called triangulation because the laser dot, the camera, and the laser emitter form a triangle. The National Research Council of Canada was among the first institutes to develop the triangulation based laser scanning technology in 1978 [8].

Although reflectance is quick and easy to scan, it is also influenced by the sparseness of the tephra, seen as a low signal intensity, and hence varies considerably across the uneven former peat surfaces, necessitating some replication of scans. The combination of reflectance and luminescence provides a technique of considerable geochronological potential for identifying distal tephras [10]. For brief discussion on scanning technique, this method is suitable for most of the object's shape other than object with a lot of holes or undercut, since its biggest concern will be on the whether the laser could reflect back to the camera at the correct direction. Which is the reason most of the time object have to be coated with special powder spray and object with too much hidden area (holes, undercuts) are not suitable or object surface is not suitable for scanning and cannot be coated. This method also has issue when measure object that is too small in size too even using the small reference gap board.

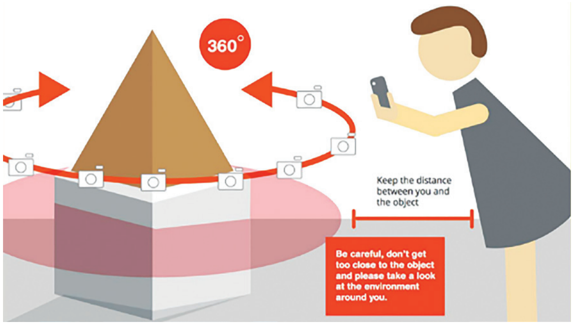


Figure 3: Camera-based acquisition [14].

Figure 4: Image registration technique [15]–[17].

2.2 *Image-based acquisition technique*

This method has high accessibility, most of the people can use them and it is easy to perform. Capturing an object with different views (Figure 3) and registering them as the surface are the key concept of this method [11]. The image registration is the process that transforms different sets of data which are multiple images into one coordinate system. The geometrical transformation aligns points in one view of the image with corresponding points in the other view of image. Normally, the geometric shapes are aligned with two images of the reference and the sensed images. The different imaging conditions are introduced according to the present differences between images [11].

This method of image registration (Figure 4) is required in remote sensing (weather forecasting, environmental monitoring) in medicine (monitoring tumor growth, treatment verification), cartography (map updating) and computer vision (automatic quality control) [12]. According to the reference, image registration is an important problem in breast imaging. It is used in a wide variety of applications that include better visualization of lesions on pre- and post-contrast breast MRI images, speckle tracking and image compounding in breast ultrasound images, alignment of positron emission, and standard mammography images on hybrid machines et cetera. It is a prerequisite to align images taken at different times to isolate small interval lesions [13].

The problem of registration arises whenever images acquired from different scanners, at different times, or from different subjects, need to be combined for analysis or visualization. In other words, image registration is the process of overlaying two images, a (the reference) and B (the target), such that they are brought into spatial correspondence with each other. The problem of aligning the two images is equivalent to the problem of estimating a transformation T, such as T(A) = B. This is also equivalent to the process of determining an unwrapped image B* (derived from A), that is closed in some numerical sense, to B [13].

Amongst different breast image registration problems, the most commonly solved or visited problem appears to be the registration of pre- and post-contrast breast MRI images. This could be because of: (i) increasing use of breast MRI over recent years as well as better standardization of MRI protocols, (ii) greater availability of images, and (iii) better image contrast and hence an easier problem to solve.

Registration is increasingly being used to integrate useful information from different modalities. This is due to the fact that although the sensitivity of mammography is reasonably high, its low specificity can be vastly increased by integrating information from mammography with images from modalities of higher specificity like PET and ultrasound. This allows simultaneous correlation of structures visible on one or both modalities and can improve the confidence of diagnosis made using only one of the modalities [13].

2.3 *Clinical C-arm imaging equipment*

A Clinical C-arm scanner [17] (Figure 5) produces a set of two-dimensional (2D) X-ray projection data obtained with a detector by rotating C-arm around the object. The number of required projections is approximately several hundreds of views. Modern multi-axis C-arm systems can provide 3D images by recording several projections around the patient and perform tomo-graphic image reconstruction. However, these advanced systems are expensive compared to standard C-arm scanners [18]. The quality of the image that the scanner can make is depended upon the way to use the C-arm to rotate and scan the object.

There are 4 methods (a to d) used for scanning the object (Figure 6):

a) *Full scan with several-hundred view*: This method, the C-arm will scan the object very carefully in every point of view.

b) *Scan with number of view*: The C-arm will scan only a small number of projection view.

c) *Scan with short rotation*: This method C-arm will capture the object with the less than theoretically. It used for scan the object only some view.

Figure 5: Clinical C-arm scanner [19].

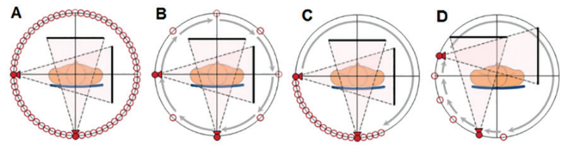


Figure 6: The different of C-arm scan configurations [20].

d) *Offset scan*: This method is very common for C-arm scanner because it can increase the scanner FOV in 2D fluoroscopy [20].

2.4 *Surface reconstruction and surface fitting*

After obtaining merged surface from both 3D laser scanner and image-based acquisition techniques, the surface reconstruction and surface fitting have been performed to complete the 3D solid structure. Surface reconstruction from point sample is a well know problem in data acquisition method. It provides fitting for scanned data, filling of surface holes and fulfill the missing part of existing models. Some defective surface regions of data may be left from the accessibility constraints during scanning. The reconstruction methods may attempt these challenges to infer the topology of the unknown surface, accurately fit (but not over fit) the noisy data, and fill holes reasonably [21]. Surface fitting is a process to fit the surface together to build 3D model.

The result can be obtained by using the surface orthogonal curvature information to reconstruct the flexible plate structure which has significant meaning for form awareness and actively monitor of structures [22]. The research object can be taken from a platy structure of one side fixed, and the surface can be divided into orthogonal curvilinear nets. The calculation of the coordinate in those nodal points can be obtained by setting moving coordinate systems on the orthogonal curvilinear nets and transformation of coordinates, the given boundary conditions, and the orthogonal curvature information of nodal points and the coupling relation of the orthogonal curvature [23].

3 Overall Processes of the Research

Before starting the first step of the proposed approach, the scope and limitation of this study have been listed and planned. Six processes were created where the advantages and disadvantages of data acquisition methods and the solutions for the difficulties in order to acquire better 3D CAD model have been explained and analyzed.

- Process 1: Preparation and Addressed Issues

For scanning method, we will focus on different types of object surface that need to be treated before scanning and the relationship between the object size and platform with different gap. As for non-scanning, we will identify the possible size of the object that can be captured from the 5 % to 75 % of the platform. In both methods, an object with minimal design (such as change in small feature or slightly different in size) is considered. The light intensity is concerned as one of the main factors during the data acquisition process for both scanning and non-scanning method. Moreover, scanning method can only detect when sensor is far away from the object for approximately 10 to 15 cm, whereas non-scanning method detects range depending on the Rotary Camera Station (RCS).

- Process 2: Designing Experiments

Experiment will be designed by considering all the scopes and limitations that we made according to objective of the projects. The research will be separated into two phases. The first phase will focus on the scanning method and collecting data while being designed to create tool to help to acquire better images for better result and can be used for the image registration method. Then, the comparison activity will be performed; scanning and non-scanning data acquisition methods with different objects while setting the working environment (light intensity) and other important factors depend on each method, such as object sizes; reference gap, surface coating for scanning method and the number of images for non-scanning method as well as degree of capturing for non-scanning method have been studied.

- Process 3: Performing Experiment and Collecting Data

The researchers have performed the experiment by considering scopes and limitations defined from the object. The data collected from the experiment will be analyzed and recorded for the design phase of the mini C-arm imaging equipment.

- Process 4: Analyze and Design New Equipment (Set Specification and Guides)

After collecting all the data from the designed experiments, the researchers will identify what are the important factors and set specification for designing the mini C-arm imaging equipment where the standard procedure with specific working environment for better results within short period of time will be raised and documented.

- Process 5: Conclusion and planning

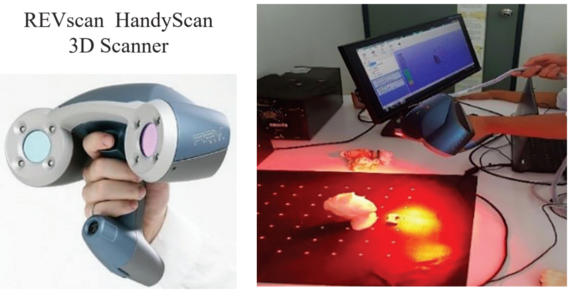
After completing the guides from specification, we can perform data acquisition process by using the guide, analysis and data that we collect from experiment in order to obtain the result for 3D CAD model. After we obtain the result for 3D CAD model, we could compare the result between two methods on many types of objects and conclude which method is the best for each type of objects. This project is separated into two phases. The first phase will use the 3D laser scanning method which has been introduced into the engineering field for decades. Then the second phase, a new technique, image registration, is introduced. The result of the two phases will be later compared to identify each method’s advantages and disadvantages.

4 Acquisition Applications

4.1 *Background of 3D laser scan (Scanning acquisition)*

The researchers started the reverse engineering technique by collecting data by using 3D laser scanner, the data were brought to study with respect to the setting parameters. Afterward, we adjust the 3D CAD model by using surface reconstruction and surface fitting to get the complete object from the scanning method.

Figure 7: Surface Preparation: (a) White Powder Spray, (b) Coated Master Part.



(a) (b)

Figure 8: Scanning Acquisition Technique: (a) REVscan - HandyScan 3D Scanner [24] (b) Experimental Setup for 3D Scanner Application.

Then summarize data and classify them according to object size and reference gap. Scanning method is used to scan the object with medium to big sizes.

Also, the researchers need to consider whether the surface needs to be coated or not. Surface treatment by using cleaning, coating and referencing point on the object if needed (Figure 7). Figure 8 shows 3D laser scanner used in this study.

Open *Geometric studio program* to fill the holes and undercut of the object in *.*STL* file until the object looks as good as the real one.

4.2 *Image registration method (Non-scanning acquisition)*

First, we try out the image registration by using freehand with mobile application and observe the result. Then we scope, define the experiment and construct the design of *Rotary Camera Station* (RCS). By using all the data from the experiment when performed we have to identify what are the significant factor during the capturing process and consider them in the design of the RCS. The information was gathered by using non-scanning method and subsequently merge all photos. According to the 3D CAD model from merging the photos using the RCS, we decide the optimal light intensity which affects the object. After receiving the object that needs to be measured or crate 3D CAD model, we identify which method should be used between *Scanning* and *Non-Scanning* method.

Non-scanning is used to capture small object. In addition, we need to consider the reference point according to object surface that we capture. Many activities are required for clearly taking images; *preparing object by adding reference, preparing reference platform, preparing working environment, setting the object into middle of reference platform, and adjusting the camera into capturing position*.

Before merging images taken from different sides and different angles by using Remake software, the 3D CAD model is constructed; for visual inspection, the overall details of features, fine curvature surfaces, and some embossed areas can be retrieved quickly. After surface reconstruction and fitting, the obtained virtual model can be transferred directly to rapid prototyping process for producing a physical prototype. However, shape and size of the aforementioned details might be slightly different from the master object since the images are randomly captured in vertical direction.

In order to obtain clean and clear virtual model, the conditions of light source such as position, direction, and intensity of light will be tested and analyzed in sequence. The key component of this study is to diminish the error of the acquisition. Besides, the strengths or weaknesses of each acquisition method, how each technique will be suitable for those who need to perform data acquisition process for reverse engineering, and a well-structural light source will be presented and discussed.

5 Fundamental Concept of Mini C-arm Rotational Camera Station

In the preliminary study, the researchers started capturing images freely by hand and the quality of taken images was not good enough; sometimes blurred. When the object was captured in different angle, the angle should be fixed before taking the photo. Moreover, all the positions and distances of the camera were around the object; these were the main reasons to design

Figure 9: The concept of mini c-arm rotational camera station.

a tool for maintaining the image quality that might later lead to better results. Recently, various types of rotary platform have been applied effectively in optical acquisition processes (e.g., 3D laser scanner, structured light system or camera-based acquisition). The benefits of the commercial C-Arm imaging devices presented recently were recorded as the reference model for the proposed design. However, its size, the light source, and the cost (ranging from 250–2500 USD) [25] might not be suitable for acquiring a small object, and applying as a budget version.

A smaller-scale design called *Mini-C Arm Rotational Camera Station* was generated under the criteria of "*rotational platform function* and *camera-based image*", since mobile phone (i.e., smartphone) camera provides good quality of the taken images where the small details as fine wrinkle or hair can be easily captured (Figure 9).

For the rotational platform, in addition, it must be fixed while rotating the arm; otherwise, the results after merging might be blurred or contain noises. Noises are represented as the unwanted regions or triangular facets which need to be eliminated in surface reconstruction process. Lastly, the arm should be adjustable in order to adjust position of the camera according to the location we need.

The developed *Mini C-arm Rotational Camera Station* embodies the following themes:

Form: The model consists of two cylinders attached to ellipsoid shapes as the center. In order to obtain convenient sizes, the form must be small enough to be carried around. Therefore, this model is designed to be portable size which has the scale less than 1 foot.

Fit: For the optimal fitness of model, the model must not clutter, should fold easily and should be uncomplicated to use when the operator is carrying the model. Also, the object will not move when placing the object in the model at any places.

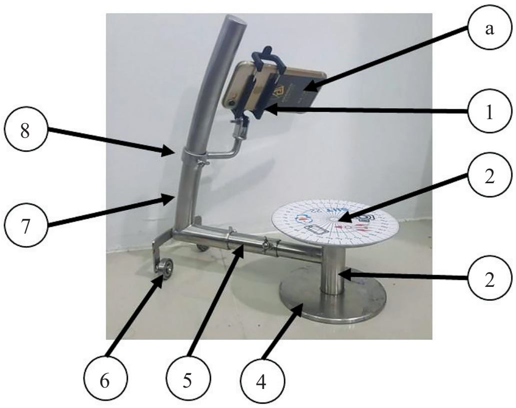


Figure 10: Mini-C arm rotational camera station.

Function: This model's aims are for operator to understand and interact with the operation within a few minutes. In addition, the capturing will be simpler when the operator adds this model to process. For this reason, everyone can understand concepts and easily proceed no matter what ages he is.

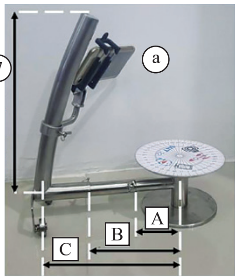
5.1 *Mini-C arm rotational camera station*

The components (Figure 10 and Table 1) can be further classified as the following components:

- ***Component 1*** is the capturing device holder which can rotate up to 180 degrees in order to adjust the camera when the adjustable arm cannot be adjusted anymore.
- ***Component 2*** is the reference platform which is used to hold the object to capture the images. Above the reference platform, it has reference paper to help the camera capture the images more easily.
- ***Component 3*** is the linear arm joint which is used to hold linear adjustable arm when this component rotates.
- ***Component 4*** is the circular base which is used to hold the reference platform to fixed position.
- ***Component 5*** is the Linear adjustable arm with joint whose length of its arm can be adjusted with 2 joints which are 6 cm, 12 cm and 20 cm in A, B, and C position respectively in the mentioned.
- ***Component 6*** is the base wheels with 2 of them to rotate around the platform.
- ***Component 7*** is the curvature adjustable arm with joint which is the fixed arm that has approximately 27 cm length.

- ***Component 8*** is the clamping joint. To adjust the different angle, the clamping joint will be moved along the fixed arm in order to obtain the degree that we want.
- ***The "a" component*** is the capturing device. We can use camera, phone camera, and car camera to take the photos of objects.

Table 1: Components of Mini C-arm rotational camera station

No.	Components	Dimensions
1.	Capturing device holder (rotate 1809)	
2.	Reference platform (∅ 14 cm)	
3.	Linear arm joint	
4.	Circular base (∅ 12 cm)	
5.	Linear adjustable arm with joint (L_A = 6 cm, L_B = 12 cm, L_C = 20 cm)	
6.	Wheels	
7.	Curvature adjustable arm with joint (27 cm)	
8.	Clamping joint	
a	Capturing device	

5.2 *Experimental setup and recommendation*

This equipment might be alternative choice to rotate the object of interest in 360 degrees smoothly with less material and maintenance cost. Capturing pictures and rotating the camera by using rotary platform to adjust the side can help the designer to easily obtain clear image without blur. The number of taking-view sides is approximately 8 sides of the object; the angle of the camera can be varied from 30 degrees to 60 degrees to make the object more realistic in the process operation.

To measure light intensity, in this study, UNI-T UT383 Lux Mini Digital Light Meters Environmental Testing Equipment Handheld Type Luxmeter Illuminometer was applied as shown in Figure 11.

6 Effect of Light Intensity During Surface Acquisition.

The section presents about the result and the environmental factors during the data acquisition process to identify what are the significant factor that may affect the result or 3D CAD model. Our goal is

(a) (b)

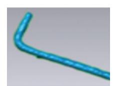
Figure 11: Mini-C arm rotational camera station (a) The device used for measuring light intensity, (b) Setting up for Non-scanning method.

to identify these significant factors and set a standard value or acceptable range to increase efficiency of the process and acquire better result.

6.1 *3D laser scanner acquisition results*

In the first section, the researchers worked on tools which had various size (i.e., hex key and combination wrench). From Table 2, the hex key and combination wrench could be scanned smoothly by using 3D laser scanner. From the result, it contained the entire features appearing in the real object. After surface modification software, the results presented almost the same as the real object.

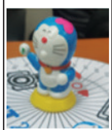
Table 2: Result from scanning method, No.1

Object Size (cm)	Scanning Time (Min.)	Light Intensity (LUX)	Master Object	3D Model
7×2×0.3	3	13		
0.5×1.5×0.5	4	13		

- Phase 1: Normal Condition

In this experiment, the researchers had tried to collect data of the object that was in the acceptable range – *Model A* (doll), and the object smaller than the recommendation of the reference board – *Model B* (gear). From Table 3, *Model A* (doll) had some undercuts and holes, after scanning by 3D laser scanner, the difficulties were shown through gaps and unconnected regions in the surface model. To fix these errors, Surface modification software was applied. However, for the black gear that was smaller than 2 cm^3, the features could not be extracted properly by 3D laser scanner even with the smallest reference gap (3 cm between two consecutive points).

Table 3: Result from scanning method, No.2

Object Size (cm)	Scanning Time (Min.)	Light Intensity (LUX)	Master Object	3D Model
3×4.5×5	5.00	13		
0.5×0.5×0.1	5.00	13		

- Phase 2: Changing the light intensity

In this section of the experiment, the *Model A* (doll) was used while changing the light intensity level to identify whether it was a factor or not and if it was what was the acceptable range. In Table 4, the *Model A* (doll) was first used without coating the surface which caused slight reflection due to the plastic surface. So, the flat white-powder spray was applied, and then the experiment was continued. As the light intensity level increased, the percentage of noise was also increased.

For scanning method, the light caused the reflection on the reference board (Figure 12) which created some errors during capturing. Presented in Figure 13 were the incomplete body 3D *model a*round two spherical shapes with small size (~ 0.7 cm). Under room condition where the light source was uncontrollable, some missed triangular facets and incomplete surface regions were found and needed to be modified for obtaining geometric details of the master object (Figure 14).

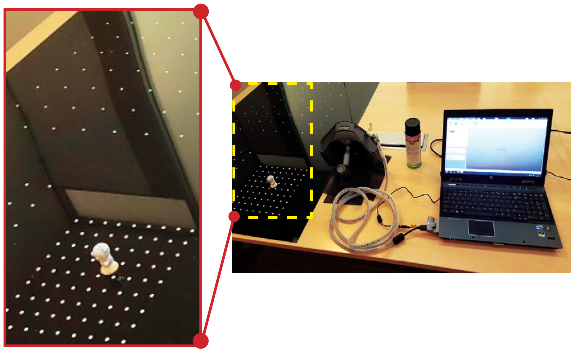
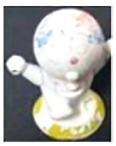
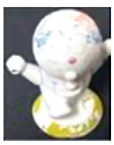
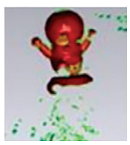


Figure 12: The light source caused the reflection on the reference board.

Table 4: Result from scanning method for lighting analysis on model No.3

Light Intensity (LUX)	Master Object	3D Model	Amount of Triangles
13			Model – 6,484 Noise – 251 % noise – 3.72% (reflection on plastic)
13			Model – 7,956 Noise – 22 % noise – 0.28%
33			Model – 14,198 Noise – 112 % noise – 0.79%
40			Model – 8,583 Noise – 323 % noise – 3.86%
81			Model – 17,434 Noise – 2,940 % noise – 16.86%

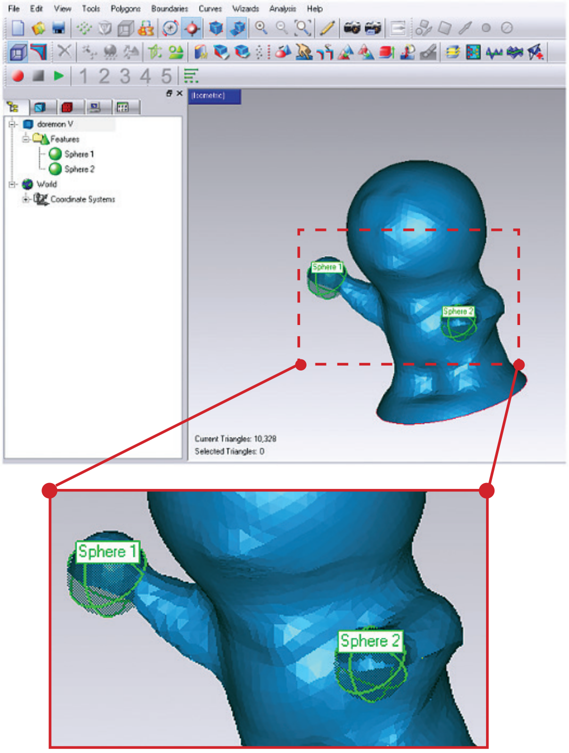


Figure 13: Incomplete body 3D model.

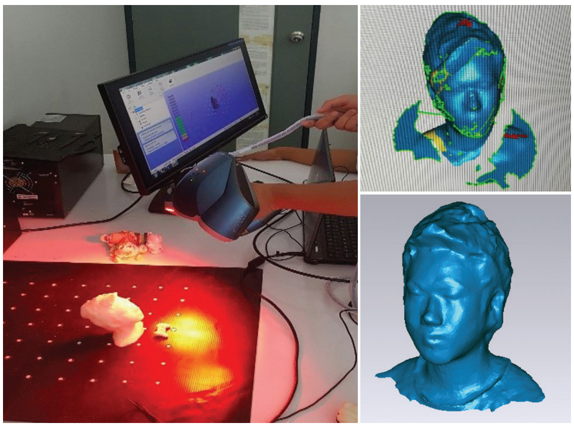


Figure 14: Surface correction required for completing surface.

The limitations of scanning method can be expressed as these following topics,

- Object surface – Shiny surface, mirroring object, rubber-like surface, and transparent objects.

All these surfaces will cause reflection or penetration of laser light causing the laser light not reflecting on

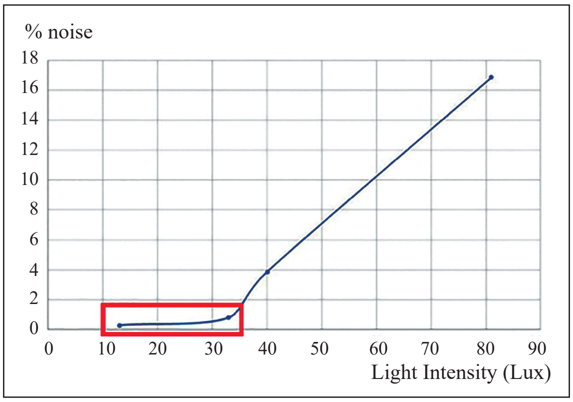


Figure 15: Recommended Light Intensity Level (Cropped Area).

the correct angle backing to the camera. Which will lead to false data of 3D CAD model.

- Object shape – Shape with undercut and holes.

These shapes are also called object with complex shape. These structures are a problem because laser light could not reach in to these structures due to the depth of the structure.

- Object color – Dark tone color.

The dark color has the characteristic of absorbing light which will affect the reflection of laser light. Leading to incomplete shape on the 3D CAD.

- Object size – Too large or too small.

The part that are too big or too small considering the spacing between the reference points. If the gap between the reference points comparing to the object are too big or too small, it will affect the scanning result.

In order to identify the appropriate structural light source for diminishing or minimizing the errors of the acquisition, the relationship between the percentage of noise (unwanted surface/triangular facet) and light intensity (lux) was researched and the results were shown in Figure 15.

From the graph, the recommended light intensity level was 13~30 lux. If the light intensity exceeded 30 lux, it would cause the increasing in percentage of noise which might lead to the increasing of processing time in the next process.

Master objects (No.1) applied in this section were shown in Figure 16(a) and (b). Since the sample models applied in this section were metal material, in order to create clean and clear virtual model where the

(a) (b)

Figure 16: Shiny metal parts (Group No.1).

(a) (b)

Figure 17: Part contains small geometric shapes (Group No.2): (a) flat spline-shaped part, and (b) spherical-shaped part.

obtained surface presented less gaps or holes, coating master models with special powder spray (flat white color) was performed for scanning attempts. One of the interesting designs for developing a new product is that creating features with spline model as the convex shape (its ends are pointy, and it has a thick middle) can make the contemporary design that will likely have a different look and feel than contemporary design.

The sample parts (No.2) contained round and curvature shapes as spline patterns (Figure 17). The model contained three main colors around its body: blue, white, and red. However, applying 3D laser scanner to acquire spherical-shaped model is quite challenging since the model curves outward and its middle is thicker than its edges.

Figure 18 presented the sample model of the group No. 3 where the small depth different features were shown on the top section (spherical-head shape and undercut-area at the bottom area) which might be difficult to detect by 3D laser scanner and camera-based acquisition techniques. The size of reference object in centimeters was 3 cm × 4.5 cm × 5 cm.

- Phase 3: Error calculation

During the scanning process, some noises which are the unwanted areas captured along with the master part

Figure 18: The sample model (Group No.3) for light intensity analysis.

Figure 19 : The scattered triangular facets found around the area of interest.

were found, and these errors could be eliminated in the surface reconstruction process. Presented in Figure 19 was the unwanted region; triangular facets. There are scattered triangular facets far apart in different directions around the object surface (i.e., the area of interest).

In order to identify the percentage of noise for checking the performance of the acquisition technique while varying the light intensity, the following formulas were applied [Equations (1) and (2)]:

$$(\textit{Total amount of triangles} - \#\,\textit{Amount of the model}) = \#\,\textit{Amount of noise} \tag{1}$$

$$\frac{\#\,\textit{Amount of noise}}{\textit{Total amount of Ttriangles}} \times 100\% = \%\textit{of noise} \tag{2}$$

Where
Total amount of triangles = All surface areas created
Amount of the model = Area of interest
Amount of noise = The scattered triangular facets

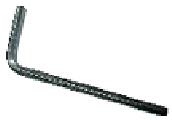
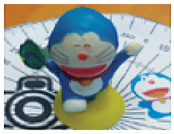
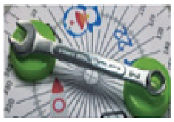
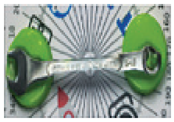
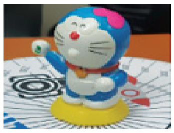
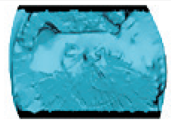
Presented in Table 4 are the results of scanning method for lighting analysis on the reference model (model No.3). The amount of triangles, and the error(s) or noise(s) unwanted region(s) or triangle(s) were listed and calculated as the percentage of noise.

The light intensity values were varied and considered as four numbers; 13, 33, 40 and 81 lux. The researchers had tried to adjust the light intensity inside the experimental room; however, it was quite difficult to control and adjust the light source (the ceiling fluorescent light) according to the recommended information (Figure 12). Finally, the two values were obtained; 13 and 33 lux. In order to compare the scanning results of the proper lighting conditions and the out-of-range ones, the extra scanning activities with 40- and 81-lux conditions were conducted and observed.

6.2 *Mini C-arm rotational camera station results*

The experiment in this section was carried out using Mini C-arm Rotational Camera Station with Samsung Galaxy S6 edge camera - 16 megapixel. The master object was the same as the scanning method experiment. The results (3D models) obtained by Mini C-arm rotational camera station were shown in Table 5. In the experiment, images were taken in three different angles: 30, 60 and 75 where, for each angle, the researchers captured 12, 12, 6 images respectively (according to the angle). Between each image was spaced out equally. For example, angle 30 with 12 images, the camera was adjusted to 30-degree angle then capturing image every 30-degree around the reference platform was performed.

Table 5: Result from Mini C-arm rotational camera station

Object Size (cm)	Amount of Images	Degree Capturing	Time (Min.)	Light Intensity (LUX)	Master Object	3D Model
7×2×0.3	12 12 6	30 60 75	4	1003		
4.5×3×5	12 12 6	30 60 75	4	1004		
10.5×1.5×0.5	12 12 6	30 60 75	4	1023		
4.5×3×5	12 12 6	30 60 75	4	1129		
10.5×1.5×0.5	12 12 12	30 60 85	4.5	1129		
10.5×1.5×0.5	12 12 6	30 60 75	4	1560		

7 Discussion and Conclusions

The scanning method provides good results due to its high accuracy, the unit price of the scanning device is very expensive. It is not what normal household could afford. For the commercial applications in the companies or industries who need to perform a reverse engineering technique or need of producing prototype. In order to support quick 3D surface acquisition with limited budgets or limited resources, capturing images in different views is introduced and recommended. The appropriate capturing angles and the location of the object that is being captured are the key components to obtain clear details of 3D model.

Mini C-arm rotational camera station presented in this research is the alternative camera-based acquisition design for supporting fast image registration process where the camera is set at the proper angle to capture the geometric shapes of the object that is placed on the platform provided. The small parts or areas could be easily detected, transformed and retrieved to be curvature regions after forming surface reconstruction.

This developed rotational station can support pocket-sized compact cameras such as new generation camera phones or smartphone, and a video camera (webcam). The capturing activity can be easily performed. With the curve and functional design of this machine can help the designer to secure the images quality and 3D CAD model.

By performing all the procedure mentioned in this research correctly we believed that operator could acquire acceptable result and save more time in producing 3D CAD model. That will be later use in reverse engineering for producing prototype or duplicate object according to the existing object.

7.1 *Preparation*

For the 3D laser scanning method, the working environment of this method must be dark (low of light intensity) to increase the quality of the result (i.e., room with all light turned off and curtain closed) also decrease noise surround of the object area [26]. Choosing the suitable reference gap on the reference board considering the object size is also important. And for the oversized object adding reference point on the object will be recommended. The surface of the object is the major factor to this method. Due to the laser is very sensitive to the surface types which will be solved by using special powder spray. As for the image registration method, the adjusting camera is the major factor to this method.

Due to a lot of preparation (such as object reference, platform reference, working environment, setting object and adjust camera), the preparation must be exactly right to reduce the longer process time in surface reconstruction process which caused by the image 3D CAD model contain the reference board in the background. This method is also suitable for variety of object especially small object which the scanning method could not process.

In the other hand, the 3D CAD model results quality is lower comparing to the result from scanning method and the reference point must be considered according to object surface that we captured. At last, the object is very sensitive to light intensity which will be solved by adjusted the light intensity measured by light meter.

7.2 *Capturing application*

The difficulties of capturing a physical object by 3D laser scanner are about the type and size of the part being scanned. Transparent, fluorescence, and glossy surfaces need to be coated before scanning attempt. Object with small size and contains small depth different cannot be detected by 3D laser scanner, the application of image processing with a camera-based acquisition technique is recommended.

Both methods, 3D laser scanner and camera-based acquisition, when all interested areas are obtained, the capturing activity is stopped immediately. The obtained images are then transferred to the registration method that is used to merge the captured images or regions in different angles and sides. During capturing activity, the position of the object has to be fixed on the platform; otherwise, the registration process cannot be accomplished since the reference points are not defined properly and some areas of interest are missed.

7.3 *Processing (Surface reconstruction and fitting)*

After the processing of 3D laser scanning method, it resolution of object must be adjusted in order to make the object clearer. Also, the object's hole and undercut

(a) (b) (c)

Figure 20: The surface models: (a) Result from 3D laser scanner, (b) Result from mini C-arm rotational camera station, (c) Result after integrating results of the two methods.

must be filled and deleted unwanted region including the area with the noise in the object. The merging processing of image registration method must be done after capturing different sides, views, distances and angles. Then, the 3D model can be edited by deleting all backgrounds including reference board and merging all of the images. After that, the object must be filled the hole and straighten up the object because this method can only produce rough surface.

Figure 20 presents the results obtained from two methods. The small depth different of the features could be revealed and extracted by camera-based acquisition method. These fulfilled the result obtained from the scanning one [Figure 20(a)]. Moreover, some good surfaces were merged and reconstructed as the integrated 3D virtual model where the errors (gaps) and missed areas were corrected [Figure 20(c)].

8 Research Contribution

The contributions of this research are summarized as follows:

- Supporting rapid product development

The proposed approach helps to speed up the first process of reverse engineering or data acquisition process. In this process 3D laser scanning and image registration method are selected because it is more common in industries and is not difficult to learn how to use them, after 3D CAD model will then be edit or reconstruct to send to the rapid prototyping machine; that will then print out the 3D model layer by layer. By performing all these consequently, the product development time will be decreased.

- Rotational Camera Station

For the image registration method, the Mini-C Arm Rotational Camera Station was developed to help operator perform data acquisition process with lesser time while controlling image quality. It is designed to provide operator to capture images at the correct angles and views. The arm also helps to hold the camera in place while capturing image to solve the issue of capturing blurred images; the blurred images affect the final result by producing distort shape or inaccurate shape.

This machine is also made to be compact and to be easily to travel with incase operator needed to bring it to the customer for data acquisition process, and it will be a reasonable size if it needs to be produced to sell too.

- Error in 3D Laser Scan Method

For this method, the type of surface is a major factor while scanning. Since the laser light has to be reflected back at the correct angle, if the surface is transparent, too dark, mirror like or reflective, it will affect the reflection of the laser to go to the unwanted direction causing the camera to register the incorrect point and produce noises. These noises or unwanted regions can be occurred when light intensity of the room is over 30 lux, because the it will cause other object to reflect light and laser will be difficult to be captured by the camera when room is not dark enough too.

In order to resolve this problem, coating the master object with special powder spray whenever possible and controlling light intensity (brightness) in the room is highly recommended. There are other types of errors happened in this method are about capturing and reconstructing the hidden areas (i.e., holes and undercuts). All these regions will be empty and need to be modified or filled in the program later; this may lead to some errors as shown in Figure 21.

- Error in Image Registration Method

In this method error can be caused when images are not captured correctly. To capture good images, operator will need to set the entire camera parameter (exposure, ISO, focus, resolution and filter) constant during the capturing process. Setting timer on the camera is also important, because when we press the shutter on the camera we may cause vibration or unnecessary movement to the camera causing images to defocus and later lead to error in the final merging. Controlling light intensity level or brightness of the

Figure 21: 3D Laser Scan Error (Master model-Left, Scanned Model-Right).

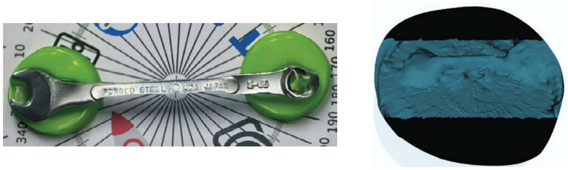


Figure 22: Error due to Defocus (Left), Error due to High Light Intensity (Right).

working environment is important too. Light source should provide the scattered light instead of the light beam or the spot light-like light source and must be in one spot the entire time to ensure that the shadow stays in the same spot during the entire capturing process. Using camera's flashlight is not recommended since it will cause the surrounding of the object dark and bright in the middle. These dark images will cause the 3D CAD model dark and difficult to work with as shown in Figure 22. The recommended light intensity will be around 600 lux (Brightness in a working office) to 1200 lux (Bright room with reading lamp on the table).

8.1 *Research recommendation*

By controlling all the significant factors, the result of the 3D CAD model was shown better surface details because there was lesser amount of noises. By reducing these unwanted noises, the designer or manufacturer will be able to perform surface reconstruction more easily with lesser time and the most important the model will be more accurate. The recommendations of data acquisition methods, scanning technique, and image-based technique will be presented as:

- Scanning Method

From the experiments, the recommended light intensity level is around 13~30 lux, because it if the room is brighter than 30 lux then it will be too bright and the reference board will cause unnecessary reflection causing more noise in the result and leads to longer processing time. The reference board is designed into 3 sections with different gap distance between the reference points. There is the big gap with 8 cm between the points, and it is suitable for big object with size 6 cm^3 ~ 15 cm^3. If the object is big then attaching extra reference points on the object is suggested.

For medium size object size around 4 cm^3 ~ 7 cm^3, the medium gap with 5 cm between each point is applied. As for the small object with size around 2 cm^3 ~ 5 cm^3, using the small reference gap section with 3 cm between each point is recommended. Since scanning method is very sensitive to the object's surface due to the reflective method. If the object surface is not suitable for scanning (i.e., transparent, mirror like, reflective), it will cause the laser to reflect at unwanted direction and create unwanted noises. This issue could be solved easily if the master object is coated with special white powder spray before scanning the object.

- Non-scanning Method

For the non-scanning method, capturing images with the same quality and condition are very important. To obtain similar quality images, first camera setting such as focus, exposure, resolution, color filter, and brightness of the working environment must be controlled well. The light intensity of the working environment should be around 600~1200 lux to have good results. Camera flash light is not recommended since the flash light causes the object to be too bright and dark at the surrounding which will lead to a total black 3D CAD model.

Object size used in this Mini C-Arm Rotational Camera Station should be limited to 5% ~ 75% of the platform. During the image capturing process, the correct way of capturing image is important. If operator capture image by hand, it may cause focus on the object to go off and result in blurred image. These will later lead to distort in geometric shape of the final 3D CAD model. The solution to this issue is to set timer on the camera or use remote control to make camera as stable as possible. The amount of images and capturing angle are also significant, and taken into account.

The optimum amount of images at each height level is 12 images or 30 degrees apart from each image where the phone camera is attached to the curvature adjustable arm (C-arm) with 3 different height levels;

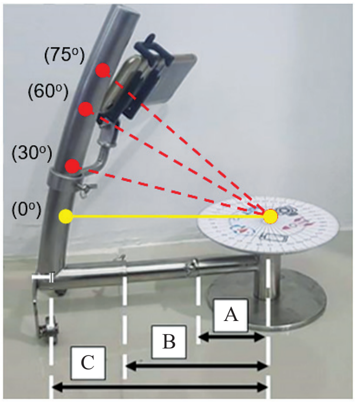


Figure 23: The height levels for supporting taking views in different (vertical) direction.

30°, 60° and 75° with respect to rotary platform direction as shown in Figure 23; the dash lines where A/B/C are the linear adjustable arms with joint. For the object that are flat, adjusting the higher level for the top view from 75° to 85° is recommended to capture more details. The last tip of capturing is to always adjust camera position slowly and gently to reduce vibration on the mini C-arm rotary platform to avoid the master object moving.

In order to identify the capability of the system developed in this study, the size comparison between the actual object and the constructed 3D model needs to be constructed and discussed; however, it is quite difficult to define and calculate. The 2D documentation or the CAD model of an object is not available, does not even exist, or no longer corresponds to the real geometry of the manufactured object itself. Reverse engineering technique has been introduced for retrieving object's digital model easily and quickly by reconstructing the CAD model from measured data by means of 3D mathematical surfaces and geometrical features representing the geometry of a physical/existing part. The geometric-shape comparison could be, probably, done only when the actual/existing object's feature contains all measurable rectangle, spherical, cylindrical, or cubic structures. The dimensions might be measured from vernier caliper, micrometer or coordinate measuring machine (CMM).

In this study, after applying the proposed mini C-arm rotational camera station, two spherical shapes (in Figure 13) were acquired and compared to the existing object which was about 8 mm in diameter, whereas the reconstructed one was around 7 mm in diameter. Moreover, for the further study, the statistical analysis should also be applied to test the hypothesis on the dimensions of actual and modelled objects.

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