3D Printing Using Digital Photogrammetric Data

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***Abstract*—The research is mainly focus on modeling of non-topographic objects based on Photogrammetry field of studies. By using 3D printing technology that is widely used nowadays, a real object could be reproduced again exactly as it is through post processing of object model formed by RGB-D camera and printing out of the post-processed file using 3D printer. In this project, a cylinder box and half part of human body are chosen for the printing purpose to represent simple and complex object respectively. Reconstruct me software was used to scan the object while the Meshmixer software was applied in the post-processing of the formed models. Distances of 0.8m, 1.0m and 1.5m were selected to scan both objects and the scanned model was saved in Stereolithography (STL) file format. Then, the formed models was uploaded in Meshmixer to filter unnecessary features like noise and unfilled holes. The cleaned model was also saved in STL file format to enable it to be uploaded in XYZ Ware software before it can be printed in da Vinci 1.0 3D printer. From this study, it was found that the methodology used can be produced the exact model of the chosen objects in three-dimensional copies with the reduced scale. In term of analysis, the studies show that the time acquired to form the 3D model increases significantly between non-complex and complex object. In conclusion, the concept of 3D printing is much related to the field of Photogrammetry especially in generating the 3D model because it involve the use of image photos, triangulation network and contouring of the object models.**

Index Term - 3D modeling, 3D scanning, 3D printing

I. INTRODUCTION

Three-dimensional (3D) printing is not a familiar term used in photogrammetry field but it actually much related to concept applied in reconstruction of 3D model and 3D scanning in photogrammetry studies. Lately, the use of 3D printing technology is widely used in developing countries over the world such as Japan, New York, United States and others. The first solid model printed was in 1981 by Hideo Kodama of Nagoya Municipal Industries Research Institute [1].

There are four ways to get a 3D model which are: download the 3D file form 3D modeling source website, create the 3D model using suitable software, capture and process the pictures of existing object and lastly scan the object using active sensing instrument. 3D models especially in Stereolithography (STL) files format are important to print out 3D models in hardcopy form using 3D printers currently available in market now. The concept used behind 3D printing is that 3D Model is cut sliced into a series of 2D planar section and these to be deposited by the printer, one above another, to construct a solid object. Although there are many types of 3D printer nowadays, they all work in similar way. Four types of 3D printers created and still been use today are included with photopolymer curing (stereolithography), powder sintering (selective laser sintering), filament extrusion (fused deposition modeling) and sheet lamination (laminated object manufacturing) [2]. Normally the user choose 3D printers suit them by two factors which are type of objects will be created and the location of 3D printer will be place.

The 3D printers can be maintained by single user or even a large sector. For a personal creation or usage, plastic material is commonly used in 3D printing of solid objects. However for the scholarly person, they have created human tissues, food and metal material using 3D printer. This capability of 3D printer to print out various objects in different material gave benefit to large sectors like education, medical, food, architecture, automotive and aerospace sectors. Almost anything can be created from 3D printers for the ease of human generation. Besides of its ease of use, this technology has many advantages in terms of time of production, quality of products and cost of production.

Generally, this research paper will discuss on the methodology used to develop 3D models and to form the model by using 3D printer.

II. AIM AND OBJECTIVE

The aim of this study is to use non-topographic photogrammeric data for 3D printing purpose. In relation to this aim, the following objectives will be achieved:-

a) To generate 3D models of a complex and a simple object using infrared scanner called as RGB-D camera.
b) To print out both virtual 3D models as solid objects using FDM 3D Printer.
c) To analyze the results between complex and non-complex of generated virtual model and printed models in term of time taken.

III. CLOSE RANGE PHOTOGRAMMETRY & 3D PRINTING

Close Range Photogrammetry is generally used for terrestrial photographs which having object distances until around 300 meters. Photographs from terrestrial is using cameras located on the ground that is handled, attached on tripods, or suspended from towers or designed attachable on other object [3]. Type of photogrammetry used in this research is lie under interpretative close range photogrammetry since an active sensing instrument is used to produce the model of real objects. Three dimensional modeling require of technical procedure and transformation of data to derive new products. As stated by Remondino and El-Hakim, there are four types of 3D modeling which based on the passive and active sensor [4]. Firstly, the image based rendering (IBR) sensor that used to create 3D environments directly from input images. Next, the image based modeling (IBM) sensor which use to recover 3D objects info through image measurements. Then, the range based modeling sensor which functioning in directly capture the 3D geometric info of an objects. Lastly was the combination of image and range based modeling that determine more details of 3D object. The RGB-D camera used in this study will be based on forth type of 3D modeling.

Through the exploration of technology used in developing countries like USA, China and Singapore, we can print out the 3D models prepared using close range photogrammetric techniques in hardcopy form using 3D printer. The 3D printing actually is an evaluation from 3D modeling technology. The basic principle underlying in 3D printing is that the 3D CAD file is sliced into a two-dimensional (2D) planar layers which then deposited and combined by the 3D printer sequentially in order to form a complete solid object. 3D printer have experience four stage of evolution in its system at early stage of its invention which are:-

a) Photopolymer Curing

The most widely used 3D printer is included with photopolymer curing. The machine is from 3D System company and named as stereolithography 3D printer, which patented by Hull in 1984. The machine system consists of a bath of photosensitive liquid resin (gum)-thick liquids that harden into transparent solid, a model-building platform, and an ultraviolet (UV) laser for curing the resin. Basically, the 2D layers are cured and bond together from bottom to up of the model sequentially.

b) Filament Extrusion

The Stratasys's company has invented this type of 3D printer through its fused deposition modeling (FDM) machine. The system key is a temperature-controlled head which extrudes the thermoplastic material layer by layer. The machine consists of filament supply, fixtureless foundation, thermoplastic or wax filament and heated FDM head that moves in x and y direction.

c) Powder Sintering

The word sinter is a verb use with an object which means to bring about agglomeration in (metal particles) by heating. The machine with powder sintering is used by DTM's company in its selective laser sintering (SLS) machine. The SLS used computer-directed laser in process of fusing together layers of specified powder material into a 3D model. The system consists of roller, powder delivery system, powder bed, fabrication piston, laser beam, and scanner system.

d) Inkjet Based System

The working principle of this printer is similar to the current 2D inkjet printer. The system consists of roller, powder delivery system, powder bed, fabrication piston, liquid adhesive supply, and ink jet head.

e) Sheet Lamination

Helisys's company who produce laminated object manufacturing machine is the only company who use the sheet lamination system of 3D printer. Unfortunately, this type of 3D printer does not exist today because overall processes show most material wasteful. Unlike other printers, this LOM requires a fix amount of material per unit height to build a part in spite of the footprint or displacement volume of the part.

IV. METHODOLOGY

The overall pipeline of research is shown in Fig.1 below. The main items focused in this research are inclusive of the setting of instrumentation, object scanning, and post processing.

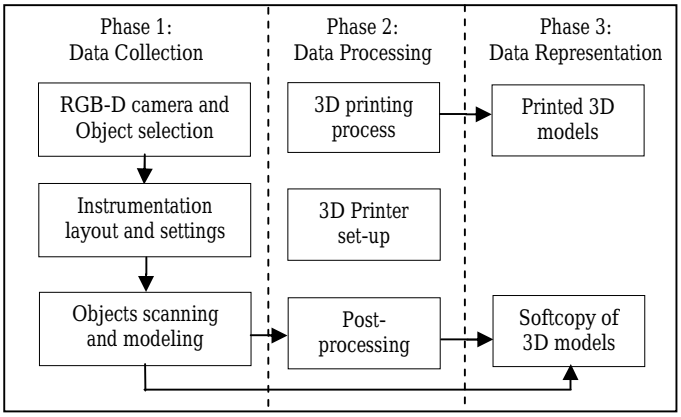

Fig.1. Pipeline of Research Methodology

A. *RGB-D Scanner and Objects Selection*

The RGB-D camera or ranging camera will be used in this research is Xtion Pro Live from ASUS company. RGB-D is acronym for Red Green Blue and Depth sensor which is mounted on most of motion sensing instrument like ranging camera used in gaming and digital signage. In relation to close range photogrammetry, this device can replace close range photographs that have taken previously to obtain 3D models of objects in our surrounding. The chosen scanner capable to detects the shape of an object in our surrounding in range 80 cm to 3.5 m. In term of its angle field of view, the instrument offer 58˚ horizontal angle, 45˚ vertical angle, and 70˚ diagonal angle [5].

This study needs simple and complex object in order to study the time taken for scanning and printing tasks. Hence a cylinder box and human body are used to represent these objects. The criteria of the objects are shown in Table 1.

TABLE I. CRITERIA OF SELECTED OBJECT

Criteria / Object	Size	Shape	Detail
Cylinder box	small	simple	less detail
Half of human body	large	complex	more detail

X : 400 mm	X : 220 mm
Y : 250 mm	Y : 220 mm
Z : 550 mm	Z : 360 mm

B. Instrumentation Settings and Layout

This research required the RGB-D camera to be moved while the object taken is remained static. The settings used for RGB-D, Xtion Pro Live through Reconstruct Me software shown in Fig.2 and the layout of object and the camera is shown in Fig.3.

Initial Setting
Volume size in square with maximum dimension of 4m length

Handling Setting
i. Start delay: 5 seconds ii. Scan duration: 12 minutes (maximum) iii. Sound: "Allow Reconstruct Me to play sounds"

Surface Setting
i. Color support: *"Colorize my reconstruction"* ii. Selfie 3D is disabled

Device Setting
i. Optimization settings: *"Maximize quality"* ii. Device selection: *"Automatically determine a device"* iii. Sensor selection: *"Automatically detect sensor"*

Fig.2.RGB-D scanner setting

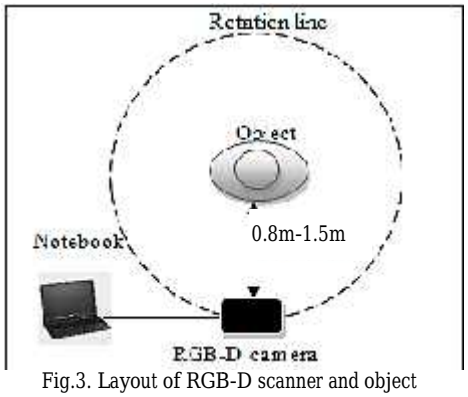

Fig.3. Layout of RGB-D scanner and object

C. Scanning and modeling of objects

The steps involved in this task were:-

a) The model formed by connecting the green dots appeared display in Reconstruct Me 3D viewport and time taken is about 5 to 15 seconds (Fig.4).
b) Camera is move slowly to the other side of the object where the green dots not connected yet.
c) Scanning ended at the same point where the scanning started so that a complete model can be produced (Fig.5).
d) Save the model in STL file format since it is the only format received by da Vinci 1.0 3D printer used in this study.

Fig.4.Green dots connect to form model during scanning job

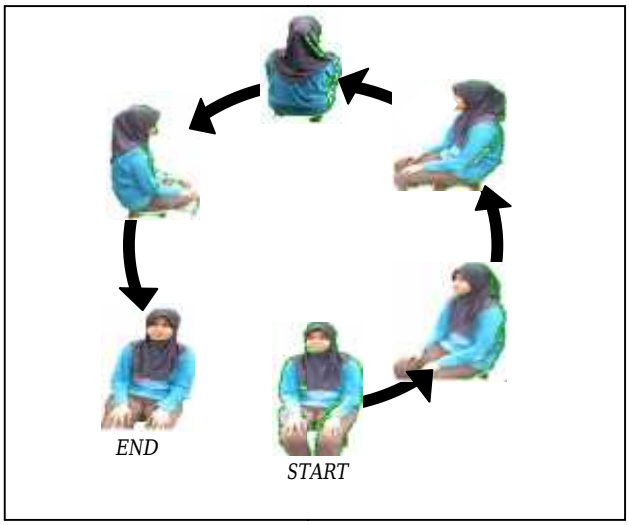

Fig. 5.The overall process of digital 3D model formation during scanning and modeling

D. *Post processing*

Since the 3D model formed contains noise, unfilled holes and unnecessary features, the model need to be post-processed (Fig.6). Meshmixer from Autodesk Inc. is used to perform this job. The steps in post-processing of this study as follows:-

a) STL files are imported and 'Inspector' tool used to automatically repair the holes, non-manifold area and disconnected area.
b) Selection tool was used to remove unnecessary features and leave features need to be printed by 3D printer only.
c) The hole at base of the model is filled either by using plane cut tool, form solid tool or erase and fill tool.
d) The digital 3D model was then go through smoothing process automatically but its original shape is still preserved.

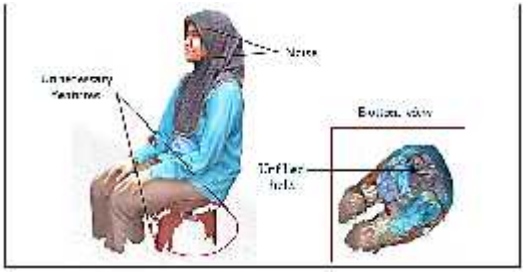

Fig.6. Deficiencies from Reconstruct Me model

E. *3D printing*

As usual 2D printing, a document needs to be set up before send to the printer. In relation to 3D printing technology, the model will be printed need to be set up in XYZ Ware before send to da Vinci 1.0 printer (Fig.7). Then, there are 7 steps required towards the FDM 3D printer used which are:-

a) Loading the 3D printer's filament in the 3D printer.
b) Calibrating the 3D printer bed and extruder.
c) Printer bed is glued with a glue stick before printing of model started.
d) ABS or PLA filament deposited from extruder and model is printed from its base to its top.
e) Object is removed once the printing job done. Raft or support printed also need to be removed before a printed model exactly as processed model is attained. Raft used to create stability and can be removed after object has been printed where as support use to create structural strength and ensure that your model does not collapse during the printing process.

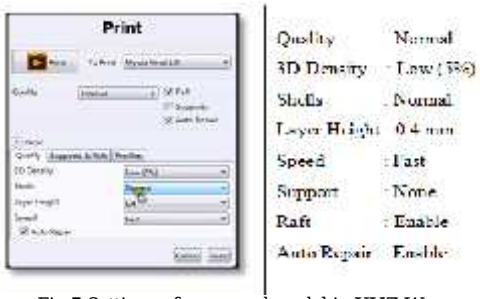

Fig.7.Settings of processed model in XYZ Ware

V. Result And Analysis

The cylinder box and half part of human body were chosen in this study represent the non-complex and complex object respectively. The complexity of the objects is determined by the size, shape and detail of the actual objects. The cylinder box used is in small size, simple shape and less detail compared to half part of human body which is larger in size, more complex shape and more detail. The original criteria of the objects will be the guideline and bench mark for this study in analyzing the data represented.

Basically there are 3 models represented in this study which are scanned model (Fig.8& Fig.9), post-processed model (Fig.10& Fig.11), and printed model (Fig.12& Fig.13).

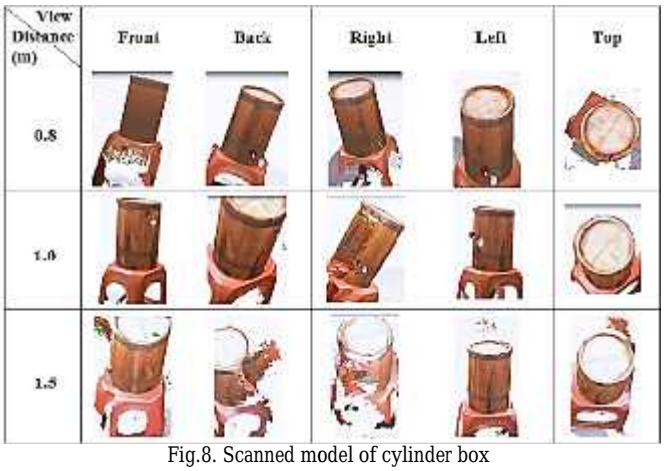

Fig.8. Scanned model of cylinder box

Fig.9. Scanned model of half part of human body

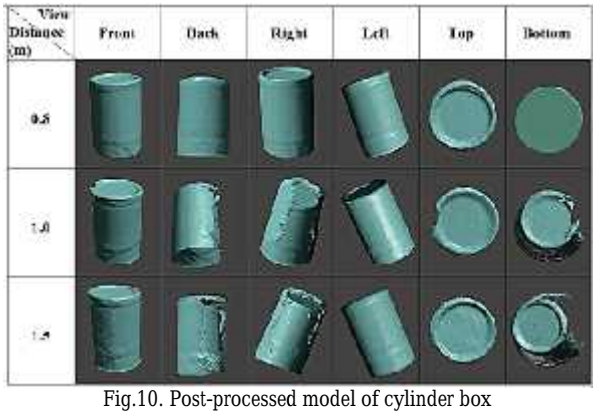

Fig.10. Post-processed model of cylinder box

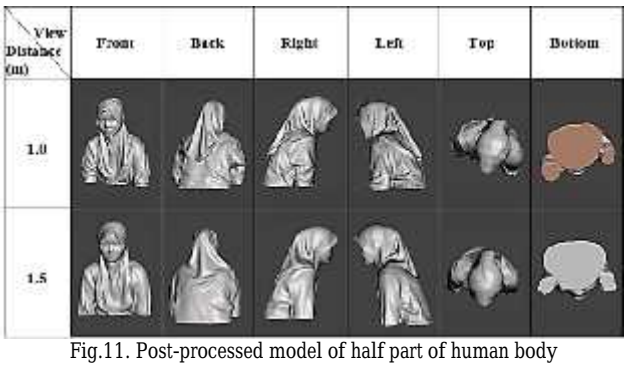

Fig.11. Post-processed model of half part of human body

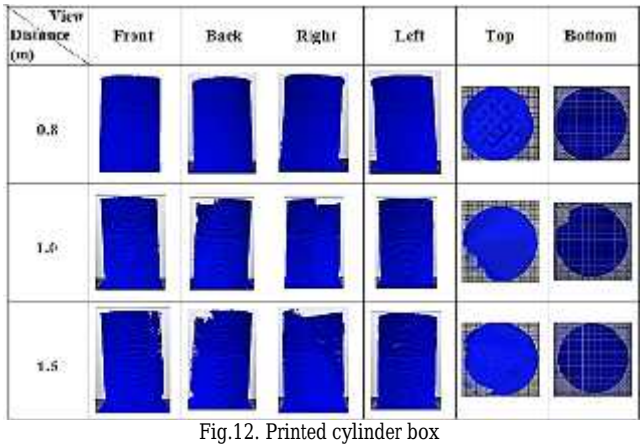

Fig.12. Printed cylinder box

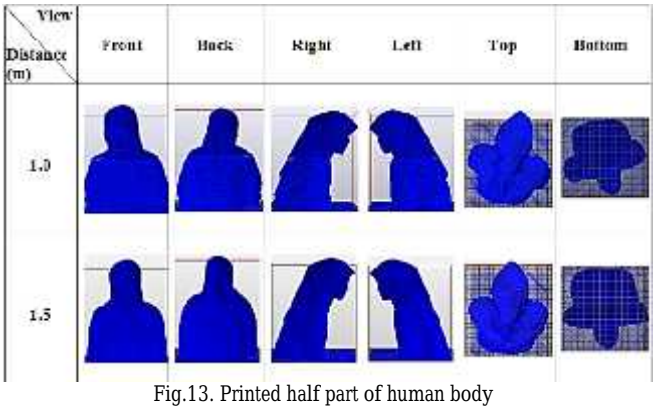

Fig.13. Printed half part of human body

A. Criteria of 3D model development

According to Fig.8 and Fig.9, although both model of half part of human body was completely formed in scanning and modeling, the complete model for cylinder box can only formed at 0.8m distance. The cylinder box scan at 1m and 1.5m is partially form due it disability to emerge with the points at the starting of scanning process. The factor that lead to this situation is that the distance between the object and the camera is not suitable with the small size of the cylinder box. Small objects need a shorter distance to completely form its model and vice versa. In term of model of human form, there is also difference in features scanned for model of human taken at 1m and 1.5m. Human model at distance 1m generate more cloud points since the floor texture also detected and scanned by RGB-D scanner.

Based on processed model shown in Fig.10 and Fig.11, the scanned model is edited using Meshmixer to leave out the features would be printed. The original shape and texture of scanned model still preserved. As stated earlier, only model of cylinder box at 0.8m is completely formed and the others are not. This might due to the problem where partially sides of the model at 1m and 1.5m cannot be formed. Looking into human model, model taken at 1m is gives more detail of wrinkles on the cloth and on face and the shape of lip are clearly seen compared to the other one taken at 1.5m. This resulting in more number of vertices and triangles of the model taken at 1m compared to other one.

Lastly for printed model shown in Fig. 12 and Fig.13, the photogrammetric concept can be seen when the XYZ Ware (software for da Vinci 1.0 3D printer) generated contours on the surface of each model before it cut sliced the model into a series of planar section. For cylinder model which do not have solid base, the XYZ Ware has generated support and raft automatically for that particular model so that it will not fall off when printing process is carried out. In general, contours generated are seem uniform for simple object like cylinder but more variety of contours are generated for complex object like human model. Hence we state that the uniformity of contour generated by 3D printer is depending on the complexity of the details of the object to be printed.

B. Time taken to scan objects

Based on Table 2, there is big difference in time taken in scanning cylinder box which its model completely form (cylinder box at 0.8m) with the one where its model not completely formed (cylinder box at distance 1.0m and 1.5m). Since the points cloud unable to connect with the points on the starting of the scanning process, it caused the model take a longer time to finish forming a complete model. For human model which have more complex detail, the human model taken at 1.5m need a short time in scanning process compared to the other one. The RGB-D scanner tend to takes longer time in scanning for human model at 1m because it has detected more additional feature like chair and floor at that particular distance compared to when it modeling the human at 1.5m. Since whole to part concept has been used by the RGB-D scanner to form a complete model, it is recommended for the user to ensure the whole shape of the object be displayed in Reconstruct Me 3D viewport during scanning process in order to determine a suitable distance for scanning that particular object.

TABLE II. TIME TAKEN TO PREPARE VIRTUAL MODEL USING RGB-D SCANNER

Object	Distance taken (m)	Min.	Sec.	Difference	Note
Cylinder box	0.8 (a_1)	1	35	-	-
Cylinder box	1.0 (a_2)	2	23	48 sec.	a_2 & a_1
Cylinder box	1.5 (a_3)	2	34	59 sec.	a_3 & a_1
				11 sec.	a_3 & a_2
Human Body	1.0 (b_1)	5	50	-	
Human Body	1.5 (b_2)	4	02	1 min 48 sec.	b_2 & b_1

C. Time taken to printed models

In term of time taken for printing job using da Vinci 1.0 3D printer, the time required to print out the 3D models are between 5 to 9 hours (Table 3). The longest time is taken by model of half part of human body at 1.0m because the model has the most detailed features than other models. A detailed model is depending on number of triangulation network for that particular model. The higher number of vertices and triangles of a model, more detailed the model is. Since the detail of a model is proportional to time taken for 3D printing process, the value of vertices and triangle is also proportional to the time taken for 3D printing. We can state that more detailed model or model with higher number of vertices and triangles require more time to be print out by a 3D printer. A lot of filaments will be needed to print out that model in hardcopy form.

TABLE III. TIME TAKEN TO PRINT OUT THE 3D MODELS

Object	Hour	Min	No. of vertices	No. of triangles
Cylinder box (0.8 m)	5	8	125, 849	231, 072
Cylinder box (1.0 m)	5	11	70, 084	134, 744
Cylinder box (1.5 m)	5	54	84, 296	157, 000
Human Body (1.0m)	9	39	201, 096	369, 385
Human Body (1.5m)	6	34	170, 166	316, 041

VI. CONCLUSION

In this study, digital image capturing using close range photogrammetry approach was applied during scanning and modeling process to achieve a complete model of an object. The distance must be remained fix and good illumination of light is important factor to achieved good quality of close range photogrammetric data. Based on the result attained in this study, the distance taken in scanning process is depending on the size of object. Small object with dimension less than 36 cm should be scan at least 0.8m while object with object 40-60 cm can be scan at distance at least 1m. RGB-D scanner has an ability to detect more detail objects that can be enhanced if the distance between the camera and object is in suitable short distance. Besides that, the degree of detail of the model also can enhanced if the volume size of cube under the initial settings is set to exactly fit the size of that particular object. In term of time taken for scanning and printing, it will take a longer time for complex object to be scan and print out rather than the simple one. This is due to the denser triangulation network needs to be form for a complex object. Based on the triangulation network formed on model, it was used to generate contours by the 3D printer software (XYZ Ware). The contours contain x, y and z values needed by the 3D printer to cut sliced the model in a series of planar section. For 3D printing purpose, the planar sections helped planning the deposition of materials like Acrylonitrile Butadiene Styrene (ABS) or Poly Lactic Acid (PLA) on the 3D printer platform from bottom to the top of the model.

In comparison with conventional photogrammetry instrument which is stereoplotter, the idea of 3D printer invention is attained from analytical stereoplotter where its tracing tip is move in x and y direction on the plotting table to produce a drawing or map from stereoscopic images. However the 3D printer invention have more advance in term of its ability to move in z direction and extruding various of materials through its nozzle that enable the instrument to print out 3D models in hardcopy form. The 3D printer's nozzle and printer platform also have ability able to heat in certain temperature depending on type of material will be used to print out a model. Hence, the material used enable to solidify before the next layer is put on top of the previous layer.

In general, this study indicating that 3D printer is a suitable tool used to print out 3D models prepared using close range photogrammetric techniques because the shape and detail of 3D models produced are still preserved after 3D printing process. However, a comparison study on accuracy of the models with the actual size of a real object using infrared scanning method used in this study is suggested to be carried out in future.

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