A Computer Method for Generating 3D Point Cloud from 2D Digital Image

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***Abstract*—In reverse engineering practice, most designer will use 3D scanner to scan on 3D physical objects to obtain point cloud data, then the point cloud data is later being processed to obtain the final 3D CAD Model. However, when the 3D physical object is not at the same location as the 3D scanner, the 3D scanning method cannot be used. To overcome this limitation, another alternative computer method is proposed to obtain 3D point cloud from 2D image. This paper will further explain on the method on how to generate 3D point clouds without 3D scanner, hence enabling reverse engineering process to be done without using 3D scanner.**

***Index Terms*—reverse engineering, 2D digital image, 3D point cloud**

I. Introduction

In product design, the fastest way to continue producing new product in the market is by copying existing product and then modifies it to become another new product. This approach is known as reverse engineering. In reverse engineering, designers will usually need an existing 3D object to start with and the first step is to obtain the point cloud data from the 3D object. This point cloud data acquisition can be done via various methods. The methods can be categorised to two types, one is the non-contact method and the other is contact method. The most common non-contact method to perform reverse engineering is via 3D scanner, while the most common contact method is to use CMM with touch probes to perform measurements on the existing object.

For non-contact method, many designers had obtained 3D point cloud from existing objects with the aid of 3D scanners. However, when the 3D physical object is not available, none of the existing methods mentioned above will work. This situation can happen due to the 3D physical object is not in the same location as 3D scanner. To overcome the mentioned problem, a computerised method is introduced to enable 3D point cloud generation without 3D scanners by utilizing 2D image to generate 3D point cloud. At first, the physical object will need to be captured as 2D digital image and the captured 2D digital image will be sent as computer data to the designer that situated in the other location through internet transfer. When the 2D image is received by the designer, and with using this computer method that can generate 3D point cloud from 2D digital image, it will enable the reverse engineering process to be done without 3D scanner. This paper will explain and illustrate the method of converting 2D images and into 3D point cloud with a proposed computerised method, and then the designers can use any techniques they prefer to continue to generate mesh surfaces in order to produce the final 3D model. This paper will also explain the theory and concept of the proposed computerised method.

II. Related Works

Reverse engineering has been adopted by mechanical designers to quickly produce parts especially when parts involve freeform surfaces. Paulic *et al.* [1] performed reverse engineering to manufacture an identical automobile button in different orientation with aid of 3D scanner in order to obtain 3D point cloud from the physical object. Reverse engineering sometime is also being used to fabricate worn or broken parts for replacement, Dúbravčík and Kender [2] had showed reverse engineering application on a damaged gear as example with the aid of 3D scanner and 3D software. Both works that performed reverse engineering uses the non contact method and they uses 3D scanner on 3D object on set in order to perform the job. Bagci [3] also explained reverse engineering objects and the digitization method used is CMM. Another recent work from Al-Ahmari and Aalam [4] also uses the CMM to perform reverse engineering and this method known as contact method also required 3D object on set and CMM machine to perform the job. Reverse engineering has also now being adopted by various people from other field mostly in medical research field such as Yoo [5] had performed reverse engineering process to reconstruct 3D surface of human bones using B-spline based interpolation method, the method of this work is effective to convert bones in point cloud form and CT scan data into 3D CAD model, however there is no mentioned on how the point cloud is obtained. Another recent work is on 3D reconstruction of human bones, Thevenot *et al.* [6] successfully reconstructs the final 3D femoral bone from CT scan images, however this method used uses CT scanned data which the equipment set up for CT scanning can be very

Manuscript received January 20, 2016; revised August 26, 2016.

doi: 10.18178/joig.4.2.89-92

expensive compare to 3D scanners and CMMs that used by the mechanical design industries. Another similar medical research work of Pan [7] developed a rapid prototype uses CT scanning combined with CAD/CAM software and stereo lithography techniques to obtain prototype of the rib bone and again used expensive CT scan equipment to obtain 3D CAD model. Another type of field named Paleontology which is a kind of field that involves extinct animals. There is previous works of Lukeneder [8] which successfully made 3D visualization of ancient animal from fossil rock. The fossil specimens are usually appeared in 2D profile with some other details embedded inside the rock. With help of tomography, the 3D model is generated, however the tomography involves assistance of x-ray as well and high cost equipment set up as well.

The previous works that performed reverse engineering had adopted different data acquisition technique but all have one common similarity that is the equipment set up is complicated and difficult to implement. This paper will introduce a simpler method of obtaining 3D point cloud by using 2D image only through a computerised method. The methodology will be explained in the next section.

III. Methodology

There is a different of this reverse engineering method where input is using 2D Image instead of 3D object. To perform digitization from 2D image can be challenging because the process is only limited to non-contact method. Also 3D scanners available in the industries cannot be used if the input object appears in 2D form. The proposed method is to use 2D image as input, utilizing the available information from the image, manipulate the information and then to create a point cloud then later generate a 3D CAD Model. The method this 2D image to 3D digitization need to go through a few major phases before it becomes a point cloud model. The last phase which is a point cloud model can be directly read in 3D CAD software.

To begin, first we need to have an input of a 2D digital image. Usually computerised images are stored as pixel in matrix arrangement and each matrix contain values of Red, Green and Blue, the value stores depends on the intensity of each component.

For example, a white colour pixel may contain 33.33% Red, 33.33% Green and 33.33% Blue. These colour pixels can also be converted into Hue, Saturation and Value model. Image pixel that stores all these colour data that can be used for matrix operation and manipulation in order to generates high variation and hence 3D point cloud. The method of 3D point cloud generation from 2D image will require the input to go through two parallel processes in order to obtain the output. The process flow contains two different processes that one is the process is to obtain height variation value which later translates into z-coordinates, while the other process of obtaining the sizing can be run parallel so that the data can be combined to form a complete 3D data of X, Y and Z coordinates. The 3D coordinates of X, Y and Z can be represented with (1), while the grid numbering of x and y can be represented with (2) and coordinate z can be represented with (3).

$$\text{3D coordinates} = [\,x\,,\ y,\ 0] + [\,0,\ 0\,,[z]\,] \qquad (1)$$

$$[\text{Grid}_{x,\,y}] = [\text{pixel}_{1,1},\ldots,\ \text{pixel}_{m,1}\,,\ \text{pixel}_{1,2},\ \ldots \\ \text{pixel}_{m,2}\,,\ldots,\ \text{pixel}_{1,n}\,,\ldots,\ \text{pixel}_{m,n}\,]^T \qquad (2)$$

$$[z] = [\text{height}_1;\ \ \text{height}_2;\ \ldots\ ;\ \text{height}_o] \qquad (3)$$

where, m= maximum row number, n= maximum column number, o= maximum height number

The generated coordinates will then be converted to point cloud and the result can be directly read in 3D CAD software to produce 3D CAD Model. For the conversion of 2D image into 3D point cloud, commercial programming software is used because it has the capability to perform operation and manipulation on image pixel as matrix. The overall process can be summarised as Fig. 1.

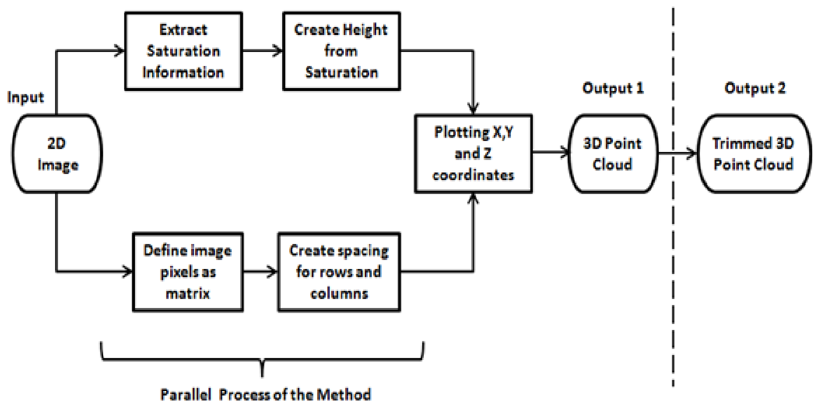

Figure 1. The overall process flow of the system from 2D Image into 3D point cloud.

IV. Results

To test on the proposed methodology, two real objects are captured as images for trial run in order to obtain results. The first is an image of a hot cup cover and the second is an image of component from grass trimmer. These two objects are chosen because both objects have different surface curvatures so that comparison can be made later based on the results. The hot cup cover has more regular form surfaces while the grass trimmer component has more free form surfaces. Fig. 2 and Fig. 3 show the respective trial run objects and the conversion process from 2D image into 3D point cloud through the proposed system, and then followed by editing and trimming the point cloud to remove the unwanted points through 3D CAD software.

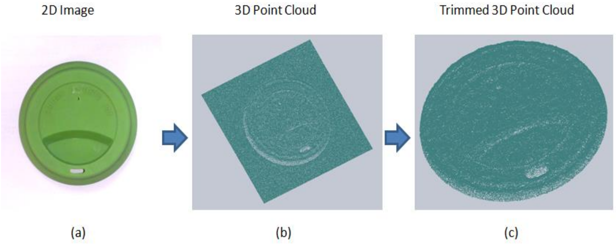

Figure 2. (a) 2D image of trial run object 1, hot cup cover, (b) 3D point cloud generated from 2D image of (a) visualised in 3D CAD software, (c) The point cloud is trimmed to resemble the actual object

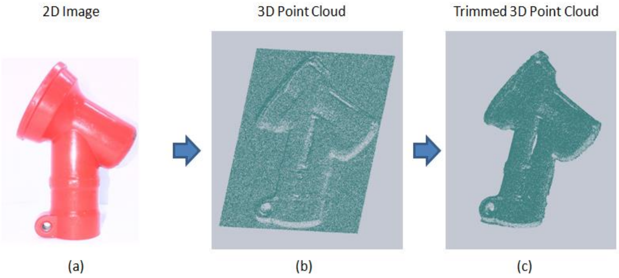

Figure 3. (a) 2D image of trial run object 2, grass trimmer component, (b) 3D point cloud generated from 2D image of (a) visualised in 3D CAD software, (c) The point cloud is trimmed to resemble the actual object

To determine whether the output point clouds contain three dimensional coordinates of x, y and z, cross section is performed on each point clouds for verification. Fig. 4 and Fig. 5 show the cross sectional view and the respective cross sectional profiles of the both trial run objects. Besides, the cross sectional profiles were also extracted and recorded as two dimensional detailed profile plots in order to demonstrate the ability of the proposed method in height determination and spacing arrangement based on available information in the 2D image.

From the results obtained, it is observed that the proposed method sees better regular form surface recognition compare to free form surface, however to justify this method has better regular form surface recognition still require more verifications by testing on different objects.

Besides, the resulted point clouds are saved as file format of .xyz so that other 3D CAD software will be able to read and process the 3D point cloud. Therefore after using this proposed method to generate 3D point cloud from 2D image, the following reverse engineering process is continued based on the user's preferred choice to choose which 3D CAD software to use for the upcoming tasks such as to trim the point cloud, to create mesh, to create surface and to create volume.

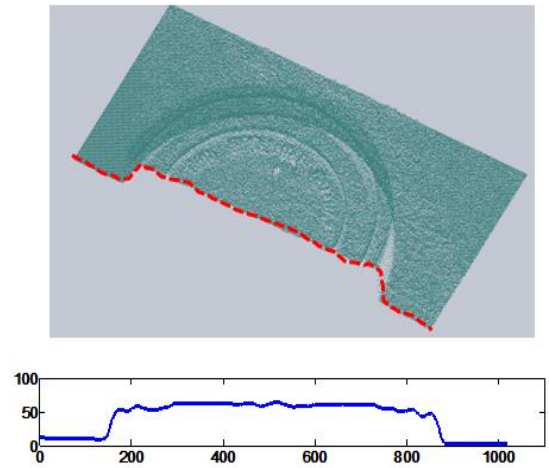

Figure 4. Trial run object 1, hot cup cover's cross sectional view in CAD software and detailed profile plot of the selected the cross section

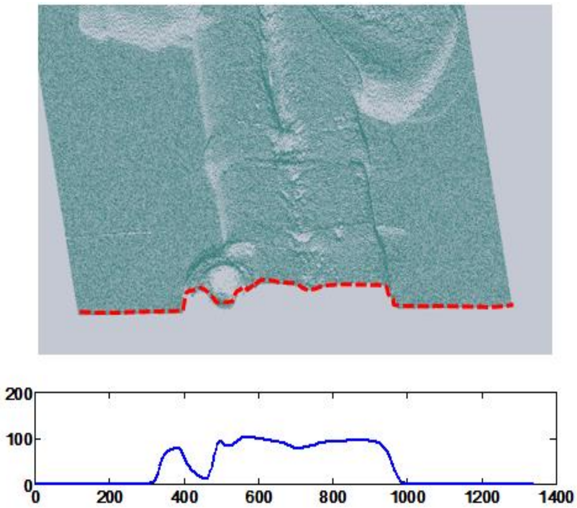

Figure 5. Trial run object 2, grass trimmer component's cross sectional view in CAD software and detailed profile plot of the selected the cross section

V. Discussions

The results showed 3D point clouds which is still lacking in shape representation provides opportunity for improvement, especially on free form objects' surface.

Looking into the method introduced, the working mechanism is based on using available information from 2D image and extraction is performed on the 2D image to gather available information for generation of 3D point data. For example, Z coordinates are extracted based on the saturation values spread across the 2D image. The detailed profile plot in the second object clearly has distorted heights as compare to the actual shape's representation. The main distorted heights are located at the region of points 600 to 800 in x-y axis. Other than the mentioned region, it is considered accurate in term of shape representation. Points from 0 to 300 is flatted background, while sudden rise in around points 300 to 380 is the edge of the object, points 380 to 500 is the round hole, points 500 to 600 together with 800 to 990 is the middle part and lastly points 990-1350 is the flatted background are considered accurate in term of shape representation.

In order to correct the height distributed, especially around the region of points 600-800 of the second object, additional function on the existing method has to be included. The improved method in future should correct the errors in around the region of points 600-800 while preserving the other regions outside the mentioned range. The future additional function should has the ability to inverse the structure of visible light that appears to be captured on 2D image, while the future method overall should demonstrate the effectiveness in correcting the heights as per illustrated in Fig. 6.

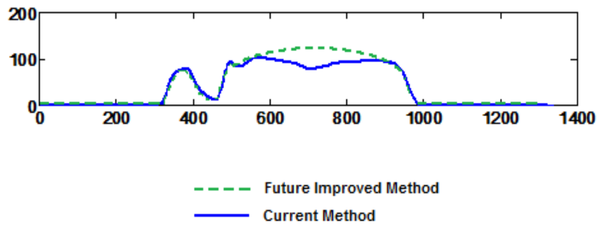

Figure 6. Future improved method developed should be able to better represent actual object's shape compare to current method.

Although this current method hasn't been able to generate 3D point clouds which are 100% accurate, this limitation can still be overcome with manual editing and also shape modification through 3D CAD software. Moreover, reverse engineering is mostly used for new product development, where in some cases and perfect accuracy is not the main requirement since the 3D point clouds are only used as the reference geometry during new product design.

In the meanwhile, some future works are already in progress for improving the heights in Z coordinates using the same input of 2D image in order to achieve better accuracy in output.

VI. Conclusion

This computer method has been tested and the results show it has capability to produce the point cloud shape resembles to the actual object, but the dimension accuracy is still under investigation and improvement. Therefore this method is only recommended for reverse engineering application that does not require high accuracy in dimensions. This computer method has a potential to generate 3D CAD models from 2D images.

Acknowledgement

This research is supported by Universiti Sains Malaysia under the Research University Grant (No: 814247).

References

[1] M. Paulic, *et al.*, "Reverse engineering of parts with optical scanning and additive manufacturing," *Procedia Engineering*, vol. 69, pp. 795–803, 2014.

[2] M. Dúbravčík and Š. Kender, "Application of reverse engineering techniques in mechanics system services," *Procedia Engineering*, vol. 48, pp. 96–104, 2012.

[3] E. Bagci, "Reverse engineering applications for recovery of broken or worn parts and re-manufacturing: Three case studies," *Advances in Engineering Software*, vol. 40, no. 6, pp. 407–418, 2009.

[4] A. M. A. Al-Ahmari and J. Aalam, "Optimizing parameters of freeform surface reconstruction using CMM," *Measurement*, vol. 64, pp. 17–28, 2015.

[5] D. J. Yoo, "Three-dimensional surface reconstruction of human bone using a -spline based interpolation approach," *Computer-Aided Design*, vol. 43, no. 8, pp. 934–947, 2011.

[6] J. Thevenot, J. Koivumäki, V. Kuhn, F. Eckstein, and T. Jämsä, "A novel methodology for generating 3D finite element models of the hip from 2D radiographs," *Journal of Biomechanics*, vol. 47, no. 2, pp. 438–444, 2014.

[7] Y. Pan, *et al.*, "The use of CT scan and stereo lithography apparatus technologies in a canine individualized rib prosthesis," *International Journal of Surgery*, vol. 12, no. 5, pp. 71–75, 2014.

[8] A. Lukeneder, "Computed 3D visualisation of an extinct cephalopod using computer tomographs," *Computers & Geosciences*, vol. 45, pp. 68–74, 2012.

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