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Implementation of 3D Object Reconstruction using Radon Transform

Siti Syazalina Mohd Sobani[1], Siti Asmah Daud[2], Nasrul Humaimi Mahmood[3]
[1,2]Faculty of Biosciences & Medical Engineering
[3]Biomedical Instrumentation and Electronics Research Group, Infocomm Research Alliance
Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[1]syazalina.sobani@yahoo.com, [2]sitiasmahdaud@gmail.com, [3]nasrul@fke.utm.my

Abstract—**This paper presents reconstruction of objects using multiple-views of 2D images. As a first step to get familiar in research field, it is simply done with several MATLAB image processing tools while acquisition of data is captured by a digital camera where the object statically stands in front of a cardboard as a background. The digital camera used is a mobile phone camera which it is fixed at a place and captures 36 different angles of views in order to get projection images for more accurate shape can be reconstructed. The 36 views are obtained using a piece of paper with reference angle drew on it in order to rotate the object. There are several image processing techniques applied on the images to reconstruction them as a 3D image which are thresholding, Radon transform, inverse Radon transform and also edge detection. The results obtained show that 3D reconstruction has successfully created where it is good enough to reconstruct exactly same shape as the original object.**

Keywords-3D reconstruction; Radon transform; inverse Radon transform; edge detection; thresholding

I. INTRODUCTION

Three-dimensional (3D) reconstruction is a process of capturing the shape and appearance of real object. It is very important in the field of computer vision, reverse engineering, Computer-aided design (CAD)/Computer-aided Manufacturing (CAM)/Computer-aided Engineering (CAE) industries, image analysis and also medical imaging. This can be accomplished either by active or passive method. The difference between these two methods is just the intrusive properties related to the object to be reconstructed.

There are many methods have been introduced for 3D object reconstruction, therefore it is necessary to study and determine the best method in order to make an accurate reconstruction by considering devices available, time consumption and cost for the method. The method adopted for this paper is passive method which using digital two-dimensional (2D) images as input data. Then, the 2D image need to undergo numbers of processing in order to calculate and obtain 3D coordinates. The fundamental of reconstructing 3D shape from a 2D image is an ill-posed problem. A sufficient number of 2D images must be obtained, or otherwise several constraint conditions for the 3D shape have to be determined. Therefore, suitable algorithms need to be constructed and specified for this reconstruction process which uses 2D images captured by digital camera and turntable setup as input data.

This paper proposed for simplicity of the processing and fast reconstruction. The details of the models are not in focus, but a simple and quick reconstruction of the object is presented. The strength of this method is highlighted on using digital camera to capture multiple-view of 2D input images of the object to be reconstructed which is relatively low cost. Next section is about literature reviews on related research for 3D reconstruction has been conducted. The methodology section explains how 3D reconstruction is done using the technique proposed, and followed by results and discussions, then conclusion and future plan for the research regarding this method.

II. RELATED RESEARCH

There are lots of research has been conducted worldwide related to 3D reconstruction and it still has many ways to improve the existing methods. W. Hu et al. proved a new way for 3D reconstruction from multiple-views point cloud. This is done using a physical constraint model of coupled particle system accompanied with Delaunay algorithm, Newtonian law of motion [1]. J. Huang et al. present 3D reconstruction using one a single image which is a hard way to be accomplished since the information and input data is very limited. The method is specifically for indoor scene that is mainly consisted of orthogonal planes and able to extracts 3D geometric structure. It is a quick and simple method that detects vanishing points, intersection lines and distinguishes objects present on the scene [2]. F. Sadjadi et al. pay special attention on 3D reconstruction of objects that are occluded and only partially visible. The works are based on passive method with two multiple-views set ups to capture 2D images of the object, one set up utilizing multiple cameras another one is single moving camera. Various sharpness metrics has been studied for the reconstruction [3]. L. Graciá et al. created a fast real time 3D reconstruction system for industrial uses which focused on accuracy of the model by calibrating the camera. The system is composed of several sequences of hardware for image capturing and software where volumetric carving is produced based on 2D silhouette to produce 3D model by generating isosurface [4]. K. Yao et al. proposed a new fast and simple approach for 3D passive reconstruction based on video and 2D images. This method does not need expensive devices, camera calibration, no special set up, and no tilt or slant angle [5].

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The idea on 3D reconstruction using RT is inspired the author for this paper. It is found that C. Pintavirooj et al. made contribution in reconstructing 3D shape using Radon Transform (RT). Cross-section images are taken using digital camera at a number of angles around the object which not stated specifically. It did not require any scanning since it is based on passive 3D reconstruction method. There are two limitations found. First, it has failed to reconstruct 3D model correctly of highly concave object because it is an invisible part from the view of camera. This problem occurs because the information taken into images are still not enough, so it is important to record sufficient data and capture more projection images. Second, there is perspective effect because parallel geometry beam has been used on photographic process [6]. As a starting point, our aims are only focused on simple experimental set up and reconstruct 3D model successfully. Other extending works on automation and details measurement and reconstruction are still on progress.

III. Methodology

Multiple-views imaging is able to reduce the complication in obtaining accurate object reconstruction. The set up of the experimental is shown in Fig. 1 where the object to be reconstructed is placed on a turntable and a digital camera which is mobile phone built-in camera is place fixed at a suitable view to capture images based on a certain angle of projection. This paper use 36 projection angles which the view angle is differ by 10° each by using a reference paper placed on the base of the cardboard acting as a turntable. The background for the image is chosen by considering the color of the object, so the images captured got more contrast and thresholding during image processing is easier to be done. There are two different objects used for the test as shown in Fig. 2. The whole processing is computed using MATLAB and there are several steps of image processing have been applied on the images captured and it is described as follows.

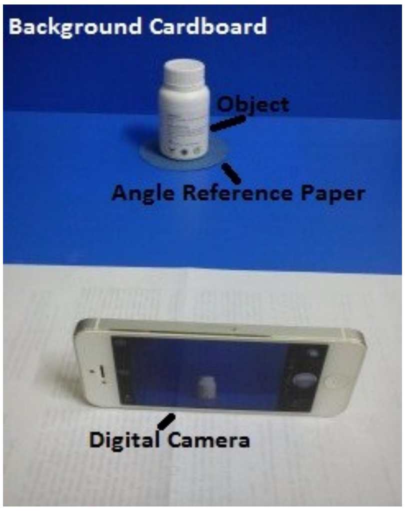


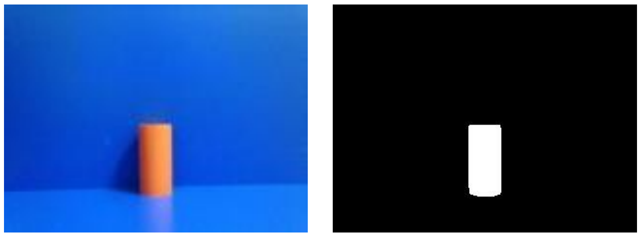
Figure 1. Experimental set up

(a) (b)

Figure 2. (a) Object1, and (b) Object2

A. Image Thresholding

Thresholding is one of digital image processing techniques to extract different colors or intensities in the image between foreground and background regions. The result obtain after thresholding will be black-and-white or also known as binary image. First, the image intensity will be defined by its brightness with range of values. Then, based on the range of values obtained, the foreground or white color will be selected while the values which are out of the range will be the background or black color [7]. Fig. 3 shows example for image of Object1 before and after thresholding being applied.



(a) (b)

Figure 3. (a) Original image, and (b) image after thresholding

Digital camera is used to capture 2D images of an object is transferred to computer for image processing to be done. All 36 images have to undergo thresholding using 'im2bw' MATLAB built-in function. The results after thresholding applied are silhouette of the object.

B. Radon Transform

Radon Transform is a type of linear transform which is used for image analysis method based on projections. X-ray images commonly used for the analysis because it is consist of density profiles of object scanned provide projection at different angles. The density profiles are directly proportional to the x-rays attenuation which has been absorbed within the object. This method allows internal structure of objects to be reconstructed. In general, 2D RT of an image represented by the function $f(x, y)$ can be defined as a series of straight line integrals through $f(x, y)$ at different offsets from the origin which is parallel to y'-axis. 2D reconstruction can be done with the knowledge of all the integrals computed along the straight lines [8,9,10,14], this can be defined mathematically as

$$R_\theta(x') =$$

$$\int_{-\infty}^{\infty} f(x' \cos\theta - y' \sin\theta, x' \sin\theta + y' \cos\theta)\, dy' \qquad (1)$$

Image projections can be computed along θ with any angle as desired where

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad (2)$$

The images are computed using RT algorithm in order to generate sinogram of 2D projections of the object slice by slice. The projections are based on 36 different angles of rotation corresponding to the object's vertical slice. For example, Fig. 4 shows 2D silhouette of Object1 with a red horizontal line acting as a referring line indicating the slice undergoes calculation by MATLAB.

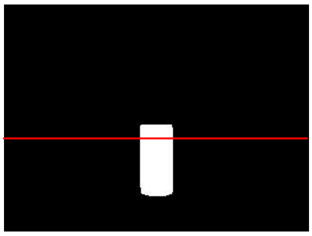


Figure 4. 2D silhouette with reference slice line

Inverse Radon Transform (IRT) is being studied for the Computed Tomography (CT) models. This method also important in various applications related to radar imaging, geophysical imaging and medical imaging. IRT is very useful in 3D reconstruction field. Filtered Back Projection (FBP) is the most common technique used to solve IRT in order to reconstruct image of sinogram obtained as results from RT calculation. The FBP is consisted of two phases, which are projection and filtration respectively [9,10,11]. The IRT has even and odd terms as in (3) and it is solved by depending on the value of n to be solved with Hilbert Transform (HT), H which is a basic tool in Fourier analysis.

$$f =$$

$$\frac{1}{2}(2\pi)^{n-1} \begin{cases} (-1)^{(n-2)/2} R + H^{n-1} \partial_t^{n-1} Rf & if\ n\ even \\ (-1)^{(n-1)/2} R + \partial_t^{n-1} Rf & if\ n\ odd \end{cases} \qquad (3)$$

The sinogram generated then used to reconstruct projections of the object slice by slice using IRT algorithm. FBP works to form projections of the sinogram data according to its slice, so that actual rotation recorded earlier can be recovered. The filtering is important to minimize noises present as low as possible. This is done using MATLAB 'iradon' function with linear interpolation for the back projection.

C. Edge Detection

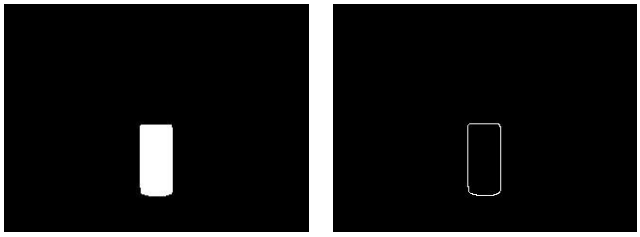
Edges can be found when the pixel intensities of an image undergo an abrupt change. It is very important in image processing applications that provide strong visual clues for image characteristic. Then, the results can be used for further processing and application such as image segmentation, line detection, and other recognition applications. For example of a simple edge model, there is one-dimensional image, f or also known as binary image which only consist of black and white colors [12,13]. The image has exactly one edge located at x such that

$$f(x) = \frac{I_r\, I_l}{2}\left(\text{erf}\left(\frac{x}{\sqrt{2}\,\sigma}\right) + 1\right) + I_l \qquad (4)$$

There is right and left sides of the edge with intensity and this can be described as

$$I_r = \lim_{X \to \infty} f(x) \text{ and } I_l = \lim_{X \to -\infty} f(x) \qquad (5)$$

Fig. 5 shows binary image of Object1 before and after application of edge detection.



(a) (b)

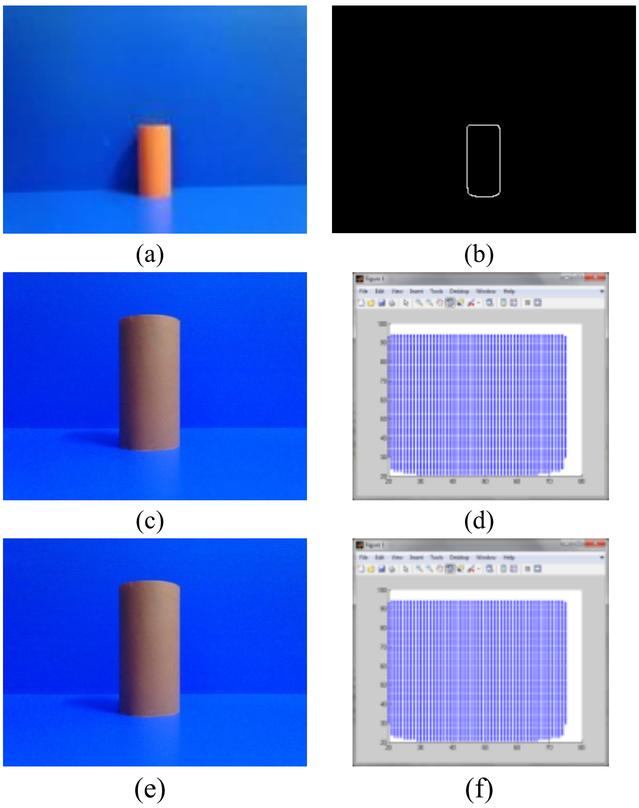
Figure 5. (a) Binary image, and (b) image after edge detection

Many techniques for edge detection have been developed, such as Sobel operator, Canny operator, Prewitt operator, Roberts operator, and Laplacian of Gaussian. The edge of the object is obtained from 2D silhouette using 'edge' function in MATLAB together with Canny operator as the edge-finding method. Canny operator is chosen because it is a technique which is good for noise reduction in the image. This helps in determining the boundary between the frame of the object and the background in the images. Boundary helps in characterize shape and size of an object in images by using MATLAB function 'bwtraceboundary' to trace the outline of the edge in the images. Then, point clouds can be collected and plotted in 3D view.

IV. Results & Discussions

The whole process is consisted of image acquisition by a digital camera, then transfer to computer to apply image processing and plot 3D surface using MATLAB. The processing is quite a time consuming but can be done roughly around fifteen minutes. The device used for the processing is a laptop with 2.40GHz Intel Core i5 processor including memory of 4GB RAM, and NVIDIA GeForce graphics card with CUDA. Fig. 6 and Fig. 7 show results of 3D plot for both two objects used which are Object1 and Object2 respectively.

Fig. 6 shows the images of Object1 which is used for the first test and results of the 3D model. Object1 is a cylinder shaped as in Fig. 6(a). There are certain views of Object1 shown for comparison purposes with results of 3D model. Fig. 6(c) and Fig. 6(e) are the side views of Object1. By referring to Fig. 6(b) which is the edge obtained from 2D silhouette, it can be seen that there is four curves at corners of Object1. When these two side views are converted to x-y-z plane view, it will be x-z view and y-z view. Since it is a cylinder shape, the object will looks the same at the side no matter what angle it is rotated. So, these are proved as in Fig. 6(d) and Fig. 6(f). Fig. 6(h) is x-y plane view or top view of 3D. The bottom part of the object is a curve and this is the reason why there are two inner contours that can be seen from the top view of the surface of 3D model. Fig. 6(j) shows x-y-z plane view or 3D view of the complete model, compared with Fig. 6(i), which is the original view of Object1.



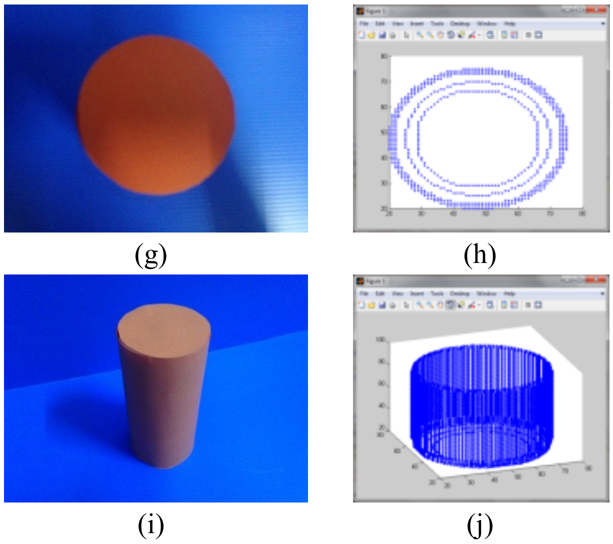
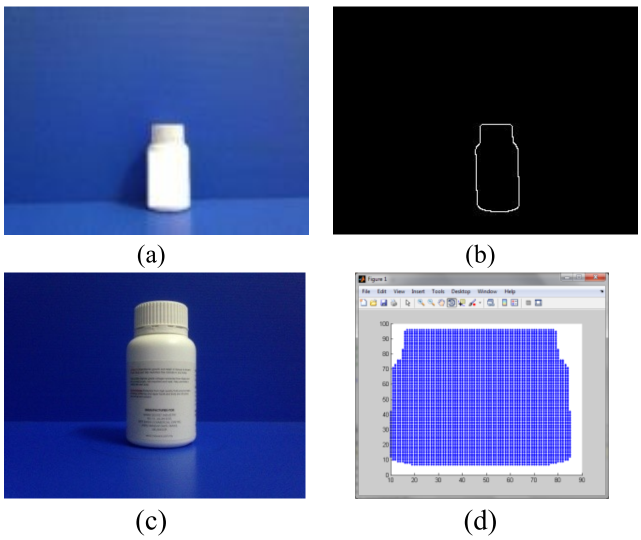
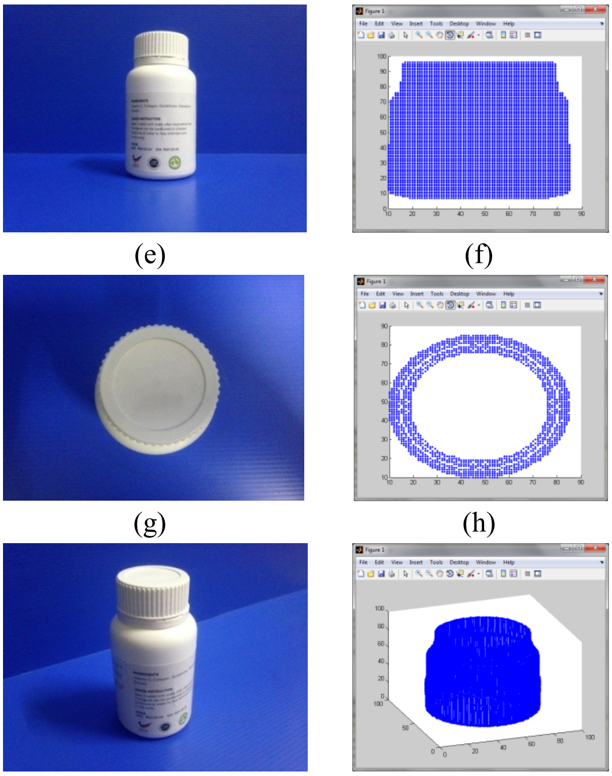


Figure 6. Different views of Object1 and the 3D model

For second test, a small bottle is used as Object2 where Fig. 7 shows the images of the object and results of the 3D model. The reason why the results obtained for this object is almost the same with what have been explained for Object1. Fig. 7(c) and Fig. 7(e) are the side views of Object2 while Fig. 7(d) and Fig. 7(f) show the results. The bottle is basically a cylinder shape but it has curve at the upper part for the lid and the fact it is always looks the same at any angle is not deniable. Fig. 7(h) is x-y plane view or top view of the 3D model, it is almost the same with Object 1. However, the contours for Object2 are close to each other compared with Object1 because the lid of the bottle is smaller than its body, this means the thick layer contours are the body of the bottle. Fig. 7(i) shows original view of Object2 while Fig. 7(j) shows 3D view of the complete model.





(e) (f) (g) (h) (i) (j)

Figure 7. Different views of Object1 and the 3D model

V. DISCUSSIONS

From the results obtained, it show that 3D plot of the objects can differentiate shape of the object clearly. It was found that, the higher the contrast of the 2D image captured, the accuracy of the 3D plotting also will increase. So, it is needed to use suitable background color to provide high contrast to the object. It is also important to design an automatic turntable which is able to turn the object according to specific angle of projection. The camera use to capture images also must be static and not easily be affected by any unintended movement. This can help to acquire more accurate input data. However, the points plotted are not very smooth. This is affected by the level of thresholding in the processing, so it is important to find a specific and consistent value of level for the thresholding which is suitable with any image to be used in the test. It is needed to make the 3D surface representations smooth, therefore triangulation method will be used as one of the solution for further research progress.

VI. CONCLUSION

The aim and objective which is to reconstruct 3D images of simple object has been focused and successfully achieved. Time consumption for the whole processing is acceptable and the results obtained also are good enough for an early stage of this research.

The 3D shape reconstructed is not smooth which is limited on edge detected from the 2D silhouette obtained from thresholding. For the future work, it is a must to find better solution to overcome weaknesses on the chosen method in order to obtain desired and more accurate result. It is suggested to make an automatic system for the processing. Then, it is good to measure the size of the reconstructed model so it can be compared with the real object for better accuracy of the reconstruction.

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