Video Processing for Dual Laser 3D Scanner Prototype based on Cloud to Cloud Method

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***Abstract*—Recently, three dimensional (3D) scanner is a continuous developing scanning technology. There are several approaches used in this technology. The first approach is by using a depth camera and the second approach is by using laser and a standard camera. Previous research had been done to develop a dual laser 3D scanner which able to scan an object with maximum size is 15x15x15 cm. By using cloud to cloud merging method, the result is quite satisfying, and it can scan a physical object and convert it to a 3D digital object with the level of size precision is more than 98%. In this research, we improve the prototype to achieve faster time processing. We change the main scanning method from using image per step into video recording. We make some adjustment to signal processing algorithm, and in result, we achieve better time processing. The time processing is reduced more than 50% of the previous research and the scale precision also getting better.**

***Index Terms*—3d scanner, video processing, cloud to cloud**

I. Introduction

Recently, generating a three-dimensional (3D) model from a physical object has been actively developed. The process is done by a system called 3D scanner. A 3D scanner technology is a real-scene copying technology that used to scan a physical object and transform them into 3D digital form [1]. This technology can be used in active fields application such as fashion, automotive, health, machinery, movie and many more. Some researches on the low-cost design of 3D scanner have been conducted. Ukida et al. [2] propose the use of image scanner to measure a 3D shape, the research use multiple light sources. This research then being developed by recovering 3D shape, color and specular reflections from the objects taken from image scanner [3]. Qun et al. [4] create a portable 3D laser scanner which able to scan 4x4 cm^2 area. While Frantis et al. [5] develop a 3D scanner using off-the-shelf sensors which use a Kinect camera. In other hands, Musaharpa et al. [6] propose a prototype of 3D scanner which able to scan 15x15 cm^2 area.

The prototype build by Musaharpa et al. [6] is a dual laser 3D scanner using two lasers and a single camera capturing images based on the rotating table movement. The prototype can construct a 3D digital image by maximizing the point cloud merging, named cloud to cloud. The point clouds are obtained from the data calculation process of multiple frames obtained from the image acquisition process by using the camera [7]. The dual laser 3D scanner technology uses a special method called triangulation method to perform the scanning process. The method uses three main components; they are a camera, laser and turntable [8]. All three elements are arranged in certain places which form a triangle and meet the requirements of the triangulation method as shown in Fig. 2.

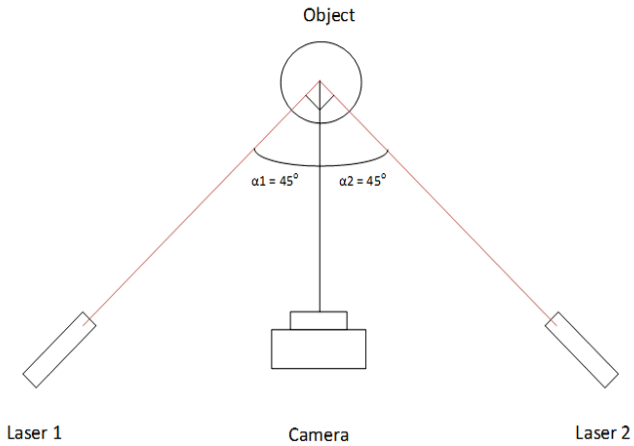

Fig. 1: Triangulation method using dual laser

The image acquisition process in [6] is done step by step. The number of frame images obtained depends on the magnitude of the angle per level of the stepper motor used to drive the turntable. Image captured when stepper motors move as much as one or several levels depending on the setting of the number of frames to be taken. From the previous research results obtained information that the higher number of frames obtained, then the 3D scanning results will be better. However, the maximum number of frames captured is 400 frames, and it takes a long time to get that number of the frame. To achieve more frames with faster time processing, we replace the use of image with video recording for the acquisition process.

This paper is organized as follows: section II describes the video processing in dual laser 3D scanner prototype. Section III examines the performances of our prototype by measuring the precision scale, frame rates and computation time of the system. Finally, Section IV concludes this study and future works.

A. Video Processing

A video is a composed image and displayed with a certain vulnerable time. The number of frames of each video varies depending on the format and camera used in the acquisition process. The higher frame rate of the camera then more frames obtained [9].

To calibrate the device, we adjust the table rotation speed that effects with the number of frames received by the camera. Equation (1) and (2) are used to obtain the desired time.

$$frame\ rate = \frac{frame\ number}{t} \tag{1}$$

$$t = \frac{frame\ number}{frame\ rate} \tag{2}$$

By knowing the desired time, then the next thing to do is adjusting the speed of the turntable to get the desired number of frames. The speed of turntable calculated using equation (3)

$$N[rpm] = \frac{number\ of\ rotation}{t} \tag{3}$$

where t is time in minutes.

To get the desired number of frames in one full rotation of the turntable, then the speed of the turntable can be calculated by entering the value of t from equation (2) to (3), hence obtained following equation,

$$Nframe[rpm] = \frac{frame\ rate}{frame\ number} \times 60 \tag{4}$$

From the equation (4), can be seen that to get more frames, the speed of the turntable should be slower. We can get information that the higher frame rate of a camera then the number of frames obtained every second is increasing, or it can also be said that the higher the fps then, the faster times needed to capture the number of specific frames. Based on this information, we formulate that to obtain the number of frames that the acquisition techniques using video recording can be considered. In another condition, we can change the camera with a higher frame rate to obtain more frames.

B. Triangulation Position

Triangulation method is used to calculate the laser line positions which fall in the object. The use of triangulation method is common in the field of 3D scanner technology. This method is used in the field of maxillo-facial surgery to reconstruct dental implant [10]. The process can be modified to match the needs of the application, such as done by Zhang et al. [11], they modified the triangulation method to do fast surface reconstruction. Modification of the triangulation method can produce an effective reconstruction with less computation time such as done by Fahim et al. [12].

In this research, the scanned object and the two lasers are positioned in the form of a triangle. The camera is placed between the two lasers to catch the laser line projection. This placement can be seen in Fig. 2. By calculating the distance between the camera with the laser and also the laser beam angle to the object, we got the optimum angle of the projected laser in the object.

The designed prototype uses a rotating platform to determine the initiating 3D point clouds coordinates. It is placed right in the center of the camera point of view. The initiating 3D point cloud then called as the center of the axis z. Equation (5) and (6) are used to determine horizontal (x) and vertical (y) coordinates. L is the distance between (z) and projected laser line. While α is the angle between the projected laser line and the camera center point of view.

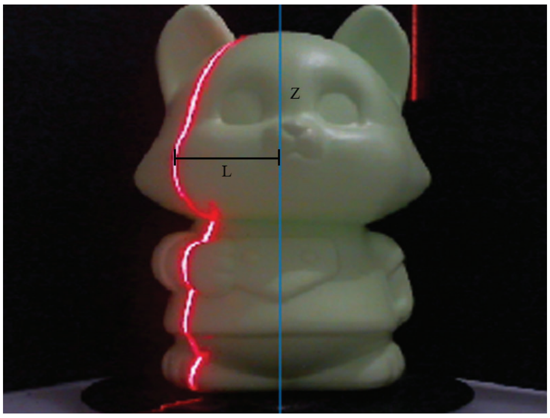

Fig. 2: Initiating 3D point clouds coordinates

$$x = L * cos(\alpha) \tag{5}$$

$$y = L * sin(\alpha) \tag{6}$$

C. Cloud to Cloud Method

Cloud to cloud is a technique to merge several 3D point clouds scan results. This method is referring to the patent owned by Rudd and Haugan [13]. In the first recording point clouds, there is a binding point that used as the merging references for the other point clouds [6]. The point clouds to be merged must have an overlap with the other point clouds. This requirement is needed to achieve an optimum merging combination [14]. In this research, the overlap reference used is the initiation 3d point cloud (z). As the angle between the two lasers is 90^o, one of the point clouds needs to be rotated by 90^o with a corresponding direction. The rotation is done by using equation (7) and (8) with the rotary axis at its center point $(0, 0)$. The x and y is the point clouds coordinates, and α is the angle between the two lasers.

$$a = x\cos\alpha - y\sin\alpha \tag{7}$$

$$b = x\sin\alpha - y\cos\alpha \tag{8}$$

The merging process then can be done by replotting the second point clouds to the first point clouds. The references of this process can be chosen from the point clouds obtained from laser one or laser two.

II. System Design

In general, the system that we designed is the development of the system that has been done in previous research [6]. The image acquisition process is not done step by step depending on the rotating table movement, but the process is changed by using video recording. While regarding hardware, we still refer to the use of dual lasers and triangulation methods that used in previous research.

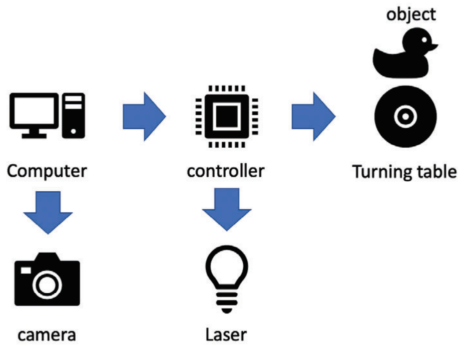

Fig. 3: System design

Basically, the 3D scanning process is divided into two stages. First is the image acquisition process and the second is the reconstruction process. At the first process, the object is placed on the turntable that integrated into the system. Two lasers and a camera are placed in a certain way that meets the triangulation method requirement. The scanning process is done by recording the video of the object, the recording process is done when the object rotates.

In the reconstruction process, the video obtained from the scanning process then extracted into frames and then converted into point cloud form. The image processing is done by first segmenting the laser light that used as a reference to determine the point clouds. Then point clouds that obtained are combined and plotted into three-dimensional shapes to form the scanned object.

A. Hardware Design

The integrated hardware design described in Fig. 3 shows that the prototype consists of an embedded controller system, two lasers, camera, and a personal computer to run the 3D reconstruction software and to control the scanning procedure. There is also a turning table which consists of a stepper motor and its driver. The prototype can scan an object with maximum size is 15x15x15 cm. Redline laser is used as the primary light source with the wavelength of the red color is 635-670 nm which is generally brighter than human eye perceives frequencies [15].

The scanned object is placed in the turntable which can rotate 360^o. A micro-stepping motor module does the rotating process. IC A4988 is used as a stepper motor driver that is complete with a built-in translator. The motor stepper can operate in several modes: full, half, quarter up to sixteenth steps [7].

B. Software Design

The camera records laser light on objects into a form of a video that processed by the designed software. The signal processing done by the software are video frame segmentation, image segmentation, determination of point clouds references,

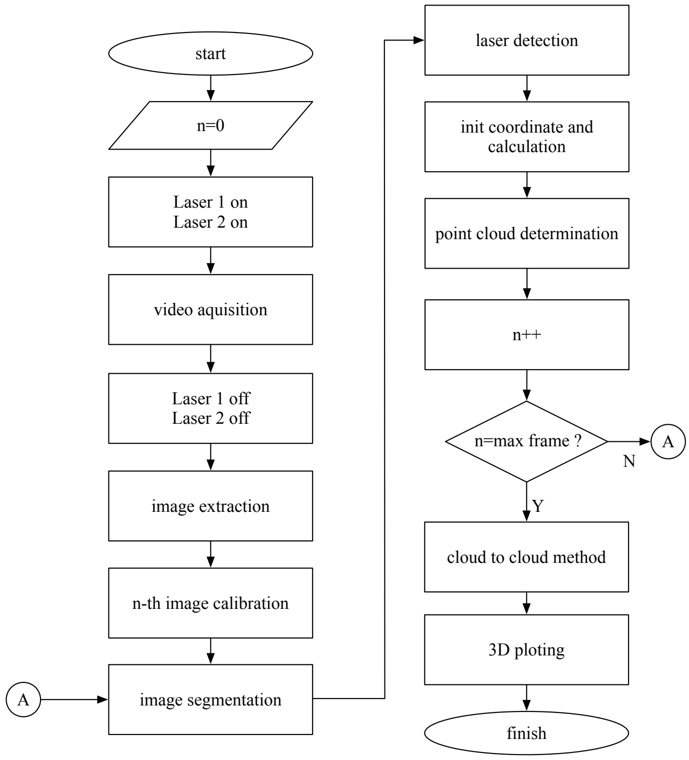

Fig. 4: Flowchart of software system

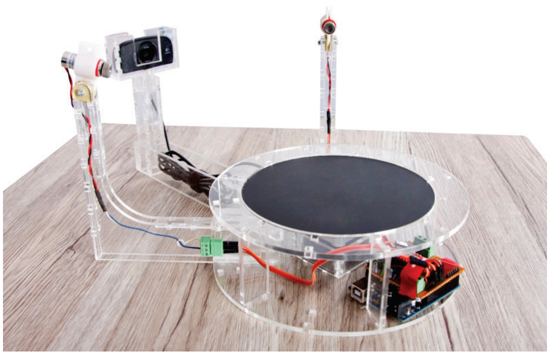

Fig. 5: Hardware implementation

cloud to cloud merging method and 3D reconstruction. The process is detailed in Fig. 4.

Image acquisition in this research is done by using the video recording process. With certain calculation as explained in equation (4) we can obtain more frames. Then the video captured can be extracted to a set of images. The next process is separating the laser beam from other objects in the frames. We use a simple thresholding method to do the segmentation. The image pixels which has the same color intensity with the laser color are then marked with red line color. In other hands, the non-marked pixels are marked with its original color [6]. The red lines obtained from this process is used to find out the coordinate reference and determine the point clouds.

Coordinates of point clouds are obtained from the calculation

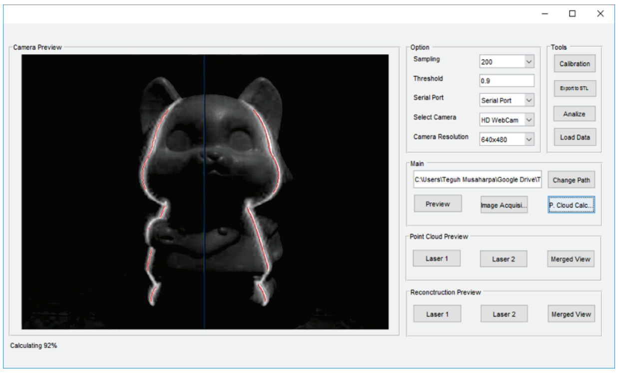

Fig. 6: Software user interface design

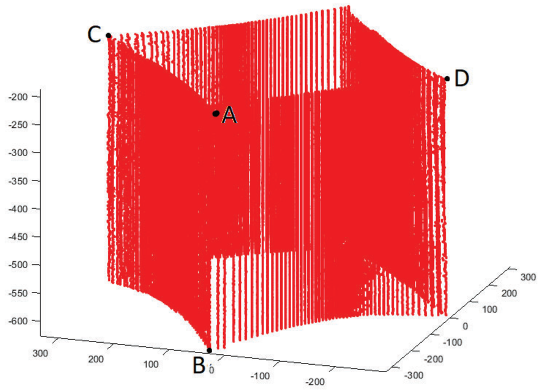

Fig. 7: Sample of point cloud calculation

of the interpolation process using trigonometric formula. The formula used to calculate the coordinate of point clouds are shown in eq.(9)-(11)

$$x_{si} = R_i \cos\left[s \times \left(\frac{360^o}{m^2} \times (m-1)\right)\right] \tag{9}$$

$$y_{si} = R_i \sin\left[s \times \left(\frac{360^o}{m^2} \times (m-1)\right)\right] \tag{10}$$

$$z_{si} = t_i \sin\theta \tag{11}$$

Point clouds obtained from the scanning process using laser 1 and laser 2 are combined by adopting the cloud to cloud merging method. In the merging process, there is a particular condition to qualify the merge process, that both of point clouds must have overlap points. Since the system rotates the objects with z axis as its center point, the overlap points are the z axis from the point clouds.

After completing one full rotation, the obtained point clouds need to be combined to form a digital 3D object. The center of z axis made as for its reference point for combining the point clouds. After all point clouds are merged, it needs to be plotted in a 3D graph so it can be seen in 3D form and represent the scanned object.

TABLE I: Data result of scanning process with video 30 fps

Number of Frame	N[rpm]	Merging Difference	Computation Time (s)	Number of Point Clouds
50	36	1.56	22.51	6148
100	18	1.34	42.42	12218
200	9	1.12	82.24	24350
400	4.5	1.03	161.87	48543
450	4	0.97	181.77	54612
600	3	0.96	241.50	72622

TABLE II: Data result of scanning process with video 15 fps

Number of Frame	N[rpm]	Merging Difference	Computation Time (s)	Number of Point Clouds
50	18	1.43	26.18	6127
100	9	1.38	47.75	12213
200	4.5	1.22	89.91	24354
400	2.25	1.15	176.02	48516
450	2	1.03	198.78	54633
600	1.5	1.04	261.57	72592

III. Result and Analysis

The scale accuracy of the scanned object is tested by comparing the ratio of length, width, and height of the real object to the scanned object. To measure the length, width and height of the object, the Euclidean equation in (12) is used to obtain the distance from one point to another.

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \tag{12}$$

By using equation (12), we can calculate the length of AB, AC and AD from the sample shown in Fig. 7. The sample object scanned is a cube then the length, width, and height of the object should be the same. Furthermore, the distance AB, AC and AD should be equal. Hence it has a 1: 1: 1 side-to-side ratio, but it still needs to be proven through testing. To find out the value of the ratio of the scanned object, then we have to find L which is the longest value of the side as a reference to determine the largest ratio value. Hence the ratio of the scanned object can be obtained with the equation (13).

$$AB : AC : AD = \frac{ab}{L} : \frac{ac}{L} : \frac{ad}{L} \tag{13}$$

By knowing comparison ratio between scanned object and real object hence can be obtained how big scale accuracy from the result of scanning. The equation can be written as follows.

$$Scale\ Precision = \frac{AB + AC + AD}{3L} \times 100\% \tag{14}$$

While to know merging accuracy of the points clouds, then we can do the approach by measuring the distance difference between point cloud from laser 1 and laser 2. The distance difference is obtained by finding the mean distance from each point of point clouds, the distance can also be obtained by using the Euclidean formula in equation (12).

From Table I and II we can see that the calculation time by using 30 fps video is faster than using 15 fps video. In the first

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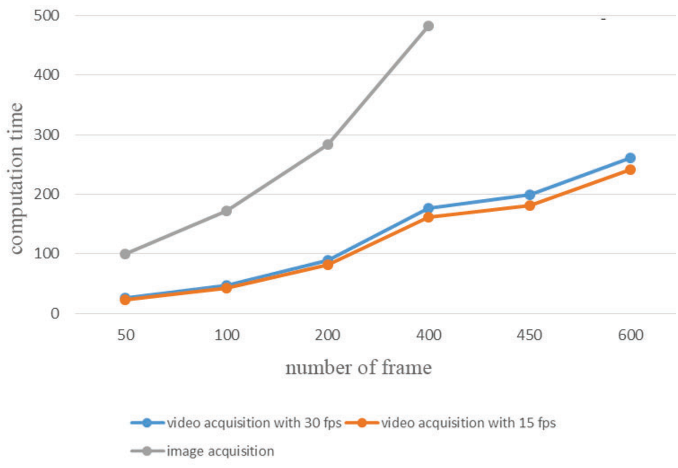

Fig. 8: Graphic relation between number of frame, image acquisition method and computation time

TABLE III: Comparison with previous research

	Number of frames	computation time (s)	scale precision (%)
image based scanning [6]	50	100,23	96,23
	100	172,34	97,67
	200	283,87	97,67
	400	486,56	98,54
video based scaning (15 fps)	50	26,18	96,34
	100	47,75	97,41
	200	89,91	97,93
	400	**176,02**	**98,32**
video based scaning (30 fps)	50	22,1	
	100	42,42	97,21
	200	82,24	97,43
	400	**161,86**	**98,68**

case, to obtain 50 frames the time processing requires up to 26.18 seconds using 15 fps video while it only requires 22.51 seconds using 30 fps videos. This happens because for 15 fps video there are only 15 frames in every single second while for 30 fps video there are 30 frames in every second of video. So, the time to get 50 number of frames for 30 fps video is twice faster than 15 fps video.

The time processing for the merging difference, precision scale and the number of the point cloud is relatively the same in each corresponding number of the frame. This similarity is caused by all of them through the same process start from image extraction from video until the reconstruction process into 3D point clouds.

IV. Conclusion

In this research, we can enhance the dual laser 3D scanner prototype which can scan an object with maximum size 15x15x15 cm. The result shows that the use of video processing instead of image processing resulting in a better performance. The time processing can be reduced more than 50% from the previous research. This time decreasing also increase the scale precision of the 3D modeling. By increasing the frame rate of the video may leads a better scale precision result. The next development of the prototype is by adding *.stl converting tools so that the scanned image can be directly edited or reprinted by using a 3D printer.

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