

Development of Low Cost 3D Scanner (LC3S) Using Matlab and FPGA

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Abstract—Nowadays, three dimensional (3D) scanners are getting more popular with the advancement and development in technology. The 3D scanner devices inspect the object and collect data on its shape and its appearance. The collected data is used to produce 3D models in digital format which is useful in several applications such as in the medical field and archival purposes. The 3D model is employed to produce a CAD drawing of body part such as bones and teeth or reproduce object using rapid prototyping and milling techniques. There are several numbers of technologies used in 3D scanners either they are contact or non-contact 3D scanners but every technology has its own advances, limitations and costs. Today, there is a need for low cost 3D scanner in the market that allows user to scan an object and print it using 3D printer. So, a low cost 3D scanner is designed to produce accurate and detailed 3D model data at minimum cost for any users. Triangulation algorithm is applied and a software for scanning and improving the image is developed using MATLAB. The software is actually based on DAVID Laser scanner software. The field-programmable gate array (FPGA) Cyclone IV is used as a microcontroller to control the speed of motors and to display scanned image using Terasic Multi-Touch LCD (MTL) in the system. Two systems are developed which one is based on David Laser Scanner software with motorized laser holder and turntable while the other scanner system is developed using MATLAB application software with only one controlled servo motor. The 3D scanned image can be seen on MTL using one or multi-touch gestures.

Index Terms—FPGA, 3D scanner, DAVID laser scanner, triangulation technique.

I. INTRODUCTION

Nowadays, developments in technology and the advancements within computer area has becoming a vital component in our daily life. Through the advancement of computer processor, three-dimension (3D) graphics have become faster [1]. Besides that, the declining cost of 3D scanning equipment also caused other applications of computer emerged such as rapid prototyping and modelling, development of realistic computer graphics in the video gaming market [2] and various large objects measurement [3].

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In fact, its innovations which emerged in 90's year were influenced by the popularity of using personal computers as well too [4].

These days, several technologies of laser scanning [5,6,7] have their own disadvantages, limitations and probably high cost. Most of the developed 3D image processing are based on David Laserscanner software due to low-cost processing 3D image that allows scanning and digitizing of 3D objects.

DAVID Laserscanner is a free software for 3D laser scanning developed by Dr.Simon Winkelbach Simon, Prof. Sven Molkenstruck and F.M.Wahlis[2]. The software operates using a computer, webcam, a background board and a line laser source. This software requires to run on the PC to process the image data from the camera and generates 3D image data in real time and display them on the computer. The quality of the scanned image is affected by many reasons such as environmental factors, the surface permeability of the surveyed object and the roughness of the surface. With the image processing technique available in MATLAB software, this problem is solved. Furthermore, it becomes perfect based on the principle of laser triangulation when using the 3D triangulation cameras and lasers [8]. It determines the projection of a light pattern [9].

Besides laser triangulation, the 3D scanner system needs a motor to rotate the object and to move the laser up and down in order to scan the object. Precise positioning operation is easier by using a stepper motor without a gear system. Thus, FPGA is used as a controller for the motors because of its flexibility and it is one of the preferred way to hardware design [10-12].

To control the stepper motor and servo motor, the driver can apply an open loop control algorithm or closed loop algorithm. There are two approaches to control current in stepper motor and servo driver. The duty cycle of switching pulse can be adjusted by using a DAC (digital to analog converter) and analog comparator[13-14]. With an applications where load torque is stable and operations are at low speed, an open loop driver is preferred since it needs a simple control algorithm and an encoder is not required [14]. The requirements from a servo motor are to turnover a wide range of speeds and also to perform position and speed. DC servo motor has been used generally at the computers, numeric number control machines, industrial equipment and speed control of alternator .

This paper presents a model of a low cost 3D scanner that is equipped with camera and laser line as an input. Besides that, the laser is moved and controlled by a stepper motor and a turntable for rotating the object is controlled by a servo motor. These motors are controlled by a controller which is implemented on Altera DE2-115 development board. A

multi-touch screen display is used to view the 3D images in all angles.

The scanning system design is described in section 2. Section 3 describes the motor and display system while section 4 discusses the results obtained from 3 sub-systems which are scanning, motor and display system. Lastly section 5 concludes the findings.

II. METHODOLOGY

The block diagram of the whole system is shown in Figure 1. The system consists three parts which are laser scanning as input of the process, the object to be placed on the turntable and the camera which records the movement of a laser line. Next, image processing and data manipulation are simulated using MATLAB application software. Lastly, the system produces a 3D image as an output result.

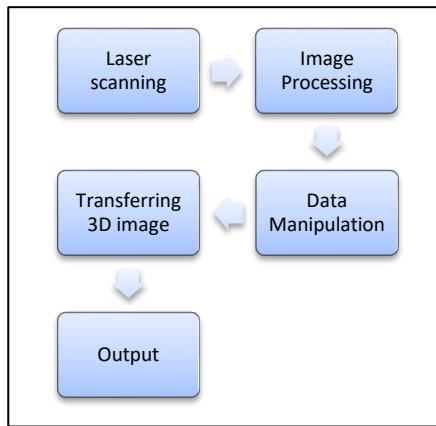


Fig. 1: Process of 3D Scanner System

A. Laser Scanning

Figure 2 shows the setup of the technique employed for the typical system. A laser line creates a vertical light plane to be projected to the object. Using a triangulation method, it helps to assist the concept of capturing an image tested using a vertical laser line that pointed straightforward to the surface of an object in order to project a distinct line on it [16]. This figure shows that a camera will take the image for each frame from the recorded video of a line on the object from a certain angle. As a result, the object must be rotated for one complete rotation using a turntable. Then, for the next step these lines are converted into a 3D coordinate points by transforming 2D coordinate of point on the web camera images. Thus, the process indicated are done using MATLAB application software.

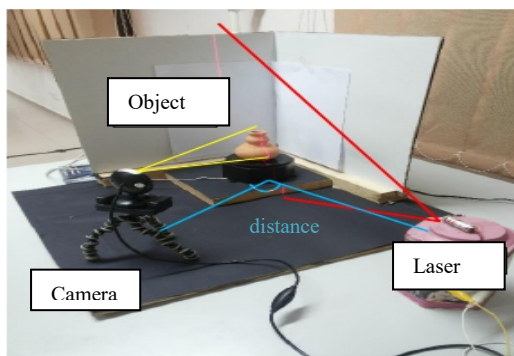


Fig.2: Equipment setup for 3D scanner

B. Image Processing Using a Matlab Application Software

Firstly, for the image processing stage, the scanning image is transferred to the software of Matlab. In order to find effective thresholding, the laser traces images acquired would undergo preprocessing technique. It involves background removal techniques or contrast adjustments. Then the image is threshold to isolate the laser trace from the rest of the image. The step of the image processing stage involves determining a discrete set of point coordinates to represent the laser trace. This could be accomplished with line thinning algorithms [17] or line walking algorithms [18].

C. Data Manipulation.

At this stage, a set of point coordinates is transformed using a transformation matrix and the linear portion of the projective distortion will be removed. Using curve fitting techniques, the data segments may be quite noisy and can be smoothed before proceeding and it depends on the algorithm used for determining the point coordinates. For a given plane, the segments of point coordinates are then rotated according to their angular position about the central axis of rotation.

D. Plot 3D image

From the Figure 3, it shows a sequential series of capturing images taken by a camera. So, each of the images will have an x-y point coordinates and the number of series will represents the z-axis. The formation of 3D form starts with the idea of circulating the position of all images around x-axis, then pointing the new x-axis downward. And next, the radial axis is formed by y-axis while z-axis becomes the direction of circulation. Thus, final transformation is done by transforming a point in polar coordinate into a Cartesian coordinate to make it easy to read the point coordinates.

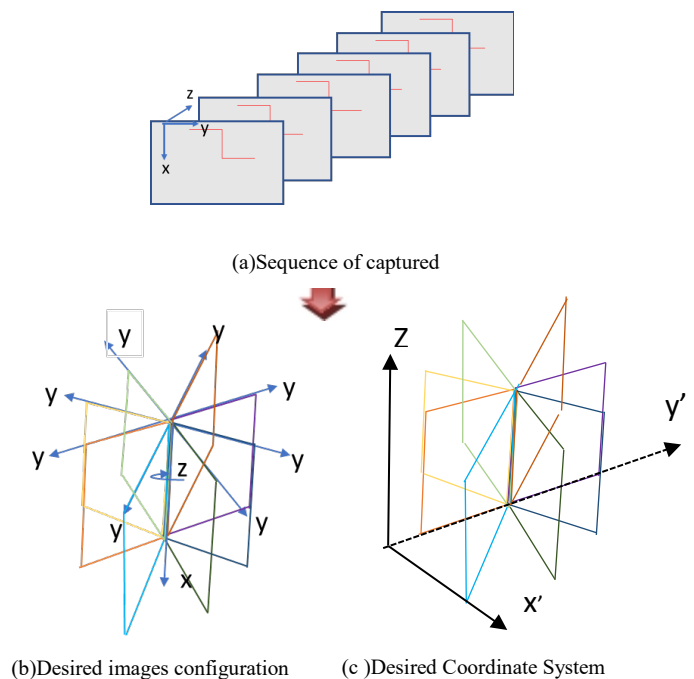


Figure 3. Transformation of 2D images into 3D Cartesian space

III. MOTOR AND DISPLAY SYSTEM USING FPGA

Fig.4 shows the basic block diagram for motorcontroller. It consists of the controller, driver and two different type of motors i.e. stepper and servo motor. The controller, FPGA, can manipulate two most important criteria which is position and speed.

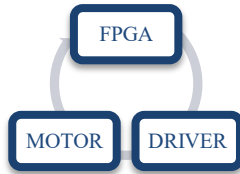


Figure 4. Block diagram of motor system

These two motors are controlled by using DIP switch on the FPGA board. The servo will be switched on to rotate the object until all the surface of the object has been scanned.

The ULN2003A is a stepper motor driver which can pass up to 500 mA per channel and has an internal voltage drop of about 1V when it is on. It also contains internal clamp diodes to dissipate voltage spikes when driving inductive loads. To control the stepper, voltage is applied to each of the coils in a specific sequence Stepper motor is playing a main role because it is used to move the laser up and down. The laser needs a constant angle in order to get the good image or result. Besides that, the speed of the stepper also need to be in optimal speed which is very slow rotation in order to ensure the laser can read all the surface of the object accurately.

Servo motor is used as a turn table to rotate the object that need to be scanned. The servo or turntable also needs an optimal speed which requires very slow rotation. This is to ensure the object is not dropped because the object has to be at constant place in order to get good result.

A. Flowchart of Motor Controller

Figure 5 shows the flowchart of the overall system. Firstly, the stepper motor module is developed by using the Quartus II software. After stepper motor module is modelled using Hardware Description Language (HDL), the second process is to run the simulation to see whether the program is correct or not. This simulation process can be done using two types of softwares, Quartus II or Modelsim to complete the simulation.

When the simulation shows that it is functional, it will go to the third phase which is implementation on the FPGA board. After all phases are tested and verified, it will be tested on the real motor to see whether the speed needed is correct or not. If not, the program is checked again to see why the desired speed is not met.

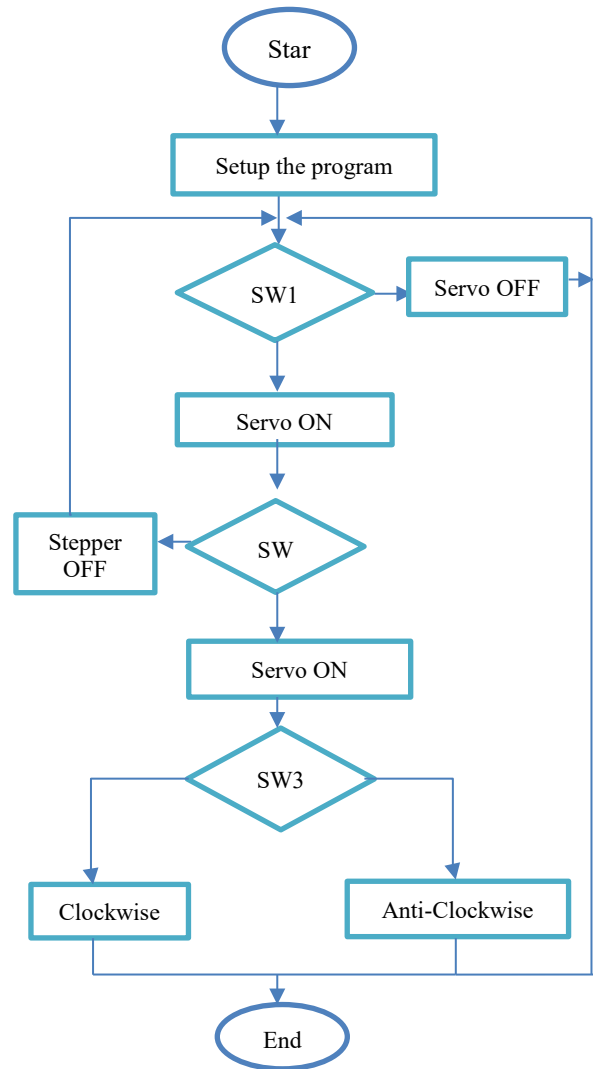


Figure 5. The algorithm for motor controller

B. Displaying Image on Multi-Touch LCD

There are several process of displaying the image on Terasic MTL module based on FPGA. The major phases required in displaying image on MTL are hardware interfacing between MTL module and FPGA DE2-115 board, converting 3d images to raw file process and controlling the multi-touch of Terasic MTL module.



Figure 6. Hardware setup for interfacing MTL module with FPGA (DE2-115) board

Figure 6 shows the hardware setup for interfacing MTL module with FPGA DE2-115 while Figure 7 shows the connection diagram that shows IDE to GPIO (ITG) adapter has been used between Terasic FPGA board and MTL module to interface both part.

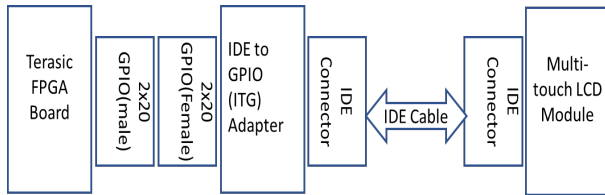


Figure 7. Connection diagram of MTL module with Terasic FPGA board

Figure 7 shows the block diagram of MTL module. MTL module consists of three major parts that is Multi-touch controller, Touch screen and LCD (800x480). All these parts have to be connected with the IDE controller to receive or send signal data to FPGA board.

Before loading data to the flash in FPGA, all the image need to be converted to raw file because flash can only read raw file image data [19]. Figure 8 shows the flowchart of converting process from 3D image to raw file.

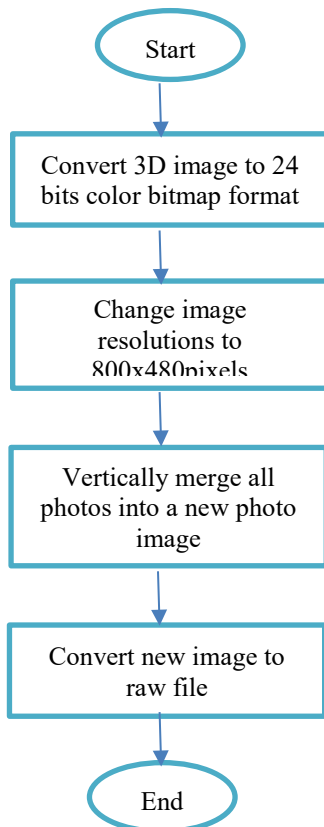


Figure 8. Process of converting 3D images to raw file.

Processed 3D image from DAVID Laserscanner or MATLAB needs to be converted to 24-bits colour bitmap format

and the resolution has to be changed to 800 (width) x 480 (height) which follow the screen size of Terasic MTL module [20]. Next, all the images vertically merge into a new photo image and finally convert the new photo to raw file. Before displaying the image, users have to run the Control Panel software to insert raw file data photos into the FLASH of the FPGA board.

Multi-touch of Terasic MTL interface module consists of several controller. Figure 9 shows the block diagram of multi-touch of Terasic MTL interface module. When the Terasic MTL module starts, the system instruct the Flash Controller to read the Red Green Blue (RGB) data of processed image that stored in the FLASH and write the data using writing port into SDRAM [21]. Next, to display the selected image on the 800x480 LCD, the VGA Controller via reading port of SDRAM retrieves the photo data and drives the LCD display with the retrieved processed image data.

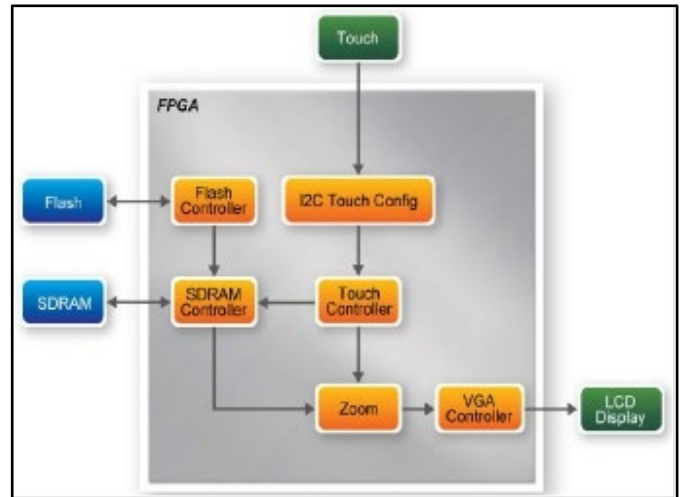


Figure 9. Block diagram of multi-touch of Terasic MTL interface module.

I2C Touch Config will retrieve an interrupt signal if user touch the MTL screen and will read touch information from touch panel. It asserts the oREADY signal and after the Touch Controller detects the signal, it will read the information and determine either a gesture or single-point touch [10]. Reading port address in SDRAM Controller will change if the gesture is detected while zooming factor in Zoom will change if zoom gesture is detected.

IV. RESULT AND DISCUSSION

A. Processing 3D image using DAVID Laserscanner Test

Processing image using DAVID Laserscanner test is setup to test the effect of lighting on the result of processed image. This is very important in processing 3D image which is to make sure the processed image can have better shape. The results of the test are taken for different lighting during laser scanning process.

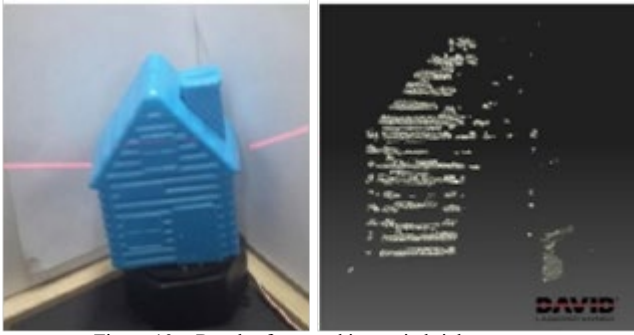


Figure 10. Result of scanned image in bright area.

As shown in Figure 10, the result of processed 3D image using David Laserscanner after the scanning process in bright area. Due to the effect of bright area, the laser is not perfectly scanned on the surface of the object. Comparing to the laser scanning process in dark area as shown in Figure 11, all the surface of the object are scanned and produces better result of processed image

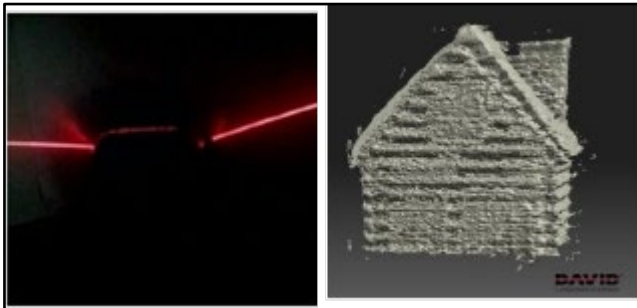


Figure 11. Result of scanned image in dark area

B. Scanning and Processin3D image using MATLAB software

Firstly, to get the accurate data captured, several objects had been scanned and some analysis was implemented. The first task was to test “The Sayong Pottery” as the targeted object. In order to get a reflecting surface perfectly, the indicated object must have an opaque surface. Then, the object was roughly placed on the turntable in the middle of it. Figure 12 shows the “Sayong Pottery” that will be tested.



Figure 12. The sayong pottery on a turntable.

The image needs to be calibrated first as shown in Figure13 to make a center line of the image. Next, the image will be cropped at the region of interest where the line laser that detected on the object and the image processing will begin to analyze the recorded video frame by frame. This line matches closely to the contour of the object cross section. In

order to get the best contrast image, the object needs to be placed on a dark background so that the software can easily detect and process the image thoroughly.

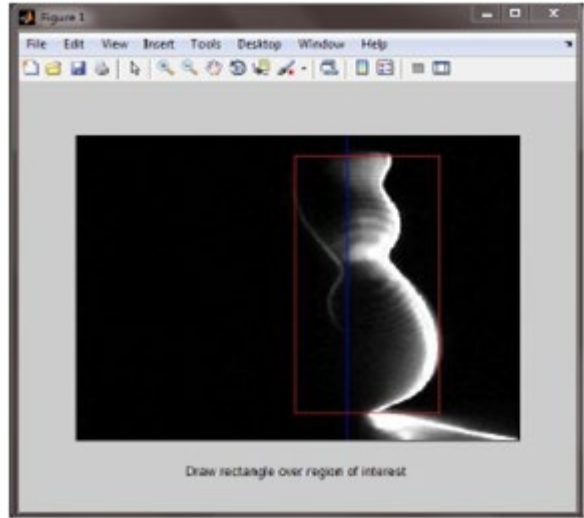


Figure 13. Calibration for a center line.

Figure 14 shows the process of analyzing each of the frames respectively. The light of a laser line determine the shape of an object. Due to some points are difficult, the system from this MATLAB software fails to detect and capture all the points because of several reasons such as light background and the surface of the objects.

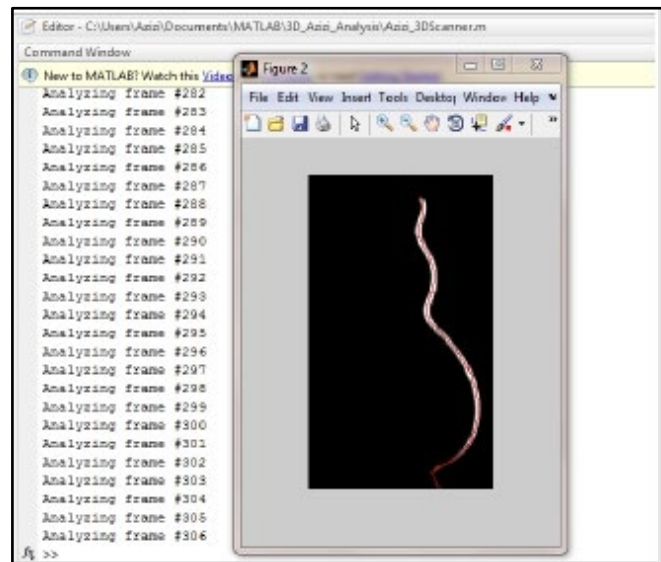


Figure 14. The process of analyzing the frame.

Figure 15 shows the final result of 3D image graph that has been implemented after the laser line is converted into a real radius on 3D graph

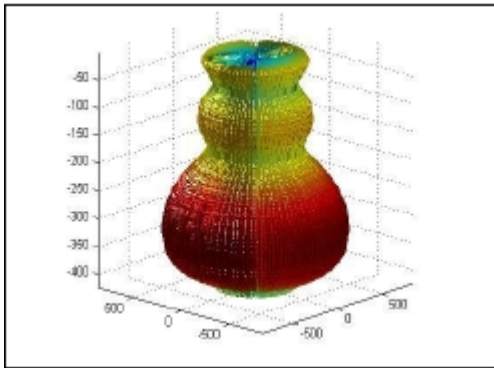


Figure 15. Result from a 3D graph.

C. Controlling Motors

Figure 16 and Table 1 show the results from simulation and condition for the coils to rotate the motor continuously. Assuming positive logic, where a ‘1’ means turning on the current through a motor winding, the control sequences will spin the motor. This sequence uses more power and but produces greater torque.

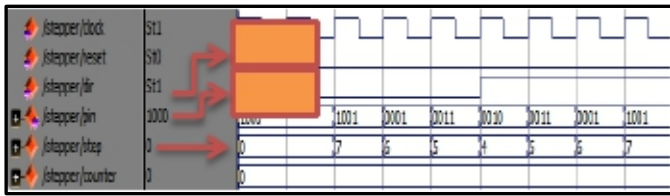


Figure 16 Stepper Motor Direction

TABLE 1. MOTOR DIRECTIONS

Direction (Step)	Coil			
	Coil 1	Coil 2	Coil 3	Coil 4
0	1	0	0	0
1	1	1	0	0
2	0	1	0	0
3	0	1	1	0
4	0	0	1	0
5	0	0	1	1
6	0	0	0	1
7	1	0	0	1

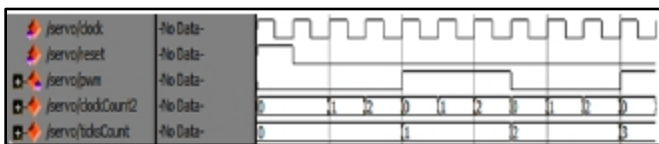


Figure 17. Servo Motor.

From the timing diagram shown in Figure 17, when the condition of the clock divider is same or equal to the clockcount2, the servor motor operates while if the clock divider is not equal to the clockcount2, the counter increases one by one. The clockcount2 keeps increasing while the pwm is “1” until the clockcount2 is not equal to clock divider.

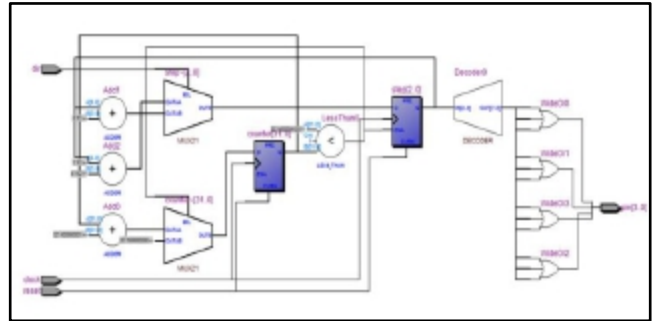


Figure 18. RTL stepper

Figure 18 shows the RTL schematic produced after synthesizing the stepper controller module. The stepper module has 2 switches where the first switch is for the stepper “ON” while the second switch is to rotate the direction either clockwise or anticlockwise.

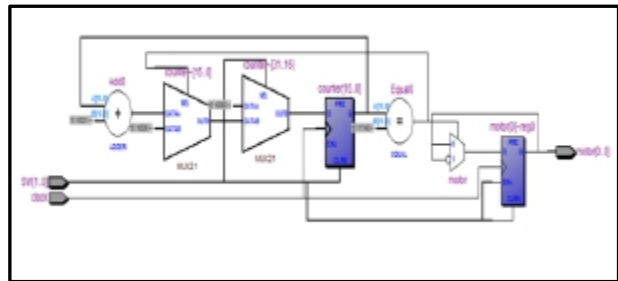


Figure 19. Servo Motor

Figure 19 shows that the RTL schematic of the servo motor. The servo module has 1 switch for turning on or off the motor. The RTL schematic for the both modules is shown in Figure 20.

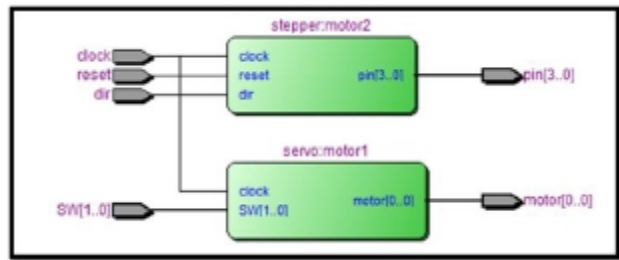


Figure 20. Top Module RTL

From Figure 21, it shows that the different type of pulse which is 3 and 5. It shows that when the period is increased, it will increase the pulse width and at the same time it will decrease the frequency. So the speed will also be reduced.

TABLE II. SPEED OF MOTOR

SW	Counter (parameter)
01	3
10	5

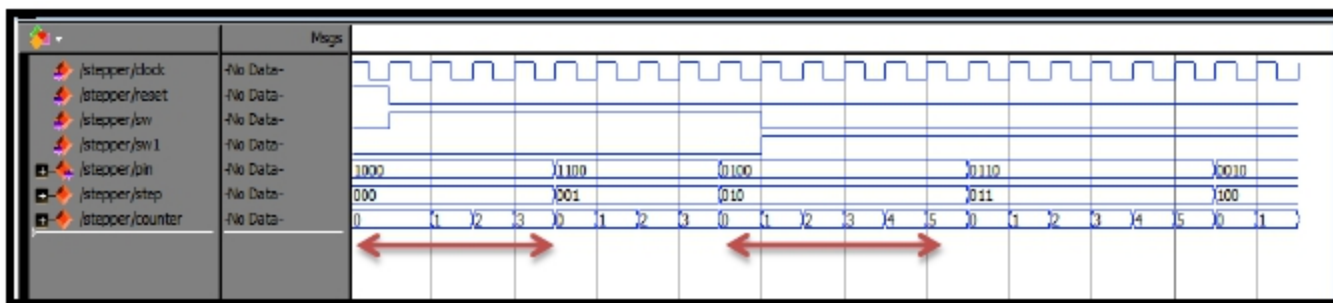


Figure 21. Stepper Motor

D. Terasic MTL module multi-touch gestures and single-touch test

Table III shows the signal value for every gesture determined by Terasic Technologies. The manufacturer already set the signal value for Touch Controller module for every gesture that touched by user on the screen.

TABLE III. SIGNAL VALUE DETERMINED BY TERASIC

Gesture	ID (hex)
One Point Gesture	
Rotate Clockwise	0x28
Rotate Anti-clockwise	0x29
Click	0x20
Double Click	0x22
Two Point Gesture	
Click	0x40
Zoom In	0x48
Zoom Out	0x49

The results shown here are the test for the different multi-touch type detection of user on the Terasic MTL module which is click one point gesture, double click one point gesture and also click two point gesture.

1) Single Click One point gesture



Figure 22. Click one point gesture

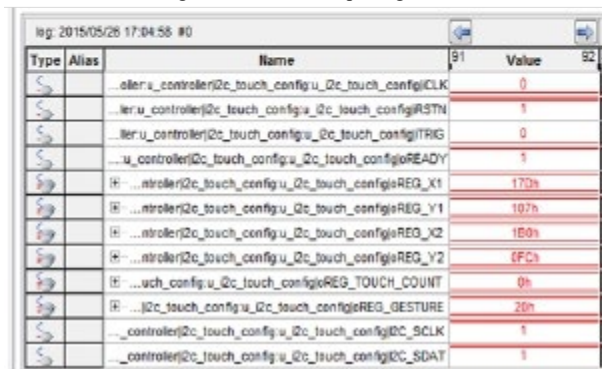


Figure 23. SignalTap II Logic Analyzer results for Click I Gesture

Figure 23 shows the result of click 1 point gesture signal value from TouchController module using SignalTap II Logic Analyzer simulated by Altera Quartus II Software. The value oREG_GESTURE signal shows 20 hexadecimal which is determined by manufactures.

2) Double click One Point Gesture



Figure 24. Double click one point gesture.

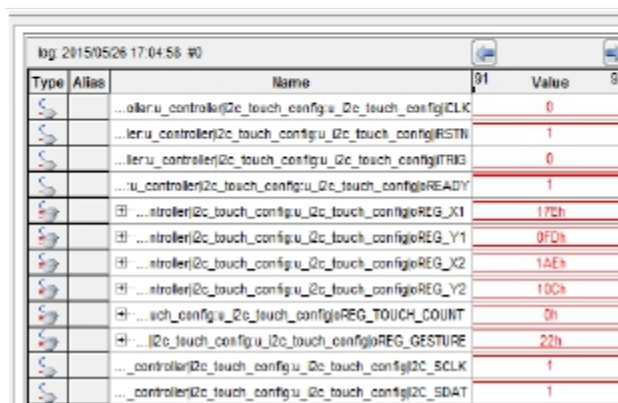


Figure 25. Double click one point gesture.

For double click one point gesture, the signal of oREG_GESTURE is 22 hexadecimal as shown in Figure 25. For the touch gesture information, signal of oREG coordinate is not considered and only read on oREG_GESTURE signal.

3) Two Point Gesture



Figure 26. Click Two Point Gesture.

Type	Alias	Name	B1	Value	B2
C		...ntroller[2c_touch_configu_2c_touch_config]CLK		0	
C		...ntroller[2c_touch_configu_2c_touch_config]RSTN		1	
C		...ntroller[2c_touch_configu_2c_touch_config]TRIG		0	
C		...ntroller[2c_touch_configu_2c_touch_config]READY		1	
IF		...ntroller[2c_touch_configu_2c_touch_config]REG_X1		171h	
IF		...ntroller[2c_touch_configu_2c_touch_config]REG_Y1		10Ch	
IF		...ntroller[2c_touch_configu_2c_touch_config]REG_X2		1AEh	
IF		...ntroller[2c_touch_configu_2c_touch_config]REG_Y2		10Ch	
IF		...ntroller[2c_touch_configu_2c_touch_config]REG_TOUCH_COUNT		0h	
IF		...ntroller[2c_touch_configu_2c_touch_config]REG_GESTURE		49h	
IF		...ntroller[2c_touch_configu_2c_touch_config]SCLK		1	
IF		...ntroller[2c_touch_configu_2c_touch_config]SDAT		1	

Figure 27. Value for Click Two Point gesture.

For a click two point gesture, Figure 27 shows the result of signal value 40 hexadecimal from TouchController module using SignalTap II Logic Analysers simulated by Altera Quartus II Software.

The results provided here shows that the hardware is interfaced correctly with the algorithm in the developed system LC3DS. The scanning system can be activated by the Terasic MTL using the provided gestures.

V. CONCLUSION

A low cost system for 3D image scanning, based on principle of triangulation method techniques is successfully developed. The scanning and processing 3D data are done using MATLAB applications software where filter is also used to get rid noise in the scanned image. Besides developing the system, the goal of this project is to improve and identify the accuracy, angle of the laser with the resolution in order to ensure that the scanning data of the objects get the best quality.

The system is improved with the constant rotation of turntable and steady movement of laser holder. This can be done by having a motor controller which can be implemented on FPGA board which provides flexibility in designing.

Based on results, the project is found to be useful to any users. Last of all, this project is hoped can be benefited completely, accepted and used and in keeping with technological development in this time and those results earns from this project can fulfill all needs consumer. Also possible with produced this project prototype, it will be a start or reference for something more effective at a time future time.

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