ECE 445
Design Review
3D Scanning Device
Using Computer Vision

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1. Introduction

A 3D scanner is a device that analyzes a real-world object to collect data on its shape and appearance. Then the collected data can be used to reconstruct digital three dimensional models. The collected 3D data is very useful for a wide variety of applications, especially for the entertainment industry in the production of movies and video games. There are plenty of technologies for digitally acquiring the shape of a 3D object. Most of the well-known 3D scanners are active scanners, which emit some kind of radiation and detect its reflection in order to probe an object. The active scanners are precise but expensive, because most active scanners are laser-based. Our project aims to make a passive 3D scanner by web-camera. The web-camera records the video around the object in 360 degree, and the video will be processed by computer vision algorithms to reconstruct the 3D model. The camera-based scanner can be used in plenty of places such as art gallery, computer accessory, and etc.

Objective

Our camera-based 3D scanner is capable of reconstructing at most a 3D model of approximately a 6`×6`×6` object. Moreover, if the object is small, the camera can be moved closer to the object along the axis, so that the image has a good resolution quality. On the other hand, the 3D scanner maintains a simple installation procedure and a friendly user interface. The user just need put the object on the scanner platform, and the platform automatically rotates the object. Our 3D scanner need rotate the object 2 times. The first rotation happens in the black cover with a LED light on the opposite direction to acquire the object shape. The second rotation needs natural light to get the color information. The product will be designed to reconstruct a general shape of the object in 3D, along with some simple color on the reconstructed model.

Benefits

- Easy installation and user-friendly
- Do no need to buy expensive laser scanner
- Ability to reconstruct the 3D model with simple web-camera
- Can represent an art craft in more detail than 2D image

Features

- Great for retailers to display merchandise online
- Rotate platform with speed control to maintain the object stable
- Image segmentation algorithm
- Self-developed 3D model reconstruction algorithm

2. Design

2.1 Design Block Diagram

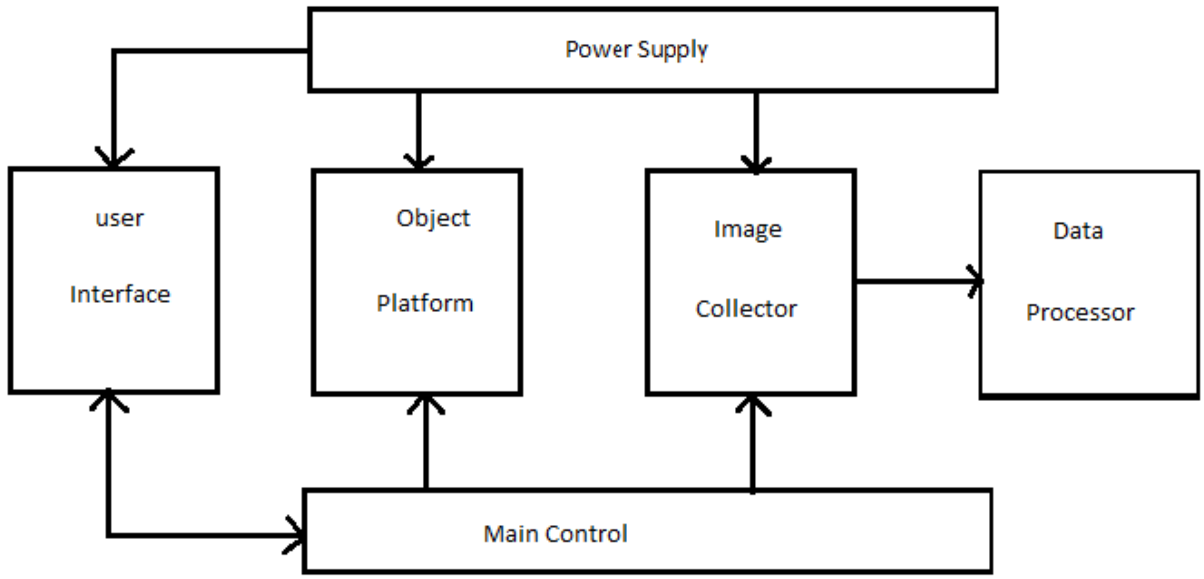


Figure 1: Block diagram for the 3D scanning device

2.2 Block Descriptions

Object Platform: The object platform unit is a basic mechanical structure that designed to hold the scanning object, the rotating arm for a camera and LED lights and one compartment to place the gear head motor and the speed control circuit. The platform receives signal from main control unit to rotate so that camera can take pictures of the object in 360 degrees.

Main Control: The main control unit controls three parts in our system. Firstly, it interacts with the user interface which allows the user to start/end the scanning process. Secondly, it controls the LED lighting and camera to collect images of the object. Thirdly, it controls the rotation of the object platform.

Power Supply: The power supply unit is a DC power supply that provides power to the object platform, control unit and data collector. This unit consists of two different DC voltage supplies. First, a 5V USB DC power supply from a PC USB port is used to provide power to the control unit and data collector.

Second, a DC battery is used to provide power to the motor in the object platform unit.

User interface: The user interface unit is contains a startup button and one LED light. By pressing the button, user can start the scanning process. Once the process is finished, the LED light will change from red to green to indicate the scanning has been complete.

Image collector: The data collector consists of a web camera and the LED light sources. LED light sources are used to create an ideal artificial lighting condition. Meanwhile, the web camera captures frame data for 3D model reconstruction. The image collector will be controlled through the main control unit.

Data processor: The duty of the data processor is to manipulate the collected frame data and output a 3D model file that can be read by other common software. This unit can be further separated into two parts: image segmentation and 3d model reconstruction. The data processor unit creates object image segmentations, removes the background, and then uses these image segmentations to reconstruct a 3D model.

2.3 Performance Specification

- Object rotating Speed: 2 rpm
- Scanning completion time: 1 minute
- Camera resolution: 640 x 480
- Scanning object size: 3 x 3 x 3 inches, 2.5kg

2.4 Schematics

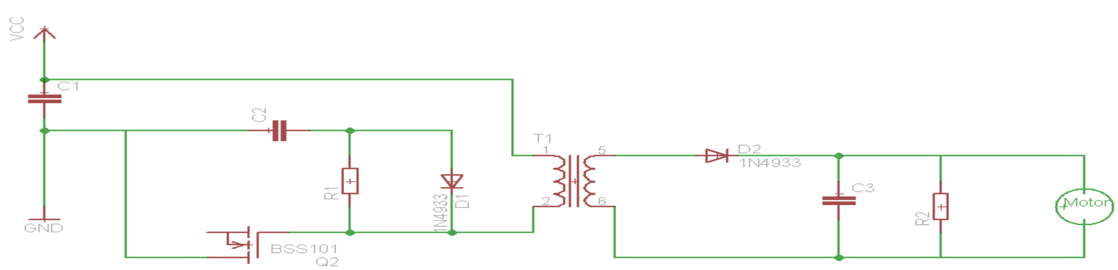


Figure 2: Buck Boost converter circuit

The buck-boost converter circuit is used to regulate the input voltage of the motor to assist motor maintain a constant rotation speed. The power source C1 represents the AA battery, and the load on the right is the DC motor. We used fly-back topology in design the DC transformer, a constant voltage level can be kept on the motor to regulate its RPM. Detailed parts model will be obtained once the gear head motor is received and the operating voltage of the motor is found. Below is the gate drive schematic of the dc converter circuit. The gate driver is used to provide switching ratio of the converter circuit

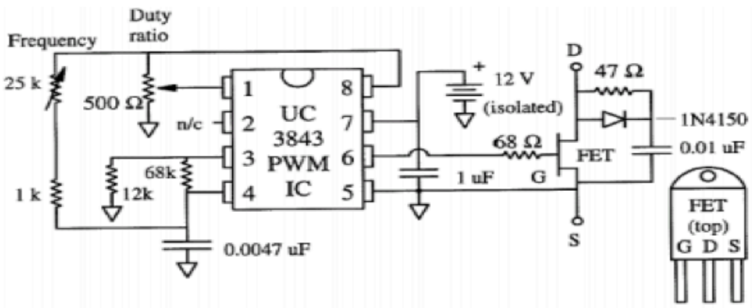


Figure 3: Gate drive circuit

Below is a simulation diagram of the buck-boost converter circuit with input at 10 V and output at 16V, where channel 1 is the diode duty ratio and channel 2 is the output voltage. From the graph, the output ripple voltage is 180 mV, only 1.125% of the output voltage. The theoretical duty ratio calculated using formula $V_{out} = \frac{D}{1-D} V_{in}$ is 61.54%, and the experimental duty ratio is 64.09%.

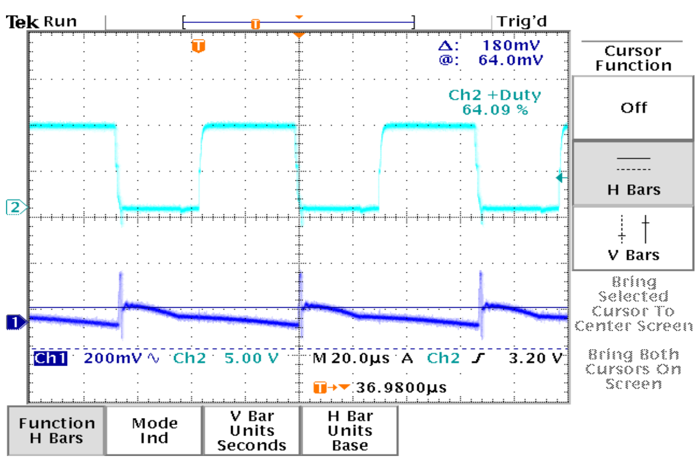


Figure 4: DC converter ripple voltage

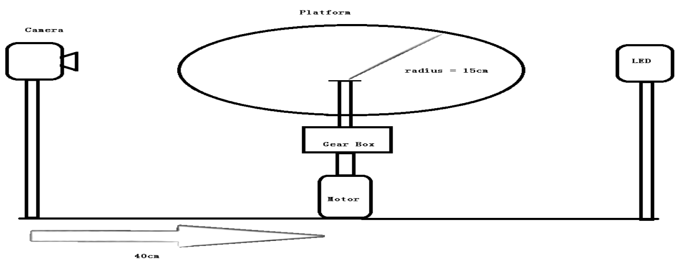
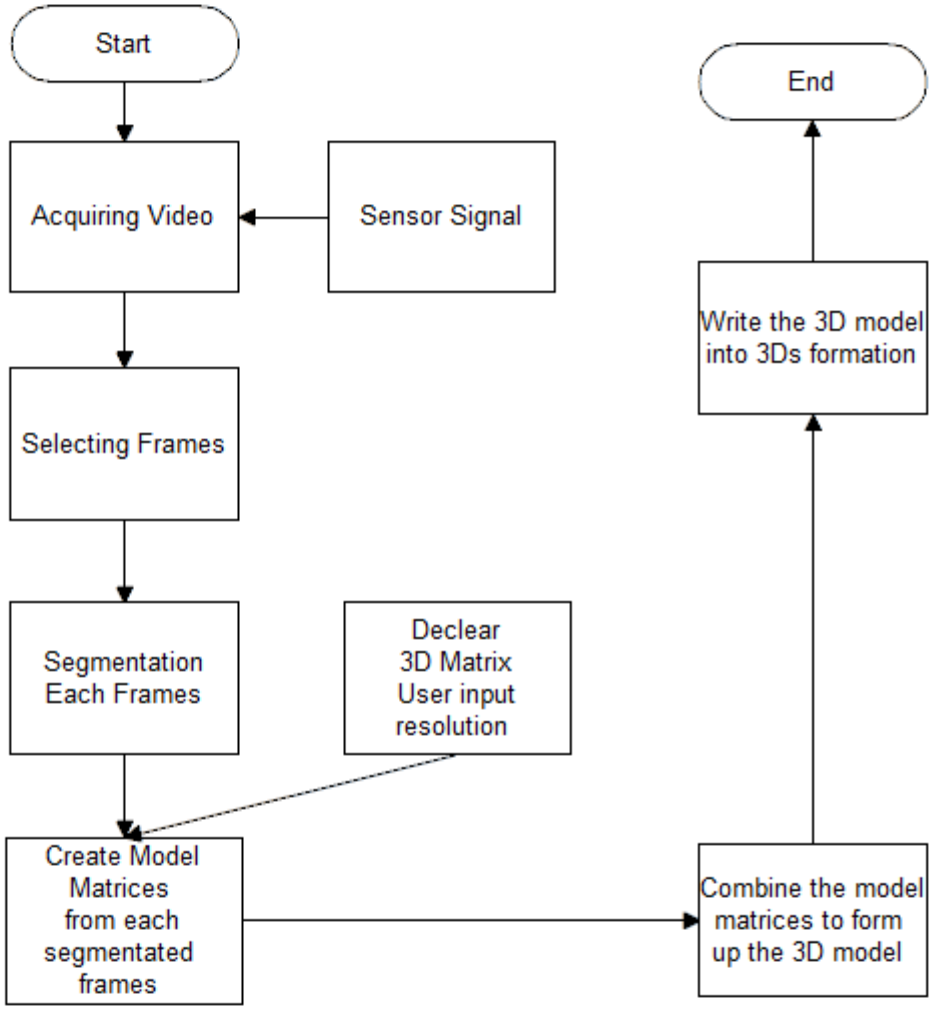


Figure 5: schematic of the 3D scanning device

With the camera and LED light on opposite sides, the scanning object will be placed at the center of the rotating platform. Distance from the camera to the center rotor is 50 cm, and the radius of the top rotating plat is 15cm. The camera and the plat will have the same altitude.

2.5 Software and Computations

2.5.1 Software Flow Chart



2.5.2 Algorithm Theory

Segmentation Algorithm:

$$I_{gray}\{i\}(x,y) = \frac{I_{red}\{i\}(x,y) + I_{blue}\{i\}(x,y) + I_{green}\{i\}(x,y)}{3}$$

$$I_{segment}\{i\}(x,y) = \begin{cases} 1 & if\ I_{gray}\{i\}(x,y) \geq t \\ 0 & if\ I_{gray}\{i\}(x,y) < t \end{cases}$$

3D-reconstruction Algorithm:

$$Cube_{init}\{i\}(x,y,z) = I_{segment}\{i\}(x,y)\times\begin{pmatrix}\frac{Dis+z}{Dis} & 0 & 0\\ 0 & \frac{Dis+z}{Dis} & 0\\ 0 & 0 & 1\end{pmatrix}$$

$$Cube_{rotated}\{i\}(x,y,z) = Cube_{init}\{i\}(x,y,z)\times\begin{pmatrix}1 & 0 & 0\\ 0 & \cos(\theta) & -\sin(\theta)\\ 0 & \sin(\theta) & \cos(\theta)\end{pmatrix}$$

$$Note: Operator\times represent\ affine\ transformation\ with\ tfm\ matrix\ (\ddots)$$

$$Cube_{segment}\{i\}(x,y,z) = Threshold(Cube_{rotated}\{i\}(x,y,z))$$

$$Cube_{finalmodel} = \bigcup_{i=1}^{num} Cube_{segment}\{i\}$$

2.5.3 Algorithm Performance

Segmentation Result:

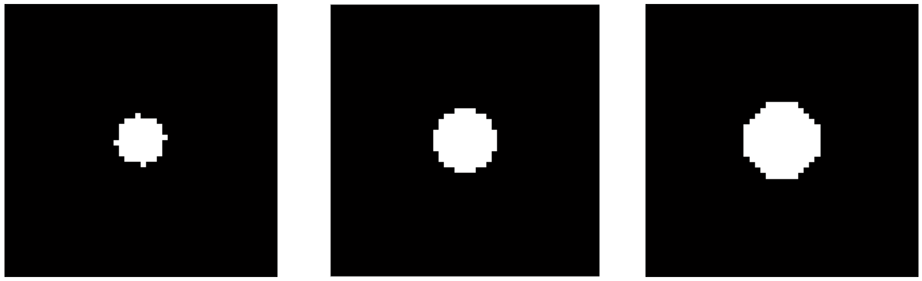
Color input

Gray

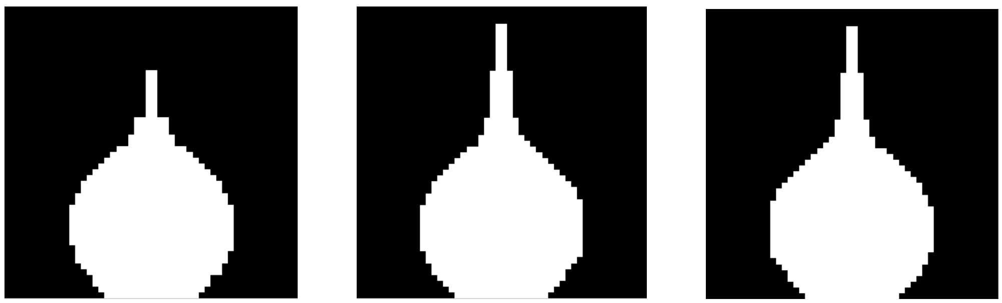
Segmentation

3D Reconstruction Result:

Input View from each angle:



Horizontal Intersection views show that the model in 3D matrix successfully reconstructed



Vertical Intersection views show that the model in 3D matrix successfully reconstructed

3. Performance requirements and Verification

Requirement	Verification
Power Unit 1. The battery needs to provide a stable 1.5V DC power source. 2. Buck-boost converter must provide a stable voltage level for the Motor. (The voltage level will be given based on the actual converting ratio of the circuit) 3. The input voltage for the motor needs to regulate motor's speed at 2RPM.	1. The voltages across the battery and the Buck boost converter's output voltage is measured using oscilloscope. 2. To ensure the motor rotates at desired speed, we will measure the voltage on the dc battery before installed it in the object platform. Then we will measure the voltage on the motor to check if the buck-boost converter functions as expected. 3. Moreover, we will change the parameter of the buck-boost converter (duty ratio) until the speed of the motor is at 2RPM.
Image Collector 1. The video recorded by the camera must have right focus on the object and also clear, not blurred for segmentation purpose. 2. The object should occupy at least half of the picture.	The recorded video will be examined by several sampled frames. 1. Using Matlab to obtain the several frames of the video. And then we will verify these sample frames by eyes. 2. The occupation of the object in the picture depends on the size of the object and also the object's distance from camera. Then we will change the distance to accommodate different sized object.
Object Platform The object Platform must rotate stably so that the object would not vibrate badly or move on the platform. 1. It must rotate at a constant speed (2 RPM). 2. It cannot badly vibrate.	1. In order to test the speed of the Object Platform, we will mark one spot on the edge of the platform. Using a timer, we can observe how many rotations the platform has gone in 2 minutes, divided by two, we can verify whether its speed is 2RPM or not. We will no multiple tests (> 4 times) to ensure the result. 2. To check the vibration, we need to test different objects on the platform to see if it stays stable when the platform rotates.
User Interface 1. The scan button must function correctly. When pressing the button, correct "startup" data package will be sent to main controller. 2. The resolution change buttons must function correctly. When pressing the resolution buttons, the resolution parameter in software input must be changed.	1. By inserting a data package receiver between User Interface and main controller to see whether the correct data package is sent out. 2. Monitor software parameters during debug mode, to see whether pressing the resolution button will make a change in the resolution parameter input to the software.

<u>Main Controller</u> 1. Main Controller must correctly response to user input. 2. It must correctly send/acquire data packages to/from web camera. 3. It must correctly control the background LED light in order to obtain the right segmentation.	1. In order to test whether the main controller can correctly correspond with user input. We need to monitor output of the main controller to see whether a correct signal is sent. Inserting testing LED light will be an easy way to see a coming signal. 2. As our web camera is built outside the main controller. We can monitor the camera performance to see whether main controller is working correctly. 3. Background LED light can also be monitored by tester. When the platform is rotating at a constant speed, background LED should be lighted up by the main controller.
<u>Data Processor</u> The data processor contains several parts. 1. Segmentation: It needs to process the input image and successfully segment the object out. 2. Given by the Segmentation image, it needs to reconstruct the image 3D model. We use 3D matrix to contain the information of 3D model. 3. It needs to represent the 3D model in 3Ds files.	The data processing result will be examined using Matlab. We will analyze the Matlab output figure and graph to check the result. 1.1 Threshold method is used in Segmentation part. Therefore, in order to achieve a good performance in segmentation process we need to check different threshold values. 1.2 Compare each segmented result with the original graph. If the pixel(x,y) on the original graph belongs to the object, then in the segmented image pixel(x,y) should has value 1. Otherwise, it has value 0. 2. Once the 3D matrix has been obtained. We will check the intersection graph horizontally and vertically. And compare these intersection graphs with the real object. 3. In this part, we need to find a method to represent the 3D model for the user. We will compare the .3Ds file with the object in shapes and colors.

- Corner cases:

  There will be a few unpredictable corner cases as well as predictable ones. Corner cases may be generated by weird colors and structures of the object. Our algorithm is not sensitive to concave surfaces. Applying different lighting conditions such as 30 or 15 degree strong light may help to detect concave surface according to the shadow. However, analyzing shadows will need higher level computer vision technique together with a more complex algorithm. Meanwhile, collecting data will take much more time. As one of the main objectives of this project is for family use, this project will tolerate some level of inaccuracy and focus more on fast algorithm and friendly user interface.

4. Cost and Schedule

4.1 Labor

Name	Rate	Hours	*2.5
Hansen Chen	$60/hour	200	$30000
Xiaobo Dong	$60/hour	200	$30000
Xingqian Xu	$60/hour	200	$30000
		Total Labor Cost	$90000

4.2 Parts list and cost

Parts	Model Number/source	Price	Qty	Subtotals
Metal Platform	N/A	$50	1	$50
DC motor	Igarashi Motors 2732	$10	1	$10
LED light	N/A	$1.00	4	$4
Camera	BNT(123WU)	$30	1	$30
Micro-controller	STM32F4DISCOVERY	$20	1	$20
USB Cable	N/A	$4.00	2	$8
Light cover	N/A	$5.00	1	$5.00
Power MOSFET	2N6756	$3.00	1	$3.00
Coupled Inductor	ECE Power lab	$2.77	1	$2.77
1.5V AA battery	Duracell AA-CTx20	$0.50	2	$1.00
			Parts Labor:	$50
			Grand Total:	$183.77

Note: For the buck-boost circuit, we were unable to give the detailed parts list and cost analysis at this time, but they will be given once the motor we ordered is received and tested next week.

4.3 Schedule

Week	Task	Leader
02/06—Proposal due	Finish Proposal;	Xingqian
	Research on Algorithm about image segmentation;	Xiaobo
	Design Object platform;	Hansen
02/13	Finish Design Review;	Xingqian
	Design image collector;	Xiaobo
	Build Object Platform;	Hansen
	Research on 3D model representation;	Xingqian
02/20—Design review	Design Review;	Hansen

	Design main controller;	Xinqian
	Build image collector;	Xiaobo
02/27	Finish Mechanical part of object platform and image collector;	Hansen
	Research on 3D model reconstruction;	Xingqian
	Design main controller;	Xiaobo
03/05	Build main controller;	Hansen
	Research on camera data collection;	Xingqian
	Coding on segmentation algorithm;	Xiaobo
03/12—Individual Report	Finish individual report;	ALL
	Finish object platform, LED , main controller and Image collector;	Hansen
	Coding on 3D reconstruction;	Xingqian
03/19—Spring Break	Testing on main controller;	Xiaobo
	Testing on object platform, LED, image collector;	Hansen
	Build user interface;	Xingqian
03/26—Mock Demos	Mock Demos;	Xiaobo
	Build interface protocol for data processor;	Xingqian
	Coding on 3D model representation;	Hansen
04/02	Test on segmentation code;	Xiaobo
	Test on interface protocol;	Hansen
04/09	Test on 3D construction code;	Xingqian
	Test on 3D representation code;	Xiaobo
04/16	Prepare for final demo;	Hansen
	Overall testing on the whole system;	Xiaobo
04/23—Final Demos	Start final paper;	Xingqian
	Final Demo;	Hansen
04/30—Final Paper	Finish final paper and Check out;	Xiaobo

Note: All group members will be responsible for the project.

5. Ethical Considerations

We agree to uphold the IEEE Code of Ethics, and will address any relevant ethical concerns about our project.

As with any engineering project, there are numerous ethical concerns to be considered throughout the course of this project. User safety and product reliance are our main concern for this project; we need to consider and avoid any electrical shock that may happen to the user since main part of the device is a metal platform. Since the device is targeted as a user-friendly scanning device, easy operation of the device must be achieved. In addition, all information obtained from outside to assist in completing this project will be given appropriate references and all outside help will be addressed at the end of this project as well.