FAMU-FSU College of Engineering
Department of Electrical and Computer Engineering

EEL4914C/4915C – ECE Senior Design Project II

Detailed Design Review and Test Plan

Design Team #: E10

Project title: **3D SCANNER**

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Executive Summary

The purpose of this project is to design a scanner that implements 3D digital images. Photogrammetry is the method that will be used to record an overall mapping of the object. To achieve this there will be a hardware and software implementations. The hardware design will be in the form of an arch where an object will be placed inside and sent to software for processing. Inside the arch will be thirteen cameras to take several high resolution photos of the artifacts with overlapping angles covering the entire surface of the object as it is being pushed through. There will be a green background to act as a difference layer to each photo to isolate the object. The photos will be stored in a file where a script will be initiated to run through each software. It will run through a series of stages with creating a point cloud as the first. Then the point cloud will be used to create a solid surface mesh, and the photographs will be used again to make a surface texture. This will finally create a photorealistic re-creation of the object. This design will ultimately be used to preserve the artifacts in the *Slavery in the Old South* found in the Meek-Eaton Southeastern Regional Black Archives Research Center and Museum (Black Archives) at FAMU. Because of the easier virtual access to these artifacts, the museum hopes that it will increase the community's engagement in these historical findings.

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1 Introduction

1.1 Acknowledgements

Team E-10 would like to thank Dr. Bernadin for securing a lab space for working as well as for meeting. The team would like to thank Dr. Dawson for establishing the project as well as providing a room at the archives that will be used for scanning the artifacts and data collecting testing.

1.2 Problem Statement

The project aims to recreate and preserve historical artifacts from the *Slavery in the Old South* display at the Meek-Eaton Southeastern Regional Black Archives Research Center and Museum (Black Archives) at FAMU. Creating accurate 3D models of the artifacts allows the artifacts to be displayed on the Internet for greater access as well as possible replication of the artifacts for display while preserving the originals.

The models will be created from the artifacts by scanning them using photogrammetry. Photogrammetry re-creates 3D scenes by analyzing photographs of the scene. The photographs will be taken of the artifacts by passing them through a frame with cameras that will capture the entire surface area of the artifact. The images will then have a difference image applied which will eliminate the background and only display the artifact. Photogrammetry software will create a point cloud from the collection of images. Mesh modeling software will create a solid surface from the point cloud and generate a texture map from the images. VBScript will be used to automate the steps of each program in the software suite.

The team has been working on getting the exact dimensions that would fit all of the hardware and allow the cameras to only have a green view. The main concern is to make the box big enough for the artifacts and have the acrylic sheet big enough to fit on the rollers. The problem was solved by finding a larger acrylic sheet to fit. Once the frame has been assembled, tests will be implemented to see the distance and quality of pictures before ordering more. The distance the camera will take pictures at will also factor into the dimension of our box. Some other problems that are being working on are the type of lights being used. The lights have to be bright, small, and cheap in order to work with the design. LEDs were selected because cheap rolls of them were found and they will provide enough light for the entire box. The script that will run through each necessary software is almost complete at this point.

1.3 Operating Environment

There is not a concern for weather because the end product will be kept indoors under room temperature. Since this will be stored in an Historical Museum, the conditions they have to preserve the artifacts should be suitable for this product. The structure is made out of PVC and should be stable as long as people do not pull on it. If there are any breaks it should be very easy and cheap to replace the broken PVC. Inside the arch will be heated due to the lights but, should not affect the cultural artifacts.

1.4 Intended Use(s) and Intended User(s)

The primary use of the device includes scanning 3 dimensional objects to produce photo-realistic re-creations of the objects. This device is intended to create models with centimeter precision or better. While the device is intended to scan artifacts it has the potential to scan a wide array of objects outside of this scope. This device is not intended to scan live or moving objects as photogrammetry will fail to generate points in the 3D space if the objects move.

The primary users of the device will be computer literate workers with minimal training. While many of the tasks will be automated, some of the tasks will have to be completed by hand. These manual tasks do not require a high degree of education, but at a minimum a technical capacity to use a personal computer and follow guided instructions.

1.5 Assumptions and Limitations

Assumptions: The best background color is green and will be used for a difference layer. One camera will be used to capture the entire surface area by moving it around the object. Non-rigid objects will be placed on an acrylic surface that will be lifted through the scanner. A single computer will be used to capture input from the camera as well as process the image data into a 3D model. A new implementation of the rail will assume the length of the box will be long enough to fit. This is used for the acrylic sheet in order for smaller object to be scanned through as the user requested.

Limitations: The final product will not exceed 5’x5’x4’. The change in size is due to the new rail and new acrylic sheet. The scanned objects cannot exceed 3’ in width (though length can potentially be unlimited given enough memory storage and processing power) so as to give the cameras enough standoff to capture the entire surface with some overlap. The cost to produce the final scanner should not exceed $1000. The device should not be used outside or where there is excessive amounts of light interference.

1.6 Expected End Product and Other Deliverables

Scanner: A 5’x5’x4’ box frame containing a camera as well as a PC for control and diffused lighting.

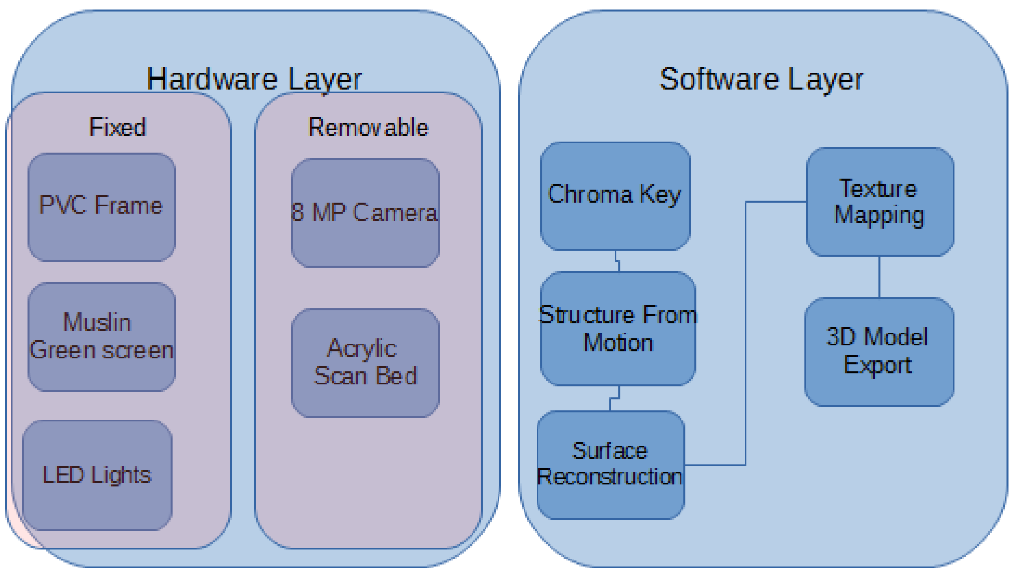
Assembly instructions: The scanner's construction may be simple to disassemble and reassemble with guided instruction to encourage portability.

User Manual: The operation of the scanner will not be complicated but there are several steps that should be followed in a particular order. This manual may be in video form or short animations.

3D models/animations: 10 artifacts will be scanned to produce 3D models. Given sufficient time, animations will be created for each model that may be used for educational purposes.

2 System Design

2.1 Overview of the System



The major physical components of the system will be a PVC frame, muslin green screens, LED light strips, and a digital camera. An acrylic scan bed can be used to scan small non-rigid objects. The PVC frame is generally cube shaped and approximately 5'x5'x4' to accommodate objects up to 3' wide. The muslin sheets are 5'x10' and can cover 2 sides of the cube each. The LED light strips are 16' and can encircle ¾ of the interior of the cube with some overlap on the bottom. The digital camera will be an 8.1 mega-pixel point and shoot camera. The acrylic scan bed will be 24"x48"x0.22" and can be mounted on the middle PVC beams.

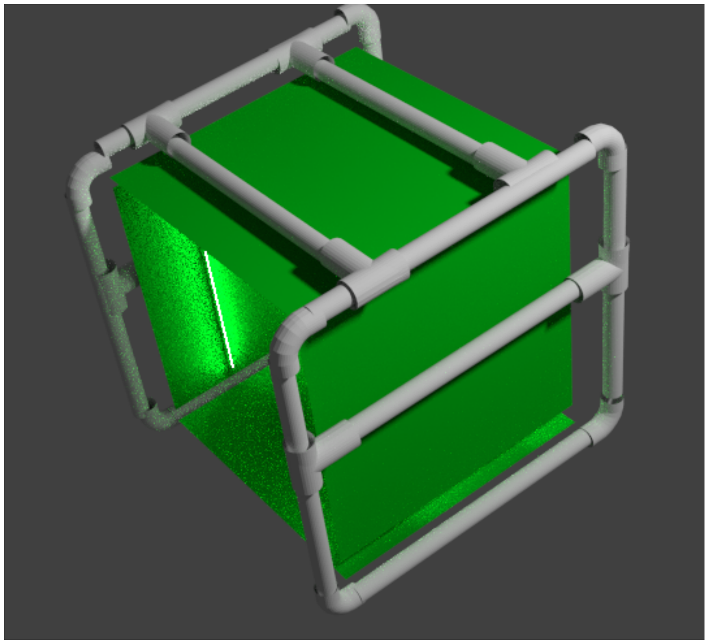


Figure 2.0: A 3-D model of the scanner created in Blender

The software components of the system include five steps to produce a 3D mesh. The first step after collecting the images is to chroma key the images to remove the background from the object. The next step is to use structure from motion to create a point cloud based on the overlapping images. The third step is to reconstruct the surface by converting the point cloud into polygonal surfaces. The fourth step is to map a texture file produced from portions of the captured images onto the new polygonal surface. The final step is to export the 3D mesh data to a useful format.

2.2 Major Components of the System

2.2.1 Hardware

Frame:

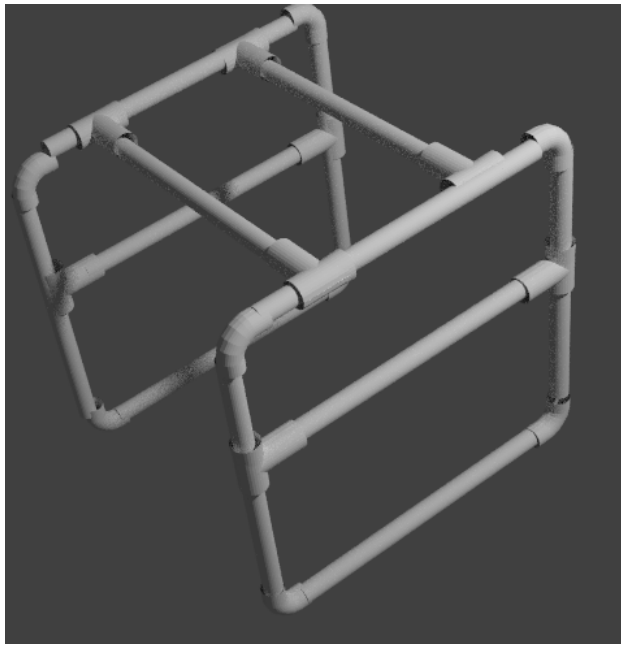


Figure 2.1: 3-D model of scanner skeleton made in Blender

Light strips and muslin:

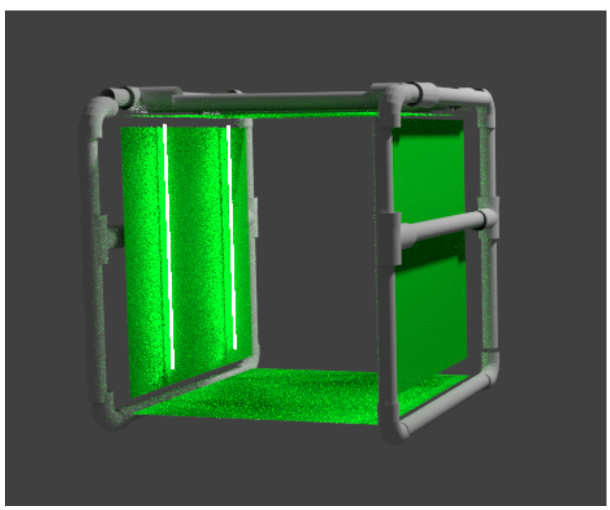


Figure 2.2: 3-D model of scanner with chromakey green background and LED strip lights made in Blender

3 LED strips will be spaced at ⅓ and ⅔ of the length of the cube. The Muslin will cover the entire interior of the cube.

2.2.1 Software

2.2.1.1 Chroma - key

Blender:

Figure 2.3: Chromakeying a subject from the background in Blender

Blender can chroma key a sequence of images and export them with the background removed, this will reduce the number of undesirable matches found in structure from motion algorithms.

GIMP:

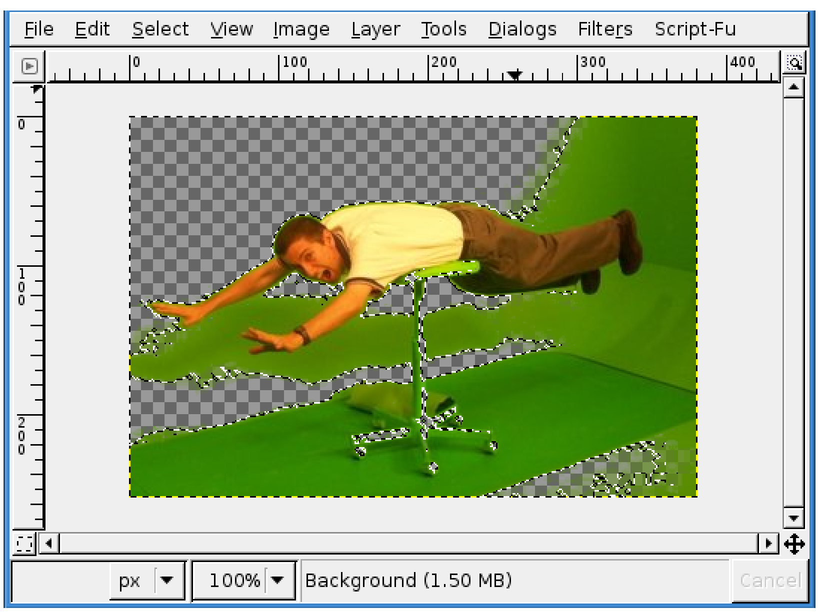


Figure 2.4: Chromakeying a subject from the background in GIMP

GIMP can select portions of an image by a color range and remove them. This is slightly different from how blender handles this in that it does not alter parts of the image that are not within the color range.

2.2.1.2 Structure from motion (SFM)

VisualSFM

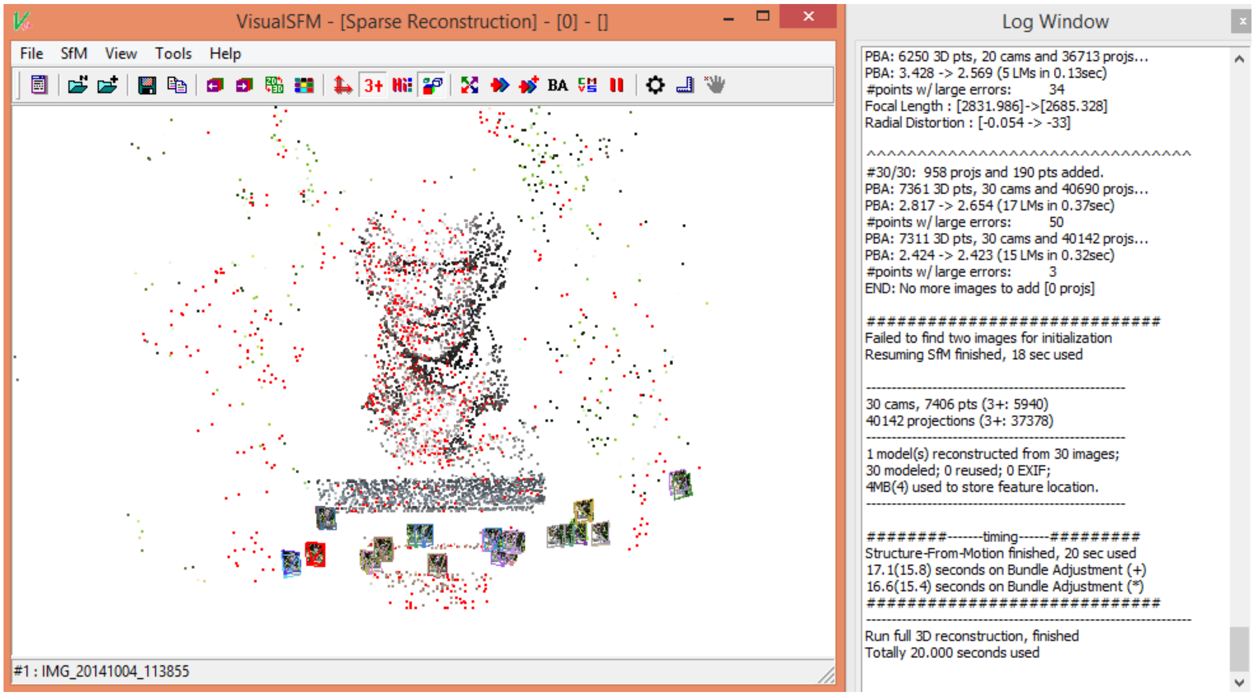


Figure 2.5: Point Cloud Reconstruction in VisualSFM

VisualSFM attempts to produce a point cloud from images as well as the angle and distance that the original photo was taken with respect to the point cloud. The latter data is used in creating a texture map in a later step.

2.2.1.3 Surface Reconstruction

MeshLab

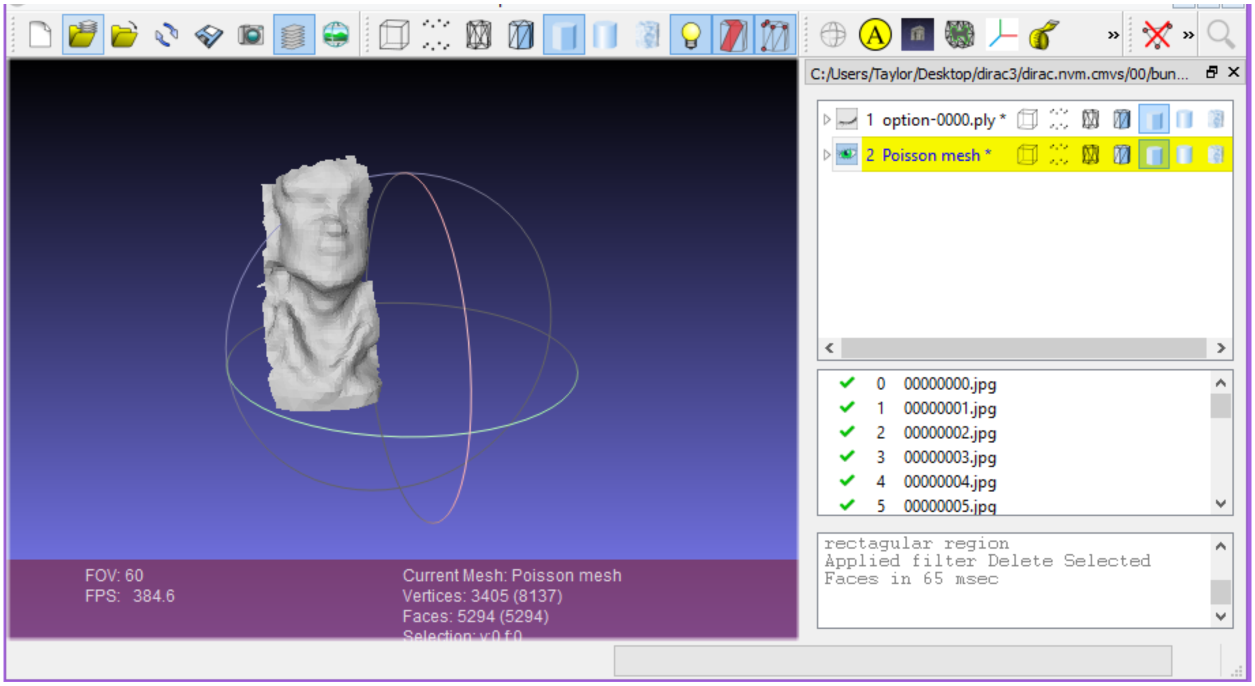


Figure 2.6: Creating a solid mesh in MeshLab

MeshLab can be used to eliminate undesirable vertices and create polygonal surfaces from the point cloud

2.2.1.4 Texture Map

Meshlab

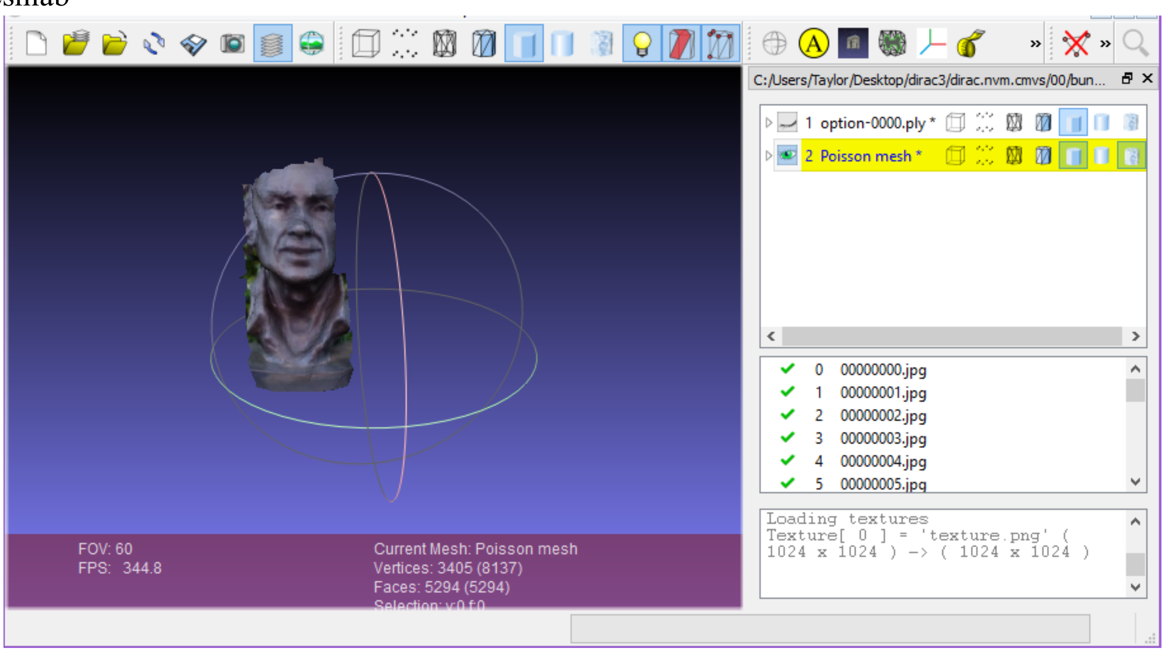


Figure 2.7: Adding texture to the mesh in MeshLab

MeshLab can use data from VisualSFM to produce a texture map based on the angles and distances of the original photos to produce a photo-realistic 3D model

2.2.1.5 Export Format

Blender

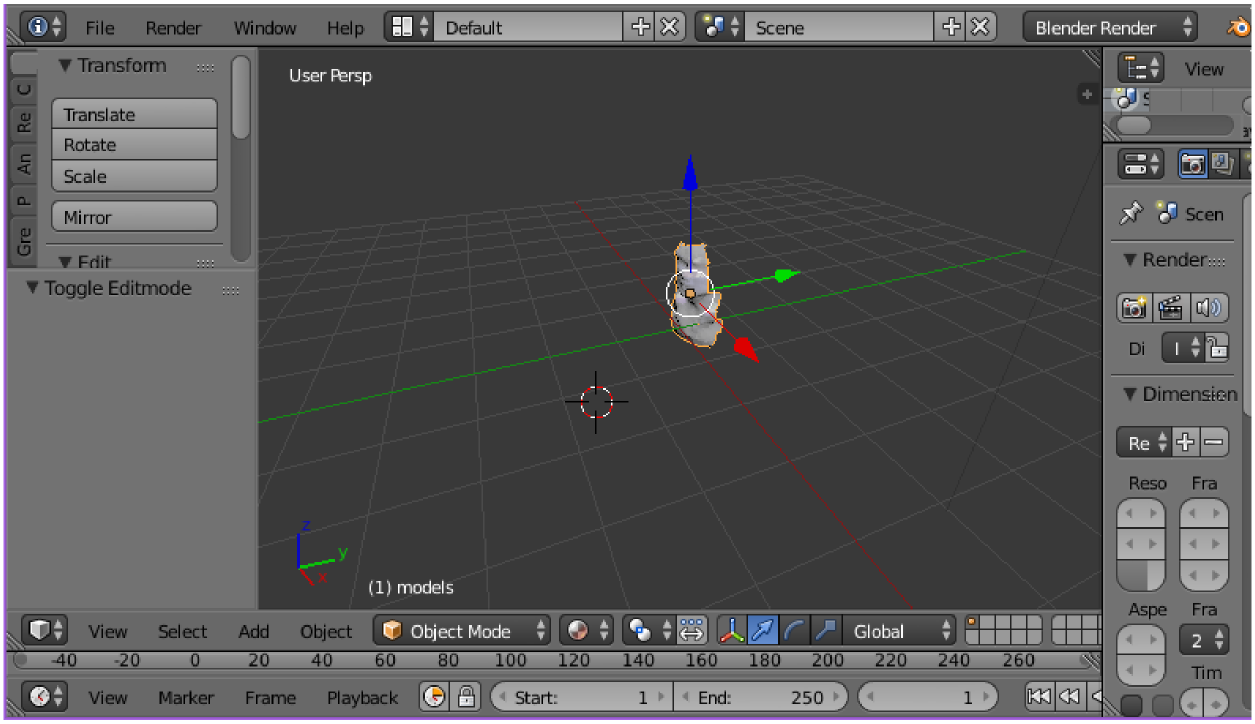


Figure 2.8: Exporting mesh into Blender

Blender can export the model to other useful formats. Blender can use the model in an animation which can then be exported to video format.

2.3 Subsystem Requirements

2.3.1 Structure Requirements Specifications

Frame Components:

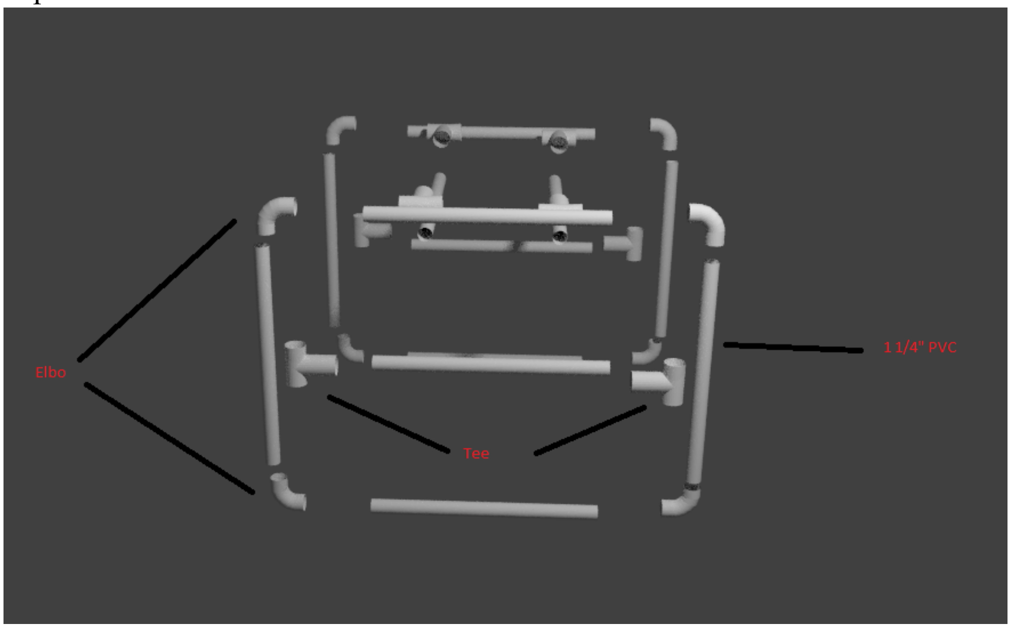


Figure 2.9: Pipe and joint arrangement for scanner skeleton made in Blender

Entire frame consists of 8 Elbows, 8 Tees, and 12 tubes (5’). The Frame is made of 1¼”PVC cut to 5’ sections.

2.3.2 Bed Requirements Specifications

2 x 4 ft Acrylic Bed

For smaller artifacts that need to be placed in the middle of the device for best lighting and picture quality, a bed will be used to keep the object within the center of the scanner in both the vertical and horizontal direction. Acrylic sheets were chosen because it is very transparent, light in weight, and strong. Another option was plexiglass, but since acrylic was plastic, it would reduce the risk of breaking and harming the artifacts. The bed is 2 feet wide and 4 feet long. This size will allow small and medium size object to be passed through the scanner easily.

Table 2.1: Acrylic Bed Requirement and Specification

Dimensions (ft)	2 x 4
Thickness (in)	0.22

2.3.3 Cover Requirements Specifications

LimoStudio 5 x 10 ft Chromakey Green Muslin

The final product of the 3-D model has to be a solid figure floating in space. There cannot be any random points floating around the solid figure and the fragments of the background seen in the final product. Therefore, the background has to be properly removed before the point cloud development. The method of choice is using difference layers, but the software needs to easily distinguish the background from the object of interest.

Chroma keying is a technique for compositing two images together based on the color hues. Using a green screen muslin can allow the software to easily detect and remove the background without manual editing.

Table 2.2: LimoStudio Chromakey Green Muslin Requirement and Specification

Dimensions (ft)	5 x 10
Material	polyester fabric
Characteristics	Non-gloss surface Lightweight and wrinkle-resistant

2.3.4 Lighting Requirement Specifications

LEDLIGHTWORLD SMD 3528-300 Flexible LED Strips

When collecting data (images) of the artifacts to create the 3D- model, the device must provide its own light source that illuminates the object evenly at every angle with little to no shadows. This can be accomplished using soft light sources or hard light sources with diffusers; however, due to the artifacts sensitivity to temperature, lighting that produces heat in the form of infrared, which can damage fragile objects and fabric. LED light sources do not disperse heat into infrared. They are also cheap and easy to find, therefore, this is the preferred choice.

The LEDLIGHTWORLD Flexible LED Strip Lights use 3528 Surface-Mount-Device (SMD) LEDs. These LED chips have the dimensions of 3.5 [mm] by 2.8 [mm] and a brightness of 5 lm. The LED chips are placed on printed-circuit board (PCB) strip. Per three LED chips, a current limiting resistor is placed to prevent large amounts of power from running through the LED components. Cut markings are available every three chips which provide size adjustments without damaging the rest of the strip. The switching cycle of the LED strip is 25 000 meaning this is the number of times the lights can be turned on and off before burning out due to the rapid heating of the electrodes needed to produce light.

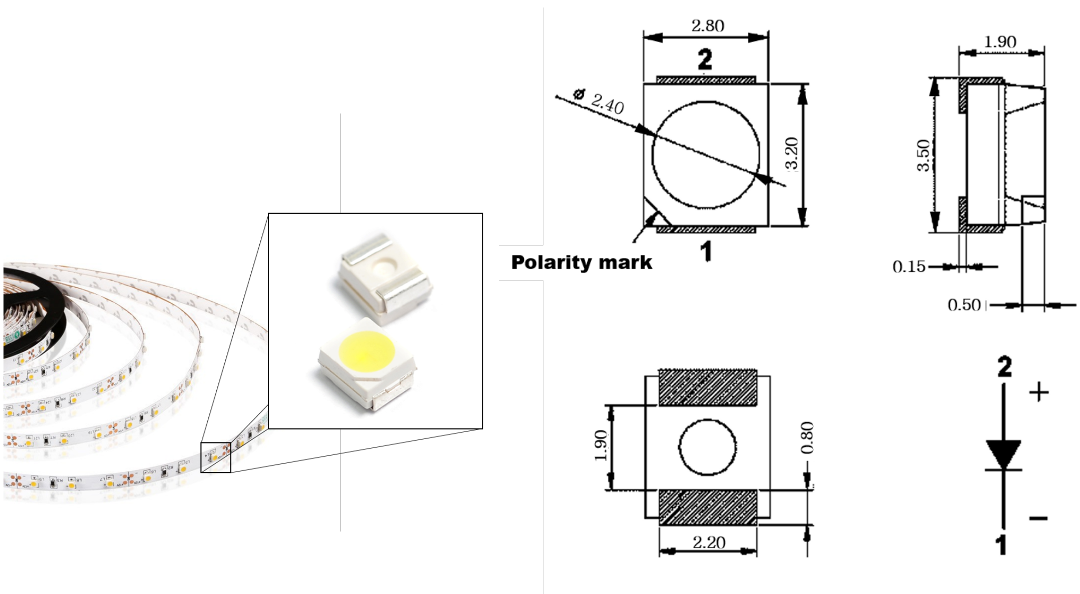


Figure 2.10: The 3528 SMD LED Chips Dimensions

The light source’s color temperature is the relationship of its hue to the light radiated from an ideal black-body radiator (i.e. the sun). Color temperature is usually measured in Kelvin and range from red to blue. Light sources stated to have a color temperature over 5,000 K with consist of a bluish white hue while temperatures below 3,000 K gives off a yellow-ish red tint. To obtain the most natural color of the object being photographed, the lighting temperature must be as close to the light provided by average midday sunlight. This ranges from 5,500 to 6,000 K depending on the supplier. Based on this information, the color option chosen for the LED lights was “pure white” which is a color temperature of 5,500 to 6,500.

Table 2.3: LEDLIGHTWORLD Flexible LED Strip Lights Requirement and Specification

Length (cm)(ft)	500 (16.4)
Quantity of LEDs	300 (60 per meter)
Voltage (V DC)	12

Power (W/m)	4.8
Lumen Output (lm/ft)	118
Color	Pure White
Color Temperature (K)	5,500-6,500
Beam Angle	120°
Wiring	One end solder with 20cm 2 color lead wire
Accessory	Double Sided Adhesive Backing
Dim Type	PWM dimmable

2.3.5 Camera Requirement Specification

The camera will be an 8 mega pixel digital camera. The specification of 8 megapixels should not be reached by "interpolation" or software enhancement. These techniques do not add any useful data to the images though they do cause the images to take up more space. Mechanical zoom is not a requirement as long as the focal length and depth of field are close to 3' to 5'. The ability to trigger the shutter from a computer is desirable but not required.

2.3.6 3-D Image Construction Software Requirement Specification

Blender will be to eliminate the background from the object of interest in the photographs. Its exported files are compatible with Visual SFM and MeshLab. It is also a free open source software.

Visual SFM is a graphic user interface that creates a 3D point cloud from a group of images that the user selects. It is free in cost, and it is an open source software which mean anyone can repair any bugs that it might have. Since this is widely used there shouldn't be any major bugs, but if there are the user should download a new version or the same version. If the map does not look correct the user will have to run the test again making sure the pictures are not blurred and the image is well placed in the lighting.

MeshLab is used for processing and editing meshes that were created using VisualSFM. They provide different cleaning filters, re-meshing filters, colorization, and more to enhance the 3D image. It is also a free open source software.

Table 2.4: Visual SFM Requirement and Specification

Recommended GPU Brands	ATI, nVidia, Intel
Minimum GPU Memory Size (GB)	1

Table 2.5: Blender Requirement and Specification

Minimum CPU	32-bit dual core 2Ghz CPU with SSE2 support
Minimum Physical Memory (GB)	2
Operational Requirements	Mouse or trackpad
Minimum Screen Resolution	24 bits 1280×768 display
Minimum GPU	OpenGL-compatible graphics card with 256 MB RAM

2.3.7 Graphic User Interface Requirement Specification

The GUI will have intuitive instructions that guide the user through the steps necessary to create a 3D mesh. The GUI will interact with the operator to obtain relevant information such as the working directory and which step to process. Then the GUI will invoke the software process based on the user input.

2.4 Performance Assessment

The user will be able to place an artifact in the scanner and with very little technical knowledge be able to rendered a 3D mesh object. Due to the user interface, the user has control in proceeding through and redoing the steps without having to learn the tools in the software programs. The product can then be uploaded online for public access. The data saved throughout the 3-D image construction process can also produce other products such as videos and interactive learning activities with the use of animation software.

2.5 Design Process

The shape of the frame has been modified to be a cube rather than an arch. This change will allow for a more simple construction process and have minimal detrimental impact. The number of LED light strips has been reduced from 4 to 2 with a single color rather than 2 colors. This should not greatly impact the light output and more lights can be added if this change does have a negative impact. The number of cameras has been reduced from 13 to 1. The cost of cameras with a high enough quality to produce a usable result was too high for 13 cameras. For now the design has been modified to allow for a single high quality camera that will move around the object to obtain the same amount of images that 13 cameras would have. The only negative impacts of this change is that the capture process will take significantly longer and more manual operation is required. The scan bed will no longer slide along rails and will instead be centered in the frame while the camera rotates around the object. This change will allow for a more uniform lighting pattern.

2.6 Overall Risk Assessment

2.6.1 Administrate Risks

This project is going to be broken up into separate task for the individual team members and the final product is going to be divided up into smaller results with earlier deadlines. With this, there can be risks of falling behind of the schedule of construction and not meeting our final deadline due to the failure of members meeting their deadlines, exceeding the maximum budget for the necessary parts for the design proposed, and not meeting the requirements of the project.

2.6.2 Failure of Meeting Deadlines

Each member is assigned a task needed for every deadline, and some of these task are independent from another while others are not. If a team member does not meet their deadline when expected, the project is as risk of being set back. If the task that was not completed is needed for another task to be finished, this can prevent a further stall in the project's progression while preventing other team members from starting or finishing their tasks. To prevent this issue from happening, a member that is ahead of schedule with their assignments and is working on an independent task could take up assist or take up the unfinished task, so the project can continue to progress.

2.6.3 Exceeding Maximum Budget

The maximum budget for this project is $1000. This customer designs the entire work station including the ios system to be included in this budget. Although, the budget will be estimated by the financial advisor throughout the project's progression, components may not meet expectations needed for the design, or broken materials during testing may not be able to be fixed but only replaced. These conditions can lead to exceeding the budget which can lead to altering parts of the design to lower cost and less efficient material to continue the project. The need to redesign the device with the alterations could lead to a great standstill in production. Unfortunately, some scenarios which could lead to this cannot be assumed, therefore, prevented; however, the processes of purchasing components will not be in bulks. If multiple of the same component is needed for the design, a sample will be purchased first and tested before buying additional ones, so if the considered material is faulty, less money is wasted.

2.6.4 Poor Photograph Collecting

For close-range photogrammetry, the camera, lens, and placement are crucial when achieving a high definition 3D model. The minimum resolution requirement should be at least 8 Megapixels. Using a camera with a lower resolution can lead to distorted mesh models and poorly detailed textures. [2].

The depth of field (DOF) is the distance between the nearest and furthest object in view that appears to be the sharpest. While collecting photos of the object of interest, the entire object must remain within this field; therefore, the camera focus ring must remain in consistent range and the aperture setting of the camera (if applicable) must be between f8 and f16, or some parts of the object will come out blurry. Blurry photos can lead to a fairly low number of auto-correlated points which cannot be reconstructed. Since the photos will be captured from less than 5 meters, autofocus can be used for all the images taken, so this is not a severe concern. A wired or wireless shutter release is also needed to minimize blur. To achieve the greatest number of auto-correlated points, photos must maintain a 60% to 80% overlap, and all import areas of the object must be visual in at least three images [2].

2.6.5 Artifact Handling Risks

The objects of interest are historical artifacts that comes from the years of slavery in America, so they are roughly 400 – 600 years old. These relics are fragile and can be damaged by moisture, sunlight, temperature, and careless handling. When handling these objects, the handler must wear gloves since the natural oils from a person's hands can damage the artifact. Tweezers and Q tips are required to manipulate the rigid objects (i.e. dolls, rags, books) when collecting data. Since the artifacts are located in the Black Archives Museum at FAMU, the museum would prefer to personally transport the objects to the college of engineering and back. It will become essential to give the museum director weeks' notice to prevent delays in the deliveries; also, there is a chance of damaging the artifacts during the transportation. As a solution, part of a media room is going to be reserved for this project on the top floor of the museum when data collecting; therefore, the team has more control on accessing the objects, and the artifacts won't be manipulated as much.

3 Design of Major Components

3.1 Frame

3.1.1 Frame Design

The frame will consist of 2 walls with connecting beams across the top. The walls will be constructed of 1¼" PVC as well as elbow and tee connectors.

3.1.2 Frame Technical Risk

3.1.2.1 Unstable Frame

The device is going to be shaped as box. PVC pipes will be the material used to create the frame skeleton since PVC pipes are inexpensive and versatile. Using PVC pipes with too small of a diameter have a higher risk of breakage. The sides, which will hold the weight of the lights and muslin, cannot bend or the frame will collapse; therefore, there is a range of diameter sizes that can be supportive enough to construct the desired frame.

3.2 Bed

3.2.1 Bed Design

As stated the bed will be acrylic and used to smaller objects to be easily scanned. Tanning beds for example sometimes use them to allow people to lay on while letting light through.

The bed will use a steel railing for holding it in the vertical center of the scanner. There will be one rail on each side of the frame, and the bed will be placed high enough for the camera to be easily positioned low enough to capture the bottom of the object yet high enough for the camera to capture the top. The railing will be covered in green to match the color of the screen. That is a very important step to eliminate it from the construction of the artifact.

3.2.2 Bed Technical Risk

3.2.2.1 Scratches

Acrylic is highly prone to getting scratched. These scratches could cause image distortion in the photographs such as blurriness or object displacement where light passes through the scratched surface. For scratch prevention, the users must be careful placing and removing the bed from rails and use acyclic-safe cleansers and scrubbers to remove debris. If scratches appear on the surface of the bed, they can be easily buffed out with sandpaper and polishers.

Figure 3.1: Severely Scratched Acrylic

3.3 Cover

3.3.1 Cover Design

The green screen will line the interior of the box including the bottom. The loops help with portability since they can be detached and fasten removing without damaging the cover. The dimensions of the muslin will be exactly the same as the frame, so it can be slightly stretched when tied reducing the amount of wrinkles that could affect the removal of the background during the photo editing.

3.3.2 Cover Technical Risk

3.3.2.1 Color Spill

Color spill occurs when the color reflects off the back screen and casts a noticeable tint on your subject. Certain areas of the object's surface absorb or reflect that color, which is typically blue or green due to chromakey screens. If the lighting is too bright, the chances of color spill are increased. To minimize this risk, a non-reflective back chromakey screen such as a fabric with a foam back should be used since the foam absorbs light, which cuts down the reflection on the object of interest. Another prevention is having the object as far away from the background as possible. The recommended distance is 8 to 10 feet, however, this cannot be accomplished with the dimensions of the frame.

3.4 Lighting

3.4.1 Lighting Design

Three strips will run vertically along the tunnel of the device starting from the base up the frame along the ceiling and to the base of the frame on the opposite side. The two outer strips will be 0.5 feet inward from the edges, and the third will be approximately 2 feet apart from the others. The lights will remain on while the device is active rather than turn on and off when needed for the snapshots because this will reduce the switching cycles of the LEDs, therefore, prolonging the lifespan.

3.4.2 Lighting Technical Risk

3.4.2.1 Inconsistent Exposure

Illustrated in the figure below, the LED diode types range in brightness. The strips using 3528 chips were chosen due to their low cost compared to the other strips using 5050 and 5630 chips. The trade-off, however, is having radius of the light being short. If the dimension of the frame is too large for the LED lights to overlap their output, there will be sharp shadows cast by the object being scanned. If this is an issue after testing, the number of strips could be increased, or new LED strip lights using chips with higher brightness per meter need to be considered.

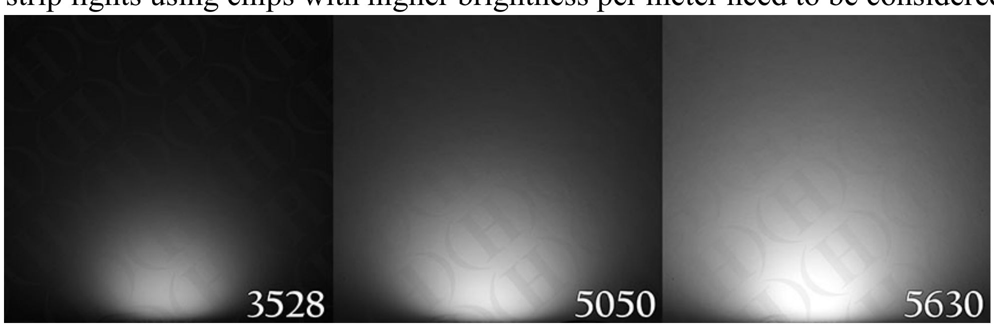


Figure 3.2: Brightness comparison between different LED SMD diodes

3.5 Camera

3.5.1 Camera Design

The single camera will rotate around the object capturing images at no more than 45° intervals. The rotation will then repeat above and below the object with the same intervals. This will allow for maximum overlap between images.

3.5.2 Camera Technical risk

3.5.2.1 Unstable Capture

manual operation of the camera increases the risk that the camera will not be stabilized at the time of the capture. This may lead to motion blur our out of focus shots.

3.6 Software/User Interface

3.6.1 Software/User Interface Design

The software required includes Blender, GIMP, VisualSFM, and Meshlab as well as a script that will provide a user interface to the aforementioned applications. Blender or GIMP will be used to remove the background from each image which will reduce the artifacts that might be produced in the point cloud. VisualSFM will be used to generate a point cloud from the captured images as well as a list of images and their data with respect to direction and distance of capture. Meshlab will produce a polygonal surface from the point cloud as well as generate a texture map from the list of images produced by VisualSFM.

3.6.2 Software/User Interface Technical Risk

3.6.2.1 VisualSFM Hardware Requirements

VisualSFM is a crucial program to this project design because it converts the photographs into a dense reconstructed cloud that can be used to create the mesh. The software requirements need to be met for the optimal results. The SiftGPU feature detection used by VisualSFM is responsible for point matching. This feature requires a large amount of GPU memory (minimum of 1 GB). If the GPU memory is too small, the results will have less features leading to different results on different machines.

4 Test Plan

In order to prevent future malfunctions for the intended user, there will be a series of test that will be carried out. Each one of them will have a form that will need to be fill to state that the task was met to the required specifications. Although there has been thorough planning time, since this is the beginning of the building phase there might be little modifications if some of the tests fail.

4.1 System and Integration Test Plan

4.1.1 Scanning of Small Objects

Test Reporting Form

Item Names:	Frame, Lighting, Camera, Muslin, acrylic integration
Tester Name:	
Test Date:	
Test Time:	
Test Location:	College of Engineering Lab
Tester ID No:	
Test No:	
Test Result:	Not Tested
Notes/Comments:	

Test Objective:
An integrated test that will ensure that small objects such as dolls and chains are able to be scanned by a complete system.

Test Description/Requirements:
Requirements:
1. Frame must be assembled
2. Lighting must be attached to frame
3. Muslin attached to frame
4. Acrylic Bed is situated inside frame
5. Camera is able to take quality pictures

Process:

The object will be placed on the acrylic bed with the lights and muslin in place and operating. The camera will then take pictures at intervals determined through previous testing. The images will then be sent to a computer to be processed by the script and form the 3D model.

Anticipated Results:

All component will integrate properly after going through individual component tests and the object will be digitized.

Requirement for Success:
3D model should not have any distorting effects such as background texture mixing with object texture and has no distortions in the 3D mesh.

Actual Results:
TBA

Reason for Failure:
TBA

Recommended Fix:
TBA

4.1.2 Scanning of Large Objects

Test Reporting Form

Item Names:	Frame, Lighting, Camera, Muslin, integration
Tester Name:	
Test Date:	
Test Time:	
Test Location:	College of Engineering Lab
Tester ID No:	
Test No:	
Test Result:	Not Tested
Notes/Comments:	

Test Objective:
An integrated test that will ensure that large objects such as beds and chairs are able to be scanned by a the system without the acrylic bed.

Test Description/Requirements:
<u>Requirements:</u>
1. Frame must be assembled

2. Lighting must be attached to frame
3. Muslin attached to frame
4. Camera is able to take quality pictures

<u>Process:</u>

The object will be placed inside the frame with the lights and muslin in place and operating. The camera will then take pictures at intervals determined through previous testing. If the intervals are unable to capture the complete object, then the object will be shift and the camera will take pictures at the intervals again until the entire object has been scanned. The images will then be sent to a computer to be processed by the script and form the 3D model.

Anticipated Results:

All component will integrate properly after going through individual component tests and the object will be digitized.

Requirement for Success:
3D model should not have any distorting effects such as background texture mixing with object texture and has no distortions in the 3D mesh.

Actual Results:
TBA

Reason for Failure:
TBA

Recommended Fix:
TBA

The main design concern is whether all of the components will work together to form a functioning system to create 3D images. To do this there will be tests over each part while it is being assembled and an overall check for the user's approval. For hardware the frame, acrylic bed, muslin, lighting and camera will be checked. Since all of the software is already provided the only code that needs checking would be the script. Below lists the items and test plan in more detail.

4.2 Test Plan for Major Components

4.2.1 Frame

Test Reporting Form

Item Names:	PVC Pipes and Joints
Tester Name:	
Test Date:	
Test Time:	
Test Location:	College of Engineering Lab
Tester ID No:	
Test No:	
Test Result:	Not Tested
Notes/Comments:	

Test Objective:

The frame is one of the first items that will be tested. It needs to be stable to put the required hardware to take quality pictures.

Test Description/Requirements:

Requirements:

1. Frame must be assembled
2. Measuring tape
3. Mallet

Process:

There will be measurements to make sure that the lengths are even for stability. Assemble using a mallet to ensure fittings are snug. Mount all hardware to frame and ensure there is minimal sagging and the frame does not collapse.

Anticipated Results:

The frame will successfully hold all of the hardware.

Requirement for Success:

Actual Results:
TBA

Reason for Failure:
TBA

Recommended Fix:

4.2.2 Acrylic Bed

Test Reporting Form

Item Name:	Acrylic Glass Sheets
Tester Name:	
Test Date:	
Test Time:	
Test Location:	College of Engineering Lab
Tester ID No:	
Test No:	1
Test Result:	Not Tested
Notes/Comments:	

Test Objective:
The test objective is to determine if the refraction of light passing through the acrylic bed distort the object enough that will affect the point cloud construction with bad image data.

Test Description/Requirements:

Requirements:
1. A well lit room
2. Handheld High Resolution Camera
3. Frame needs to be assembled
4. Rails need to be installed for holding the acrylic bed
5. A small enough object that needs to use the bed for scanning

Process:
In a well lit room, the framed should be assembled and rails installed. To avoid scratching the surface, the acrylic bed needs to be carefully placed on the mount at the center of the scanner for easy access when taking photographs. Place the small object in the center of the bed.

With the handheld high resolution camera, manually take photographs at different angles of the object using the recommended technique for proper data collecting. Take the photographs underneath the object with the same method.

Upload the photographs on the computer and begin the point cloud reconstruction process in VisualSFM. Record the success or failure based on the pictures taking through the acrylic bed.

Anticipated Results:
If the photographs taken below the object receive an red X during the process, VisualSFM is having difficulties determining the distance and angle in which the photographs were taken; therefore, these photographs are unusable. Otherwise, these photographs will not negatively affect the outcome of the point cloud.

Requirement for Success:
When taking photographs are taken through the acrylic medium, the object maybe be displaced; however, the size and colors will not be distorted. This may be enough to have a successful point cloud reconstruction.

Actual Results:
TBA

Reason for Failure:
TBA

4.2.3 Software

Test Reporting Form

Item Name:	VBScript - Scripting
Tester Name:	
Test Date:	

Test Time:	
Test Location:	College of Engineering Lab
Tester ID No:	
Test No:	1
Test Result:	Not Tested
Notes/Comments:	

Test Objective:

Make sure the script run not only runs though each of the programs but activates the correct functions flawlessly. Test that either Blender or GIMP removed the green background completely. Check if VisualSFM created an accurate point cloud representation with the photos. Open MeshLab file and make sure there are not any strange objects that might have been reconstructed too. Finally, make sure the 3D image is an acceptable representation for the user.

Test Description/Requirements:

Requirements:

1. Starts
2. Runs though programs
3. Activates correct functions in each software
4. Provides an end product suitable to the user's standard

Process:

The first step would be to run the script and to see if the end product contains errors. If so, the only way to test if the script works is to check each file that was created in the software. Then the last step would try to run it under any harsh conditions to see if there are constraints that might occur. This could mean needing to activate some functions sooner and/or delaying others.

Anticipated Results:

Requirement for Success:

Actual Results:
TBA

Reason for Failure:
TBA

4.2.4 Lighting

Test Reporting Form

Item Name:	3528 Flexible LED Strip Lights
Tester Name:	
Test Date:	
Test Time:	
Test Location:	College of Engineering Lab/Outdoors
Tester ID No:	
Test No:	1
Test Result:	Not Tested
Notes/Comments:	

Test Objective:

The objective test is to determine how the LEDs' color temperature (hue) affects the object's natural color.

Test Description/Requirements:
Requirements:
1. Handheld High Resolution Camera
2. Portable test object
3. Photograph taken of the test object outside during a sunny midday for comparison
4. Photograph editing software

Process:

Take photographs of the test object outside (preferably against a white wall) during the middle of the day when the sunlight does not produce a reddish or bluish hue. Pick the clearest photographs.

In an unlit room, set up the test object against a white wall with the LED strip lights adjusted so the light is dispersed evenly against the object's surface. Take shots of the object at the same angle as the one taken outside and pick the clearest photographs.

On a photo editing software, compare the two photographs. If the photos taken inside seemed distinguishably discolored, adjust the temperature option to see if the colors of the photographs taken outside and inside have similar hues.

Anticipated Results:

The object's colors will be similar (but not exact) in the indoor and outdoor photographs.

Requirement for Success:
Using LED lights that has a color temperature range between 5,500 to 6,000 K as this is the recommend color temperature for light sources to mimic midday daylight.

Actual Results:
TBA

Reason for Failure:
TBA

Recommended Fix:
If increasing the red hue in the indoor photographs increases the similarity in color to the outdoor photographs, the color temperature of the LED lights should be lower, and if the increasing the bluish hue in the indoor photographs improves the color of the object, the color temperature of the LED lights should be higher.

Test Reporting Form

Item Name:	3528 Flexible LED Strip Lights
Tester Name:	
Test Date:	
Test Time:	
Test Location:	College of Engineering Lab/Outdoors
Tester ID No:	

Test No:	2
Test Result:	Not Tested
Notes/Comments:	

Test Objective:

The test objective is to determine if object receives an even overall light exposure with no or soft shadows at the angles and distance expected for the camera to be positioned on the frame.

Test Description/Requirements:

Requirements

1. The frame needs to be assembled
2. Background muslin should be attached to the frame since LED strips will be attached to the muslin
3. Narrow object that will use not the bed for scanning
4. Clear tape

Process:

When the frame is assembled with the muslin attached, the lights should be taped onto the muslin with the clear tape to mimic the adhesive backing on the LED strips. The LEDs will be approximately 0.5 feet inward from the opening and 2 feet apart from each other.

A tall object is chosen because it'll have a reasonable value of surface area needed to be illuminated and can show the efficiency of lighting from lower placement of lights compared to lights positioned higher. The object is narrow to show how far the brightness of the light reach in the center of the device furthest away from the lights where the small objects will be positioned.

The object should be examined a third of the way inside of the scanner right after the first LED strip. Notes should be taken of the parts of the object that have shadows and the sharpness of these shadows. Adjust the object for optimal light exposure. Reposition the object to be in the middle of the object. Again adjust for optimal light exposure and take notes of the shadows. Finally, reposition the object right before the last LED strip and take notes. The exact position (in feet) should also be recorded of the object when it received the best lighting in each position.

Anticipated Results:

Due to the large number of LED chips in the overall system (900 LED diodes in total), the object will be illuminated thoroughly on its top and middle surfaces, but dimmer on the lower areas due to less overlap of lighting.

Requirement for Success:
Each LED chip must illuminate enough light to overlap with others output.

Actual Results:
TBA

Reason for Failure:
TBA

Recommended Fix:

Readjust LED lights or buy additional strips if needed. Worse case, buy different LED strips that use LED SMD diodes with higher brightness (i.e. 5050 or 5630 as shown in figure)

4.2.5 Chroma Key Background

Test Reporting Form

Item Name:	Chromakey Green Muslin
Tester Name:	
Test Date:	
Test Time:	
Test Location:	College of Engineering Lab
Tester ID No:	
Test No:	1
Test Result:	Not Tested
Notes/Comments:	

Test Objective:
The test objective is to determine if the color of the muslin will be reflected onto the objects known as color spill.

Test Description/Requirements:
Requirements:
1. The frame should to be assembled
2. Background muslin should be attached to the frame and LED strips should be placed onto the muslin using clear tape
3. Test object (preferably light in color)
4. Clear tape

Process:
When the frame is assembled with the muslin attached, the lights should be taped onto the muslin with the clear tape to mimic the adhesive backing on the LED strips. The LEDs will be approximately 0.5 feet inward from the opening and 2 feet apart from each other.

Anticipated Results:
Since the muslin is not glossy and a darker hue of green, its color will not reflect onto the object.

Requirement for Success:
Having a non-reflective light absorbing background. The lights cannot be too bright as this can increase the chances of color spill.

Actual Results:
TBA

Reason for Failure:
TBA

Recommended Fix:
Purchase a non-reflective back chromakey screen such as a fabric with a foam back. The foam absorbs light, which cuts down the reflection on the object of interest.

4.2.6 Camera

Test Reporting Form

Item Name:	Camera - Capture Minimum Angles
Tester Name:	

Test Date:	
Test Time:	
Test Location:	College of Engineering Lab
Tester ID No:	
Test No:	1
Test Result:	Not Tested
Notes/Comments:	

Test Objective:
The test objective is to determine the minimum number of angles that need to be captured to produce a useful result. More angles mean more images required to capture increasing disk space requirements and processing time.

Test Description/Requirements:
Requirements:

1. Object should be centered in scanning system
2. Capture images at 45° intervals
3. Process images and determine if output meets quality standards
4. adjust intervals based on results

Process:
Images captured at 45° intervals are processed through VisualSFM to determine if a point cloud can be generated. If the test fails then the intervals are reduced by half. If the test succeeds the interval will be increased by half. This binary type search will quickly determine the best number of angles.

Anticipated Results:
45° intervals will likely succeed at generating a point cloud

Requirement for Success:
generated point cloud strongly resembles the 3D object

Actual Results:

TBA

Reason for Failure:
TBA

Recommended Fix:
TBA

Test Reporting Form

Item Name:	Camera - Capture Minimum Resolution
Tester Name:	
Test Date:	
Test Time:	
Test Location:	College of Engineering Lab
Tester ID No:	
Test No:	1
Test Result:	Not Tested
Notes/Comments:	

Test Objective:
The test objective is to determine the minimum resolution that needs to be captured to produce a useful result. More pixels mean increased disk space requirements and processing time.

Test Description/Requirements:
Requirements:

5. Object should be centered in scanning system
6. Capture images at 8 Megapixels
7. Process images and determine if output meets quality standards
8. adjust resolution based on results

Process:

Images captured at 8 megapixels are processed through VisualSFM to determine if a point cloud can be generated. If the test fails then the resolution is increased. If the test succeeds the interval will be decreased by half.

Anticipated Results:
8 megapixels will likely succeed at generating a point cloud

Requirement for Success:
generated point cloud strongly resembles the 3D object

Actual Results:
TBA

Reason for Failure:
TBA

Recommended Fix:
TBA

4.3 Summary of Test Plan Status

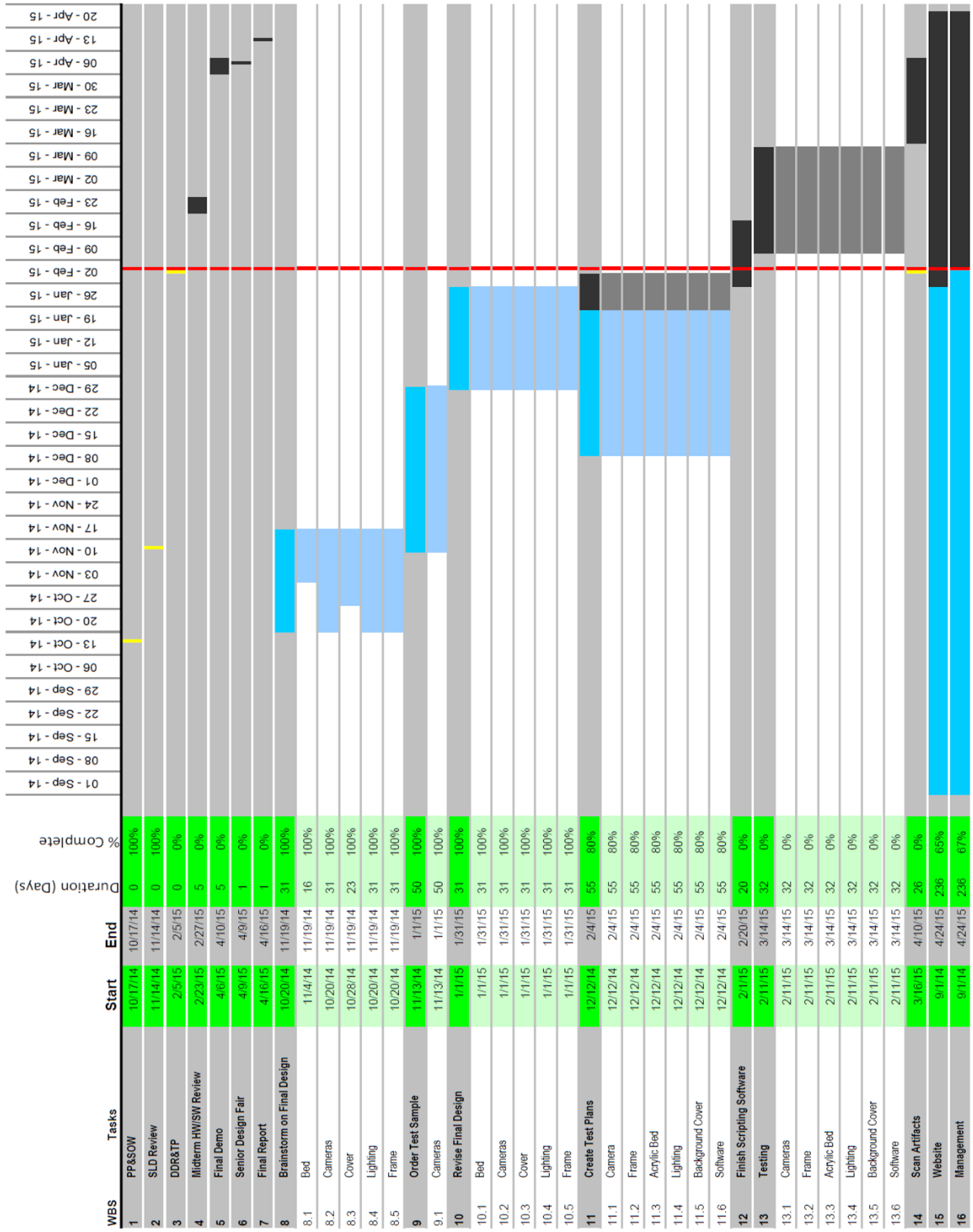
Following a brief description, provide a table that will act as a checklist of all tests given in the test plan. This checklist will allow the manager to indicate the date each test was completed and the result of the test (pass/fail). The table should be organized similar to the test plan you have provided, and allow for multiple attempts of a test in case of failure.

Currently the items are being ordered and shipped. Once they have arrived they will be and the results will be check off the list below.

Test Plan Checklist/Status

	Status	Second Status (if Failure)
Test	Pass/Fail/ Awaiting	Pass/Fail/Awaiting
PVC Frame - Stability	Awaiting	
Acrylic Bed - Image distortion	Awaiting	
LED Strip Lights - Natural Lighting	Awaiting	
LED Strip Lights - Even Exposure	Awaiting	
Software - Compile and User Friendly	Awaiting	
Camera - Capture Minimum Angles	Awaiting	
Camera - Capture Minimum Resolution	Awaiting	
Integration - Scanning of Small Objects	Awaiting	
Integration - Scanning of Large Objects	Awaiting	

5 Schedule



WBS	Tasks	Start	End	Duration (Days)	% Complete
1	PP&SOW	10/17/14	10/17/14	0	100%
2	SLD Review	11/14/14	11/14/14	0	100%
3	DDR&TP	2/5/15	2/5/15	0	0%
4	Midterm HW/SW Review	2/23/15	2/27/15	5	0%
5	Final Demo	4/6/15	4/10/15	5	0%
6	Senior Design Fair	4/9/15	4/9/15	1	0%
7	Final Report	4/16/15	4/16/15	1	0%
8	Brainstorm on Final Design	10/20/14	11/19/14	31	100%
8.1	Bed	11/4/14	11/19/14	16	100%
8.2	Cameras	10/20/14	11/19/14	31	100%
8.3	Cover	10/28/14	11/19/14	23	100%
8.4	Lighting	10/20/14	11/19/14	31	100%
8.5	Frame	10/20/14	11/19/14	31	100%
9	Order Test Sample	11/13/14	1/1/15	50	100%
9.1	Cameras	11/13/14	1/1/15	50	100%
10	Revise Final Design	1/1/15	1/31/15	31	100%
10.1	Bed	1/1/15	1/31/15	31	100%
10.2	Cameras	1/1/15	1/31/15	31	100%
10.3	Cover	1/1/15	1/31/15	31	100%
10.4	Lighting	1/1/15	1/31/15	31	100%
10.5	Frame	1/1/15	1/31/15	31	100%
11	Create Test Plans	12/12/14	2/4/15	55	80%
11.1	Camera	12/12/14	2/4/15	55	80%
11.2	Frame	12/12/14	2/4/15	55	80%
11.3	Acrylic Bed	12/12/14	2/4/15	55	80%
11.4	Lighting	12/12/14	2/4/15	55	80%
11.5	Background Cover	12/12/14	2/4/15	55	80%
11.6	Software	12/12/14	2/4/15	55	80%
12	Finish Scripting Software	2/1/15	2/20/15	20	0%
13	Testing	2/11/15	3/14/15	32	0%
13.1	Cameras	2/11/15	3/14/15	32	0%
13.2	Frame	2/11/15	3/14/15	32	0%
13.3	Acrylic Bed	2/11/15	3/14/15	32	0%
13.4	Lighting	2/11/15	3/14/15	32	0%
13.5	Background Cover	2/11/15	3/14/15	32	0%
13.6	Software	2/11/15	3/14/15	32	0%
14	Scan Artifacts	3/16/15	4/10/15	26	0%
15	Website	9/1/14	4/24/15	236	65%
16	Management	9/1/14	4/24/15	236	67%

Figure 5.1: Gantt Chart showing Milestones, fall schedule, and current spring schedule

Table 5.1: Descriptions of tasks

ID	Task	Description	Completion Status
8	Brainstorm On Final Design	This task requires the whole team to come together to discuss option on how to construct the frame, how the lighting system needs to be set up, how the cameras are placed, and how the bed that artifacts are scanned on is connected to the frame.	100%
9	Order Test Samples	After the brainstorming is complete, the purpose of this task is to order sample parts that will be used in testing the viability of those components. If those components are viable then the remaining parts will be ordered to complete the prototype.	100%
10	Revise Final Design	After discovering that the sample cameras were of an ineffective resolution for image capturing, the team redesign several components in order to reduce cost and efficiency. Components that were changed were the number of cameras, the frame design, and the method for taking photos.	100%
11	Create Test Plans	Test plans are created to test whether or not the system is functioning properly. Test plans are created for the camera, frame, lighting, background cover, software, and functionality as a whole.	100%
12	Finish Scripting Software	The scripting is used to link together all the software that will be used in the process of retrieving the 3D model of the object being scanned.	Not Started
13	Testing	Testing is a phase where the team tests each component according to the test plans created prior.	Not Started
14	Scan Artifacts	This phase is after the testing phase where the team take the prototype to the museum and test the completed system	Not Started
15	Website	The website is a team site that is running on the senior design webspace. It functions according to the guidelines given and will be updated with advanced functionality in the future.	65% ongoing maintenance
16	Management	This task is essentially ensuring that the project is completed on time and within budget.	ongoing

6 Budget Estimate

A. Engineers	Total Hours	Base Pay	Total Pay
Aubrey Tharpe	360	$30.00	$10,800.00
Taylor Wagner	360	$30.00	$10,800.00
Rachelle Dauphin	360	$30.00	$10,800.00
Nicolas Cardenas	360	$30.00	$10,800.00
Total:	-	-	$43,200.00
B. Fringe benefits	-	29% rate of A	$12,528.00
C. Total Personnel Costs	-	-	$55,728.00

D. Expenses				
Item	Distributor	Costs ($)	Quantity	Total ($)
Samsung ES10 8.1MP	Donated by Taylor	0.00	1	$0.00
Acrylic Sheet	Home Depot	57.00	1	57.00
PVC Pipe	Home Depot	$4.49	6	26.94
PVC Elbow	Home Depot	$1.19	8	9.52
PVC Tee	Home Depot	$1.74	8	13.91
Green Screen Muslin 5’ x 10’	Amazon	15.00	2	30.00
LED Strip Lights	LEDLightsWorld	35.95	3	107.85
LED Power Adaptor	LEDLightsWorld	7.90	3	23.70

Computer	Walmart	500.00	1	500.00
Other	-	-	-	150.00
Total Cost:	-	-	-	918.92

7 Conclusion

Overall the design is coming along great. The scanner will be constructed with PVC for the frame generally forming a box. A green screen will be used to assist with removing the background from each image for maximum point autocorrelation. The camera will be strategically placed to capture the entire surface area with at least 60% overlap. An acrylic sheet will be used as a scanning bed for smaller and non-rigid objects that cannot be flipped without changing their shape. The clear colorless sheet should allow for the camera below the sheet to scan the underside of the objects. LED strips will provide an even amount of lighting by being evenly spaced in the box. The captured images will be processed by Blender to eliminate the background from each image. The images will then be processed by VisualSFM to generate a sparse and later a dense 3D point cloud. Meshlab will use the dense 3D point cloud to generate a solid surface as well as use the list.txt of picture files generated by VisualSFM to generate a texture map. Blender will import the .obj file generated by Meshlab where modifications can be made to the object or it can be exported to more desirable formats.

8 References

[1] J.A. Marin, J.E. Armstrong, and J.L. Kays, “Elements of an Optimal Capstone Design Experience,” Journal of Engineering Education, January 1999, pp. 19-22.

[2] Barnes, Adam. 2013. “Good Photos vs. Bad Photos for Close-range Photogrammetry”.*Geospatial Modeling & Visualization*. CAST Technical Publications Series. Number 12144. 7 August 2013. 10 October 2014.

[3] Changchang Wu, “Basic Usage”, *VisualSFM : A Visual Structure from Motion System.* Copyright 2006-2012 Changchang Wu. 08 October 2014.

[4] Changchang Wu, “Limitations and Issues”, *VisualSFM : A Visual Structure from Motion System.* Copyright 2006-2012 Changchang Wu. 08 October 2014.

[5] P. Cignoni and G. Ranzuglia, “Features”, *MeshLab*. Copyright 2014 Dice. All Rights Reserved. SourceForge is a Dice Holdings, Inc. service. 14 October 2014.

[6] “User Manual”, *Blender.* Creative Commons Attribution ShareAlike. 11 October 2014.

[7] “Documentation” *GIMP* - The *GNU Image Manipulation Program.* GIMP Team. 2001-2014. 16 October 2014.

Appendices (optional)

1.

2.

3.