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

EEL4914C/4915C – ECE Senior Design Project II

FINAL REPORT

Project title: **3D SCANNER**

Team #: E10

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EEL4914C/4915C – ECE Senior Design Project II

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Executive Summary

The purpose of this project was 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 is in the form of a box where an object will be placed inside on a transparent acrylic sheet and a series of images are sent to software for processing. The box frame is covered by a white background to act as a featureless layer for each photo to isolate the object. For the software design, it runs through a series of stages with creating a point cloud as the first using the images previously captured. Then the point cloud is used to create a solid surface mesh, and the photographs are used again to make a surface texture. This creates a photorealistic re-creation of the object. This design is to 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. Shonda Bernadin for securing a lab space for working, guidance throughout the design process, and the contribution of providing components needed for the project. The team thanks Dr. Victor DeBrunner for his insights in image processing and advice he provided. The team also thanks Dr. Dawson for establishing the project and providing a room at the archives for the opportunity of scanning the artifacts and data collecting testing.

1.2 Problem Statement

The project aimed 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 were to be created from the artifacts by scanning them using photogrammetry. Photogrammetry re-creates 3D scenes by analyzing photographs of the scene. The photographs were to be taken of the artifacts by using a handheld camera that would capture the entire surface area of the artifact by encircling it and taking more on complex geometry parts that the artifact might have to achieve greater detail. Photogrammetry software would have created a point cloud from the collection of images. Mesh modeling software would have finally created a solid surface from the point cloud and generated a texture map from the images of the artifact.

The frame has the dimensions of 64.5” x 52.5” x 66.5” so that at least one side of the large artifacts can fit inside the 52.5” side. The main concern was to make the box big enough for the artifacts and have the acrylic sheet. For the larger objects, the acrylic sheet would be removed to allow the object to fit inside. Due to the delay in receiving the components for the hardware design, most testing was done without the hardware, and photographs were taken using a handheld camera, the team members’ cellphones with 720p quality or higher, against a plain background (i.e. white wall, towel, or desk). Another problem was what type of lights were to be used. The lights have to be bright, small, and cheap in order to work with the design. LED strips were selected at first because they were cheap and flexible. The lights appeared bright enough to illuminate the frame; however, after receiving the two purchased strips, it was concluded that more lighting was needed. At the end, fluorescent lights were used with umbrella diffusers which would stand outside of the frame pointing inwards.

1.3 Operating Environment

There is not a concern for weather because the end product would have been kept indoors under room temperature. Since this would have been stored in a 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 when assembled with the acrylic bed in place as a weight. If parts of the PVC frame were to break, replacement would be cost efficienct and need little technical skill. Since the lighting will be placed outside of the box, the heat disbursement of the lights 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 photorealistic re-creations of the objects. This device was 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 was 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 task could be automated, some of the tasks require manual editing. 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 white and is used as a featureless layer. One camera is used to capture the entire surface area by moving it around the object. Non-rigid objects are placed on an acrylic surface that is to be lifted through the scanner. A single computer is to 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 is 64.5” x 52.5” x 66.5”. The change in size was to allow for larger artifacts to fit through it. This size can be extended since the frame was created from PVC pipes to allow for larger widths. However, the acrylic bed was designed to accommodate the final product without modifications. The scanned objects cannot exceed 3’ in width without the creation of extensions (though length can potentially be unlimited given enough memory storage and processing power) so as to give the user sufficient room to capture the entire surface with overlapping. The cost to produce the final scanner does not exceed $1000. The device should not be used outside and cannot be used where there is excessive amounts of light interference such as taking pictures in the direction of bright sunlight.

1.6 End Product and Other Deliverables

Scanner: A 64.5” x 52.5” x 66.5” box PVC frame, diffused lighting, and acrylic bed.

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 is available in appendix A and on the team’s website as a viewable document. A short video of the process is available on the teams website for download as well.

3D models: The objects that were produced during testing are available along with the objects data that created it.

2 System Design

2.1 Overview of the System

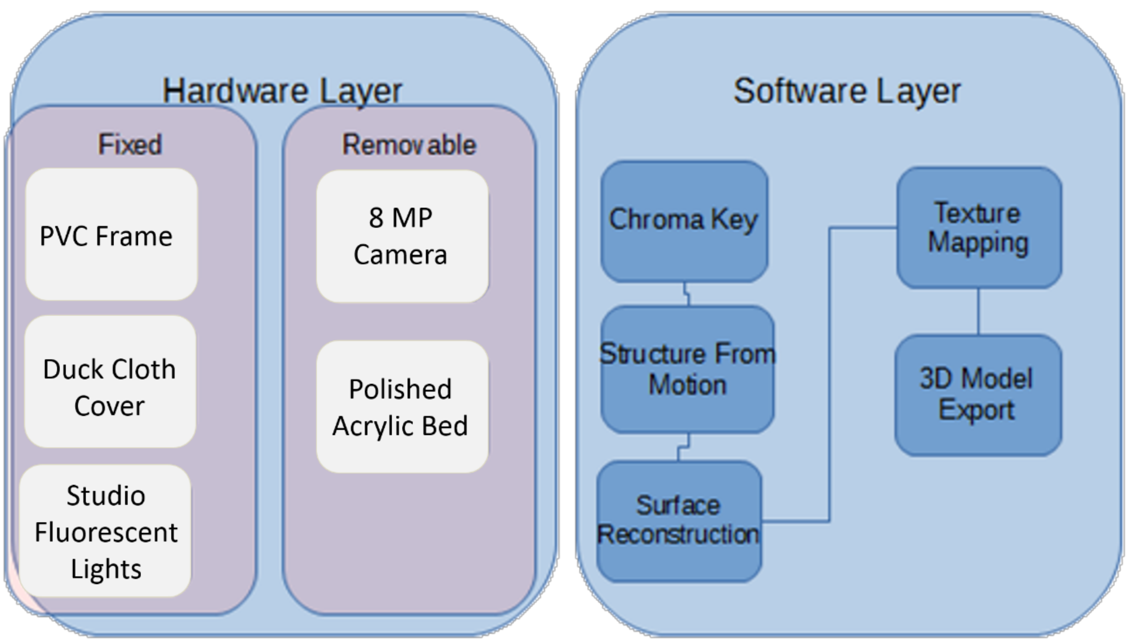


Figure 2.1: A System Overview Block Diagram

The major physical components of the system will be a PVC frame, white screens, studio fluorescent lights, and a handheld digital camera. An acrylic scanning bed can be used to scan small non-rigid objects. The PVC frame is generally cube shaped with the dimensions of 64.5" x 52.5" x 66.5" to accommodate objects up to 3' wide. The sheets can cover sides of the cube each to provide a sufficient studio for the pictures that will be taken. The light sources are on each side to illuminate the object evenly. The digital camera will be an 8 megapixel point and shoot camera. The polished acrylic scanning bed is 54" x 24" x 0.5" and is to be mounted to the middle PVC beams. There is a user manual attached in Appendix A to walk through the different programs.

The first step is to use the pictures to create a point cloud based on the overlapping images. The second step is to reconstruct the surface by converting the point cloud into polygonal surfaces. The third 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

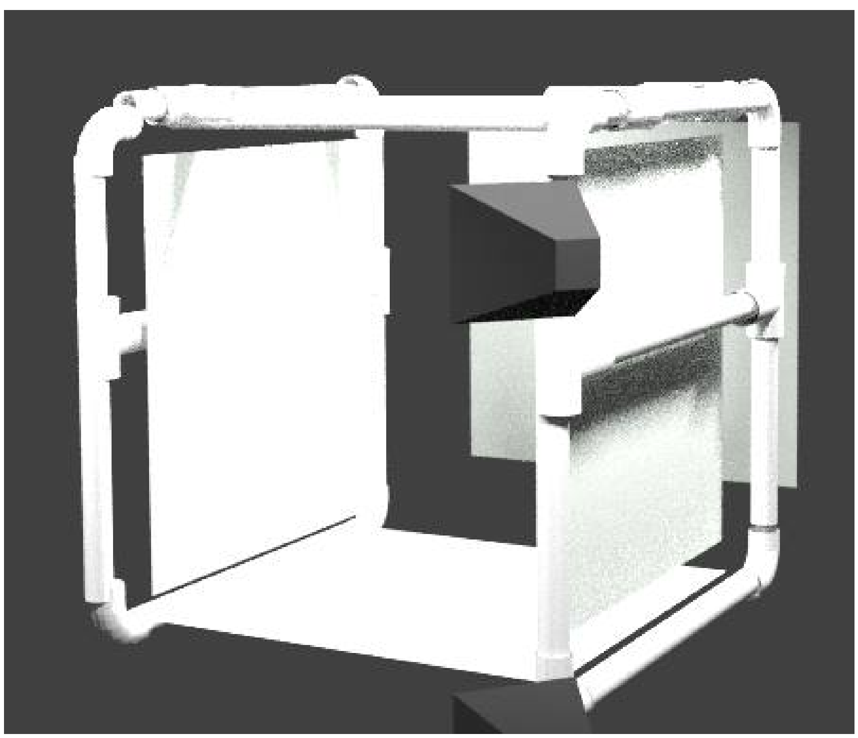


Figure 2.2: 3-D model of the scanner's hardware design

2.2.1.1 Frame

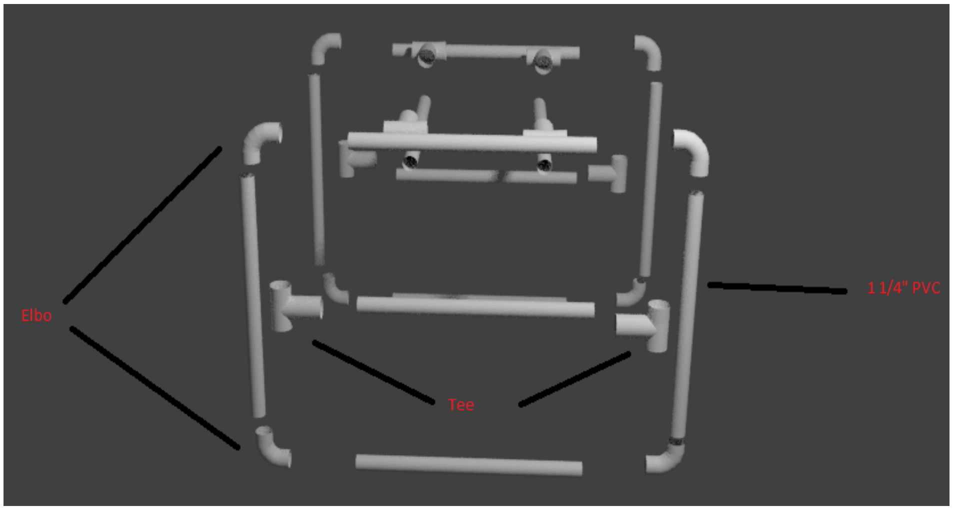


Figure 2.3: Exploded 3-D model of scanner skeleton

The frame consist of PVC pipes with 1 ¼'' diameters. There are 12 PVC pipes and 16 PVC joints (elbows and tees, 8 each).

2.2.2 Software

2.2.2.1 VisualSFM

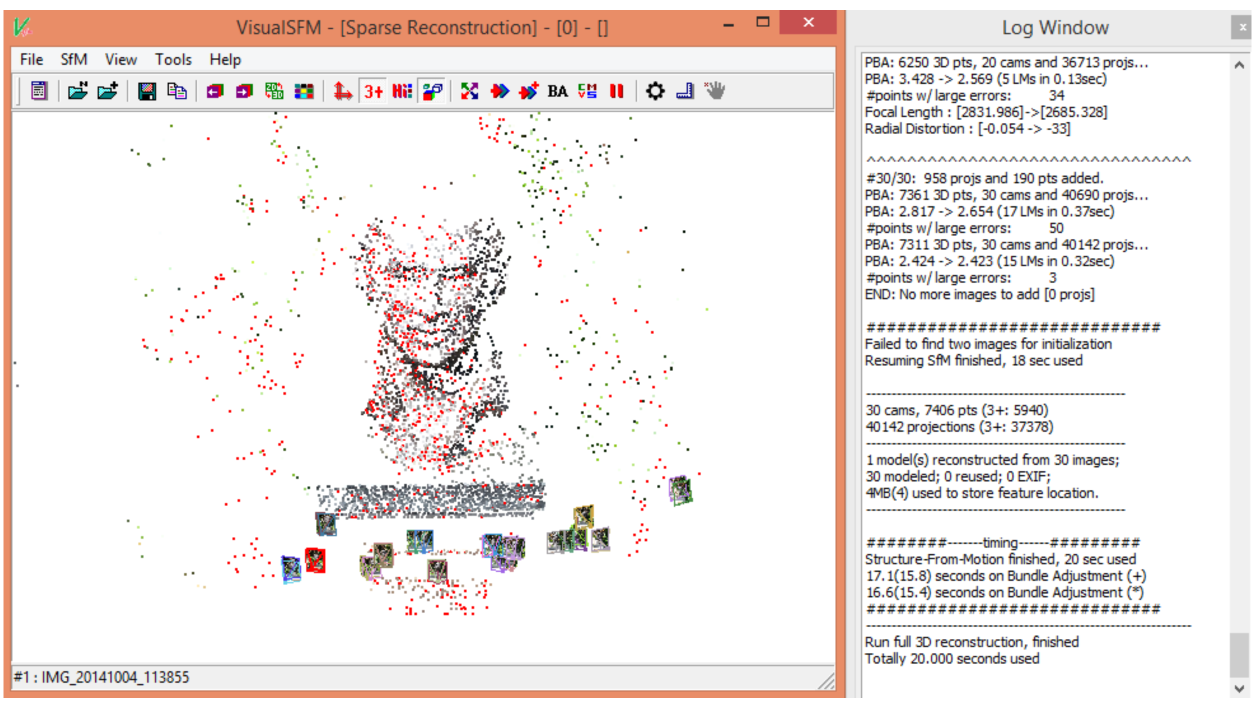


Figure 2.4: Point Cloud Reconstruction in VisualSFM

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 the next step.

2.2.2.2 MeshLab

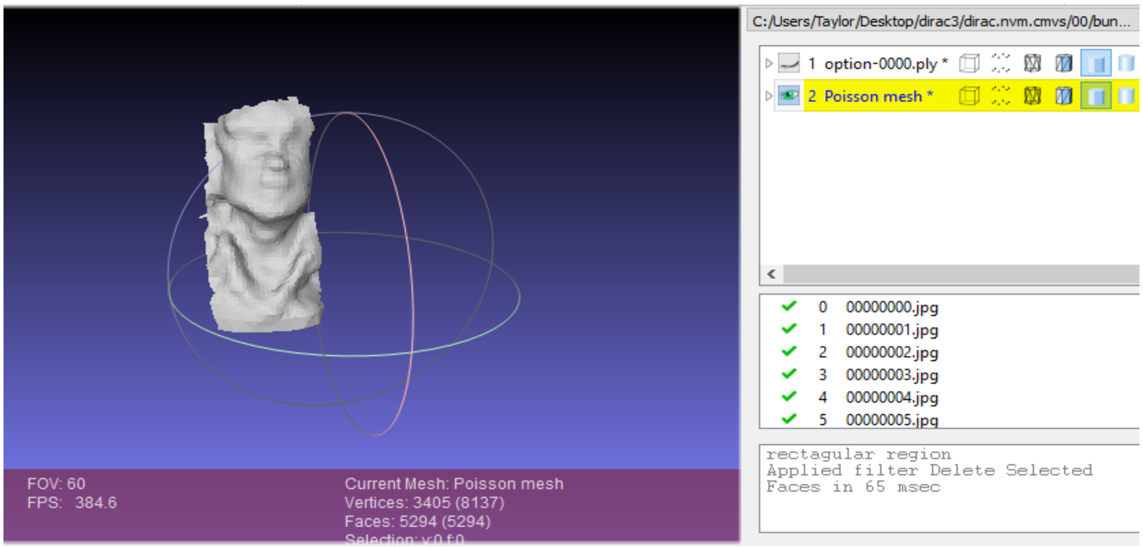


Figure 2.4: Creating a solid mesh in MeshLab

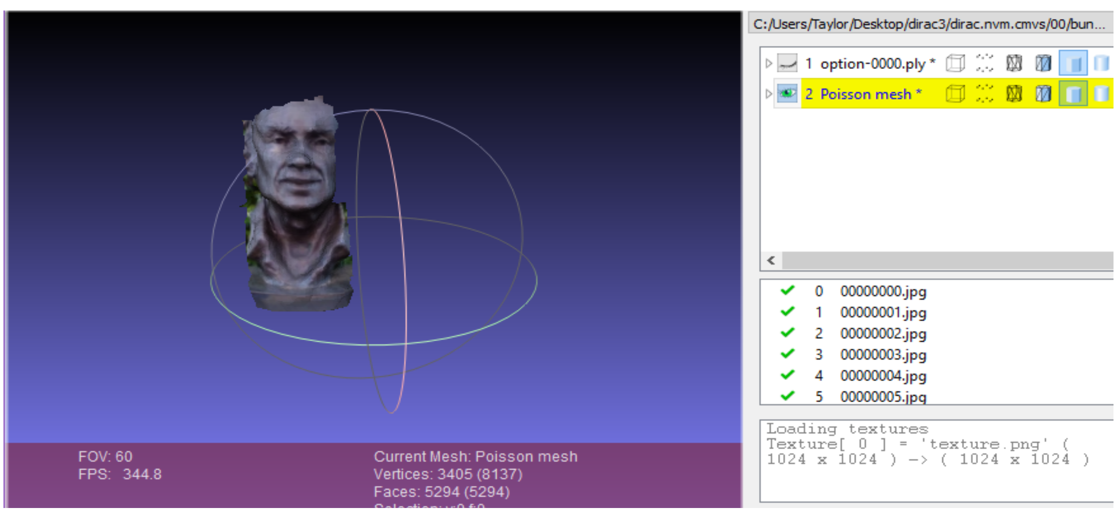


Figure 2.5: Adding texture to the mesh in MeshLab

MeshLab is used to eliminate undesirable vertices and create polygonal surfaces from the point cloud. It then uses data from VisualSFM to produce a texture map based on the angles and distances of the original photos to produce a photorealistic 3D model.

2.2.2.3 Blender

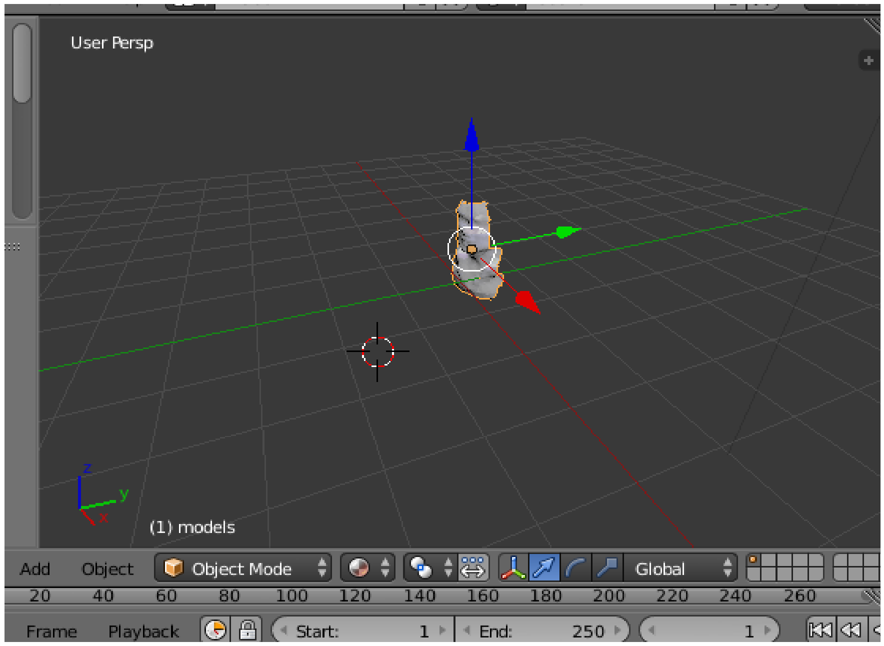


Figure 2.6: Exporting mesh into Blender

Blender is a 3D modelling/animation suite. It is not part of the reconstruction process but can be used to export the model to other useful formats. Blender can use the model in an animation which can then be exported to video format but cannot create 3D models with photogrammetry.

2.3 Performance Assessment

The user was able to place an artifact in the scanner and with very little technical knowledge be able to follow the instructions presented in the user manual to render a 3D mesh object. Reconstructed objects have been uploaded online and can be downloaded. The data saved throughout the 3-D image reconstruction process can also produce other products such as videos and interactive learning activities with the use of animation software.

2.4 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 LEDs have been replaced with a 600W studio lighting kit to avoid shadows and having shadows included in the reconstruction process. After performing testing, a white background was determined to reduce noise which is why there was a slight change in the background color. 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 impact of this change is that the capture process will take significantly longer and more manual operation is required. This is offset by the precision at which the pictures can be captured at whereas the 13 cameras would have been in a fixed position. The scan bed no longer slides 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.

2.5 Overall Risk Assessment

2.5.1 Failure of Meeting Deadlines

Each member was assigned a task needed for every deadline, and some of these task are independent from another while others are not. If a team member did not meet their deadline when expected, the project was as risk of being set back. Fortunately, all of the deadlines have been met and a system was built to scan and create 3D models. The only part that was not done was testing cultural artifacts. This was due to the trouble in eliminating the background for clean images.

2.5.2 Exceeding Maximum Budget

This project stayed within the maximum budget, $1000. The budget was estimated by the financial advisor throughout the project's progression and even though there was a possibility that new parts needed to be replaced during testing the budget was still not exceeded. If going over the budget was a possibility, a new design would have to be created or more money would have to be added to the budget. The need to redesign the device with the alterations lead to a great standstill in production while a new design was created due to the cost of 13 cameras. Fortunately, there were not any scenarios where major components broke. Most of them could be bought locally and easily replaced.

2.5.3 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 5 Megapixels though results have been achieved with a 1 megapixel video of resolution 1280 x 720. Using a camera with a lower resolution tended to lead to distorted mesh models or poorly detailed textures [2].

The depth of field (DOF) is the distance between the nearest and farthest 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 lead to a fairly low number of auto-correlated points which cannot be reconstructed well. Since the photos have been 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].

3 Design of Major Components

3.1 Frame

3.1.1 Frame Design

The frame is a cube consisting of 2 walls with connecting beams across the top. The walls are constructed of 1¼" PVC as well as elbow and tee connectors.

3.1.2 Frame Technical Risk

3.1.2.1 Unstable Frame

This was a concern when designing the scanner. In the original design it had to support the cover as well as lights. Fortunately, the lights are no longer attached to the PVC and weight on it is not a concern. The acrylic bed is not an issue either. The frame's walls are slightly pushed out when the frame is attached giving the frame a slight trapezoidal shape securing its stability.

3.2 Bed

3.2.1 Bed Design

A polished acrylic bed was used to place smaller objects on to be easily scanned. The original design for the bed was to have it lay on railings. This design was scrapped because without the 13 camera design there is no need for the bed to move. The design that was chosen was a stationary acrylic bed such that photos could be taken by circling the object on the bed. It 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. Most importantly is that it is clear enough to avoid any distortion with the lighting that will affect the artifact's reconstruction process.

Glass was considered as an alternative to the acrylic bed. Glass is more rigid and can only be scratch by hard, sharp surfaces such as a rock or metal. However, due to the brittleness of glass, acrylic was chosen in favor because it is stronger than glass, just as transparent, and can be custom made to fit any need.

3.2.2 Bed Technical Risk

3.2.2.1 Scratches

Acrylic is prone to getting scratched like any other plastic. However, it is a hard plastic and is less prone to scratches than other plastics of equivalent transparency. 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 very fine grit sandpaper, polishers, and a clean microfiber cloth to ensure that scratches are not reintroduced into the acrylic. If glass was chosen, it would have be much more expensive and much more brittle.

Figure 3.1: Severely Scratched Acrylic

3.3 Cover

The white cloth background lines the interior of the box. The cover is transportable since it is easy to remove due to its light weight. The cover is attached at the corners of the frame and it portabile since they can be detached and fasten removing without damaging the cover. The dimensions of the cloth is approximately the same with the frame, so it is slightly stretched when tied reducing the amount of wrinkles that could cause unwanted point detection from the background. If there are an excessive number of wrinkles, they can be removed by ironing or steaming the fabric.

3.4 Lighting

3.4.1 Lighting Design

PHOTOGRAPHY PHOTO PORTRAIT STUDIO LIGHTING KIT

Originally there were two strips that ran along the tunnel of the PVC structure, however after some testing, it has been concluded that the LED strips do not provide enough light distribution, and they were contributing to the reflection of the background color onto the objects. Instead of using this light source, the CFL panels on the ceiling provided enough soft lighting to photograph objects and receive good results from the software. With this, fluorescent lighting was chosen to be the new light source for the design. These fluorescent light stands are positioned outside of the frame pointing inwards. The white umbrella is placed directly in front of the light source to help diffuse the light spreading it out at a large range. In conclusion, this light source was more efficient when comparing the test results.

3.5 Camera

3.5.1 Camera Design

The single camera will need to be rotated around the object capturing images at no more than 45º intervals. The rotation will then be repeated 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

Since this is a huge part of the whole process, an unsteady picture taking posses a significant risk. This greatly damaged the quality of the some of the 3D reconstruction processes and caused the user to retake all the pictures and start again. This becomes more apparent when getting frames from a video as there are many motion blur pictures that must be removed.

3.6 Software

3.6.1 Software Design

The software required includes VisualSFM and Meshlab. VisualSFM was 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. A white cloth background is used to remove the noise from each image which reduces the amount of unnecessary point cloud pixels being produced. Meshlab produces 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 is 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

To help for this project to progress for the future researchers, there were a series of test involving finding the proper technique in taking the photographs rather than the overall design. This can make the software manual manipulation at a minimum and the final 3D meshes having realistic structures and detailed, undistorted textures of the objects of interest. If the manual manipulation can be significantly reduced, this could lead to creating an automatic approach involving a camera with programmed movements and a program script that runs the software with little user interaction.

4.1 System and Integration Test Plan

4.1.1 Scanning Small Objects

Scanning small object were the main focus of scanning due to the convenience of transportation and easier manipulation. Most of the objects within the collection of the artifacts were smaller in size, so providing a system that can effectively scan objects relatively small was priority. The focus was to achieve the optimal technique and further understanding of the photogrammetry software chosen and their limitations. While scanning, the emphasis were on

1. The number of photographs used to render a point cloud.
2. The effectiveness of blurriness, lighting and resolution of the photographs.
3. The range of overlapping required for higher point matching.
4. The amount of time required for dense cloud reconstruction on different systems.
5. The values chosen during the Poisson reconstruction (mesh construction).

Since the test objects varied in shape, smoothness, shininess, and other features, the trial and error method was used during most of the testing rather than a systematic approach. With all the collected data of the results, a few system of techniques were finalized to render the 3D models.

4.2 Test Plan for Major Components

Most of the hardware test occurred during the same time of since the complexity of the design is low.

4.2.1 Frame

The frame was one of the first items that was tested. It needed to be stable to hold the required hardware for efficient data collecting. While constructing the frame the joints would twist and distort the shape of the box. This was a concern because the frame may sway when additional weight (i.e. cover and lights) were added. To resolve this issue, PVC primer and cement was added inside of the joints on the outer corners of the frame. They were then locked into place on the adjacent pipes. The joints connecting the middle pipes did not receive the cement to maintain some disassembly and mobility. In conclusion, the frame became more rigid; however, lost some mobility efficiencies since it cannot be fully disassembled.

4.2.2 Lighting

The first light source used with documentation was sunlight which provided the Dirac statue 3D model. To mimic this light source, LEDs with a color temperature of 5,500-6,500 was chosen. After installing the LEDs onto the green muslin and frame, the amount of light illuminated from the LEDs were noticeably dim. They provided inconsistent exposure to the bottom of the frame, and it intensified the color spill of the green screen since the light source was directly on the background. The results were clear from Test Result B.1 “Taylor’s Shoe” in appendix B. With these flaws, it was concluded to use the CFL panels from the ceiling of the room, with their evenly disputed light, as the light source during testing. It gave better results in Test Result B.2 “Calculator” and Test Result B.3 “Snake” in appendix B. The ceiling light panels were used further until the fluorescent light kit was installed during Test Plan B.5 “Doll 2” which were more effective than the LED strips.

4.2.3 Cover

One of the main concerns about the Chroma key green screen muslin was color spill. From the results of the Test Result B.1, the color of the cover reflected onto the object, and the amount was very noticeable. Removing color spill requires expert knowledge in photo editing software, so the green screen muslin was considered inefficient. For Test Result B.3 “Snake”, the background was a greyish blue consistency which produced very little discoloration of the test object when rendering. As a conclusion, duller colors were considered and white was eventually chosen since it will help reflect light illuminating the object better without discoloration.

4.2.4 Software

4.2.4.1 Visual SFM

The efforts of receiving a very detailed sparse cloud depends on receiving a large number of point matches between pictures. This value is increased with overlapping of pictures; however, if there is too much overlapping, it could cause the program to crash due to excessive processing. This issue surfaced while using the technique of video frames. With videos, the amount of overlapping between frames are very high to maintain the effect of motion, but with more than 90 percent of the pixels matching between corresponding frames, Visual SFM crashes. As a solution, five or six corresponding frames would be removed to prevent this event from happening. Blurred frames must also be removed since it disrupts the assembly of the point cloud.

4.2.4.2 MeshLab

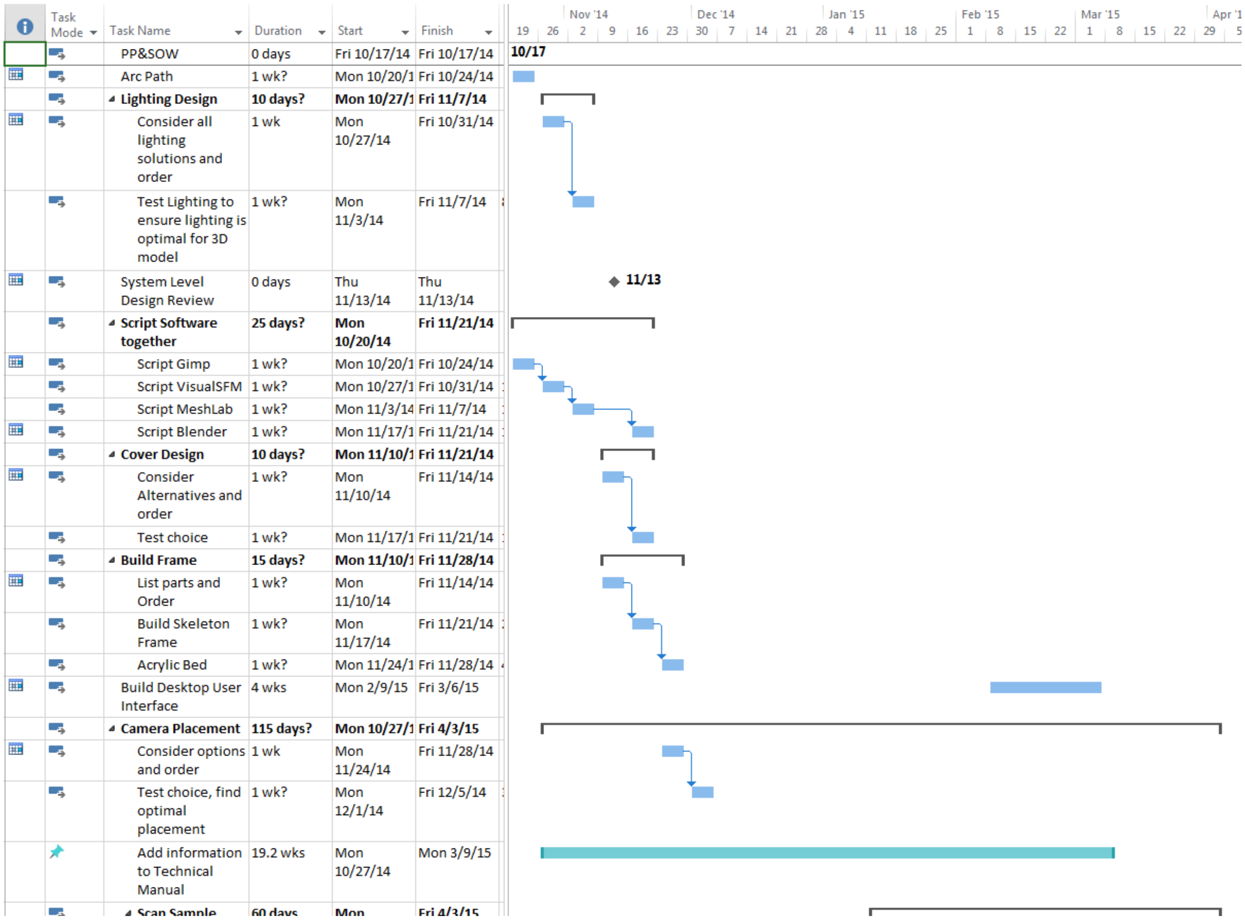
For the mesh construction, the values of the Poisson reconstruction affected the resulting mesh’s smoothness and features. By the trial and error method, altering the values helped smooth out the mesh while retaining key features. If the octree depth and the solver divide remained on their default settings and the sample value was altered, smoothness of the mesh from more samples, however, less features are retained. If less samples are used during the rendering, the mesh will consist of too many features that are either noise or miscalculations that causes the mesh to look distorted. The higher numbers of octree depth causes a “puffy effect” on the mesh, but this helps eliminate distortion. Usually having the values high allows the mesh’s shape to be more accurate; however, in the case of Test Result B.1 “Taylor’s Shoe”, that's not always true. The corrections lead to a miscalculation, and the shoe looked disfigured, but this result also was affected by the poorly made dense reconstruction.

4.3 Summary of Test Plan Status

Each test plan used different methods of hardware to achieve the best results from the software. Due to the scanning environment, the background and lighting affected the outcome of the point cloud, mesh, and texture map. The technique when data collecting (whether with snapshots or videos) affected these outcomes as well. The processes of these tests are described in more detailed in Appendix B.

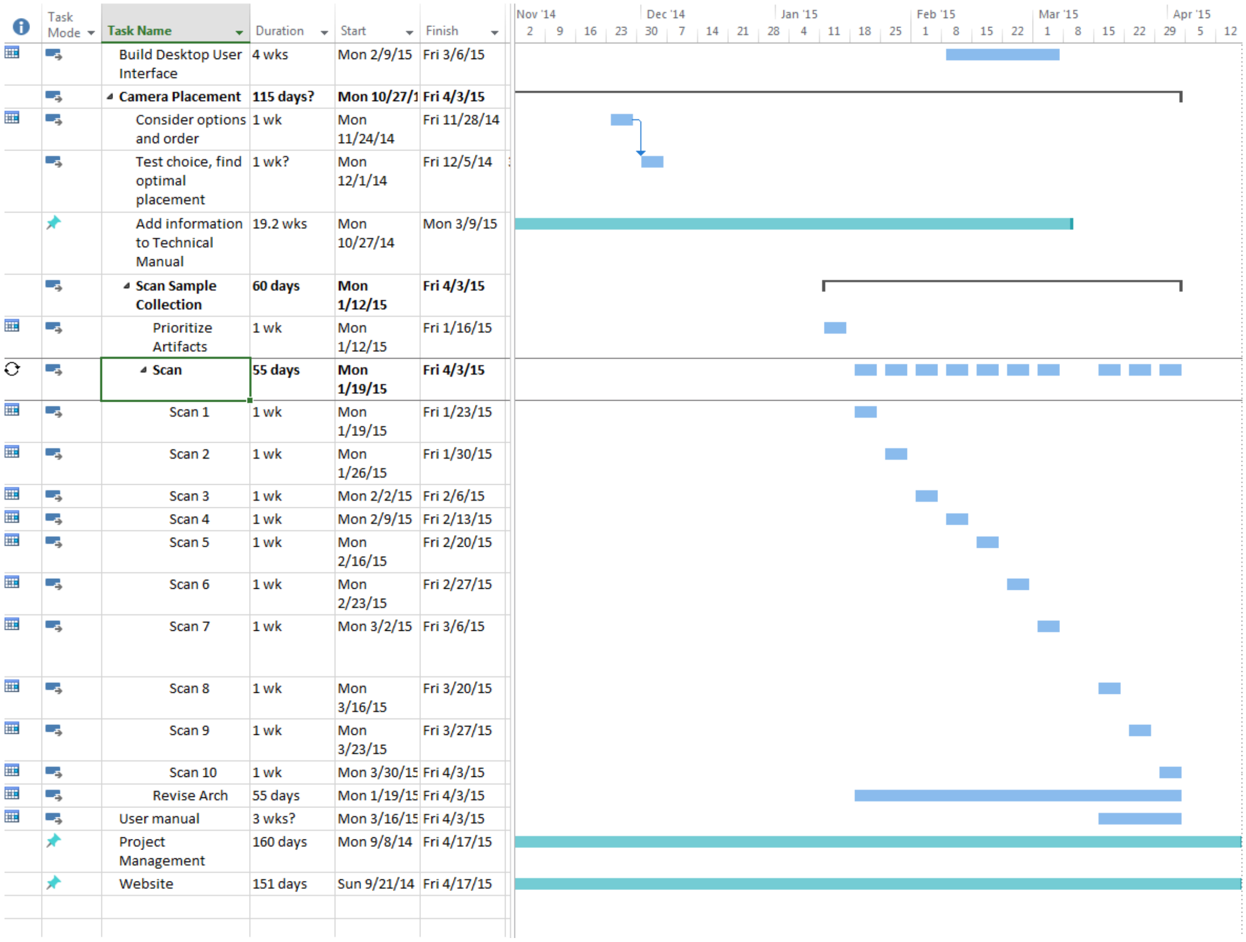
Test Results	Pass/Fail					
	Hardware			Software		
	Background	Frame	Lighting	Point Cloud	Mesh	Texture
B.1 Taylor's Shoe	Fail	Pass	Fail	Fail	Fail	Fail
B.2 Calculator	Pass	-	Pass	Pass	Pass	Pass
B.3 Snake	Pass	-	Pass	Pass	Pass	Pass
B.4 Tigger	Pass	-	Pass	Fail	Fail	Pass
B.5 Doll	-	-	Fail	Pass	Pass	Pass
B.6 Doll 2	Pass	Pass	Pass	Pass	Pass	Pass
B.7 Taylor	-	-	Fail	Pass	Pass	Pass

5 Schedule



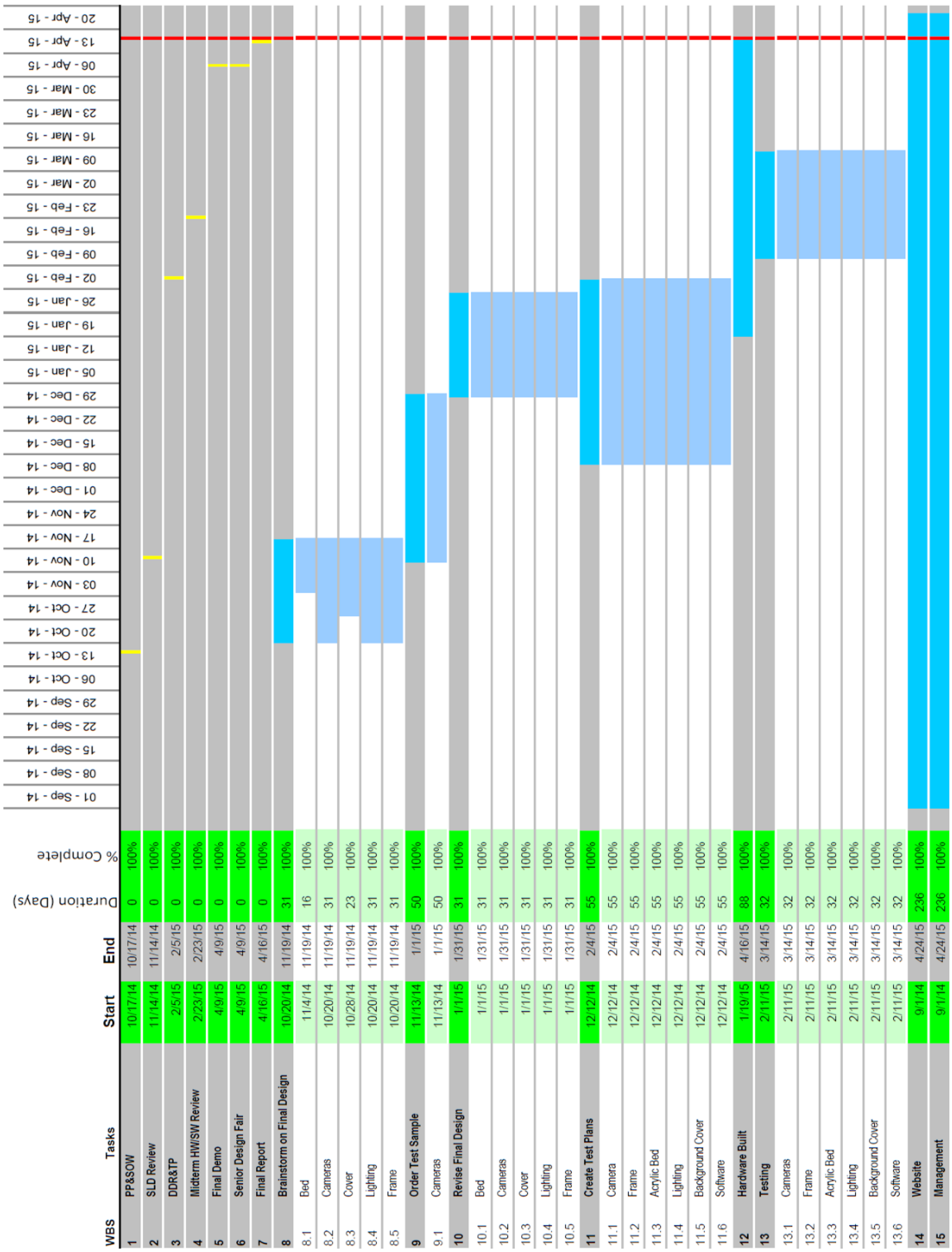
Task Name	Duration	Start	Finish
PP&SOW	0 days	Fri 10/17/14	Fri 10/17/14
Arc Path	1 wk?	Mon 10/20/1	Fri 10/24/14
Lighting Design	**10 days?**	**Mon 10/27/1**	**Fri 11/7/14**
Consider all lighting solutions and order	1 wk	Mon 10/27/14	Fri 10/31/14
Test Lighting to ensure lighting is optimal for 3D model	1 wk?	Mon 11/3/14	Fri 11/7/14
System Level Design Review	0 days	Thu 11/13/14	Thu 11/13/14
Script Software together	**25 days?**	**Mon 10/20/14**	**Fri 11/21/14**
Script Gimp	1 wk?	Mon 10/20/1	Fri 10/24/14
Script VisualSFM	1 wk?	Mon 10/27/1	Fri 10/31/14
Script MeshLab	1 wk?	Mon 11/3/14	Fri 11/7/14
Script Blender	1 wk?	Mon 11/17/1	Fri 11/21/14
Cover Design	**10 days?**	**Mon 11/10/1**	**Fri 11/21/14**
Consider Alternatives and order	1 wk?	Mon 11/10/14	Fri 11/14/14
Test choice	1 wk?	Mon 11/17/1	Fri 11/21/14
Build Frame	**15 days?**	**Mon 11/10/1**	**Fri 11/28/14**
List parts and Order	1 wk?	Mon 11/10/14	Fri 11/14/14
Build Skeleton Frame	1 wk?	Mon 11/17/14	Fri 11/21/14
Acrylic Bed	1 wk?	Mon 11/24/1	Fri 11/28/14
Build Desktop User Interface	4 wks	Mon 2/9/15	Fri 3/6/15
Camera Placement	**115 days?**	**Mon 10/27/1**	**Fri 4/3/15**
Consider options and order	1 wk	Mon 11/24/14	Fri 11/28/14
Test choice, find optimal placement	1 wk?	Mon 12/1/14	Fri 12/5/14
Add information to Technical Manual	19.2 wks	Mon 10/27/14	Mon 3/9/15
Scan Sample	**60 days**	**Mon**	**Fri 4/3/15**

Figure 5.1: Fall schedule from Project Proposal, Milestone 2:



Task Name	Duration	Start	Finish
Build Desktop User Interface	4 wks	Mon 2/9/15	Fri 3/6/15
Camera Placement	115 days?	Mon 10/27/1	Fri 4/3/15
Consider options and order	1 wk	Mon 11/24/14	Fri 11/28/14
Test choice, find optimal placement	1 wk?	Mon 12/1/14	Fri 12/5/14
Add information to Technical Manual	19.2 wks	Mon 10/27/14	Mon 3/9/15
Scan Sample Collection	60 days	Mon 1/12/15	Fri 4/3/15
Prioritize Artifacts	1 wk	Mon 1/12/15	Fri 1/16/15
Scan	55 days	Mon 1/19/15	Fri 4/3/15
Scan 1	1 wk	Mon 1/19/15	Fri 1/23/15
Scan 2	1 wk	Mon 1/26/15	Fri 1/30/15
Scan 3	1 wk	Mon 2/2/15	Fri 2/6/15
Scan 4	1 wk	Mon 2/9/15	Fri 2/13/15
Scan 5	1 wk	Mon 2/16/15	Fri 2/20/15
Scan 6	1 wk	Mon 2/23/15	Fri 2/27/15
Scan 7	1 wk	Mon 3/2/15	Fri 3/6/15
Scan 8	1 wk	Mon 3/16/15	Fri 3/20/15
Scan 9	1 wk	Mon 3/23/15	Fri 3/27/15
Scan 10	1 wk	Mon 3/30/1:	Fri 4/3/15
Revise Arch	55 days	Mon 1/19/1:	Fri 4/3/15
User manual	3 wks?	Mon 3/16/1:	Fri 4/3/15
Project Management	160 days	Mon 9/8/14	Fri 4/17/15
Website	151 days	Sun 9/21/14	Fri 4/17/15

Figure 5.2: Spring schedule from Project Proposal, Milestone 2



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	100%
4	Midterm HW/SW Review	2/23/15	2/23/15	0	100%
5	Final Demo	4/9/15	4/9/15	0	100%
6	Senior Design Fair	4/9/15	4/9/15	0	100%
7	Final Report	4/16/15	4/16/15	0	100%
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	100%
11.1	Camera	12/12/14	2/4/15	55	100%
11.2	Frame	12/12/14	2/4/15	55	100%
11.3	Acrylic Bed	12/12/14	2/4/15	55	100%
11.4	Lighting	12/12/14	2/4/15	55	100%
11.5	Background Cover	12/12/14	2/4/15	55	100%
11.6	Software	12/12/14	2/4/15	55	100%
12	Hardware Built	1/19/15	4/16/15	88	100%
13	Testing	2/11/15	3/14/15	32	100%
13.1	Cameras	2/11/15	3/14/15	32	100%
13.2	Frame	2/11/15	3/14/15	32	100%
13.3	Acrylic Bed	2/11/15	3/14/15	32	100%
13.4	Lighting	2/11/15	3/14/15	32	100%
13.5	Background Cover	2/11/15	3/14/15	32	100%
13.6	Software	2/11/15	3/14/15	32	100%
14	Website	9/1/14	4/24/15	236	100%
15	Management	9/1/14	4/24/15	236	100%

Figure 5.3: Final Schedule demonstrating what was accomplished

The major difference in the two schedules are camera placement, script and desktop interface, and the scanning of the artifacts. The team regrets that it was not able to scan any of the artifacts from the museum. One of the bigger setbacks was the initial design with 13 cameras. While it appeared to be a great decision, once the cost of a sufficient camera was discovered to be far more than the $2.50 camera that the team had originally believed was sufficient, the decision was made to use a single camera system but keep a modified frame design to allow the scanning of the underside of objects. This design also had the added benefit that objects with complex geometry can be photographed with special emphasis on the complexities in order to recreate those parts more accurately. The script became a problem when the team discovered that objects could not be automatically cleaned up inside meshlab. This part should be done manually to allow for the subjectiveness of the human eye to determine what was actually part of the object. VisualSFM has a command line interface which allows the point cloud process to happen quicker since there is nothing visually displaying. This could have been automated but since meshlab was unable to be automated the script was dropped along with a desktop interface. The scanning of the artifacts was a very regrettable loss to the schedule. Throughout both semester objects were tested to find a good method for taking photos for visualSFM. This was a rather tedious process as it usually took hours to know if visualSFM was going to give a good point cloud for creating a mesh. This unanticipated issue caused the loss of time that would have been spent scanning artifacts. However, it was necessary as the artifacts could not get scanned without a proper method.

6 Final Budget and Justification

6.1 First Budget

Item	Distributer	Costs ($)	Quantity	Total ($)
USB 8MP Webcam	TVC-Mall	2.50	13	32.50
Acrylic Sheet	Amazon	15.00	1	15.00
PVC Pipe	Home Depot	3.00	8	24.00
PVC Joints	Home Depot	0.50	8	4.00
Green Wrapping Paper	Amazon	15.00	4	60.00
USB Hub	Amazon	4.00	2	8.00
Computer	Walmart	500.00	1	500.00
Other	-	-	-	150.00
Total Cost:	-	-	-	793.50

6.2 Final Budget

Used Material			
Item	Cost ($)	Quantity	Total ($)
Polished Acrylic	221.25	1	221.25
PVC Pipe	2.25	12	27.00
PVC Elbow	1.19	8	9.52
PVC Tee	1.74	8	13.92
Fluorescent Lights with Umbrella Diffusors Kit	47.51	1	47.51
White Translucent Cover	2.00	2	4.00

Unused Material			
Green Screen Muslin	15.00	2	30.00
LED Lights	53.93	2	107.86
LED Power Adaptor	23.70	1	23.70
Total			484.76

The total budget for the first estimate without the computer would be $293.50 and the current budget is at $484.76. The major price difference was the acrylic bed being a few hundred over what was originally found. This was because the original was not in the system school system to buy, would take too long to ship, and might not have been sturdy enough. Instead a local vendor was found that can cut custom sizes, which is why it is expensive. The second major difference is the lighting. The original cost did not include any lighting whereas the current cost of lighting is $47.51. The last major difference is the camera cost in the first budget. One of the webcams was purchased, tested, and deemed low quality. Instead cameras on a phone seemed to be very sufficient in order to capture quality pictures.

7 Conclusion

The scanner is constructed of PVC for the frame generally forming a box. A white duck cloth cover was used to assist with removing the background features from each image for maximum point autocorrelation. The camera was strategically placed to capture the entire surface area with at least 60 percent 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 sheet allowed for the camera below the sheet to scan the underside of the objects. Studio fluorescent lighting provided an even amount of lighting. They are placed on the outside and shine inward to illuminate the object. The captured images are processed by VisualSFM to generate a sparse and later a dense 3D point cloud. Meshlab uses 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. Overall the design of the system has been finished and has met the required specifications. 3D models have been successfully generated using the system built.

8 References

[1] 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.

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

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

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

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

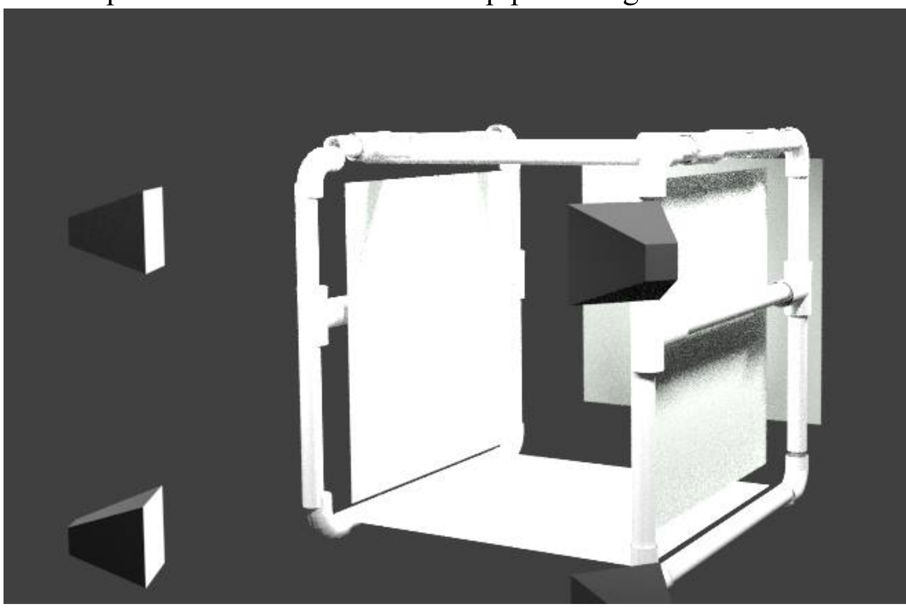
[6] “Documentation” *GIMP* - The *GNU Image Manipulation Program.* GIMP Team. 2001-2014. 16 October 2014.

Appendix A – User’s Guide

User Manual

Guide for Assembly

The frame is a 26 piece kit. The top length is cemented together to make it easier to put together as well as ensure the parts do not rotate. The other pipes fit together to form the image below.



There are four pipes that are approximately 5’ in length in the middle and on the bottom. The middle is connected with T pipe fittings and the bottom two are connected with elbow fittings. There are 8 pipes that are approximately 2.5’ in length that make up the height. These connect into the T fittings and the elbows that are connected to the 5’ pipes as well as the top pieces. These are the walls of the frame. The walls are connected together through 2 pipes that are also approximately 5’ in length. These are connected through the T fittings on the top pieces.

The acrylic bed is then laid on top of the middle pipes spanning the empty space. It should fit snuggly with the 3” cutouts under the braces on each side and reinforce the frame with its length and weight. The lights are setup such that the umbrellas are pointing towards the interior as this will diffuse the lighting and create an even illumination.

Guide for Taking Photographs for VisualSFM

Background

Photos for VisualSFM should be either taken with a still camera to ensure crisp photos of the object of interest at a resolution of at least 1280 x 720 or a video of equivalent resolution. It is advisable to take photos or video at a much higher resolution such as 5 megapixels or higher this will provide more detail and achieve a more accurate model. Videos can be dumped into individual frames. VLC media player has this capability. VLC media player's filter option called scene video filter under all setting inside preferences. The video should be played with the scene filter on and the pictures will collect into a folder that was specified when the filter was created. The issue with video is that while it's quicker than taking individual photos, there is motion blur that must be manually searched for to ensure that only the crisp photos are the ones being used by VisualSFM. This makes pictures easier to deal with but slower to create. As a rough guideline, photos should have at least around 60 percent overlap between the pictures to ensure that VisualSFM can match the two pictures more is better.

Best method for taking pictures

The basics of this method comes from a sphere.
Assume that a beach ball is to be the scanned object. The beach ball should be held with either fishing wire or placed on a transparent surface to allow pictures to be taken from above as well as under. To take the pictures the user sets the camera such that pictures are taken from a fixed distance from the beach ball while keeping the camera focused on the center of the beach ball. Then, the user circles around the beach ball taking pictures at that fixed distance and taking pictures at least two more pictures at different distance from the beach ball with each increment around the beach ball. This gets at least three pictures from each position and increases overlap significantly. The user starts from the top of the beach ball keeping the camera pointed towards the center while at that distance and takes pictures all around the beach ball. This process is repeated at increments going down towards the bottom of the beach ball. Ensure that the camera is always focused towards the center of the beach ball and at a fixed distance.

For more complicated objects such as a teddy bear or a shoe, the same process described above can be used. The areas of the object with complicated surfaces such as shoelaces with a shoe or decoration with a teddy bear should have more photos around those areas to get the details of those spots better.

For larger objects or long straight object, the sphere shape does not necessarily make sense to use. For these objects, a capsule shape should be used while still maintaining the guidelines of the sphere. A capsule is when a sphere is split into and joined on two ends of a cylinder. It's the shape of many pills used in the pharmaceutical industry.

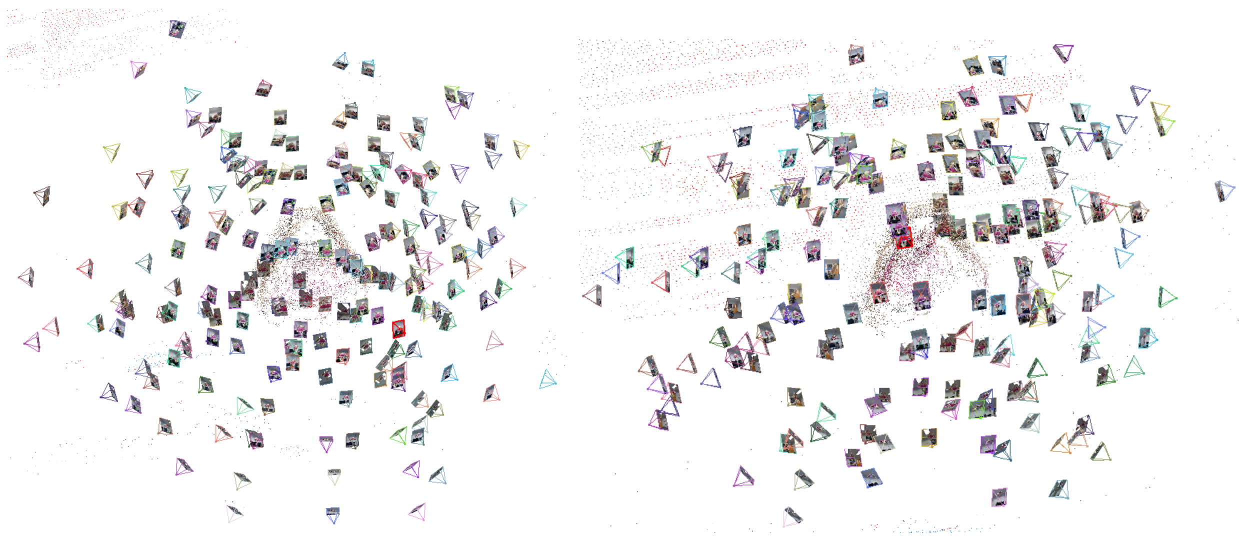
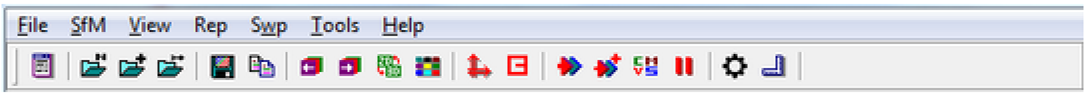
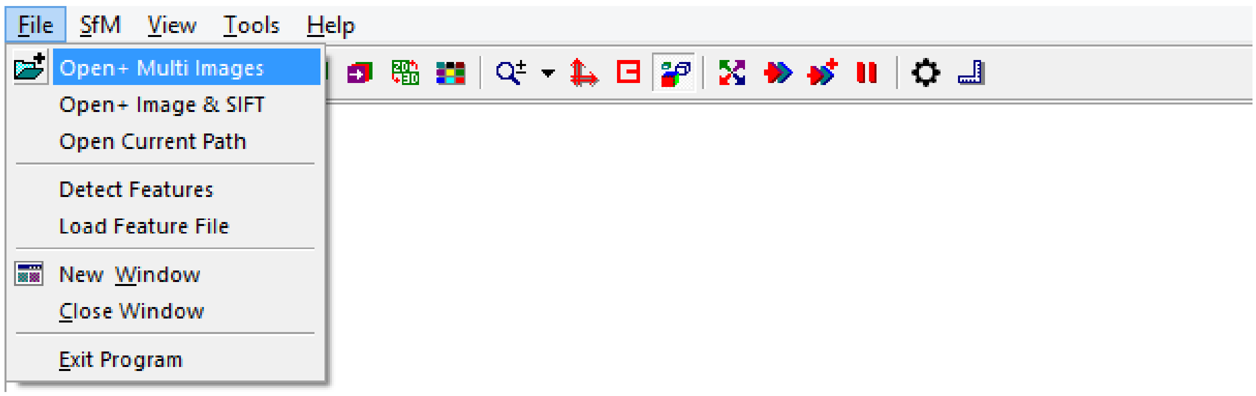


Figure 1: Examples of spherical method for object capture. Notice there are three pictures at each position with different distances.

VisualSFM



1) Click File and Open+ Multi Images



or

2) Select all of the images that will be apart of the mesh then click Open.

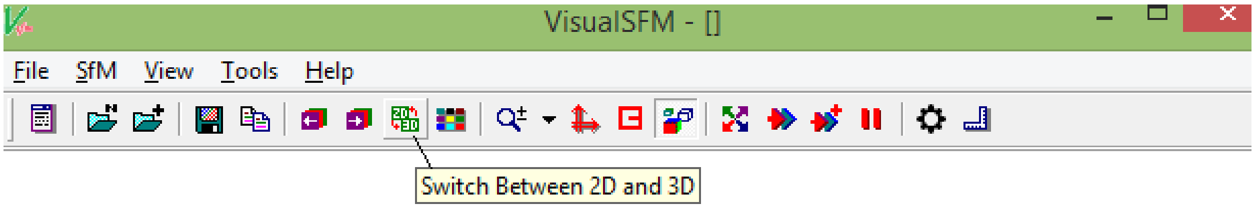
3) Click Compute Missing Matches in the tool bar.

4) Wait until "Compute Missing Pairwise Matching, finish" message is in the Log Window. This may take a between a few seconds to a few hours depending on the performance of the machine it's being ran on and the number of pictures.

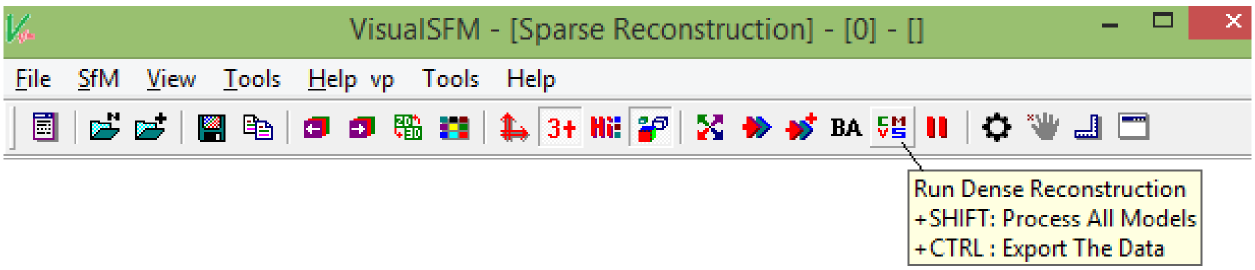
5) Click Compute 3D reconstruction in the tool bar.

6) Wait until "Run full 3D reconstruction, finished" message is in the Log Window.

7) If the top of VisualSFM does not says VisualSFM - [Sparse Reconstruction] then click the Switch Between 2D and 3D button to ensure that the CMVS button is available.



7) Click the CMVS, run Dense Reconstruction, button in the tool bar.



8) Name the file and click save.

9) Wait until "Run dense reconstruction, finished" message is in the Log Window.
This could take very long depending on the amount of pictures and the performance of the machine.

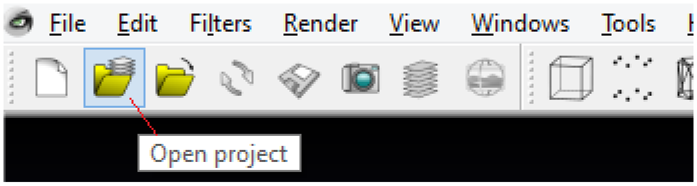
10) While the VisualSFM window is selected, Hitting the Tab Key on the keyboard will alternate between the sparse and dense view.

Tips:

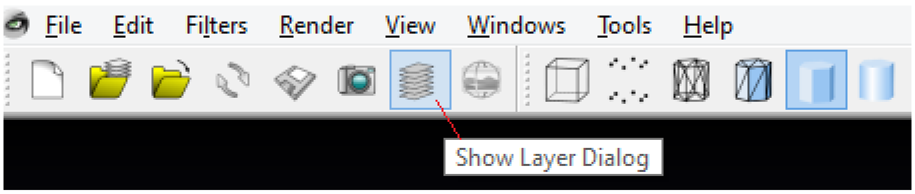
It is best to have only one sparse reconstruction. This means all the pictures that were taken are in one model and it creates the best point cloud. To check if VisualSFM generated more than one model the up and down arrow keys allow the user to switch between the models. If the user is unable to do so then there must only be the current sparse cloud that was created.

MeshLab

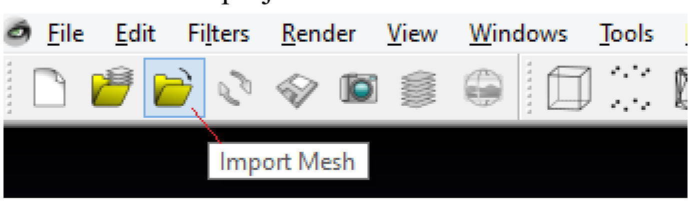
1) Open MeshLab version 1.3.4BETA or above.
2) Click on Open project.



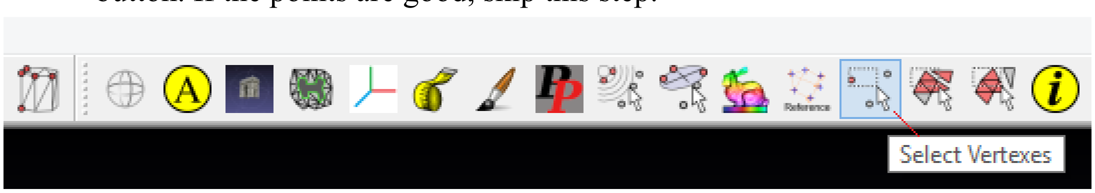
3) Navigate to the directory where VisualSFM put the dense reconstruction. Open the file that was created by VisualSFM. It should be a file with a .nvm extension.
4) Open the layers panel by clicking Show Layer Dialog

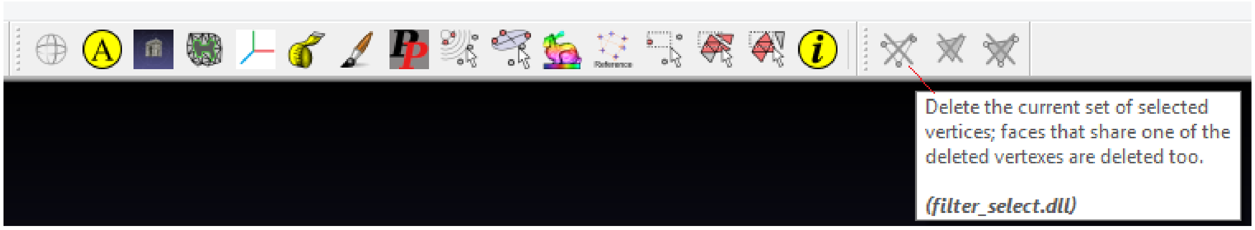


5) Right click on the mesh that was initially loaded by MeshLab and choose delete current mesh. This is the sparse reconstruction and does not have the details needed to recreate a good mesh.
6) Click on the Import Mesh button and open the file called example.0.ply where example is what that project was named when it was created. This is the dense reconstruction.

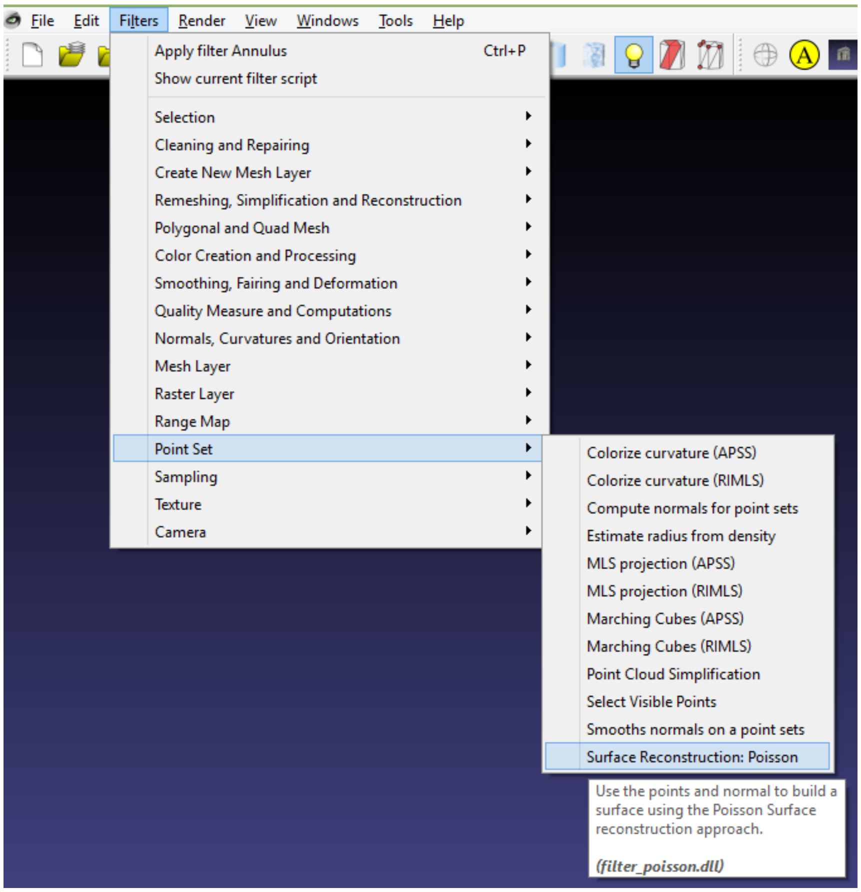


7) This is the clean up step where the dense reconstruction is cleaned to generate a better mesh. By clicking on Select Vertexes, the vertices of the dense reconstruction can be selected. This allows the user to select vertices for deletion. To delete the points selected, click the delete button shown below. This button corresponds to the Select Vertexes button. If the points are good, skip this step.

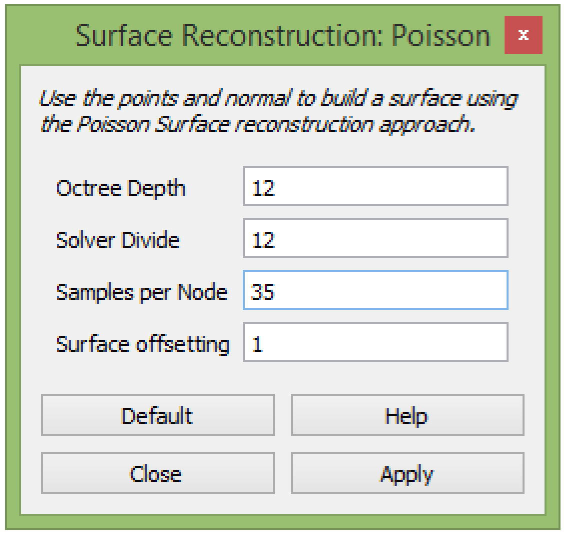




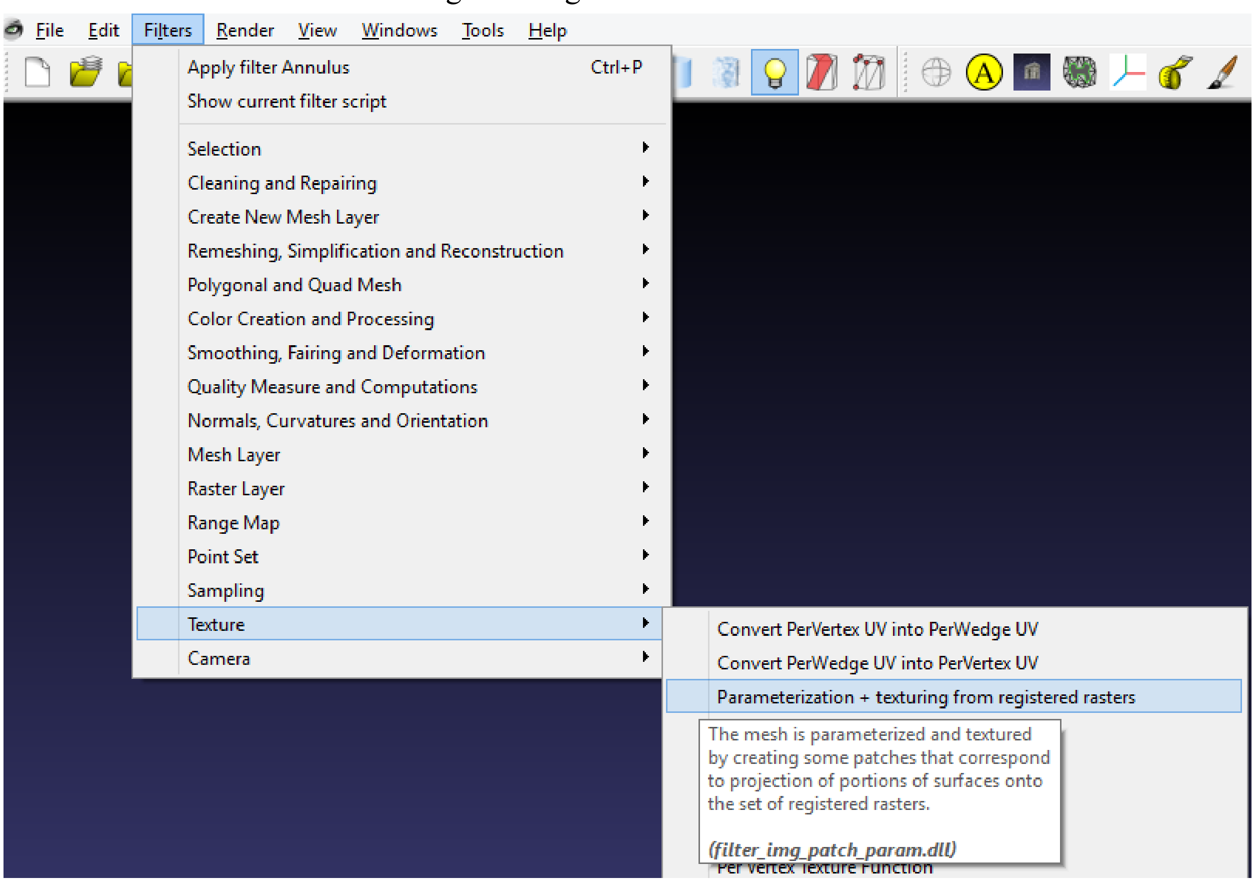
8) Now that the point cloud is cleaned and ready for reconstruction, make sure that the point cloud is selected in the Layer panel to the right. At the top of the window select Filter, then find Point Set, then click Surface Reconstruction: Poisson.



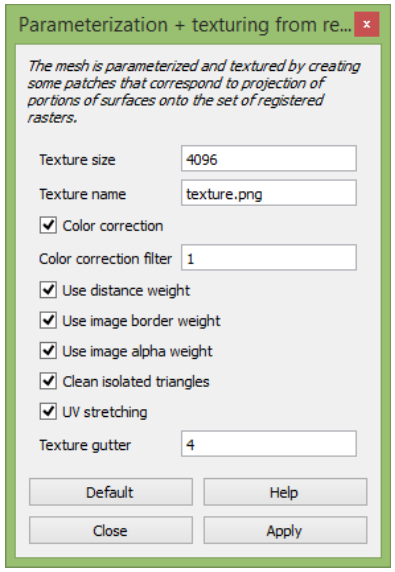
9) This part creates the actual mesh that could be printable if great care was taken when the photos were taken and during the clean up on step 7. In the Surface Reconstruction: Poisson window, choose 12 for the Octree Depth, 12 for the Solver Divide, 35 for the Samples per Node, and leave surface offsetting to 1. This combination of setting typically gave good result. If the mesh generated is not adequate enough, more samples tends to smooth out model as well as lessen the key features while less samples make the model rougher with more key features shown. The user is encouraged to test these setting to achieve a more appropriate mesh if desired.



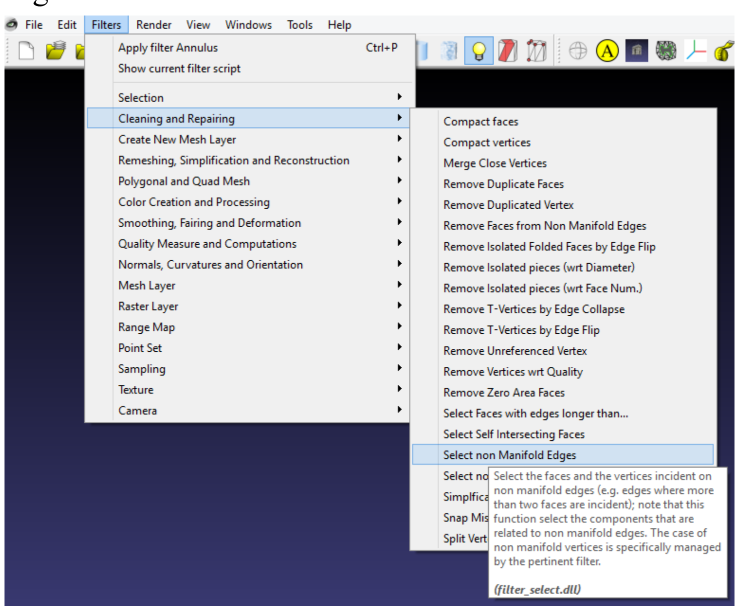
10) Now that there is a mesh that looks like the object being scanned, it's time to add the texture onto the object. Select Filters from the top, go down to Texture, then click on Parameterization + texturing from register rasters.



11) Now that the Parameterization + texturing from register rasters window is open, the setting are shown below that are typically used. The texture size can be reduced to 1024 for speed but if accuracy is desired higher texture sizes are better. If doing multiple different meshes, the texture name can be changed such that one texture won't overwrite another texture. Ensure that the poisson mesh that the texture belongs to is selected in the Layers panel to the right. Click apply.



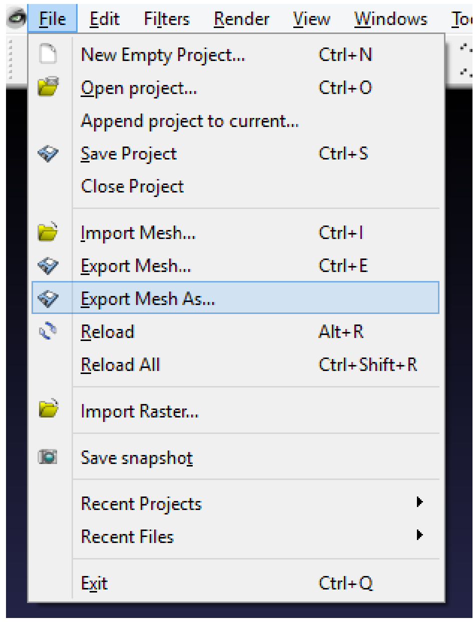
12) If there are non-manifold edges present in the mesh, select filter then go to Cleaning and Repairing. Click on Select non Manifold Edges. Click apply in the new window and then delete those edges.



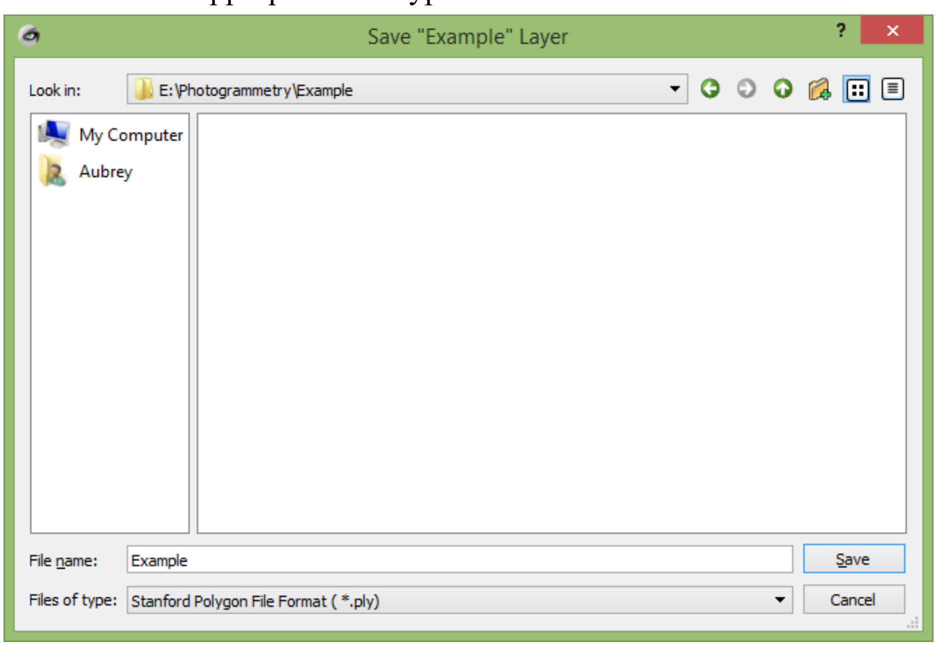
12) At this point the mesh is finished and it has a texture made for it. The next step will cover exporting the new mesh and associating a texture to it. If desired, MeshLab can render it

with more color and more light. These settings are at the top. Select Render and the options will be in Lighting and Color.

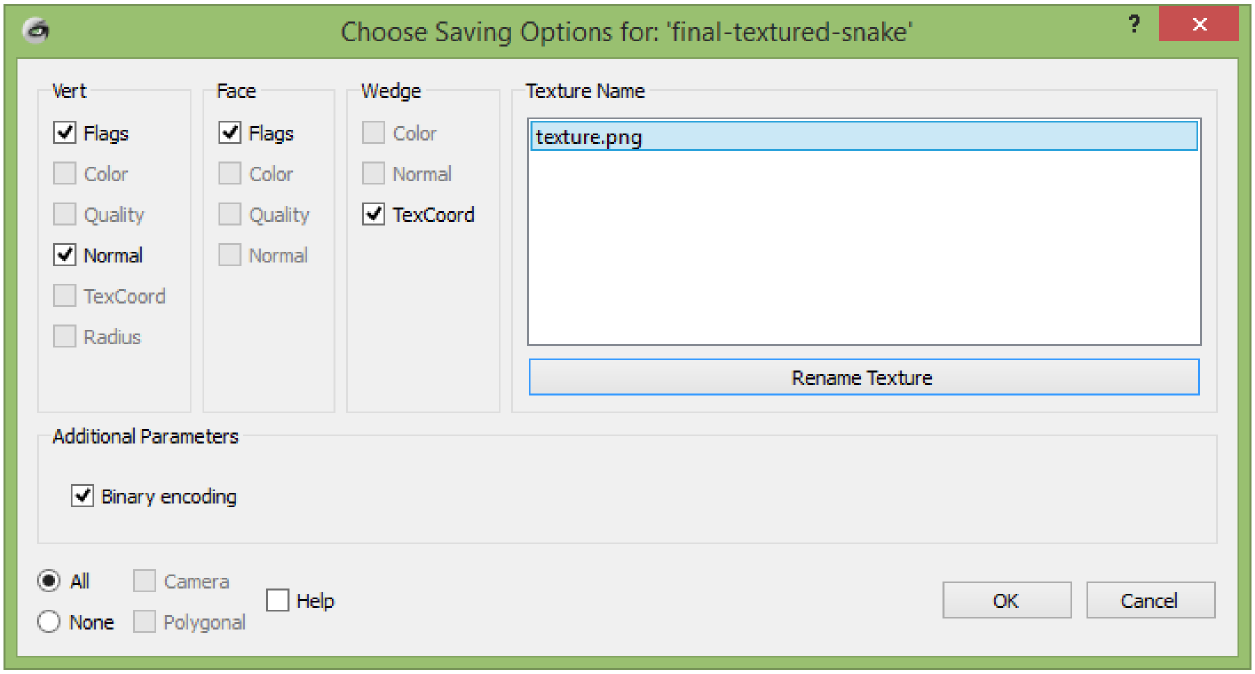
13) To export the newly created mesh, select file then go down to Export Mesh As…



14) In the save window, navigate to the directory that the mesh is to be created in and save it under a name. If a particular type of file is needed select the drop down menu Files of type: and select the appropriate file type.



15) Select the options shown below and select the texture that is to be associated with the model then click OK.



16) Move the texture to the same directory that the model is in and keep them together.

The model is finished. It can be opened in Meshlab again via the Import Mesh button or it can be opened in other softwares so long as the software can open the type of file that it was exported in.

Appendix B – Complete Test Reports

Test Results B.1 Taylor's Shoe

Item Name:	Talyor's Shoe
Tester(s) Name:	Aubrey Tharpe, Taylor Wagner, Nicolas Cardenas
Test Date:	23 February 2015
Test Time:	5:47 PM
Test Location:	College of Engineering Research Lab
Test No:	1
Overall Test Result:	Fail
Notes/Comments:	Background: Fail Frame: Fail Lighting: Fail Point Cloud: Fail Mesh: Fail Texture: Fail

Figure B.1: Final 3D model of Taylor's shoe

Taylor's shoe was scanned within the frame structure using the green screen muslin and LED strip lights. The camera used was a cellphone's back camera and took 4:3, 8 megapixel photos. The number of photos used during the sparse point cloud reconstruction was 70. During the mesh construction, the Poisson reconstruction values for the octree depth, solver divisor, samples per node, and surface off setting were 6, 6, 15, and 1 respectively.

As a result, the mesh was incomplete and lumpy since most of the points accumulated on one side of the shoe. This was the result of taking most of the pictures at one angle of the shoe. The texture was able to cover the gaps in the mesh making it look more complete, and texture's detail looked well enough to distinguish what type of object was in the model; however, due to the color spillage, this was a failure as well.

Test Results B.2 Calculator

Item Name:	Calculator
Tester(s) Name:	Aubrey Tharpe, Taylor Wagner, Rachelle Dauphin, Nicolas Cardenas
Test Date:	23 February 2015
Test Time:	7:41 PM
Test Location:	College of Engineering Research Lab
Test No:	2
Overall Test Result:	Pass
Notes/Comments:	Background: Pass Frame: N/A Lighting: Pass Point Cloud: Pass Mesh: Pass Texture: Pass

Figure B.2: Final 3D model of Rachelle's calculator

Rachelle's calculator was scanned on the desk in the College of Engineering research lab using the CFL panels on the ceiling as the light source. The camera used was a cellphone's back camera and took 4:3, 13 megapixel photos. The number of photos used during the sparse point cloud reconstruction was 76. During the mesh construction, the Poisson reconstruction values for the octree depth, solver divisor, samples per node, and surface off setting were 12, 10, 1, and 1 respectively.

As a result, the mesh was incomplete but maintained a similar structure to the real object. The mesh was incomplete because the object lied on a solid opaque surface. The texture's detail looked well enough to distinguish what type of object was in the model. The viewer is able to see the text on the calculator and the colors and depth of the buttons. The mesh was not smooth enough to keep the texture consistent; however, this test was an overall pass.

Test Results B.3 Snake

Item Name:	Snake
Tester(s) Name:	Aubrey Tharpe, Taylor Wagner, Rachelle Dauphin, Nicolas Cardenas
Test Date:	23 February 2015
Test Time:	8:03 PM

Test Location:	College of Engineering Research Lab
Test No:	3
Overall Test Result:	Pass
Notes/Comments:	Background: Pass Frame: N/A Lighting: Pass Point Cloud: Pass Mesh: Pass Texture: Pass

Figure B.3: Final 3D model of toy snake

The toy snake was scanned on the desk in Dr. Bernadin's research lab at the College of Engineering using the CFL panels on the ceiling as the light source. The camera used was a cellphone's back camera and took 4:3, 8 megapixel photos. The number of photos used during the sparse point cloud reconstruction was 133. During the mesh construction, the Poisson reconstruction values for the octree depth, solver divisor, samples per node, and surface off setting were 15, 15, 35, and 1 respectively.

During the sparse cloud reconstruction, the snake could be seen being formed. The sparse cloud was very detailed before being dense reconstructed. The result of this was from using more photographs, and using the "burst" feature on the phone. This allows the user to take continuous photographs while moving slowly around the object of interest. With this, the percentage of overlapping was higher. As a result, the mesh, although still incomplete due to the opaque background, was very smooth and had an accurate shape compared to the real object. The texture's detail came out with very little distortion looking precisely like real object. The viewer is able to see the ridges on the side of the snake as well as notice the smooth glossy texture of the polished wood. This test had the overall best results with indoor scanning.

Test Results B.4 Tigger

Item Name:	Tigger
Tester(s) Name:	Rachelle Dauphin
Test Date:	22 March 2015
Test Time:	12:18 AM
Test Location:	Senior Design Lab
Test No:	4
Overall Test Result:	Fail
Notes/Comments:	Background: Pass Frame: N/A Lighting: Pass Point Cloud: Fail Mesh: Fail Texture: Pass

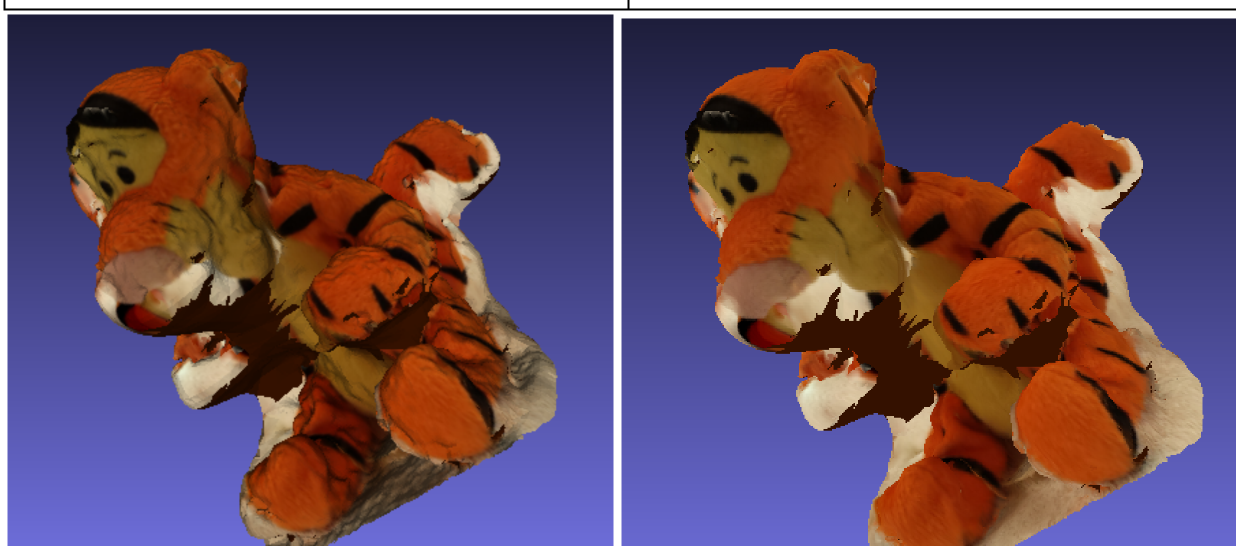


Figure B.4: Final 3D model of Tigger stuff animal toy. The final model with the light source option turned on (left) and turned off (right).

Tigger teddy bear was on a white towel in the College of Engineering senior design lab using the CFL panels on the ceiling as the light source. The camera used was a cellphone's back camera and took 4:3, 13 megapixel photos. The number of photos used during the sparse point cloud reconstruction was 78 since the computer used to create the 3D model had a low quality processor and graphics card causing the construction to take much longer than the previous tests if more photos were used. During the mesh construction, the Poisson reconstruction values for the octree depth, solver divisor, samples per node, and surface off setting were 12, 10, 1, and 1 respectively.

During the sparse cloud reconstruction, the structure of the teddy was noticeable however the chest and neck was not developed because the angles taken of the animal were too high. The sparse cloud was detailed from different angles picking up the back of the teddy bear as well. The result of this was from taking photographs from multiple angles front, side, and back of Tigger. The “burst” feature was also used for this. At first the overlapping was too high causing Visual SFM to crash. After removing some of the identical pictures, the program was able to complete the sparse cloud without issues. As a result, the mesh wrapped around from side to side and the top, but it was incomplete at the bottom due to the opaque background and high angles the pictures were taken. The mesh was lumpy and the shape was very distorted due to the missing points around the neck and chest.

A noticeable difference is when the program light source option is turned on or off. When on (the default setting) the mesh looked extremely lumpy, and the furry texture of the stuff animal is unseen; however, when this option was turned off, the mesh appeared smoother and the texture of the teddy bear was more visible. Due to the poor construction of the mesh, the test was an overall failure.

Test Results B.5 Doll

Item Name:	Doll
Tester(s) Name:	Aubrey Tharpe
Test Date:	7 April 2015
Test Time:	12:31 AM
Test Location:	College of Engineering Research Lab
Test No:	5
Overall Test Result:	Pass
Notes/Comments:	Background: N/A Frame: N/A Lighting: Pass Point Cloud: Pass Mesh: Pass

	Texture: Pass

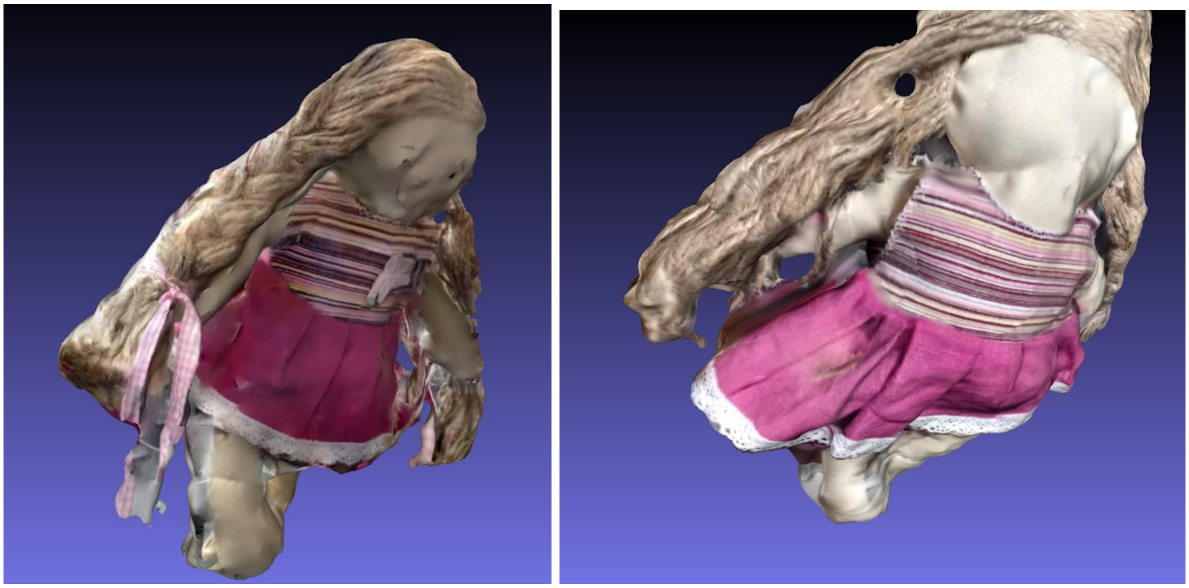


Figure B.5: Final 3D model of a rag doll. The final model from the front view (left) and back view (right).

The rag doll was scanned in the College of Engineering research lab using the CFL panels on the ceiling as the light source. To accomplish making a solid mesh, a new approach was tried which involves tying the doll with invisible fishing line and hanging it from the ceiling. Its feet were tied to a solid nonmoving object to keep the doll from rotating during scanning. The camera used was a cellphone's back camera and took 4:3, 8 megapixel photos. The number of photos used during the sparse point cloud reconstruction was 204. During the mesh construction, the Poisson reconstruction values for the octree depth, solver divisor, samples per node, and surface off setting were 15, 15, 35, and 1 respectively.

This was the first method that received an enclosed mesh. The pictures were taken at fixed angles and distances. The mesh was slightly distorted due to the difficulties of capturing the frontside of the doll since it was hung close to the computers while suspended in the air. Overall, the texture's detail looked well enough to distinguish what type of object is in the model. The viewer is able to see the texture of the hair and dress. The mesh was not smooth enough to keep the texture consistent; however, this test was an overall pass.

Test Results B.6 Doll 2

Item Name:	Doll 2
Tester(s) Name:	Aubrey Tharpe

Test Date:	9 April 2015
Test Time:	2:45 PM
Test Location:	College of Engineering Ground Floor
Test No:	6
Overall Test Result:	Pass
Notes/Comments:	Background: Pass Frame: Pass Lighting: Pass Point Cloud: Pass Mesh: Pass Texture: Pass

Figure B.6.1: Final 3D model of a rag doll second attempt. The final model from the back view (left) and front view (right).

The rag doll was scanned using the PVC frame and white translucent sheets as a cover. The fluorescent lights and umbrella diffusers were set up and used for the first time. The fishing line method was used again where its waist was tied to the upper pipes of the frame and the feet were tied the lower ones. The video recording method was chosen taking a 1280 x 720 video with a cellphone. The video was uploaded into VLC to turn the video into individual frames. After removing identical and blurry frames, the number of photos used during the sparse point cloud reconstruction was 273. During the mesh construction, the Poisson reconstruction values for the octree depth, solver divisor, samples per node, and surface off setting were 15, 15, 35, and 1 respectively.

Improved results were achieved, and the dense cloud required little clean up of unwanted floating points. The mesh contained a little distortion but was enclosed. It has been concluded that the mesh was capable of being exported and used for 3D printing.

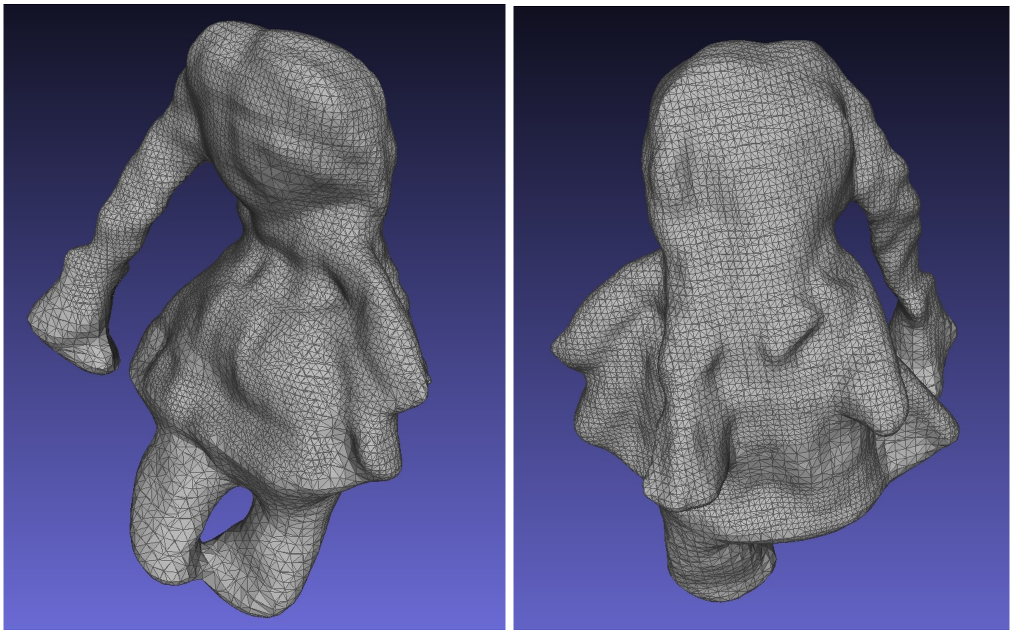


Figure B.6.2: Wireframe view of the 3D model of a rag doll. The back view (left) and front view (right).

The texture was more detailed than the previous attempt. Parts of the dress are more visible, such as the material used to make the flower on the doll's chest. Overall, the mesh is very well detailed and the viewer is able to see what material was used to create the doll's body, hair, dress, and accessories. The mesh came out smooth and accurately shaped. This test was successful.

Test Results B.7 Taylor

Item Name:	Taylor
Tester(s) Name:	Aubrey Tharpe, Taylor Wagner, Rachelle Dauphin, Nicolas Cardenas
Test Date:	9 April 2015
Test Time:	3:53 PM
Test Location:	College of Engineering Ground Floor

Test No:	7
Overall Test Result:	Pass
Notes/Comments:	Background: N/A Frame: N/A Lighting: Fail Point Cloud: Pass Mesh: Pass Texture: Pass

Figure B.7: Final 3D model of Taylor

Taylor was scanned on the College of Engineering ground floor using the CFL panels on the ceiling and the sunlight as the light source. Taylor would be the largest test object for scanning. Again, the video recording technique was used taking a 1280 x 720 video with a cellphone. The video was uploaded into VLC to turn the video into individual frames. After removing identical and blurry frames, the number of photos used during the sparse point cloud reconstruction was 568. During the mesh construction, the Poisson reconstruction values for the octree depth, solver divisor, samples per node, and surface off setting were 15, 15, 35, and 1 respectively.

For the mesh, the lower regions of Taylor's body was distorted due to the lack of overlapping at that angle; however, his upper body came out well shaped after cleaning up the noise surrounding him. The back of Taylor's body was disfigured and discolored due the camera facing towards sun. It can be concluded that an intense light source would cause the camera to focus on trying to correct the light source rather than the object being scanned. Overall, the details of Taylor's face and shirt are well defined and the mesh doesn't contain exaggerated feature that distorts the layout of the texture map. Although the scan was mainly successful for the upper body of Taylor, this test was successful overall.