**Freshman Summer Project 2012**

**360**° **Structured Light Scanner**

**User Manual**

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**Glossary of Terms**

***Any word which is underlined in the document has been defined here for your convenience***

**Intrinsic Calibration** - details the optical properties of a camera or projector. The *Camera Calibration* and *Projector Calibration* functions of the program fulfill this task.

**Extrinsic Calibration** - defines the positional relationship between a camera and a projector.  Requires that both camera and projector are intrinsically calibrated. Each camera must be extrinsically calibrated in order to use it for scanning.

**Camera Gain** - adjusts the brightness of the camera feed.

**System Components**

***Physical Components***

***Computer***

* + CPU: Intel Core i5-2500 CPU @ 3.30GHz per core
  + Memory: 8GB DDR3 RAM
  + Hard Drive: 500GB
  + Video Card:
    - Primary: NVIDIA GTX 550 Ti (2GB GDDR5 RAM)
    - Secondary: NVIDIA GT 520 (1GB DDR3 RAM)
    - Tertiary: NVIDIA GT 520 (512MB DDR3 RAM)
  + Operating System: Microsoft Windows 7 Enterprise 64-bit
  + Peripherals: Multiple monitors

***Scanner***

* + Projectors: 4x Optoma PK320 Pico-Projectors
  + Cameras: 4x Point Grey Chameleon Color Cameras
  + Camera Lenses: 4x 16mm Edmund Optics C-mount lenses
  + 1x 80/20 Ten Series 1x2 48 inch bar
  + 3x 80/20 Ten series 1x1 12 inch bar
  + 2x 80/20 Ten series 1x1 24 inch bar
  + 2x 80/20 Ten series 1x2 24 inch bar
  + 8x Oben knuckle joint with knob adjustment
  + 4x 80/20 Ten Series 12-hole 90 degree joining plate
  + 4x 80/20 Ten Series 8-hole 90 degree joining plate
  + 2x 80/20 Ten Series 5-hole tee joining plate
  + 8x Edmund Optics knuckle with knob adjustment

***Table Mounted Version only***

* + 16x 80/20 Ten Series 2-hole inside corner bracket
  + 110x 80/20 Ten Series 1/4-20 X .687 Slide-In T-Nut

***Tripod Mounted Version only***

* + 96x 80/20 Ten Series 1/4-20 X .687 Slide-In T-Nut

***Software Components / Dependencies***

* OpenCV – <http://opencv.org/>
* FlyCapture2 – <http://www.ptgrey.com/products/pgrflycapture/flycapture_camera_software.asp>
* TBB – <http://threadingbuildingblocks.org/>
* Boost – <http://www.boost.org/>
* PCL – <http://pointclouds.org/>
* Meshlab – <http://meshlab.sourceforge.net/>
* Helix Toolkit – <http://helixtoolkit.codeplex.com/>

**Setup**

***Software Installation and Setup***

* FlyCapture2: Register for an account at <http://www.ptgrey.com/> (Point Grey) and download the FlyCapture2 software. Install only the drivers you are required to use for your cameras (Firewire or USB), and disable “Managing Processor States”.
* OpenCV Install: Download OpenCV from <http://opencv.org/> version 2.4.2 (the version that the program was developed for; using newer versions are possible, but are not guaranteed to work). Install OpenCV into “C:\libs\opencv\” and add an entry into the PATH\* for “C:\libs\opencv\build\x86\vc10\bin”.
* Threading Building Blocks: Download the release from <http://threadingbuildingblocks.org/> and install it into “C:\libs\tbb\” and add “C:\libs\tbb\bin\ia32\vc10” to the PATH\*.
* PCL: Download <http://pointclouds.org/downloads/> into any desired location and select the option to add the install directory to the PATH during the installation. Also, you will need to add “C:\Program Files (x86)\PCL 1.6.0\3rdParty\FLANN\include” and “C:\Program Files (x86)\PCL 1.6.0\bin” to the Path.
* Visual Studio 2010 Redistributable (x86): Download from Microsoft and install.
* Boost (required only for compilation): Download the 1.50 release from <http://boost.org/> and install it into “C:\libs\boost\”.
* Meshlab(Optional, allows for viewing of point clouds and meshes outside of this program): Download and install Meshlab from <http://sourceforge.net/projects/meshlab/files/meshlab-devel/MeshLabDevel_v132BETA/> .

\* To add files into the PATH, go to the Windows Start menu (or Start screen), and type into search “Environment Settings”, and select “Edit System Environment Variables”. From here, click the button “Environment Variables…” and under the header “System Variables”, scroll down to the Variable with the name “PATH”. Highlight it, and click “Edit...”. At the end of the Variable Value line, add a “;” then the directory listed above. (For example, the OpenCV line should be “;C:\libs\opencv\build\x86\vc10\bin”).

***Compiling (not required)***

To compile the Structured Light Scanner program, obtain a copy of the source, and open StructuredLight.sln (Visual Studio 2010 or higher required). Once open, go to the Build directory, and click “Build Solution”. Once it finishes compiling, there will be the program in the bin/ directory, just copy the config.default.xml into the bin directory and rename it to config.xml.

***Environment***

The type of environment required to run the scanner is a dark area. There can be lights on nearby, however, this will increase the amount of noise in the scan. The system also needs to be in a location in which the projector and camera pairs will not be moved. If the projector and camera pairs are moved, the extrinsic calibration will need to be redone, as otherwise, the scans will not properly be constructed.

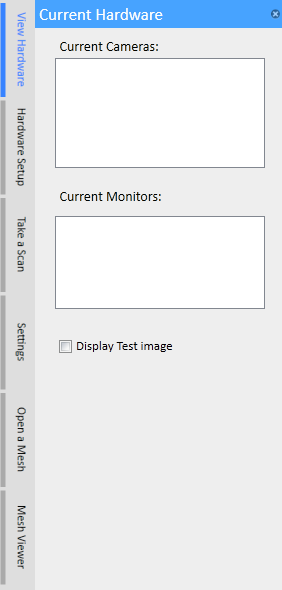
***Calibration Boards***

If you need to create a new calibration board, you can find a .png file of the pattern used in “C:\libs\opencv\doc” under the file name “acircles\_pattern.png”. Open this file in Paint.NET or some other graphical editing program and adjust the brightness as needed (alternatively, you can use the copy in the bin directory which has already been edited). Print this out, and you are ready to calibrate the system.

**Running the Software**

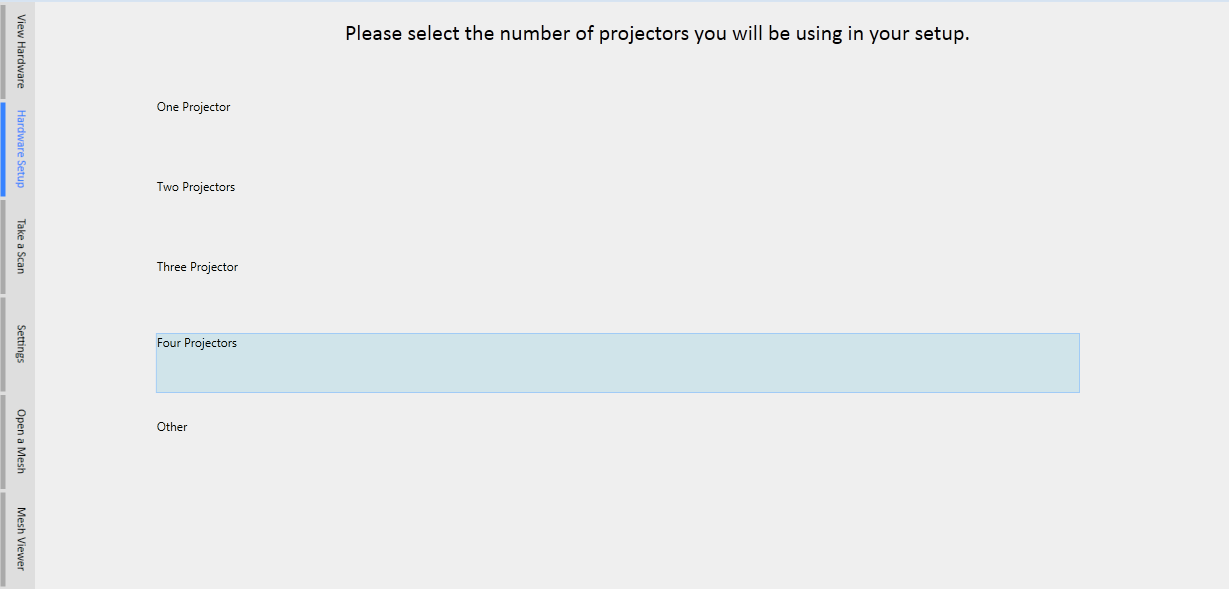
The Structured Light Scanning software (StructuredLight.GUI.exe) is a GUI designed to assist the user in creating a 3D model of an object. This program will walk you through the main steps on how to set up the scanner, how to use different system configurations, and how to take a scan. In this program, the sidebar on the left of your screen is the main controller for the program. It contains all of the functions of the program, and contains 6 tabs that control all functions of the scanner.

***View Hardware***

**Figure 1 – The Current Hardware Tab**

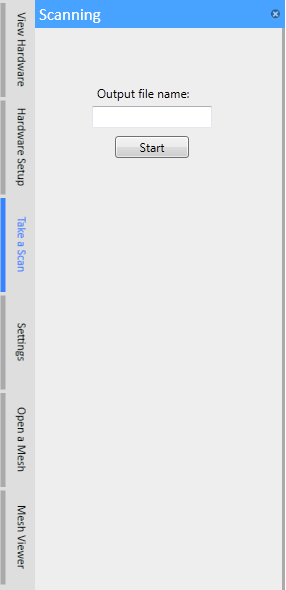
This tab displays all of the cameras and monitors that are currently detected in the program. If a camera or projector that you are attempting to use does not appear in this list, the program cannot detect it, so make sure that the camera or projector is plugged in, turned on, and the drivers are installed. For monitors, if you need help detecting which monitor you are attempting to use, you can click the “Display Test Image” checkbox to display an image with text on it on the monitor you have selected.

***Hardware Setup***

**Figure 2 – The Hardware Setup page, displaying the option of how many projectors will be used**

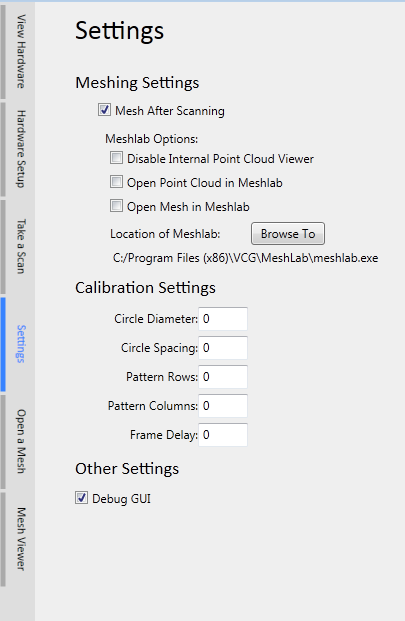
This tab sets up the system and makes it ready to take a scan. This can be re-run at any point to calibrate any new cameras, and deal with any system changes. First, you will have to select the number of projectors that will be in your setup. You will be taken to a new page in which it will display a graphical representation of your system, at which point, you will be required to fill in the information about your system. Click on “Select Camera” to bring up a new window that will walk you through how to select and calibrate your camera or “Select Projector” to bring up a new window that will walk you through how to select and calibrate the projector once the cameras have been calibrated. The next step is to do extrinsic calibration, which aligns the cameras and projectors into a common coordinate system. It will tell you how to perform extrinsic calibration, and have the camera preview open to show you what the camera is able to view. Once this is finished, the setup is complete, and you are now able to take a scan.

***Take a Scan***

**Figure 3 – Taking a Scan tab, displaying the initial setup required before scanning**

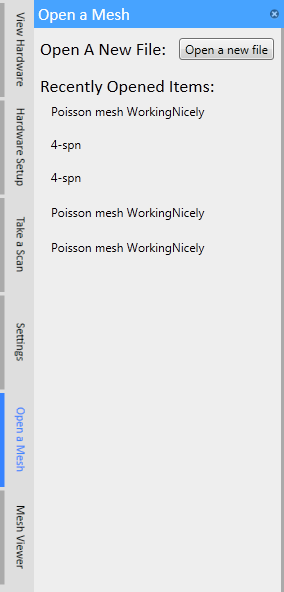
This tab will allow you to take a scan with the scanner if you have properly set up the system. If you have not set up the system yet, please click on the “Hardware Setup” tab and follow the instructions for using it first. To be able to take a scan, you may first decide on what to name the file that the scanner will output if you do not wish to use the default naming scheme. Next, click on the “Start” button, and the scan will begin on using all projectors and cameras last set up in Hardware Setup. The images from the different cameras will be displayed on the screen as the scan progresses. Once the scan has completed, the mesh will be generated (optional), and the mesh will be displayed in the Mesh Viewer (optional). If the program locks up during this process, reopen the program and try again. Sometimes, the cameras will not send all of the information successfully, which will cause the program to crash. If the scan ends up not aligning properly (between the different camera-projector pairs), you may want to load each aligned point cloud separately, and manually align them in Meshlab. The automatic alignment works best if you have the front of the subject pointed directly at the first camera you set (the root camera-projector pair) when setting up the system.

***Settings***

**Figure 4 – Settings Tab**

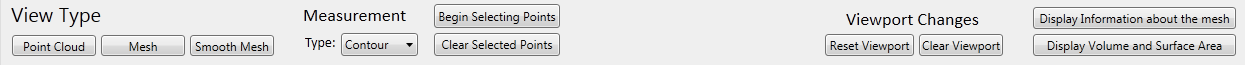
This tab allows you to change different configuration options for the system and how it operates. Under the “Meshing Settings” header, all options related to what happens after a scan takes place exist. You can hover your mouse over the option to view more information about what each option does. Under the “Calibration Settings” header, you can change options that relate to which type of calibration board the system will be looking for when doing calibration. These settings do not normally need adjusting.

***Open a Mesh***

**Figure 5 – Open a Mesh Tab, displaying 5 recently opened mesh files**

This tab allows you to open mesh files on your hard drive in the Mesh Viewer. It has the option for opening a mesh from a new file (“Open a new file” button), or selecting a recently opened mesh file to view in the Mesh Viewer.

***Mesh Viewer***

**Figure 6 – Mesh Viewer options**

This tab allows you to view the current mesh file and take various measurements, including straight distance, contour, and volume measurements.

***View Type***

It is possible to control which type of data you are seeing by clicking on the View Type options, “Point Cloud”, “Mesh”, and “Smoothed Mesh”. These options control whether you see a point cloud, a mesh, or mesh with smoothed faces (to make it look less striated).

***Viewport Changes***

Under “Viewport Changes”, you can reset the camera with “Reset Viewport” or remove the current mesh from the screen with “Clear Viewport”.

***Measurement***

To be able to take different measurements on the mesh, you must first select which type of measurement you would like to do. In the “Type” selection dropdown, you can select from “Contour”, “Direct”, or “Cut”.

***Contour***

To take a contour measurement, first start by verifying that the Type is set to “Contour”, and then begin by pressing “Begin Selecting Points”. This will allow you to double click on the mesh, at which point you will select 3 points from which it will determine the distance between them on the mesh. After double clicking on the mesh 3 times, the calculation will be done, and the result will be displayed in the upper left corner of the Mesh Viewer.

***Direct***

To take a direct measurement, first start by verifying that the Type is set to “Direct”, and then begin by pressing “Begin Selecting Points”. This will allow you to double click on the mesh at which point you will select 2 points from which it will determine the distance between them. After double clicking on the mesh twice, the calculation will be done, and the result will be displayed in the upper left corner of the Mesh Viewer.

***Cut***

To cut the mesh into 2 parts, first start by verifying that the Type is set to “Cut”, and then begin by pressing “Begin Selecting Points”. This will allow you to double click on the mesh at which point you will select 3 points which are on the plane which will be used to cut the mesh. After selecting the three points, the mesh will be split into 2 parts, one blue, and one white, and it will ask you to double click on the side which you want removed, leaving only one half of the mesh left. If you do not wish to choose either side, you may double click on any of the grey part of the screen to go back and not select either side. After double clicking on one of the two pieces, it will remove that half, and change the others color back to its original color.

***Display Information and Volume Calculation***

To get the volume of the current mesh, you can click on the button “Display Volume and Surface Area”, which will calculate the estimated volume and surface area of the current mesh. The results will then be displayed in the upper left corner of the Mesh Viewer. To display more information about the number of faces and vertices that the mesh has, you can click on “Display Information about the mesh” which will display this information in the upper left corner of the Mesh Viewer.

**Troubleshooting**

***Hardware Troubleshooting***

**The program can’t find the cameras.**

*Make sure the cameras are plugged into the computer properly. If they are, make sure the Point Grey drivers for the cameras are installed.*

**The program displays a black image when a camera is selected after initially plugging into the computer.**

*Restart the program, as sometimes, the cameras will not properly interface with the computer after initially being plugged in. After the restart, they should work correctly.*

***Software Troubleshooting***

**The program opens for a brief moment, then stops working and closes.**

*Make sure that all of the required programs outlined in Software Installation and Setup have been installed correctly and try again.*

**While scanning, the scan stops, and is not able to move on.**

*The computer is not able to handle all of the cameras sending the data at the same time. (This occurs because USB2 is not able to properly handle the amount of data that is being streamed from all cameras at the same time). One solution would be to use Firewire-based cameras (or anything other than USB). You will not be able to use any data from that scan and you will have to try again.*

**An error notification pops up during the saving of a scan.**

*To be able to see whether the extrinsic calibration is wrong for your system, the scans from each camera are available to view in the bin directory. You can view these different scans in Meshlab (or other mesh viewing software, if you do use Meshlab to view them, you must scroll down to the next item “****Notes on opening a .ply file in Meshlab from the bin folder****” to be able to open the file). If your system’s extrinsic calibration is the cause of the error notification, when opening “*0\_FILENAME.ply*”, “*1\_aligned\_FILENAME.ply*”, “*2\_aligned\_FILENAME.ply*” (replacing “FILENAME” with the name of the scan you took), the scans will not look like the object you are scanning (so the different scans will be in the wrong places, for example, if you are scanning a person, the side of their face might be far off in the distance, or in the middle of their head). If you see this, you need to redo the system’s extrinsic calibration. However, if there is nothing recognizable from the scans that you have opened, the problem is possibly the combination of the environment (read in the Environment section above) that the system is in and the extrinsic calibration being wrong. You also may have the apertures too low on the cameras you are using, so check under “View Hardware” in the GUI that the camera can see the object well (when the projector is displaying whatever color it is supposed to be displaying).*

*If the extrinsic calibration is not the problem, and the file “all\_aligned\_FILENAME.ply” exists (replacing “FILENAME” with the name of the scan you took), then the extrinsic calibration is certainly not your issue. The issue is probably then that the scan is too detailed to be able to generate a mesh for it (as the memory required to do so is larger than what the program/computer can handle). Unfortunately, there is nothing that can be done about this, so let’s hope that it never occurs! (You can attempt to generate a lower quality poisson mesh in Meshlab from the file listed above).*

**Notes on opening a .ply file in Meshlab from the bin folder**

*Before you can open them with Meshlab, you must open the .ply file in a text editor such as Notepad++ (any text editor will work, however, they may be terribly slow to open the file and/or crash). You need to replace all instances of “#IND” with “00000” in the file. To do this, press “Control+H” to open the replace box (in most editors, otherwise, look under the menus for Find/Replace). In the Find box, put “#IND” and in the Replace box, put “00000”, and then click “Replace all in document” (or “Replace all” if this option does not exist in your text editor). Save the file, and it should now load in Meshlab, even though an error will still pop up in Meshlab saying that the mesh failed to load (which it did not).*