High Resolution 3D Scanner for Factory Automation Using DLP® Technology

User's Guide

Texas Instruments

Literature Number: DLPU032A
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Contents

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About This Guide

The 3D Scanner Reference Design enables faster evaluation of scanning applications utilizing DLP® platforms. This guide walks the user through the installation, calibration, and operation of the 3D Scanner Reference Design.

Related Documentation from Texas Instruments

DLPC900 Datasheet: *DLPC900 Digital Controller for Advanced Light Control*, DLPS037

DLP6500FLQ Datasheet: *DLP6500FLQ 0.65 1080p MVSP Type A DMD*, DLPS040

DLP6500FYE Datasheet: *DLP6500FYE 0.65 1080p MVSP S600 DMD*, DLPS053

User's Guide: *DLP® LightCrafter ™ 6500 and 9000 EVM User's Guide*, DLPU028

User's Guide: *DLP® Advanced Light Control SDK for Lightcrafter™ EVMs*, DLPU042

Assembly Guide: *TIDA-00362 Camera Trigger Cable Assembly*, http://www.ti.com/lit/df/tidreb7/tidreb7.pdf

If You Need Assistance

Refer to the DLP and MEMS TI E2E Community support forums:
http://e2e.ti.com/support/dlp__mems_micro-electro-mechanical_systems/default.aspx

Minimum System Requirements

- PC with 1GHz, or faster, 32-bit (x86) processor
- 2GB RAM
- 10GB of free hard-disk space
- Microsoft® Windows® 7 SP 1
- Microsoft Visual C++ 2010 Redistributable
- Microsoft Visual C++ 2012 Redistributable
- Microsoft .NET Framework 4.5.1
- USB 3.0 port
- USB 2.0 port
- Qt Creator 5.3.2 Integrated Design Environment (IDE)
- OpenCV v2.4.10 Libraries
- Point Grey FlyCapture® v2.9 SDK
- MeshLab v1.3.3
- DLP® LightCrafter 6500™ Evaluation Module
- Point Grey Grasshopper®3 USB 3.0 Camera

Note: The 3D Scanner Reference Design installation and setup is written for users that are familiar with navigating through Windows command line prompts.

Note: The 3D Scanner Reference Design was created with the above listed versions of each software tool. Using newer versions of the software tools may render the code inoperable.

Introduction to the 3D Scanner Reference Design

1.1 The 3D Scanner Reference Design is an active 3-dimensional photography system that generates a digital representation of a physical object. The data generated by the 3D Scanner Reference Design can be analyzed, or otherwise manipulated, to provide information to automated systems about their environment. The information created by the 3D Scanner Reference Design allows machines to make intelligent decisions in a dynamic environment. Applications include 3D metrology, factory automation and robotic vision.

1.2 Structured Light

Structured light is a method to achieve 3-dimensional photography of objects by manipulating lighting conditions of a scene under study. The 3D Scanner Reference Design projects a series of time-multiplexed and three phase patterns to extract spatial data from a scene. The 3D Scanner Reference Design leverages the highly-programmable DLP digital micromirror device to rapidly display patterns reducing data acquisition times. DLP is also light source agnostic, making it well suited for structured light applications using solid-state – near infrared, visible, or ultraviolet light – or laser-based illumination.

1.3 How the 3D Scanner Reference Design Works

The 3D Scanner Reference Design consists of a LightCrafter 6500 evaluation module and a camera interfacing with a host PC. The 3D Scanner Reference Design utilizes multiple DLP Advanced Light Control SDK for Lightcrafter™ EVMs (hereto referred to as the DLP ALC SDK) modules to perform necessary calculations on the host PC.

1.3.1 Projector and Camera Modules

The host PC must send and receive data from both a projector and camera. In this reference design, a Point Grey Grasshopper3 camera is used with a LightCrafter 6500 module that enables easy, feature-rich use of the projector.

1.3.2 Calibration

The DLP ALC SDK contains a calibration module to estimate intrinsic and extrinsic parameters of both the camera and projector. An example of the estimated parameters include focal point, lens distortion, and spatial orientation of the camera to the projector. The calibration routine must be performed any time the projector and camera change orientation with each other, or the devices are replaced.

1.3.3 Pattern Projection

Pattern projection is handled by a structured light module in the DLP ALC SDK. The module generates vertical and horizontal Gray coded patterns or phase shifted patterns that are sent to a LightCrafter 6500 projector. The firmware file is prepared and uploaded to the projector using the LightCrafter 6500 module.

1.3.4 Image Capture

Each projected pattern is captured by the Point Grey Grasshopper3 global or rolling shutter camera or a compatible OpenCV camera (such as a webcam). The images are stored in an image class and the information in the series of images is decoded by the structured light class.

1.3.5 Information Decoding

The structured light class performs decoding of the captured images to determine which projector ray the camera ray detects.

1.3.6 Point Cloud Reconstruction

Objects in view of both the camera and projector will cause different rays from the camera and projector to intersect each other. This intersection can be calculated by using the Gray coded and/or phase-shifted ray information from the projector along with the detected ray information from the captured images. This intersection of rays determines an object's real point in space. The geometrical ray intersection calculations are performed by a geometry module in the DLP ALC SDK for each intersecting point.

The points generated by the geometry module are stored in a collection called a point cloud. The point cloud is all of the known points from a captured scene. Software tools and algorithms can be produced to use point clouds to create solid surfaces. MeshLab is the software tool used to view point clouds during the 3D Scanner Reference Design development.

Installing the 3D Scanner Reference Design

2.1 Before using the 3D Scanner Reference Design application, a few software dependencies and the reference design software itself must be installed. The Point Grey FlyCapture 2+ SDK supplies the drivers required for operating the Point Grey Grasshopper3 USB camera, and MeshLab acts as a 3D viewer for the generated point cloud files. Please read the following sections for more detailed instructions.

2.2 Installing the Point Grey FlyCapture® 2+ Full SDK

The Point Grey software development kit (SDK) supplies the required drivers for image capture when using the Point Grey cameras. This section walks the user through set up of the FlyCapture2 Full SDK.

Warning: Ensure that Microsoft .NET Framework is installed along with the Visual C++ redistributables listed in the *Minimum System Requirements*.

1. Go to the Point Grey download site, located at http://www.ptgrey.com/support/downloads and download the FlyCapture2 Full SDK for the appropriate operating system, as shown in Figure 2-1.

   Note: When developing with the DLP ALC SDK, install the 32-bit version of the FlyCapture SDK to ensure compatibility with the MinGW compiler used in later steps.

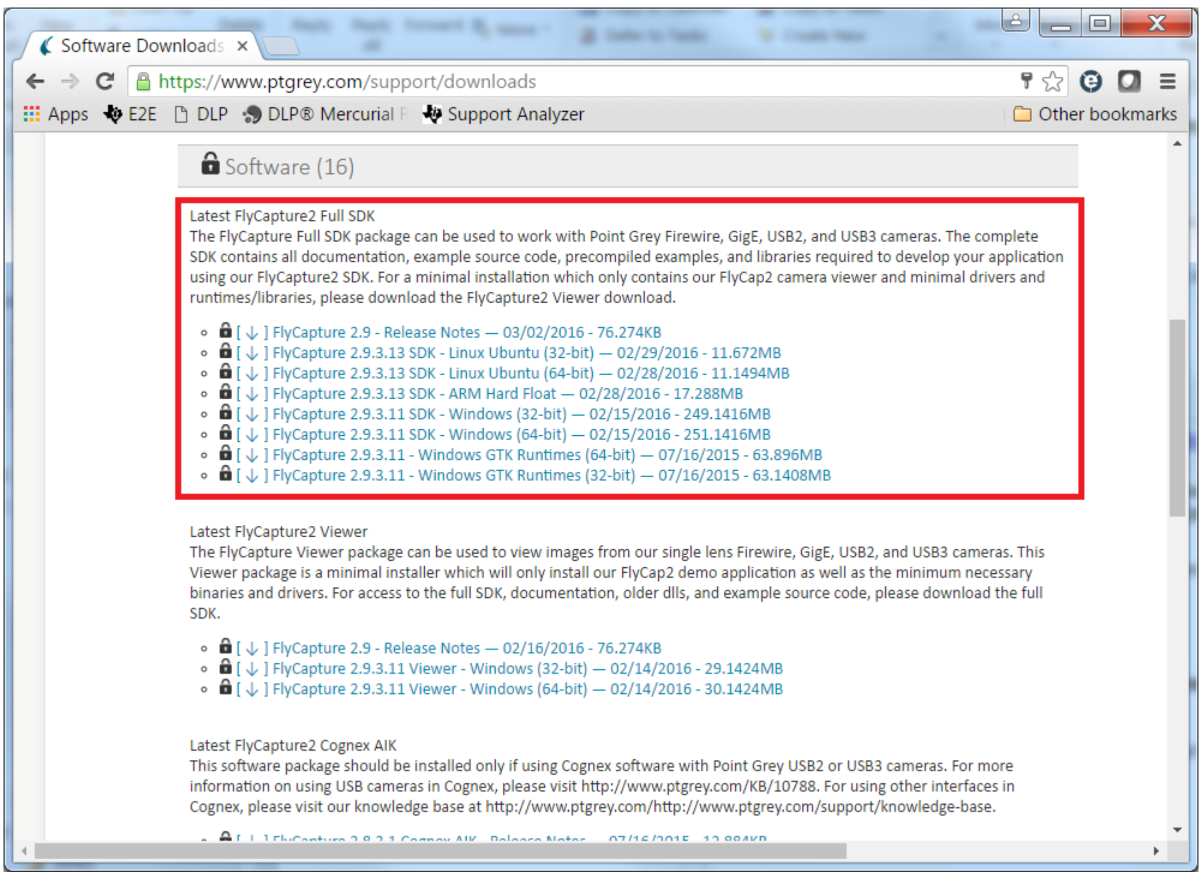


Figure 2-1. Point Grey Software Downloads Page

2. Run the downloaded installation file and click the "Install" button, as shown in Figure 2-2.

   Note: If the Microsoft .NET Framework has not already been installed, the FlyCapture installer will attempt to install it.

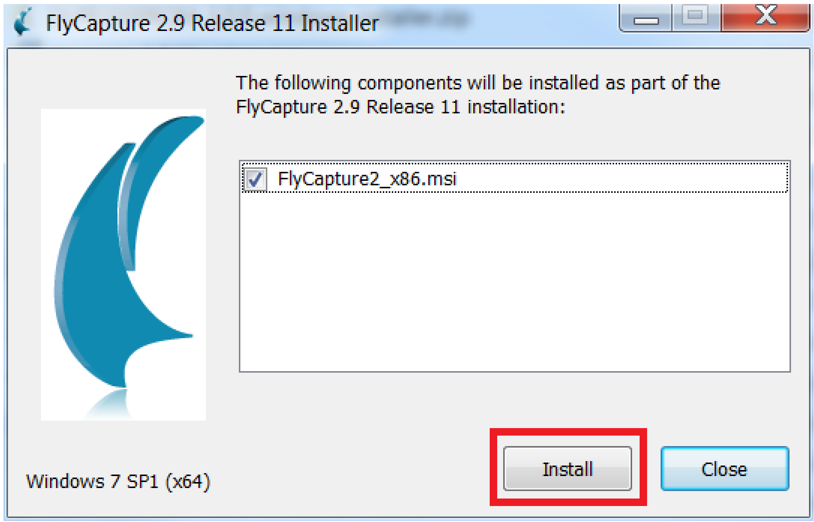


Figure 2-2. Setting Up the FlyCapture2 Install

3. After extraction of the installation components, the installer will begin with a welcome page as shown in Figure 2-3. Click the "Next" button to continue.

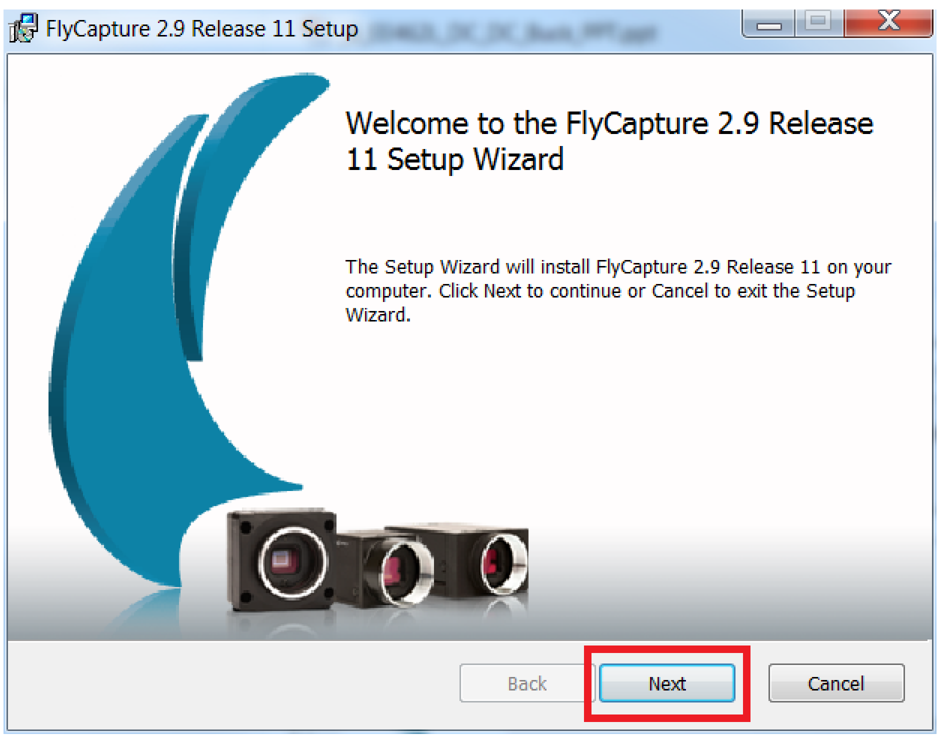


Figure 2-3. FlyCapture2 Installation

4. Read and accept or decline the end-user license agreement for the FlyCapture2 SDK as shown in Figure 2-4. If the license agreement is declined, the SDK will not be installed. Click the "Next" button to continue.

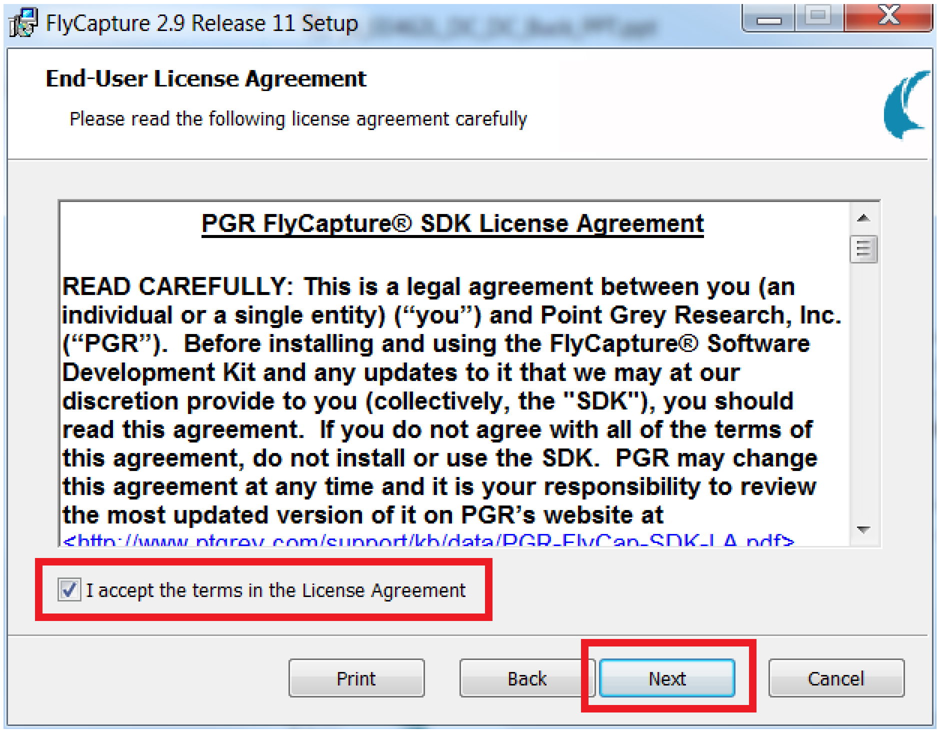


Figure 2-4. FlyCapture2 SDK Licensing Agreement

5. Read the online release notes and click the "Next" button, shown in Figure 2-5, to proceed with the installation.

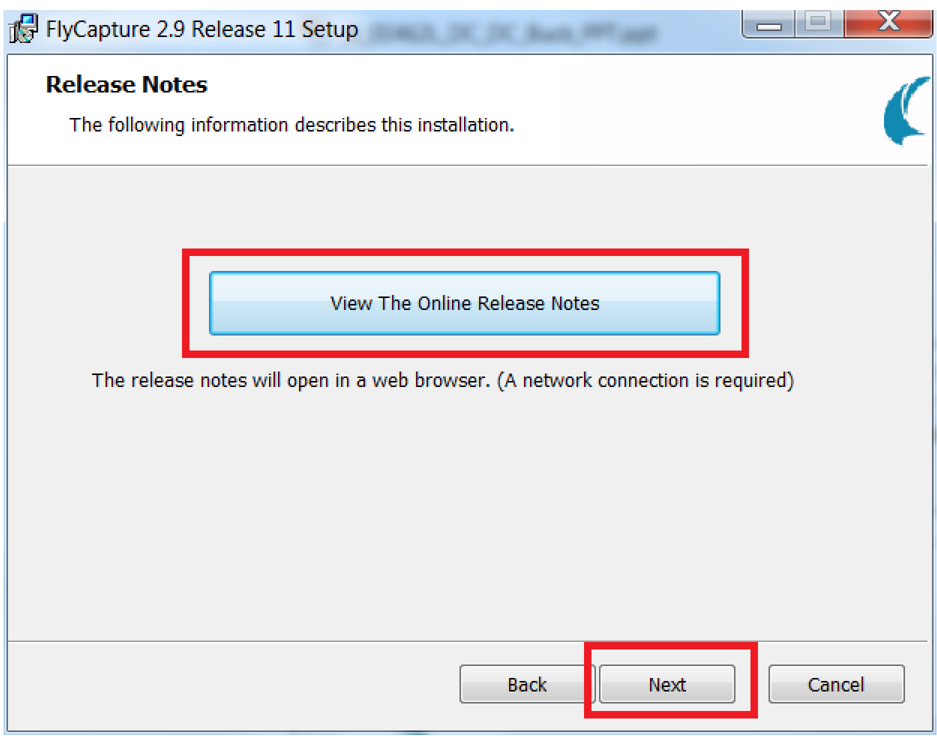


Figure 2-5. FlyCapture2 SDK Release Notes

6. Fill out the required Name and Organization fields and click the "Next" button, shown in Figure 2-6, to proceed with the installation.

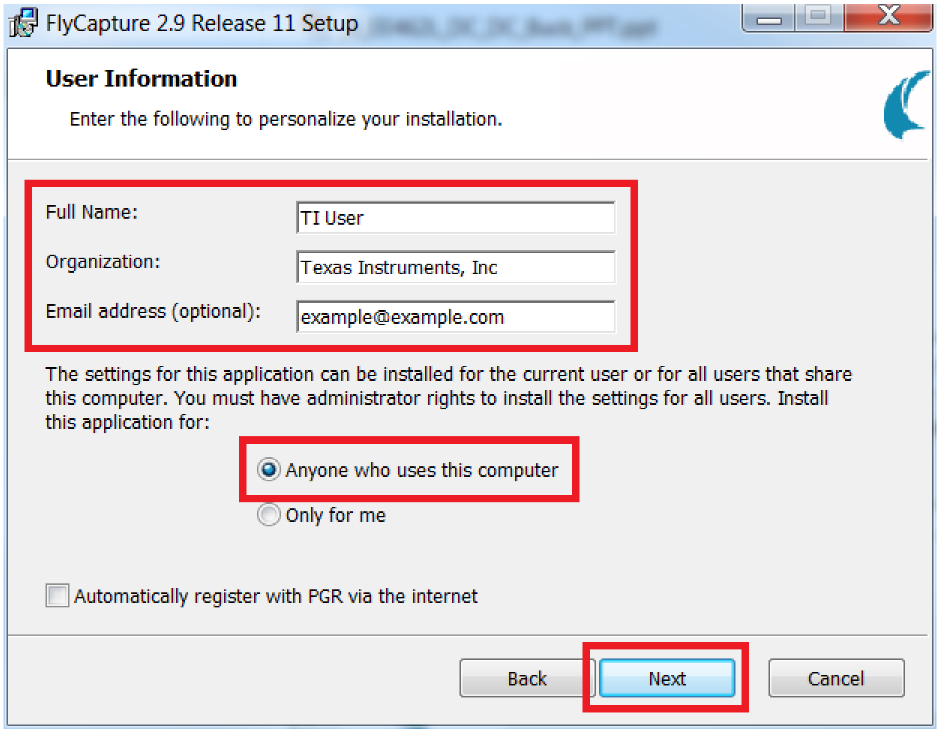


Figure 2-6. FlyCapture2 SDK User Information

7. Choose the installation directory where the FlyCapture2 SDK will be installed. Click the "Next" button, highlighted in Figure 2-7.

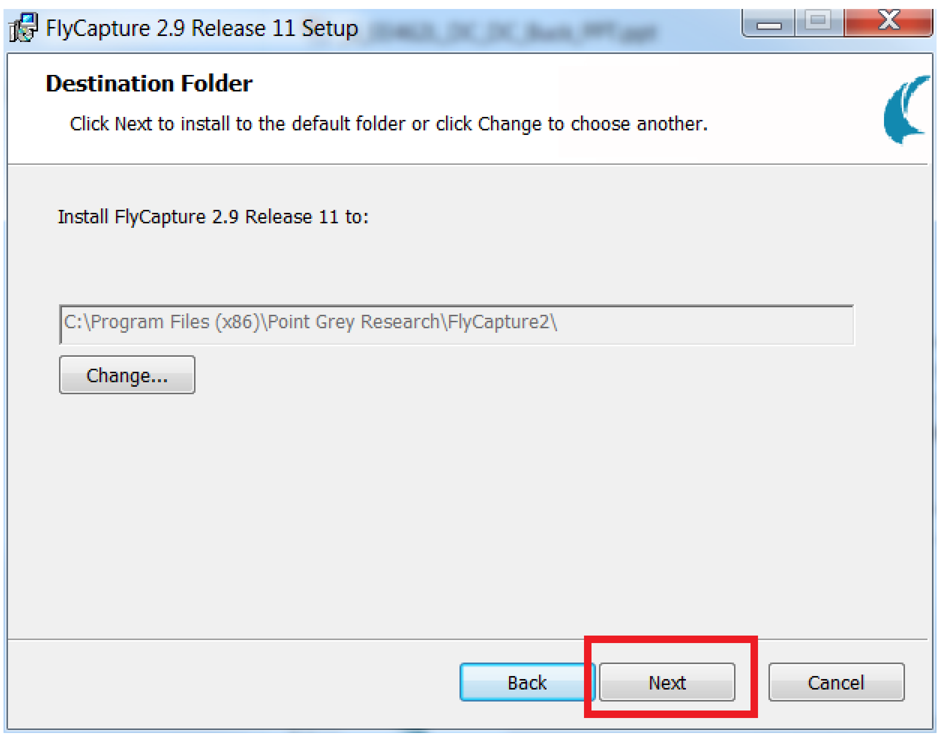


Figure 2-7. FlyCapture2 SDK Installation Path

8. Click the button labeled "Complete" to install the entire FlyCapture2 SDK, shown in Figure 2-8.

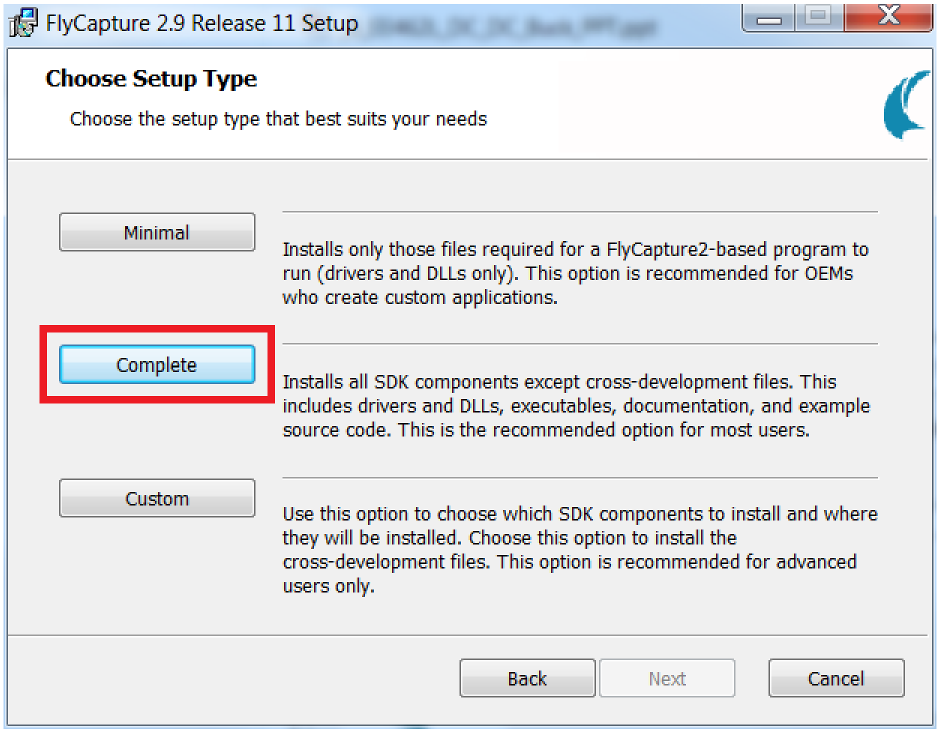


Figure 2-8. FlyCapture2 SDK Installation Options

9. Pick the camera interface that will be used. For the 3D Scanner Reference Design, the USB interface is utilized. Select "I will use USB cameras," uncheck the box "Install USBPro", and then click the "Next" button. The "Next" button and USB selection is shown in Figure 2-9.

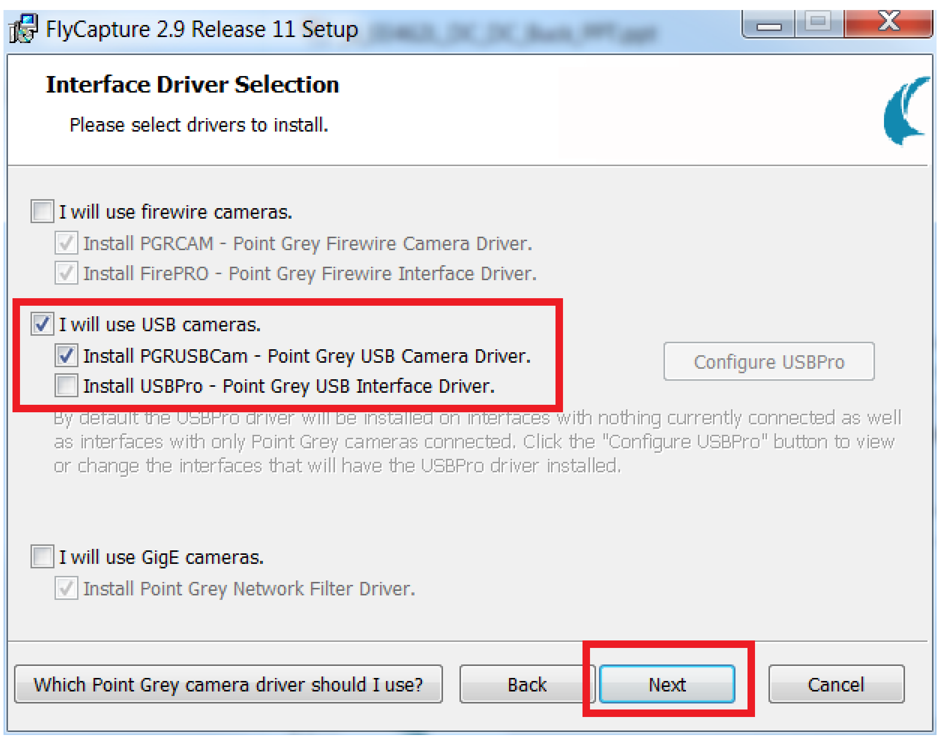


Figure 2-9. Camera Interface Selection for FlyCapture2 SDK

10. Once your options have been selected, the FlyCapture2 installer will confirm the settings. Check the box labeled "Click to confirm," then click the "Next" button, shown in Figure 2-10.

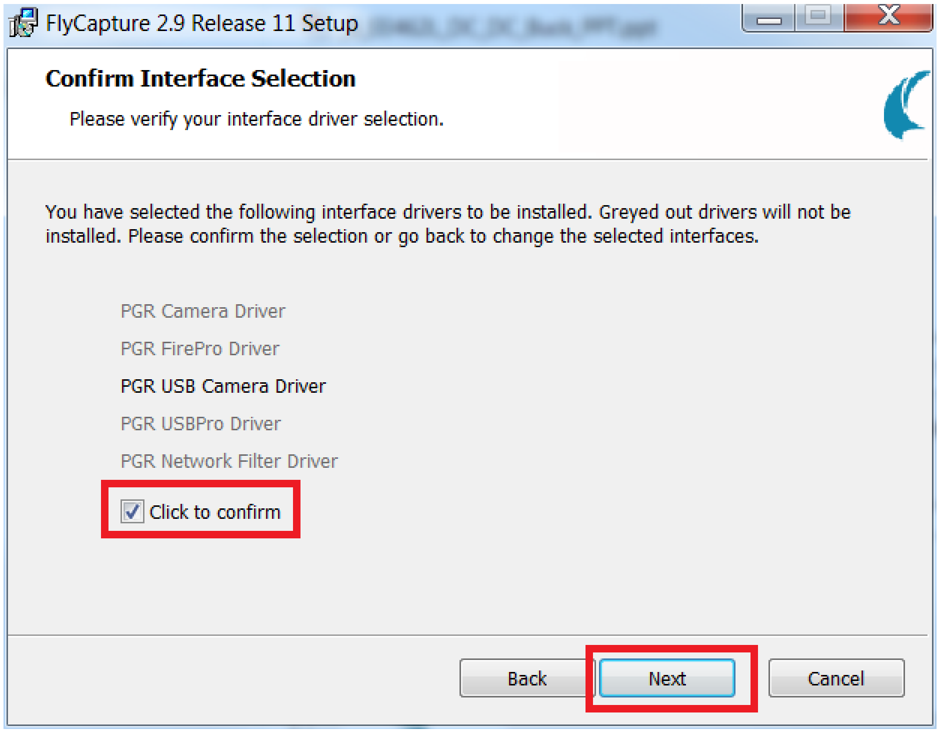


Figure 2-10. Confirm Camera Interface Selection for FlyCapture2 SDK

11. Allow FlyCapture2 to manage processor idle states while the SDK is in use. Accept the default selection and click the "Next" button, shown in Figure 2-11.

    Note: This option keeps the CPU running as long as the application executable or the Point Grey GUI is active. This can significantly increase the computer's power consumption. After any experiment being run, restore the power option to their previous default. On a Windows machine, search for and select "power options" in the Start Menu. Click "More Power Options" then "Change Plan Settings" and finally select "Restore Default Settings."

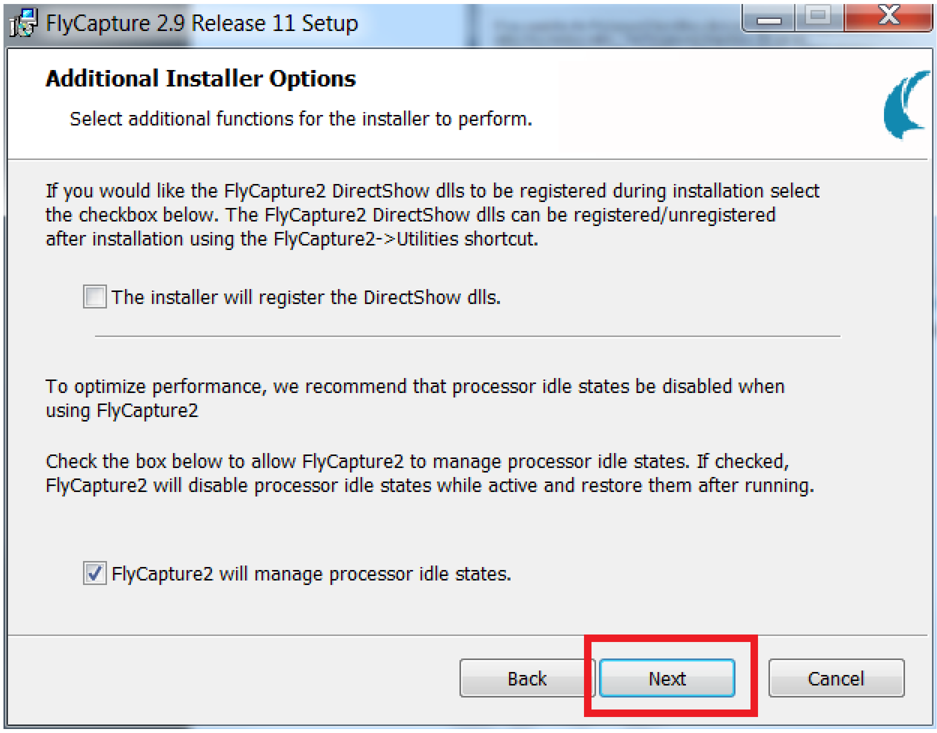


Figure 2-11. Idle State Management Selection for FlyCapture2 SDK

12. Click the "Install" button, shown in Figure 2-12, to continue the installation.

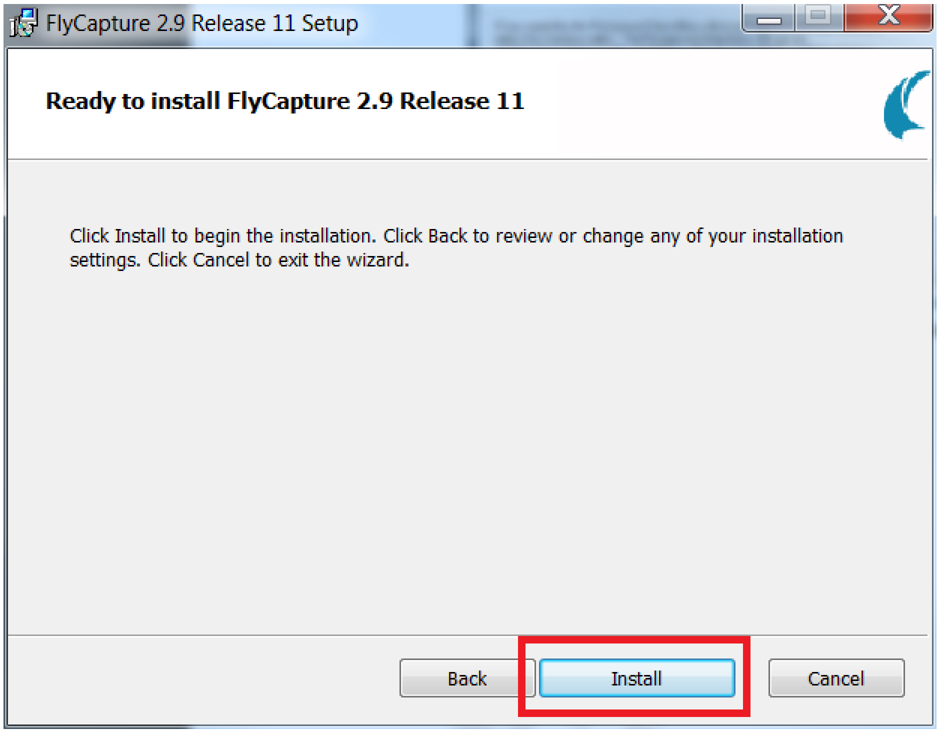


Figure 2-12. Install FlyCapture2 SDK

13. Wait for the FlyCapture2 SDK files to install. The progress bar is shown in Figure 2-13.

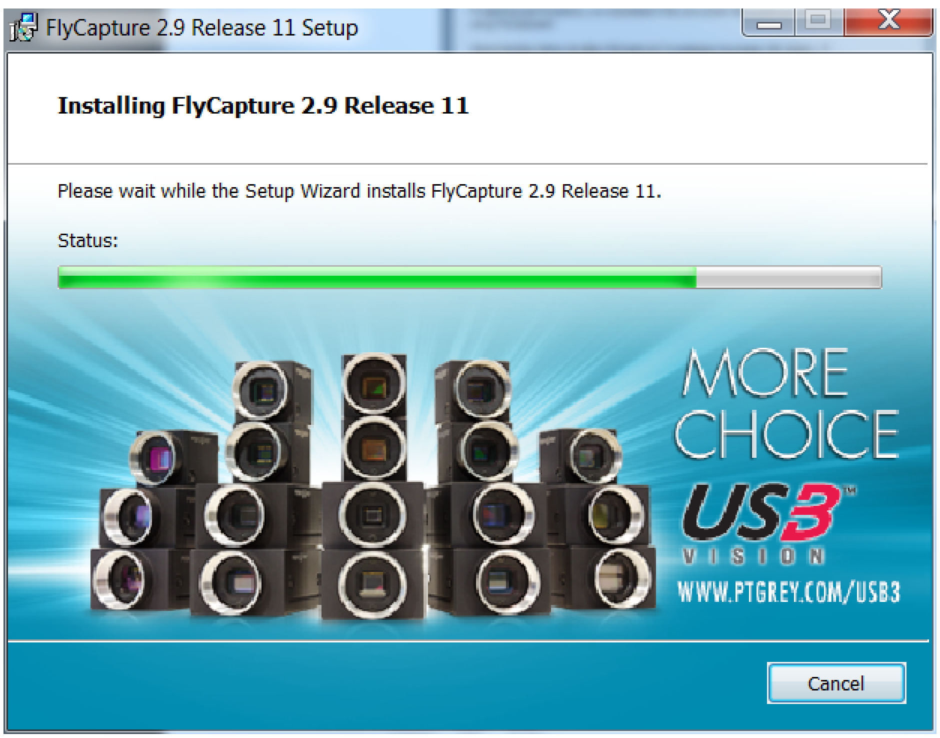


Figure 2-13. FlyCapture2 SDK Installation Progress Bar

14. After the installation is complete, click the "Finish" button shown in Figure 2-14.

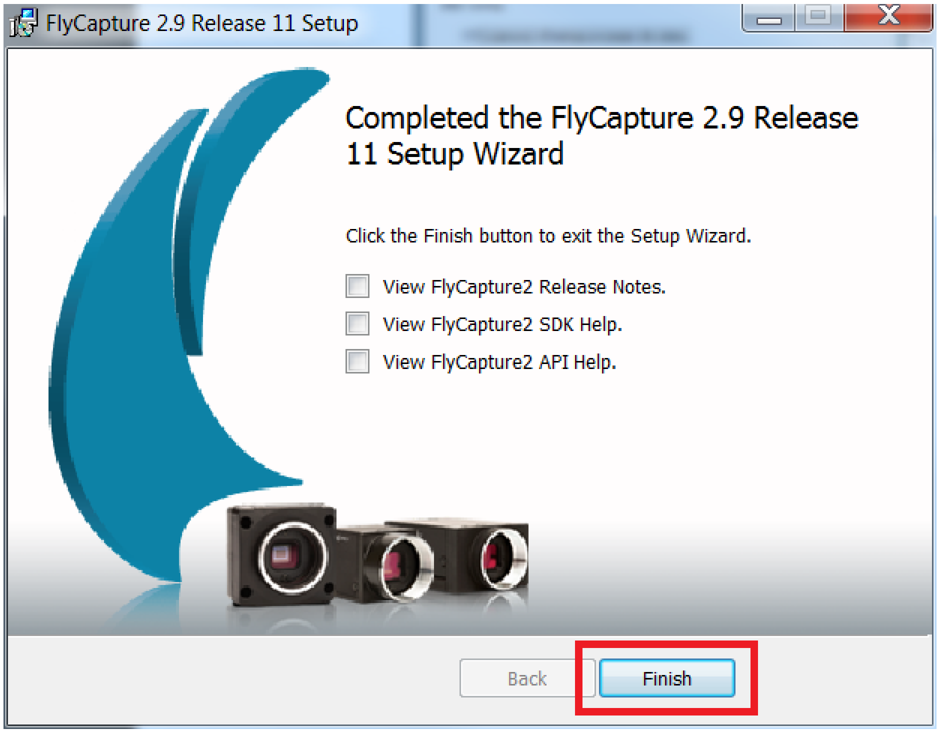


Figure 2-14. FlyCapture2 SDK Finish Installation

2.3 Installing MeshLab

MeshLab is the software utility recommended to view pointclouds generated by the reference design. Installation of MeshLab is detailed in this section.

1. Go to the MeshLab website located at http://meshlab.sourceforge.net/ and download MeshLab V1.3.3 (or higher) executable.
2. As a system administrator, run the downloaded installation file and click the "Next" button as shown in Figure 2-15.

   Note: If the files fail to install, make sure the installation program is run with administrator privileges. Running without administrator privileges will cause the installation to fail.

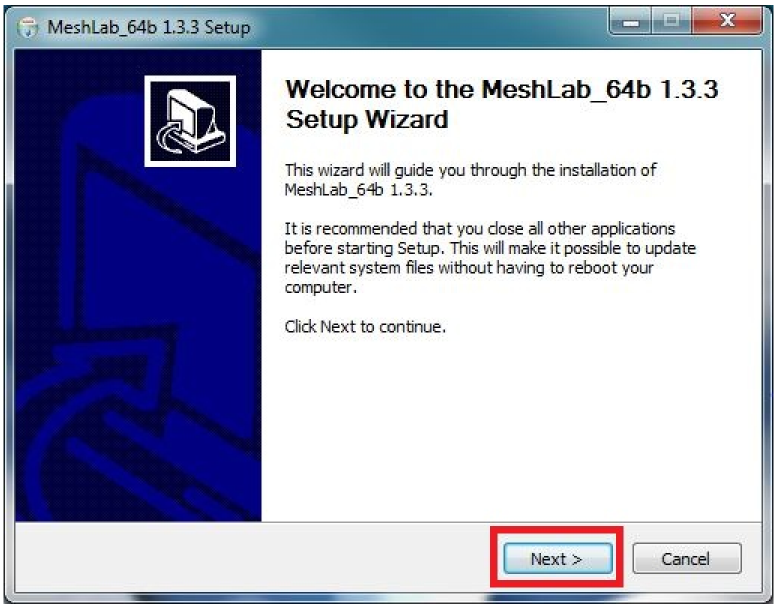


Figure 2-15. MeshLab Installer Initial Screen

3. Read and accept the end-user license agreement and the privacy agreement by clicking the "I Agree" button once for each agreement, as shown in Figure 2-16.

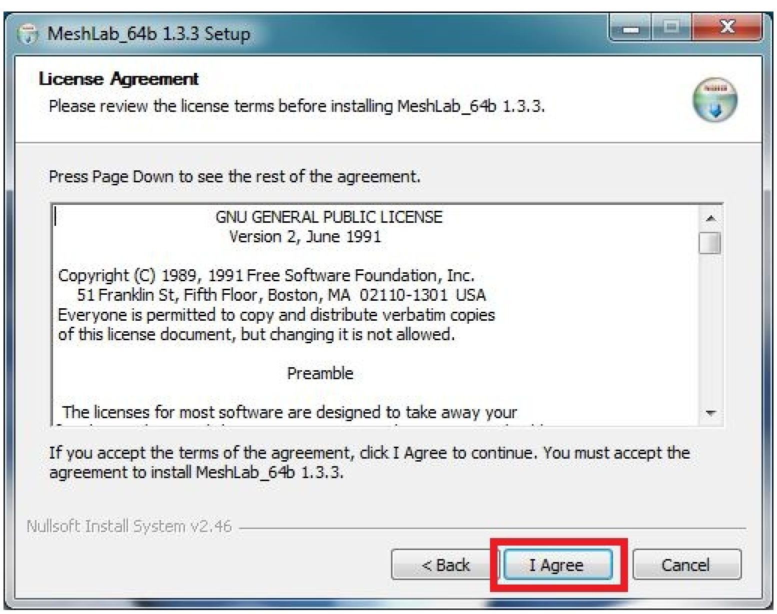


Figure 2-16. MeshLab End User License Agreement

4. Choose the installation directory for the MeshLab program, shown in Figure 2-17.

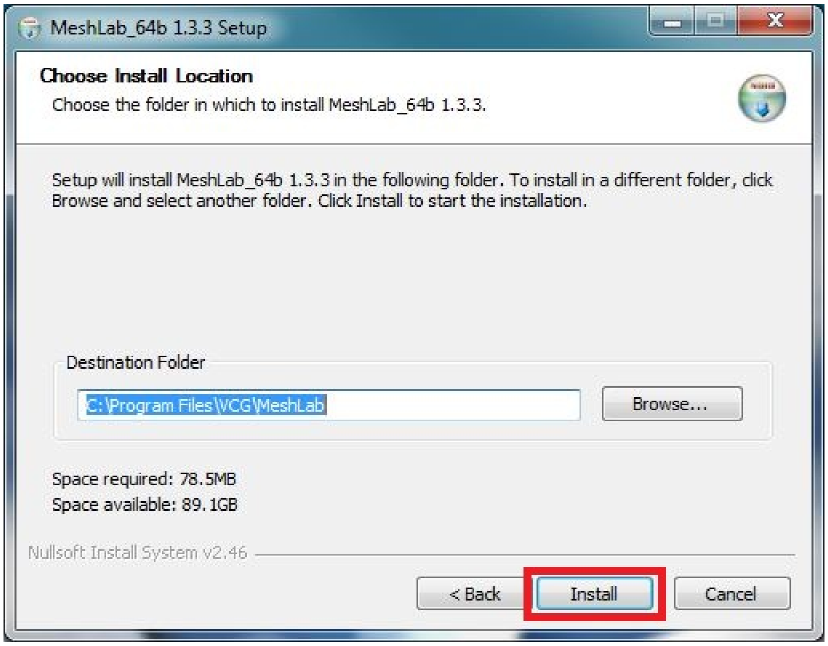


Figure 2-17. MeshLab Installation Path

5. Allow the files to be installed and, once completed, click the "Finish" button, highlighted in Figure 2-18.

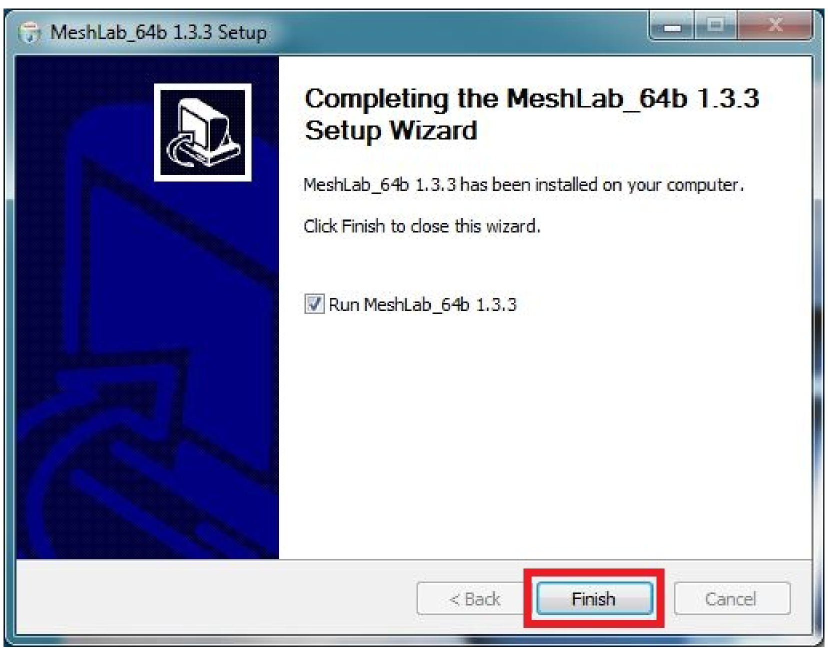


Figure 2-18. MeshLab Installation Completed

2.4 Downloading the 3D Scanner Reference Design

Compiled Windows binaries for the 3D Scanner Reference Design are offered for convenience. The binaries can be downloaded from the "Software" section of the reference design tool page at http://www.ti.com/tool/TIDA-00362.

To build the source code for the reference design as well as the DLP Advanced Light Control SDK, please refer to DLPU042.

2.5 Installing the 3D Scanner Reference Design

1. Decompress the "tidca56.zip" file in a convenient location.
2. Install the 3D Scanner Reference Design by executing the file "TIDA00362-***-windows-installer.exe," as shown in Figure 2-19.

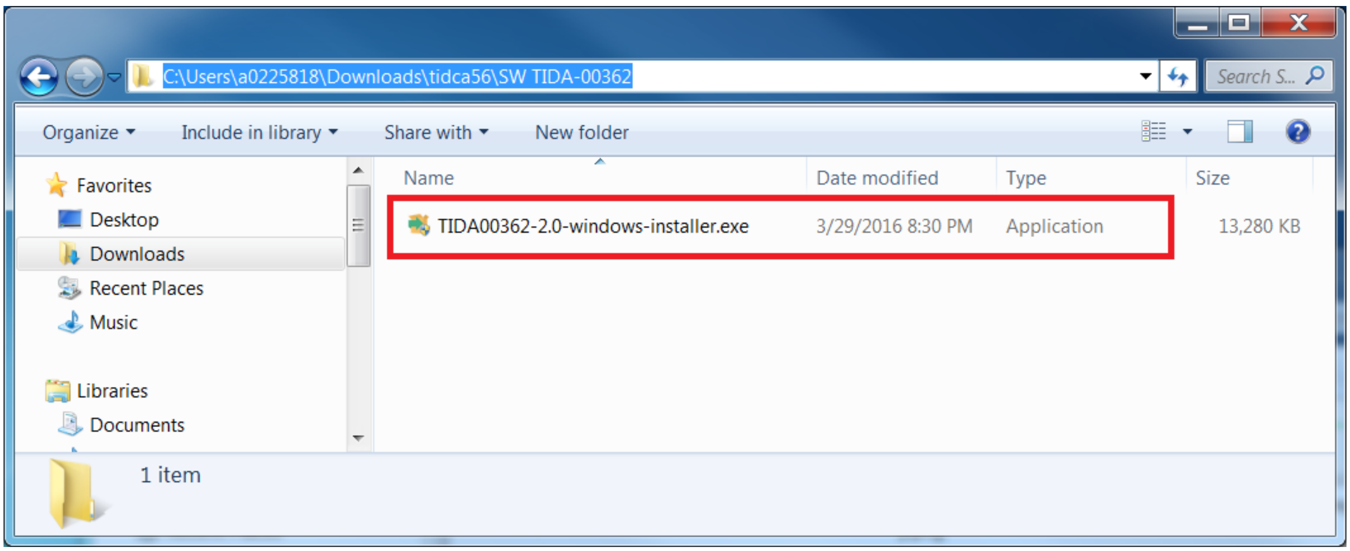


Figure 2-19. 3D Scanner Reference Design Installation Executable

3. Click the "Next" button on the install wizard setup screen, as shown in Figure 2-20.

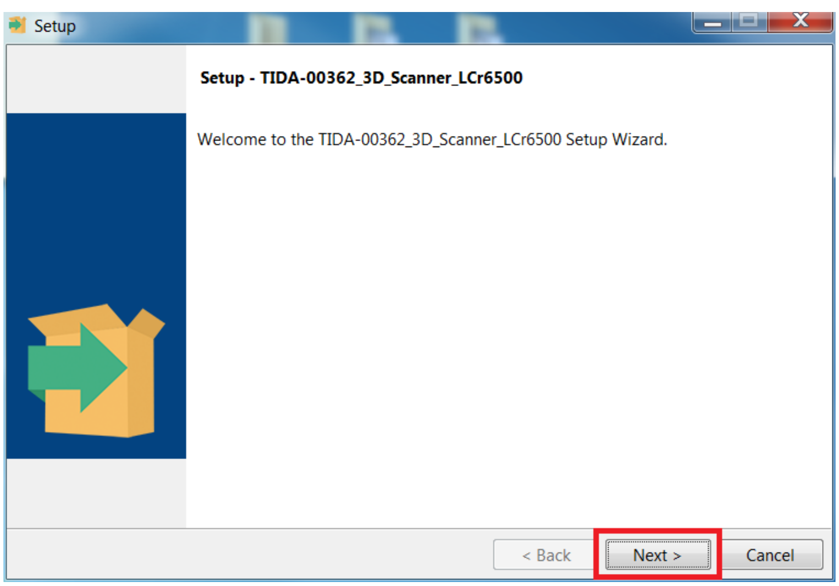


Figure 2-20. 3D Scanner Reference Design Setup Wizard Screen

4. Read and review the license agreement for the 3D Scanner Reference Design, as shown in Figure 2-21. Click the "I accept the agreement" radio button and then click the "Next" button to continue installing the software.

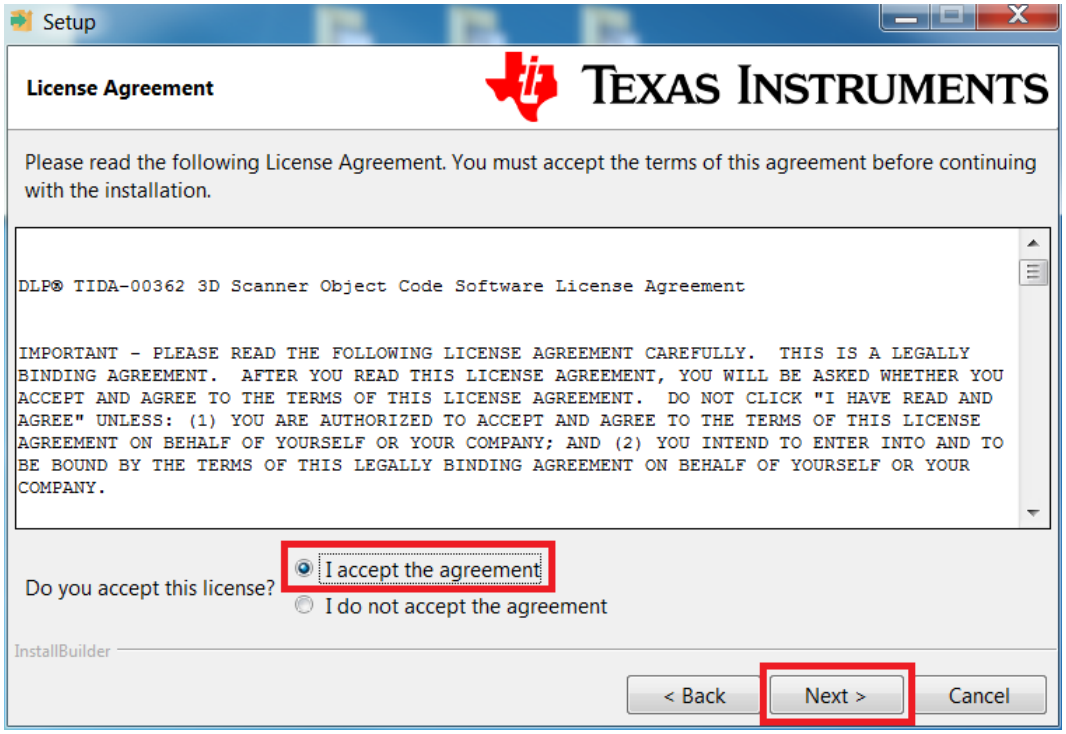


Figure 2-21. 3D Scanner Reference Design License Agreement Screen

5. Select an installation path where the reference design software will be located. Click the "Next" button, as shown in Figure 2-22 to continue installing the software.

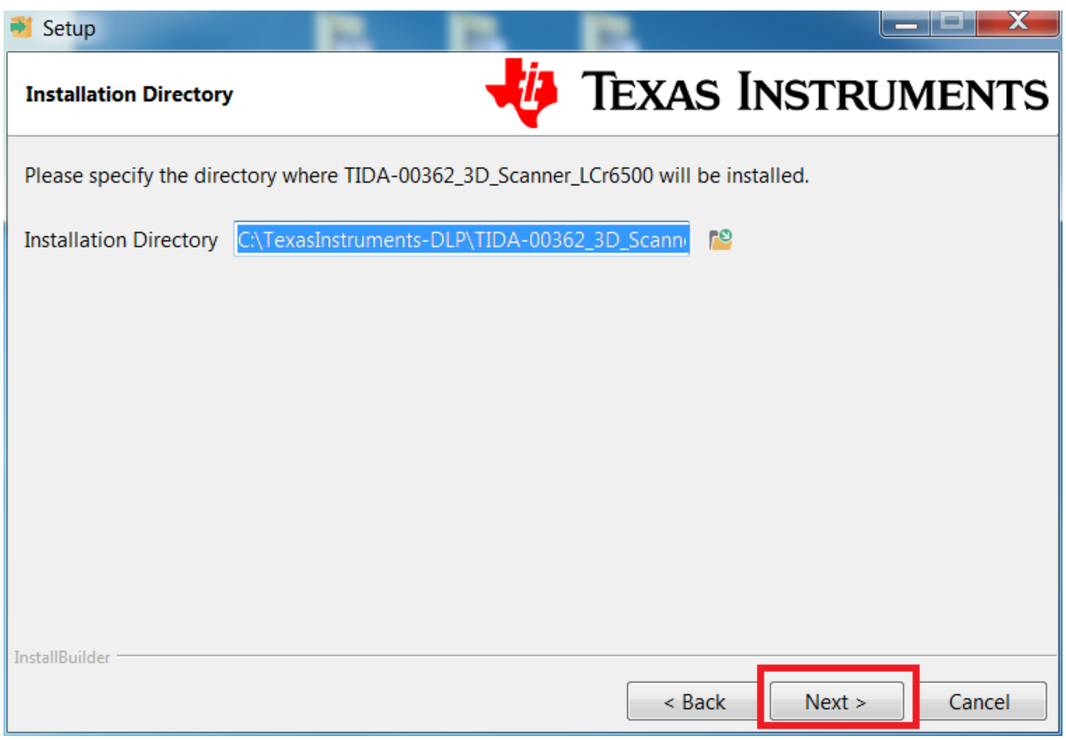


Figure 2-22. 3D Scanner Reference Design Installation Path Selection

6. The installer is ready to install, click the "Next" button to start the process, as shown in Figure 2-23.

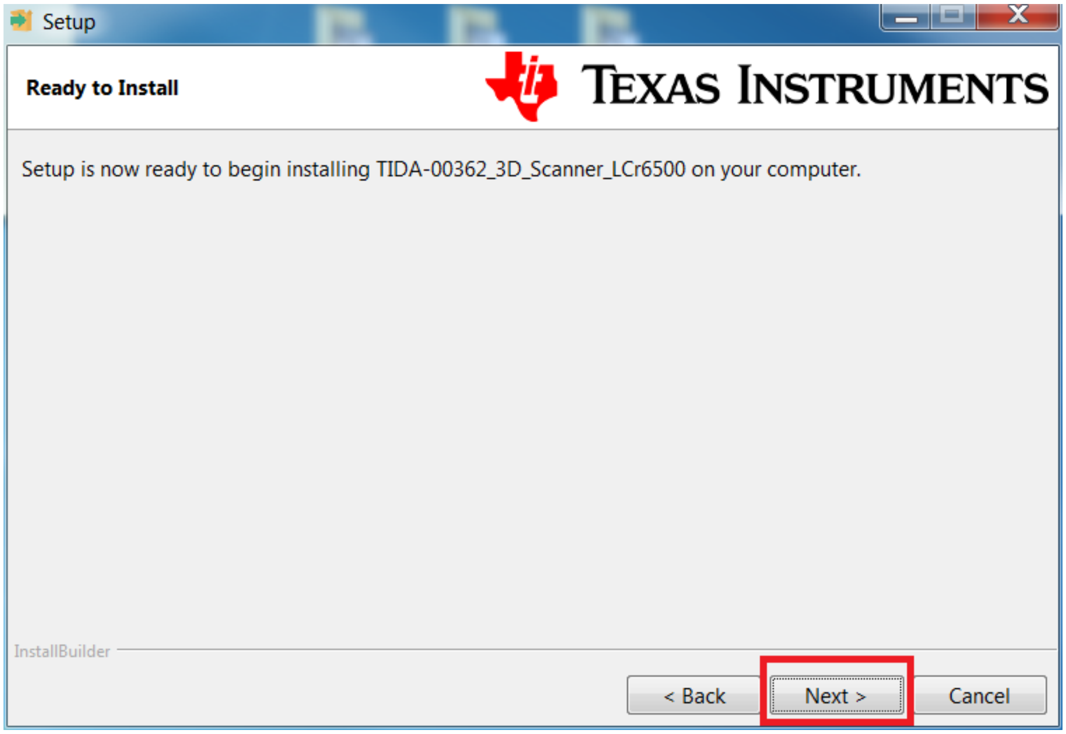


Figure 2-23. 3D Scanner Reference Design Installation Confirmation

7. Wait for the files to install in the location specified, as shown in Figure 2-24.

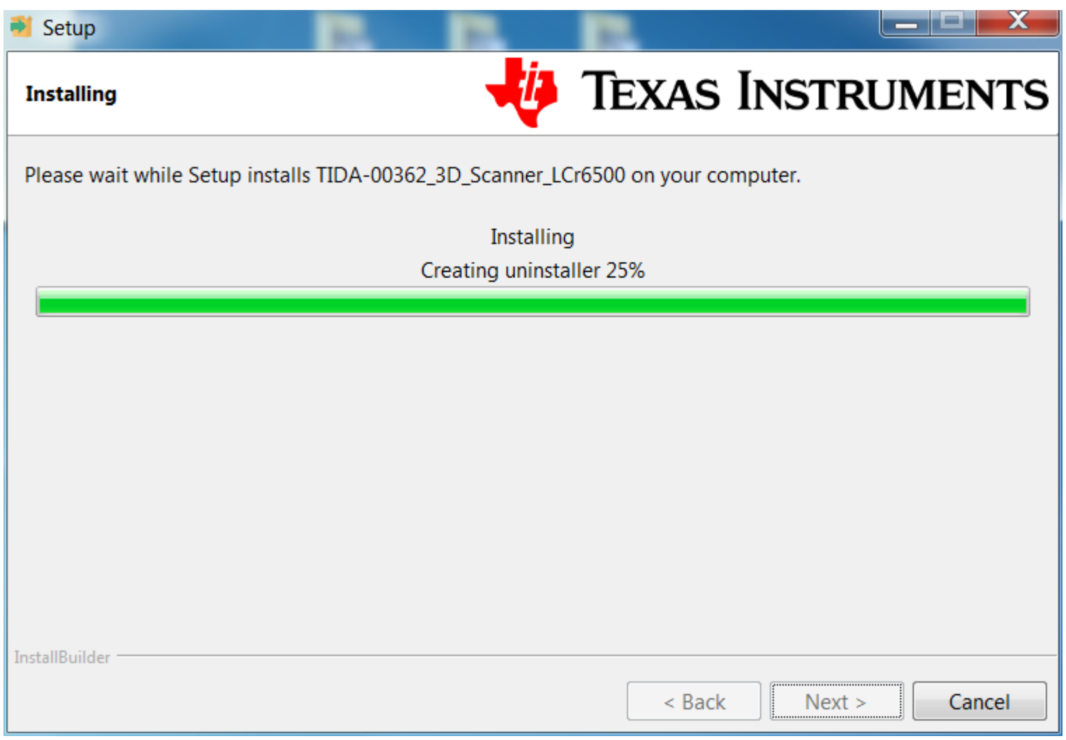


Figure 2-24. 3D Scanner Reference Design File Installation Progress

8. Once the files have been extracted and installed, click the "Finish" button to close the installer, as shown in Figure 2-25.

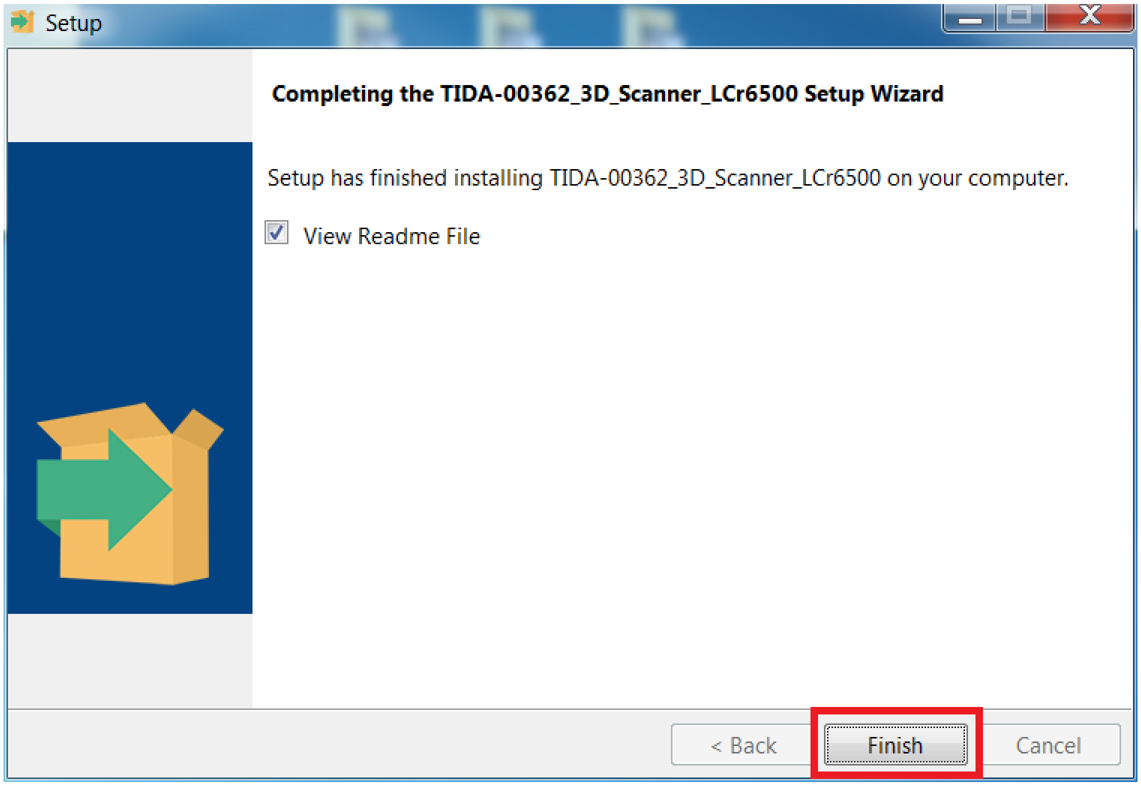


Figure 2-25. 3D Scanner Reference Design Installation Completion

Using the 3D Scanner Reference Design

3.1 The 3D Scanner Reference Design application allows users to quickly create a 3D scanner; complete with calibration, setup, and scanning routines. The application generates the calibration board required to calibrate the 3D scanner, as well as preparing the LightCrafter 6500 EVM with its own calibration and structured light patterns. After preparing the calibration board and the LightCrafter 6500 EVM, the user may calibrate the camera and projector. After the calibration procedures are complete, the application is ready to perform 3D scans. Please follow all instructions to properly setup and use the 3D scanner.

3.2 Connecting the Hardware When Using a Point Grey Grasshopper3 Camera

When using the 3D Scanner reference design with a Point Grey Grasshopper3 camera the following hardware is needed:

- LightCrafter 6500 EVM & power supply
- Point Grey Grasshopper3 USB 3.0 camera and lens
- ViALUX STAR-065 optics and light engine
- 2/3" 8mm F/1.8 Ultra High Resolution Fixed-Focal Lens
- USB 2.0 A to B Cable
- USB 3.0 A to micro-B Cable
- TIDA-00362 Camera Trigger Cable
  - Assemble the **required** cable using the instructions from the TIDA-00362 Camera Trigger Cable Assembly Guide: http://www.ti.com/lit/df/tidreb7/tidreb7.pdf (Drawing No. 2514095)

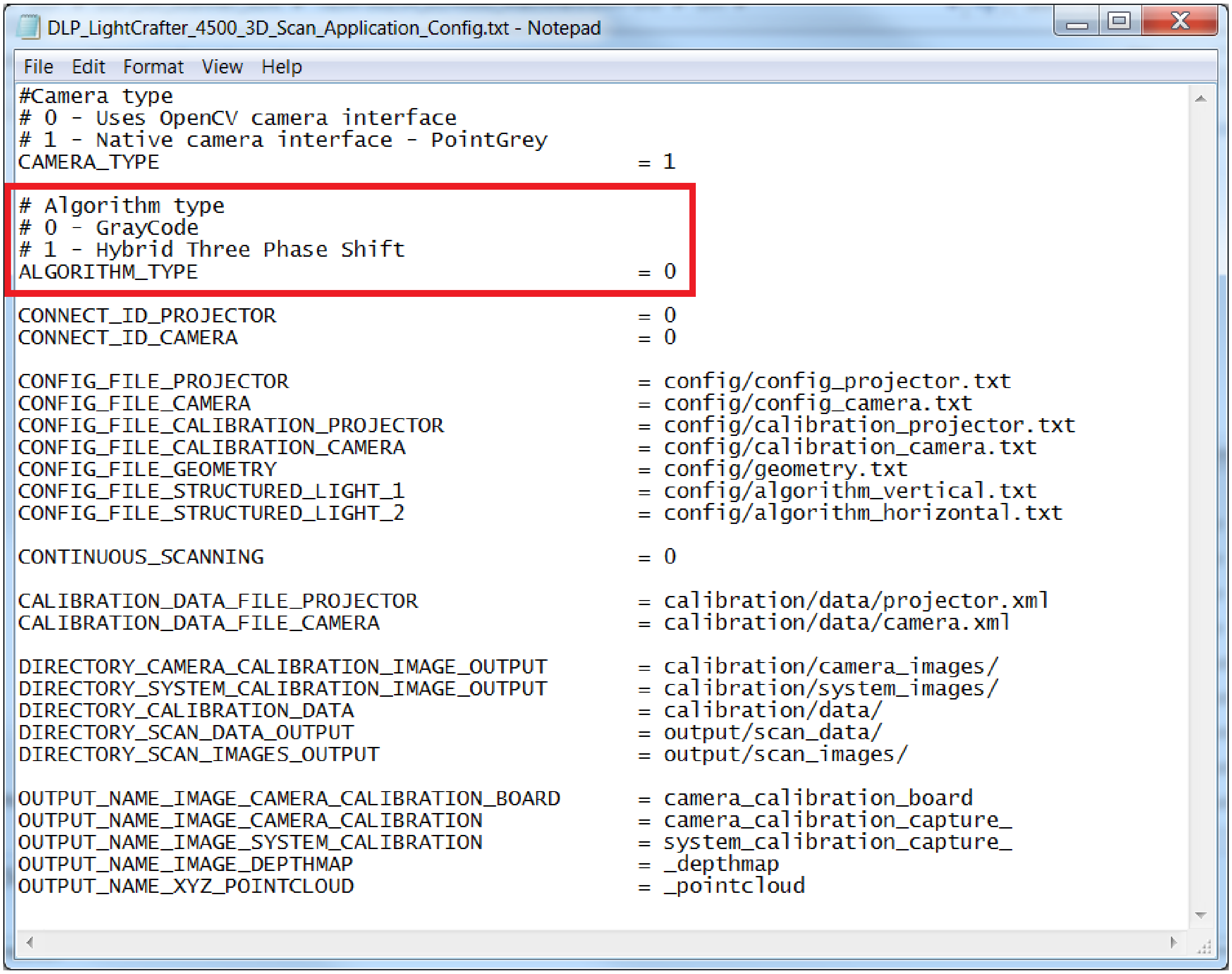
Connect the hardware as follows:

1. Power the LightCrafter 6500
2. Connect the LightCrafter 6500 to the PC's USB 2.0 port using the USB 2.0 cable
3. Connect the Point Grey camera to the PC's USB 3.0 port using the USB 3.0 cable
4. Connect the camera trigger cable to the Point Grey camera's GPIO port and the LightCrafter 6500 input trigger connector J20

3.3 Configuring the Camera and Scan Type

This design features two methods of scanning: binary Gray code scanning and hybrid three-phase scanning. It also allows the user to use the native Point Grey interface or the OpenCV camera interface. To change the scan type, do the following:

1. After installing or building the design, find *DLP_Lightcrafter_6500_3D_Scan_Application_Config.txt* in the build or install folder for the reference design.
2. Open the text file.




```
#Camera type
# 0 - Uses OpenCV camera interface
# 1 - Native camera interface - PointGrey
CAMERA_TYPE                                  = 1

# Algorithm type
# 0 - GrayCode
# 1 - Hybrid Three Phase Shift
ALGORITHM_TYPE                               = 0

CONNECT_ID_PROJECTOR                         = 0
CONNECT_ID_CAMERA                            = 0

CONFIG_FILE_PROJECTOR                        = config/config_projector.txt
CONFIG_FILE_CAMERA                           = config/config_camera.txt
CONFIG_FILE_CALIBRATION_PROJECTOR            = config/calibration_projector.txt
CONFIG_FILE_CALIBRATION_CAMERA               = config/calibration_camera.txt
CONFIG_FILE_GEOMETRY                         = config/geometry.txt
CONFIG_FILE_STRUCTURED_LIGHT_1               = config/algorithm_vertical.txt
CONFIG_FILE_STRUCTURED_LIGHT_2               = config/algorithm_horizontal.txt

CONTINUOUS_SCANNING                          = 0

CALIBRATION_DATA_FILE_PROJECTOR              = calibration/data/projector.xml
CALIBRATION_DATA_FILE_CAMERA                 = calibration/data/camera.xml

DIRECTORY_CAMERA_CALIBRATION_IMAGE_OUTPUT    = calibration/camera_images/
DIRECTORY_SYSTEM_CALIBRATION_IMAGE_OUTPUT    = calibration/system_images/
DIRECTORY_CALIBRATION_DATA                   = calibration/data/
DIRECTORY_SCAN_DATA_OUTPUT                   = output/scan_data/
DIRECTORY_SCAN_IMAGES_OUTPUT                 = output/scan_images/

OUTPUT_NAME_IMAGE_CAMERA_CALIBRATION_BOARD   = camera_calibration_board
OUTPUT_NAME_IMAGE_CAMERA_CALIBRATION         = camera_calibration_capture_
OUTPUT_NAME_IMAGE_SYSTEM_CALIBRATION         = system_calibration_capture_
OUTPUT_NAME_IMAGE_DEPTHMAP                   = _depthmap
OUTPUT_NAME_XYZ_POINTCLOUD                   = _pointcloud
```

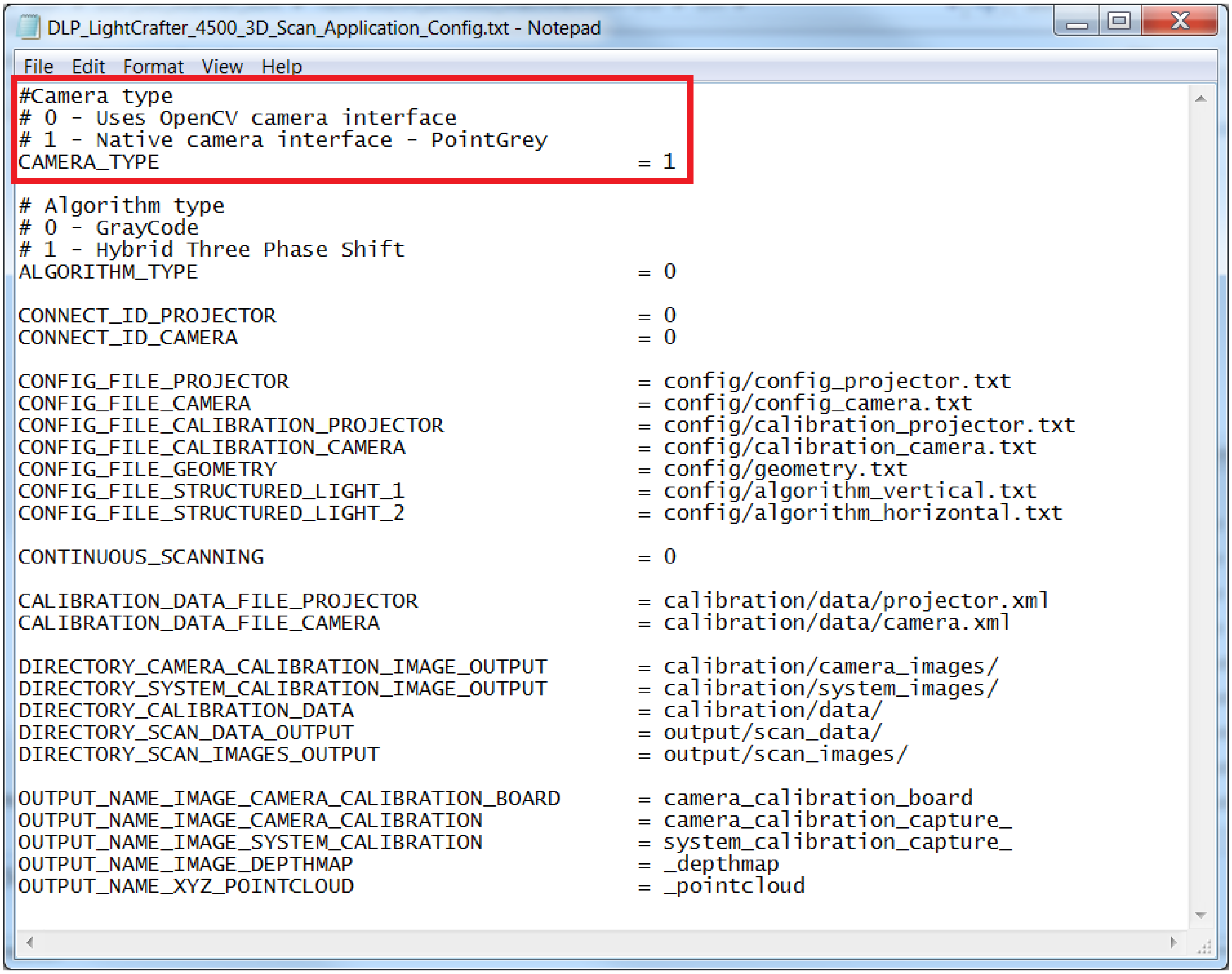
Figure 3-1. Application Configuration File - ALGORITHM_TYPE

3. To perform a Gray code scan, ALGORITHM_TYPE should be set to "1". To perform a hybrid three phase shift scan, ALGORITHM_TYPE should be "0." Figure 3-1 shows where the value should be changed.
4. Once a selection has been made, save the file. Close and reopen the reference design executable (if it was running) for the changes to take effect.

   Note: For untriggered cameras such as a webcam, three-phase hybrid scanning will not work due to the precise timing required. In general, any unsynchronized camera will not work with three-phase hybrid scanning.

To change the camera interface type, do the following:

1. Follow steps 1 and 2 in the previous set of instructions for changing the scan type.
2. To change the camera type, CAMERA_TYPE, as shown in Figure 3-2, will have to be edited. Enter "0" to use the OpenCV interface and "1" to use the native camera interface.

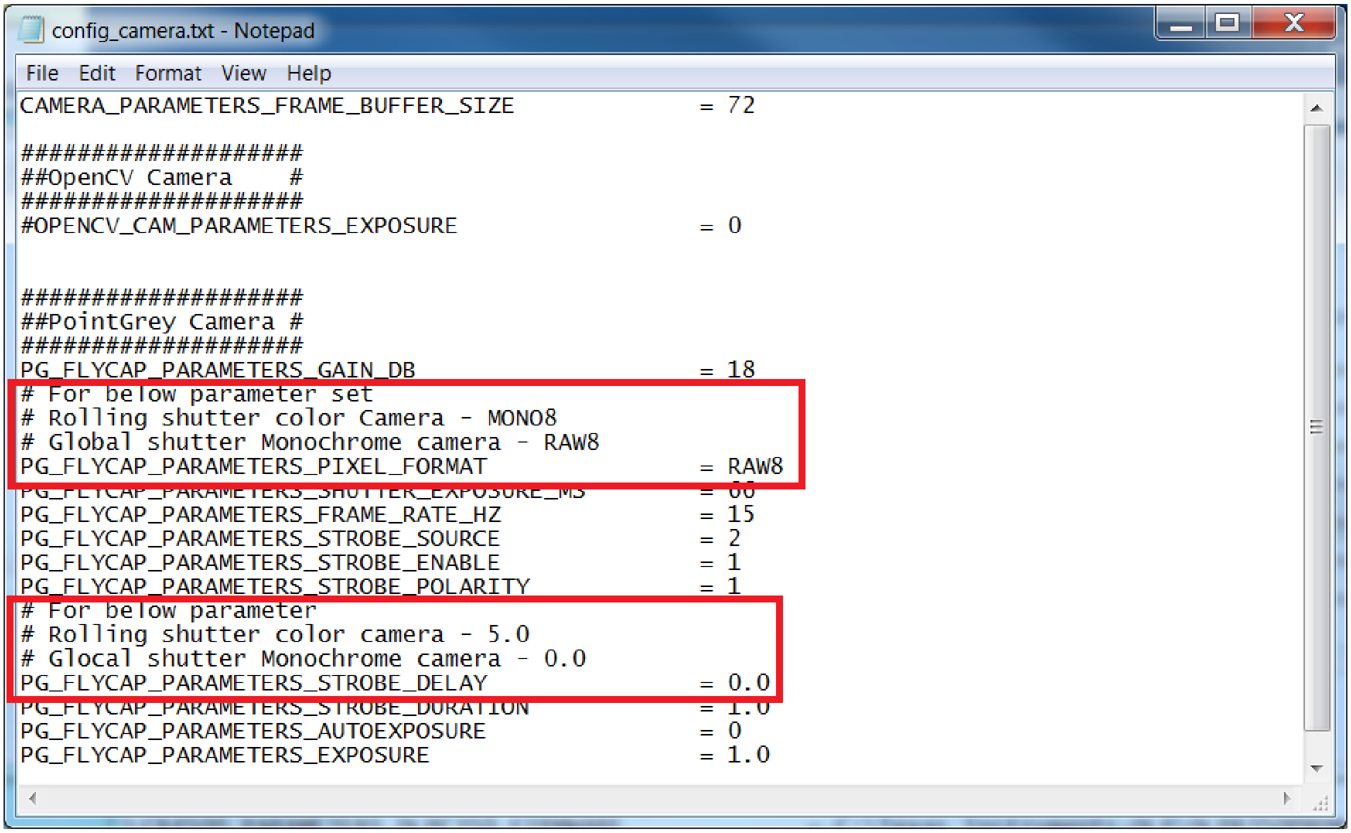



```
#Camera type
# 0 - Uses OpenCV camera interface
# 1 - Native camera interface - PointGrey
CAMERA_TYPE                                    = 1

# Algorithm type
# 0 - GrayCode
# 1 - Hybrid Three Phase Shift
ALGORITHM_TYPE                                 = 0

CONNECT_ID_PROJECTOR                           = 0
CONNECT_ID_CAMERA                              = 0

CONFIG_FILE_PROJECTOR                          = config/config_projector.txt
CONFIG_FILE_CAMERA                             = config/config_camera.txt
CONFIG_FILE_CALIBRATION_PROJECTOR              = config/calibration_projector.txt
CONFIG_FILE_CALIBRATION_CAMERA                 = config/calibration_camera.txt
CONFIG_FILE_GEOMETRY                           = config/geometry.txt
CONFIG_FILE_STRUCTURED_LIGHT_1                 = config/algorithm_vertical.txt
CONFIG_FILE_STRUCTURED_LIGHT_2                 = config/algorithm_horizontal.txt

CONTINUOUS_SCANNING                            = 0

CALIBRATION_DATA_FILE_PROJECTOR                = calibration/data/projector.xml
CALIBRATION_DATA_FILE_CAMERA                   = calibration/data/camera.xml

DIRECTORY_CAMERA_CALIBRATION_IMAGE_OUTPUT      = calibration/camera_images/
DIRECTORY_SYSTEM_CALIBRATION_IMAGE_OUTPUT      = calibration/system_images/
DIRECTORY_CALIBRATION_DATA                     = calibration/data/
DIRECTORY_SCAN_DATA_OUTPUT                     = output/scan_data/
DIRECTORY_SCAN_IMAGES_OUTPUT                   = output/scan_images/

OUTPUT_NAME_IMAGE_CAMERA_CALIBRATION_BOARD     = camera_calibration_board
OUTPUT_NAME_IMAGE_CAMERA_CALIBRATION           = camera_calibration_capture_
OUTPUT_NAME_IMAGE_SYSTEM_CALIBRATION           = system_calibration_capture_
OUTPUT_NAME_IMAGE_DEPTHMAP                     = _depthmap
OUTPUT_NAME_XYZ_POINTCLOUD                     = _pointcloud
```

Figure 3-2. Application Configuration File - CAMERA_TYPE

To change between using a global shutter monochrome camera and a rolling shutter color camera, edit the following:

1. Open *config_camera.txt*.
2. Figure 3-3 highlights the parameters that must be changed depending on the type of camera used. For a rolling shutter color camera, make sure PG_FLYCAP_PARAMETERS_PIXEL_FORMAT is set to "MONO8." If the camera is global shutter monochrome camera, set to "RAW8." Similarly, edit the PG_FLYCAP_PARAMETERS_STROBE_DELAY to "5.0" for rolling shutter color cameras and "0.0" for global shutter mono-chrome cameras.



```
config_camera.txt - Notepad
File Edit Format View Help
CAMERA_PARAMETERS_FRAME_BUFFER_SIZE                 = 72

####################
##OpenCV Camera     #
####################
#OPENCV_CAM_PARAMETERS_EXPOSURE                     = 0


####################
##PointGrey Camera #
####################
PG_FLYCAP_PARAMETERS_GAIN_DB                        = 18
# For below parameter set
# Rolling shutter color Camera - MONO8
# Global shutter Monochrome camera - RAW8
PG_FLYCAP_PARAMETERS_PIXEL_FORMAT                   = RAW8
PG_FLYCAP_PARAMETERS_SHUTTER_EXPOSURE_MS            = [illegible]
PG_FLYCAP_PARAMETERS_FRAME_RATE_HZ                  = 15
PG_FLYCAP_PARAMETERS_STROBE_SOURCE                  = 2
PG_FLYCAP_PARAMETERS_STROBE_ENABLE                  = 1
PG_FLYCAP_PARAMETERS_STROBE_POLARITY                = 1
# For below parameter
# Rolling shutter color camera - 5.0
# Glocal shutter Monochrome camera - 0.0
PG_FLYCAP_PARAMETERS_STROBE_DELAY                   = 0.0
PG_FLYCAP_PARAMETERS_STROBE_DURATION                = 1.0
PG_FLYCAP_PARAMETERS_AUTOEXPOSURE                   = 0
PG_FLYCAP_PARAMETERS_EXPOSURE                       = 1.0
```

Figure 3-3. Camera Shutter and Color Settings

3.4 Creating the Calibration Board

This section guides the user through the generation and measurement of the camera calibration board.

1. Start the 3D Scanner Reference Design program, installed in Section 2.5, by running the executable file, as shown in Figure 3-4.

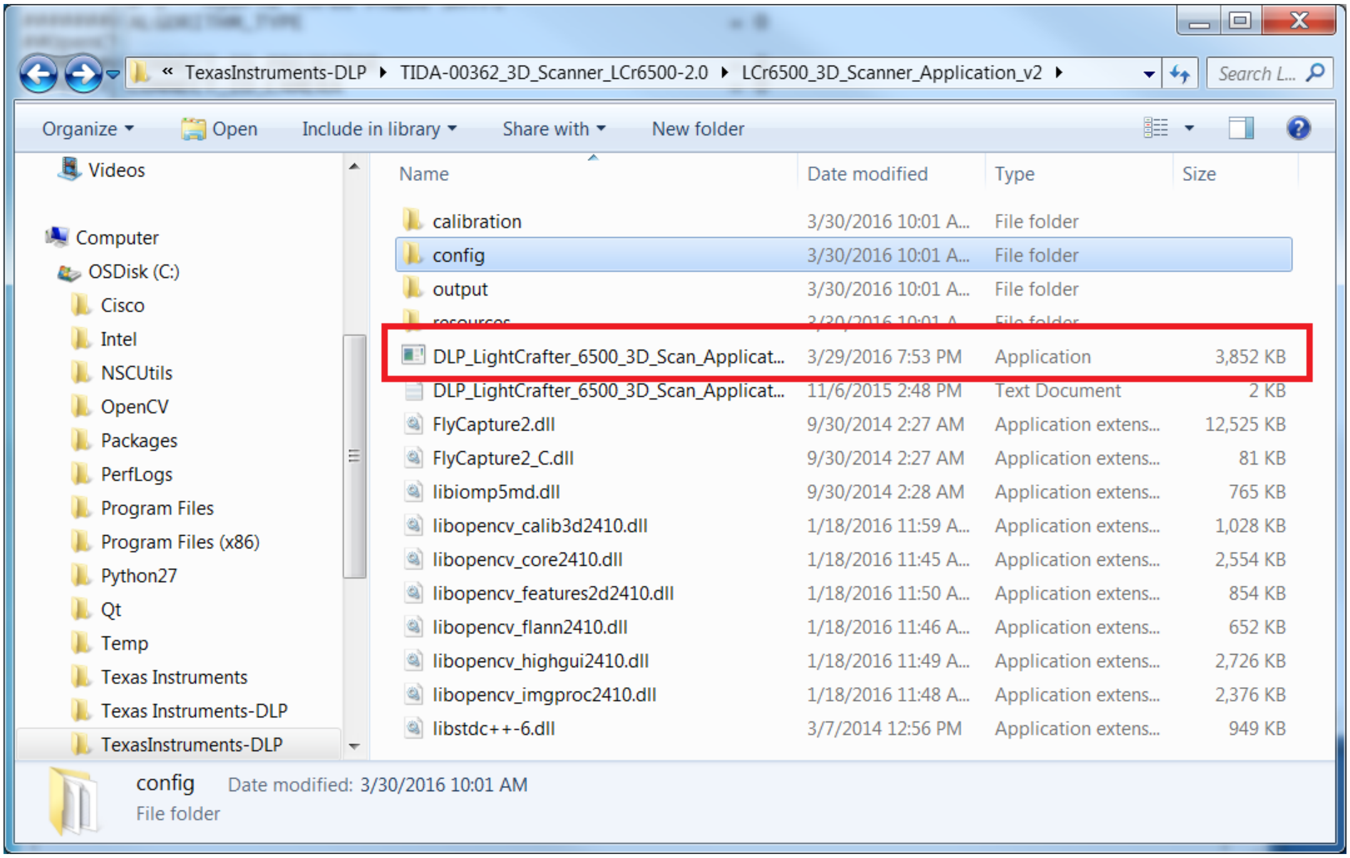


Figure 3-4. Running the 3D Scanning Command Line Program

2. Run the "1: Generate camera calibration board and enter feature measurements" option by entering "1" in the command line menu, as shown in Figure 3-5.

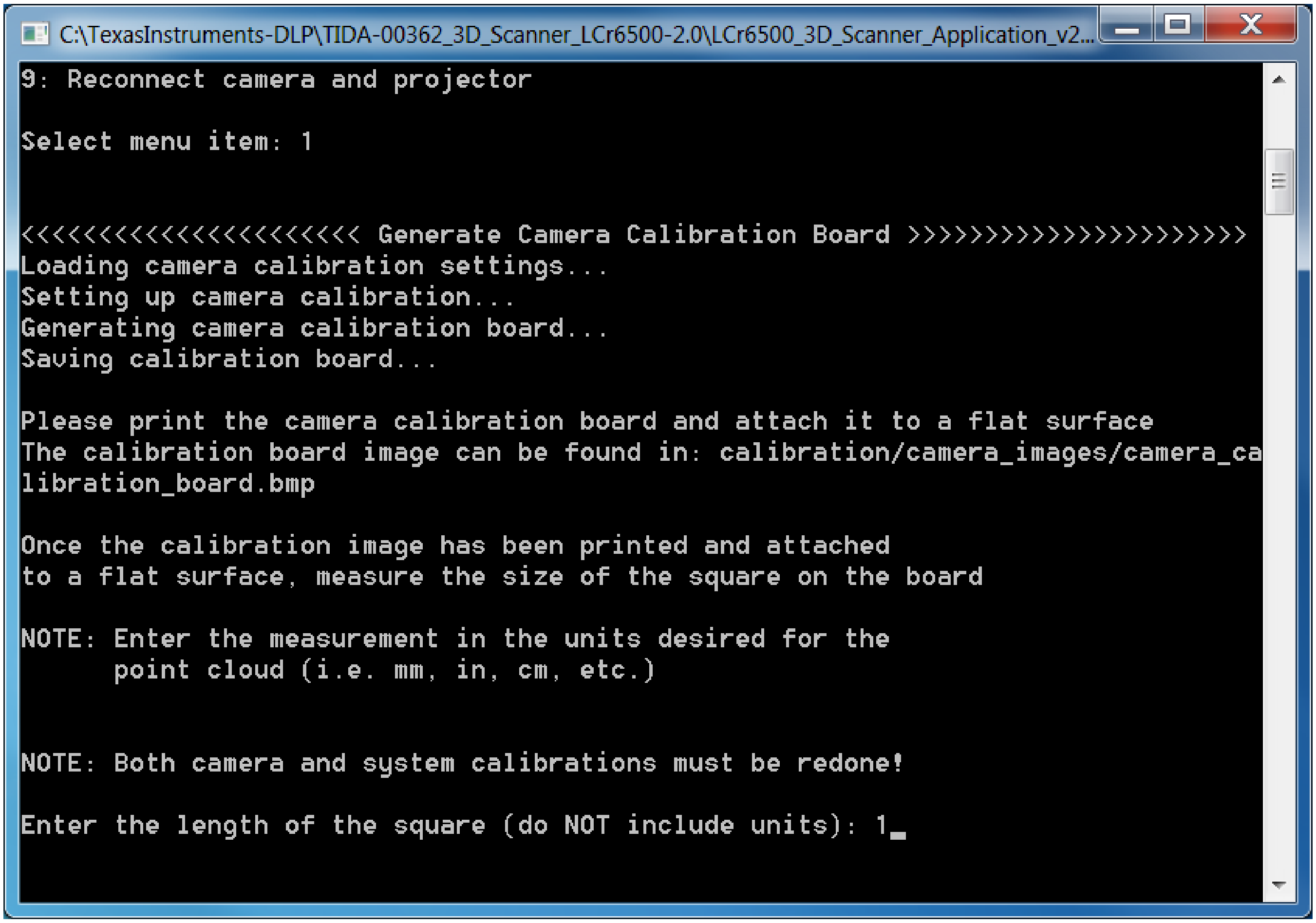


Figure 3-5. Command Line Menu Prompt

3. Once the command has been entered, the program will generate the calibration board. Print the camera calibration board image that is found in the location indicated in the prompt (calibration/camera_images/camera_calibration_board.bmp). The camera calibration board should be approximately half the size of the total projection area.
4. Attach the printed calibration board to a flat, white surface that is larger than the projection area, as shown in Figure 3-6. The number of squares on the grid can be changed in the configuration files for the program. The default grid is 7 x 10.

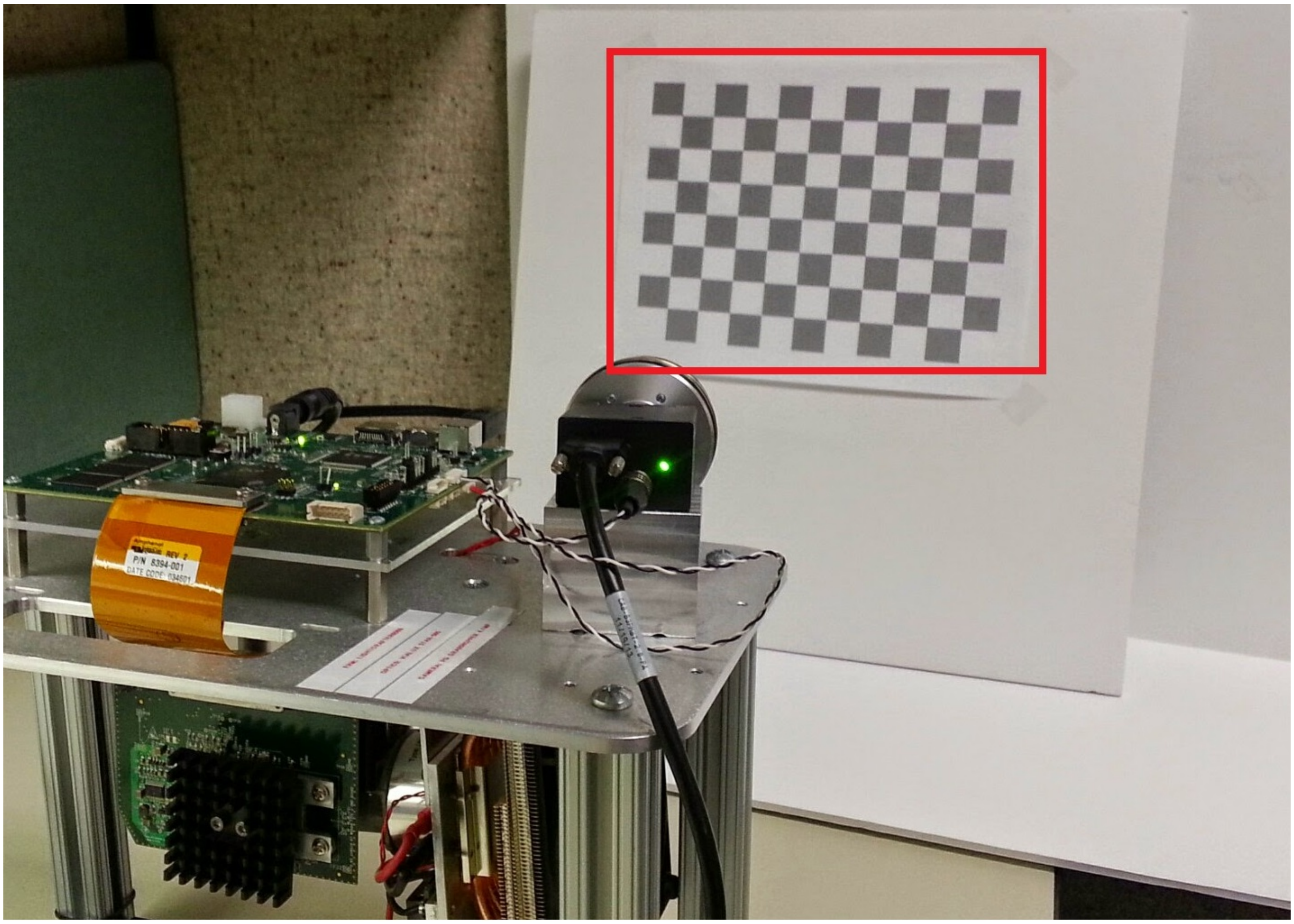


Figure 3-6. Calibration Board Attached to Flat Calibration Surface

5. After attaching the camera calibration board to the calibration surface, measure the length of one side of one of the squares on the grid and type the number into the command prompt as shown in Figure 3-6. Do not enter any units in the command line. Hit enter to continue.

   Note: The generated point clouds will show unitless distances. The actual units depend on how you measured your calibration board. For example, if each square is 2 cm wide, enter "2" into the prompt. The generated point clouds will show distances which appear unit-less but are actually in centimeters.

3.5 Preparing the Projector

The LightCrafter 6500 must be prepared with the calibration images and structured light patterns for calibration and object scanning, respectively. The 3D Scanner Command Line program will prepare the projector with the necessary images by selecting menu option "3: Prepare system for calibration and scanning" by entering "3" in the command line, as shown in Figure 3-7. The projector needs to be prepared after every initialization.

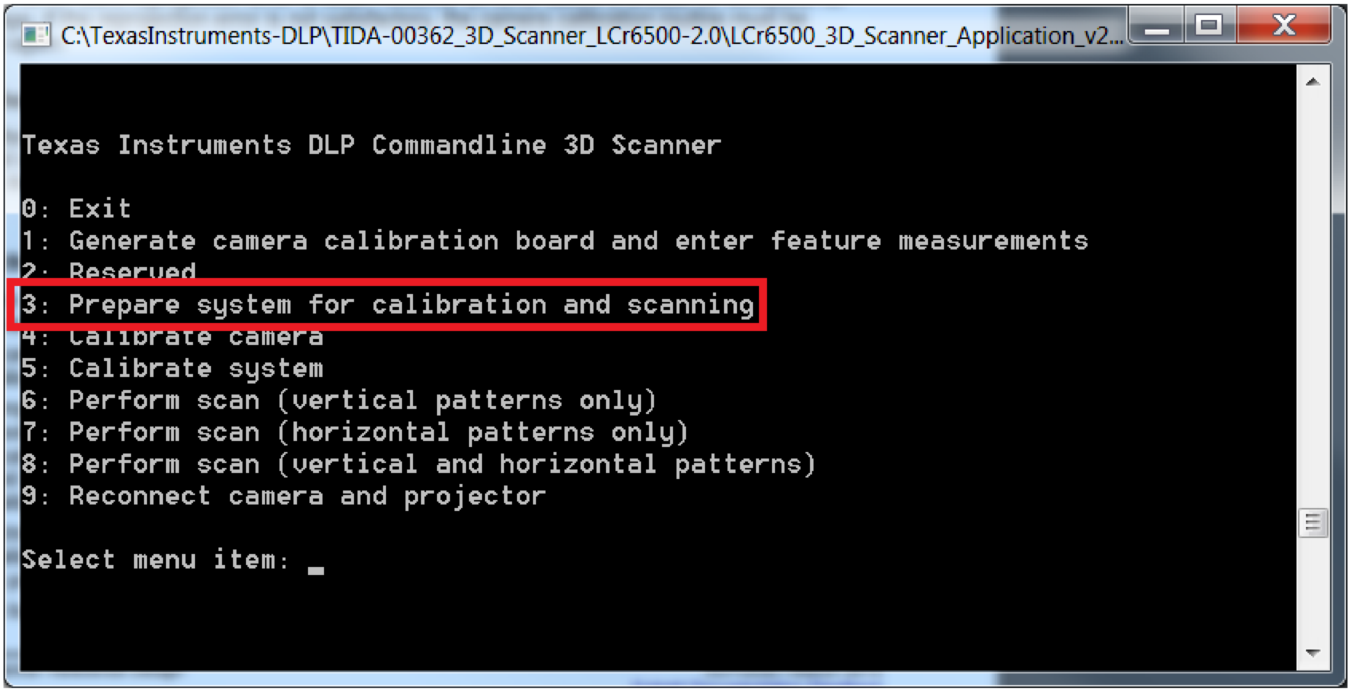


Figure 3-7. Prepare Projector Step

Every time the 3D Scanner application is run, the system must be prepared for calibration and scanning, as shown in Figure 3-7.

3.6 Calibrating the Camera

This section guides the user through the process of creating the physical connections between the LightCrafter 6500, the host PC, and the Point Grey Grasshopper3 camera and calibrating the camera.

Warning: Section 3.4 must be completed before the camera can be calibrated.

1. Connect the GPIO output trigger from the camera to the projector’s input trigger, using the cable detailed in the file "TIDA-00362-CAMERA_TRIGGER_CABLE_ASSEMBLY.pdf", as shown in Figure 3-8.

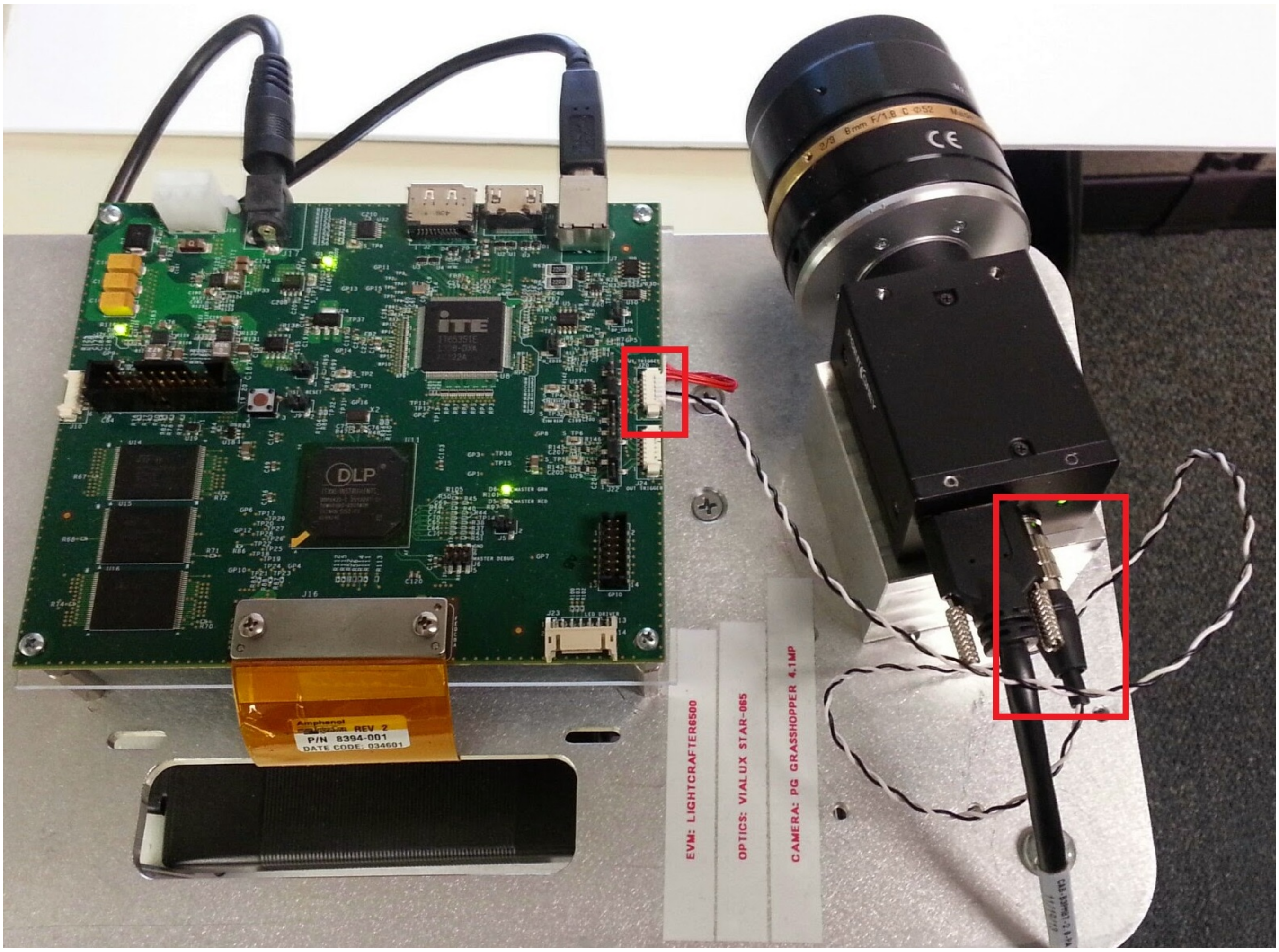


Figure 3-8. Connecting the Camera to the Host PC

2. Connect the Point Grey Grasshopper3 camera to the host PC's USB 3.0 port.
3. Connect the LightCrafter 6500 to the host PC's USB 2.0 port.

4. Make sure there is sufficient distance between the camera and the projector. The camera and projector should be separated by a 20 to 45 degree angle as formed by the object being scanned, shown in Figure 3-9.

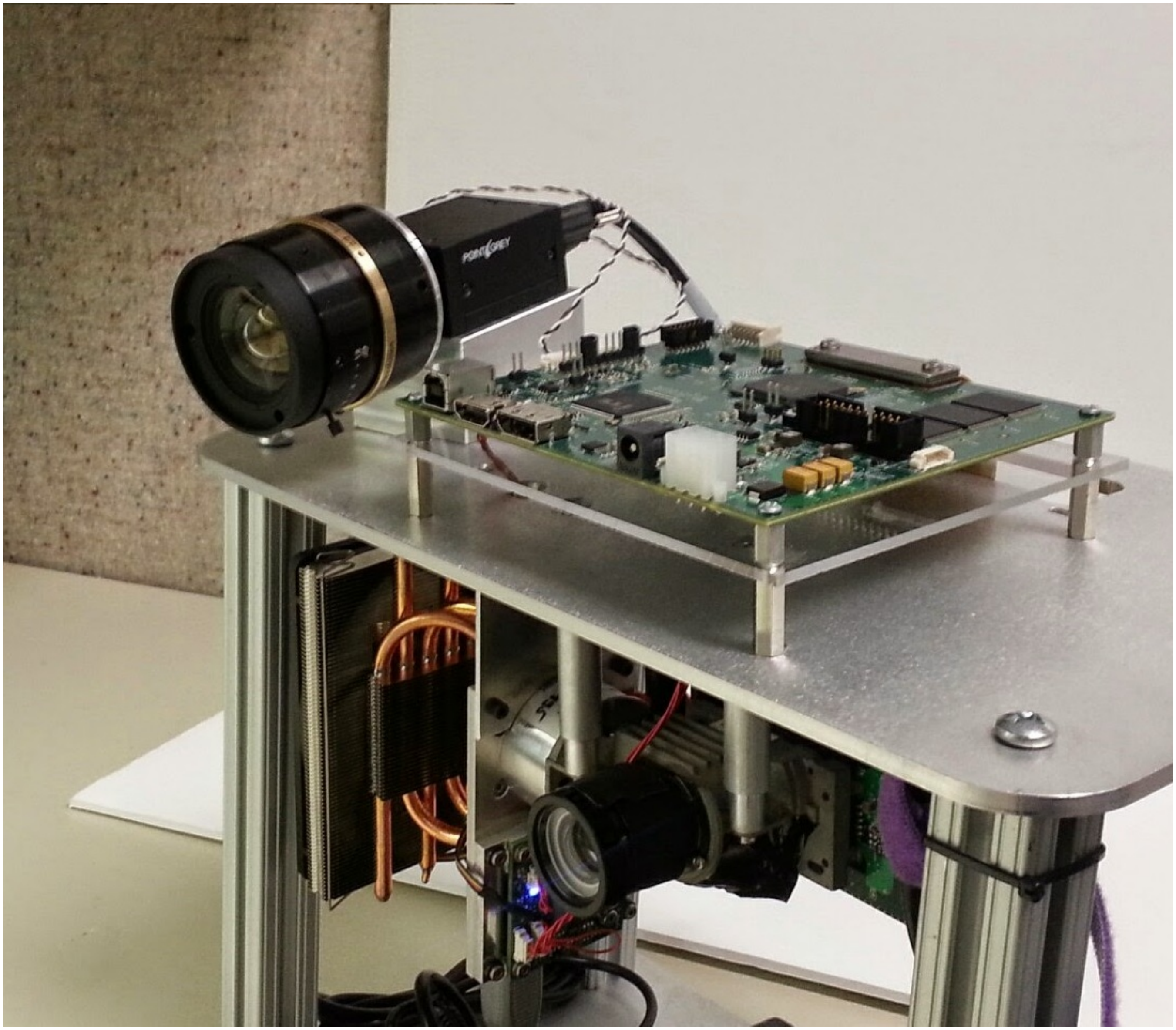


Figure 3-9. Projector, Camera, Object Spatial Orientation

5. Enter menu option "4" to start the camera calibration. Follow the prompts and directions on the screen during the entire process.

6. A live camera view window will appear on the host PC. Position the camera calibration board entirely in the frame, as shown in Figure 3-10.

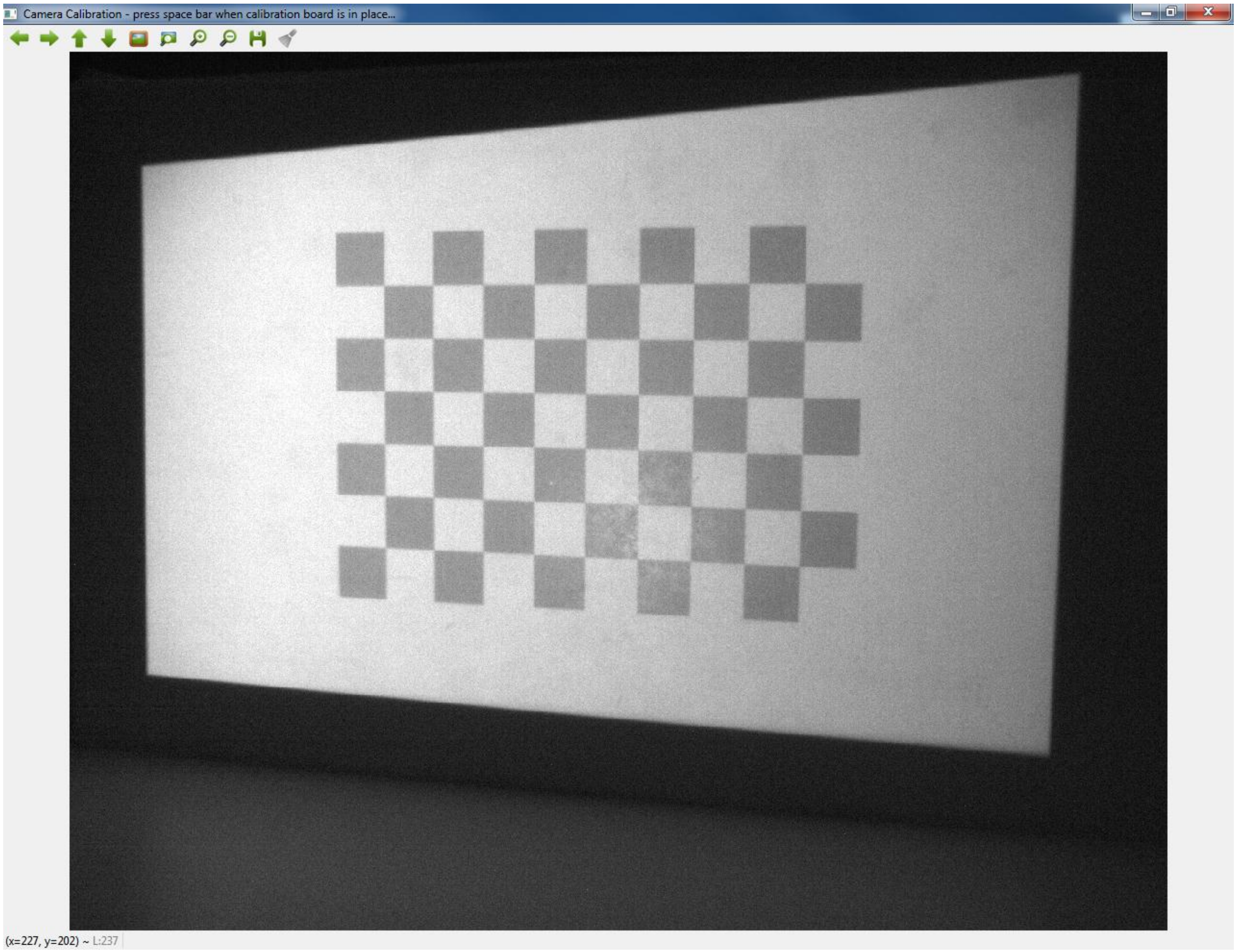


Figure 3-10. Camera Calibration Board Live View

7. Stop down the aperture as low as possible while still being able to discern the gray and white squares on the calibration board and minimize all sources of glare. Make sure the projection area is in focus, and lock the aperture and focus. An example of an overexposed image is shown in Figure 3-11, and an example of an underexposed image is shown in Figure 3-12.

Note: If the camera's aperture size or focus is changed after this step, the resulting point cloud data will be impacted. Perform camera calibration routine again if the results are undesired.

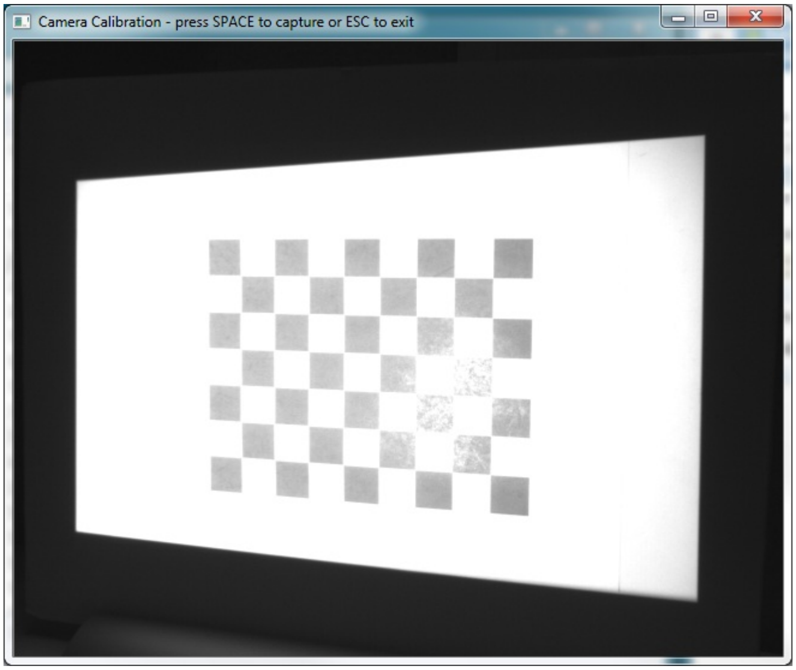


Figure 3-11. Overexposed Camera Capture

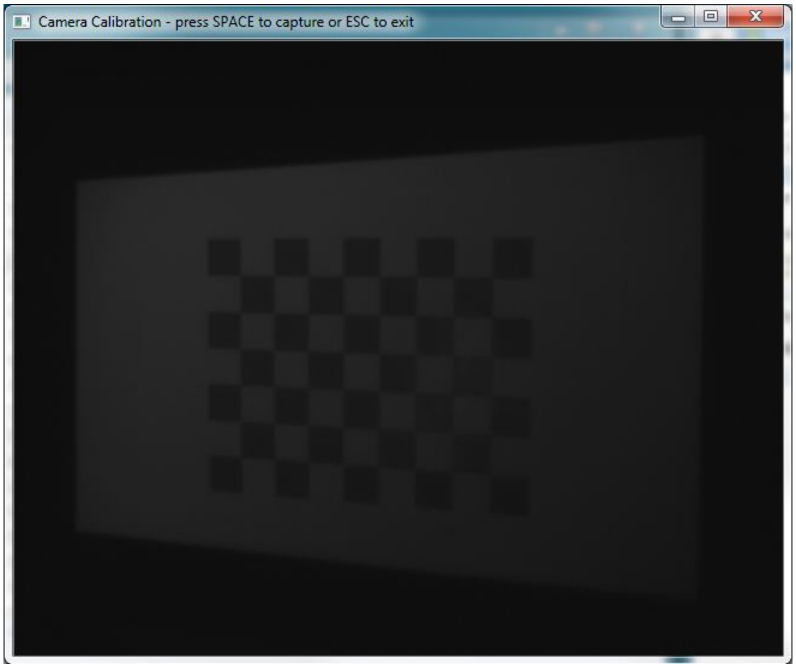
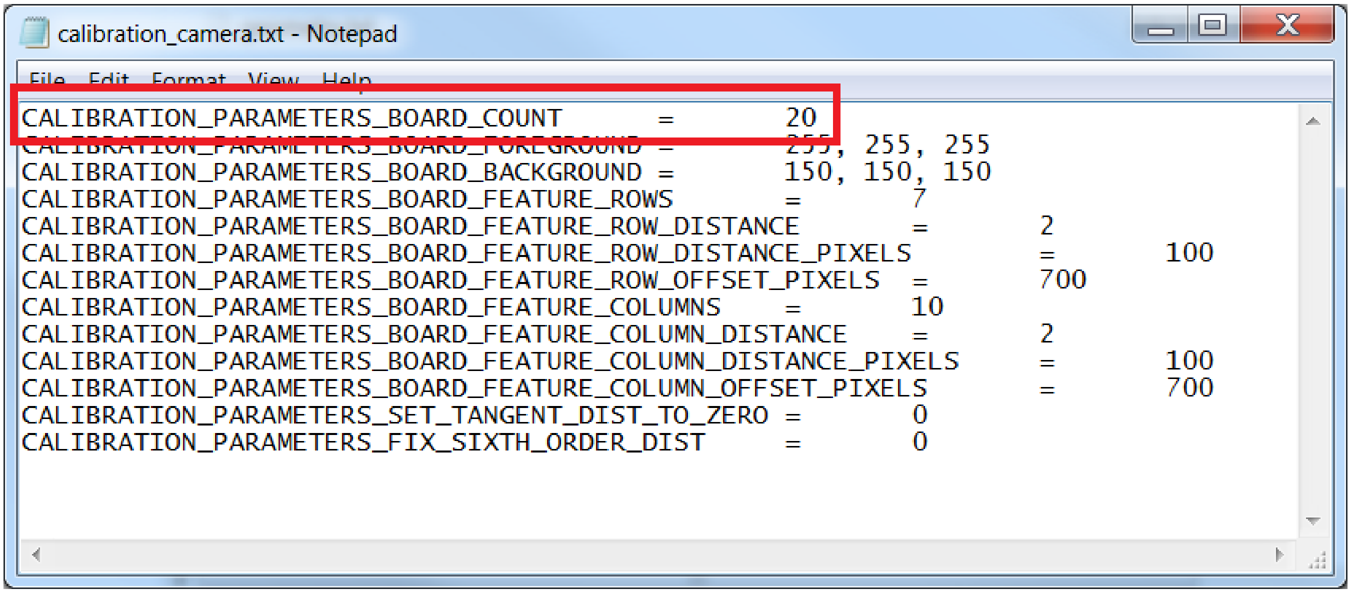


Figure 3-12. Underexposed Camera Capture

8. Click on the live camera view window on the host PC and verify the calibration board is in focus.
9. From the live camera view window, position the camera at varying angles and distances from the projection surface. Place the grid in different areas of the camera's view and press the SPACEBAR to capture images. Default settings require twenty calibration images although this parameter can be adjusted. In \config, find *calibration_camera.txt*. Figure 3-13 highlights the parameter which specifies the number of calibration images. Some recommended calibration images are shown in Figure 3-14 to Figure 3-23. It is okay to move the camera at this point in the calibration procedure.



calibration_camera.txt - Notepad

File Edit Format View Help

```
CALIBRATION_PARAMETERS_BOARD_COUNT        =        20
CALIBRATION_PARAMETERS_BOARD_FOREGROUND =        255, 255, 255
CALIBRATION_PARAMETERS_BOARD_BACKGROUND =        150, 150, 150
CALIBRATION_PARAMETERS_BOARD_FEATURE_ROWS        =        7
CALIBRATION_PARAMETERS_BOARD_FEATURE_ROW_DISTANCE        =        2
CALIBRATION_PARAMETERS_BOARD_FEATURE_ROW_DISTANCE_PIXELS        =        100
CALIBRATION_PARAMETERS_BOARD_FEATURE_ROW_OFFSET_PIXELS  =        700
CALIBRATION_PARAMETERS_BOARD_FEATURE_COLUMNS    =        10
CALIBRATION_PARAMETERS_BOARD_FEATURE_COLUMN_DISTANCE     =        2
CALIBRATION_PARAMETERS_BOARD_FEATURE_COLUMN_DISTANCE_PIXELS     =        100
CALIBRATION_PARAMETERS_BOARD_FEATURE_COLUMN_OFFSET_PIXELS       =        700
CALIBRATION_PARAMETERS_SET_TANGENT_DIST_TO_ZERO =        0
CALIBRATION_PARAMETERS_FIX_SIXTH_ORDER_DIST      =        0
```

Figure 3-13. Camera Calibration Configuration File

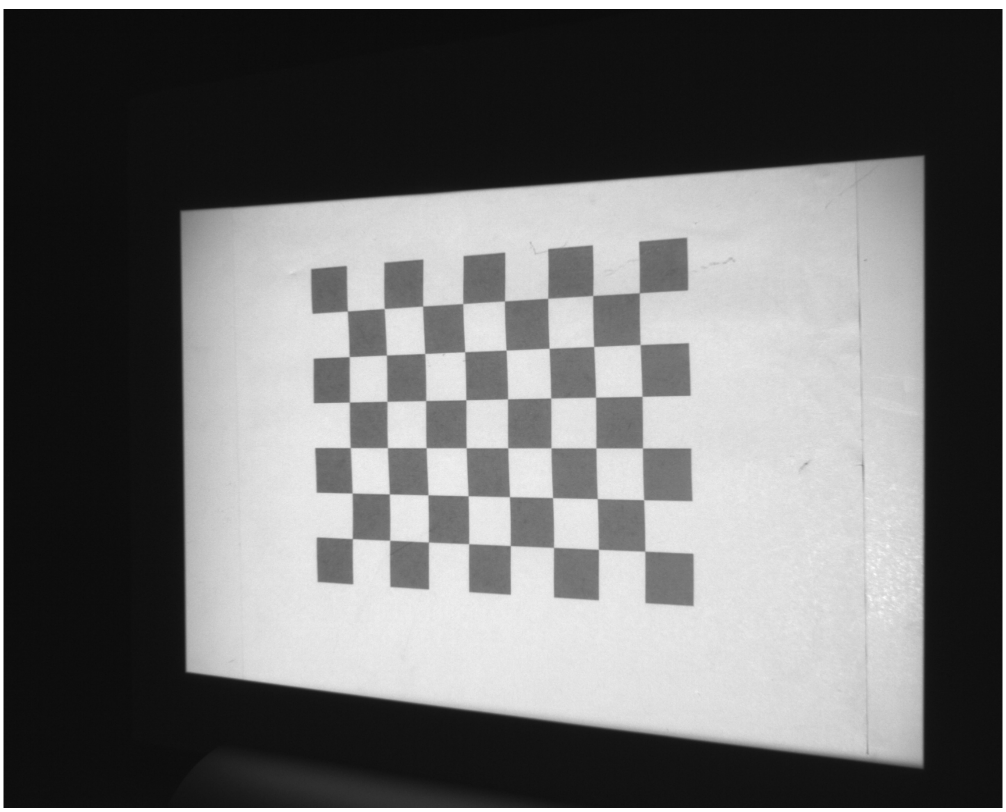


Figure 3-14. Calibration Board Image Capture Position 1

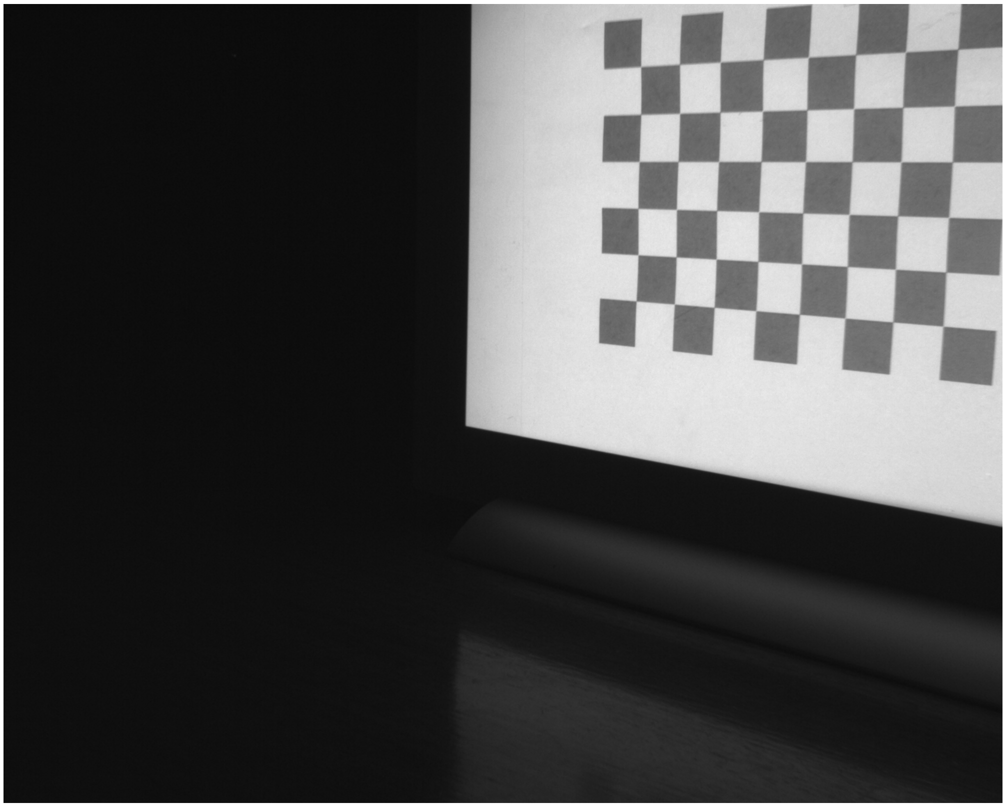


Figure 3-15. Calibration Board Image Capture Position 2

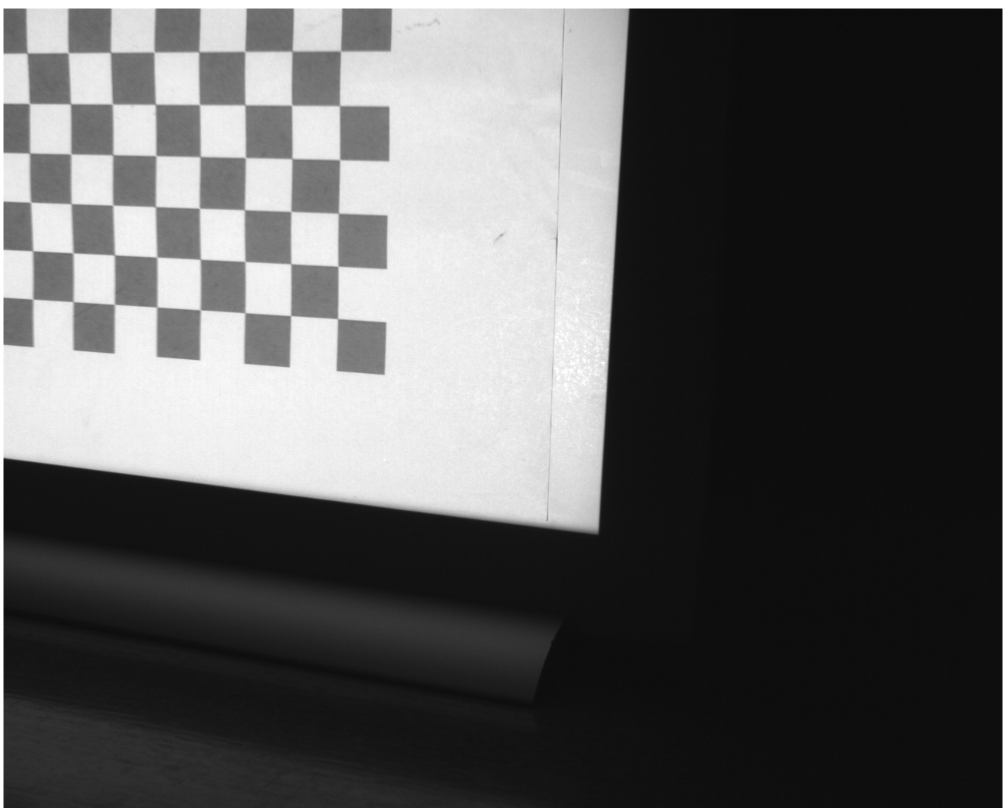


Figure 3-16. Calibration Board Image Capture Position 3

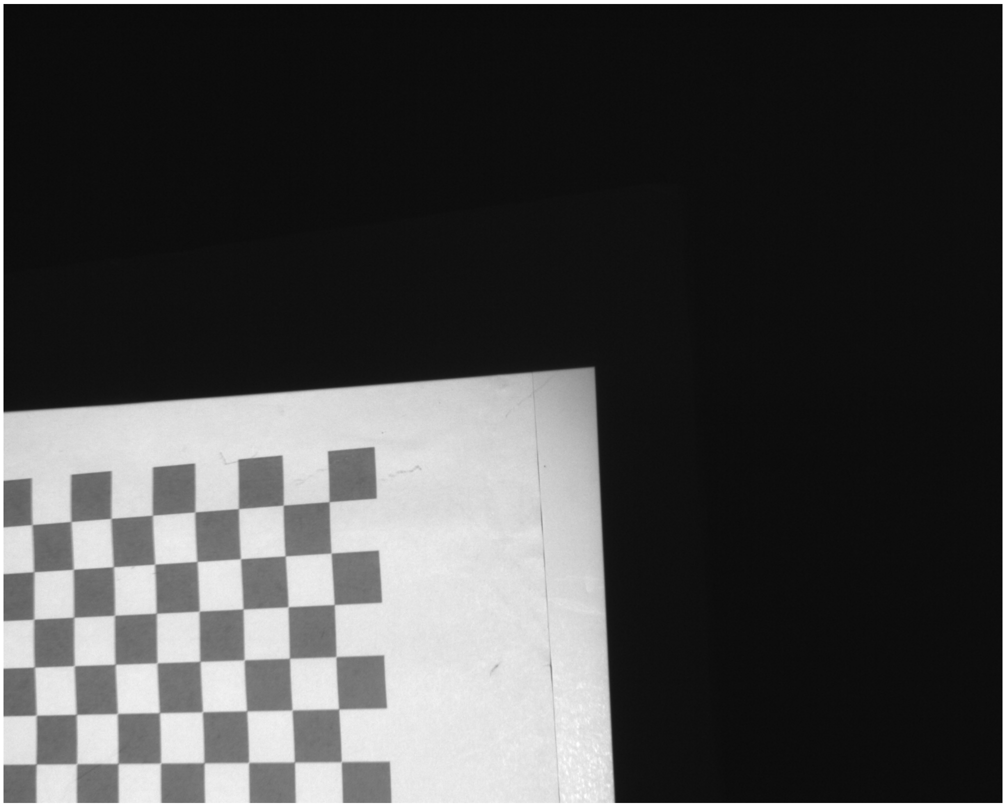


Figure 3-17. Calibration Board Image Capture Position 4

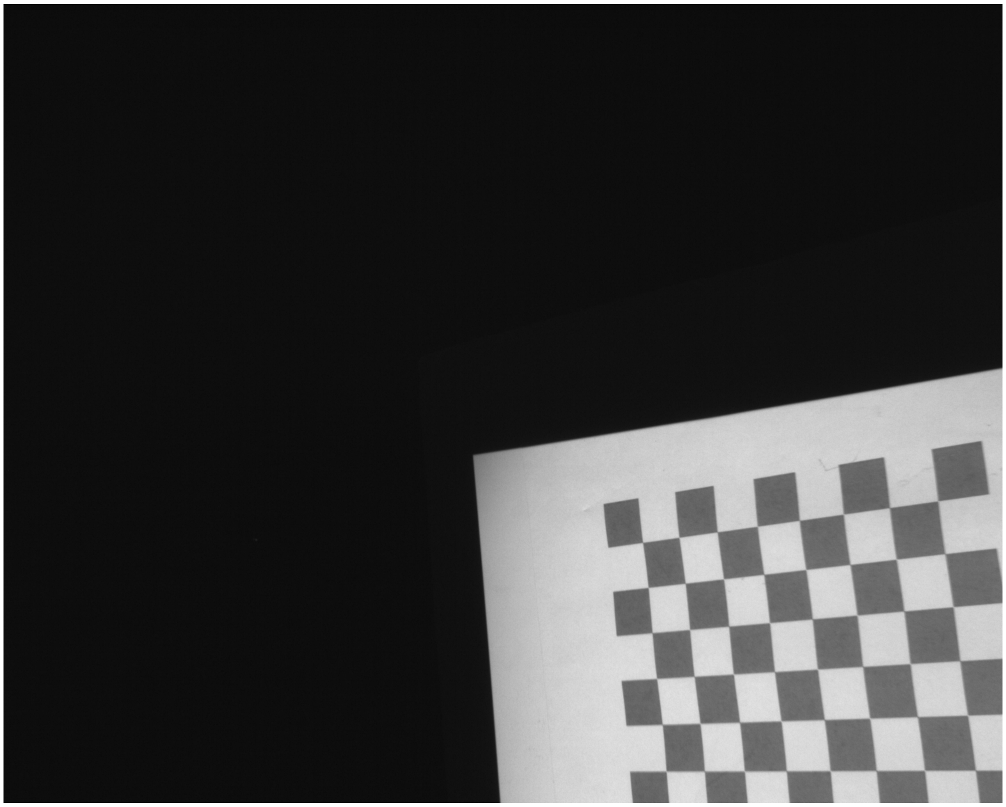


Figure 3-18. Calibration Board Image Capture Position 5

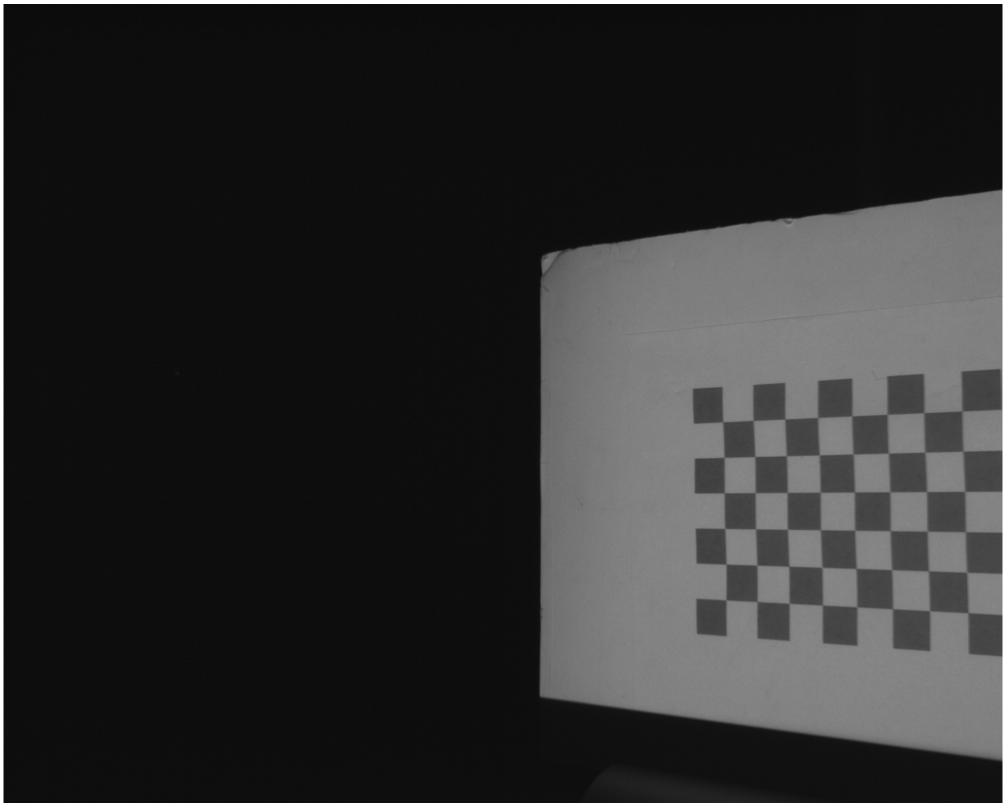


Figure 3-19. Calibration Board Image Capture Position 6

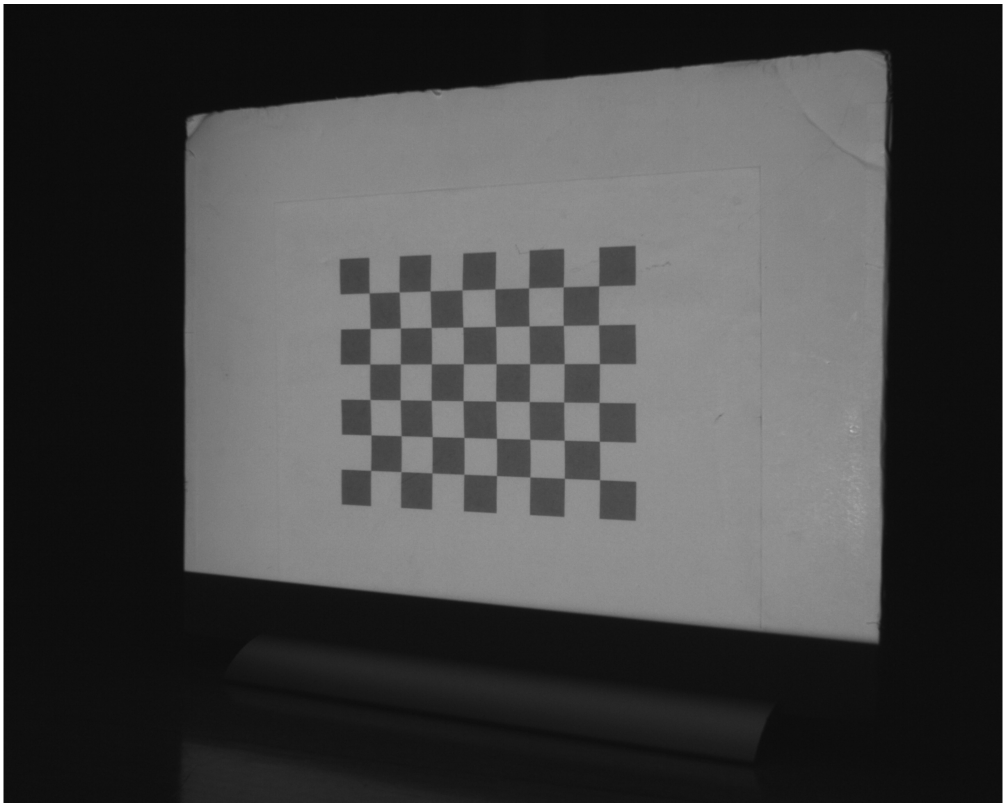


Figure 3-20. Calibration Board Image Capture Position 7

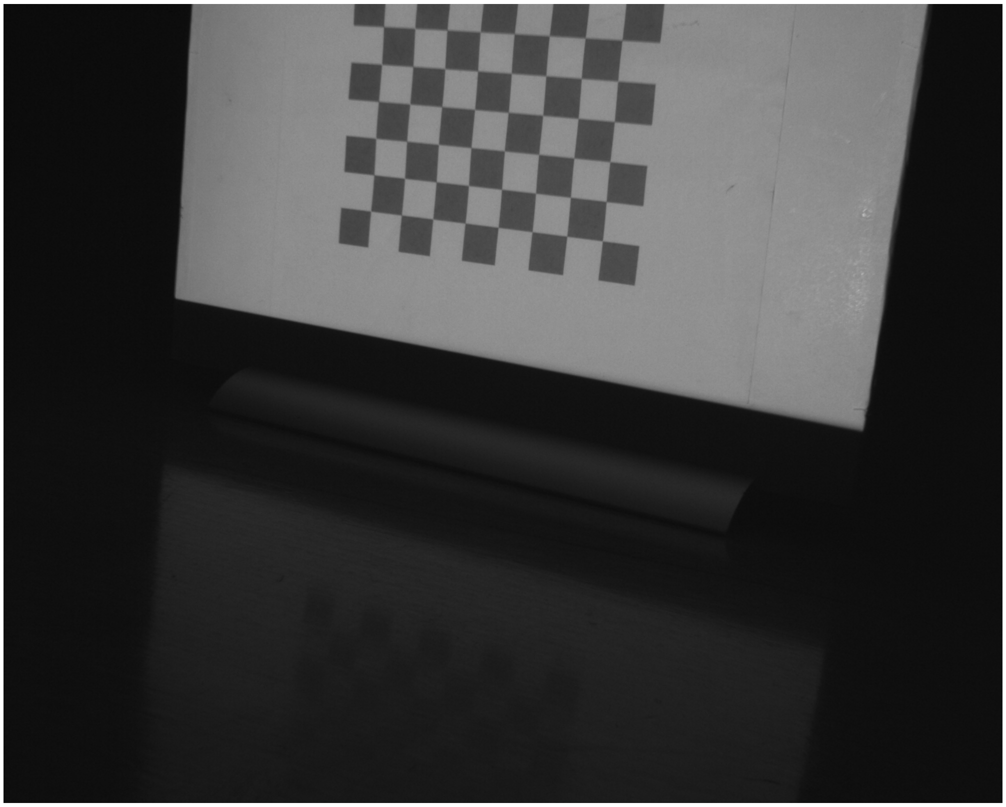


Figure 3-21. Calibration Board Image Capture Position 8

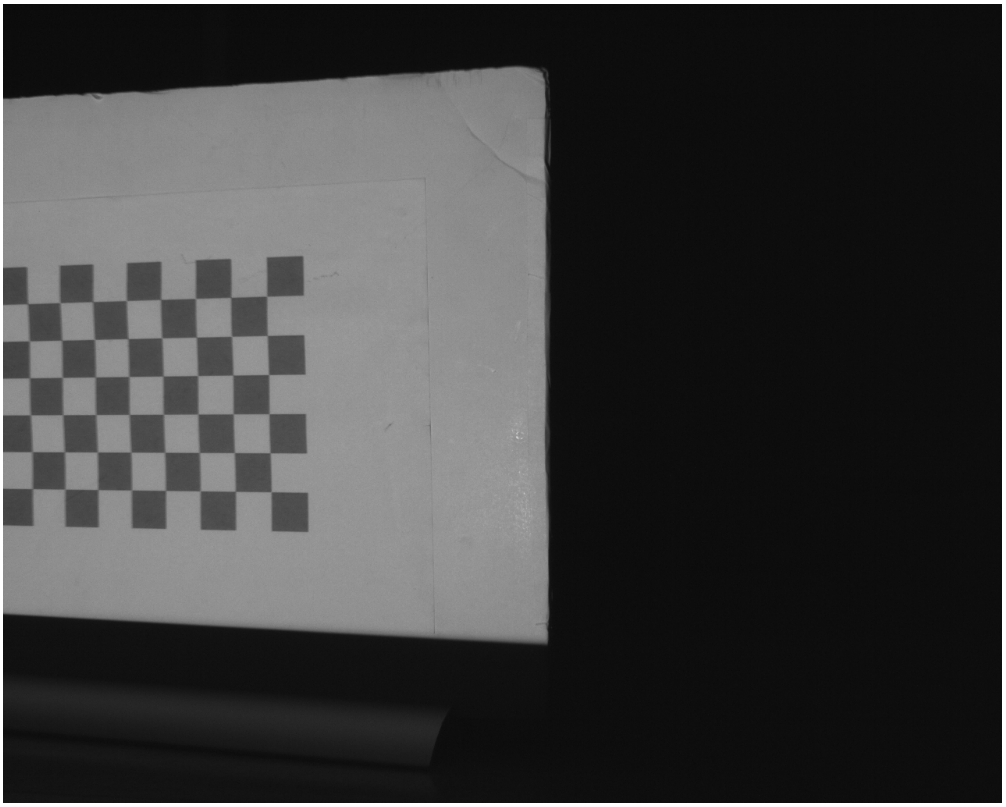


Figure 3-22. Calibration Board Image Capture Position 9

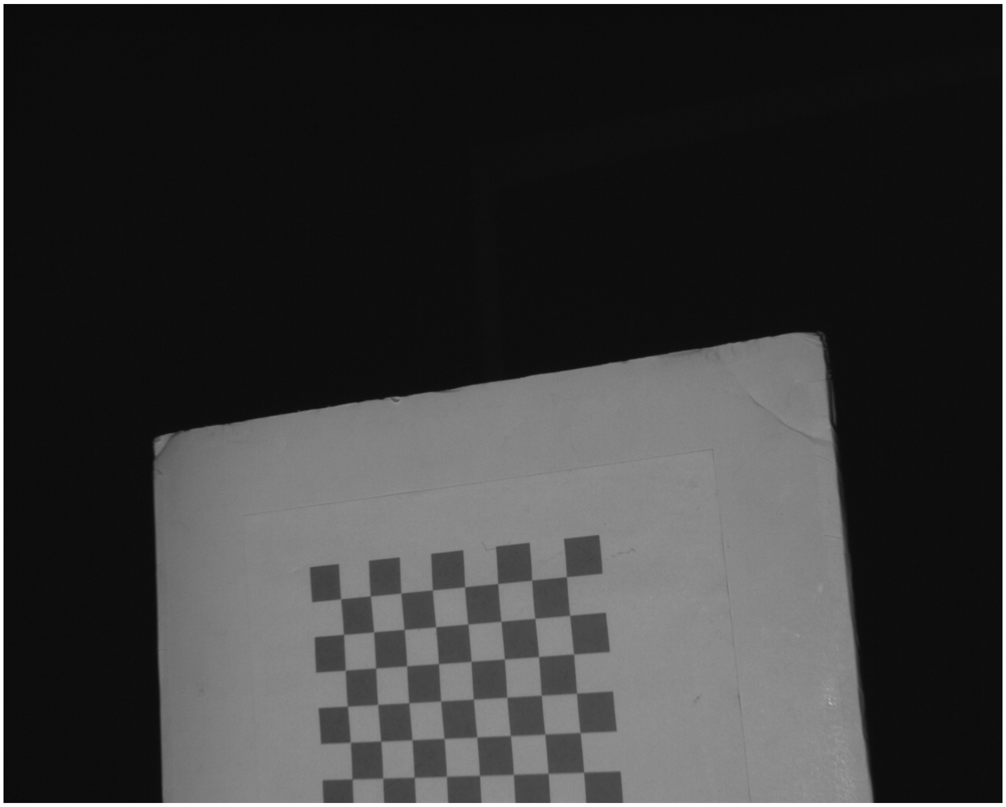


Figure 3-23. Calibration Board Image Capture Position 10

10. The calibration process estimates the lens focal length, focal point, lens distortion, and the translation and rotation of the camera relative to the calibration board. The calibration procedure will generate a reprojection error. Zero reprojection error is ideal, however an error below 2 should be adequate for typical usage. If the reprojection error is not satisfactory or if initial scans are not providing good results, run the camera calibration routine again.

3.7 Calibrating the Projector

This procedure calibrates the projector and projector/camera system. Only perform this procedure with a valid camera calibration already completed.

1. Once the camera calibration is complete and the system has been prepared, the system calibration can be performed. Start the system calibration process by entering "5" in the command line prompt. Read the directions in the prompt in detail. Default calibration will require 5 images. To change this, open *calibration_projector.txt* in \config. Figure 3-24 shows the parameter to change.

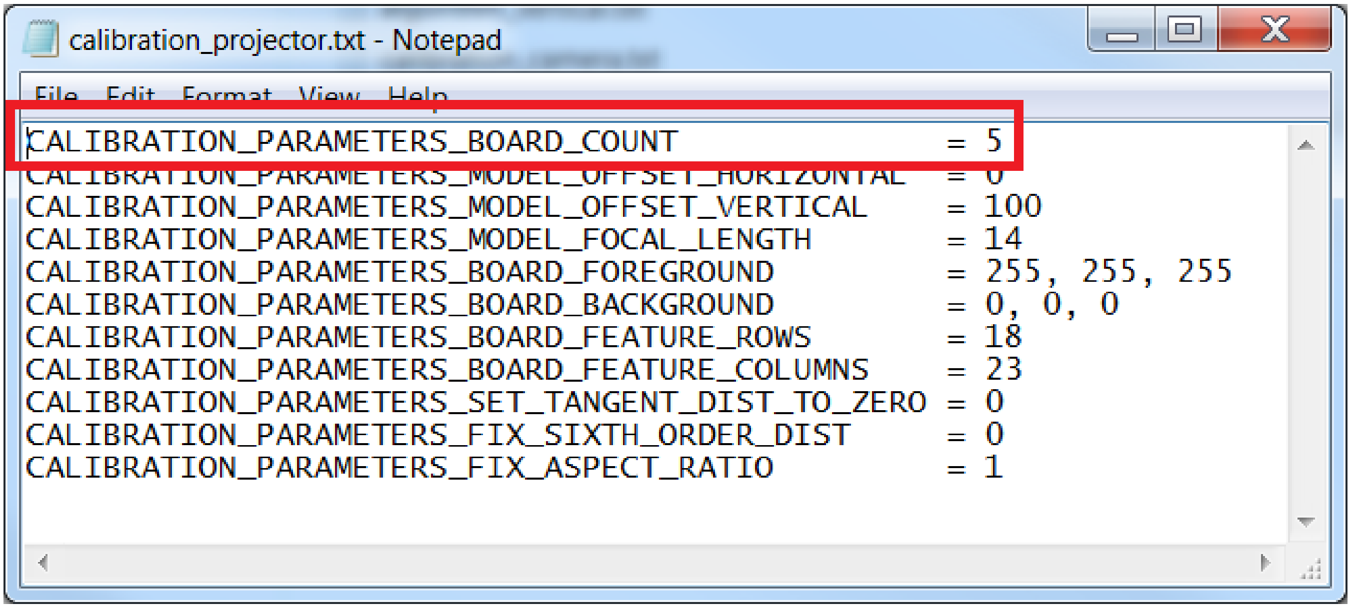


Figure 3-24. Number of Projector Calibration Shots

2. The projector will display a calibration board. The projected calibration board should be larger than the camera calibration board but still fall entirely on the calibration surface. Adjust the camera's position to center the projected calibration board in the live view.
3. Select the live camera view window and press the spacebar to capture the centered calibration board. Avoid glare from the projected board or the captured image is discarded by the software. Rotate the angle of the backstop on all 3 axes in the captured images. Figure 3-25 to Figure 3-35 show some recommended projector calibration capture orientations. The camera captures three patterns after the spacebar is clicked: solid white, black and white chessboard, and solid black.

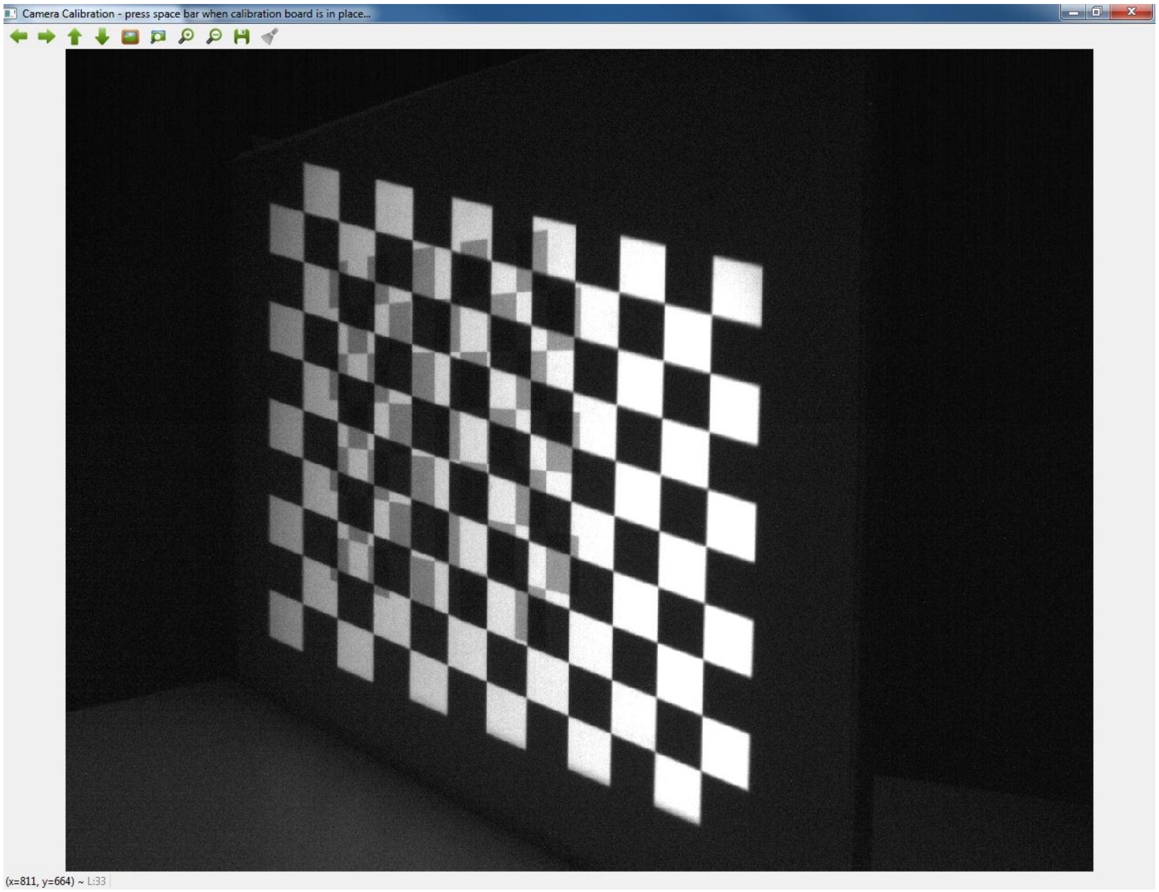


Figure 3-25. Projector Calibration Chessboard Capture

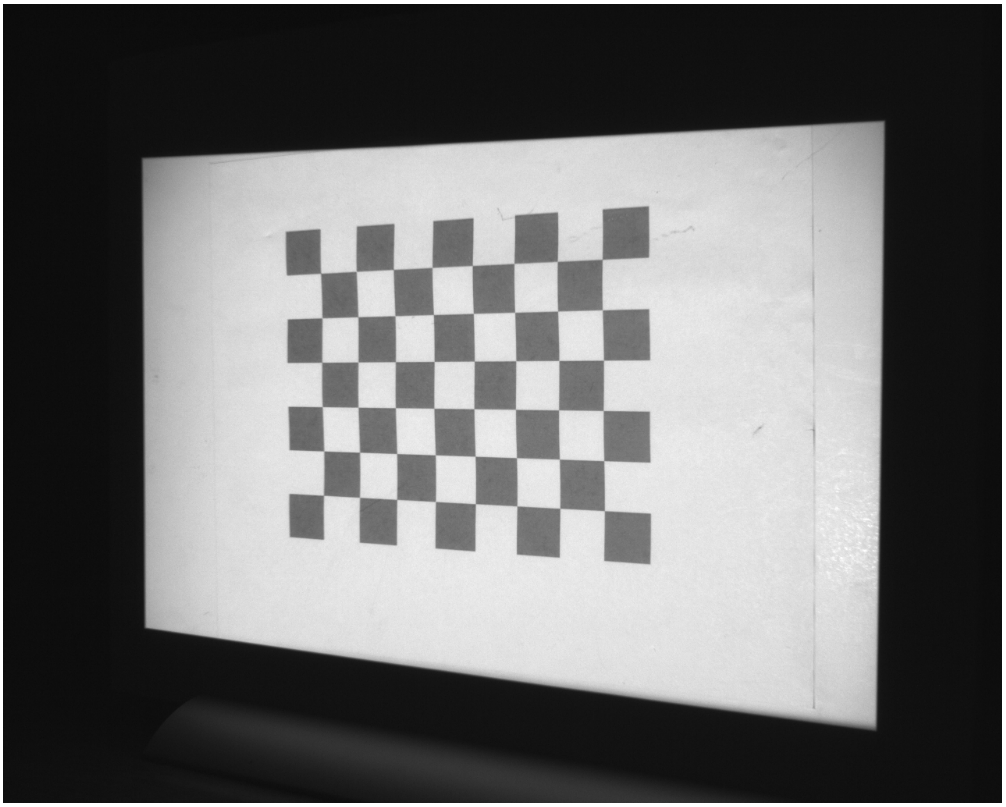


Figure 3-26. Projector Calibration Board Capture Position 1

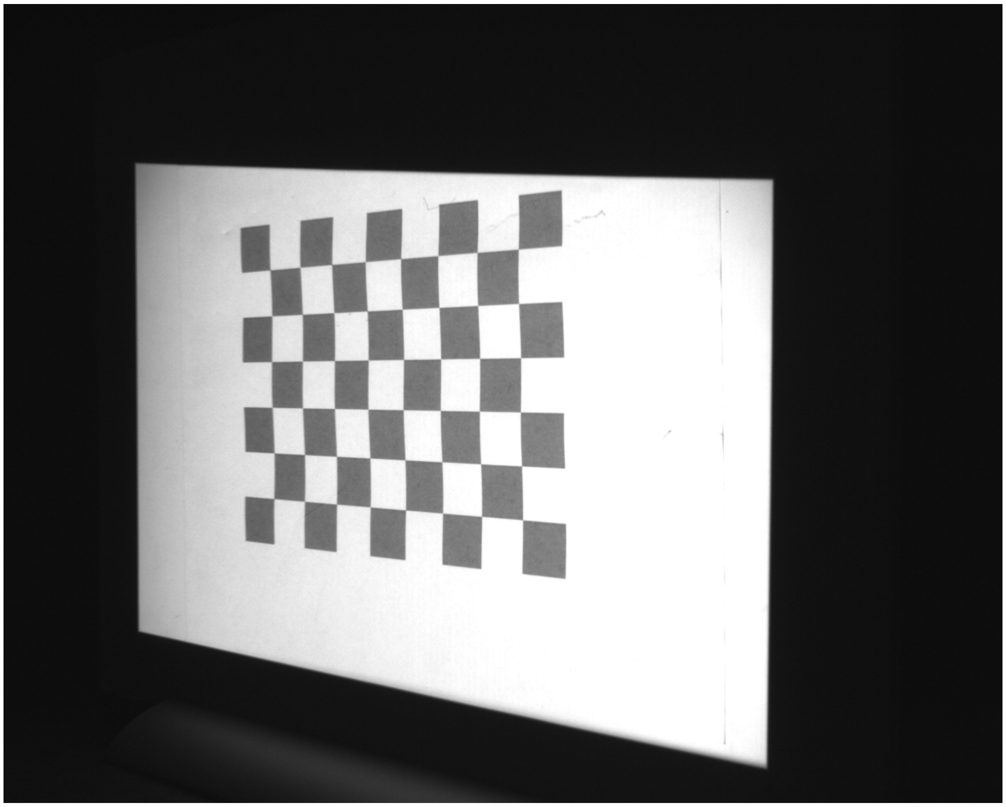


Figure 3-27. Projector Calibration Board Capture Position 2

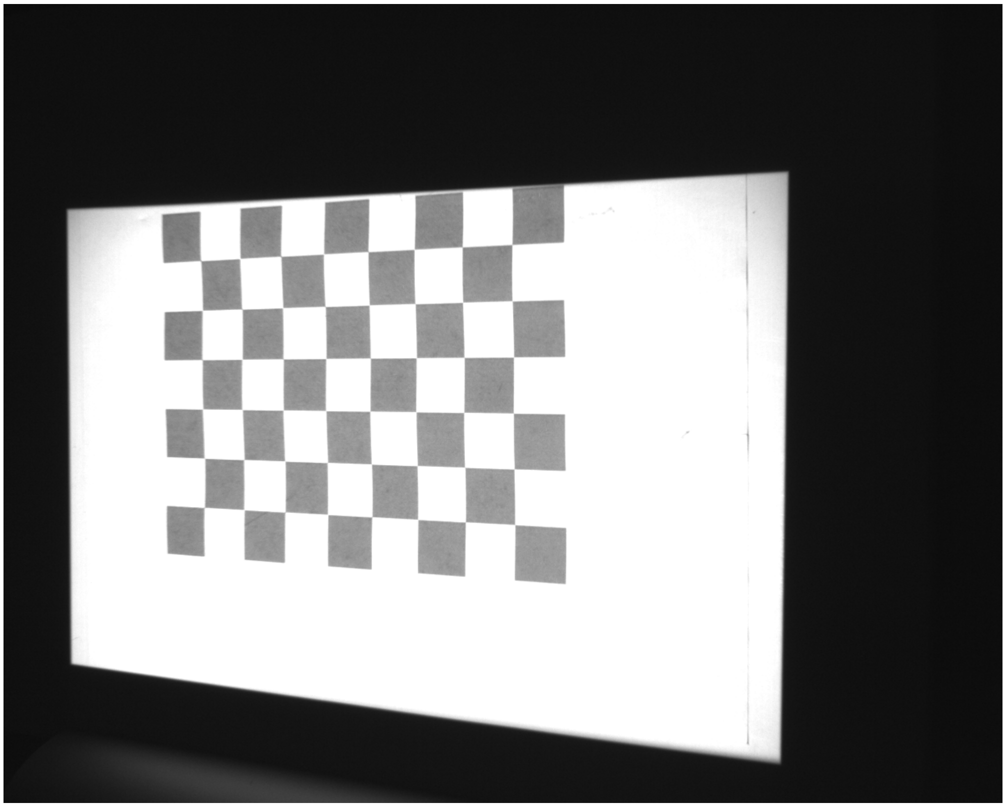


Figure 3-28. Projector Calibration Board Capture Position 3

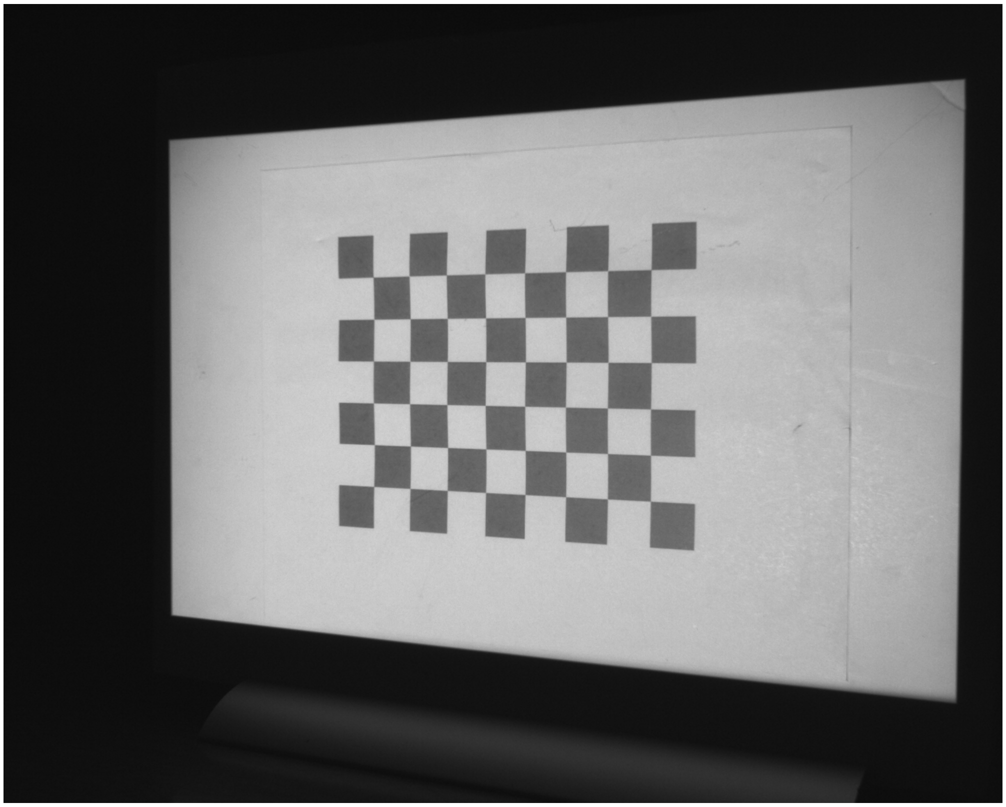


Figure 3-29. Projector Calibration Board Capture Position 4

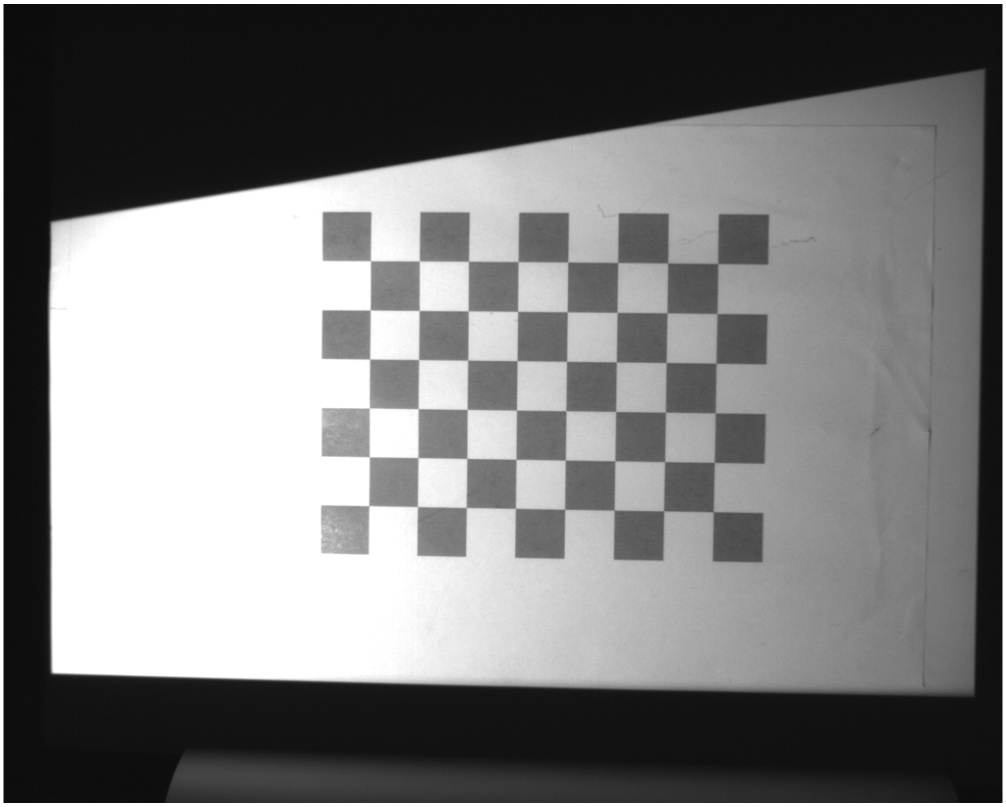


Figure 3-30. Projector Calibration Board Capture Position 5

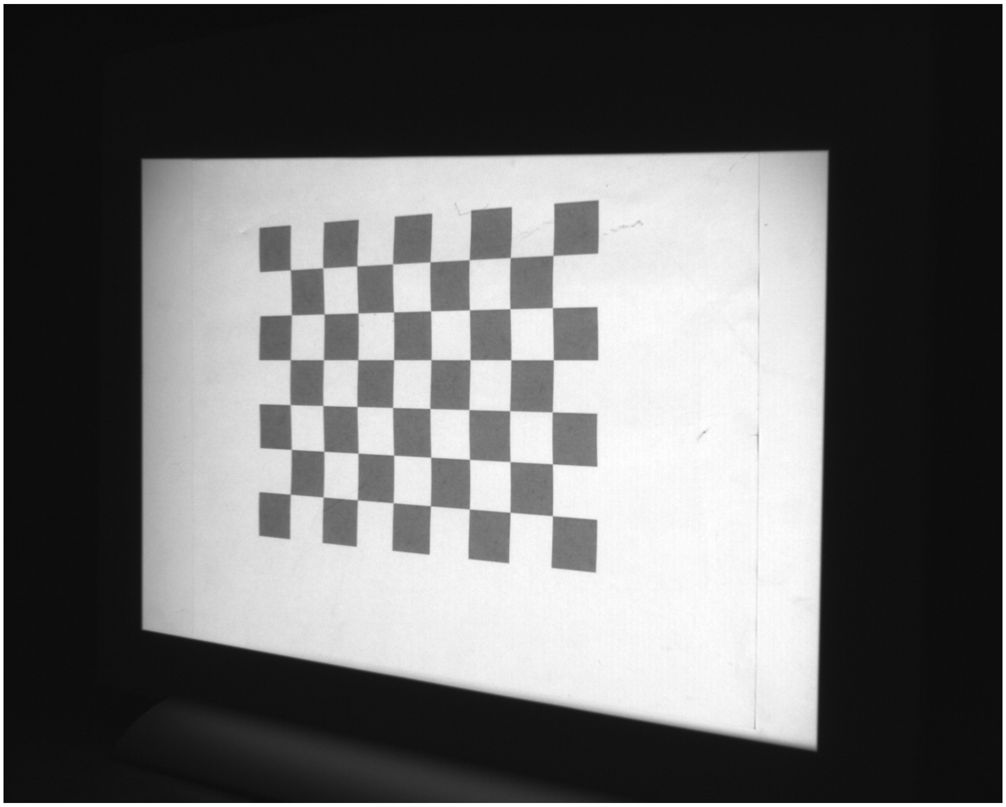


Figure 3-31. Projector Calibration Board Capture Position 6

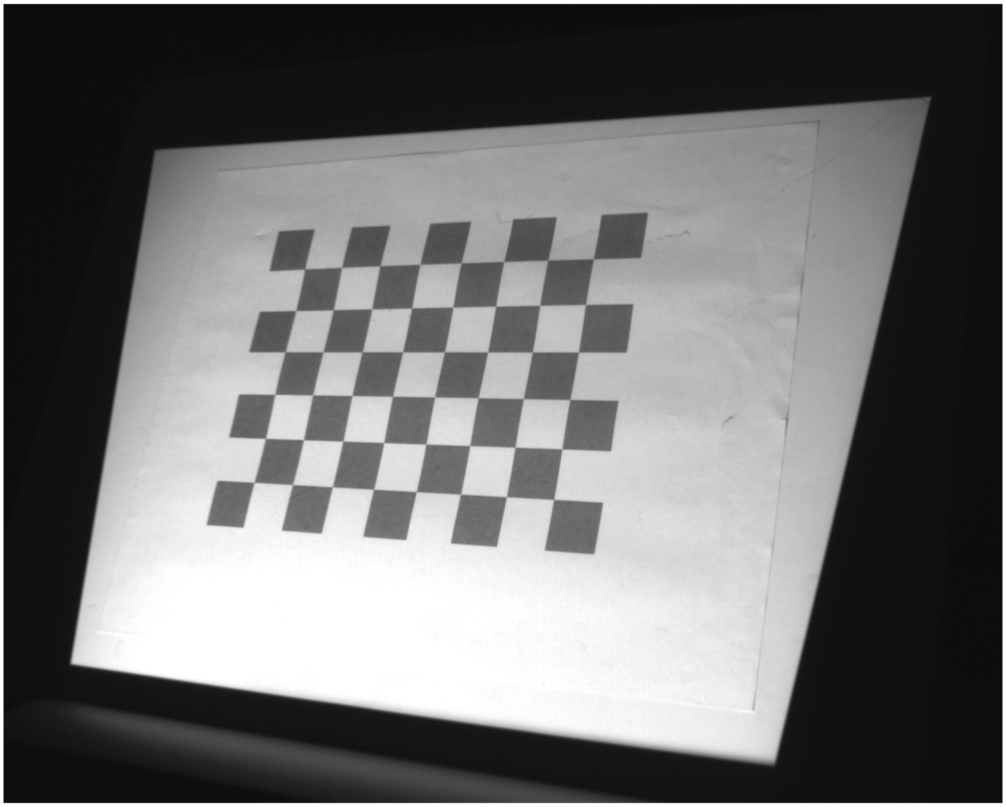


Figure 3-32. Projector Calibration Board Capture Position 7

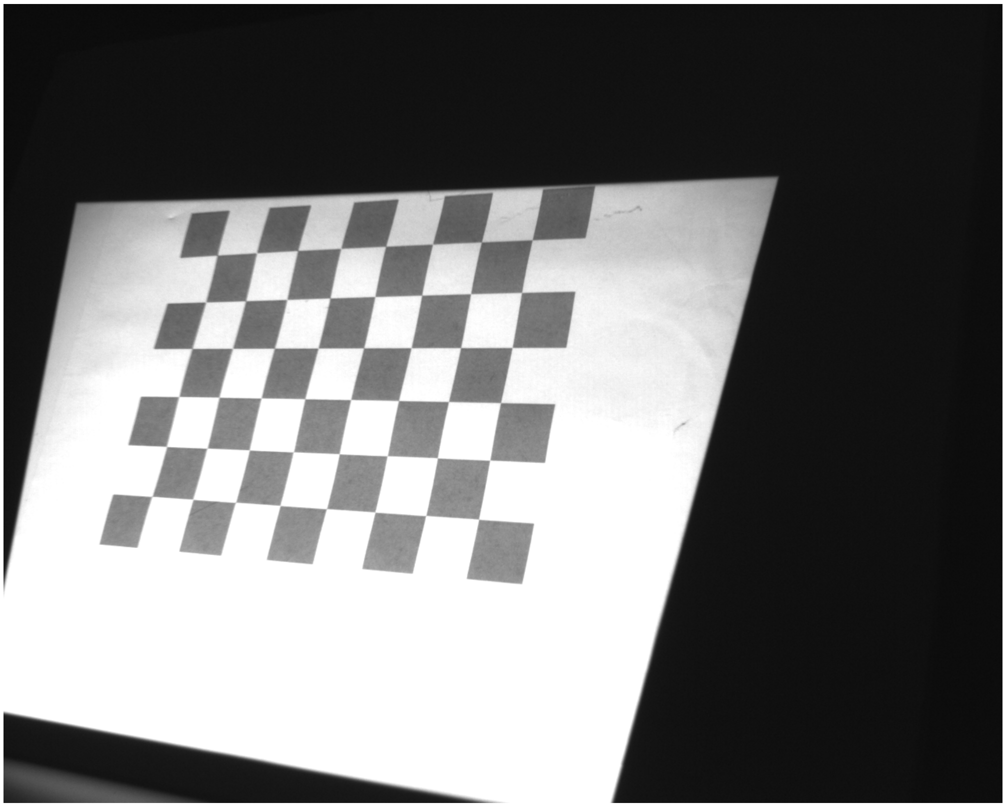


Figure 3-33. Projector Calibration Board Capture Position 8

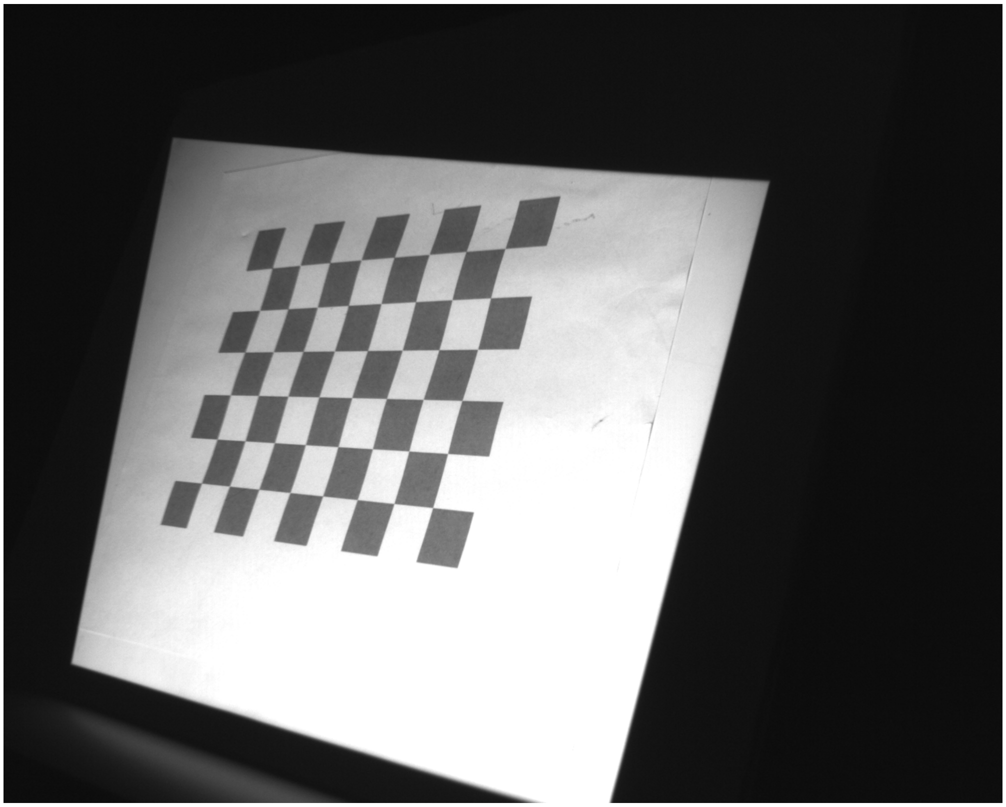


Figure 3-34. Projector Calibration Board Capture Position 9

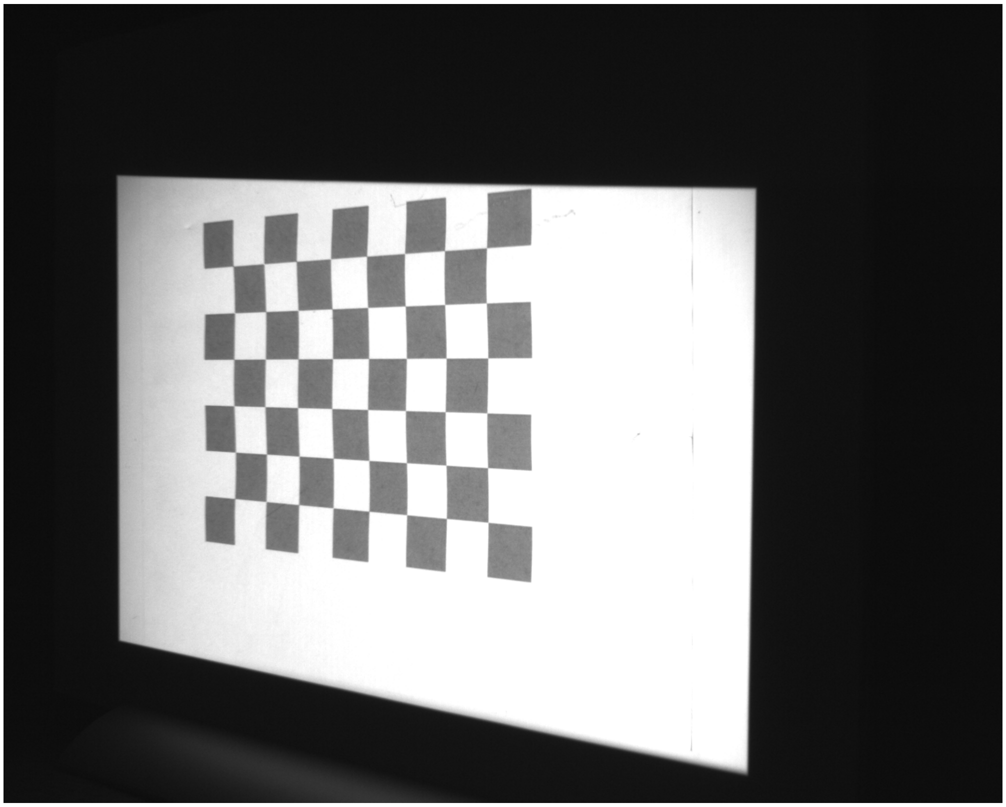


Figure 3-35. Projector Calibration Board Capture Position 10

4. Repeat step 3 a total of five times, capturing various angles and positions of the calibration board by rotating and moving the calibration surface. Ensure the projected calibration board falls entirely on the calibration surface in each capture.
5. The system calibration process estimates extrinsic and intrinsic parameters, and lens distortion parameters, for the projector. The system calibration also estimates the camera-projector orientation. The calibration procedure will generate a reprojection error similar to the camera calibration. Zero reprojection error is ideal, however an error below 2 should be adequate for typical usage. If the reprojection error is not satisfactory, verify the calibration as detailed in Section 3.8 before performing the calibration again.

3.8 Calibration Verification

Once system calibration is complete, the calibration should be verified. Scan a flat, white surface, like the backdrop for the printed calibration image, by entering the perform scan command "8" in the command line menu. The output depth map should look similar to Figure 3-36.

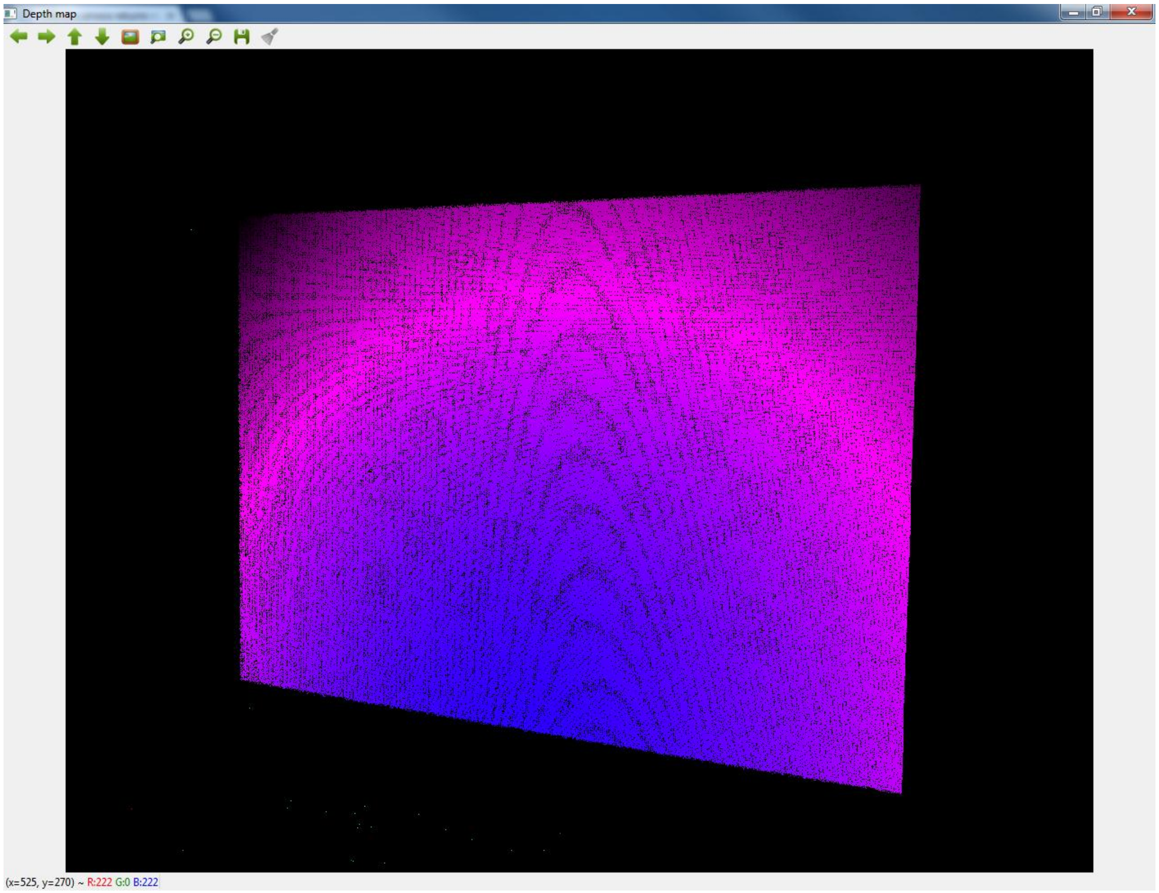


Figure 3-36. Typical Depth Map of a Flat Surface

If the depth map is missing a significant amount of points, as shown in Figure 3-37, check the camera/projector synchronization by looking at the captured images and verifying the gray coding is displayed correctly. It is also possible that the scene was not static. Please ensure that the objects being scanned are not moving.

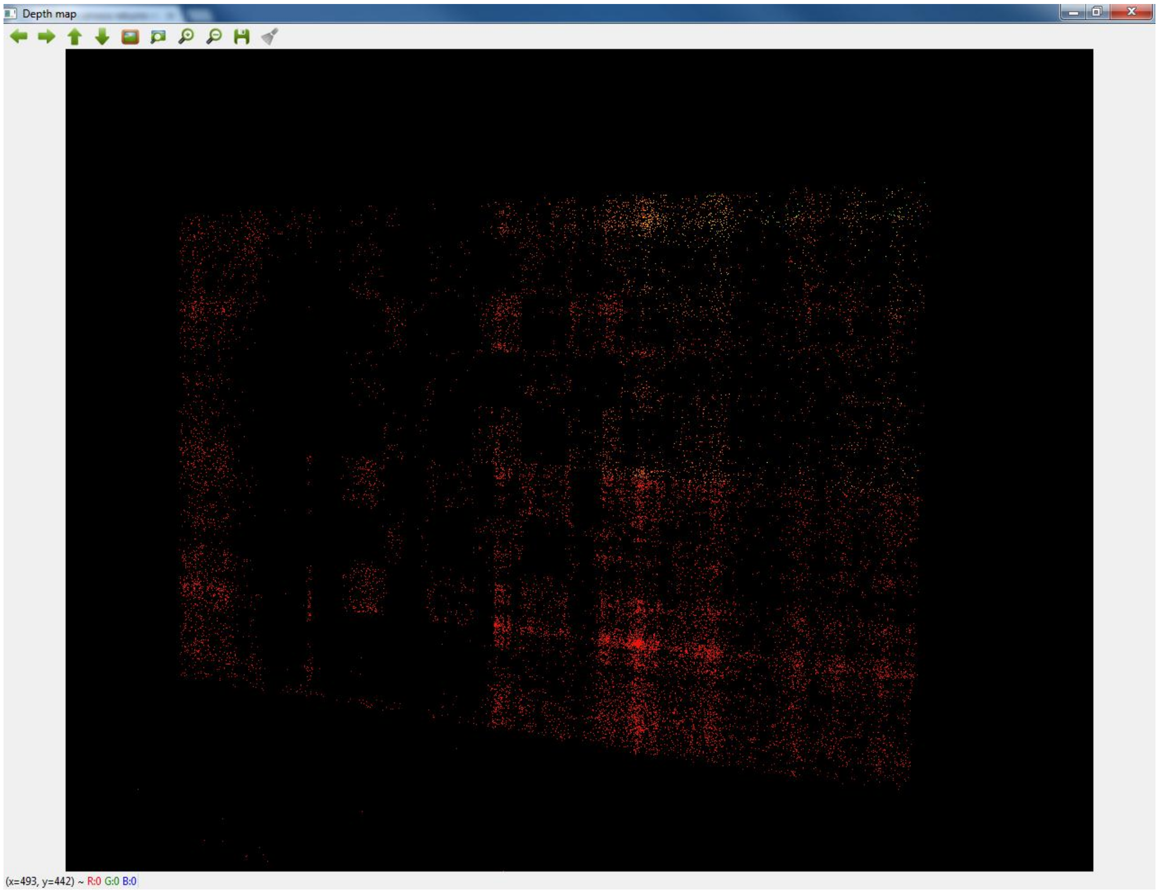


Figure 3-37. Deficient Depth Map of a Flat Surface

When the depth map is acceptably dense, open the output point cloud file using MeshLab. Inspect the point cloud for accurate reproduction of the scanned board. An example of an acceptable point cloud displayed in MeshLab is shown in Figure 3-38.

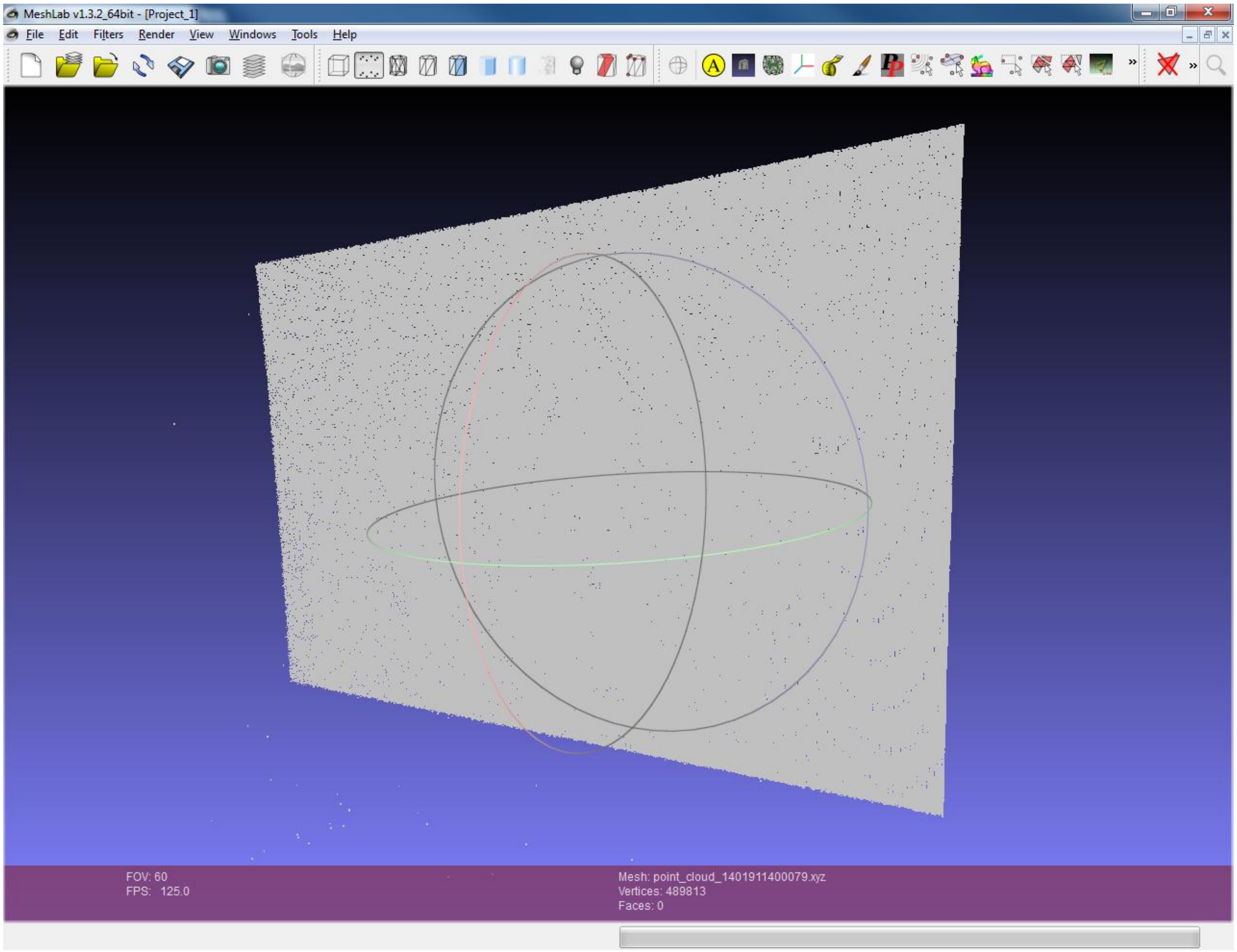


Figure 3-38. Point Cloud of a Flat Surface

If the depth map is twisted or distorted around the edges, the calibration should be performed again with special attention paid to placing the printed calibration board close to the edges of the camera frame. An example of an unacceptable point cloud displayed in MeshLab is shown in Figure 3-39.

Note: The 3D Scanner Reference Design is capable of very accurate measurements. If the flat surface being scanned has a perceivable twist in it, verify that the surface is not twisted as well before performing the calibration routine again.

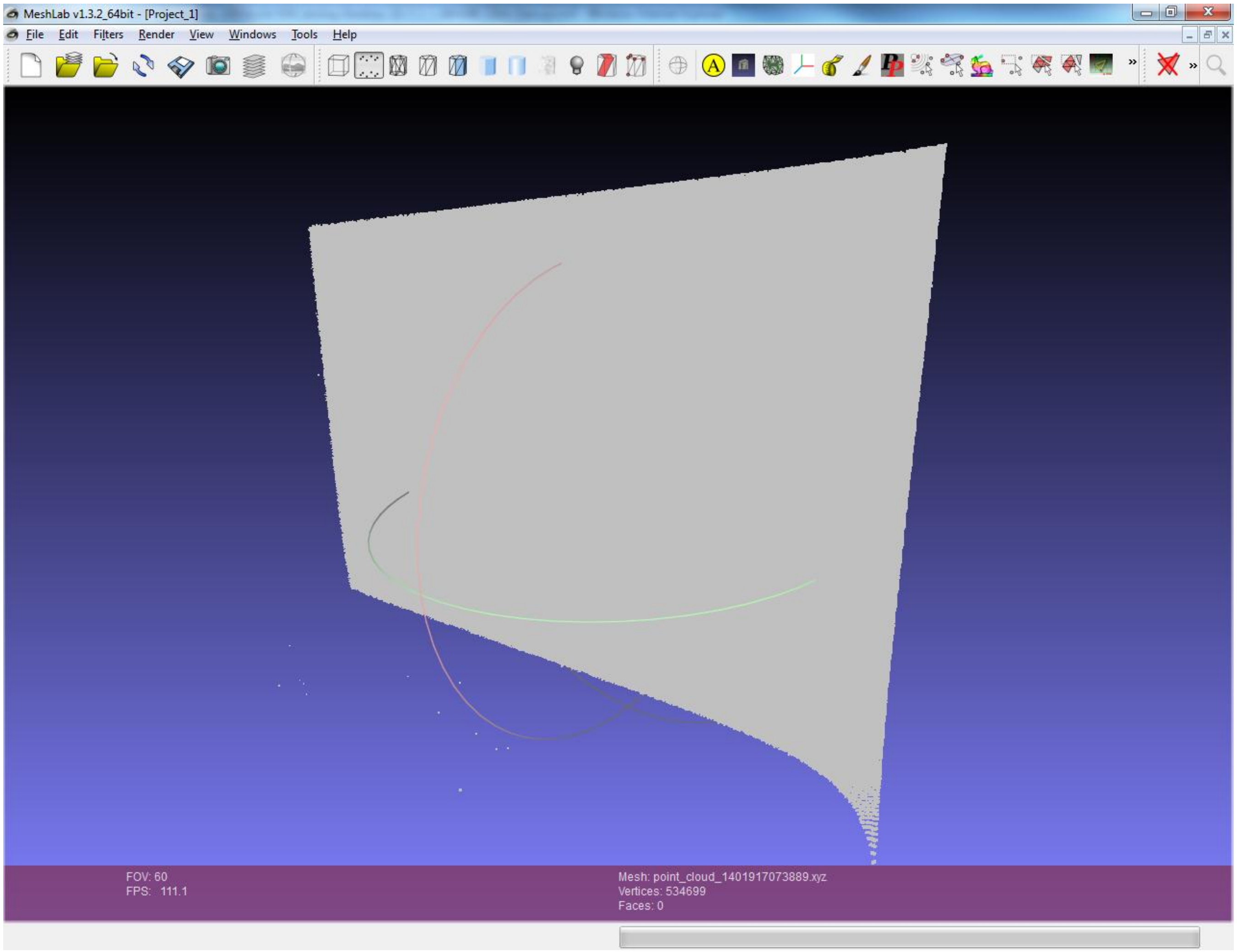


Figure 3-39. Point Cloud of a Flat Surface Generated With Poor Calibration Data

3.9 Scanning Objects

With the system calibration complete and verified, scanning of an object is done by placing the object of interest in the field of view of the camera and projector. Run the 3D Scanner executable file and enter the perform scan command "8." The object is scanned and a depth map image will open up. The output point cloud is saved as an XYZ file in the ../output/scan/ directory, viewable in MeshLab, as shown in Figure 3-40.

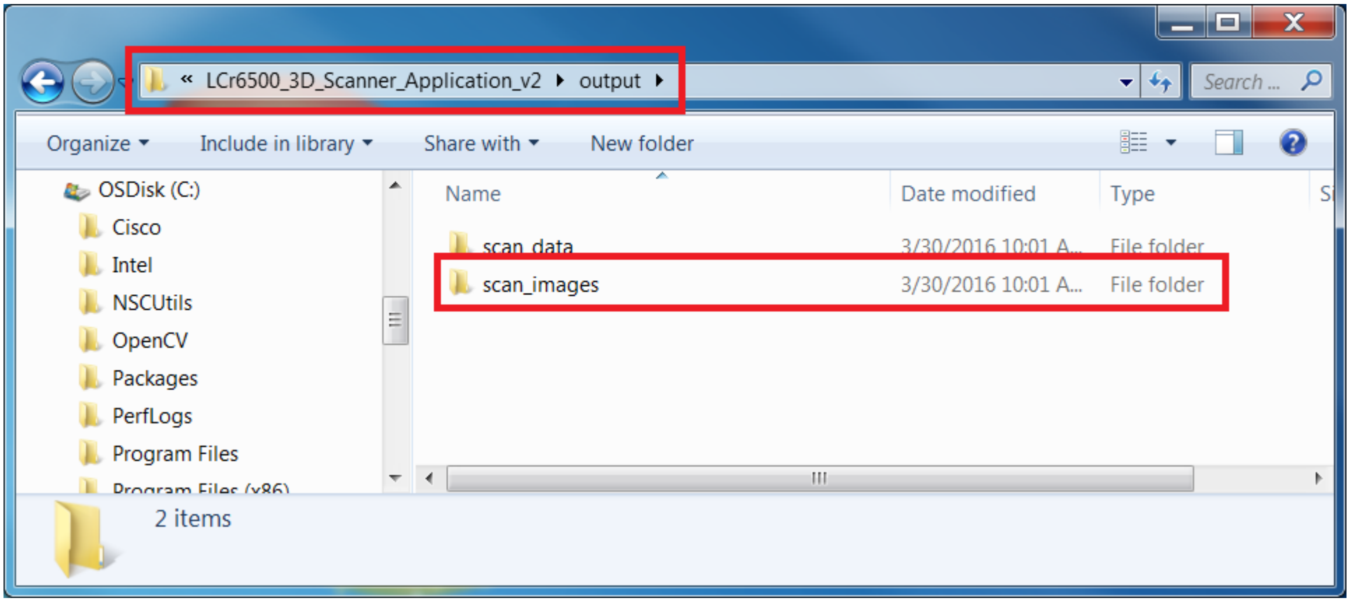


Figure 3-40. Point Cloud File Location for Use With MeshLab

Troubleshooting

4.1 General Troubleshooting Steps

This chapter details the troubleshooting steps for common problems encountered by users.

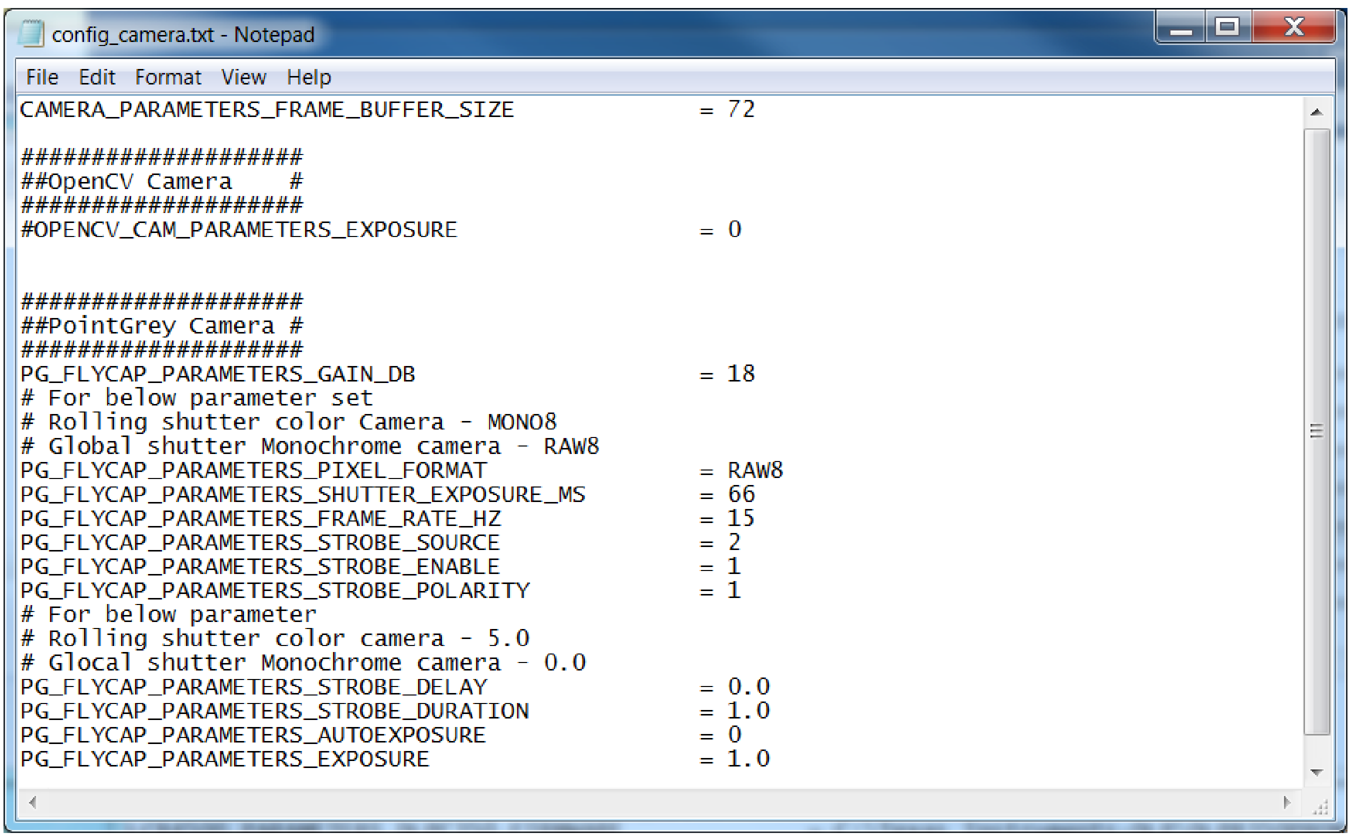
- **Problem:** The LightCrafter 6500 projector will not connect to the 3D Scanner program.

  Solution: Make sure the LightCrafter 6500 GUI is not running on the PC. Reset the LightCrafter 6500, and reconnect using menu option "9."

- **Problem:** The projected images do not appear in the camera's live view on the PC.

  Solution: It is likely that the LightCrafter 6500 and camera are not synchronized. Try reducing the frame rate of the camera, reducing the shutter speed, and increasing the exposure time and pattern period of the projector. These settings can be changed in the "config_camera.txt" and the "config_projector.txt" files in the ../config/ folder, respectively. The camera settings file is shown in Figure 4-1, and the projector settings are shown in Figure 4-2. In the example shown below, the camera frame rate is set to 15 frames per second. The projector exposure and period are set to 60,000 microseconds. The formula for the conversion to and from frame rate to exposure is:

$$10^6 = \text{Camera Frame Rate} \times \text{Projector Exposure Time} \quad (1)$$




```
CAMERA_PARAMETERS_FRAME_BUFFER_SIZE                 = 72

####################
##OpenCV Camera     #
####################
#OPENCV_CAM_PARAMETERS_EXPOSURE                     = 0


####################
##PointGrey Camera #
####################
PG_FLYCAP_PARAMETERS_GAIN_DB                        = 18
# For below parameter set
# Rolling shutter color Camera - MONO8
# Global shutter Monochrome camera - RAW8
PG_FLYCAP_PARAMETERS_PIXEL_FORMAT                   = RAW8
PG_FLYCAP_PARAMETERS_SHUTTER_EXPOSURE_MS            = 66
PG_FLYCAP_PARAMETERS_FRAME_RATE_HZ                  = 15
PG_FLYCAP_PARAMETERS_STROBE_SOURCE                  = 2
PG_FLYCAP_PARAMETERS_STROBE_ENABLE                  = 1
PG_FLYCAP_PARAMETERS_STROBE_POLARITY                = 1
# For below parameter
# Rolling shutter color camera - 5.0
# Glocal shutter Monochrome camera - 0.0
PG_FLYCAP_PARAMETERS_STROBE_DELAY                   = 0.0
PG_FLYCAP_PARAMETERS_STROBE_DURATION                = 1.0
PG_FLYCAP_PARAMETERS_AUTOEXPOSURE                   = 0
PG_FLYCAP_PARAMETERS_EXPOSURE                       = 1.0
```

Figure 4-1. Camera Configuration File

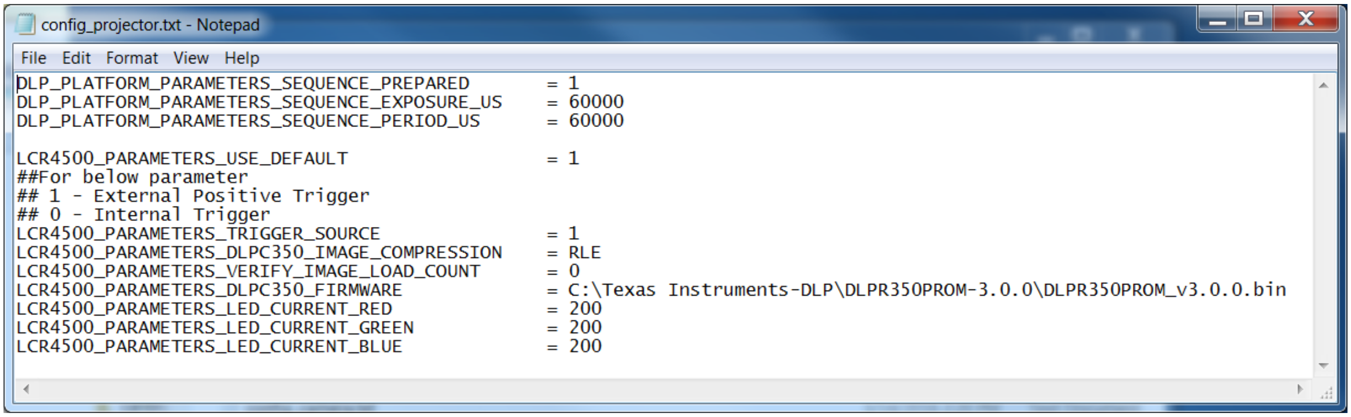


Figure 4-2. Projector Configuration File

- **Problem:** The camera appears to be running at a very low frame rate causing slow scan rates.

  Solution: Close the 3D Scanner program by entering "0" at the main menu. Click the Windows Start button and search for "flycap2." Open the Point Grey FlyCap2 software, as shown in Figure 4-3.

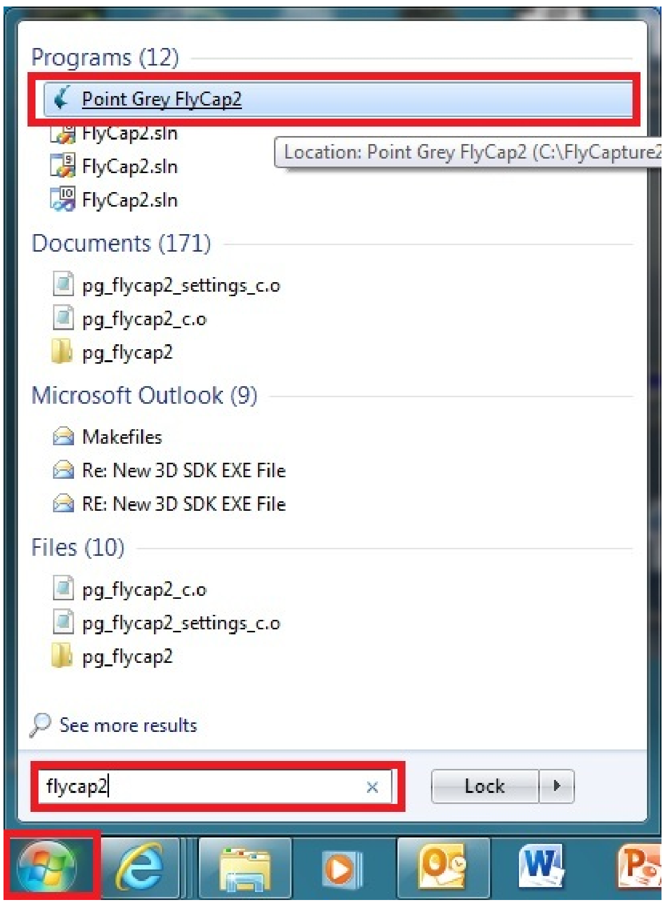


Figure 4-3. FlyCap2 Software Utility Shortcut

Select the camera in use, in the case of a single camera, it will already be selected. Click the Configure Selected button, as shown in Figure 4-4.

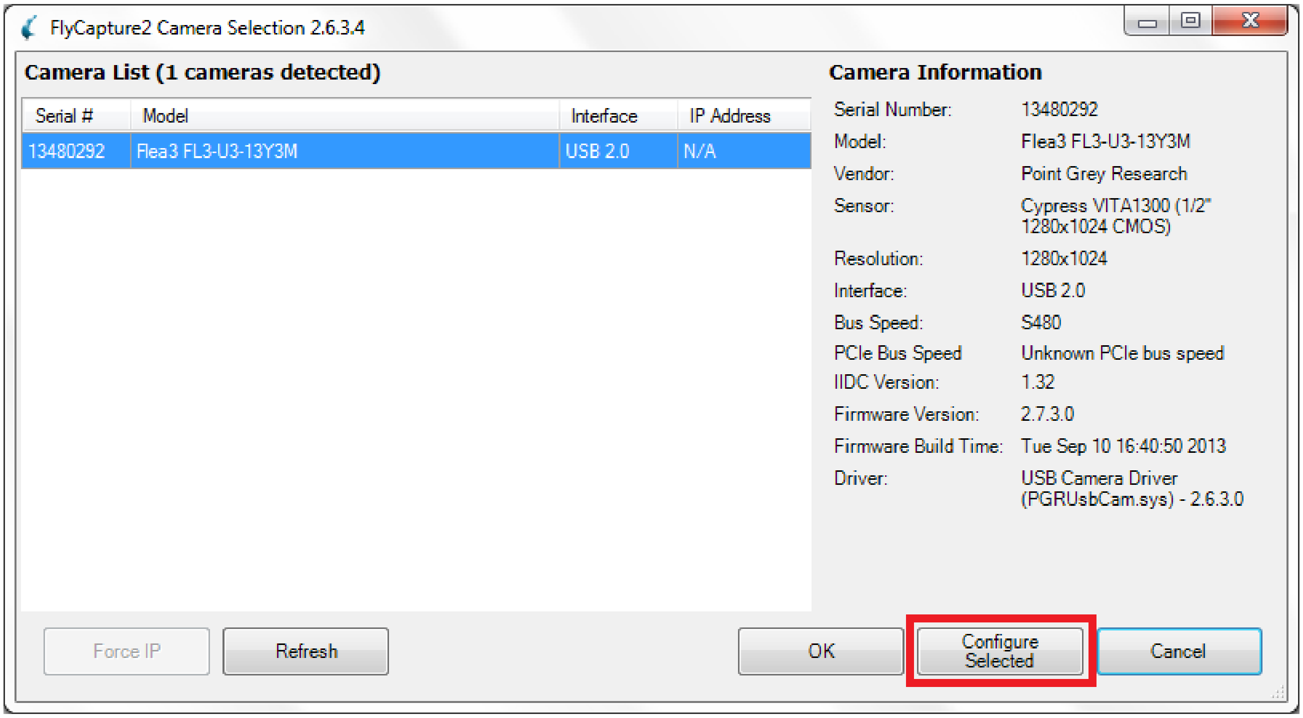


Figure 4-4. Configure Selected Camera in FlyCap2 Software

Enter the Advanced Camera Settings tab on the left of the screen, make sure the memory channel is set to default. Click the Save button, as shown in Figure 4-5.

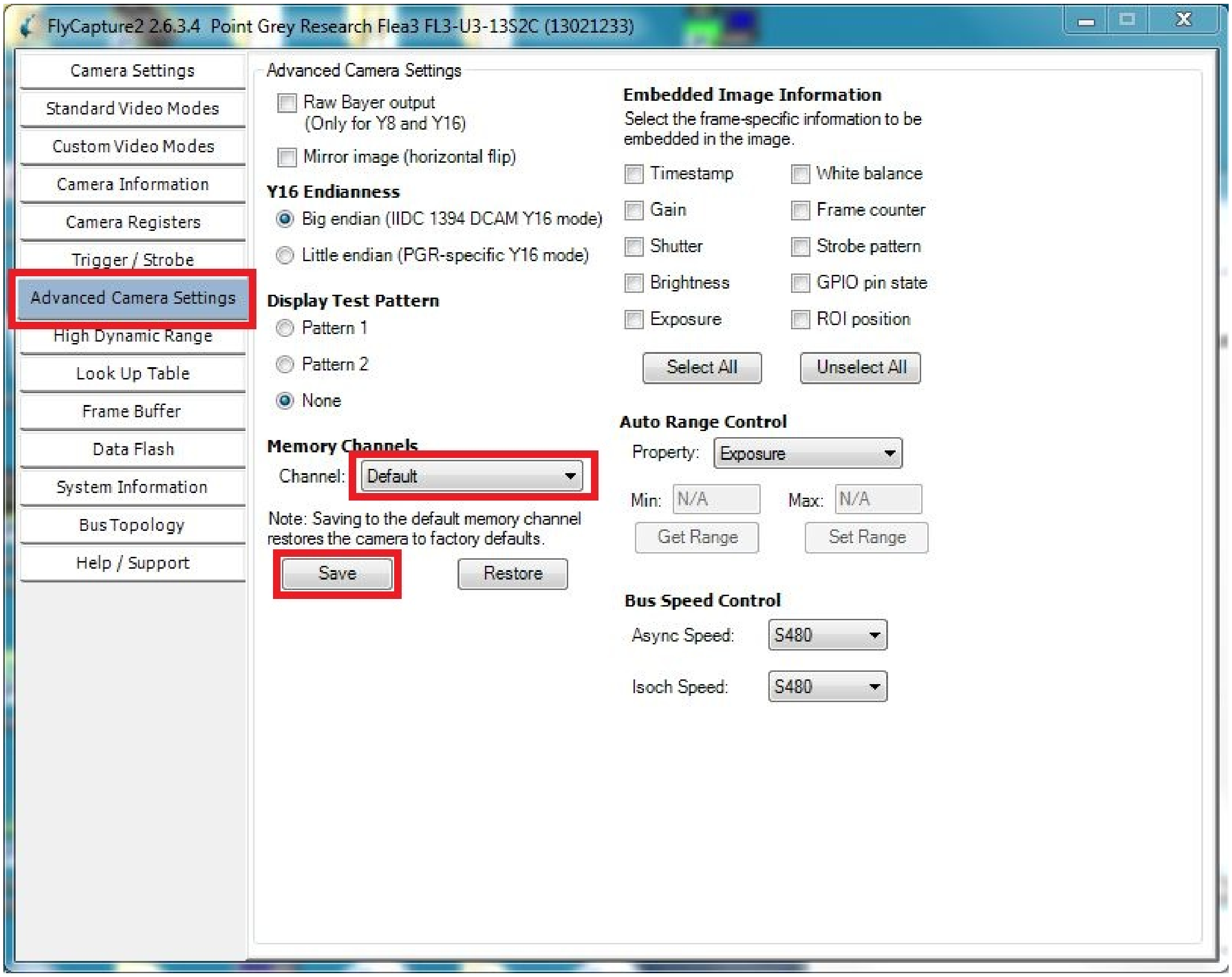


Figure 4-5. Restore Factory Camera Settings in FlyCap2 Software

FlyCap2 software will prompt the user that the default setting will load the factory settings. Click the OK button, as shown in Figure 4-6.

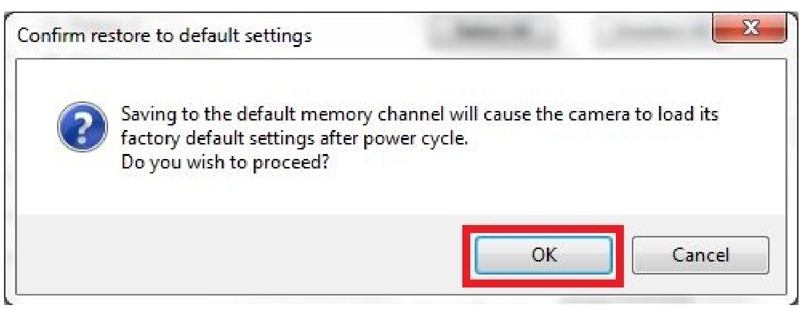
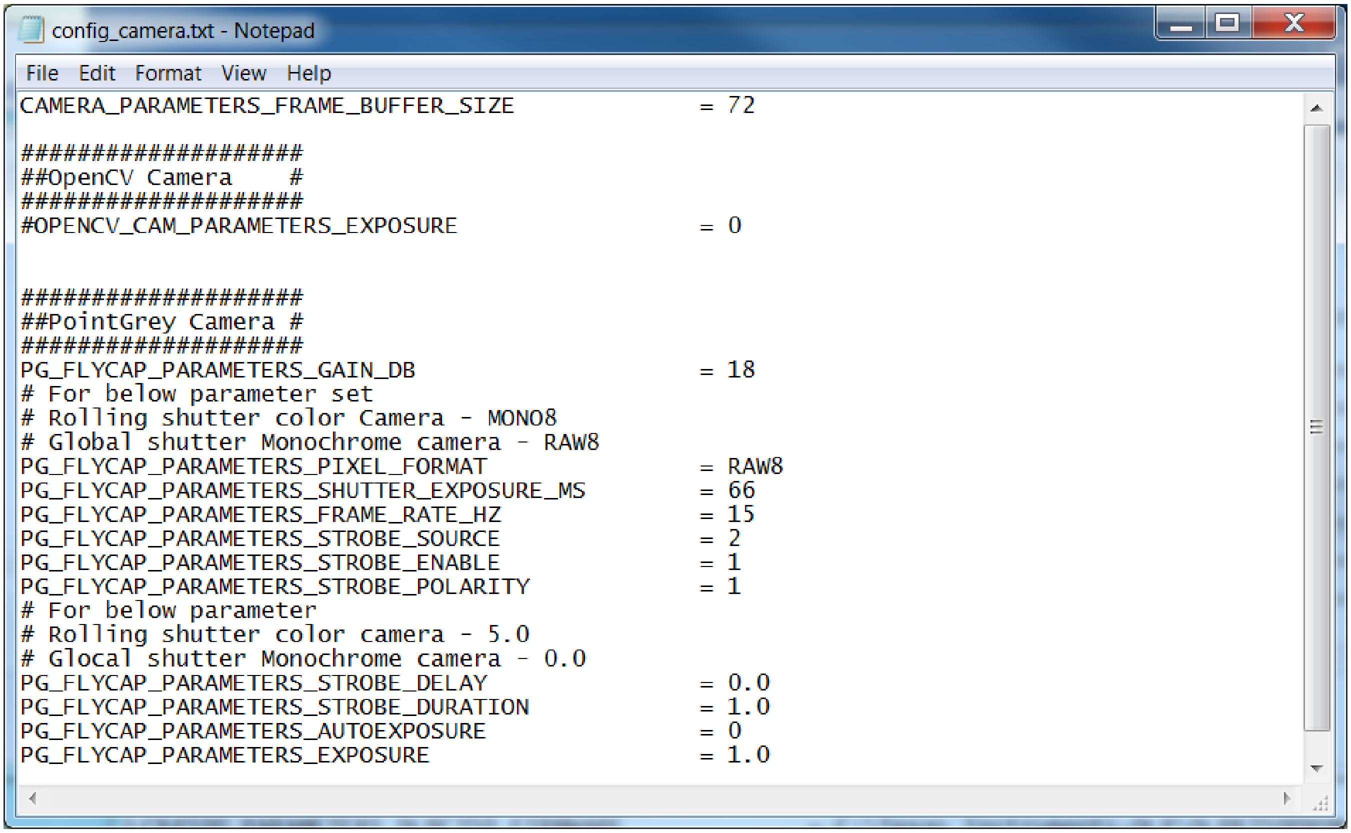


Figure 4-6. Confirm Factory Camera Settings in FlyCap2 Software

After the factory settings have been sent to the camera, disconnect the Grasshopper3 camera from the PC. Wait 3 seconds with the camera depowered before plugging the camera back in to the PC. Restart the 3D Scanner program and try to scan an object to verify the solution.

- **Problem:** The host PC does NOT have a USB 3.0 port to connect the Grasshopper3.

  Solution: The Grasshopper3 camera can be connected to a USB 2.0 port but must be run at a lower frame rate. Open the file named "config_camera.txt" in the ../config/ folder and change the value for "PG_FLYCAP_PARAMETERS_FRAME_RATE_HZ" to "30" or less, as shown in Figure 4-7. Change the projector exposure and period in the "config_projector.txt" file according to the above frame rate/exposure time equation.



config_camera.txt - Notepad

File Edit Format View Help

```
CAMERA_PARAMETERS_FRAME_BUFFER_SIZE               = 72

####################
##OpenCV Camera    #
####################
#OPENCV_CAM_PARAMETERS_EXPOSURE                   = 0


####################
##PointGrey Camera #
####################
PG_FLYCAP_PARAMETERS_GAIN_DB                      = 18
# For below parameter set
# Rolling shutter color Camera - MONO8
# Global shutter Monochrome camera - RAW8
PG_FLYCAP_PARAMETERS_PIXEL_FORMAT                 = RAW8
PG_FLYCAP_PARAMETERS_SHUTTER_EXPOSURE_MS          = 66
PG_FLYCAP_PARAMETERS_FRAME_RATE_HZ                = 15
PG_FLYCAP_PARAMETERS_STROBE_SOURCE                = 2
PG_FLYCAP_PARAMETERS_STROBE_ENABLE                = 1
PG_FLYCAP_PARAMETERS_STROBE_POLARITY              = 1
# For below parameter
# Rolling shutter color camera - 5.0
# Glocal shutter Monochrome camera - 0.0
PG_FLYCAP_PARAMETERS_STROBE_DELAY                 = 0.0
PG_FLYCAP_PARAMETERS_STROBE_DURATION              = 1.0
PG_FLYCAP_PARAMETERS_AUTOEXPOSURE                 = 0
PG_FLYCAP_PARAMETERS_EXPOSURE                     = 1.0
```

Figure 4-7. Camera Configuration File Settings for USB 2.0

- **Problem:** Attempting to scan an object, or take any captured image, causes a fatal error in the operating system.

  Solution: The Point Grey software can cause issues if the 3D Scanner program is terminated unexpectedly due to unterminated camera execution threads. If your 3D Scanning program is closed in any way **other** than entering "0" into the command prompt, put the PC into sleep mode – or restart the PC entirely – before attempting to take a picture with the camera.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (March 2015) to A Revision	Page
• Restructured document to follow format of DLP user guides	6
• Added link to DLP ALC SDK in *Related Documentation from Texas Instruments*	6
• Updated screen shots for installation process in Section 2.2	10
• Updated screen shots and steps for TI installer in Section 2.5	21
• Updated Section 3.3 to include detailed configuration file information and scan types	26
• Updated screen shots of the program and configure files in Section 3.4	29
• Updated trouble shooting scenarios, eliminated out of date cases, and added detailed screen shots in Section 4.1	56

IMPORTANT NOTICE

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