Introducción a la Fotografia 3D

UBA/FCEN Marzo 27 – Abril 12 2013

Clase 7 : Miercoles Abril 10

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Course Schedule

- Structured Lighting
- Robust Pixel Classification
- ***Projector Calibration / Structured Light Reconstruction***
- Projector Calibration / Structured Light Reconstruction
- Surface Reconstruction from Point Clouds
- Elementary Mesh Processing

Summary of Camera Calibration

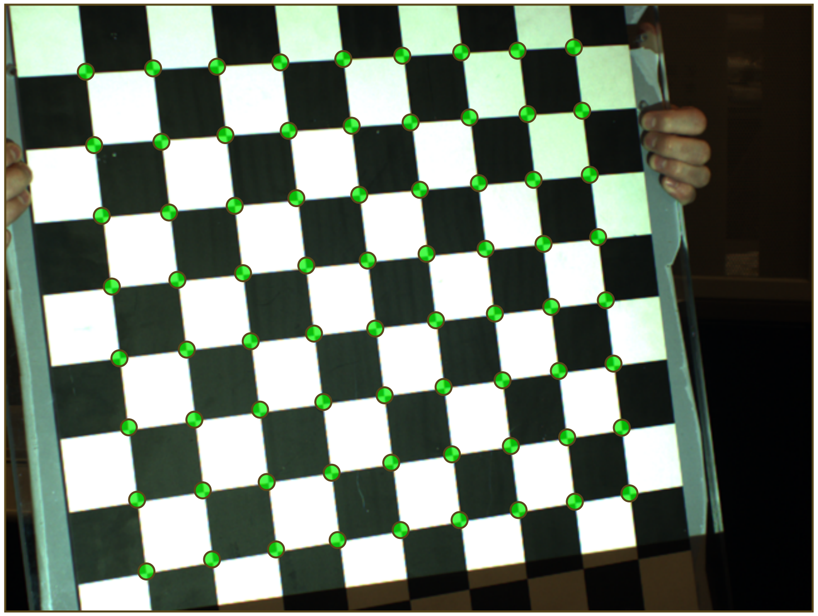
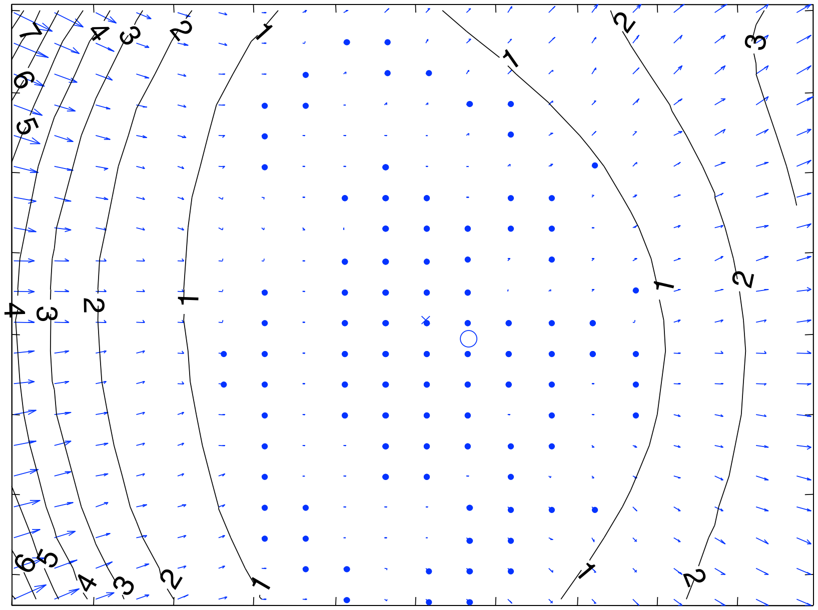


Image Sequence for Camera Calibration



Estimated Camera Lens Distortion

Camera Calibration Procedure

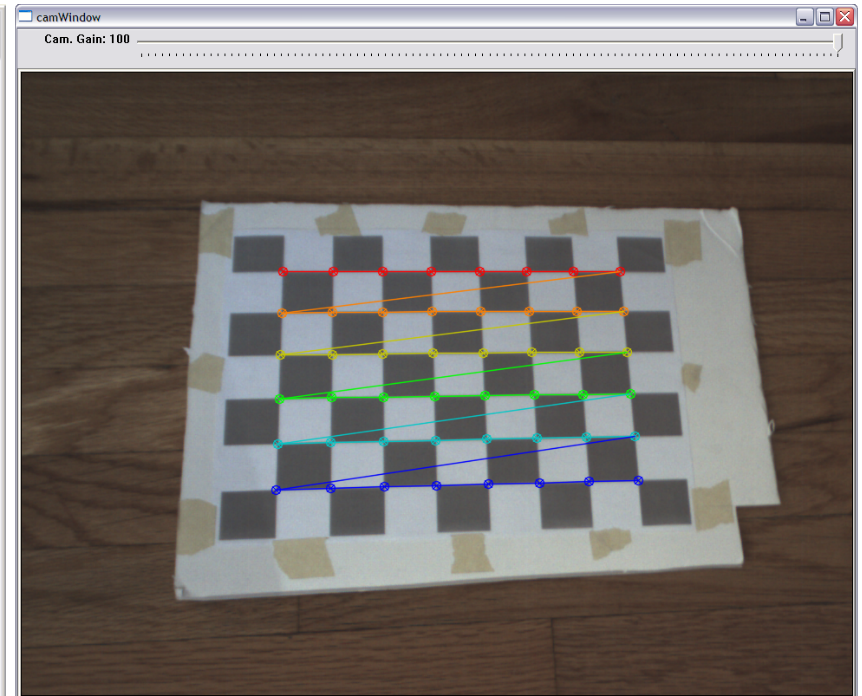
- Use the *Camera Calibration Toolbox for Matlab* or *OpenCV*

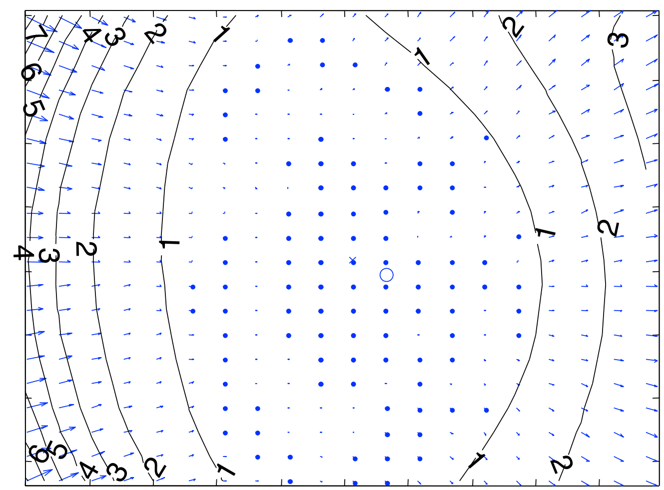
Normalized Ray	Distorted Ray (4^{th}-order radial + tangential)	Predicted Image-plane Projection
$x_n = \begin{bmatrix} X_c/Z_c \\ Y_c/Z_c \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix}$	$x_d = \begin{bmatrix} x_d(1) \\ x_d(2) \end{bmatrix} = \left(1 + kc(1)\,r^2 + kc(2)\,r^4 + kc(5)\,r^6\right) x_n + dx$ $dx = \begin{bmatrix} 2\,kc(3)\,x\,y + kc(4)\,(r^2 + 2x^2) \\ kc(3)\,(r^2 + 2y^2) + 2\,kc(4)\,x\,y \end{bmatrix}$	$x_p = fc(1)\,(x_d(1) + alpha\_c * x_d(2)) + cc(1)$ $y_p = fc(2)\,x_d(2) + cc(2)$

Demo: Camera Calibration in OpenCV

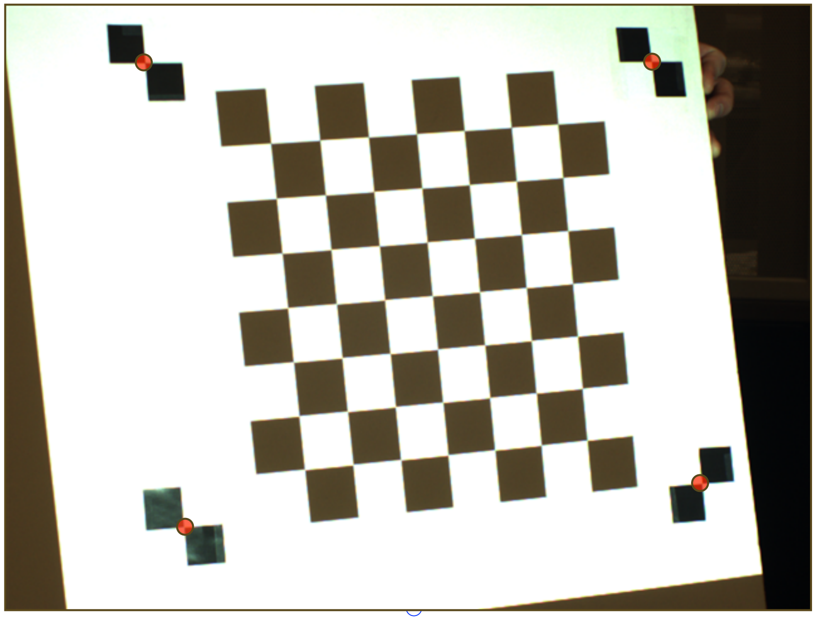
c:\Documents and Settings\Douglas\Desktop\Active Projects\3D Scanning ...

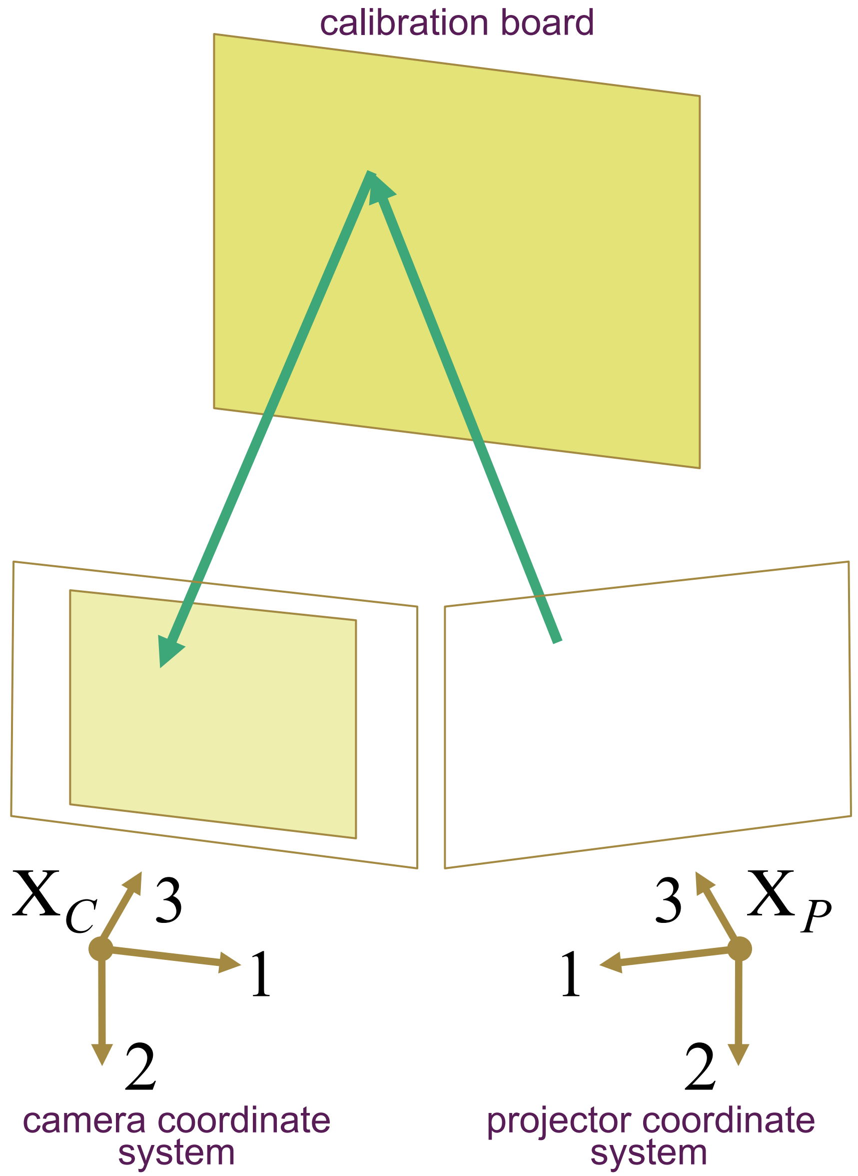
```
[Structured Lighting for 3D Scanning]
Reading configuration file "./config.xml"...
Initializing camera and projector...
Enabling Bayer mode for Logitech QuickCam 9000...
Creating output directory (overwrites existing object data)...
Camera has not been intrinsically calibrated!
Projector has not been intrinsically calibrated!
Projector-camera system has not been extrinsically calibrated!

Press the following keys for the corresponding functions.
'S': Run scanner
'B': Estimate background
'R': Reset background
'C': Calibrate camera
'P': Calibrate projector
'A': Calibrate camera and projector simultaneously
'E': Calibrate projector-camera alignment
'ESC': Exit application

> Calibrating camera...
Creating camera calibration directory (overwrites existing data)...
Enter the maximum number of calibration images, then press return.
+ Maximum number of images = 15
Press 'n' (in 'camWindow') to capture next image, or 'ESC' to quit.
+ Captured frame 1 of 15.
+ Captured frame 2 of 15.
+ Captured frame 3 of 15.
+ Captured frame 4 of 15.
+ Captured frame 5 of 15.
+ Captured frame 6 of 15.
+ Captured frame 7 of 15.
+ Captured frame 8 of 15.
+ Captured frame 9 of 15.
+ Captured frame 10 of 15.
+ Captured frame 11 of 15.
+ Captured frame 12 of 15.
+ Captured frame 13 of 15.
+ Captured frame 14 of 15.
+ Captured frame 15 of 15.
Calibrating camera...
Saving calibration images and parameters...
Camera calibration was successful.
Camera calibration:
+ Intrinsic parameters =
   1311.368    0.000 770.787
      0.000 1315.449 609.661
      0.000    0.000   1.000
+ Distortion coefficients =
      0.051   -0.147    0.003   -0.005    0.000
```





Projector Calibration

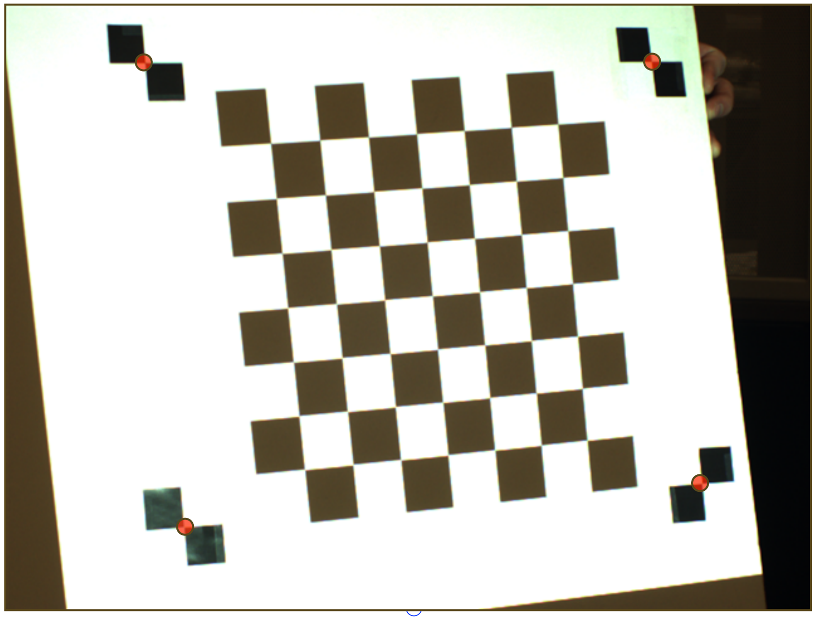




Calibration Procedure

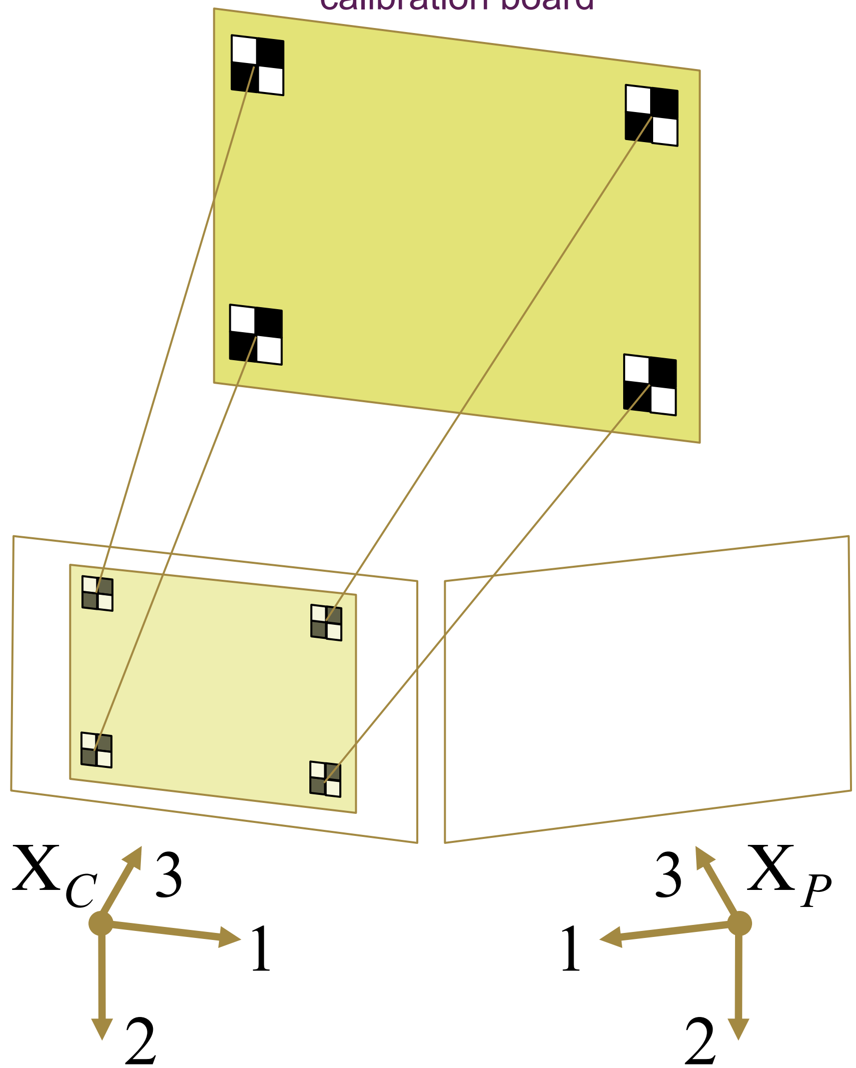
- Consider projector an inverse camera (maps intensities to 3D rays)

Projector Calibration

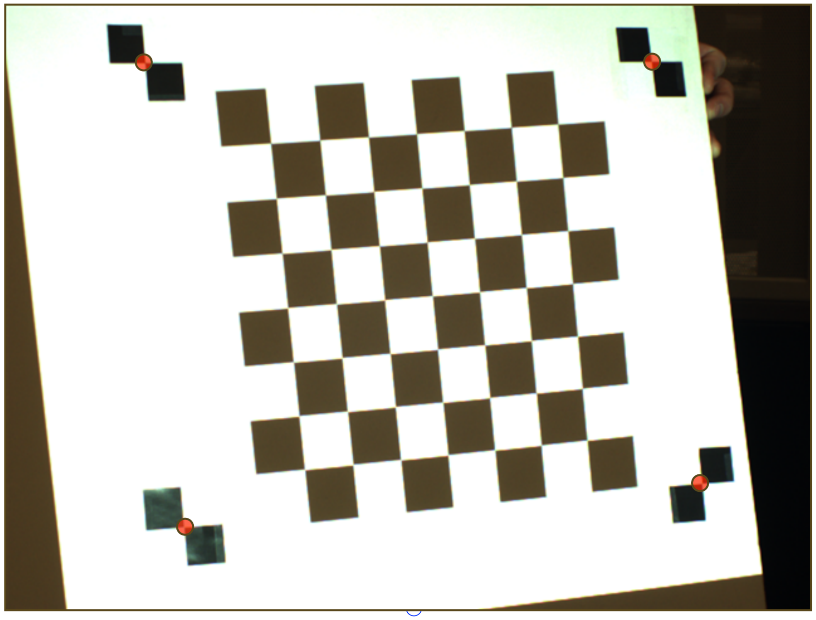


Calibration Procedure

- Consider projector an inverse camera (maps intensities to 3D rays)
- Identify printed fiducials in each image

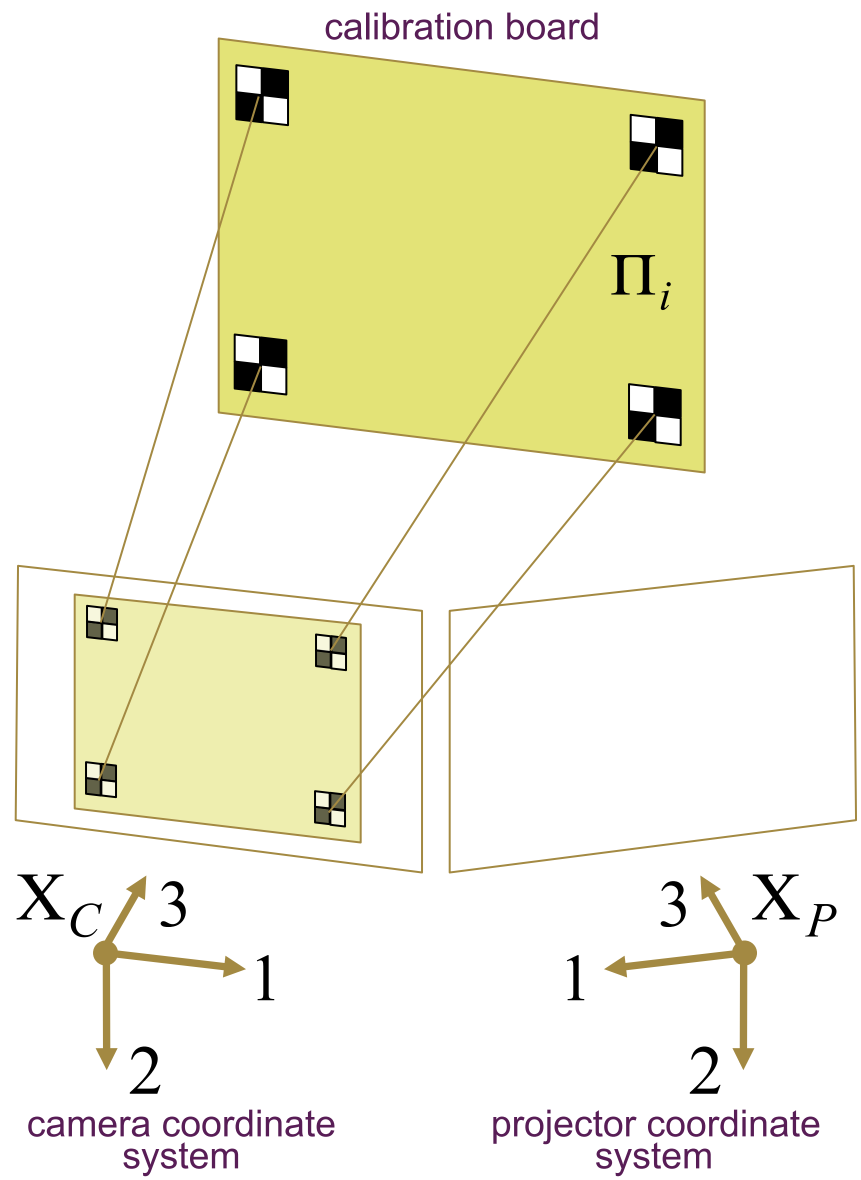


Projector Calibration

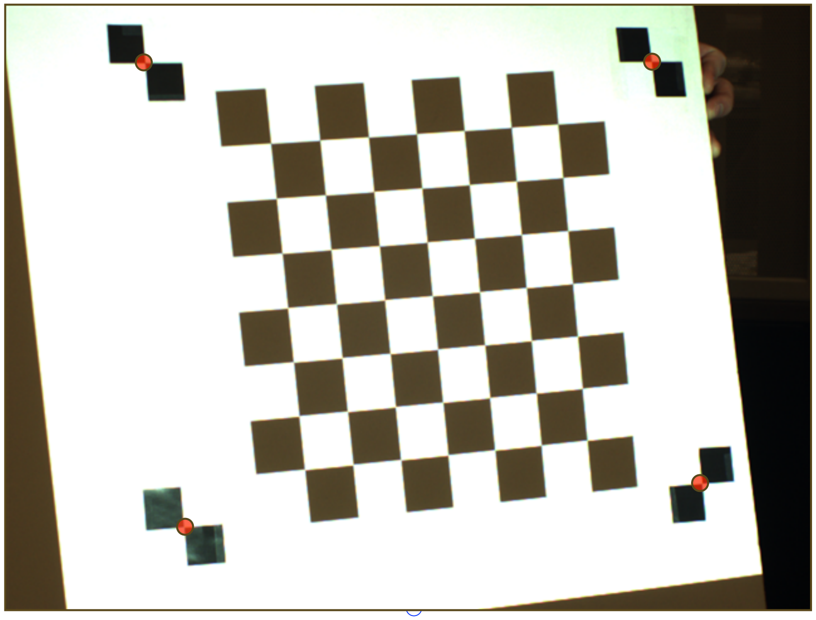


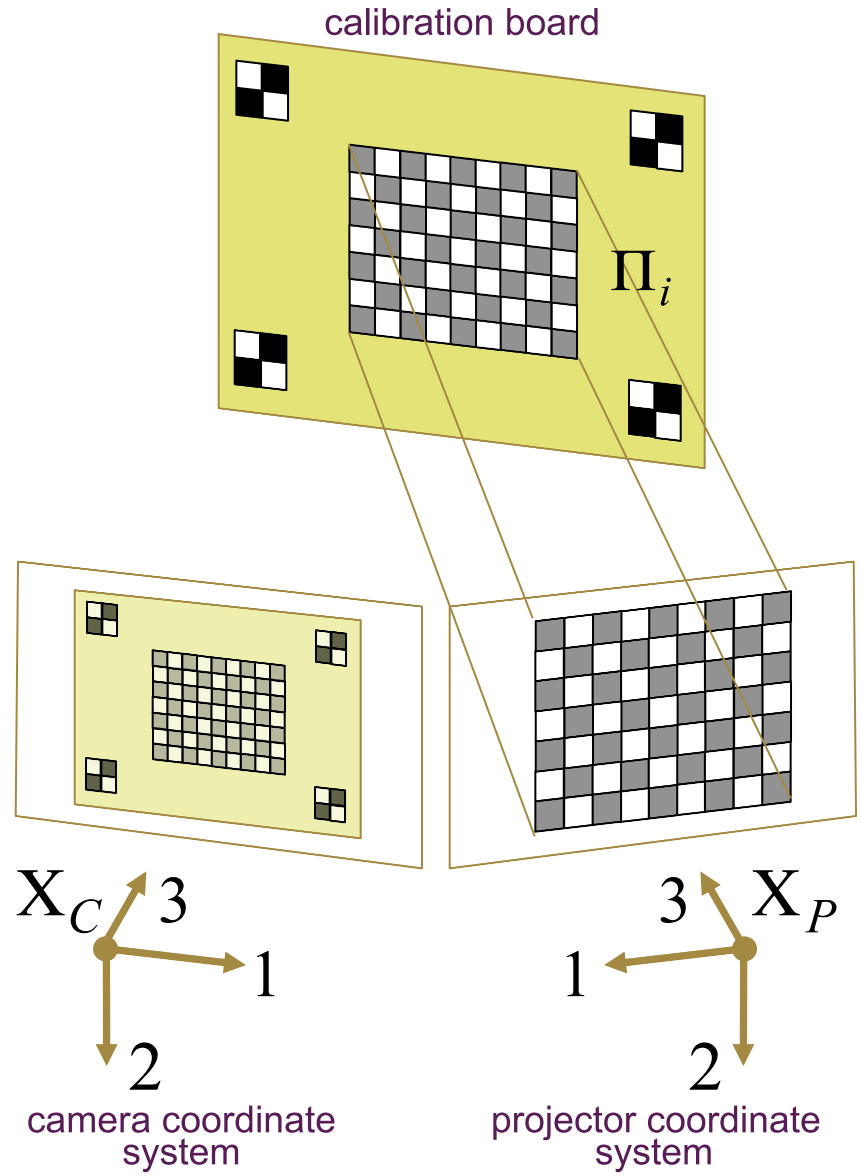
Calibration Procedure

- Consider projector an inverse camera (maps intensities to 3D rays)
- Identify printed fiducials in each image
- Use fidicials to find 3D calibration plane



Projector Calibration

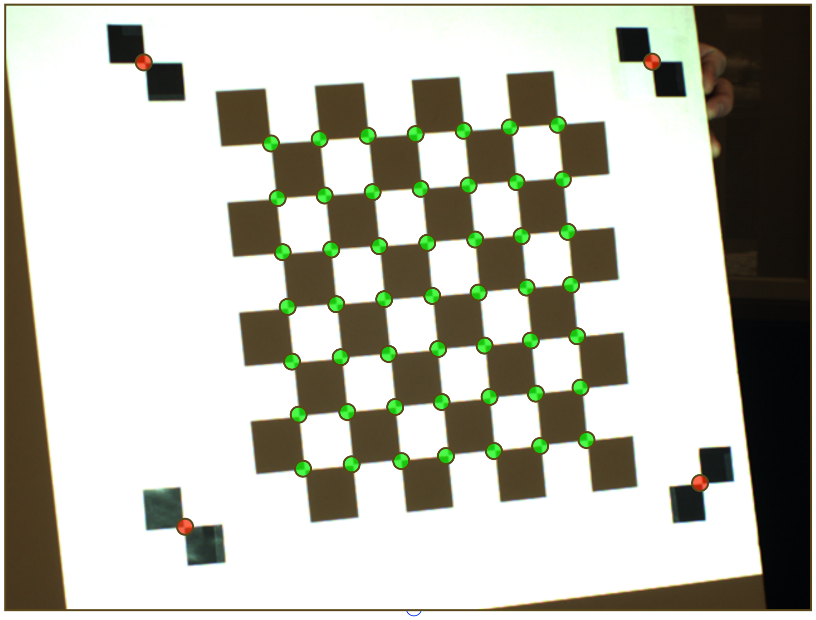




Calibration Procedure

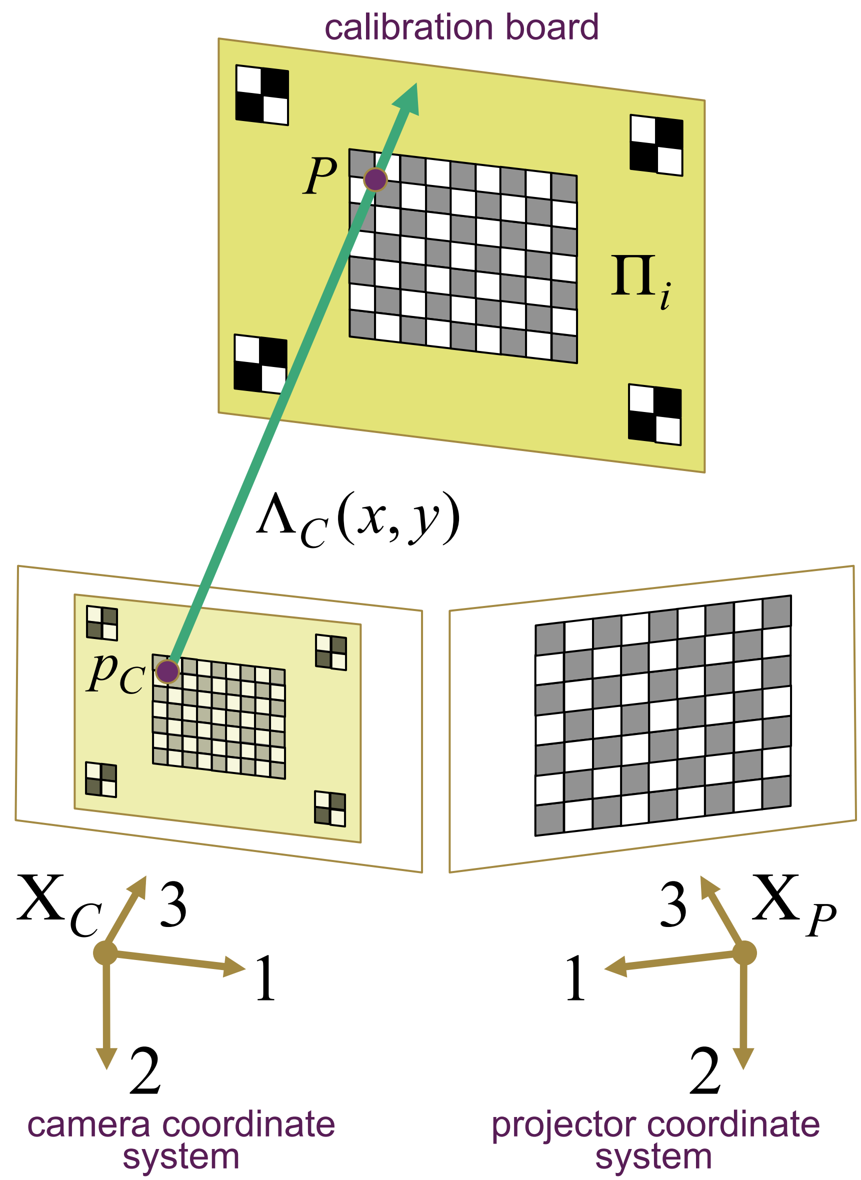
- Consider projector an inverse camera (maps intensities to 3D rays)
- Identify printed fiducials in each image
- Use fidicials to find 3D calibration plane
- Project checkerboard on calibration board

Projector Calibration

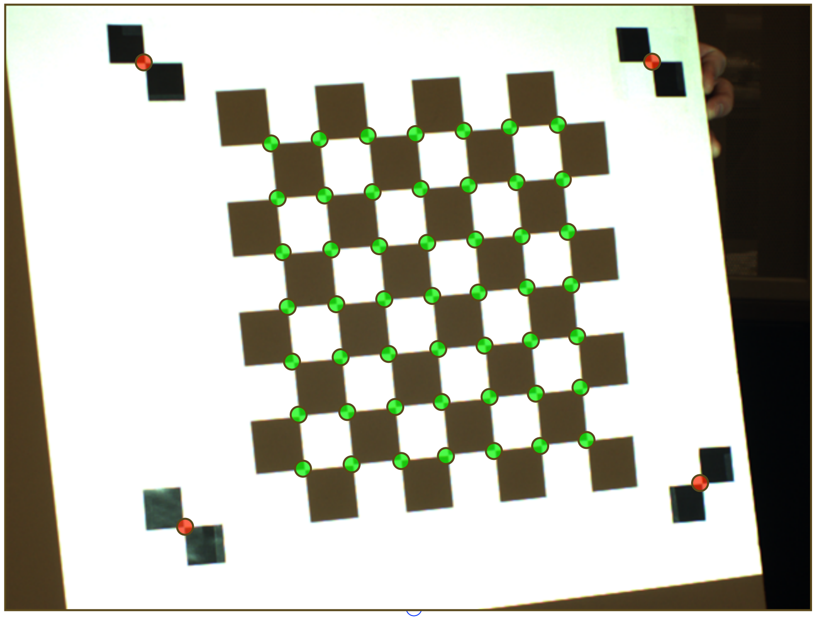


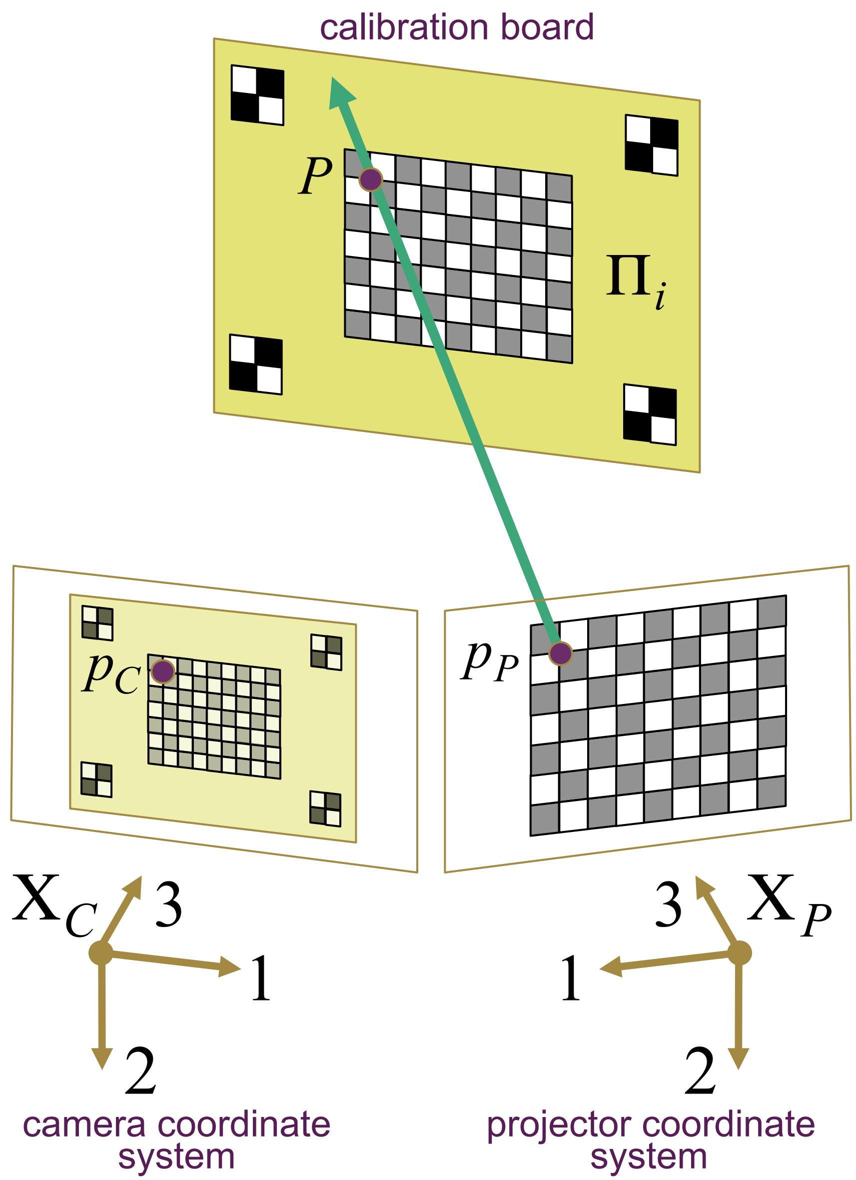
Calibration Procedure

- Consider projector an inverse camera (maps intensities to 3D rays)
- Identify printed fiducials in each image
- Use fidicials to find 3D calibration plane
- Project checkerboard on calibration board
- Find ray-plane intersection for each corner



Projector Calibration

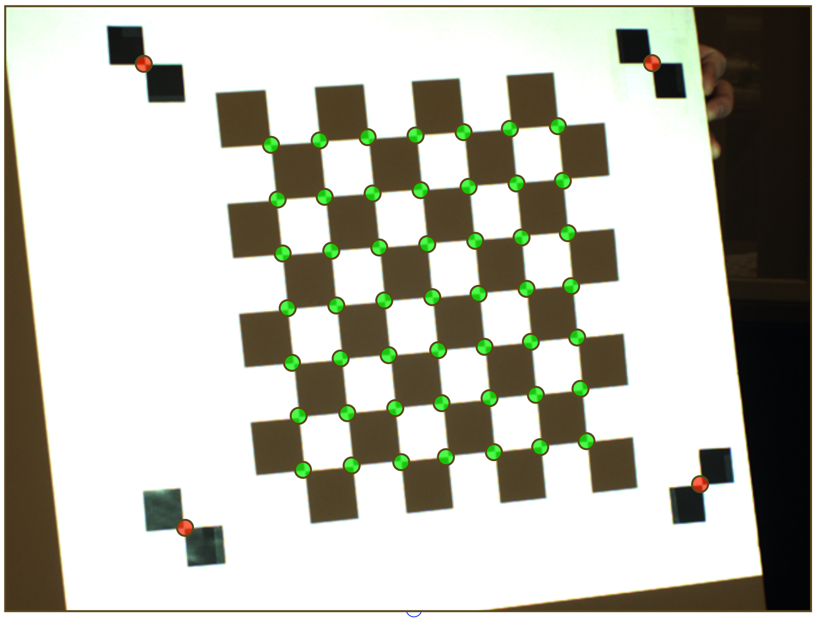




Calibration Procedure

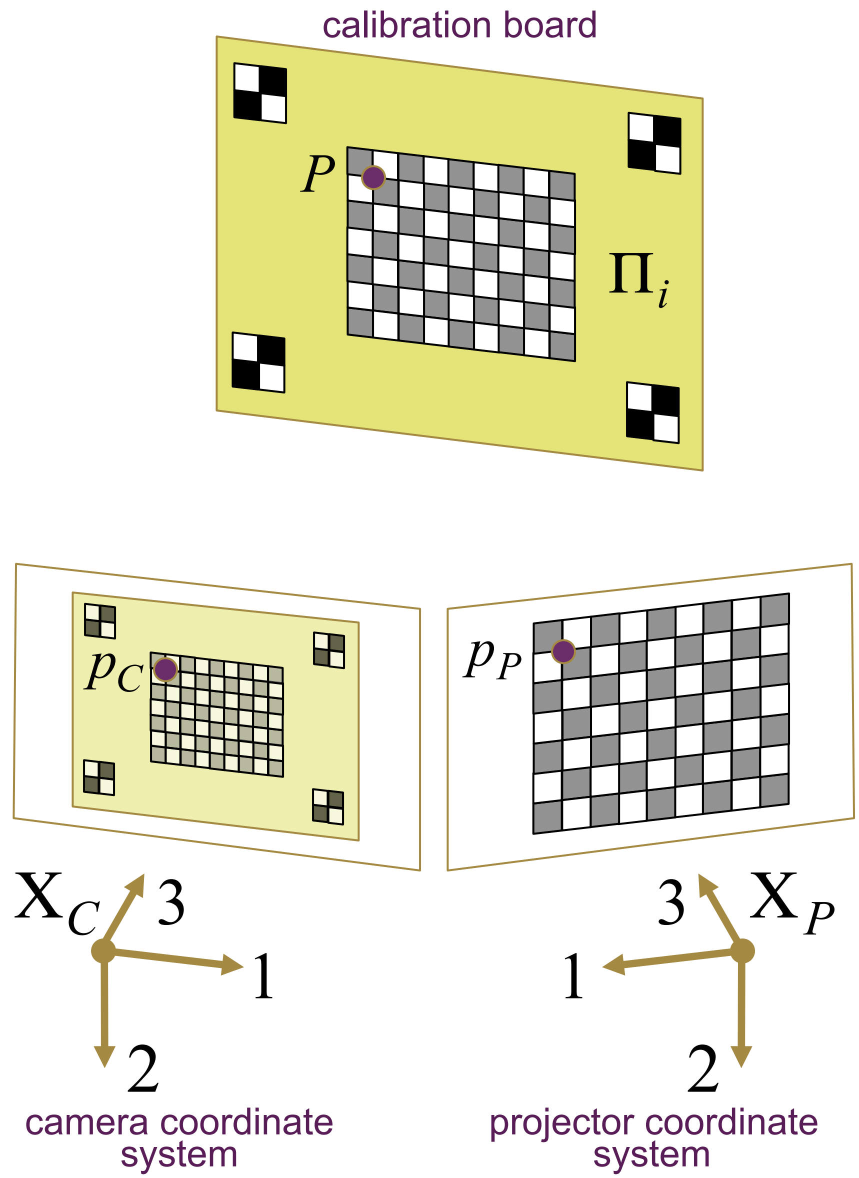
- Consider projector an inverse camera (maps intensities to 3D rays)
- Identify printed fiducials in each image
- Use fidicials to find 3D calibration plane
- Project checkerboard on calibration board
- Find ray-plane intersection for each corner

Projector Calibration

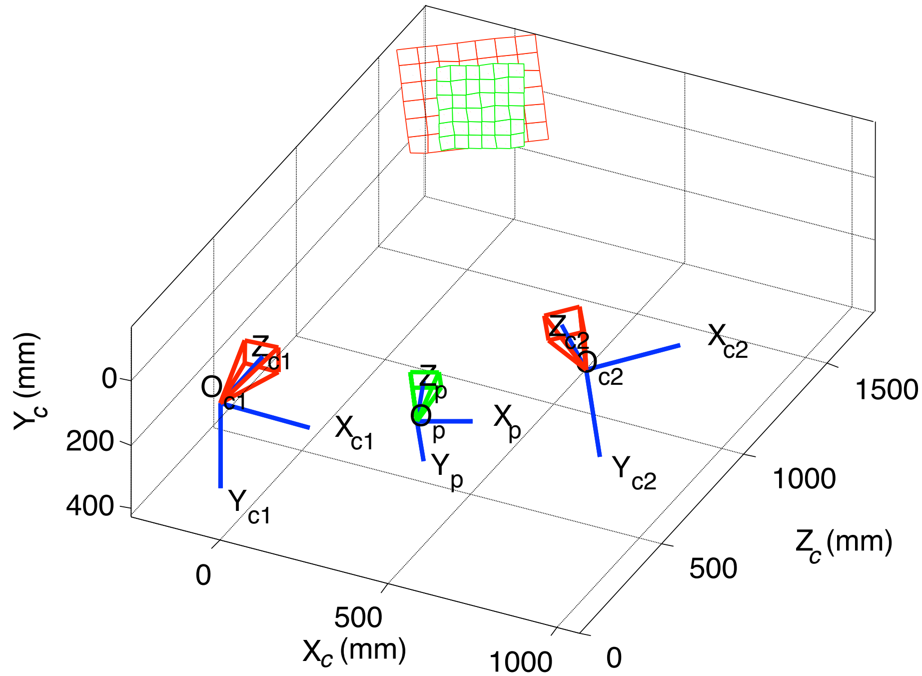


Calibration Procedure

- Consider projector an inverse camera (maps intensities to 3D rays)
- Identify printed fiducials in each image
- Use fidicials to find 3D calibration plane
- Project checkerboard on calibration board
- Find ray-plane intersection for each corner
- Use 2D→3D correspondences to estimate intrinsic/extrinsic projector calibration (and radial distortion model)



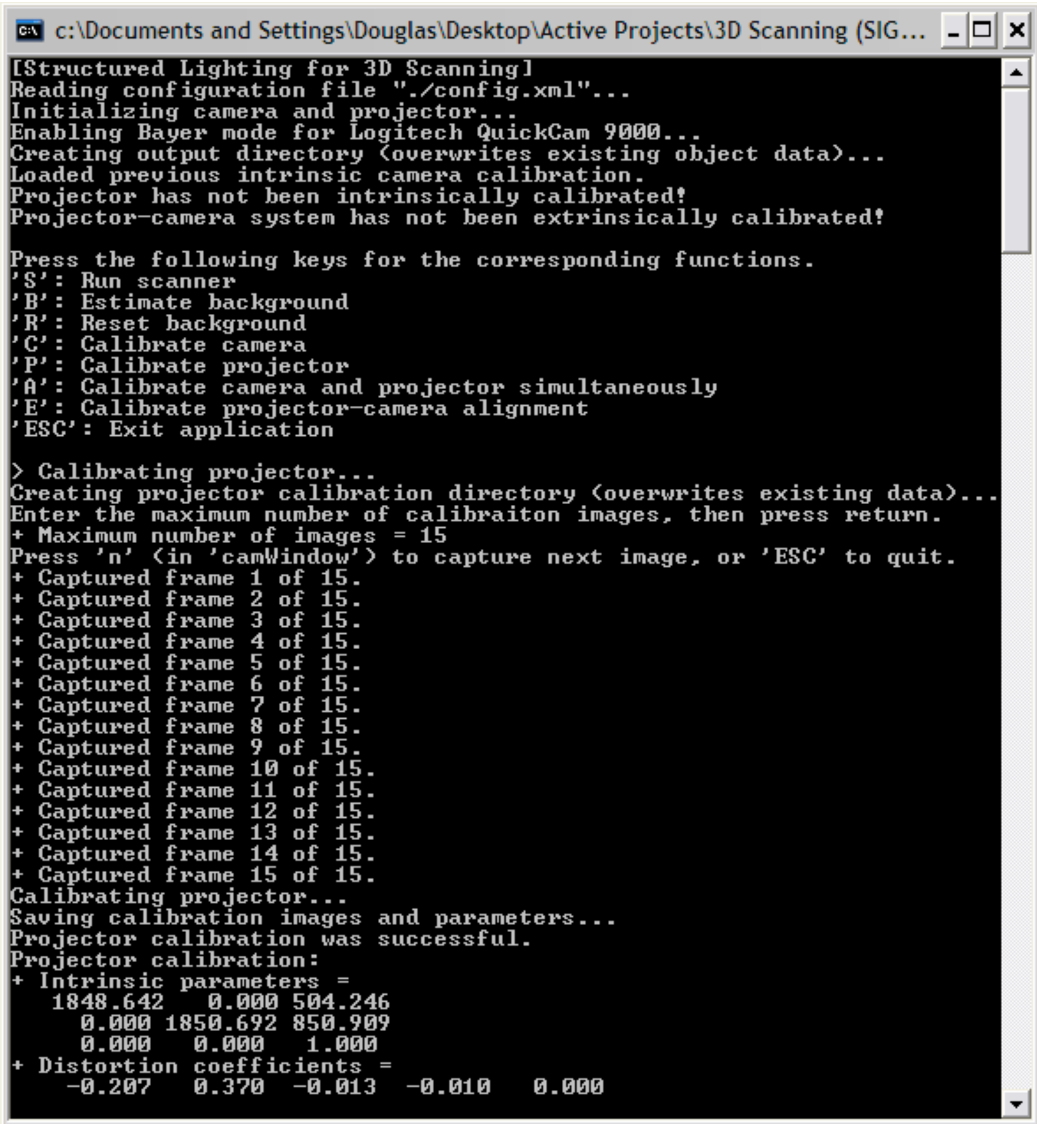
Projector-Camera Calibration Results

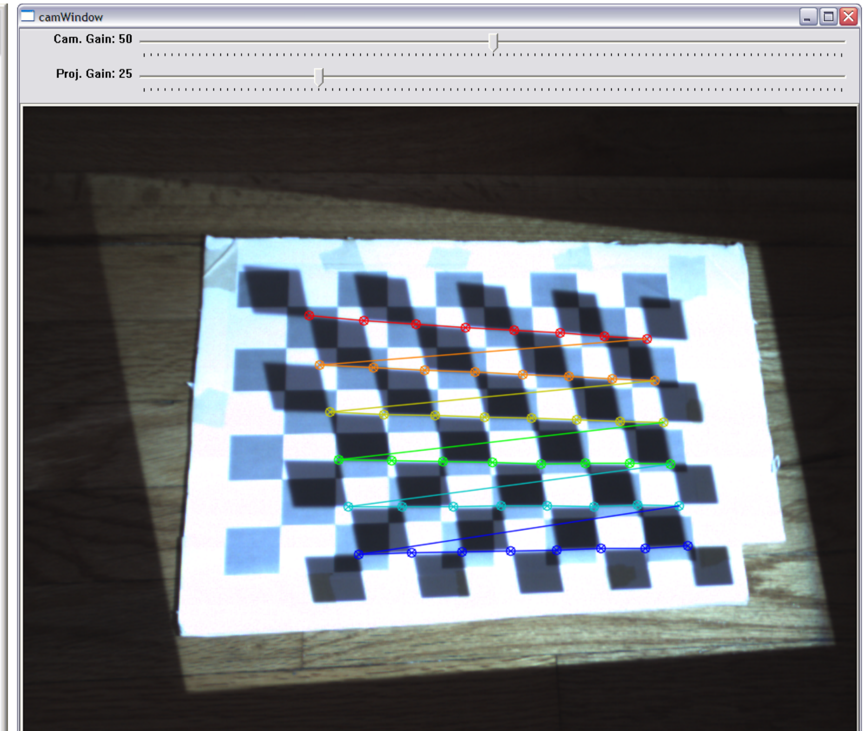


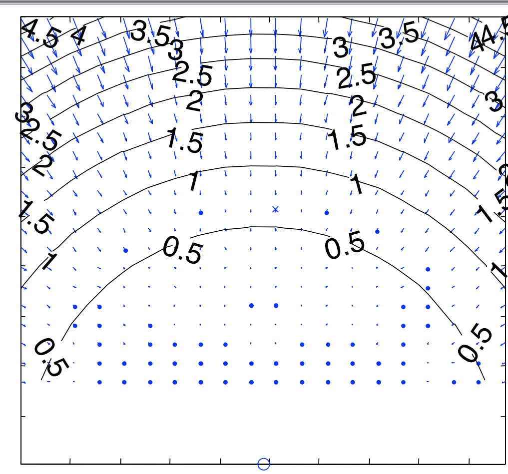
Projector-Camera Calibration Results

- Implemented complete toolbox for projector-camera calibration (available for *Matlab* and *OpenCV*)
- Sufficient accuracy for structured lighting applications
- Software and documentation available on the course website

Demo: Projector Calibration in OpenCV

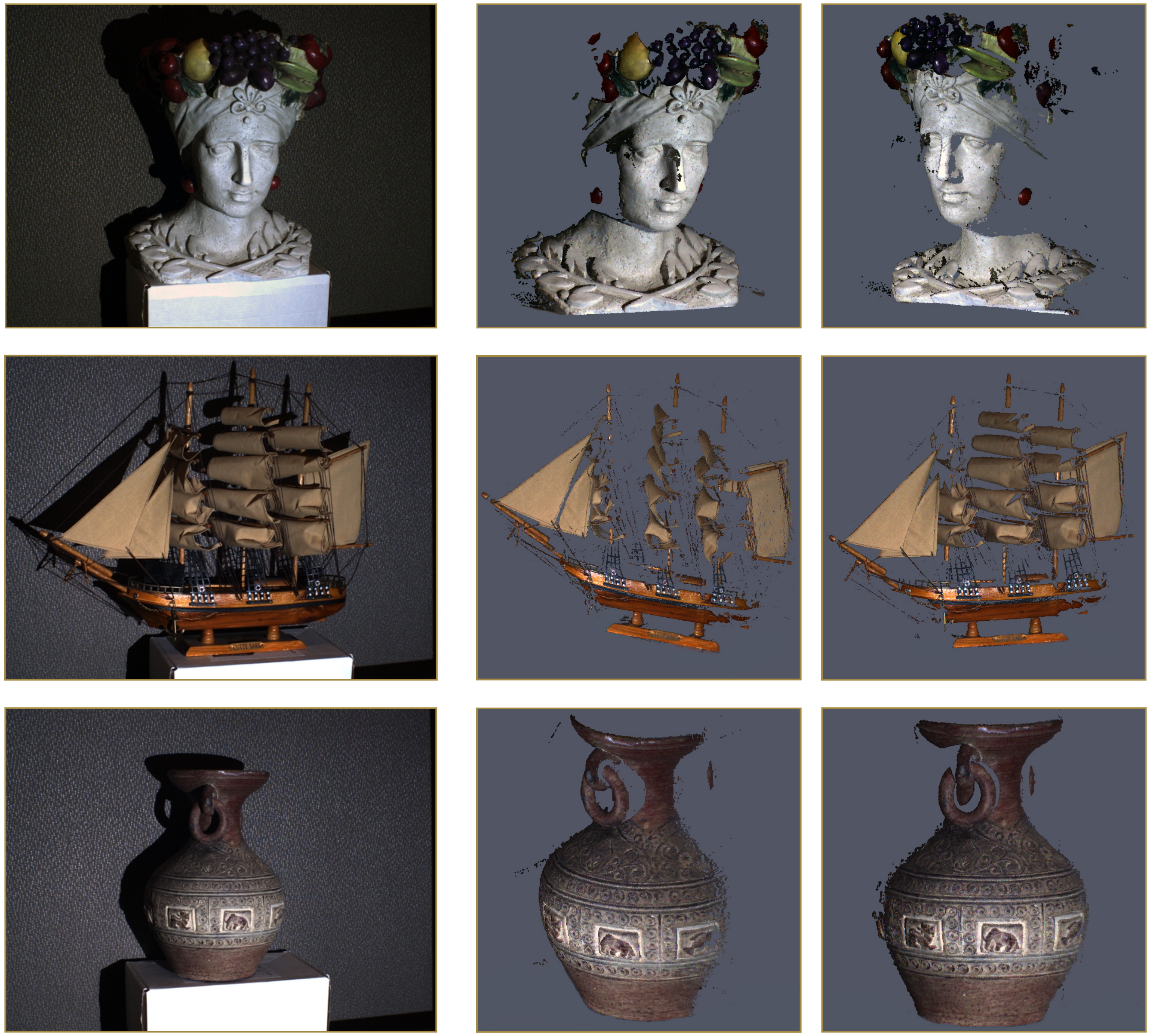




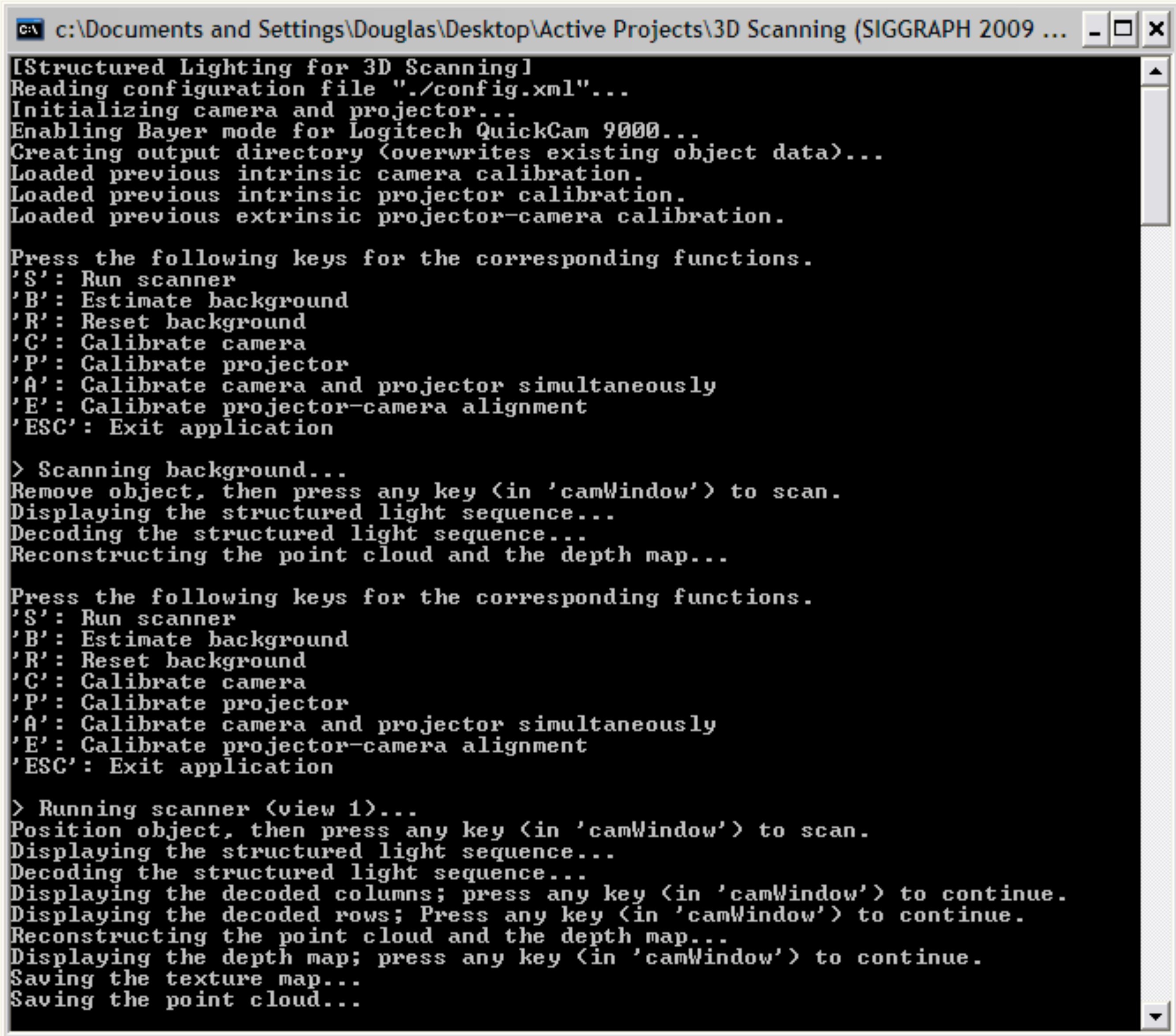


Structured Lighting Reconstruction Results

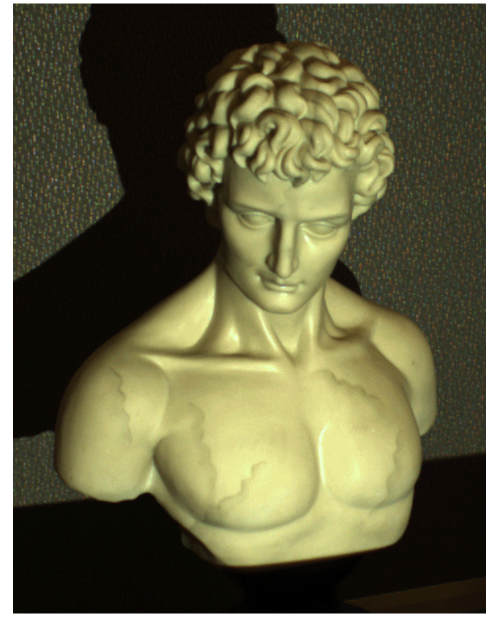
Additional Reconstruction Examples

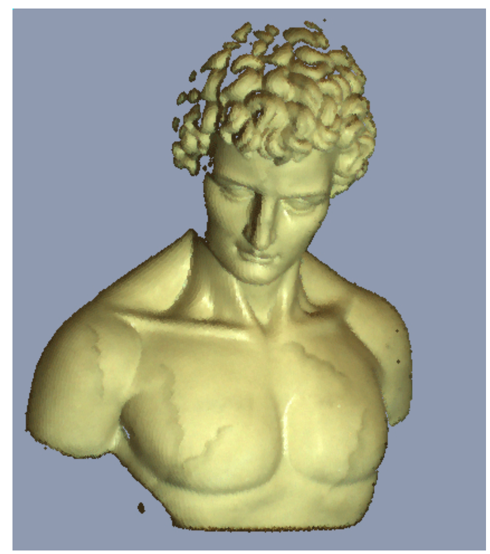


Demo: Putting it All Together

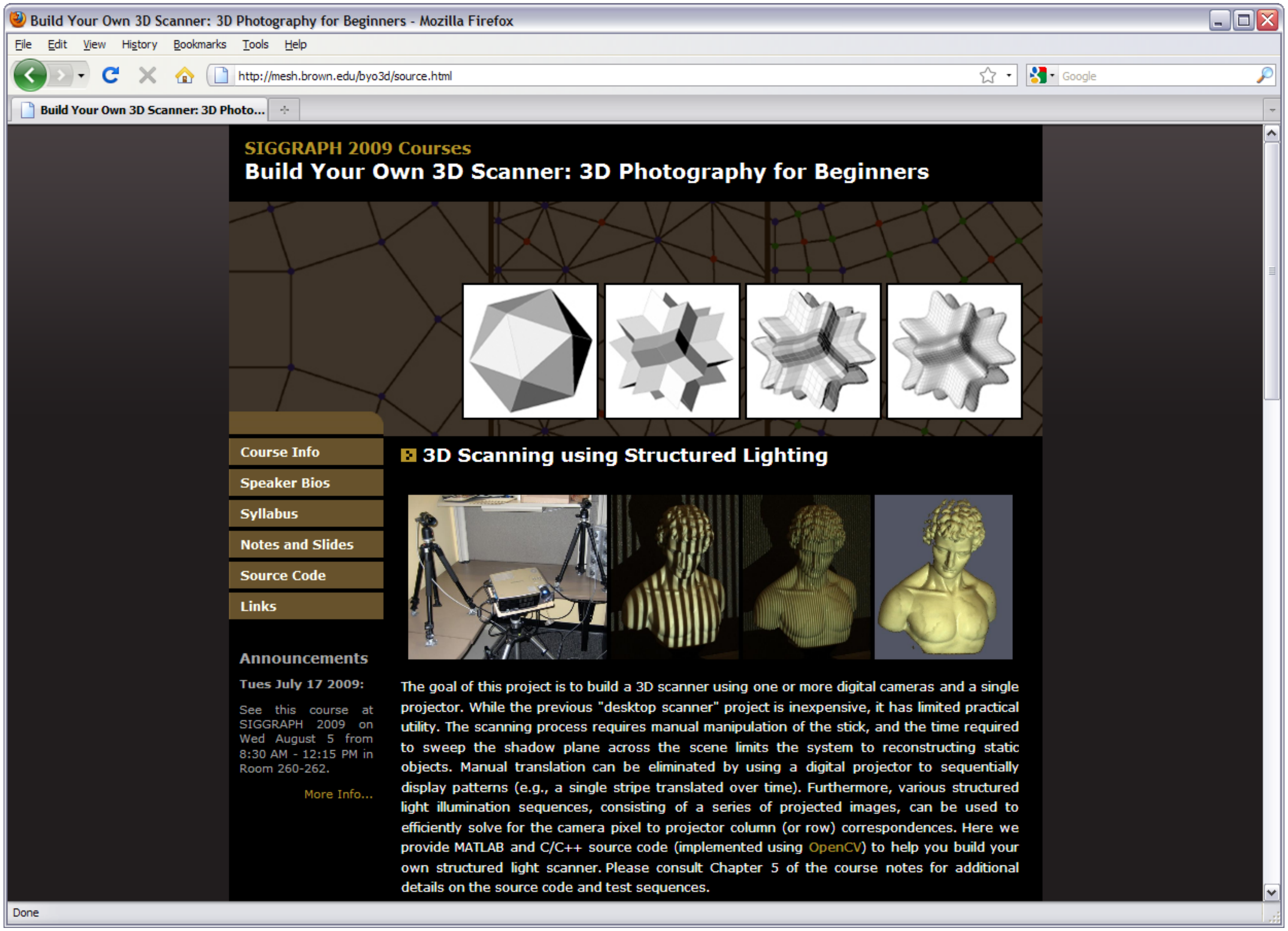


```
c:\Documents and Settings\Douglas\Desktop\Active Projects\3D Scanning (SIGGRAPH 2009 ...
[Structured Lighting for 3D Scanning]
Reading configuration file "./config.xml"...
Initializing camera and projector...
Enabling Bayer mode for Logitech QuickCam 9000...
Creating output directory (overwrites existing object data)...
Loaded previous intrinsic camera calibration.
Loaded previous intrinsic projector calibration.
Loaded previous extrinsic projector-camera calibration.

Press the following keys for the corresponding functions.
'S': Run scanner
'B': Estimate background
'R': Reset background
'C': Calibrate camera
'P': Calibrate projector
'A': Calibrate camera and projector simultaneously
'E': Calibrate projector-camera alignment
'ESC': Exit application

> Scanning background...
Remove object, then press any key (in 'camWindow') to scan.
Displaying the structured light sequence...
Decoding the structured light sequence...
Reconstructing the point cloud and the depth map...

Press the following keys for the corresponding functions.
'S': Run scanner
'B': Estimate background
'R': Reset background
'C': Calibrate camera
'P': Calibrate projector
'A': Calibrate camera and projector simultaneously
'E': Calibrate projector-camera alignment
'ESC': Exit application

> Running scanner (view 1)...
Position object, then press any key (in 'camWindow') to scan.
Displaying the structured light sequence...
Decoding the structured light sequence...
Displaying the decoded columns; press any key (in 'camWindow') to continue.
Displaying the decoded rows; Press any key (in 'camWindow') to continue.
Reconstructing the point cloud and the depth map...
Displaying the depth map; press any key (in 'camWindow') to continue.
Saving the texture map...
Saving the point cloud...
```





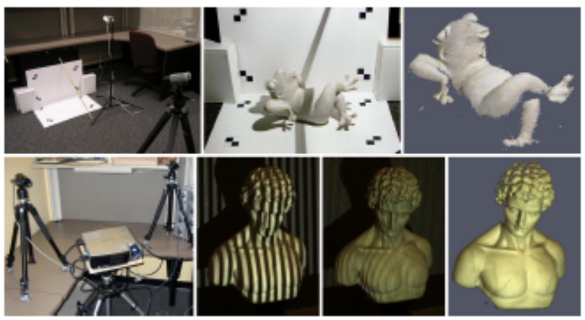
How to Get the Source Code



http://mesh.brown.edu/byo3d

For More Details

Build Your Own 3D Scanner:
3D Photography for Beginners



SIGGRAPH 2009 Course Notes
Wednesday, August 5, 2009

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SIGGRAPH2009

Chapter 5

Structured Lighting

In this chapter we describe how to build a structured light scanner using one or more digital cameras and a single projector. While the "desktop scanner" [BP] implemented in the previous chapter is inexpensive, it has limited practical utility. The scanning process requires manual manipulation of the stick, and the time required to sweep the shadow plane across the scene limits the system to reconstructing static objects. Manual translation can be eliminated by using a digital projector to sequentially display patterns (e.g., a single stipe translated over time). Furthermore, various *structured light* illumination sequences, consisting of a series of projected images, can be used to efficiently solve for the camera pixel to projector column (or row) correspondences.

By implementing your own structured light scanner, you will directly extending the algorithms and software developed for the swept-plane systems in the previous chapter. Reconstruction will again be accomplished using ray-plane triangulation. The key difference is that correspondences will now be established by decoding certain structured light sequences. At the time of writing, the software accompanying this chapter was developed in MATLAB. We encourage the reader to download that version, as well as any updates, from the course website at `http://mesh.brown.edu/dlanman/scan3d`.

5.1 Data Capture

5.1.1 Scanner Hardware

As shown in Figure 5.1, the scanning apparatus contains one or more digital cameras and a single digital projector. As with the swept-plane systems,

http://mesh.brown.edu/byo3d