Structured Light for 3D Scanning
Implementation Details

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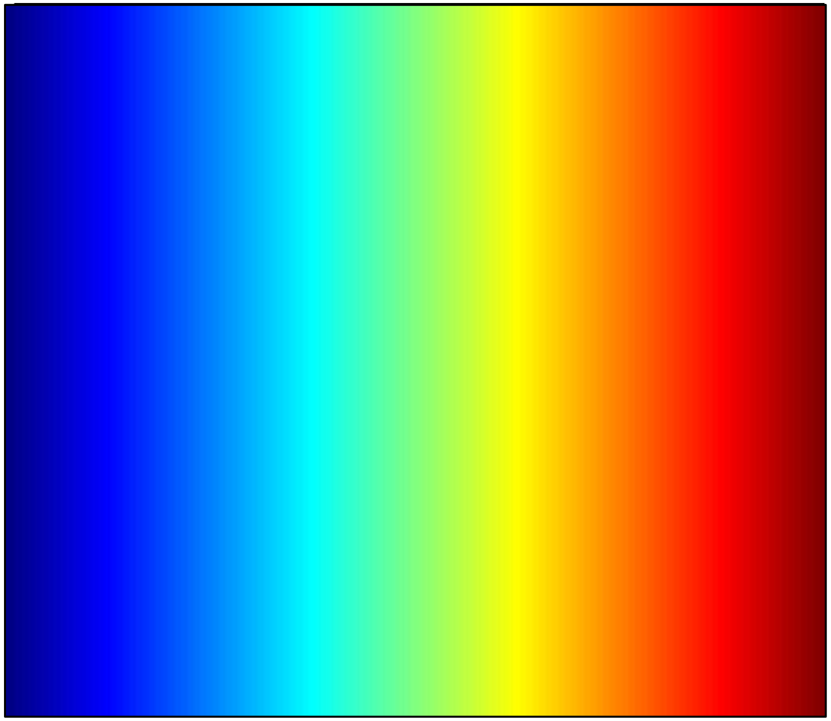
BROWN

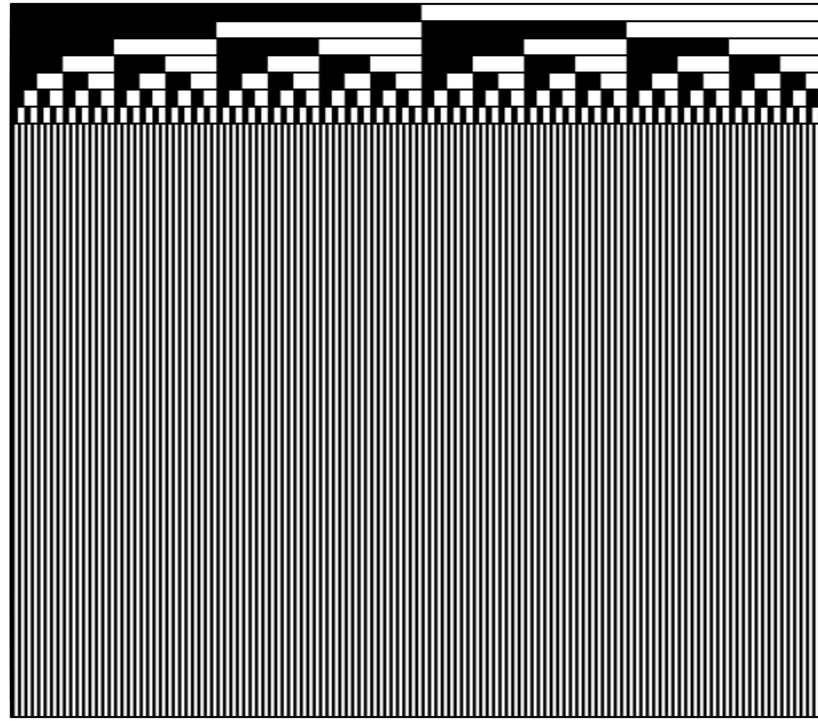
Gray Code Structured Lighting



3D Reconstruction using Structured Light [Inokuchi 1984]

- Recover 3D depth for each pixel using ray-plane intersection
- Determine correspondence between camera pixels and projector planes by projecting a temporally-multiplexed binary image sequence
- Each image is a bit-plane of the Gray code for each projector row/column

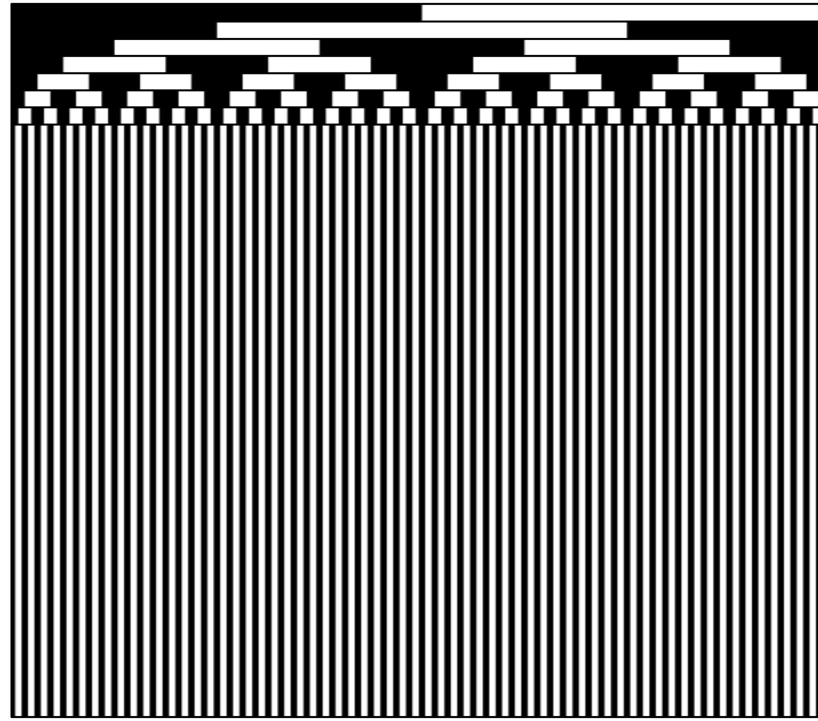
Gray Code Structured Lighting



Binary Image Sequence

- Each image is a bit-plane of the binary code for each projector row/column
- Minimum of 10 images to encode 1024 columns or 768 rows
- In practice, 20 images are used to encode 1024 columns or 768 rows
- Projector/camera(s) must be roughly synchronized

Gray Code Structured Lighting



Gray Code Image Sequence

- Each image is a bit-plane of the Gray code for each projector row/column
- Requires same number of images as a binary image sequence, but has better performance in practice

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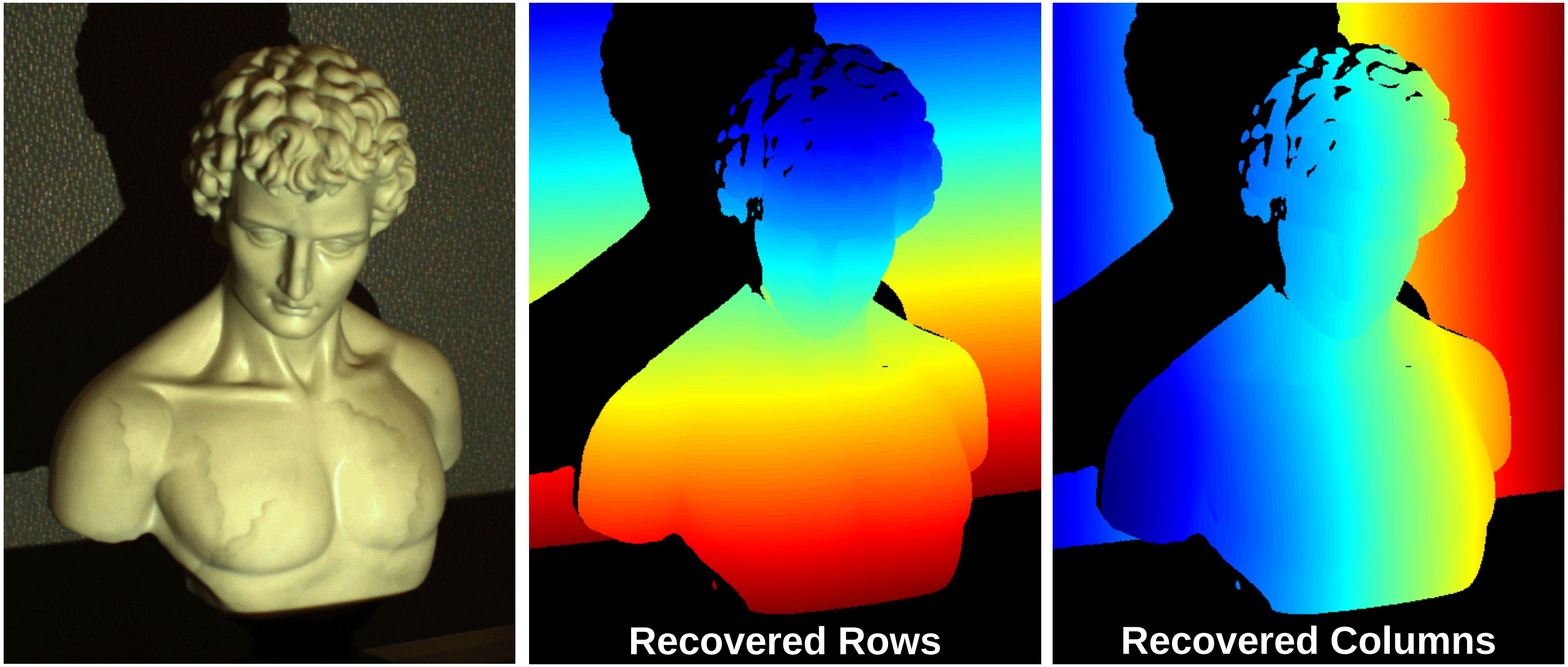
Bin2Gray(B,G)
G ← B
for i ← n-1 downto 0
    G[i] ← B[i+1] xor B[i]
```

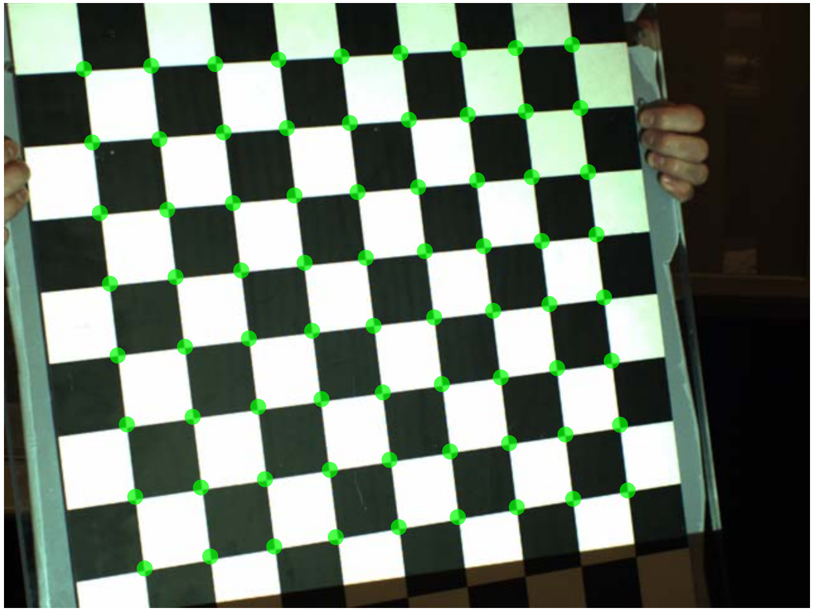
Gray Code Structured Lighting

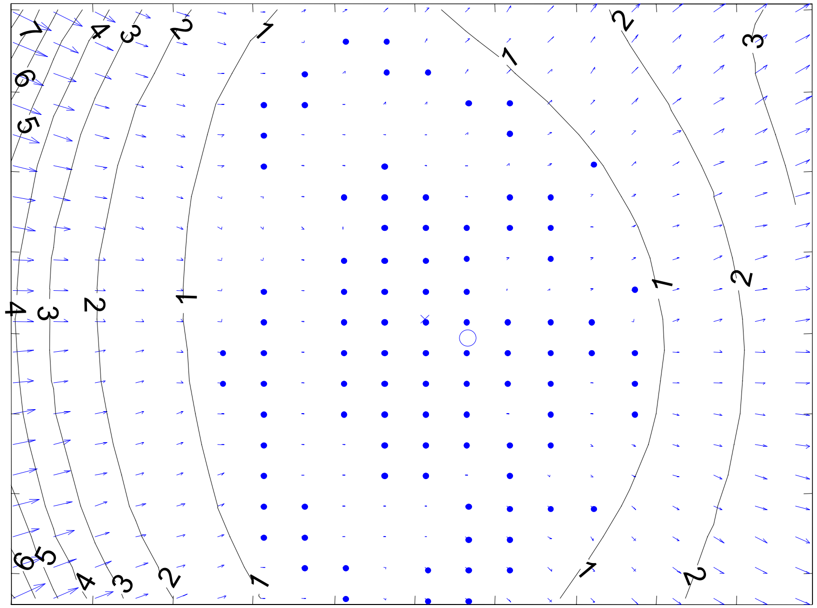


3D Reconstruction using Structured Light [Inokuchi 1984]

- Our implementation uses a total of 42 images
  (2 to measure dynamic range, 20 to encode rows, 20 to encode columns)
- Individual bits assigned by detecting if bit-plane (or its inverse) is brighter
- Decoding algorithm: Gray code → binary code → integer row/column index

Overview of Projector-Camera Calibration





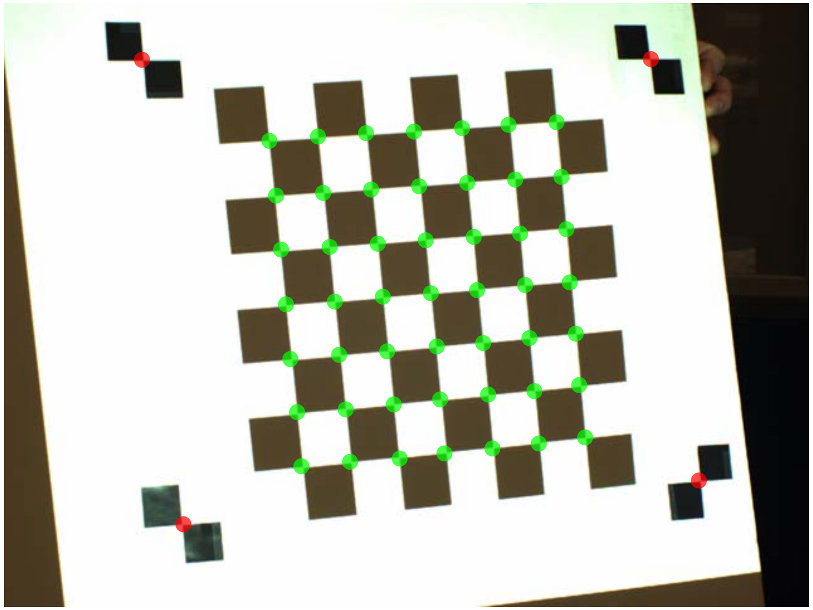
Estimated Camera Lens Distortion

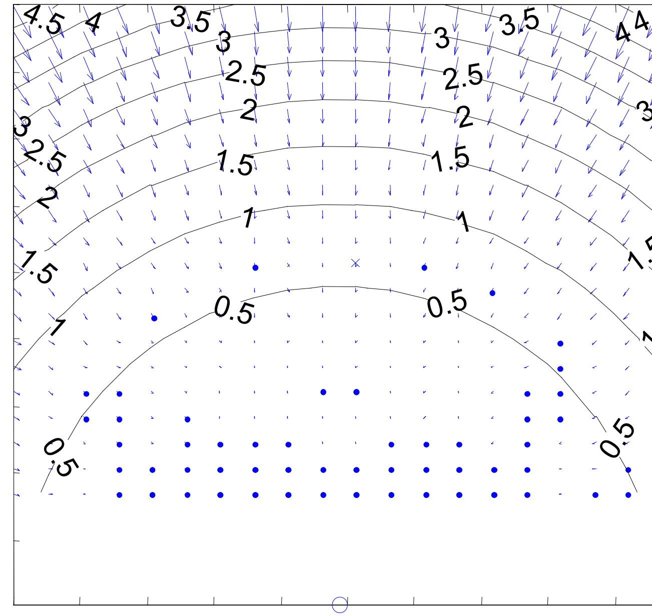
Camera Calibration Procedure

- Uses the *Camera Calibration Toolbox for Matlab* by J.-Y. Bouguet

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

Overview of Projector-Camera Calibration



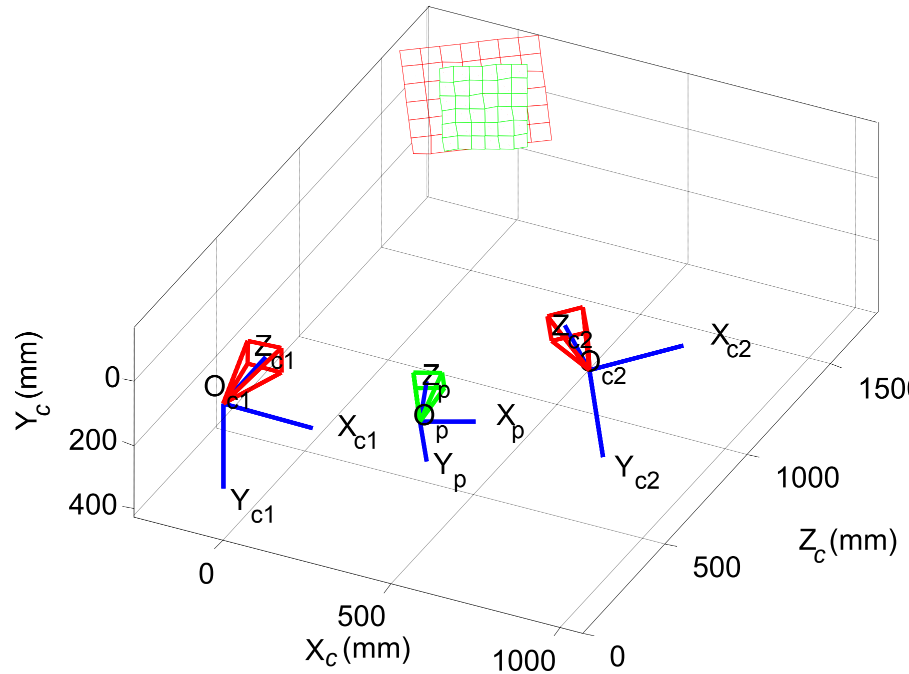


Estimated Projector Lens Distortion

Projector Calibration Procedure

- Consider projector as an inverse camera (i.e., maps intensities to 3D rays)
- Observe a calibration board with a set of fidicials in known locations
- Use fidicials to recover calibration plane in camera coordinate system
- Project a checkerboard on calibration board and detect corners
- Apply ray-plane intersection to recover 3D position for each projected corner
- Use *Camera Calibration Toolbox* to recover intrinsic/extrinsic projector calibration using 2D$\rightarrow$3D correspondences with 4th-order radial distortion

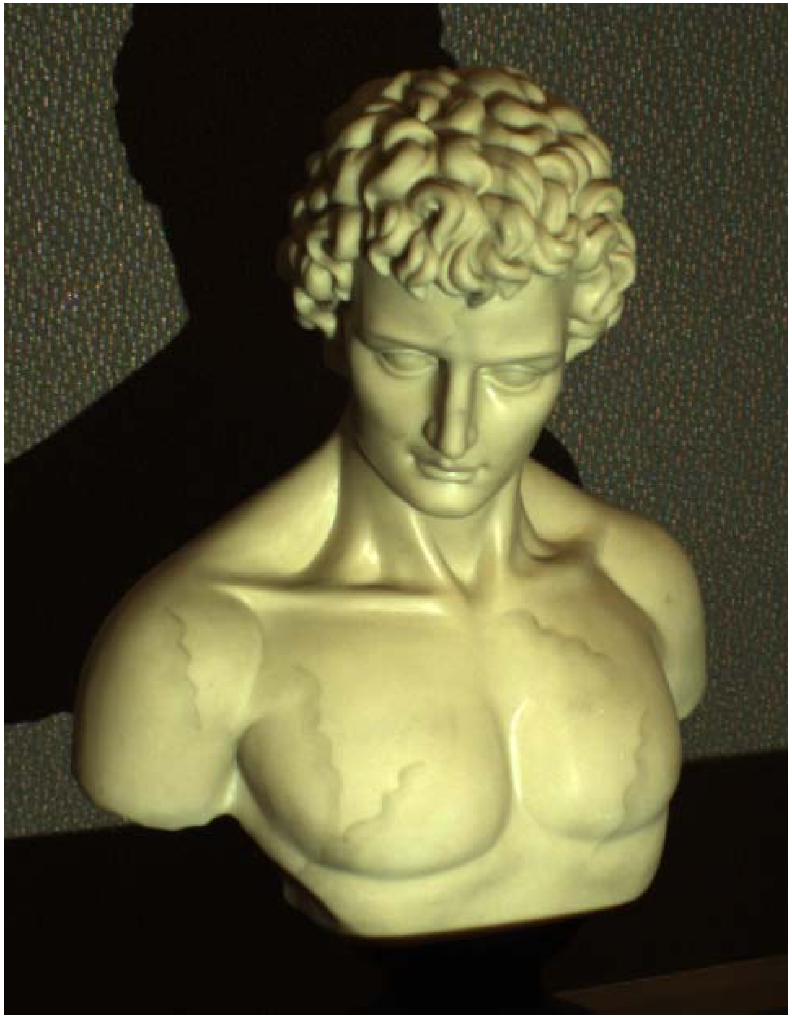
Overview of Projector-Camera Calibration



Projector-Camera Calibration Results

- Implemented complete toolbox for projector-camera calibration
- Sufficient accuracy for structured lighting applications
- Future version will incorporate final global bundle adjustment

Gray Code Structured Lighting: Results



References

3D Reconstruction using Structured Light

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Projector and Camera Calibration Methods

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Visual Hull: Silhouette-based 3D Reconstruction

7. A. Laurentini. The Visual Hull Concept for Silhouette-based Image Understanding. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 1994.