Spring 2018 ENGN2502 --- 3D Photography
Robust Pixel Classification
Lecture 11

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The Problem

- 3D Scanning with Structured Light
- Binary Patterns
- Each pixel corresponds to a surface point
- Pixel intensity = superposition of direct and indirect illumination components
- Codeword bit decisions must be based only on direct illumination component
- When indirect illumination is strong, decisions can be incorrect

References

- **Robust Pixel Classification for 3D Modeling with Structured Light**, by Yi Xu and Daniel G. Aliaga, Graphics Interface 2007

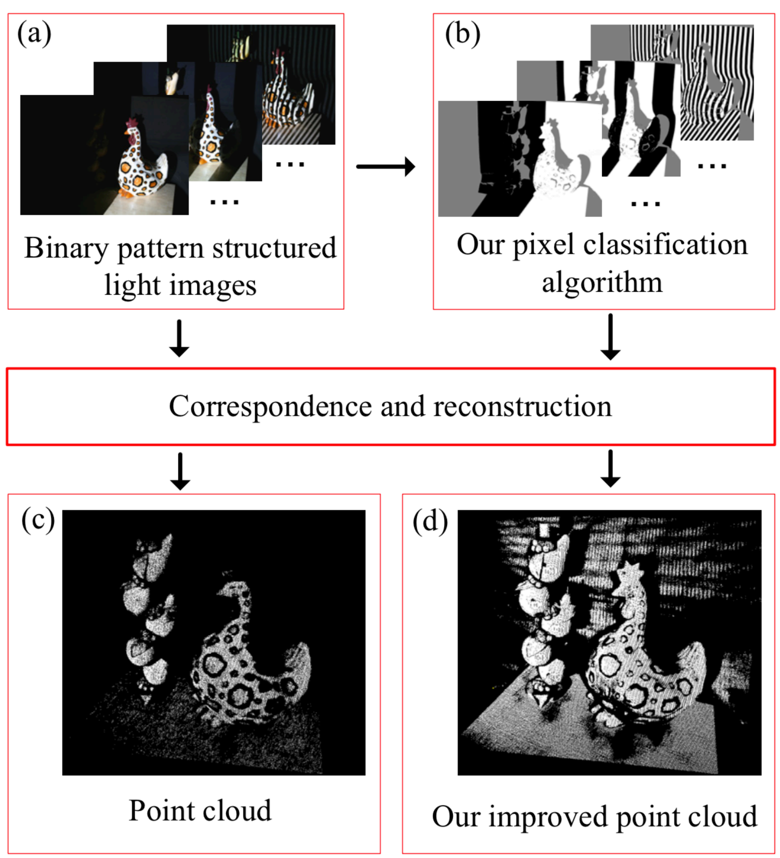
- **Fast Separation of Direct and Global Components of a Scene using High Frequency Illumination**, by Shree K. Nayar, Gurunandan Krishnan, Michael D. Grossberg, and Ramesh Raskar. Siggraph 2006.

Thresholds

- Most methods assume that a scene point is brighter when it is illuminated
- If a point is in shadow, it should have 0 intensity, but due to inter-reflection, it has large intensity
- Some methods use a single global threshold for all pixels.
- Some methods are based on projecting pairs of complementary patterns, and using the average of the two methods as a per pixel threshold
- Other methods use different exposure times, different projected intensities, and post-processing to remove outliers.

Robust Classification

- Pixel intensities in interval [0:255]
- For each pixel estimate tight intervals for when the pixel is on, and when the pixel is off.
- Use these intervals to classify each pixel as on (white), off (black), or uncertain (gray)



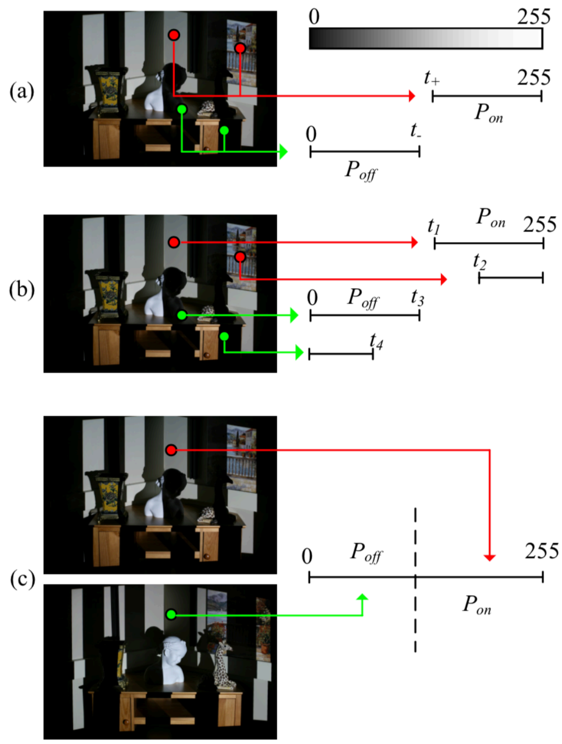


Figure 2. Pixel Intervals. a) A simple method classifies pixel using two user-defined thresholds. b) An adaptive method computes the albedo for each pixel and uses that for classification. c) A more expensive method classifies a pixel according to whether the pixel or its inverse is brighter.

Algorithm

- Use the high frequency binary patterns to decompose each pixel intensity into a total direct component, and a total indirect component, using Nayar et. al. method.

$$p = \begin{cases} d + ion & \text{If pixel is on} \\ ioff & \text{If pixel is off} \end{cases}$$

$$ion \in [0, itotal] \qquad Pon \subseteq [d, d + itotal]$$
$$ioff \in [0, itotal] \qquad Poff \subseteq [0, itotal]$$

Case 1 : $\boxed{d > i_{total}}$

- The two intervals are totally separated

$p < i_{total} \rightarrow$ pixel is *off*
$p > d \rightarrow$ pixel is *on*
otherwise $\rightarrow$ pixel is *uncertain*

Case 2 : $\boxed{d \approx 0}$

- If the direct illumination component is smaller than a minimum threshold, classify the pixel as uncertain.

Case 3 : $\boxed{d > i_{total}}$

- The pixel has a relatively stronger indirect component and the two intervals overlap near the middle range.

$$
\begin{aligned}
&p < d \rightarrow \text{pixel is } \textit{off} \\
&p > i_{total} \rightarrow \text{pixel is } \textit{on} \\
&\text{otherwise} \rightarrow \text{pixel is } \textit{uncertain}
\end{aligned}
$$

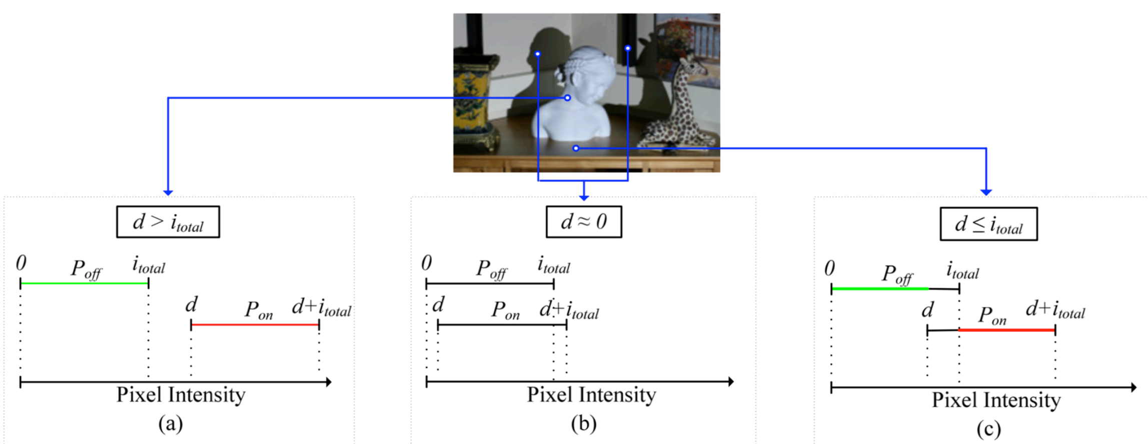


Figure 3. Pixel Classification Scenarios. a) The two intervals are completely separated when $d > i_{total}$. b) The two intervals are indistinguishable when $d \approx 0$. c) The two intervals overlap when $d \leq i_{total}$.

Combining the Three Rules

- Single pattern classification rules

$$
\boxed{
\begin{array}{l}
d < m \rightarrow \text{pixel is } \textit{uncertain} \\
p < \min(d, i_{total}) \rightarrow \text{pixel is } \textit{off} \\
p > \max(d, i_{total}) \rightarrow \text{pixel is } \textit{on} \\
\text{otherwise} \rightarrow \text{pixel is } \textit{uncertain}
\end{array}
}
$$

Dual Pattern Classification Rules

- Projecting two complementary patterns

$$
\boxed{
\begin{array}{l}
d < m \rightarrow \text{pixel is } \textit{uncertain} \\
d > i_{total} \wedge p > \overline{p} \rightarrow \text{pixel is } \textit{on} \\
d > i_{total} \wedge p < \overline{p} \rightarrow \text{pixel is } \textit{off} \\
p < d \wedge \overline{p} > i_{total} \rightarrow \text{pixel is } \textit{off} \\
p > i_{total} \wedge \overline{p} < d \rightarrow \text{pixel is } \textit{on} \\
\text{otherwise} \rightarrow \text{pixel is } \textit{uncertain}
\end{array}
}
$$

Classification Results

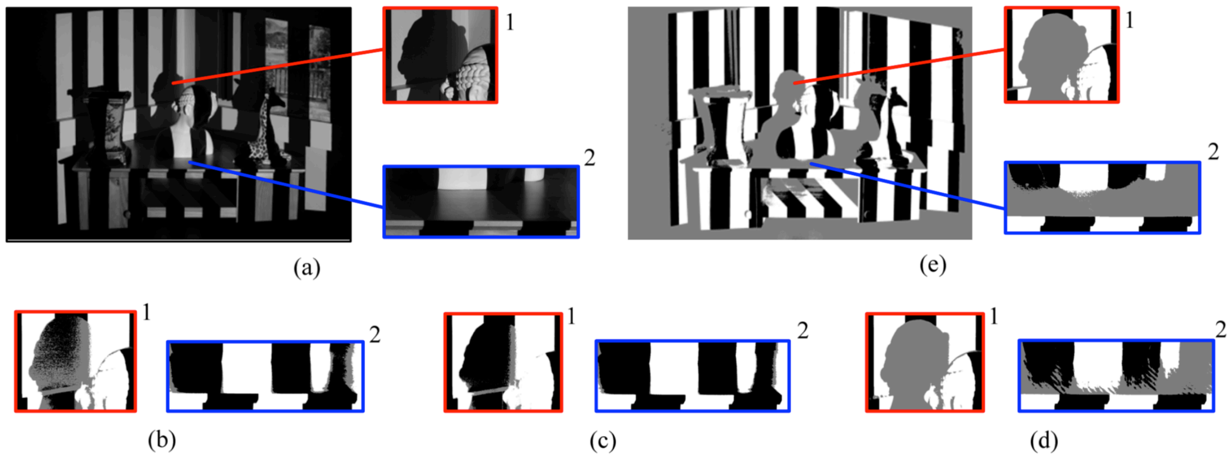


Figure 4. Classification Results. White pixels are classified as on, black pixels are classified as off, and gray pixels are uncertain. a) We show an input image with a pattern projected onto the scene with zoomed-in areas of a shadow (rectangle 1) and of a table top with strong inter-reflection (rectangle 2). b) Classification results on zoomed-in areas using standard method 1. c) Classification results on zoomed-in areas using standard method 2. d) Classification results using our algorithm with structured light pattern separation. e) Classification results using our algorithm with additional pattern images separation.

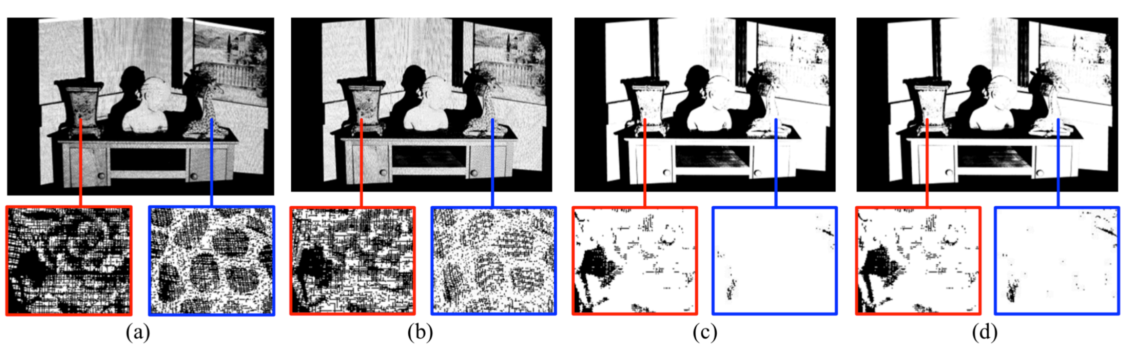


Figure 5. Binary Images for Decoded Pixels. White means a pixel can be decoded without any uncertainty. Images are generated using: a) standard method 1, b) standard method 2, c) our method using structured light pattern images for separation, and d) our method using additional pattern images for separation. More decoded pixels lead to a brighter image.

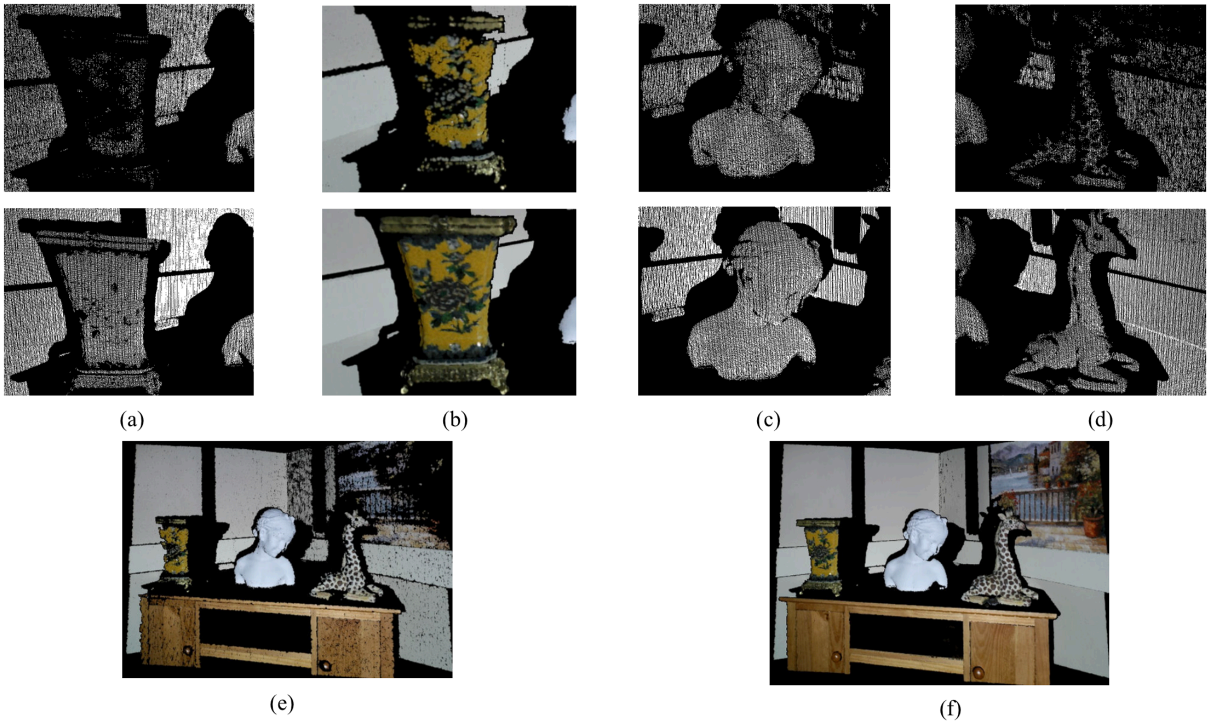


Figure 8. Point Clouds. In (a-d), pictures in the first row are generated using standard method 2. Pictures in second row are generated using our algorithm: a) a close up view of the vase, b) point-based rendering of the vase, c) a close up view of the bust, and d) a close up view of the giraffe. e) The point-based rendering of the entire scene using standard method 2. f) The point-based rendering of the entire scene using our method.

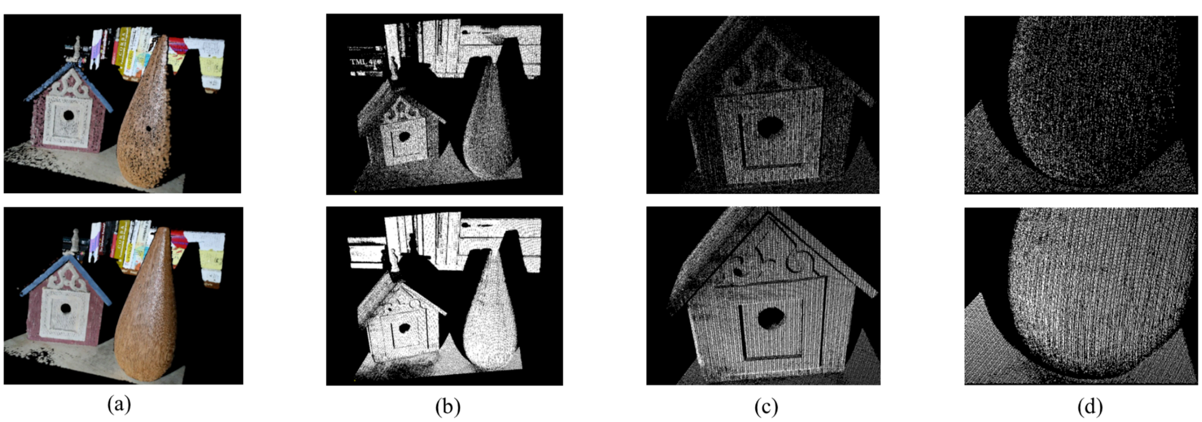


Figure 9. Objects Scene Point Clouds. a) Point-based rendering of the scene. b-d) Several views of the reconstructed point clouds. The first row are the results using standard method 2 and the second row are the results using our method.