3D Camera for Mobile Device

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What is 3D imaging?

- Collect data on a real-world object
- Analyze the collected data
- Construct 3D image
Why 3D imaging?

- Medical Imaging
- Entertainment
- Security applications
- Autonomous navigation system
Active stereometric scanner

[Bronstein, Bronstein, Gordon & Kimmel ‘03]

Active stereometric scanners

Structured light projections

Time-multiplexed patterns

Passive stereo

Active stereo hierarchy
Project definition and goals

Creating a mobile 3D camera system:

- **System requirements:**
  - Mobile
  - Stand-alone
  - Automatic

- **Objectives:**
  - Real-time
  - Accuracy
  - Low cost

Existing system: standard camera, projector, PC
Outline

Introduction

3D Reconstruction Algorithm

Mobile System Structure

Results
Projective model

- **Forward projection (linear)**
  \[ T : (x_w, y_w, z_w) \rightarrow (x_c, y_c, y_p) \]

- **Backward projection**
  \[ (x_w, y_w, z_w) = T^{-1} (x_c, y_c, y_p) \]
Projection matrices

Based on pin-hole model:

Composed of:

- Camera/projector parameters (focal distance…)
- Rotation matrix
- Translation vector
Algorithm phases

Phase 1 – Calibration (performed once)
- Determining the projection matrices $C_c$ and $C_p$

Phase 2 – Decoding
- Computing the projection coordinate $y_p$

Phase 3 – Reconstruction
- Finding the world coordinates $w$
Decoding

- **Input:**
  - [Images of illuminated and not illuminated faces]
  - [Images of N coded light patterns]

- **Preprocessing:**
  1. **Normalization:**
  2. **Thresholding:**
Decoding (cont.)

\[ y_p = \sum_{k=1}^{N} 2^{N-k} B_k(x, y) \]

\( B_k \) – \( k \)th binary pattern, \( 1 \leq k \leq N \)

Output:

\( y_p \) – projector coordinate for each pixel

Projected coded light patterns
Reconstruction

Input: \( \begin{align*} & C_c, C_p - \text{projection matrices} \\ & x_c, y_c, y_p - \text{projector and camera coordinates} \end{align*} \)

• Using the back projection:

\[
\begin{pmatrix} x_w, y_w, z_w \end{pmatrix} = T^{-1} \begin{pmatrix} x_c, y_c, y_p \end{pmatrix}
\]

• Output: \( x_w, y_w, z_w - \text{world coordinates} \)
Structured light scanner

- Projecting time multiplexed patterns
- 2D image acquisitions
- 3D reconstruction
System implementation

- Adaptations due to limited hardware
- Fixed point
- Task division between three processors
- Driver modifications
- BeagleBoard©
- OMAP 3530 TI
- I/O devices: Camera and Projector
System

Beagleboard ©

Device built in the EE workshop

TI DLP Pico Projector

Logitech QuickCam Pro 9000
Challenges
Task division

Series of coded images (2D) → Decoding → Reconstruction → ARM

Images capturing → 3D coordinates

DSP

GPU

Coded light projection

DVI

Output 3D image

Camera

USB

Projector
Implementation steps

I. Patterns projection: 7 alternating green and black stripes

II. Image capture: storing intensity image

III. 3D reconstruction: performed in the DSP
Outline

- Introduction
- 3D Reconstruction Algorithm
- Mobile System Structure
- Results
Demo
Results

Deborah
Results

Dani
Results
Performance analysis

• **Accuracy**: $RMS = 0.50 - 1 \text{ [mm per pixel]}$

• **Complexity**: $O(\#\text{pixels} \cdot \#\text{patterns})$

<table>
<thead>
<tr>
<th>TASK</th>
<th>EFFECTIVE TIME (sec)</th>
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<tbody>
<tr>
<td>DSP reconstruction</td>
<td>0.24</td>
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<tr>
<td>ARM reconstruction</td>
<td>1.19</td>
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<tr>
<td>(for comparison)</td>
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<table>
<thead>
<tr>
<th>TASK</th>
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</thead>
<tbody>
<tr>
<td>Acquisition</td>
<td>2.81 (*)</td>
</tr>
</tbody>
</table>

(*) Multiple projections (software sync)
Summary

Suitable solution for mobile devices

Active stereometric scanner

3D reconstructed face

System prototype
Achievements

- Miniaturization
  - Mobile system

- Accuracy
  - Accurate 3D reconstruction

- Real time reconstruction
  - 4 reconstructions per second

- Low cost
  - Common devices

- Low power
  - Energy efficient devices
Thanks

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