Phase Messaging Method for Time-of-flight Cameras

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Camera-Display Communication
Related work: QR codes

Related work: Visual MIMO

Other related work

Our work

Phase Messaging Array (PMA) → Time-of-flight Cameras
Time-of-Flight Cameras

ToF camera sensor

PMD CamBoard Nano
SoftKinetic DS311
Swiss Ranger SR4050
Time-of-Flight Cameras

PMD CamBoard Nano
SoftKinetic DS311
Swiss Ranger SR4050

ToF camera sensor
Infrared LEDs
Time-of-Flight Cameras

SoftKinetic DS311

Phase difference

\[ \phi = 2\pi f_m \tau \]

Depth

\[ d \propto \phi \]

\[ d = \frac{c\tau}{2} \]

\[ f_m = 15 MHz \]
Phase Messaging Array (PMA)

LED

Light Detection

Phase Modulation

Data Processing
Intuitive Solution

LED

Light Detection

Phase Modulation

Data Processing

Time-of-flight Camera

Time(second)

Phases(deg)
Our Solution

- Photo Detector
  - LED

Diagram:
- LED
- Light Detection
- Phase Modulation
- Data Processing

Graph:
- Time (second) vs. Phases (deg)

Date: 5/3/2014
Phase Modulation

- Phase Shifting
Phase Modulation

• Messaging and Signal Selection

<table>
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<tr>
<th>A₁</th>
<th>A₀</th>
<th>output</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
<td>p₀</td>
</tr>
<tr>
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<td>p₁</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>p₂</td>
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<tr>
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<td>1</td>
<td>p₃</td>
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Phase Modulation

• Message Recovery

<table>
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<tr>
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<th>A0</th>
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<td>p2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>p3</td>
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</tbody>
</table>

272.6 323.5 172.4 p2 p3 p0
232.9 276.8 327.1 p1 p2 p3
182.3 236.7 242.3 p0 p1 p1

p2 p1 p0 p3 p2 p1 p0 p3 p1
10 01 00 11 10 01 00 11 01
Experiments

PMA

SoftKinetic DS311

Five independent experiments
8000 random bits/experiment
Average accuracy 97.8%
Experiments

• Data rate analysis
  – 9 LEDs
    • One for synchronization indicator
    • Another 8 for messaging
  – 4 candidate phases => 2 bits/LED
  – ToF camera
    • 60 fps => 8x2x60 = 960bps
Applications

• Dual use of cameras
  – Imaging (original use)
  – Communication (added channel)

• Applications
  – Object recognition: ID beacon
  – Navigation: path marker
  – Robotics: line of sight communication
Conclusions

• Propose a camera-display communication methodology based on a low-cost continuous-wave ToF camera

• Implement Phase Messaging Array (PMA)

• Demonstrate high messaging accuracy in experiments