Making any planar surface into a touch-sensitive display by a mere projector and camera

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Introduction & Motivation

Bigger Display vs. Portability
Introduction & Motivation

Mobile Phone

DC

DV

DLP Pico Projector

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Previews Works

Additional Sensors
- *Light Touch* (IR optical sensors)
- *DiamondTouch* (capacitive sensor array)
- *Smartskin* (mesh-shaped antenna)
- *Skinput* (bio-acoustic sensing array)
- *LightSpace, Omnitouch* (Kinect)

Computer Vision
- [Letessier2004] -- Fingertip tracking, not touching detection
- [Marshall2008] -- Color change of the fingernail
- [Song2007, PlayAnywhere2005] -- Shadow casted by finger
- [Fitriani2007] -- Deformation on soft surface
Main Contributions

- Using only off-the-shelf devices
- Achieving 3D sensing without explicit 3D reconstruction
- Use of prior knowledge to enhance robustness
System Prototype

~500mm

~400mm

HDMI
Power
IEEE1394
Hardware Trigger
Sync. Signal
Pico Projector
CCD Camera
Overview

Imperceptible Structured Light

- Texture Image
- Subtraction Image
- Embedded Pattern Image

Hand Segmentation → Fingertip Detection → Touch Detection

Radiometric  Geometric

Priors in Pro-Cams
Priors in Projector-Camera System

- Geometric (Homography)
  \[ \Pi_C \xrightarrow{H_{CP}} \Pi_P \]
  Camera's image plane \hspace{0.5cm} Projector's projection panel

- Radiometric
  \[ C_{pre} = VP + C \]
Embedding Codes into Video Projection

\[ I_i(x, y) = O_i(x, y) + P(x, y), \]
\[ I'_i(x, y) = O_i(x, y) - P(x, y), \]
\[ P(x, y) = \begin{cases} \Delta, & \text{when } B(x, y) = 1; \\ 0, & \text{when } B(x, y) = 0. \end{cases} \]

\[ S(x, y) = \max_i [C_i(x, y) - C'_i(x, y)], \quad i = \{R, G, B\}. \]
## Embedded Pattern Design Strategy

<table>
<thead>
<tr>
<th>Method</th>
<th>Array Size</th>
<th>Win. Size</th>
<th>Alph.</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Morita 1988]</td>
<td>24 * 24</td>
<td>3 * 4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>[Kiyasu 1995]</td>
<td>18 * 18</td>
<td>4 * 2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>[Salvi 1998]</td>
<td>29 * 29</td>
<td>3 * 3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>[Spoelder 2000]</td>
<td>65 * 63</td>
<td>2 * 3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>[Albitar 2007]</td>
<td>27 * 29</td>
<td>3 * 3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>[Desjardins 2007]</td>
<td>53 * 38</td>
<td>3 * 3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>[Chen 2008]</td>
<td>82 * 82</td>
<td>3 * 3</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

### Summary of typical spatial coding methods

- **Constraints of Pattern Generation**
  - Code Uniqueness
  - Large Hamming Distance
Hand Segmentation & Fingertip Detection

(a) Approximate segmentation

(b) H-channel

(c) Refined hand region

(d) Hand contour and detected fingertips
Touch Detection Through Homography
Experiments -- Display Quality Evaluation

![Graph showing experiment results]

Scores

Embedded Intensity Δ

0 1 2 3 4 5 6 7 8 9 10

5 10 15 20 25

Flukeying  Image Deterioration  User Satisfaction

0.2 0.4 0.2 0.2 0.4 0.2 0.2 0.2

4.3 3.6 5.7 7.2 4.5 2.8 4.9 2.3
Experiments -- Touch Accuracy Evaluation

<table>
<thead>
<tr>
<th>Surface</th>
<th>Illumination</th>
<th>( \epsilon ) (px)</th>
<th>FRR/FAR (%)</th>
<th>( \epsilon ) (px)</th>
<th>FRR/FAR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray</td>
<td>Dark</td>
<td>2.98</td>
<td>1.12/0.45</td>
<td>3.05</td>
<td>1.32/0.48</td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td>3.04</td>
<td>1.23/0.57</td>
<td>3.12</td>
<td>1.54/0.61</td>
</tr>
<tr>
<td>Artifact</td>
<td></td>
<td>3.12</td>
<td>1.77/0.67</td>
<td>3.20</td>
<td>1.76/0.63</td>
</tr>
</tbody>
</table>

Comparison with recent depth-camera sensing based methods

In [2], the informal observed spatial error of finger detection on planar surface was between 3-6 pixels,

In Omni-Touch [6], the FRR and FAR of finger click detection on four different surfaces were 0.8% and 3.3%.
## Experiments -- *Efficiency Evaluation*

<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Hand Seg.</th>
<th>FTip Loc.</th>
<th>Touch Det.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (ms)</td>
<td>14.63</td>
<td>1.32</td>
<td>1.74</td>
<td>17.69</td>
</tr>
</tbody>
</table>

Average processing time
Conclusion

- This paper explores the possibility of replacing the display panel and the mouse-and-keyboard by a mere projector and camera.

- Limitations
  - Hand segmentation depends on radiometric parameters
  - Too fast hand movement
  - Single hand operation