Computer Vision and Robotics
Institut d'Informàtica i Aplicacions
Universitat de Girona

Underwater Robotics

Computer Vision

Digital Hardware Architectures for real-time computer vision

Three-dimensional vision
Three-dimensional vision
Three-dimensional vision

3D digitiser system

Laser and camera scan the scene together. The linear motion is known to the system. The calibration and reconstruction by Projective Geometry principles (Chen & Kak, 1987).
Three-dimensional vision

Real-time Range finder

5x5 photodiodes sensor. Hamamatsu S7585

Constant speed laser rotation. The time between a known reference optical switch and the impact of the laser image between 2 consecutive PDs is measured (Yokoyama et. al. 1994).
Three-dimensional vision
Coded structured light pattern projection
Three-dimensional vision

Cloud of points

Surface interpolation
Computer Vision Architectures

RTC

MAGTRAK
Computer Vision Architectures

MAGCL
2001. Modular distributed Architecture, allowing pipe-line and parallel interconnection of different modules. Each module includes 1 FPGA and 1 DSP, which makes the most calculation-intensive tasks.

MIRAGE. 2002. 'Sandwich' type modular architecture. Additional boards may be added through 3 low-profile connectors.

Allows the operation with 2 CVBS/RGB cameras and digital cameras. Implementation of a real-time 3D architecture.
A 30 Cloud-of-points per second three-dimensional digitiser: THE 3-DIMENSIONAL CAMERA
Tree-dimensional Vision (3D camera)

Operation principle
(Triangulation)

3D point

2D point

Focal point

KNOW

3D point = f(2D point)
3D Gathering Process (I)

- Image
  - ROI selection
  - Peak detection
- Time Computation
  - Scanning angle calculation
- 3D Acquisition
  - Range-map computation
  - Calibration parameters
- 3D Graphics acceleration
- Colour
  - Triangle Normals
  - Triangle computation
- Computer processing or visualisation

Reconstrucció 3D

Vision Architecture

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3D Gathering Process (II)

3D Acquisition ➔ High Speed High Accuracy

3D Acceleration ➔ Realistic Animation
Tree-dimensional Vision (3D camera)

Accuracy (Peak detection)

Energy profile

Peak location

Interpolated peak location

Actual peak location

Peak location uncertainty

1 error unit

(x_0, y_0)

(x, y)

Linear approximation

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Tree-dimensional Vision (3D camera)

Projective Calibration (I)

\[ \mathcal{H}_L(\alpha) = \begin{pmatrix} h_{11}(\alpha) & h_{12}(\alpha) & h_{13}(\alpha) \\ h_{21}(\alpha) & h_{22}(\alpha) & h_{23}(\alpha) \\ h_{31}(\alpha) & h_{32}(\alpha) & 1 \end{pmatrix} \]
Tree-dimensional Vision (3D camera)

**Projective Calibration (II)**

\[ \begin{align*}
LH_1(\alpha) &= \begin{pmatrix}
    h_{11}(\alpha) & h_{12}(\alpha) & h_{13}(\alpha) \\
    h_{21}(\alpha) & h_{22}(\alpha) & h_{23}(\alpha) \\
    h_{31}(\alpha) & h_{32}(\alpha) & 1
\end{pmatrix} \\

wT_L &= \begin{pmatrix}
    t_{11} & t_{12} & t_{13} & t_{14} \\
    t_{21} & t_{22} & t_{23} & t_{24} \\
    t_{31} & t_{32} & t_{33} & 1
\end{pmatrix} \\

wT_L(\alpha) &= wT_L \cdot LH_1(\alpha) = \begin{pmatrix}
    d_{11}(\alpha) & d_{12}(\alpha) & d_{13}(\alpha) \\
    d_{21}(\alpha) & d_{22}(\alpha) & d_{23}(\alpha) \\
    d_{31}(\alpha) & d_{32}(\alpha) & d_{33}(\alpha) \\
    d_{41}(\alpha) & d_{42}(\alpha) & 1
\end{pmatrix}
\end{align*} \]
Tree-dimensional Vision (3D camera)

**Projective Calibration (III)**

![Diagram](image)

- 3D Point (in mm)
- 2D point (in pixels)

\[ \mathbf{w} P = \mathbf{w} \mathbf{T}_I (\alpha) \mathbf{l} P \]

Known by calibration
Pros

- Easy calibration process
- Reconstruction by matrix multiplication
- $\alpha$ is the only dependence
- Noise robustness
- No precision mechanics needed for camera-laser alignment

3D Reconstruction

$$w P = w T_I(\alpha) \cdot I P$$

Very Fast 3D acquisition
High accuracy
Low cost mechanics

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THE 3-DIMENSIONAL CAMERA as a CMOS design approach
Tree-dimensional Vision (3D camera)

CMOS Image Sensor Floorplan

Row Selector

K-Winner-Take-All Circuit

Subpixel Accuracy Peak detector

Pixel Circuit

Output

Row-Select line

Bite line

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Tree-dimensional Vision (3D camera)

Pixel Circuit

• APS (Active Pixel Sensor)
• Example:

![Pixel Circuit Diagram]
Tree-dimensional Vision (3D camera)

K-Winner-Take-All Circuit

Row Pixels

K-Winner-Take-All Circuit

Analog Inputs

Digital Outputs

0 0 1 1 1 1 0 0
4 Winners

Laser Peak
Global Reconstruction (I)

Laser Scanner

6 DOF sensorised arm

Angular sensors (optical encoders)

Global accuracy $\geq$ Scanner accuracy

High resolution optical encoders
Tree-dimensional Vision (3D camera)

Global Reconstruction (II)

Photodiodes

Waveguide

Silicon angular sensor

Small
Compact
Rough
Robust
High Resolution
Cheap

LED

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ShapeSens: SPIN-OFF proposal
Product Idea

- Sub-píxel Detection
- Vision Architecture
- Projective Calibration
- Software running on Real-time O.S.

Real-time three-dimensional Laser Scanner “3D camera”
Aplications

Industry
• Automotive
• Aerial
• Space
• Quality assurance
• Inverse engineering
• Rapid prototyping
• 3D modelling
• Automatic machine guidance

Medicine
• Assisted surgery
• Dermatology
• Stetics

Robotics
• 3D environment Perception
• 3D mapping
• Navigation

Cinema
• Virtual scenery creation
• Realistic 3D graphic creation

Virtual Reality
• Virtual worlds from Real worlds
• Augmented Reality

Archaeology
• Digitisation of whole ruins for realistic virtual visits
• Ancient craftsman parts 3D reconstruction

Art
• Artwork retorting
Business plan

**ShapeSens**

- Laser technology
- Silicon
- Electronics
- CMOS image sensors
- Lenses
- Mechanics

Representative

End users

Training program
## Our Competitors

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Accuracy(um)</th>
<th>Resolution</th>
<th>Speed(points/s)</th>
<th>3D data type</th>
</tr>
</thead>
<tbody>
<tr>
<td>INO</td>
<td></td>
<td>250</td>
<td>256 points/field</td>
<td>230400</td>
<td>Profile</td>
</tr>
<tr>
<td>MINOLTA</td>
<td>Vivid 910</td>
<td>40</td>
<td>307000 points/frame</td>
<td>122800</td>
<td>Cloud of points</td>
</tr>
<tr>
<td>3SHAPE</td>
<td>H-100</td>
<td>10 a 100</td>
<td>100 a 700 um</td>
<td>3500</td>
<td>Profile</td>
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<tr>
<td>KREON3D</td>
<td></td>
<td>5</td>
<td></td>
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<td>Profile</td>
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<tr>
<td>AXILA</td>
<td>G-SCAN</td>
<td></td>
<td></td>
<td>16000</td>
<td>Profile</td>
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<tr>
<td>HYMARC</td>
<td></td>
<td>25</td>
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<td>10000</td>
<td>Profile</td>
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<tr>
<td>IVP</td>
<td>M50</td>
<td></td>
<td>1536 Z values</td>
<td>15360000</td>
<td>Profile</td>
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<tr>
<td>ORIGIN</td>
<td>RS400</td>
<td>13</td>
<td>500 xy points</td>
<td></td>
<td>Cloud of points</td>
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<tr>
<td>PERCEPTRON</td>
<td>ScanWorks</td>
<td>50</td>
<td>420 um</td>
<td>23040</td>
<td>Profile</td>
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<tr>
<td>POLHEMUS</td>
<td>FastScan Cobra</td>
<td>1000</td>
<td>500 um</td>
<td></td>
<td>Profile</td>
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<tr>
<td>SURPHASER</td>
<td>Model 25</td>
<td>25</td>
<td></td>
<td>200000</td>
<td>Cloud of points</td>
</tr>
<tr>
<td>STEINBICHLER</td>
<td>Comet T-Scan</td>
<td>30</td>
<td>150 um</td>
<td></td>
<td>Profile</td>
</tr>
</tbody>
</table>
Performance of Our product

Accuracy: 40 um
Resolution: 98 um
Speed*: 20000000 points/s
3D data type: Cloud of points / Profile

* 30 clouds of points per second
Expectations

Rapid Prototyping: An example

RP users worldwide produced 3.55 million models and prototype parts in 2001. This is a growth of 18.3% from the 3 million produced in 2000*.

Almost any 3D industry (Hw or Sw) has experienced a significant growth, despite the decline in overall industry growth.