Construction and Calibration of a Low-Cost 3D Laser Scanner with 360º Field of View for Mobile Robots

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1. SENSOR OVERVIEW
2. SENSOR CONSTRUCTION
3. INTRINSIC CALIBRATION
4. APPLICATION TO MOBILE ROBOTS
5. CONCLUSIONS
1. SENSOR OVERVIEW
- Low-cost 3D rangefinder with 360° field of view
- Based on an off-the-shelf 2D rangefinder
- Continuous spinning around the optical center of the 2D device
- It weighs 1.9 kg and its maximum dimensions are 125x170x222 mm.

The UNO-motion 3D rangefinder
The design is an evolution of a previous device [Morales et al., 2011]

- Faster acquisition time
- 360º field of view
- No visible wires
- Intensity data

**Hokuyo UTM-30LX with the pitching configuration**

**Hokuyo UTM-30LX-EX with the rolling configuration**
## Comparison with commercial multi-beam models by Velodyne

<table>
<thead>
<tr>
<th>Specifications</th>
<th>HDL-64E</th>
<th>HDL-32E</th>
<th>UNOmotion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical resolution</td>
<td>0.42°</td>
<td>1.33°</td>
<td>0.25°</td>
</tr>
<tr>
<td>Vertical field of view</td>
<td>26.8°</td>
<td>41.34°</td>
<td>67.5°</td>
</tr>
<tr>
<td>Maximum range</td>
<td>120 m</td>
<td>70 m</td>
<td>30 m</td>
</tr>
<tr>
<td>Scan acquisition rate</td>
<td>5 – 20 Hz</td>
<td>10 Hz</td>
<td>0 – 1.48 Hz</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>0.09 – 0.35°</td>
<td>0.16°</td>
<td>0 – 6.67°</td>
</tr>
</tbody>
</table>

[Image of HDL-64E S2 sensor]

[Image of HDL-32E sensor]
2. SENSOR CONSTRUCTION
Main components of the 3D laser scanner

- 2D sensor
- Ball bearing
- Belt
- Gear
- Motor
- Encoder
- Motion controller
- Slip Ring
- Rotation axis

The 3D optical center coincides with 2D optical center

An slip ring provides unrestrained rotation
**Blind cone produced by the rotation of the blind area of the 2D scanner**

The blind zone of the 2D sensor is 90º wide.

The radius of the cone base is equal to the height $h$ of the optical center.
**Functional diagram of the 3D laser rangefinder**

The 2D sensor and the motion controller are accessed independently.

The 2D synchronization signal is captured by the motion controller.
3. INTRINSIC CALIBRATION
Data synchronization: 2D scans and rolling angles are received through different communication ports (Ethernet-USB).

2D static scans (in red) do not match the dynamic 2D scans (in blue).

Synchronization is achieved by applying a gap of 8 times the 2D scanning time.
Computing Cartesian coordinates: Small errors in the attachment of the 2D device to the rotating mechanism provoke a distorted point cloud.

**Ideal formula without construction misalignments**

\[
\begin{pmatrix}
  x \\
  y \\
  z
\end{pmatrix}
= \rho
\begin{pmatrix}
  C(\alpha)C(\theta) \\
  S(\alpha) \\
  C(\alpha)S(\theta)
\end{pmatrix}
\]
Boresight calibration: misalignment angles can be obtained by iterative maximization of the flatness and the area of planar patches from a single 3D scan [Morales et al., 2014]

\[
\begin{pmatrix}
  x \\
  y \\
  z
\end{pmatrix} = \begin{pmatrix}
  C(\alpha_0) C(\theta) + S(\beta_0) S(\alpha_0) S(\theta) & C(\alpha_0) S(\beta_0) S(\theta) - C(\theta) S(\alpha_0) \\
  C(\beta_0) S(\alpha_0) & C(\beta_0) C(\alpha_0) \\
  C(\alpha_0) S(\theta) - S(\beta_0) C(\theta) S(\alpha_0) & -S(\alpha_0) S(\theta) - C(\alpha_0) S(\beta_0) C(\theta)
\end{pmatrix} \begin{pmatrix}
  \rho C(\alpha) \\
  \rho S(\alpha)
\end{pmatrix}
\]

After calibration with $\beta_0 = 0.5^\circ$ and $\alpha_0 = -0.02^\circ$

Small translation errors cannot be detected due to 2D measurement limitations
4. APPLICATION TO MOBILE ROBOTS
- UAVs: the sensor can be placed upside-down at the bottom of the vehicle

The maximum scanning resolution is pointing to the ground.
Outdoor mobile robot Andabata: the sensor is installed centered and on a mounting to avoid shadows from the robot.

Increasing the height of the sensor improves the point of view, but the radius of the blind circle around the robot also grows in proportion.
Extrinsic parameters on Andabata: the height of the 3D sensor above the ground and the rolling angle of the longitudinal axis of the robot.

Calibration has been performed by aligning the robot with a corridor and extracting planes.

The height is 72.3 cm and the angle is -150.5°.
A 3D scan inside of a warehouse

A 360° 3D scan is completed with a 180° rotation
5. CONCLUSIONS
CONCLUSIONS

- A low-cost 3D laser scanner with 360° field of view have been constructed
  - It is based on continuous spinning of a 2D device around its optical center
  - Intrinsic and extrinsic parameters have been calibrated
  - With direct sunlight, the maximum range of the Hokuyo-30LX-EX reduces to 15 m
CONCLUSIONS

Future work

► To build local navigation maps for the mobile robot Andabata
► To correct distortions in the 3D point cloud during movement

Web page

► http://www.uma.es/isa

Thank you! ¡Gracias!