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

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OUTLINE

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1. SENSOR OVERVIEW

SENSOR OVERVIEW

- ***Low-cost 3D rangefinder with 360º field of view***
- ***Based on an off-the-shelf 2D rangefinder***
- ***Continuous spinning around the optical center of the 2D device***
- ***It weights 1.9 kg and its maximum dimensions are 125x170x222 mm.***

The UNO-motion 3D rangefinder

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SENSOR OVERVIEW

- ***The design is an evolution of a previous device [Morales et al., 2011]***

UNO-laser

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

UNO-motion

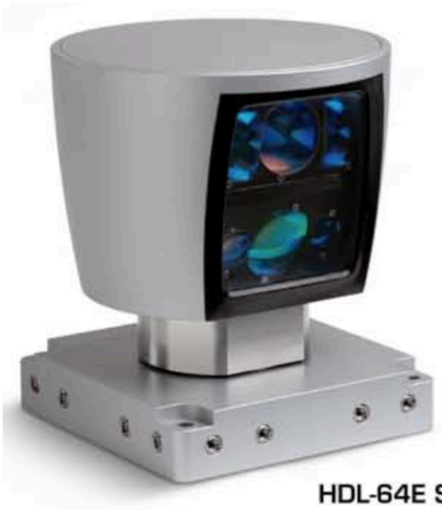
Hokuyo UTM-30LX with the pitching configuration

Hokuyo UTM-30LX-EX with the rolling configuration

SENSOR OVERVIEW

- ***Comparison with commercial multi-beam models by Velodyne***

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


HDL-64E S2


HDL-32E

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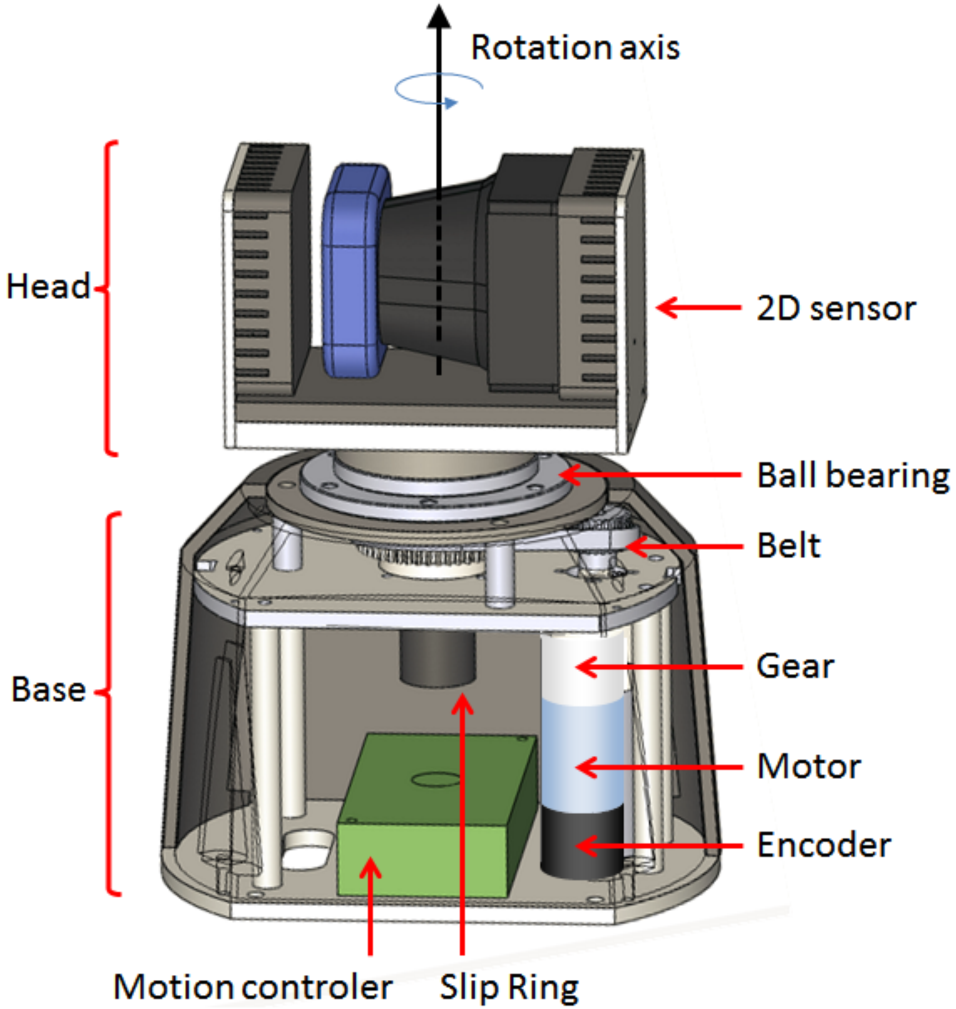
2.
SENSOR CONSTRUCTION

SENSOR CONSTRUCTION

- *Main components of the 3D laser scanner*

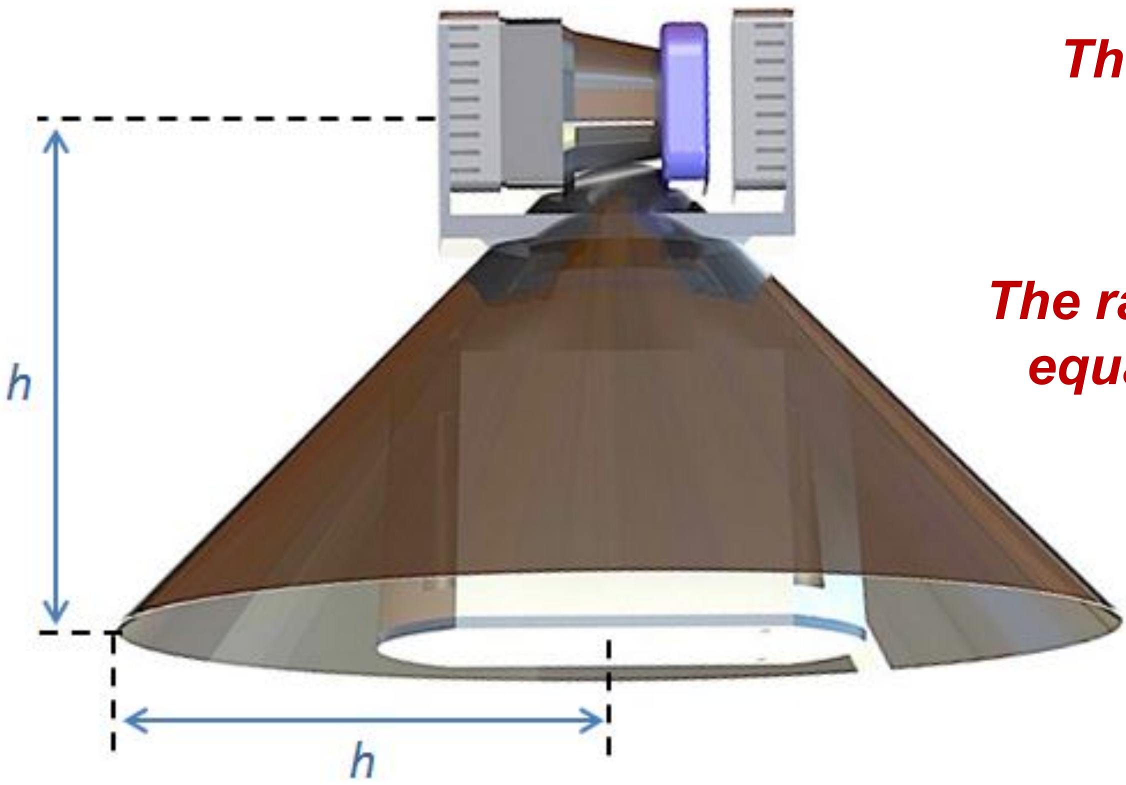


The 3D optical center coincides with 2D optical center

An slip ring provides unrestrained rotation

SENSOR CONSTRUCTION

- *Blind cone produced by the rotation of the blind area of the 2D scanner*

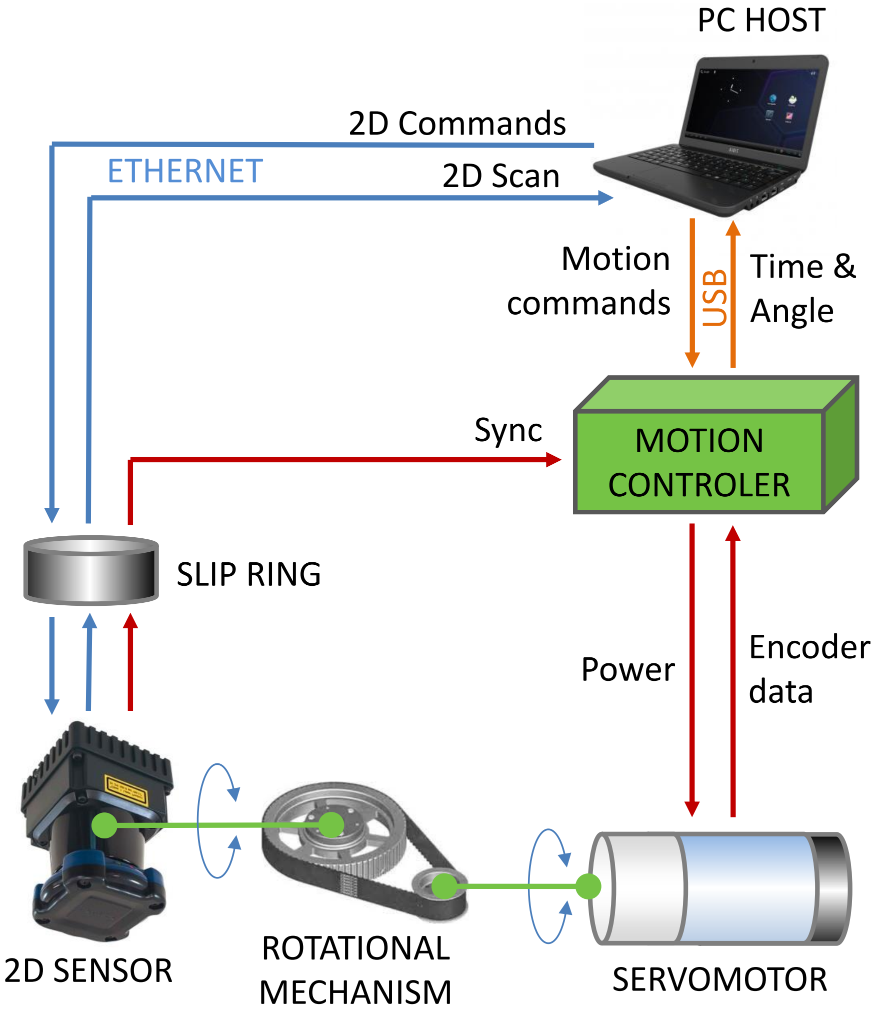


The blind zone of the 2D sensor is 90º wide

The radius of the cone base is equal to the height h of the optical center

SENSOR CONSTRUCTION

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

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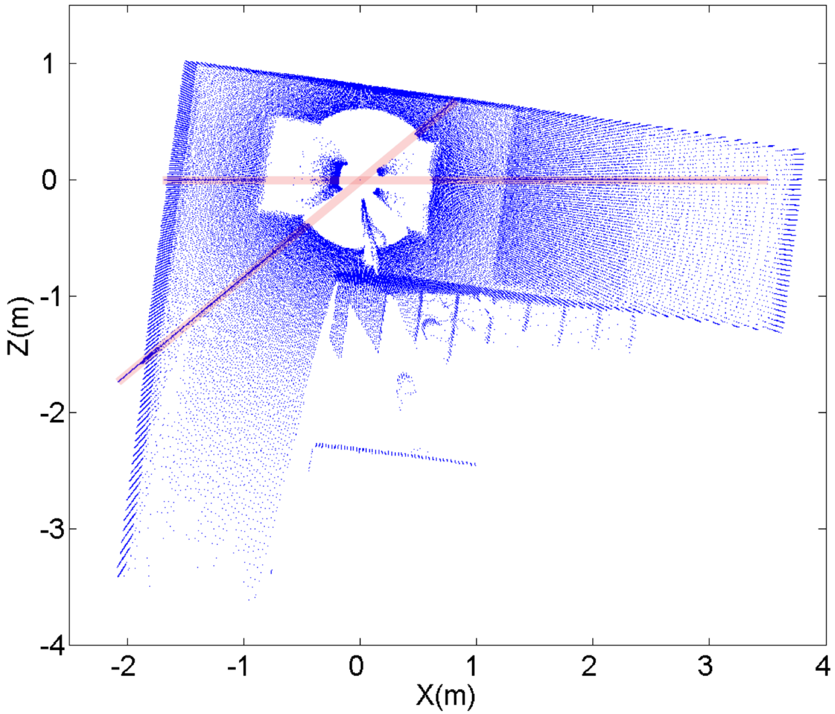
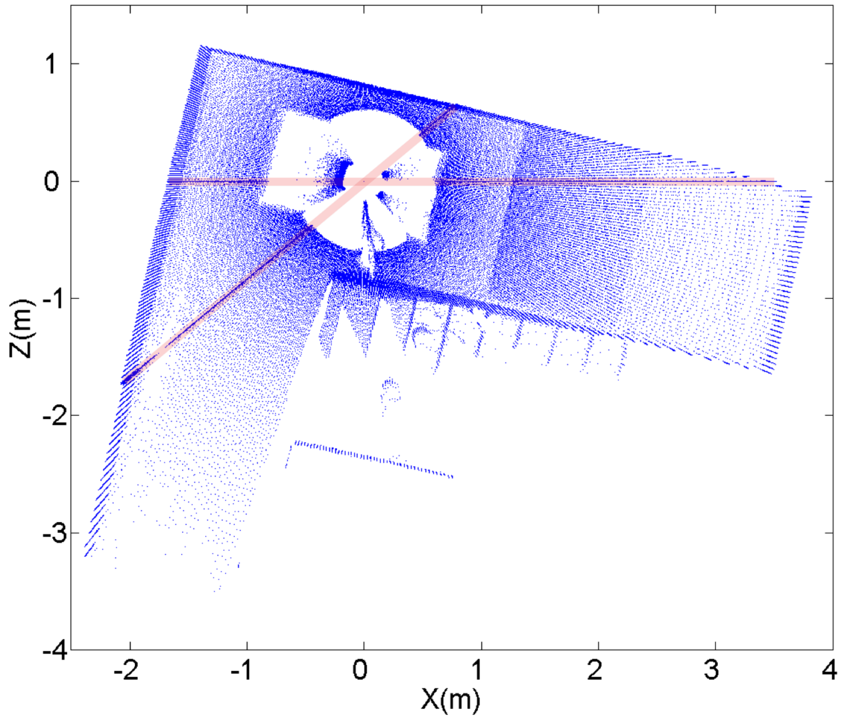
3.
INTRINSIC CALIBRATION

INTRINSIC CALIBRATION

- **Data synchronization: 2D scans and rolling angles are received through different communication ports (Ethernet-USB)**



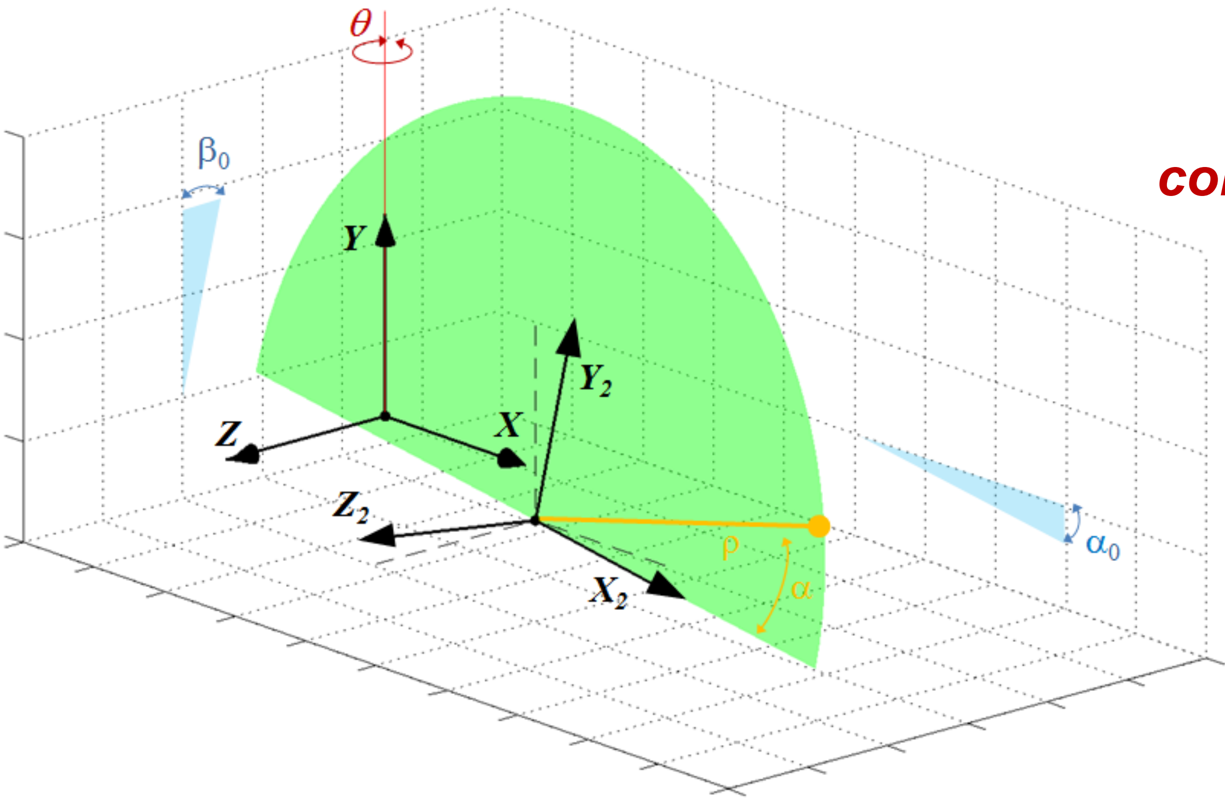
2D static scans (in red) do not match the dynamic 2D scans (in blue)



Synchronization is achieved by applying a gap of 8 times the 2D scanning time

INTRINSIC CALIBRATION

- **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

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \rho \begin{pmatrix} C(\alpha)\,C(\theta) \\ S(\alpha) \\ C(\alpha)\,S(\theta) \end{pmatrix}$$

INTRINSIC CALIBRATION

- **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]**

After calibration with β_0= 0.5º and α_0= -0.02º

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

Small translation errors can not be detected

due to 2D measurement limitations

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4.
APPLICATION TO MOBILE ROBOTS

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

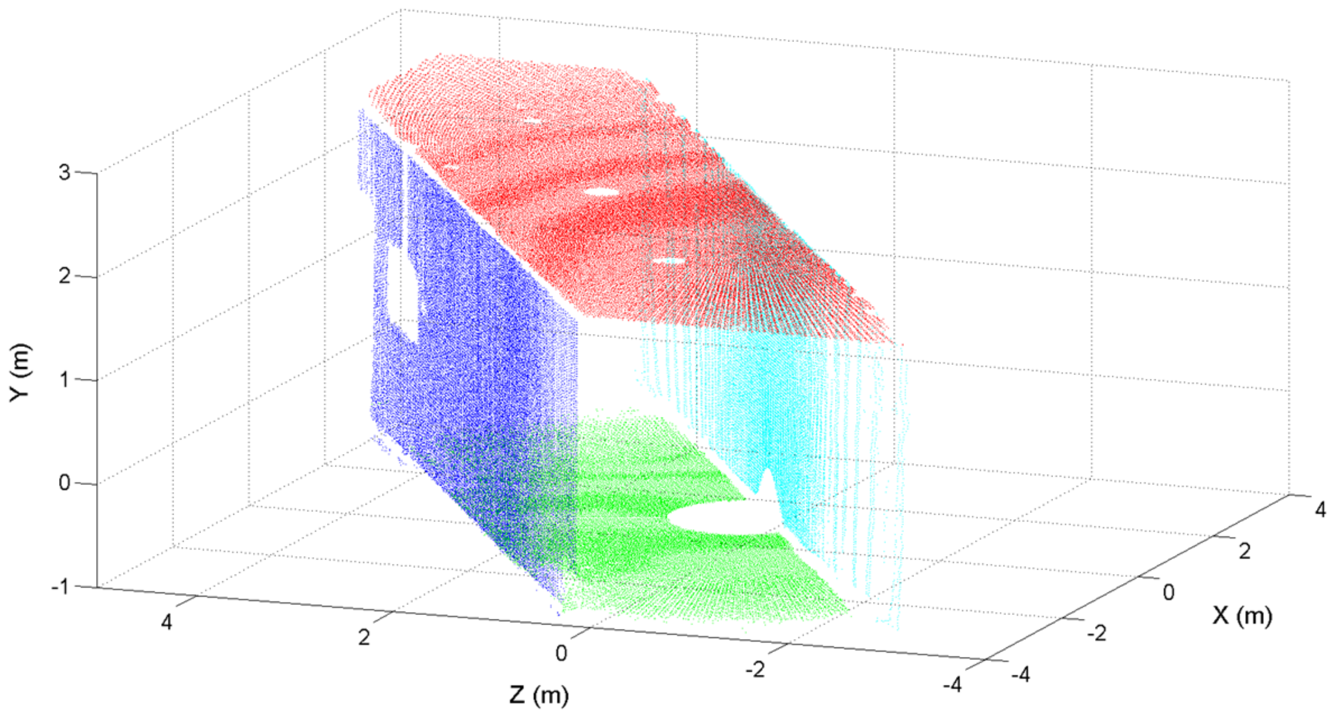
APPLICATION TO MOBILE ROBOTS

- **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

APPLICATION TO MOBILE ROBOTS

- **Extrinsic parameters on Andabata: the height of the 3D sensor above the ground and the rolling angle of the longitudinal axis of the robot**

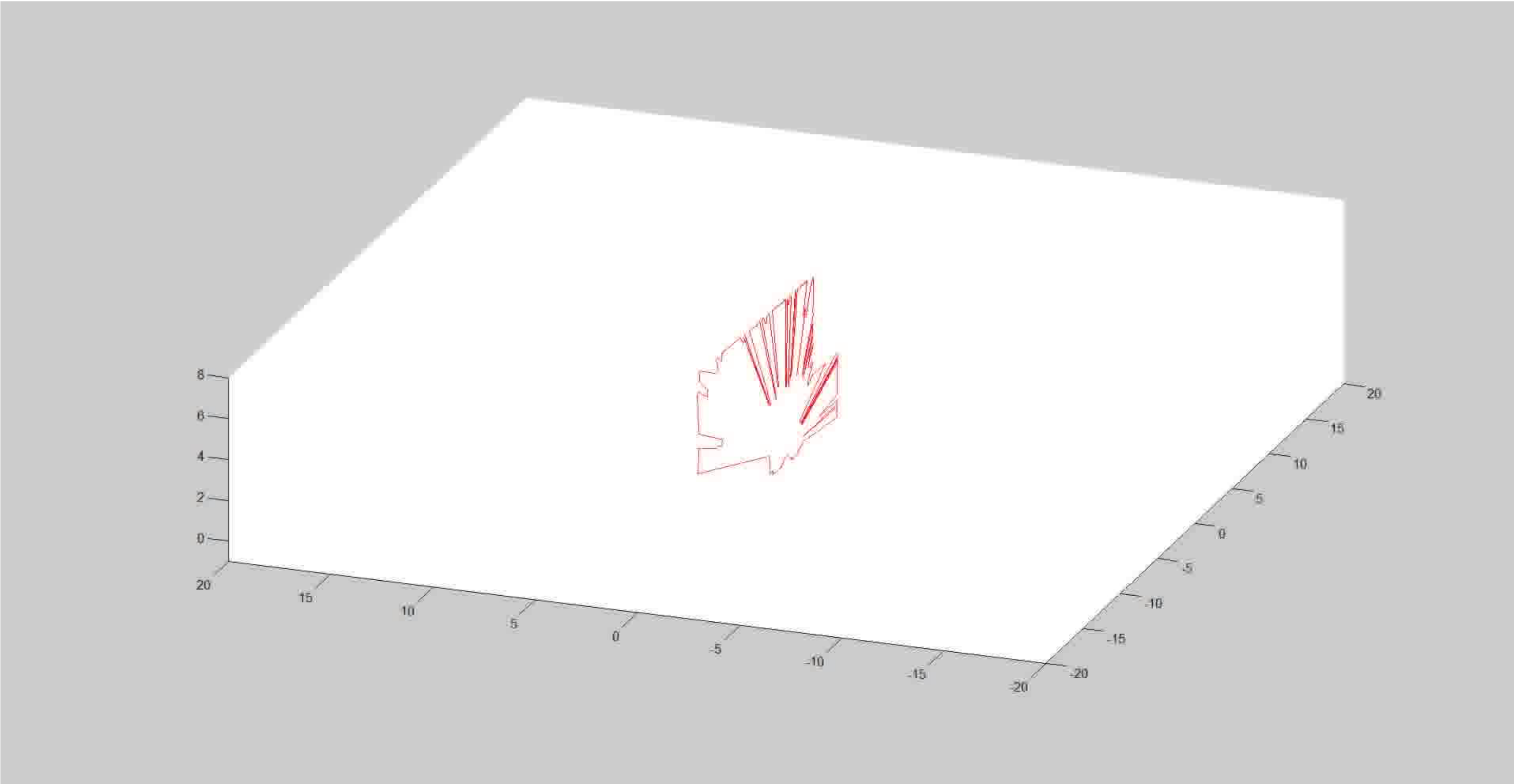


Calibration has been performed by aligning the robot with a corridor and extracting planes

The height is 72.3 cm and the angle is -150.5º

APPLICATION TO MOBILE ROBOTS

- **A 3D scan inside of a warehouse**



A 360º 3D scan is completed with a 180º rotation

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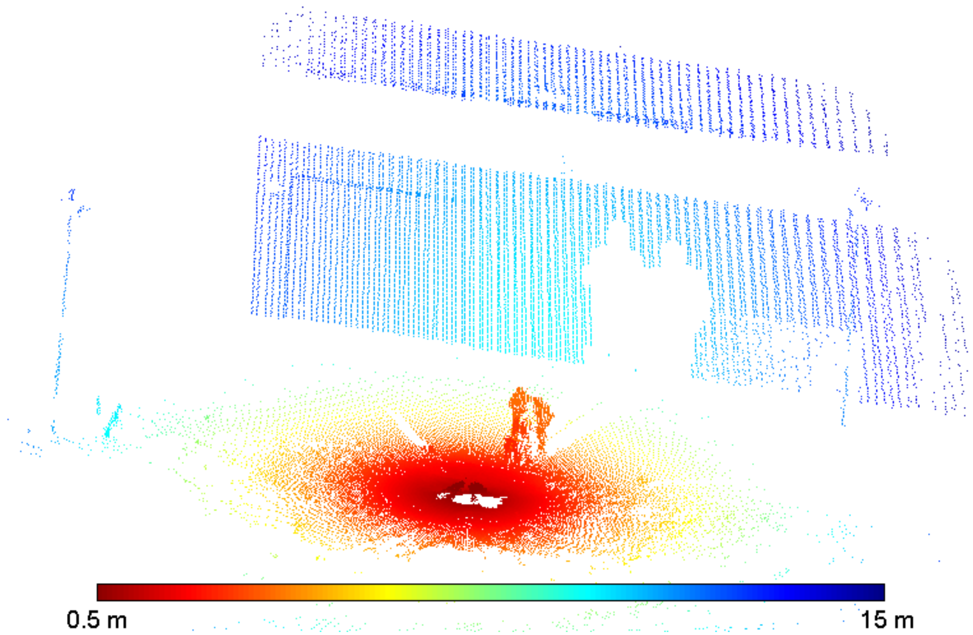
5.
CONCLUSIONS

CONCLUSIONS

- **A low-cost 3D laser scanner with 360º 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*



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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!**