PROJECTION-BASED AR FOR HUMAN SUPPORT IN THE SHIPBUILDING SECTOR

INTRODUCTION

AIMEN, 13th June 2024

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101006798

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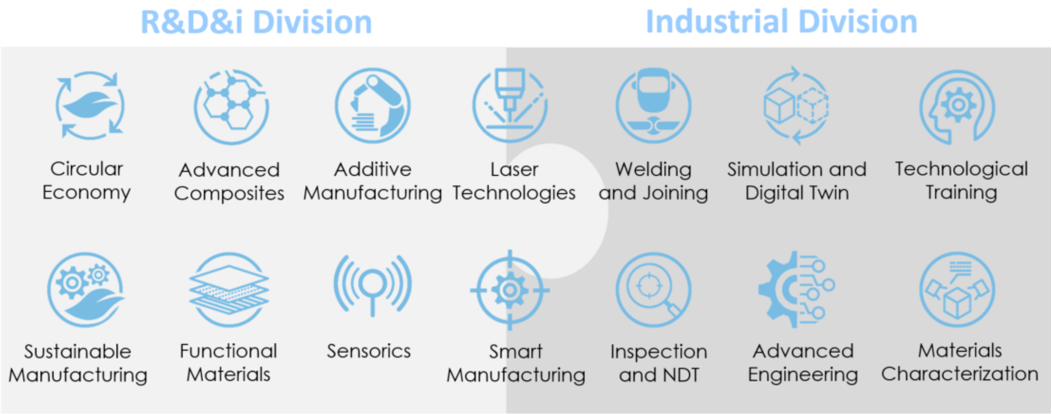
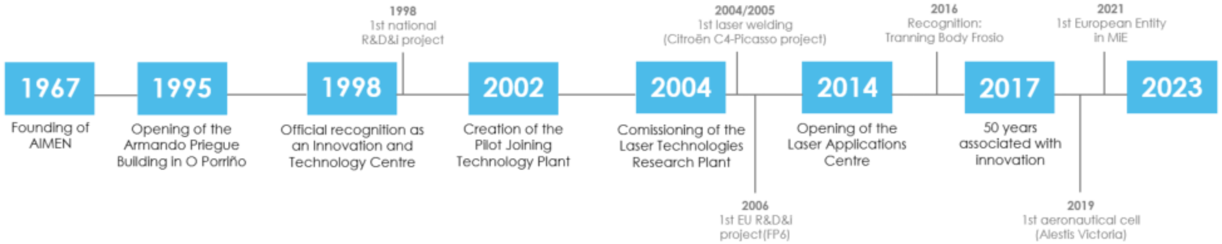
Aimen is a multi-sector innovation and Technology Centre that develops **R&D&i activities** and provides **technological services** tot the industry fields of **Materials, Advanced Manufacturing Processes, Digitalization and Sustainability**





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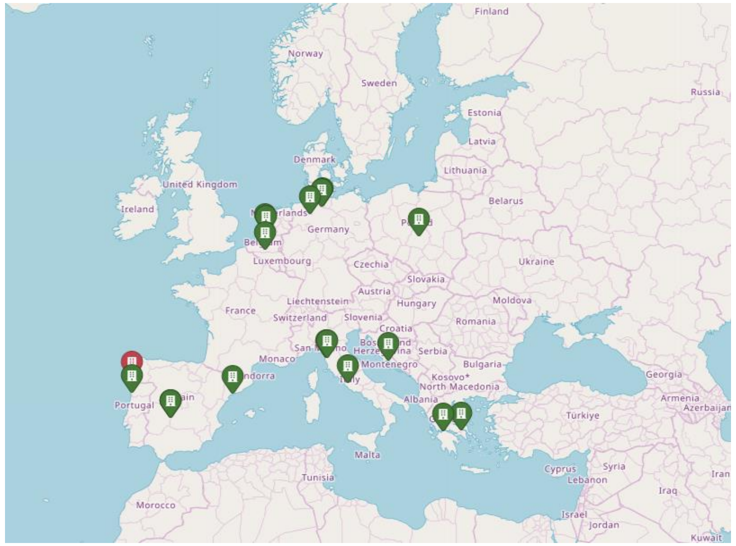

- 18 partners
- 9 countries

Mari4_YARD aims to implement a portfolio of worker-centric solutions, by relying on novel collaborative robotics and abiquitous portable solutions, enabling modular, flexible, reconfigurable and usable solutions targeting the execution of key labor-intensive tasks by preserving industry-specific workers' knowledge, skills and biomechanics health status.

Project Information

Mari4_YARD
Grant agreement ID: 101006798

DOI
10.3030/101006798

EC signature date
6 November 2020

Start date 1 December 2020 — **End date** 30 November 2024

Funded under
SOCIETAL CHALLENGES - Smart, Green And Integrated Transport

Total cost
€ 5 913 440,00

EU contribution
€ 4 998 824,76

Coordinated by
ASOCIACION DE INVESTIGACION METALURGICA DEL NOROESTE
Spain

aimen · BALance · BRODOSPLIT · Netherlands Maritime Technology · nodosa group · Sant'Anna · Canonical Robots · CMT · deepblue · EWF · GIZELIS Robotics · GHENOVA · INESCTEC · IUVO · LMS · TRANSITION · TUHH · WEGEMT

H2020-MG-3-7-2020: Improved Production and Maintenance Processes in Shipyards

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DIDACTIC FACTORIES NETWORK

Open and real-scale demonstrators for workforce training at the EU level to accelerate the adoption of novel methodologies in shipbuilding.

Scope

Network of centres and general-purpose showroom facilities that will remain open to allow for training and skilling-up for given technologies.

Main Objectives

- Provide upskilling and re-skilling of shipyards workforce
- Demonstration of technologies that could be used to advance shipyard processes
- Provide infrastructure for third parties to test new technologies and solutions (technology developers and system integrators)

aimen TECHNOLOGY CENTRE | Sant'Anna Scuola Universitaria Superiore Pisa | INESCTEC | TUHH Technische Universität Hamburg | LMS Laboratory for Manufacturing Systems & Automation

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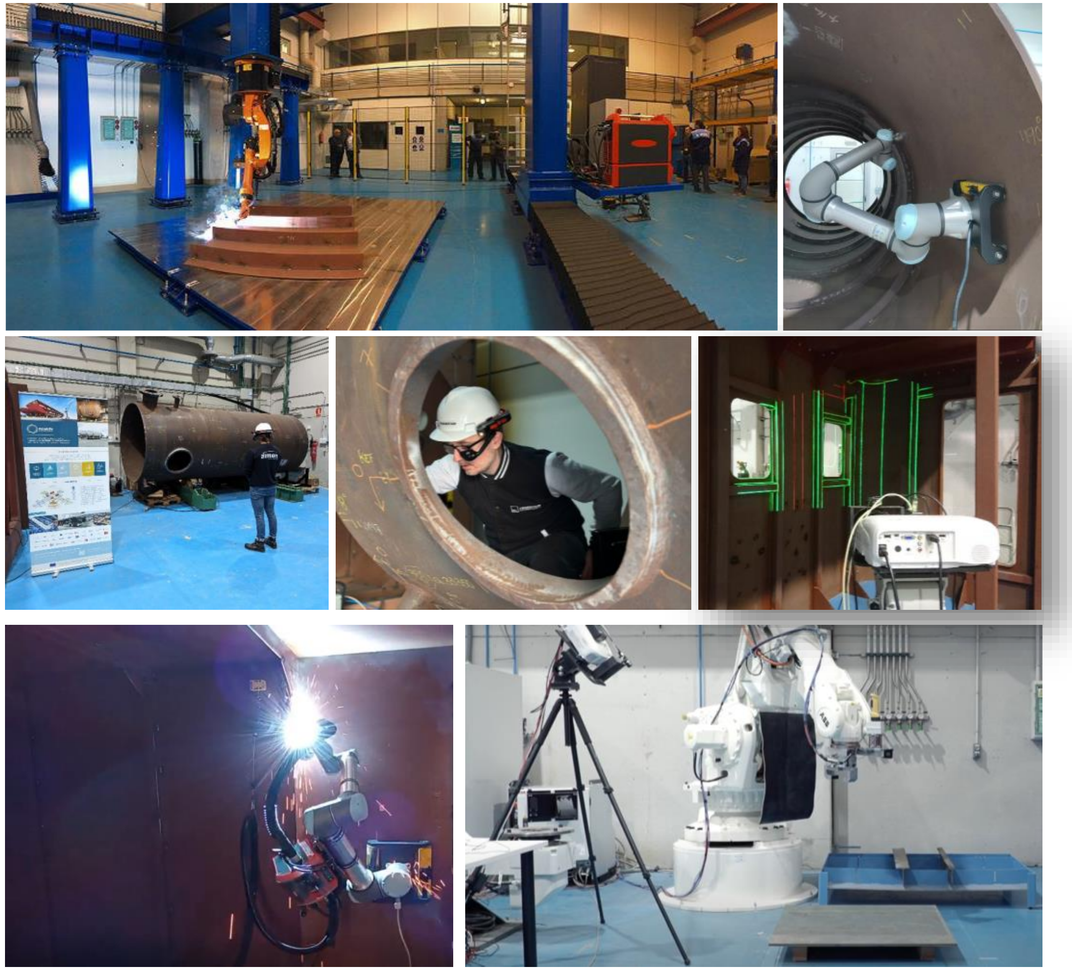
AIMEN DIDACTIC FACTORY

- Training and upskilling capabilities enabling the workforce transition towards Industry 4.0
- A general-purpose testbed for assisting in the industry adoption of digital-centric solutions (INDUSTRY 5.0).

AR/VR TOOLS

ROBOTICS

EXOSKELETONS



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PeneloPe CLOSED-LOOP DIGITAL PIPELINE

RED 5R ROBÓTICA EN FABRICACIÓN

CDTI Centro para el Desarrollo Tecnológico Industrial

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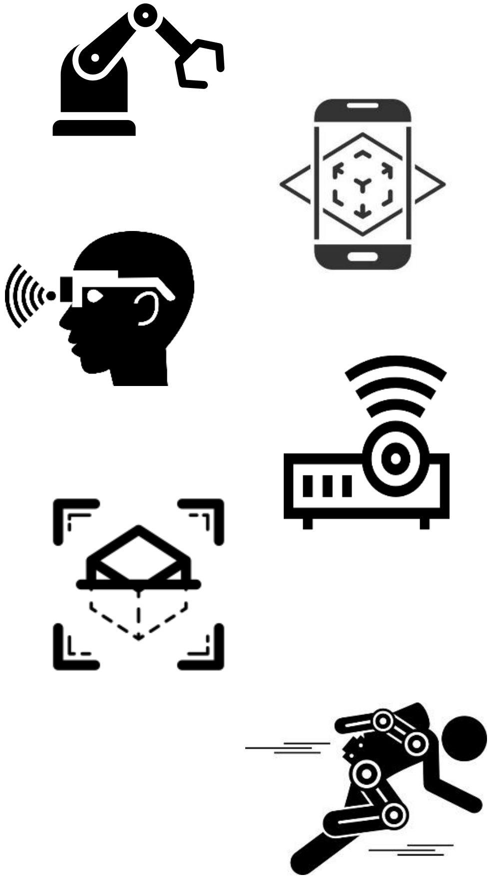
TECHNICAL OBJECTIVES

To implement a portfolio of worker-centric tools (TRL 7)



- High-payload collaborative robots for assisting operators and acting as work-holding devices
- Flexible and mobile manipulators (Easy to deploy)
- Projectors and handheld devices providing instructions to operators in the manufacturing processes
- Head Mounted Displays for training.
- Digitalization and reverse engineering (3D scanning)
- Upper-limb and lumbar exoskeletons

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AGENDA

Hour	Topic
9:00-9:20	Reception & welcome coffee
9:20-9:30	Mari4_YARD Project
9:30-10:30	AIMEN (theoretical part)
10:30- 11:00	Coffee break
11:00-12:00	AIMEN (theoretical -practical part)
12:00-13:30	INESCTEC (theoretical part)
13:30-14:30	Lunch
14:30-15:30	INESCTEC (theoretical &practical part)
15:30- 15:45	Questions & final remarks
15:45-16:00	Visit to AIMEN Didactic Factory

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Thank you for your attention!

Projection based AR for human support in the shipbuilding sector

[Survey link]

Please fill the feedback survey once completed the training

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Thanks!!

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3D Projection with a Pan/Tilt Unit

Alejandro Grajeda & Abel Feijóo

AIMEN

29th of November 2023

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Hour	Topic
9:00-9:20	Reception & welcome coffee
9:20-9:30	Mari4_YARD Project
9:30-10:30	AIMEN (theoretical part)
10:30-11:00	Coffee break
11:00-12:00	AIMEN (practical part)
12:00-13:30	INESCTEC (theoretical part)
13:30-14:30	Lunch
14:30-15:30	INESCTEC (theoretical & practical part)
15:30-15:45	Questions & final remarks
15:45-16:00	Visit to AIMEN facilities

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Presentation

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Background

What are your expectations?

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Index

- Introduction to PTU
- Mechanical evolution
- Electronics and control
- Specifications
- Applications
- Point Cloud Capture
- Point Cloud Stitching

- Localization
- Projection
- GUI
- Questions
- Quiz
- Video

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- Introduction to PTU

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- Introduction to PTU

- PTU (Pan Tilt Unit)
  - What is it?

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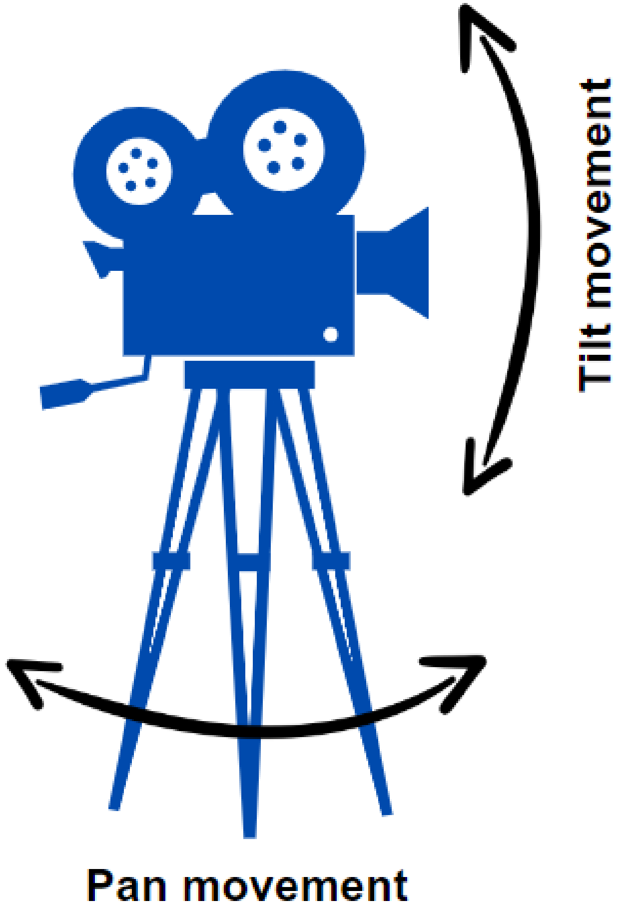
- Introduction to PTU

- PTU (Pan Tilt Unit)
    - What is it?



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- Introduction to PTU

- PTU (Pan Tilt Unit)
  - Advantages:
    - More FOV
    - Reduce economical costs

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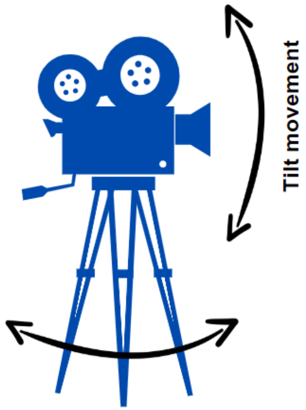
- Introduction to PTU

- PTU (Pan Tilt Unit)
  - Payload?



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- Mechanical evolution

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• Mechanical evolution. First version

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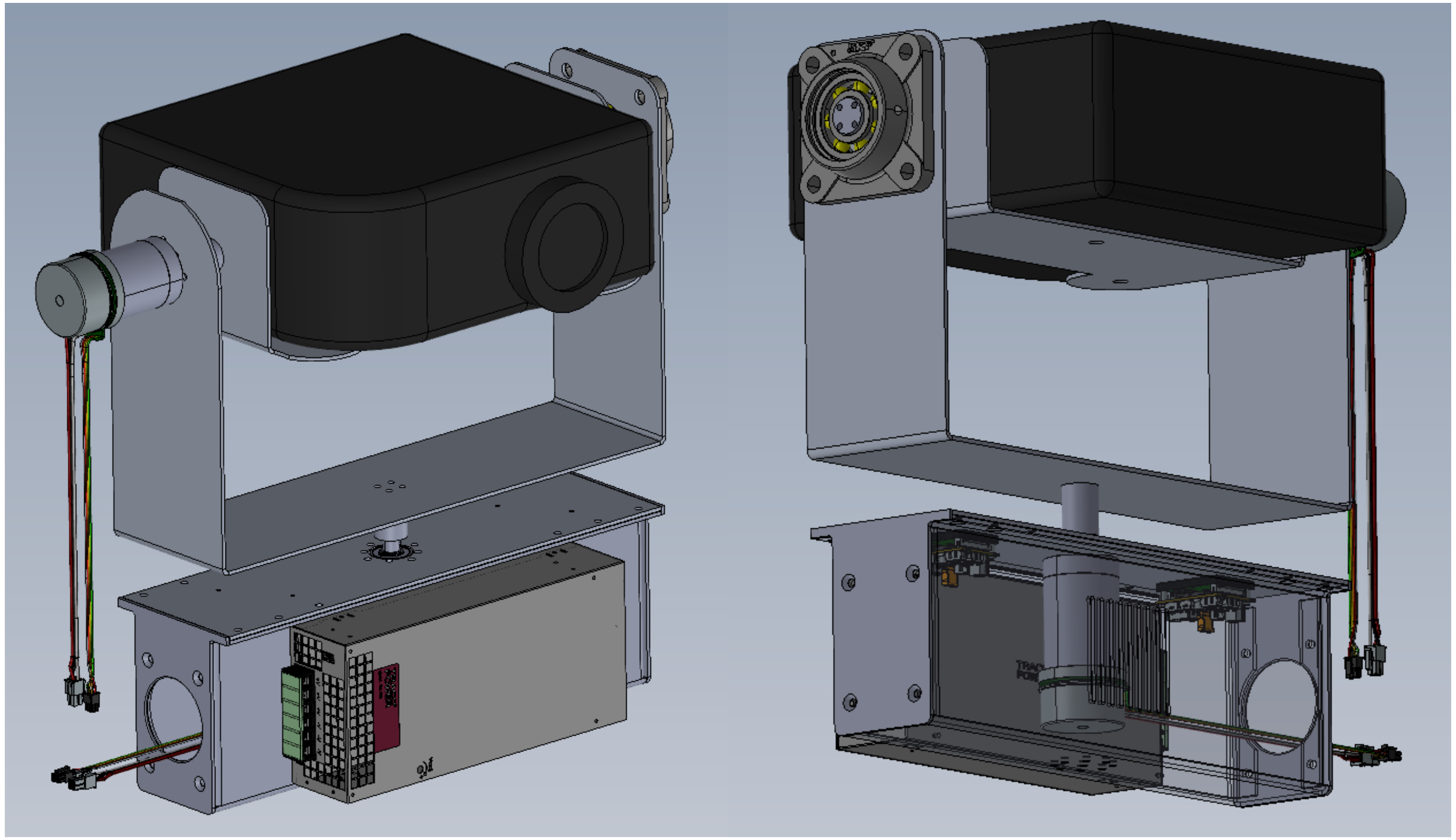
- High speed and robust configuration
- Payload: Projector
- Motor controllers in lower link



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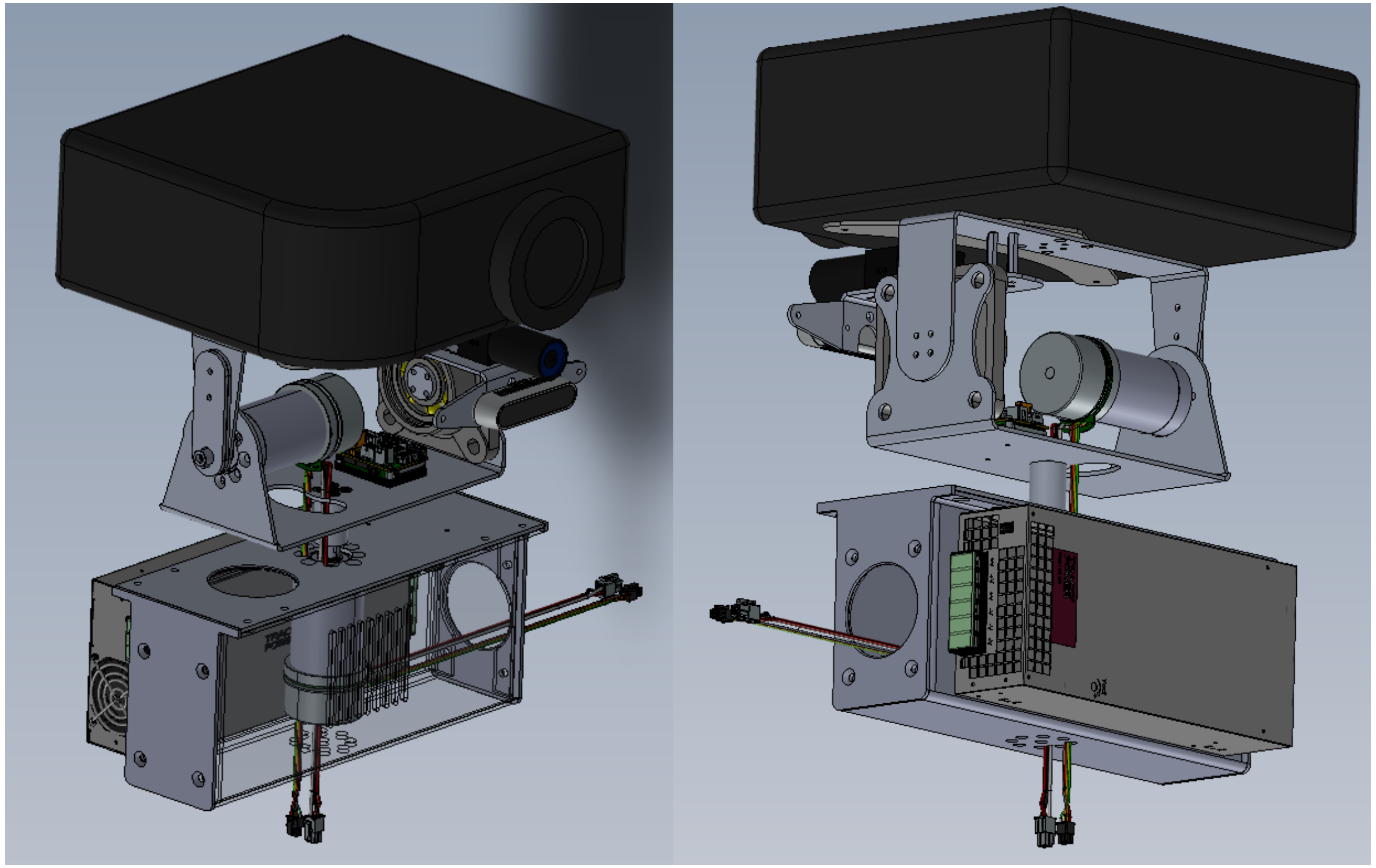
• Mechanical evolution. Second version

Changes:

- More compact configuration
- Universal fixture for cameras
- Motor controllers in both links



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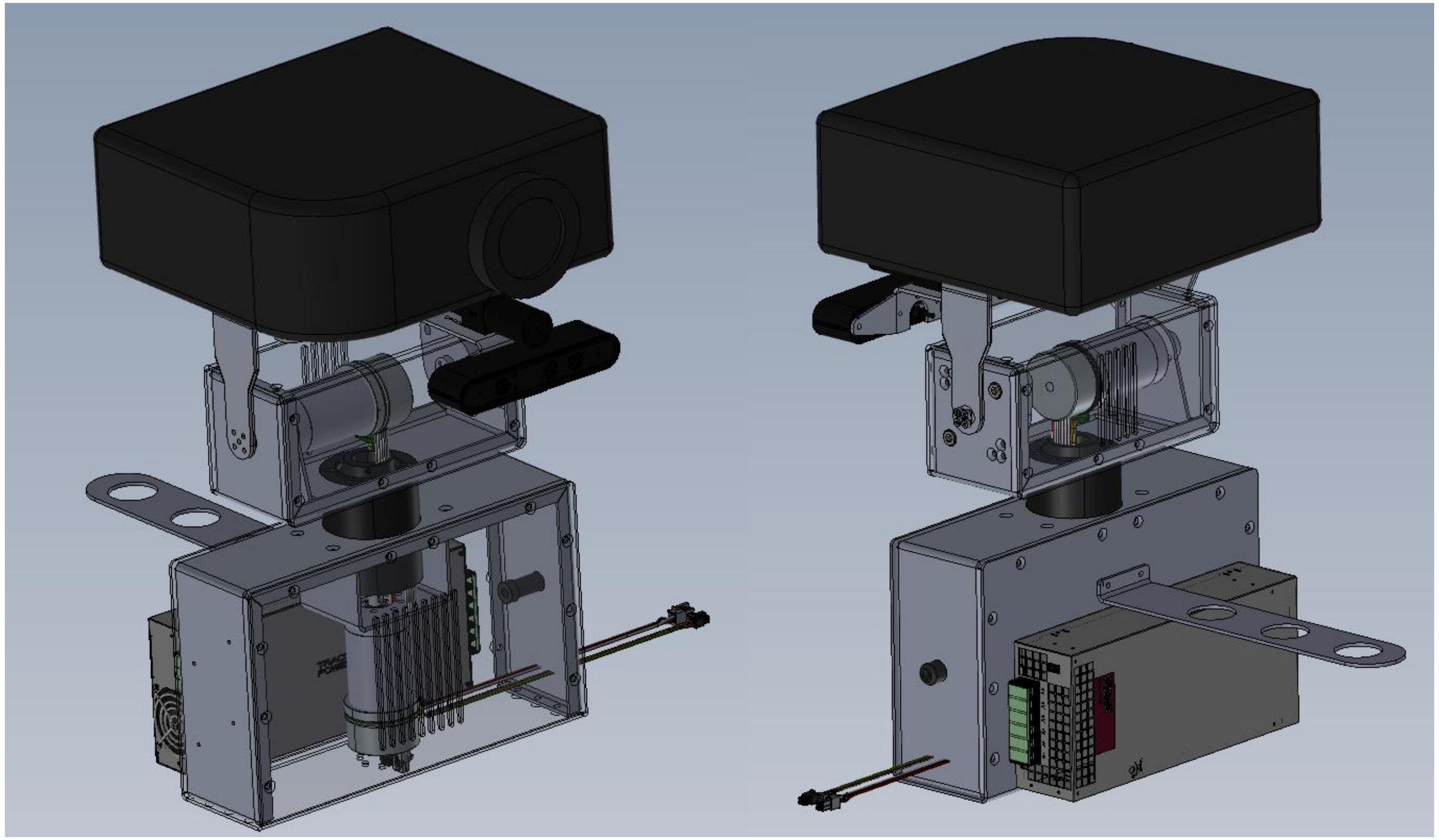
• Mechanical evolution. Third version

Changes:

- Compact and close configuration
- Payload: different cameras
- Motor controllers in lower link
- Slip ring between links



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• Mechanical evolution. Fourth version

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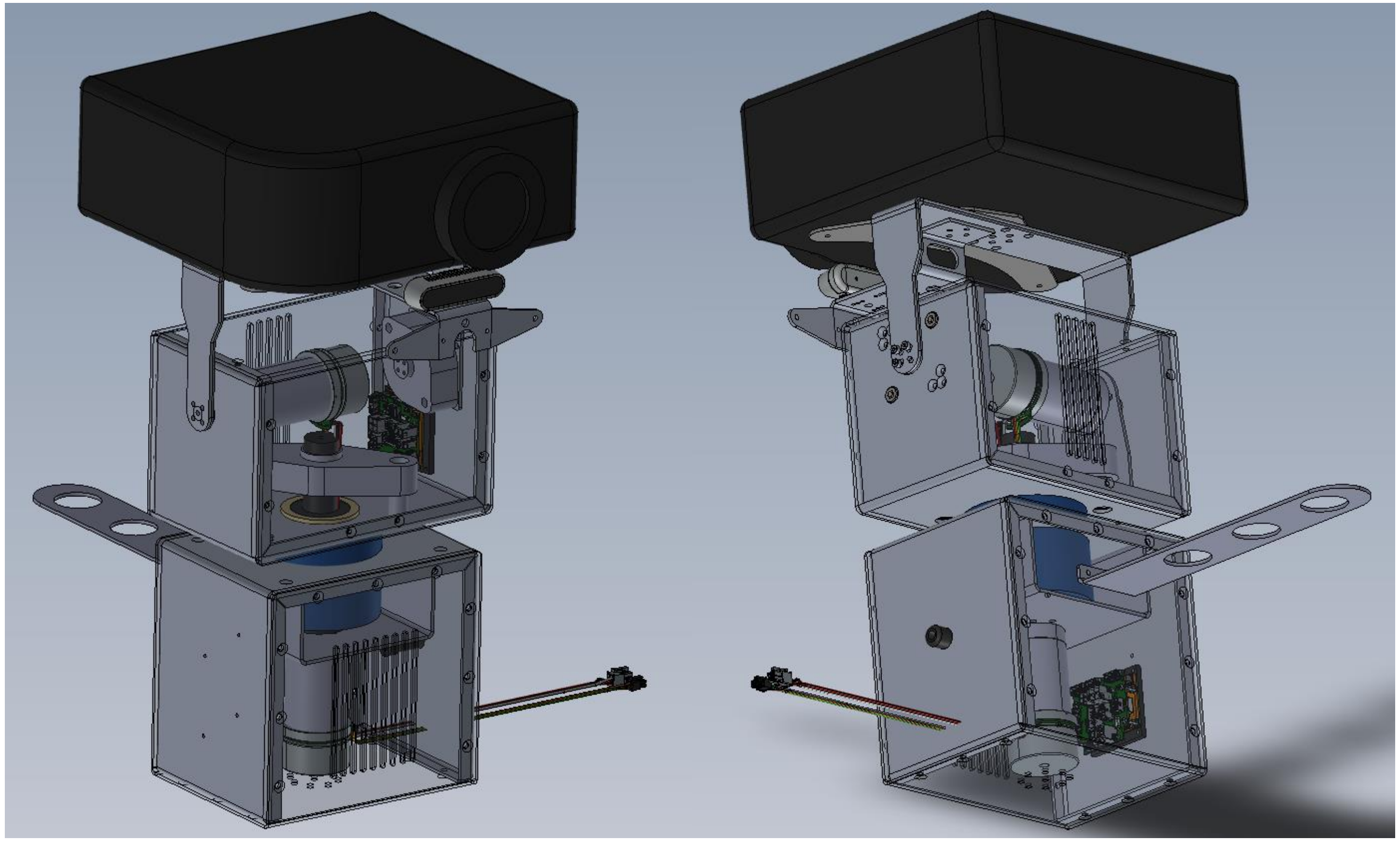
Changes

- Payload: different cameras
- Motor controllers in both links
- Slip ring between links
- More robust axis with bearing



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• Mechanical evolution. Fifth version

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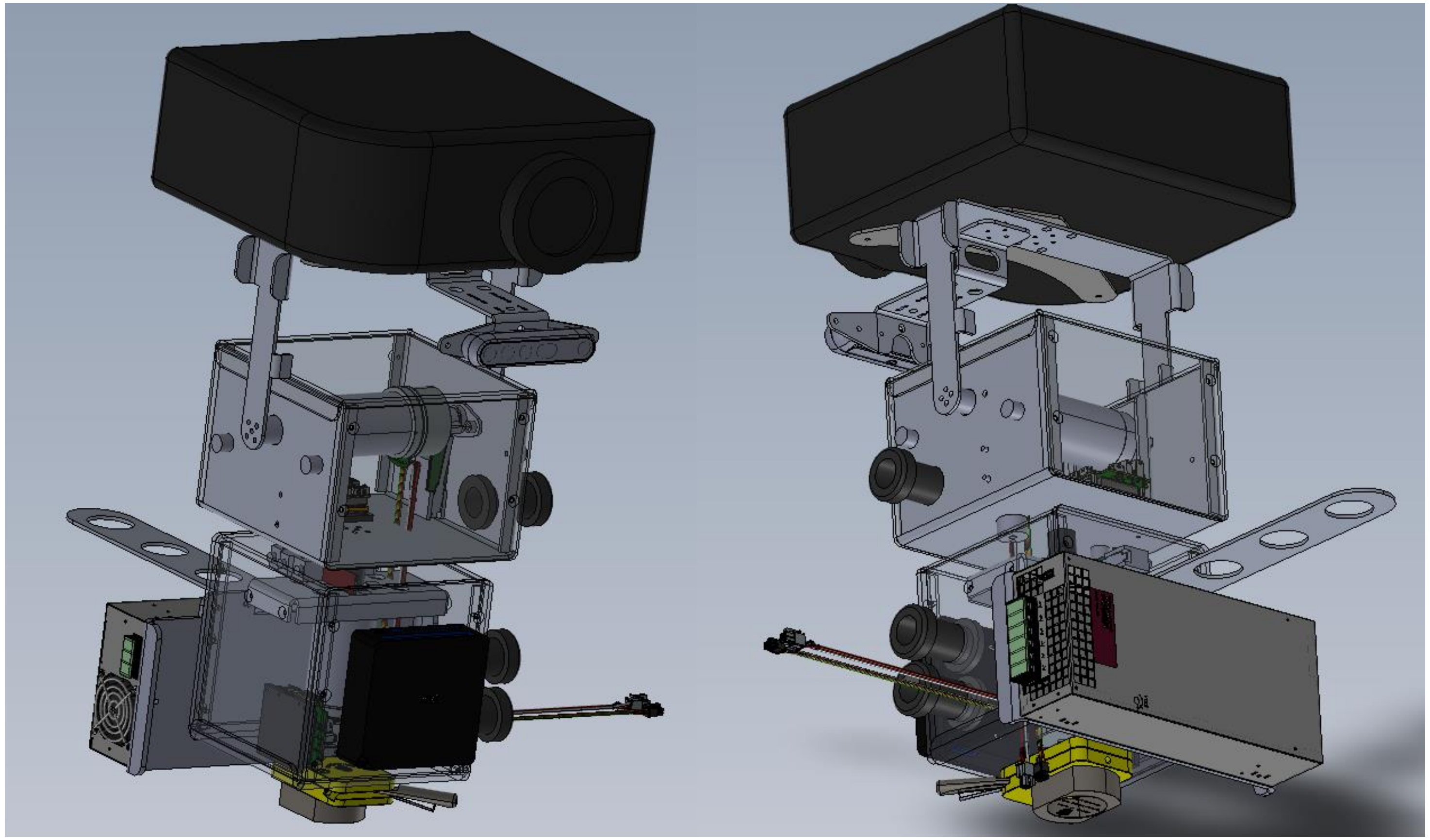
Changes

- Compact, close and balanced configuration
- Payload: different cameras
- Motor controllers in both links
- Magnet hook and pc support
- Cable glands, limit switches and rubber stops



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• Mechanical evolution. Final version

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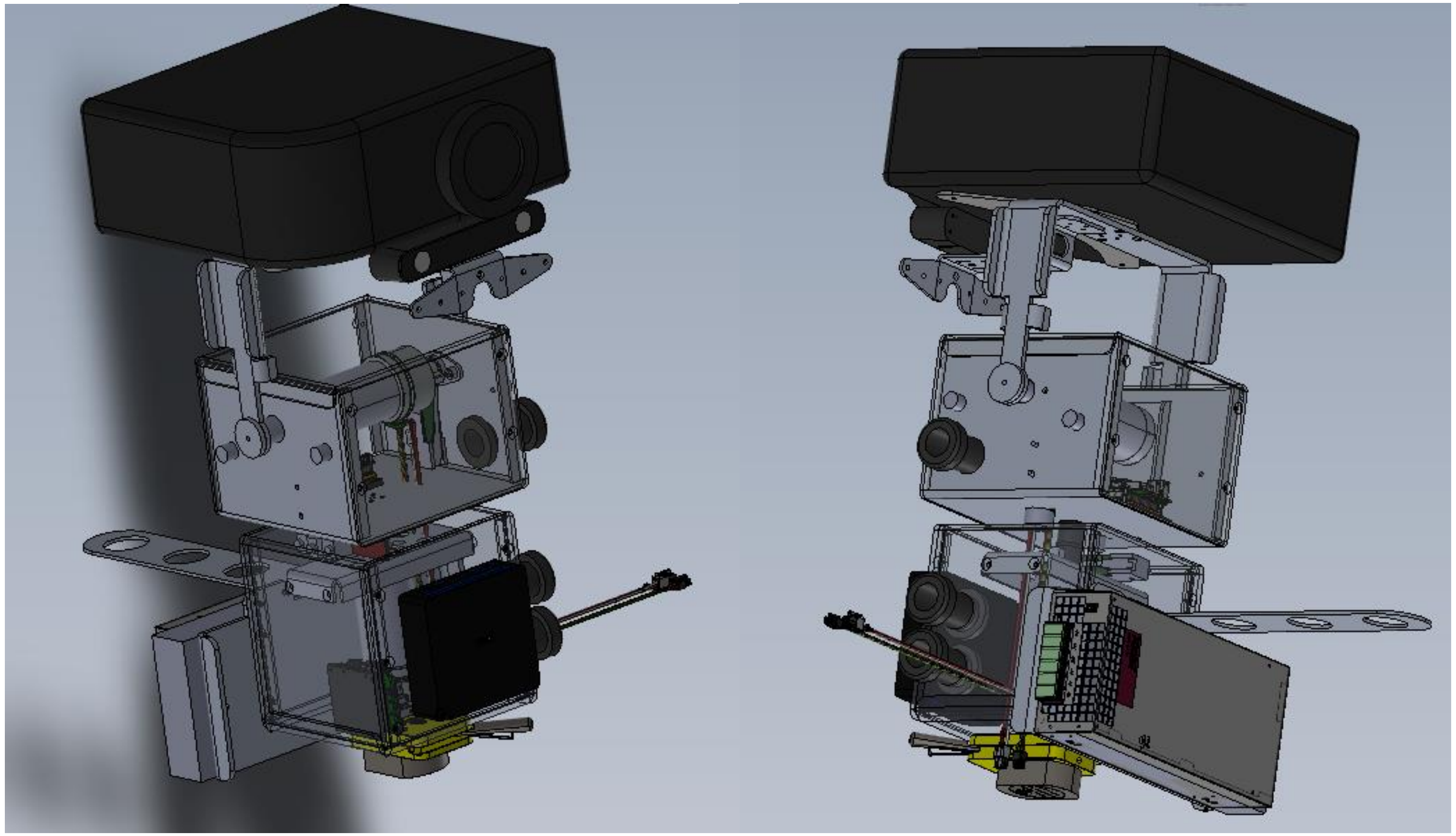
Changes:

- Compact, close and simetric configuration
- Payload: different cameras
- Motor controllers in both links
- Payload headband more robust



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- Electronics and control

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• Electronics and control

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- 2x Motors: EC60 brushless with gearbox and encoder
- 2x Motor controllers: EPOS4 Maxon
- 3x Limit switches

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- Electronics and control

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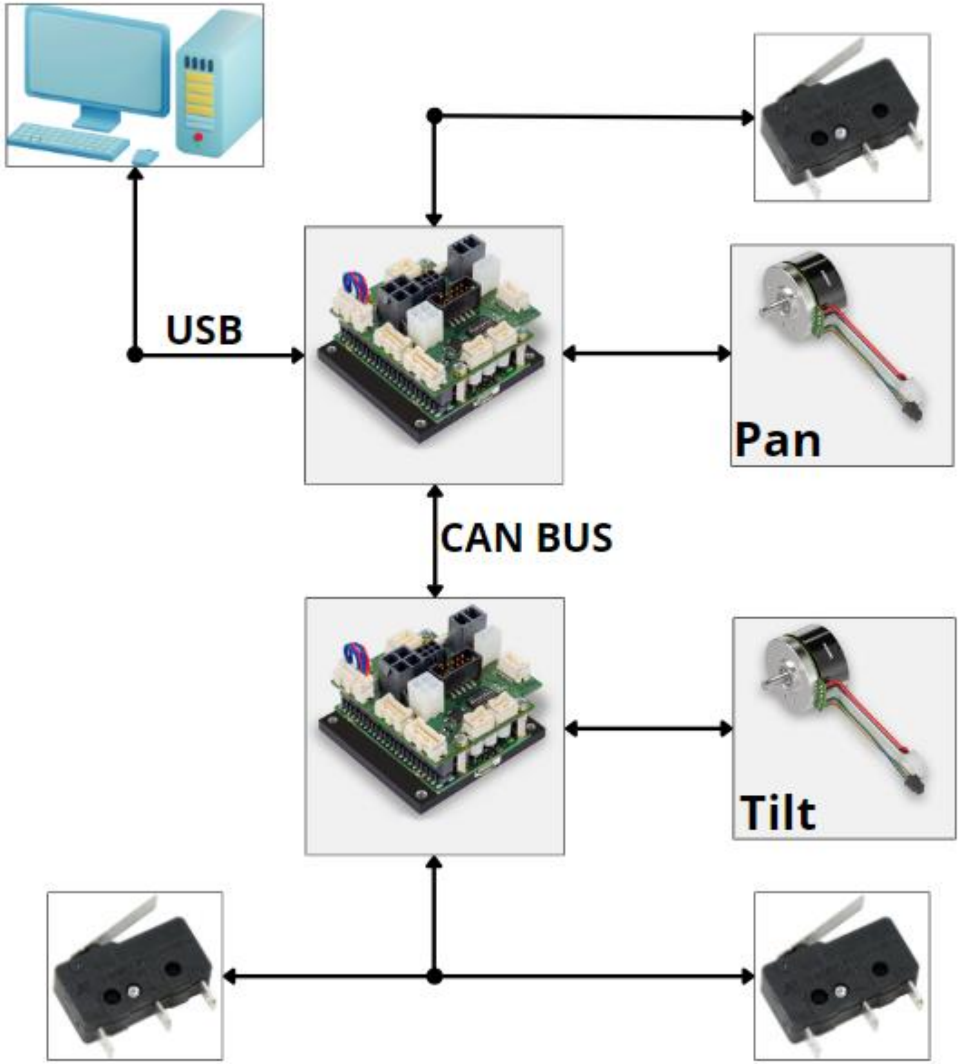

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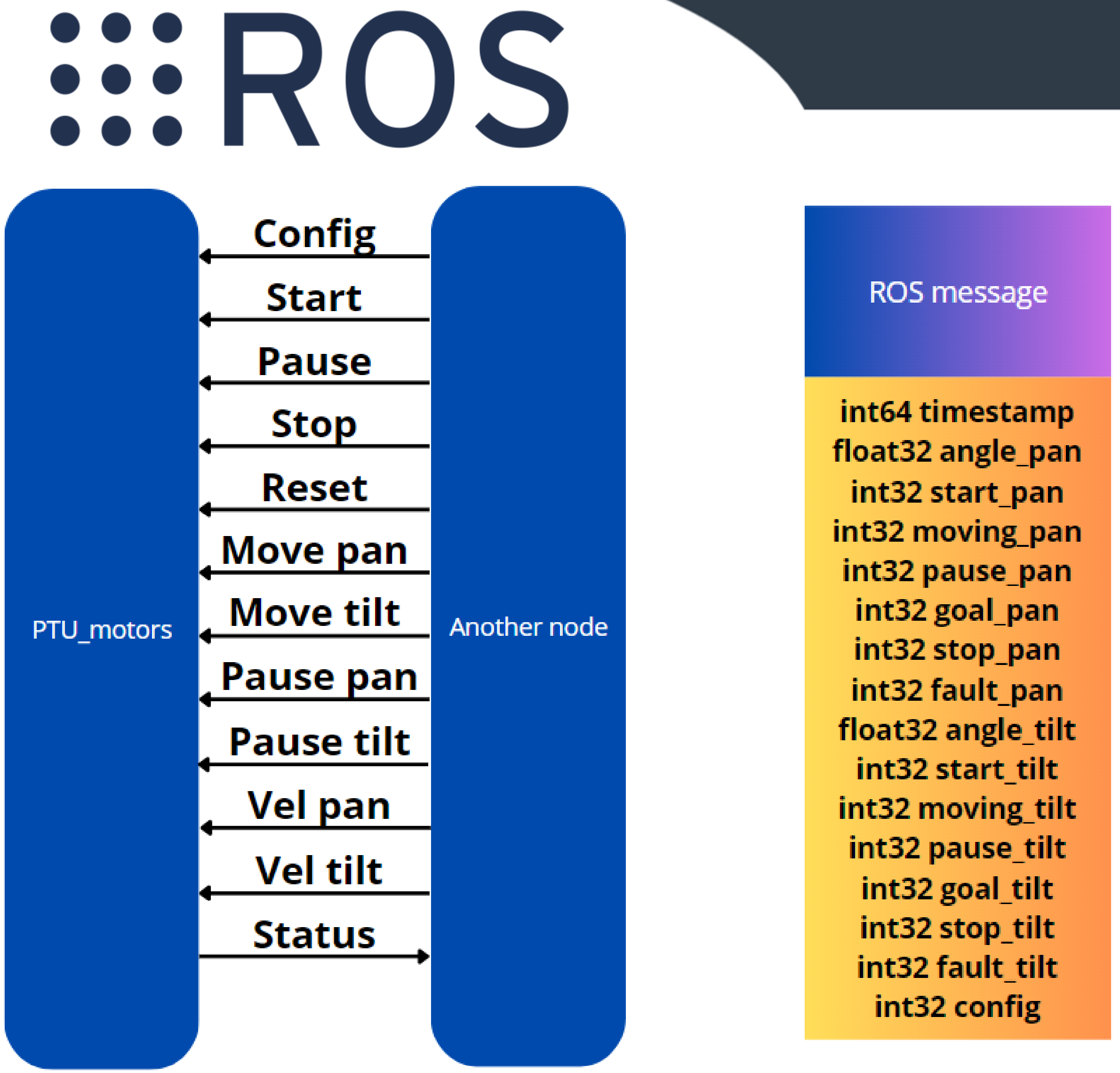

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• Electronics and control

LIBRARY

```
#include "maxon_motor_controllers/Definitions.h"
```

MOTORS

```
VCS_ActivateProfileVelocityMode(p_DeviceHandle, p_usNodeId, &p_rlErrorCode);

VCS_MoveWithVelocity(p_DeviceHandle, p_usNodeId, velocity, &p_rlErrorCode);

VCS_GetPositionIs(p_DeviceHandle, p_usNodeId, &currentPosition_pan, &p_rlErrorCode)
```

Speed PID Control

LIMIT SWITCH

```
VCS_GetAllDigitalInputs(p_DeviceHandle, p_usNodeId, &switchs, &p_rlErrorCode);
```

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- Specifications

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• Specifications

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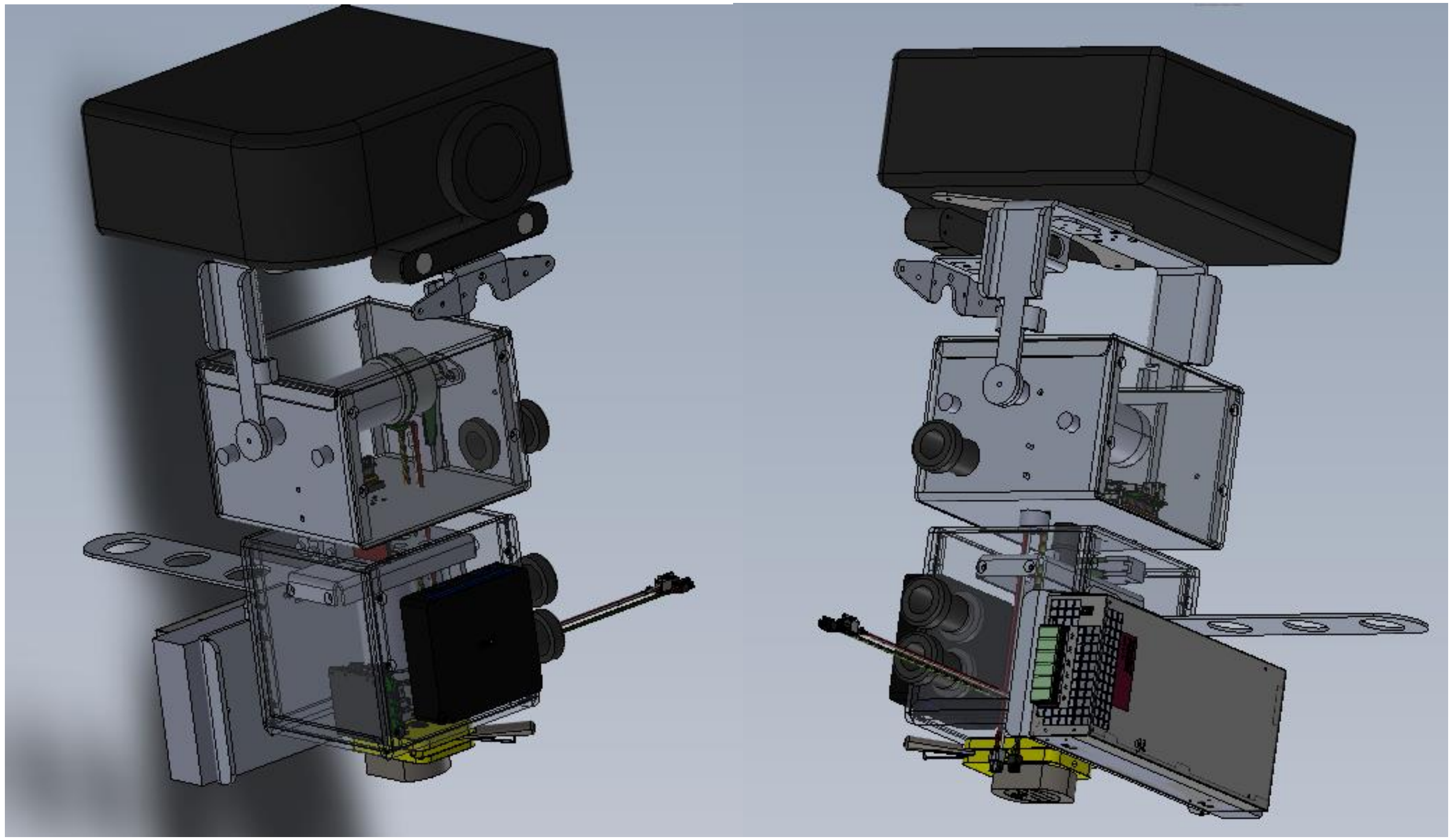
- Range of movements: (Pan: 0-306° Tilt: ±66.5°)
- Maximum speed: (Pan: 45°/s Tilt: 22.5°/s)
- Accuracy: 1°
- Payload: EPSON EH-TW5400 and Zed2i (1280x720 at 60 fps)
- Maximum Payload: 9,5kg
- Voltage supply: DC12V
- Weight: 10,4kg
- Dimmensions: 222Dx272Wx460H
- COMMS: USB, HDMI, USB-CAN



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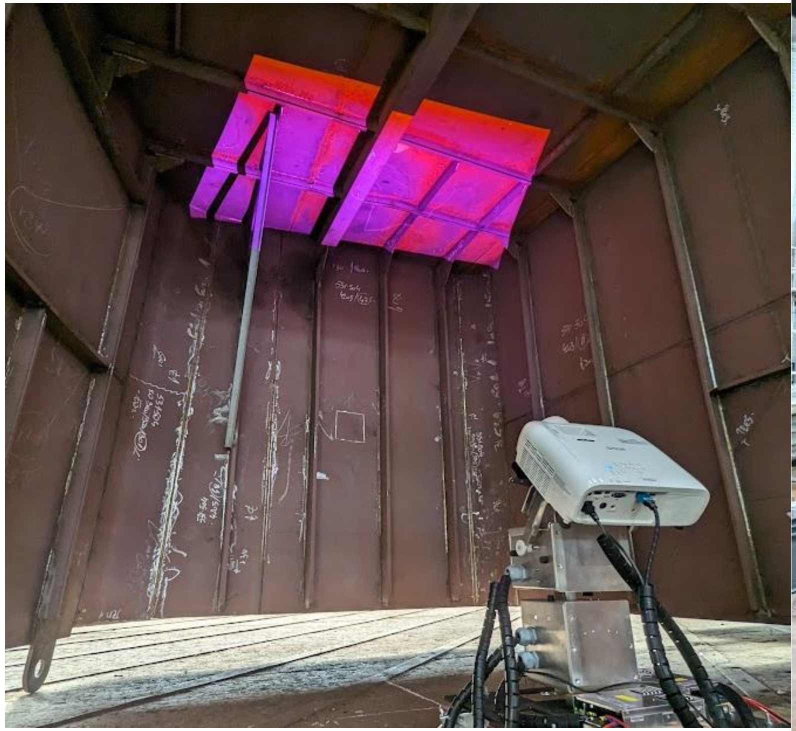

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- Applications. Scan and project in ship sctrutures

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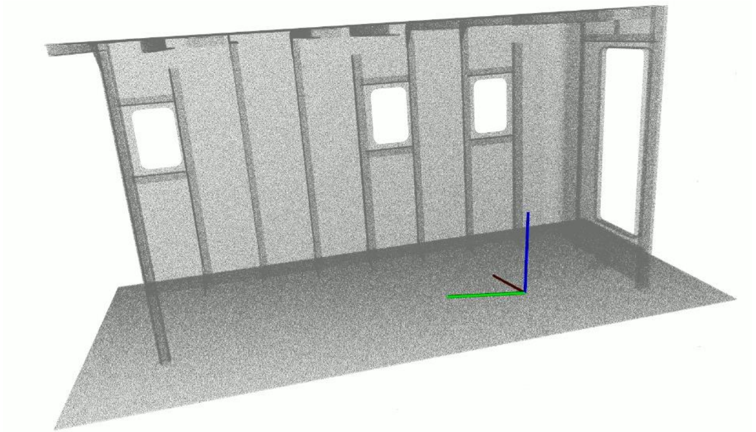
Real ship structure



Pointcloud

Projection on structure

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• Other applications

• **Identification of structural failures in damaged buildings.**

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- Other applications

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- **Projection of pipes and cables in a home.**

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• Other applications

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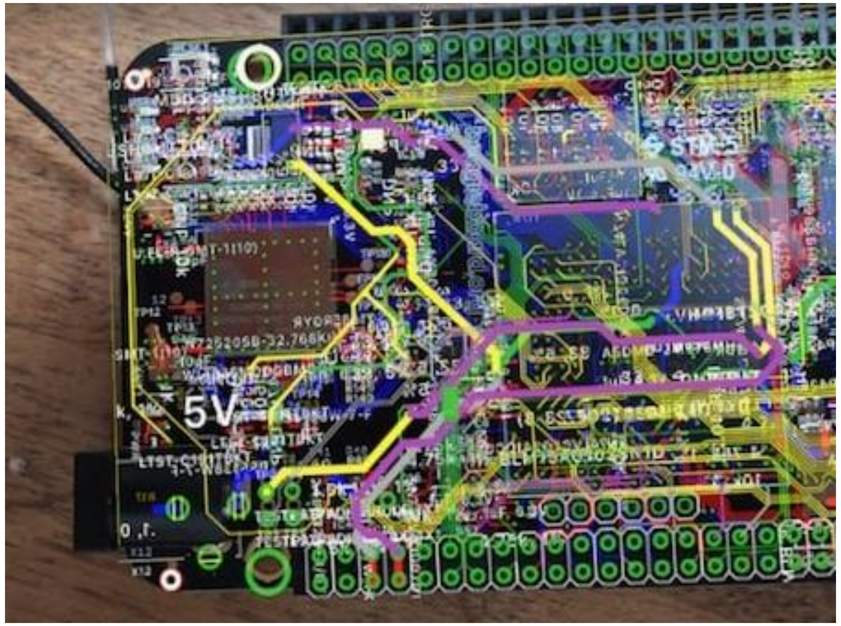
- **Inspection of tiny components.**



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- Point Cloud Capture

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• Point Cloud Capture with **Zed2i Camera**

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- Neural Depth Sensing.
- Built-in Next-Gen IMU, Gyroscope, Barometer & Magnetometer
- 120° Wide-Angle Field Of View
- Aluminium Frame with Thermal Control
- IP66 protection from water and dust
- Secure USB Type-C connection (1.5m locking cable included)

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- Zed2i ROS Wrapper

- Camera Information.
- Raw Image. (Left & Right)
- Rectified Image. (Left & Right)
- Registered Depth Map.
- Registered Point Cloud. (RGB)
- Camera Pose.

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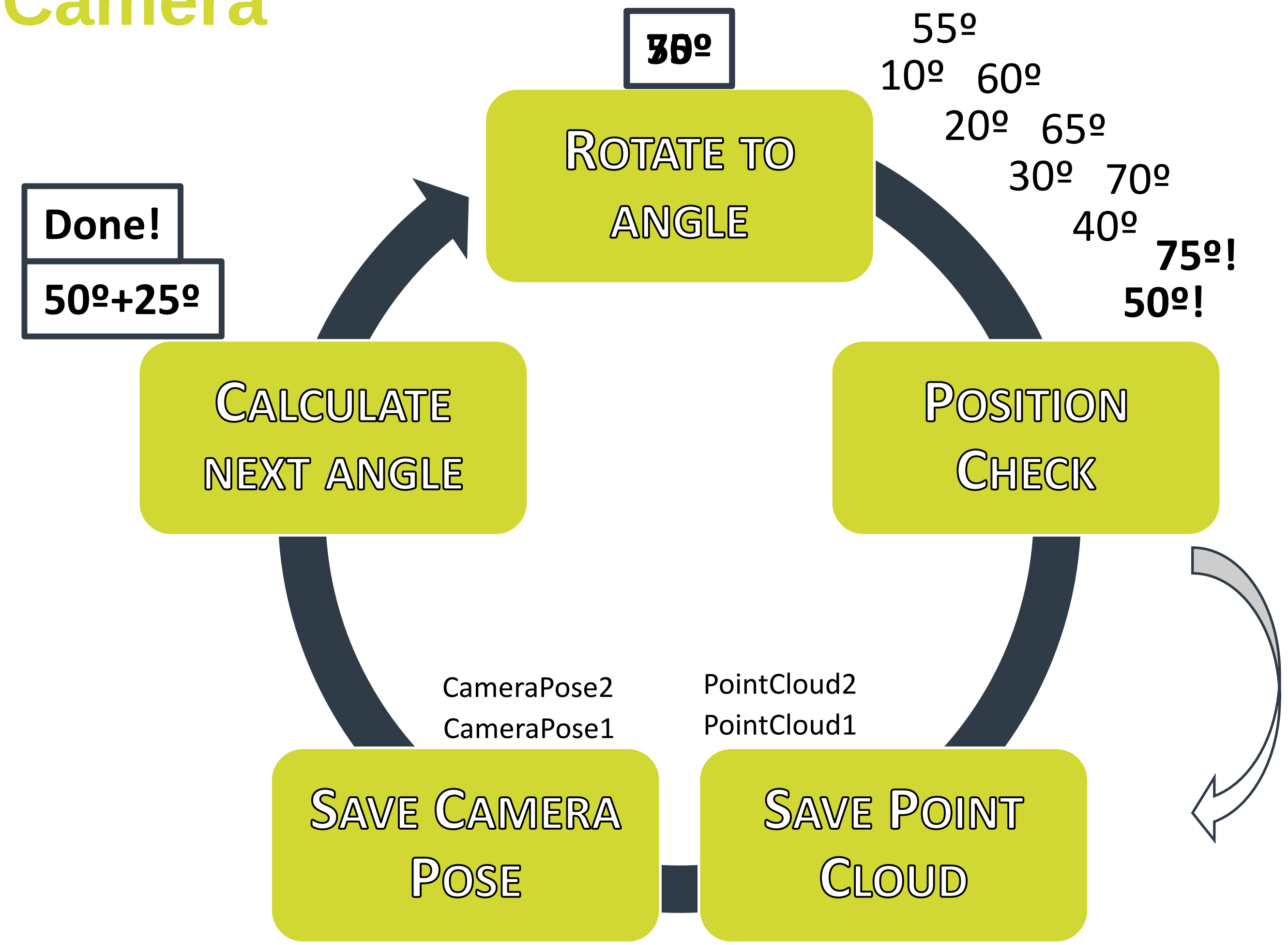
- Point Cloud Capture with **Zed2i Camera**

Inputs

- Start Angle → **50º**
- End Angle → **75º**
- Number of Steps → **2**

Outputs

- List of Point Clouds → **PointCloud1, PointCloud2**
- List of Camera Poses → **CameraPose1, CameraPose2**



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- Point Cloud Capture with **Zed2i Camera**

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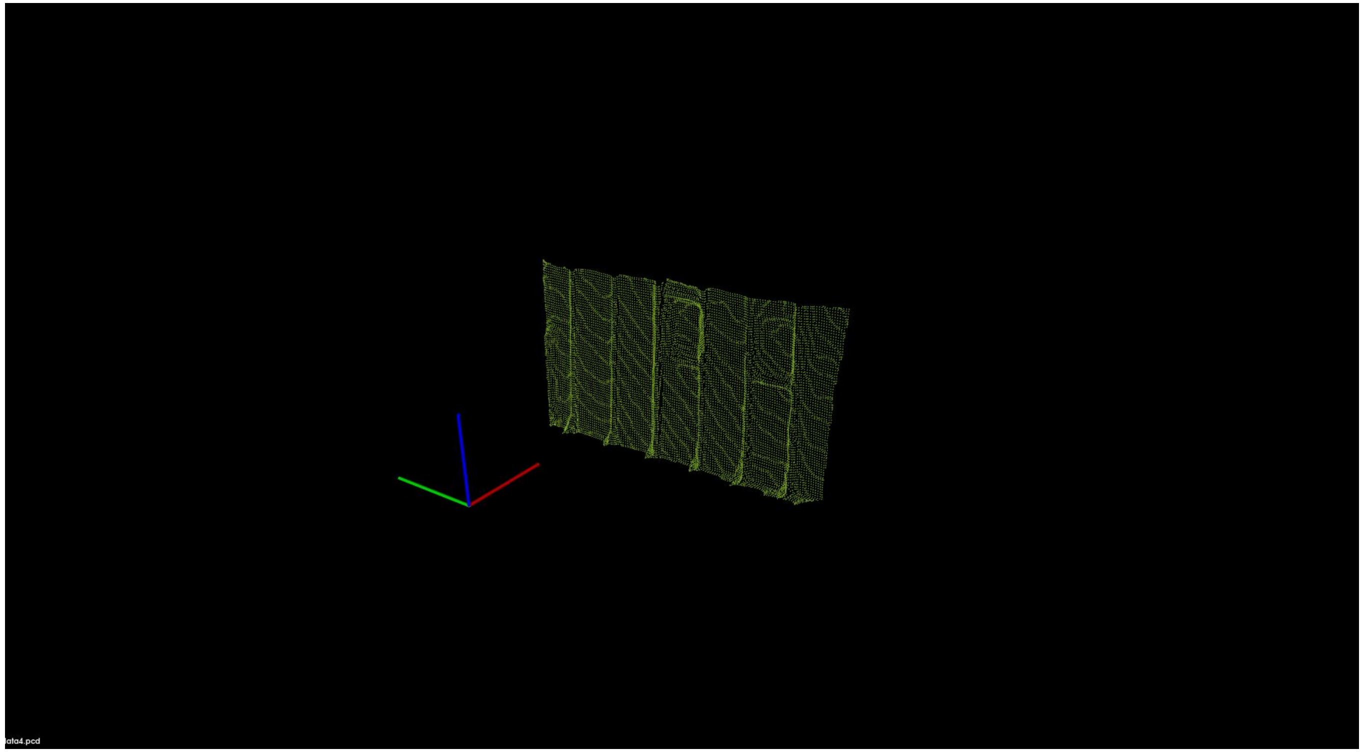

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• Point Cloud **Stitching**

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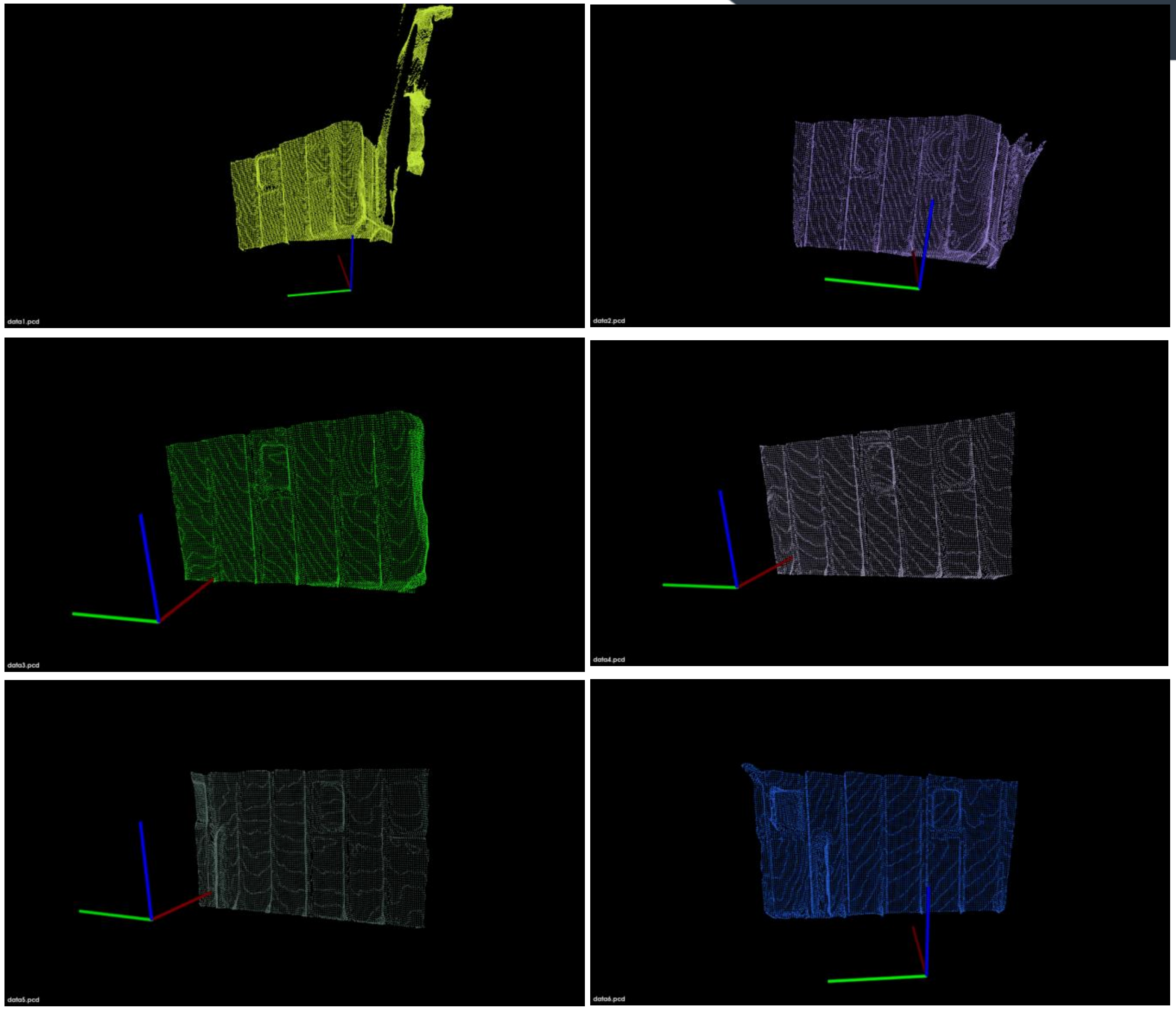
Goal:

- To generate one coherent point cloud with the captured data.

Process:

- Focus on first point cloud.
- Move it towards the next point cloud.
- Optimization algorithm (ICP).
- Repeat for all captured point clouds.



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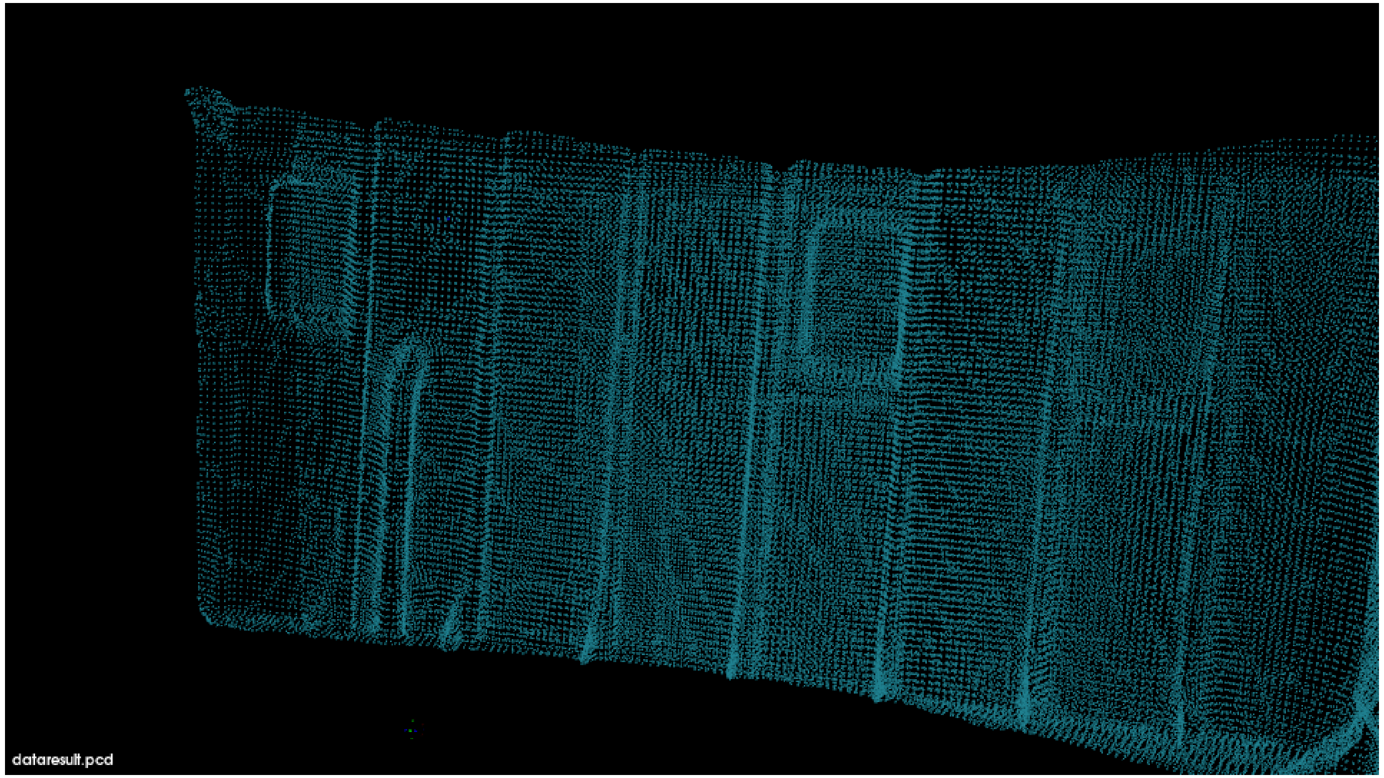

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• Point Cloud **Stitching**

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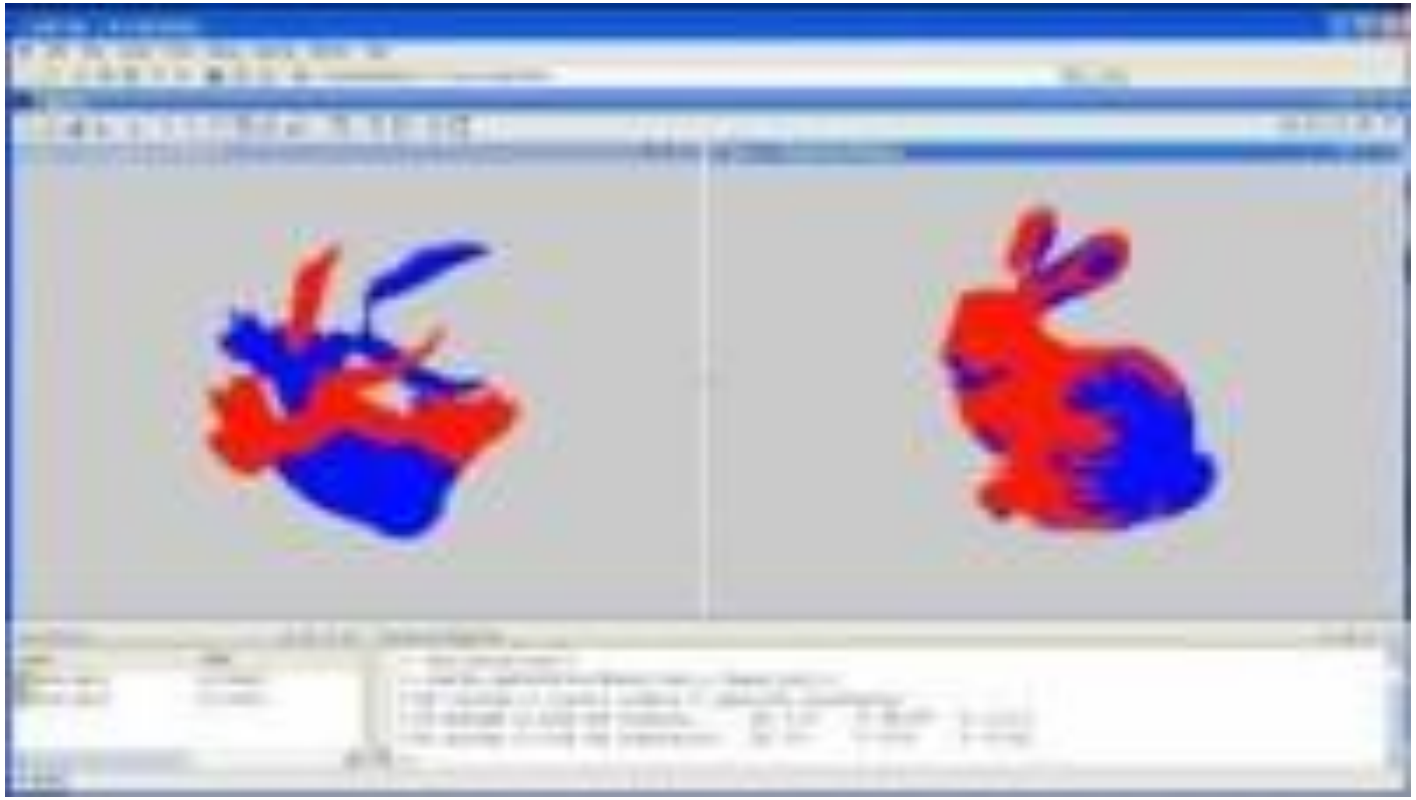
- Feature Identification.
- Point cloud matches the real object.
- Good localization in the CAD model.



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• Localization

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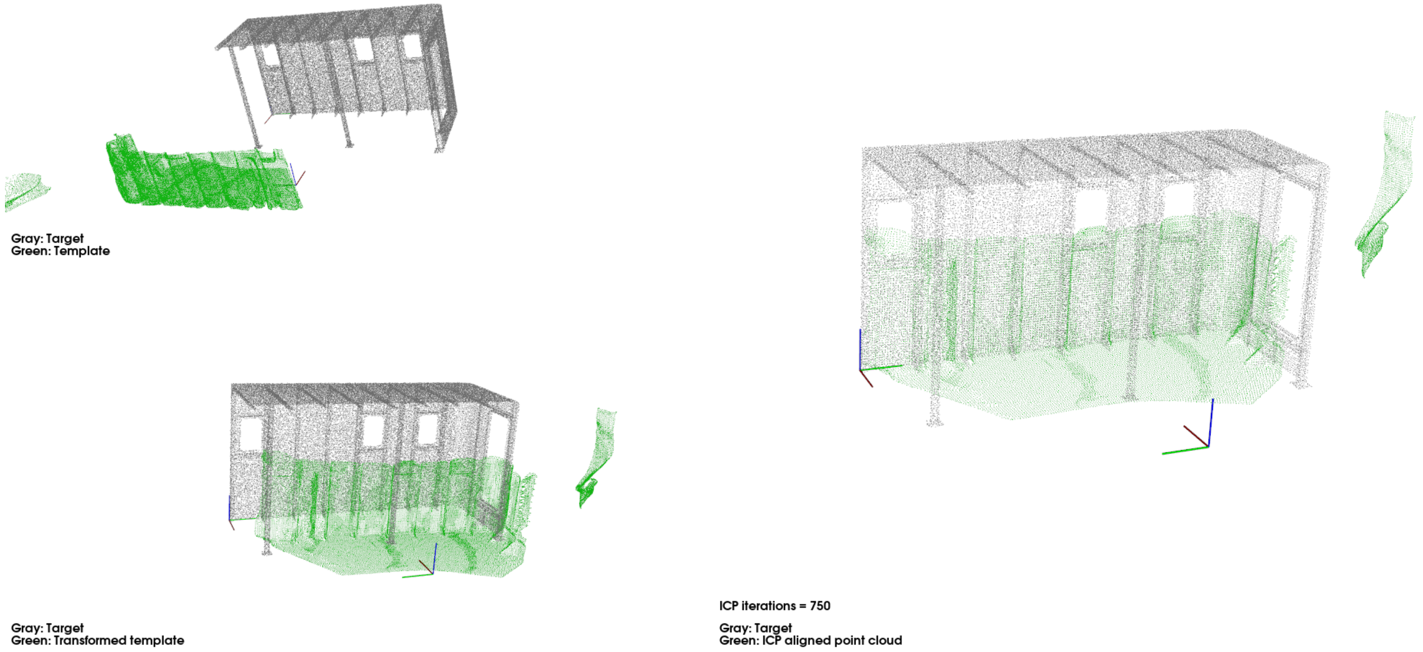
Inputs

- Stitched Point Cloud
- CAD Model
- Initial Projection Pose (Guess)

Outputs

- Refined Projection Pose



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- Projection

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Inputs

- Refined Projection Pose
- 3D Coordinates of features

Outputs

- 2D Projection of Features.

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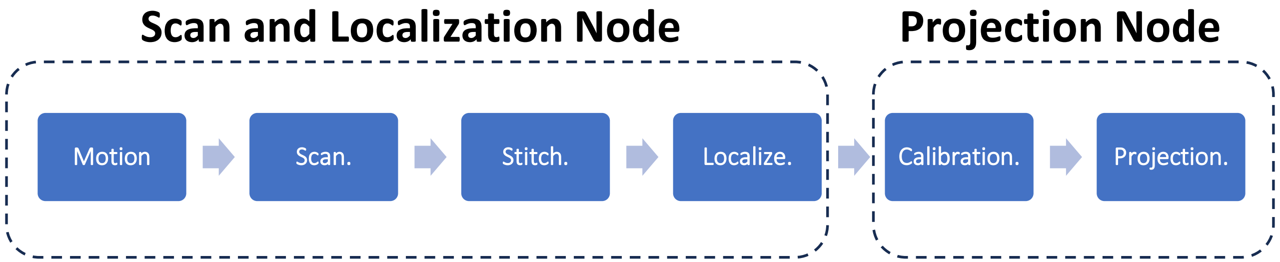
- ROS Layout



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- Graphical User Interface

Main Window

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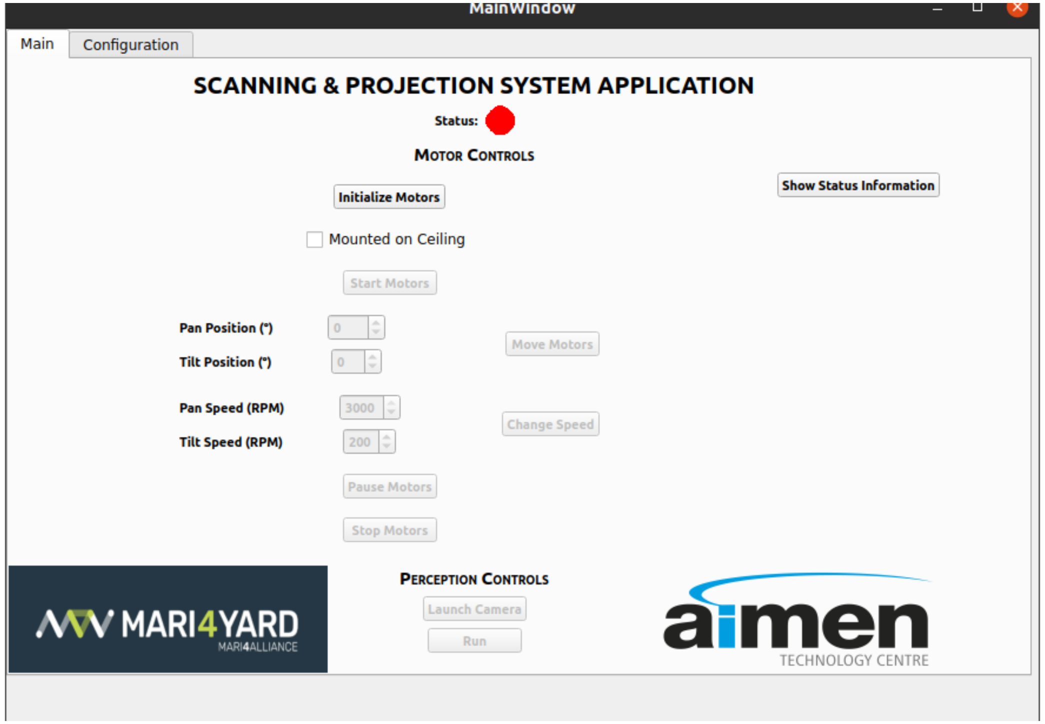
Functionalities:

- Initialize and check motors.
- Move motors.
- Change motors speed.
- Launch camera.
- Run application.



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• Graphical User Interface

Main Window

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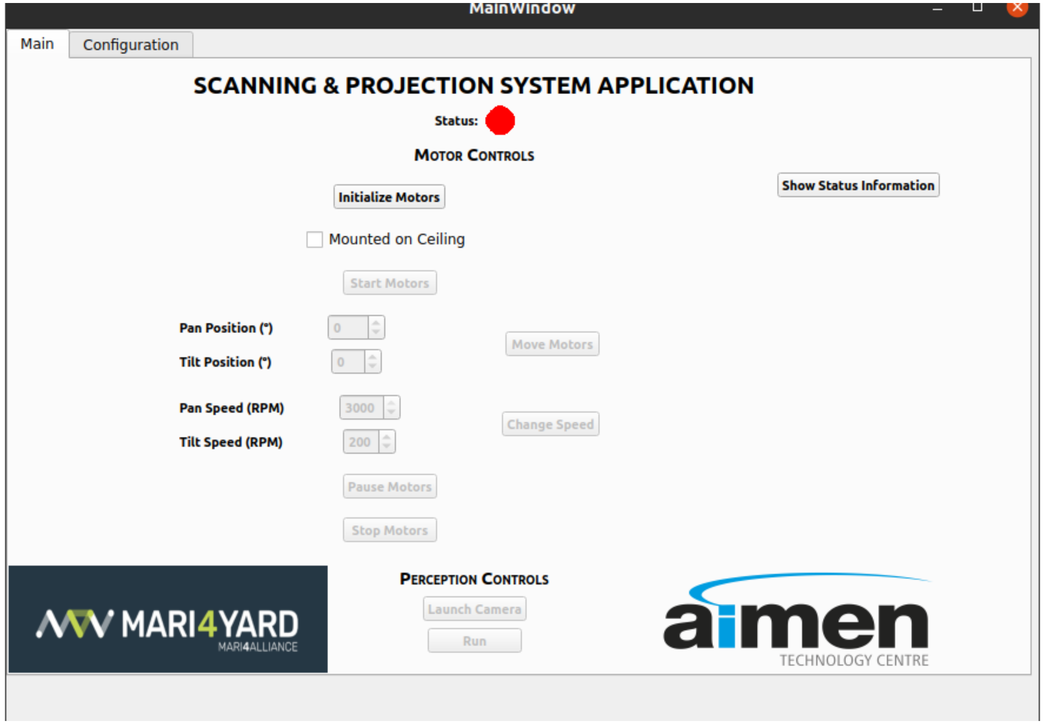
Background:

- Initializes ROS communications.
- Publishes and reads messages.
- Starts and stops ROS nodes.



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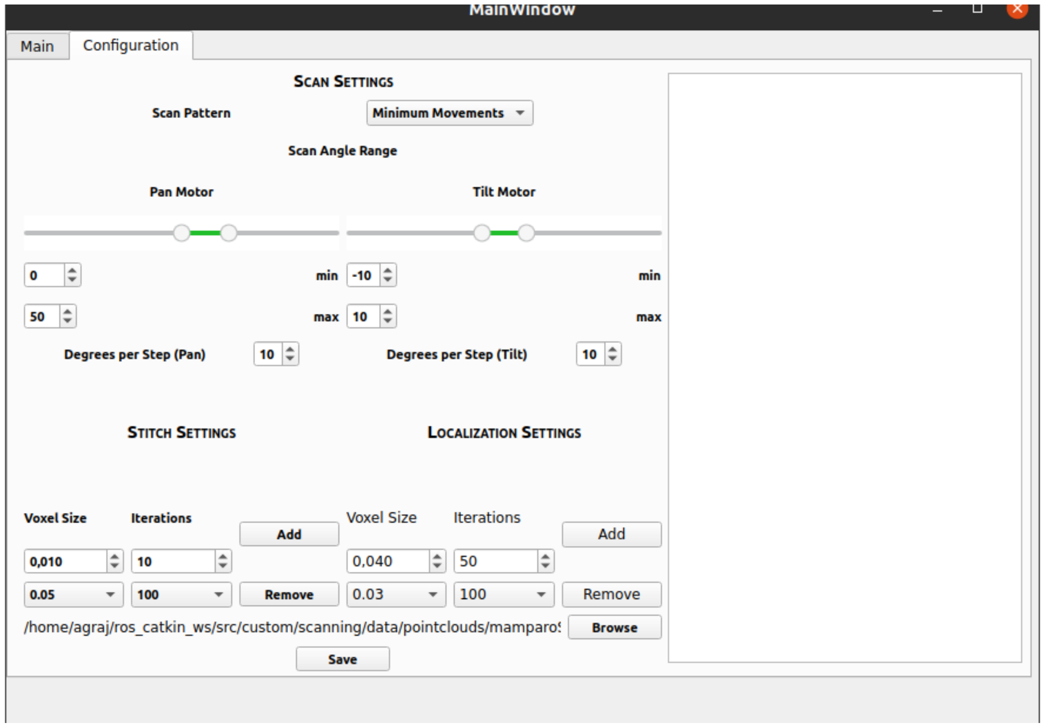
• Graphical User Interface

Configuration Window



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Functionalities:

- Change scan range. (Pan and Tilt)
- Define angles per step.
- Change stitch settings.
- Change localization settings.
- Select CAD to localize in.
- Save settings.

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Questions?

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COFFEE BREAK

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3D Projection with a Pan/Tilt Unit

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Thank you for your attention!

Alejandro Grajeda & Abel Feijóo

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LUNCH BREAK

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Spatial augmented reality for human support in shipyards

Carlos M. Costa
Robotics researcher
INESC TEC

AIMEN – June 13, 2024

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798

Context

1. Production of ships currently requires the operator to interpret CAD drawings and assembly documentation for knowing how and where to perform operations such as:
   i. Laying out the ship foundations and support structures.
   ii. Perform cutting and welding operations.
   iii. Assemble components, such as pipes, stiffeners, brackets, cable trays, among many others.
2. The interpretation of the drawings and documentation may lead to mistakes and the operator may perform an inaccurate measurement of the place of cutting, welding or assembly.
3. As such, augmented reality systems can help the operator work faster and with higher accuracy by projecting in the environment the spatial information required to perform the cutting, welding and assembly operations.

Examples of ship bulkheads.

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Overview of projection mapping system functionalities for shipbuilding

- Projects on the environment the cutting information that was extracted from CAD model for improving the productivity of the operator.
- Uses 3D perception to estimate the 6 DoF pose of the projector in relation to the target object in the environment.
- Avoids the usage of measuring tapes and printed drawings by the operator resulting in a reduction of operator marking time of around 70%.
- Human operator has both hands free to perform his tasks while he is observing the projected information to know where to cut the ship sections.

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Projection mapping for cut openings in silos

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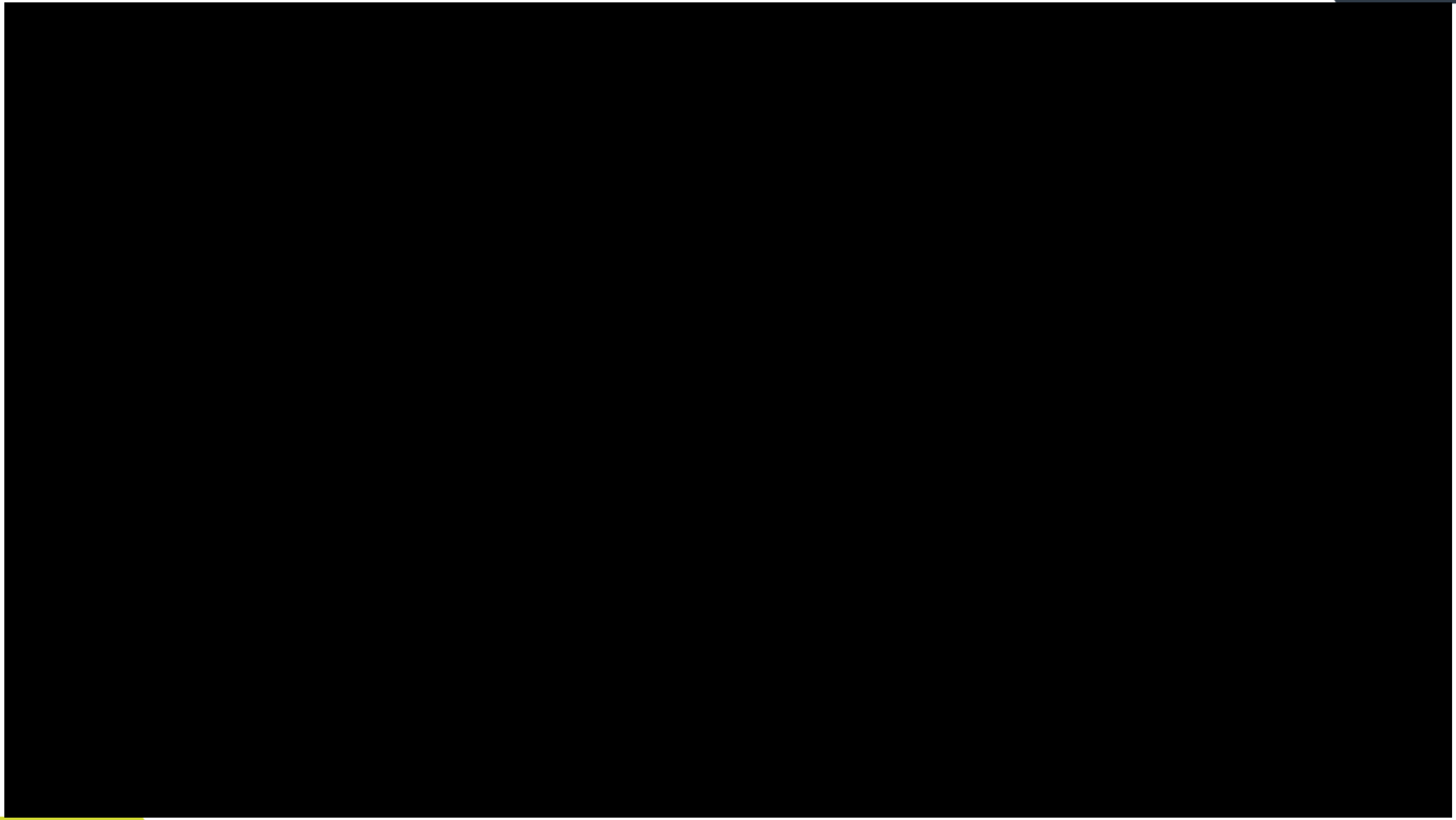
Projection mapping for tack welding of beam structures



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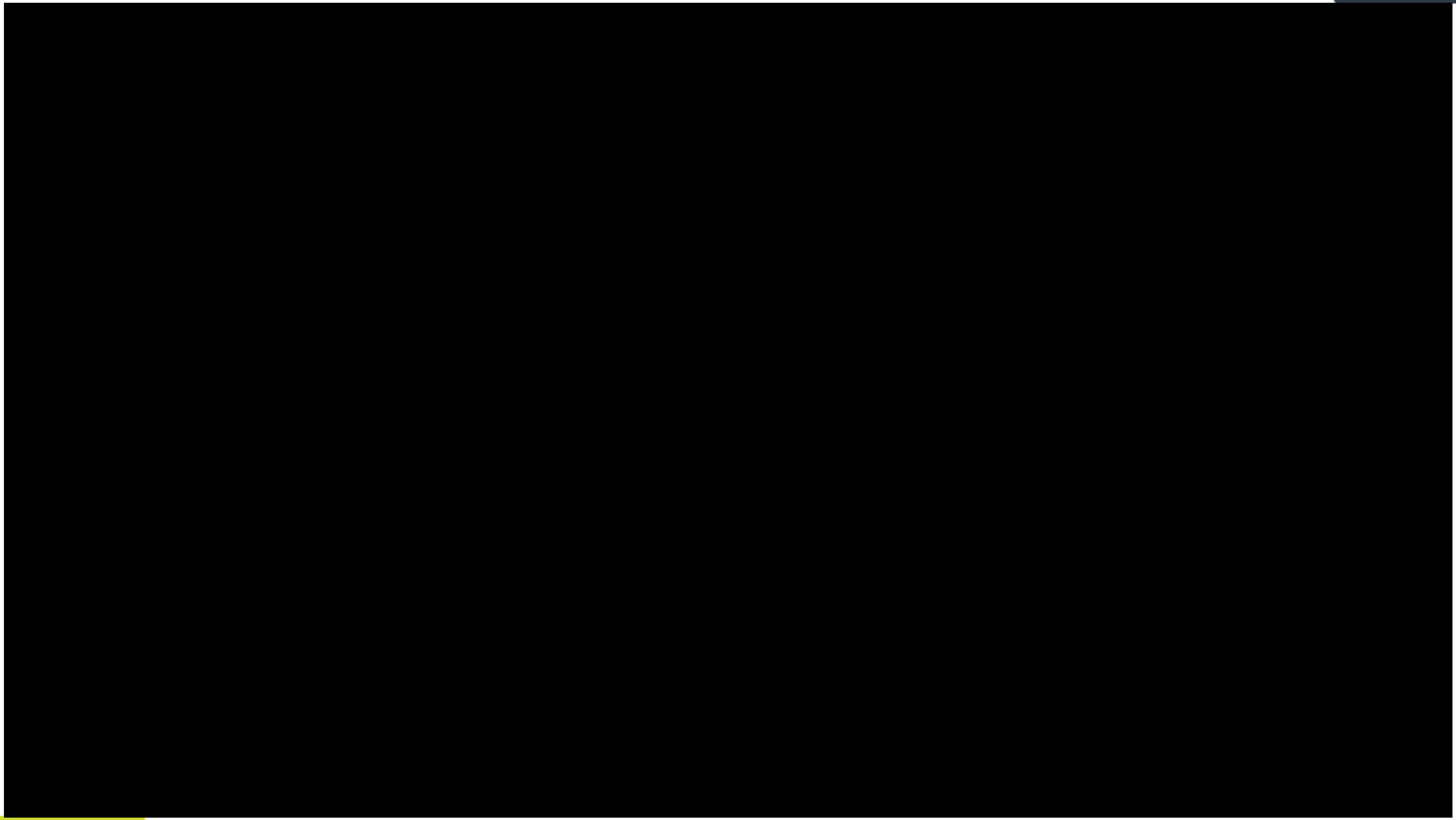
Projection mapping for assembly operations and Human-Machine interface



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Overview of main stages required for performing projection mapping

Calibration

Estimation of the intrinsic and extrinsic parameters of the projector and the 3D sensor.

Required for modeling the projection and sensing hardware and known the spatial relation between them.

3D sensing and perception

Estimation of the relative translation and rotation between the target object and the 3D sensor and projector.

Required for rendering the target object from the correct perspective.

Rendering and projection

Generation of the projection image with the target information retrieved from the CAD model along with other metadata.

Spatial dimensions are critical for cutting and welding tasks.

Intuitive instructions are critical for assembly tasks.

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Calibration of intrinsic and extrinsic parameters of projector and camera

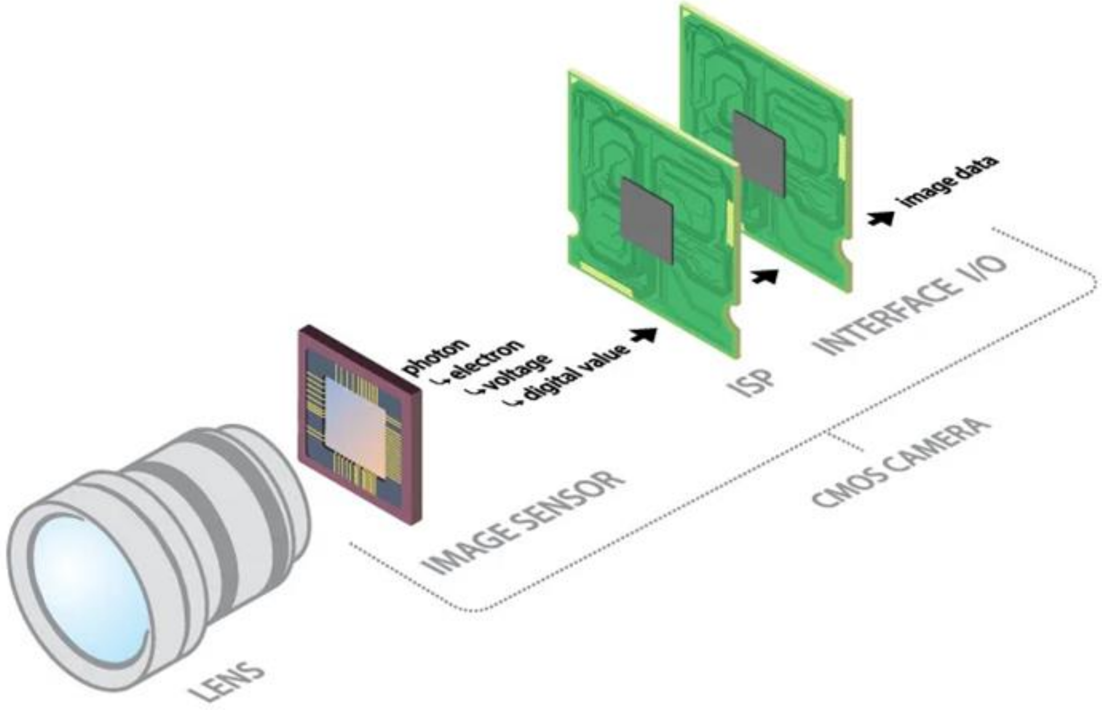

Diagram of a digital camera with the lens, CMOS image sensor and boards to process and transfer the data.

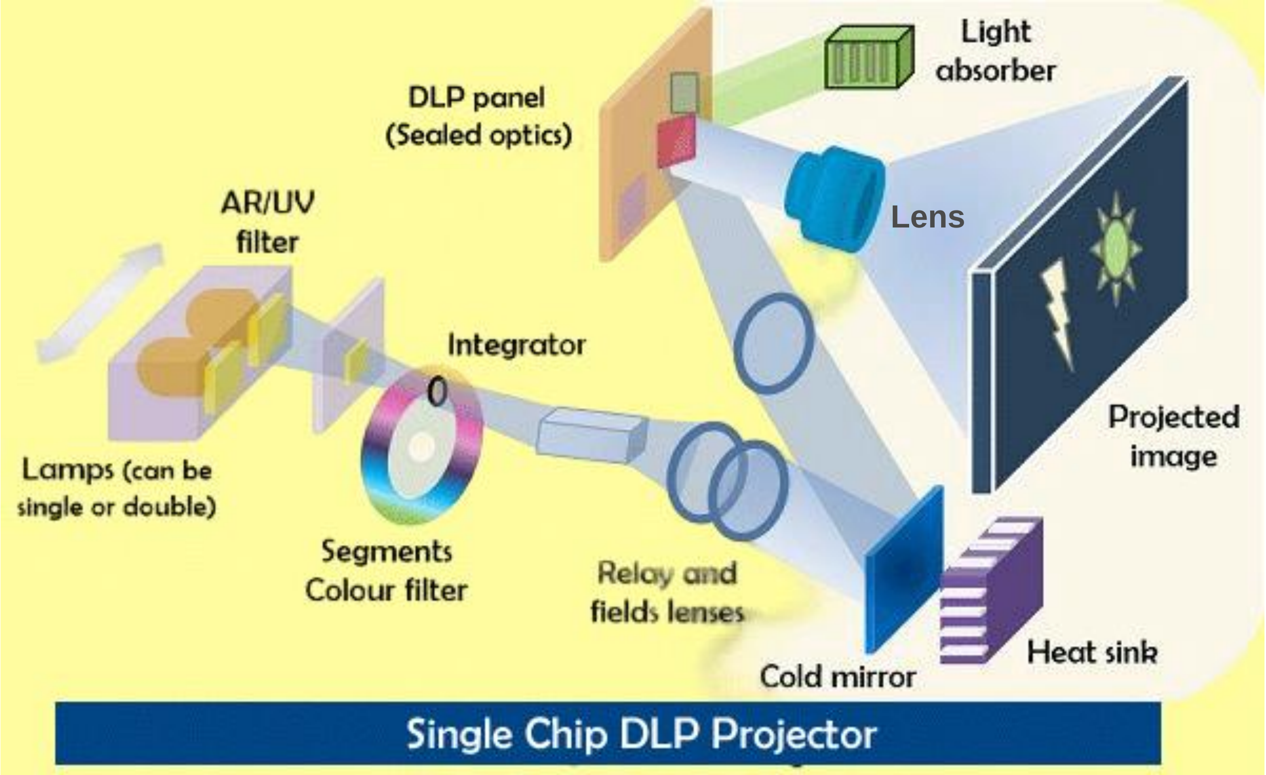

Diagram of a projector with the light source, color wheel, mirror, DMD ship and lens.

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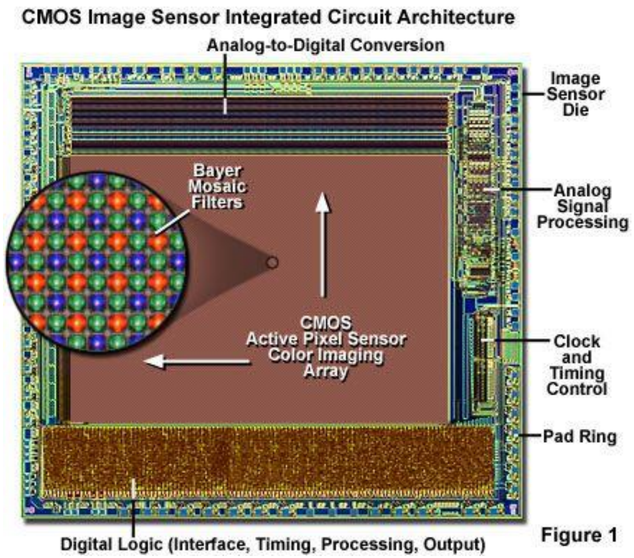
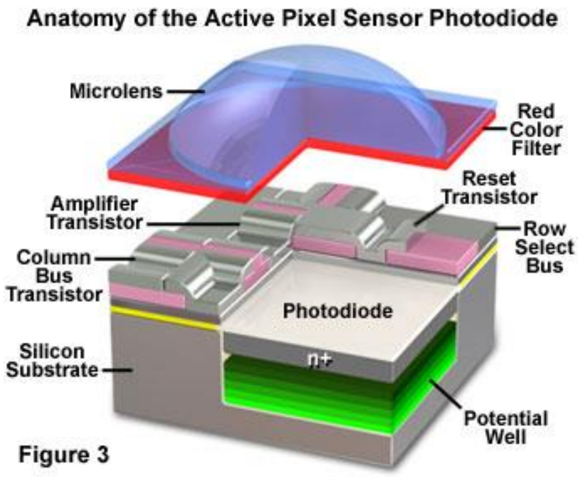
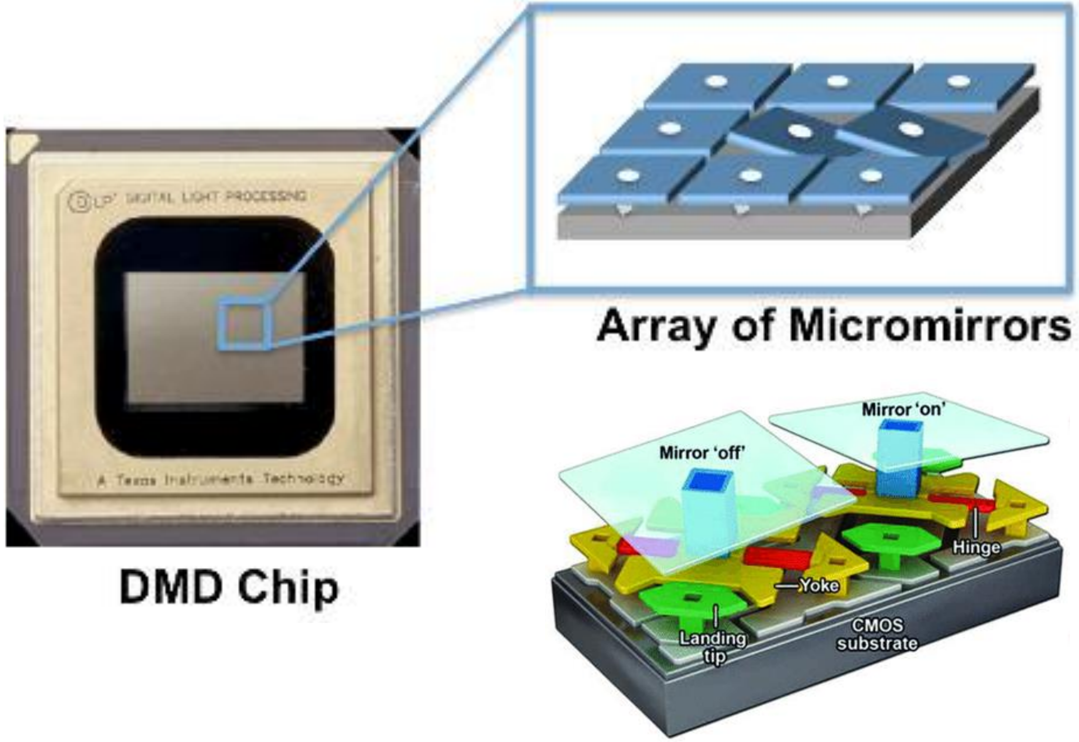
Calibration of intrinsic and extrinsic parameters of projector and camera



Camera CMOS sensor.



CMOS pixel photodiode that **captures** light.



Projector DMD chip and example of the mirror that **reflects** the light associated with each pixel.

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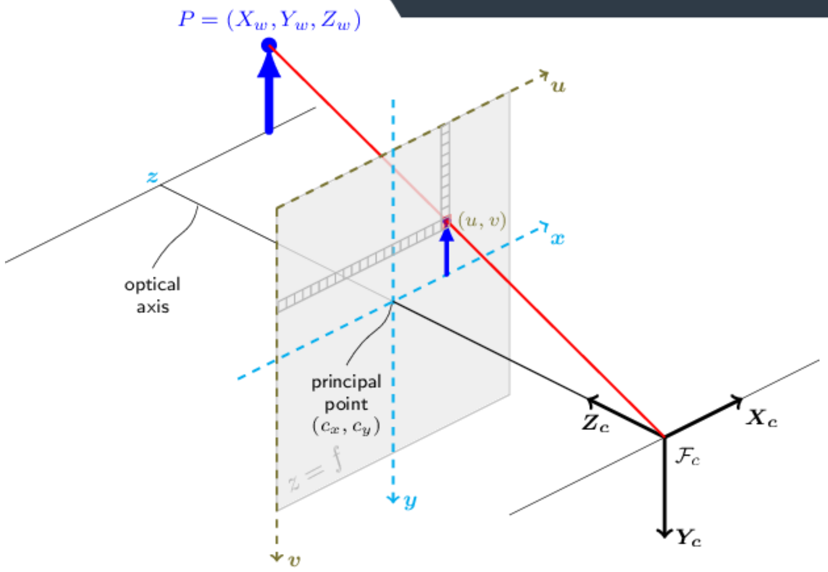
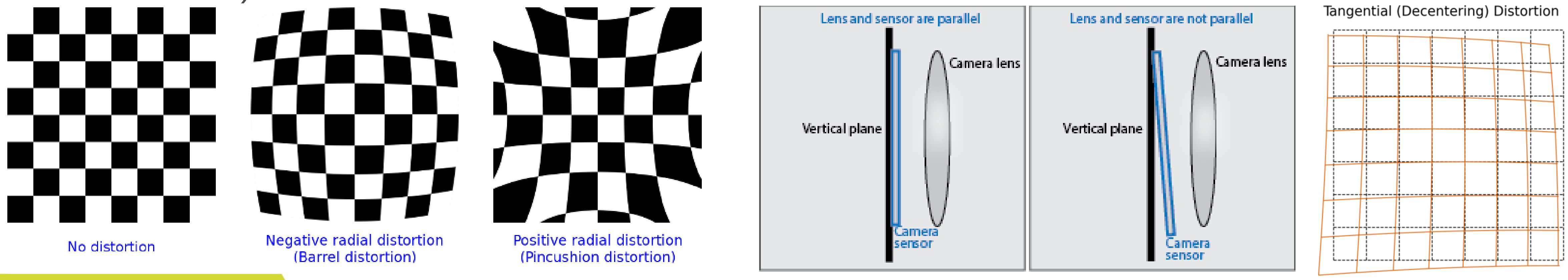
Calibration of intrinsic and extrinsic parameters of projector and camera

1. For accurately projecting information into the environment, it is necessary to model and simulate the projector hardware inside the 3D virtual world that has the CAD models and then render the projection images that will contain the marking information.

2. A projector can be considered as an inverse camera, in which it projects light through a lens instead of capturing it, and as such, for calibrating a projector it can be used the same mathematical models and software (OpenCV) for estimating the intrinsic parameters (focal lengths, principal point and lens distortion correction parameters) and extrinsic parameters (rotation and translation between the projector and the camera).



Pinhole camera model.



Examples of lens distortion.

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Calibration of intrinsic and extrinsic parameters of projector and camera

1. The camera intrinsic parameters (fx, fy, cx, cy) along with the radial (k1, k2, k3, k4, k5, k6) and tangential (p1, p2) lens distortion parameters can be computed using cv::calibrateCamera.
2. The calibration requires the detection of a 2D pattern and the associated 3D points.
3. For the camera, the 3D points are created based on the physical dimensions of the printed asymmetric circles pattern.
4. For the projector, the 3D points are computed using a ray-plane intersection algorithm, in which every projected circle center detected in the camera image is projected into the 3D plane of the physical pattern. For doing this step, the camera must be calibrated before the projector and then the rvecs and tvecs parameters returned by cv::calibrateCamera can be used to create the plane equation for each observed physical pattern.

$$A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$$

Intrinsic parameters.

$$\begin{bmatrix} x'' \\ y'' \end{bmatrix} = \begin{bmatrix} x' \frac{1+k_1 r^2 + k_2 r^4 + k_3 r^6}{1+k_4 r^2 + k_5 r^4 + k_6 r^6} + 2p_1 x' y' + p_2 (r^2 + 2x'^2) \\ y' \frac{1+k_1 r^2 + k_2 r^4 + k_3 r^6}{1+k_4 r^2 + k_5 r^4 + k_6 r^6} + p_1 (r^2 + 2y'^2) + 2p_2 x' y' \end{bmatrix}$$

Radial and tangential lens distortion parameters.

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

Extrinsic parameters.

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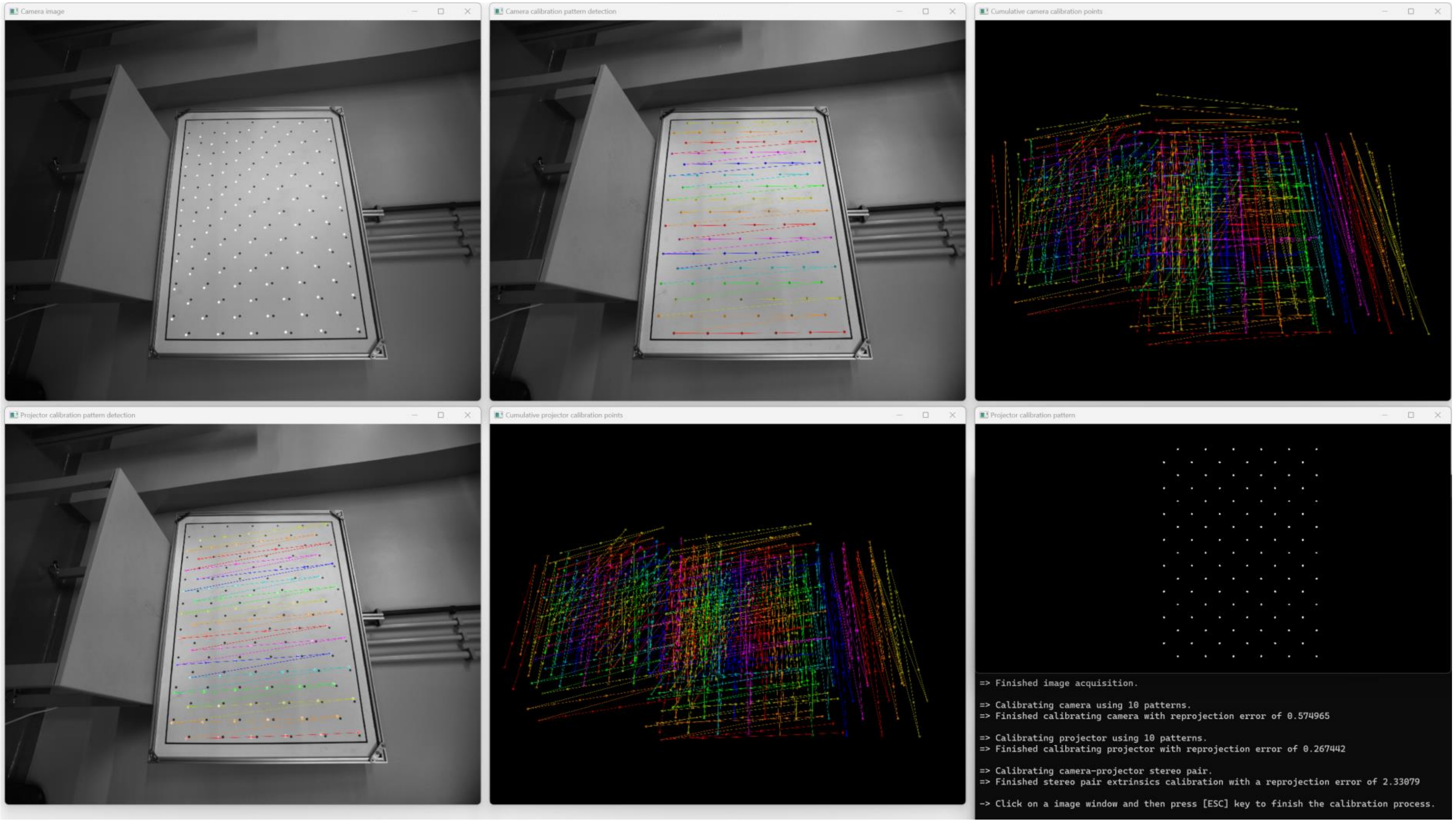
Calibration of intrinsic and extrinsic parameters of projector and camera



User interface with the detection of the printed and projected asymmetric circles patterns for calibrating the projector and the Mako G-507C camera.

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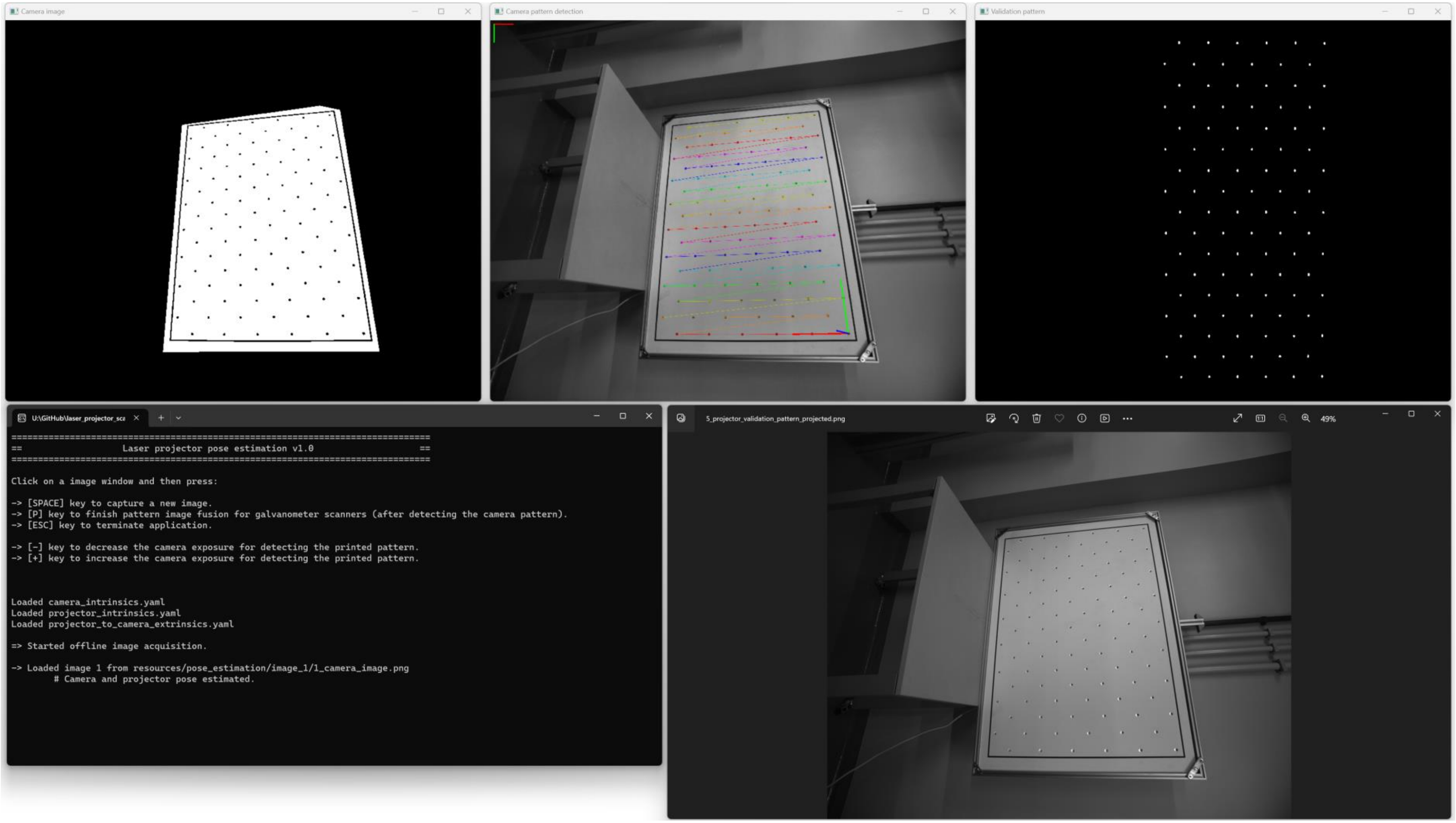
Validation of calibration



User interface for estimating the pose of a pattern and then create a validation image created using the intrinsic and extrinsic parameters for being projected for validating and evaluating the calibration.

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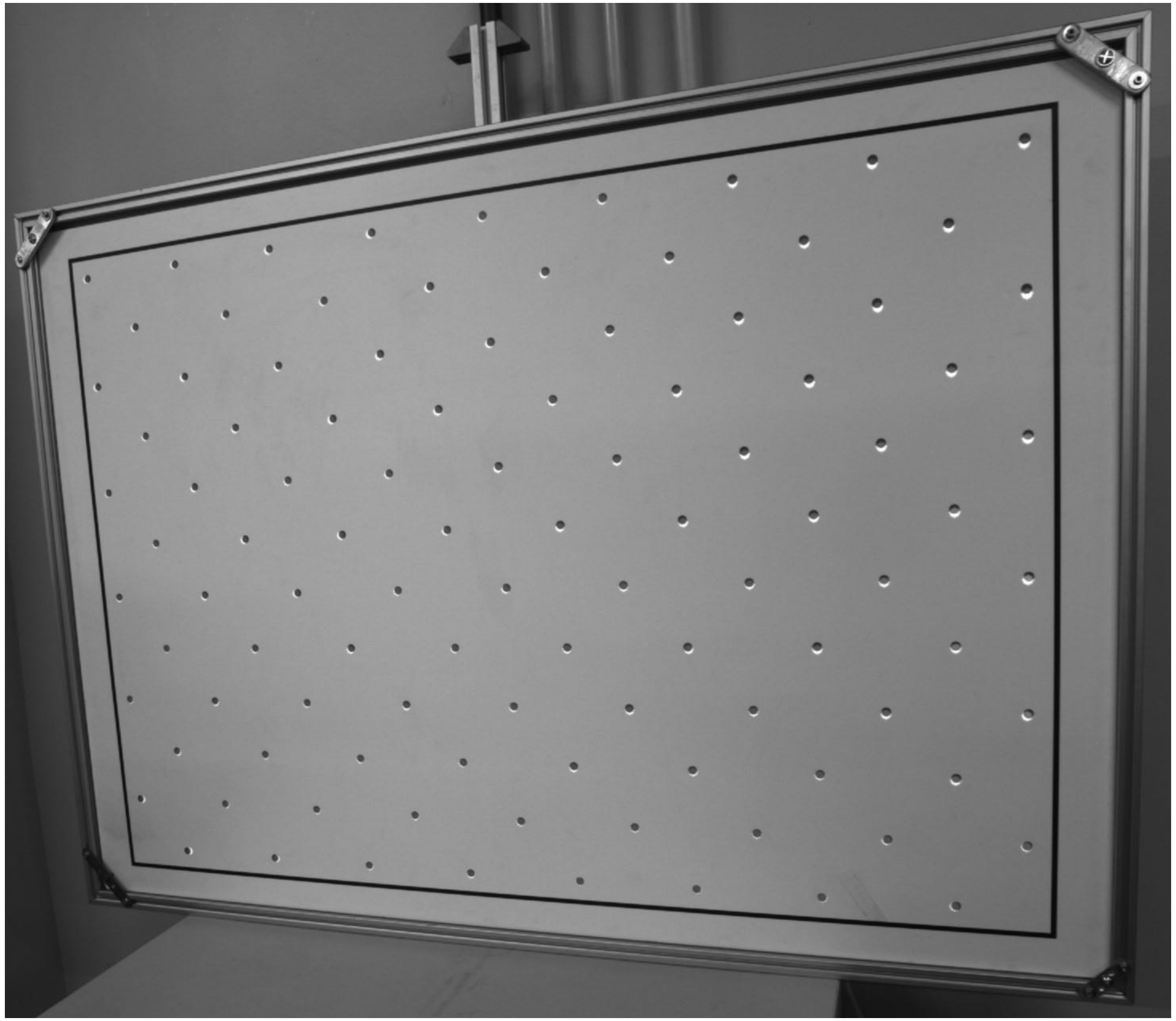
Validation of calibration



Validation image projected into the printed pattern, in which the projected white circles had an error below 4.5 mm in relation to the center of the black printed circles (which have a diameter of 9 mm).

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Calibration of extrinsics parameters between projector and 3D sensor

1. In order to use the 6 DoF pose computed using ICP from the 3D sensor data (for setting the projector pose within the virtual world that has the CAD models), it is necessary to calibrate the 3D rotation and 3D translation between the 3D sensor and the projector.
2. The 3D rotation and 3D translation extrinsic parameters between the 2 cameras can be computed using cv::stereoCalibrate, which receives as input, several pairs of images captured from the Mako G-507C camera (that was used to calibrate the projector) and the 2D camera image from the 3D sensor (RGB sensor in the case of the Asus Xtion Pro Live).
3. The Mako G-507C was used to calibrate the projector instead of the RGB camera from the Asus Xtion Pro Live, because the Mako G-507C has a much higher resolution (2464x2056), which results in better calibration of the projector. After calibration, the Mako G-507C can be removed from the projection platform, which only needs the projector and the 3D sensor to operate.
4. For improving the factory calibration of the Asus Xtion Pro Live, the intrinsic and extrinsic parameters of the RGB and IR cameras were calibrated using the software presented previously.
5. The images were captured with the maximum resolution supported by the sensor, which is 1280x1024.
6. The projection and rectification matrices were computed using cv::stereoRectify.

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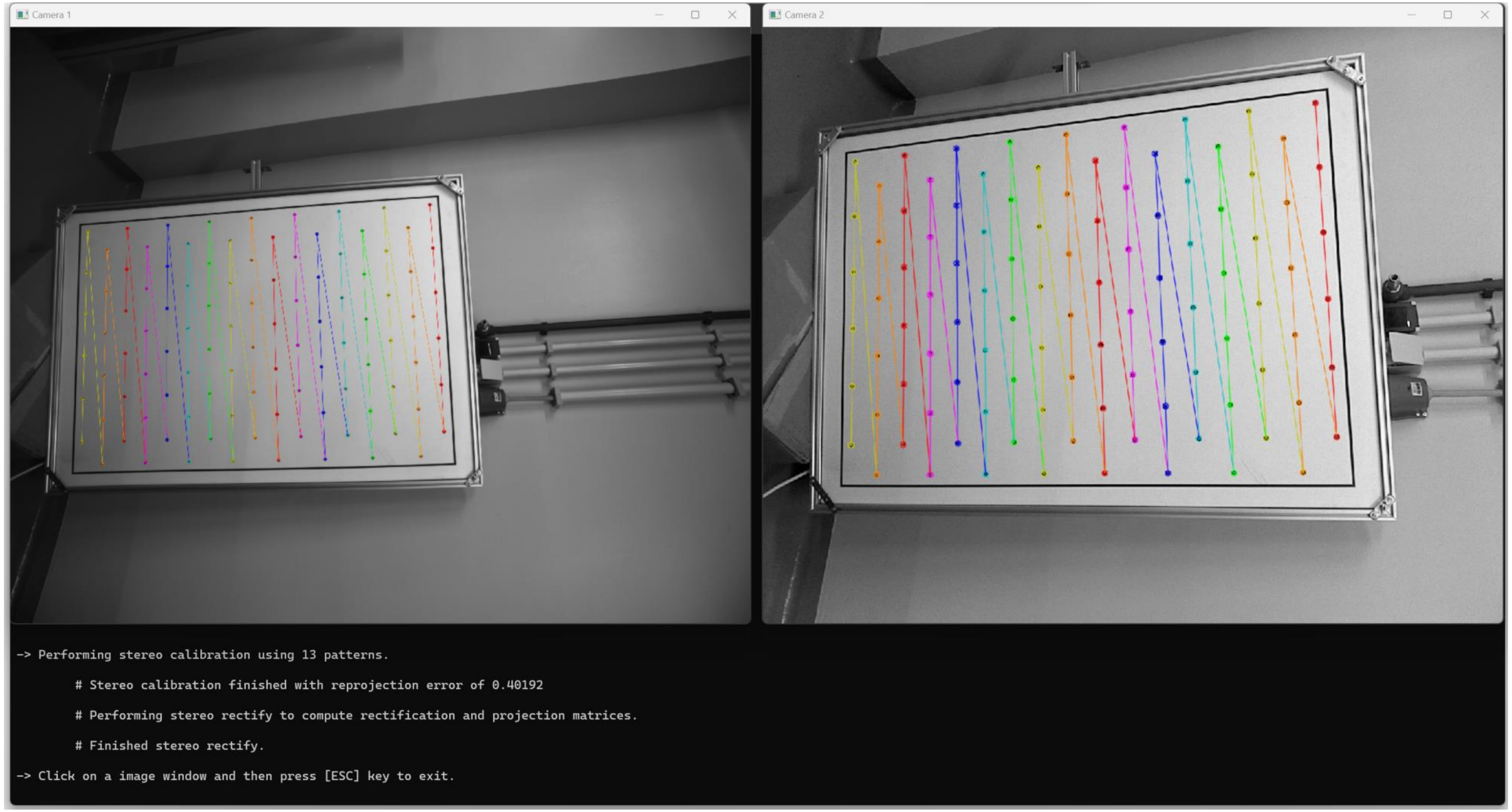
Calibration of extrinsic parameters of projector and 3D sensor



User interface with the detection of the printed asymmetric circles patterns for calibrating the extrinsics between the Mako G-507C camera and the Asus Xtion Pro Live RGB camera.

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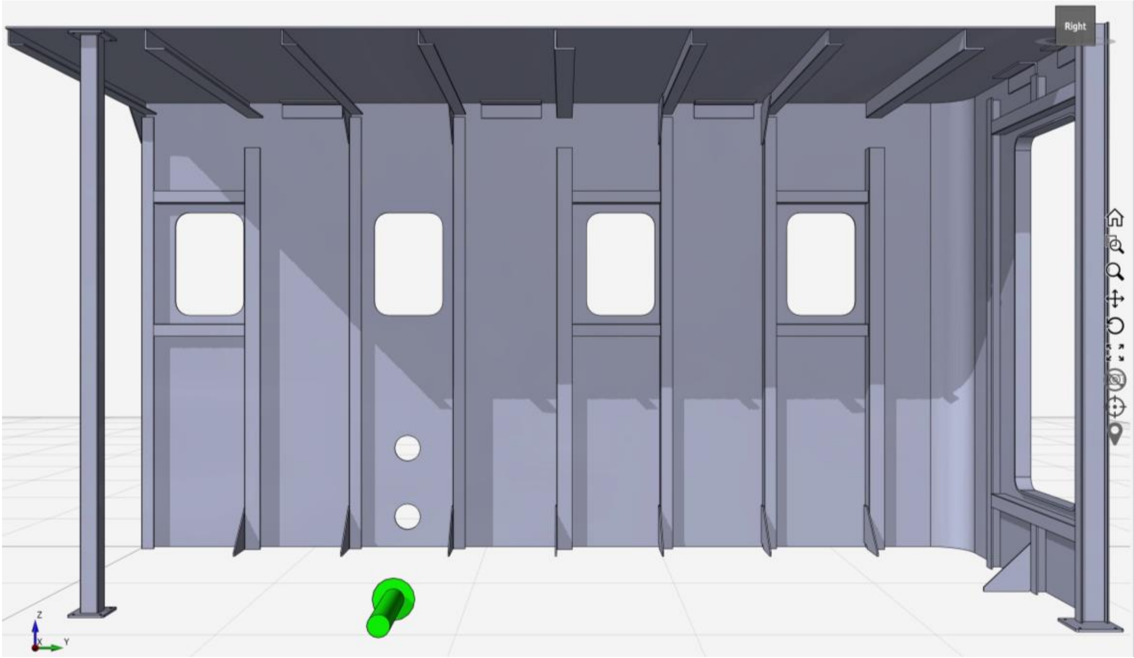
6 DoF pose estimation – Reference point cloud

1. For projecting accurate marking information into the ship walls, it is necessary to compute the 3D rotation and 3D translation between the projector and the ship structure coordinate system.
2. For optimizing the perception speed and reliability, currently the surfaces to use as a reference point cloud are carefully selected by an expert that performs an analysis of the CAD model and chooses the surfaces that are likely to allow a good convergence for the point cloud matching algorithm while also avoiding surfaces that are redundant and slowdown the alignment process.
3. From the CAD on the left, the surfaces on the center image were extracted and then the point cloud on the right image was generated in [meshlab] using the surface midpoint subdivision algorithm with 2 mm of edge threshold and the clustered vertex sampling algorithm with a cell size of 10 mm to ensure uniform point density, which is important for the point cloud matching algorithms.



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6 DoF pose estimation – Segmentation and point cloud alignment

1. The 3D perception system starts by loading the reference point cloud from a .ply file and capturing a new point cloud of the ship surfaces using the 3D sensor.
2. A voxel grid of 10 mm is used to downsample the sensor data to speed up the processing in the following stages.
3. A RANSAC algorithm is used to segment the largest plane (the ship wall), and then it is selected the points that are above that plane and facing the camera.
4. The initial pose that the operator provided in the GUI is used to perform an initial alignment of the sensor point cloud in relation to the reference point cloud.
5. The Iterative Closest Point (ICP) algorithm from the Point Cloud Library (PCL) is used to perform the point cloud registration and compute the 6 DoF pose of the 3D sensor in relation to the coordinate system of the reference point cloud that was extracted from the CAD model.
6. For validating the alignment, it is computed the percentage of points from the sensor point cloud that have a correspondence with short distance in relation to the reference point cloud and also the percentage of points in the reference point cloud that have a correspondence with short distance in relation to the sensor point cloud. If these overlap percentages are above the predefined thresholds, then the alignment is considered valid. Otherwise, an error is shown to the user in the GUI to readjust the initial pose.

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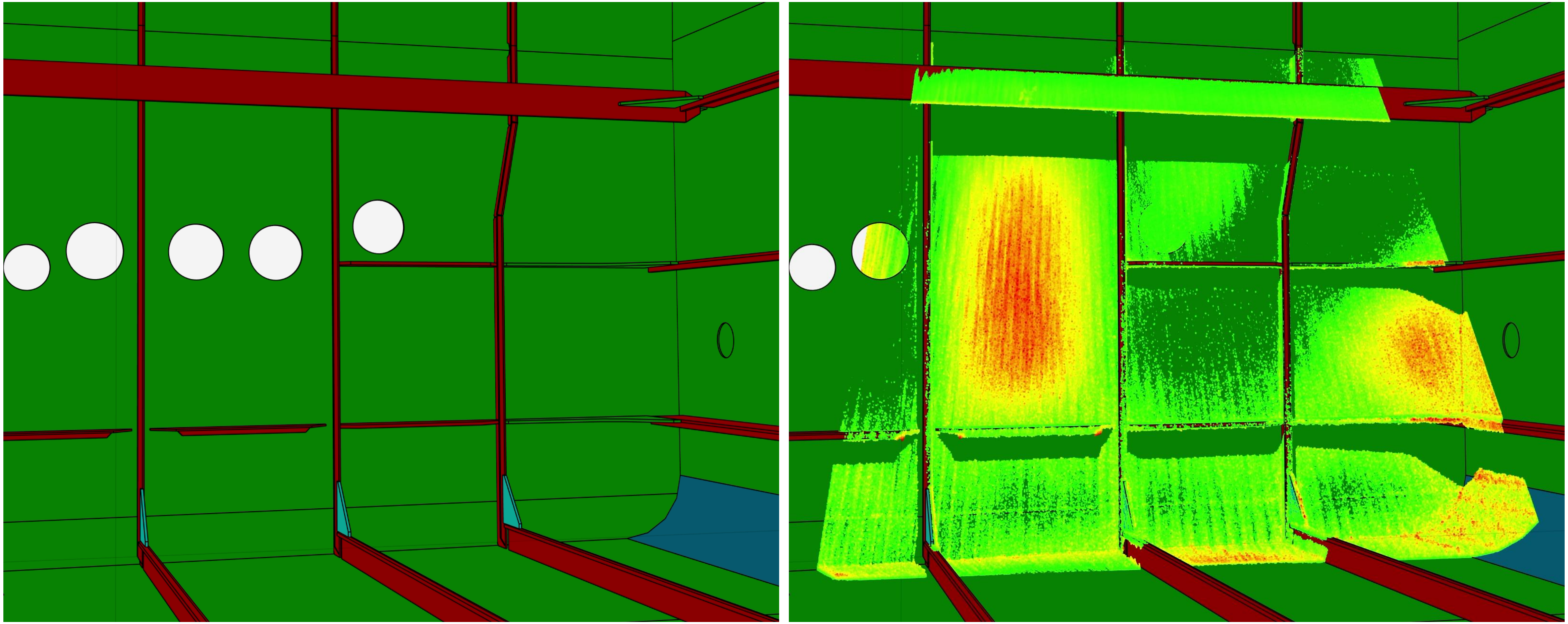
6 DoF pose estimation – Zivid 2+ L110



Example of alignment of the CAD model with the sensor data
(shown with red to green color-coded gradient to represent the points distance to the CAD model) for the ceiling of the ship wall using the Zivid 2+ L110 3D sensor.

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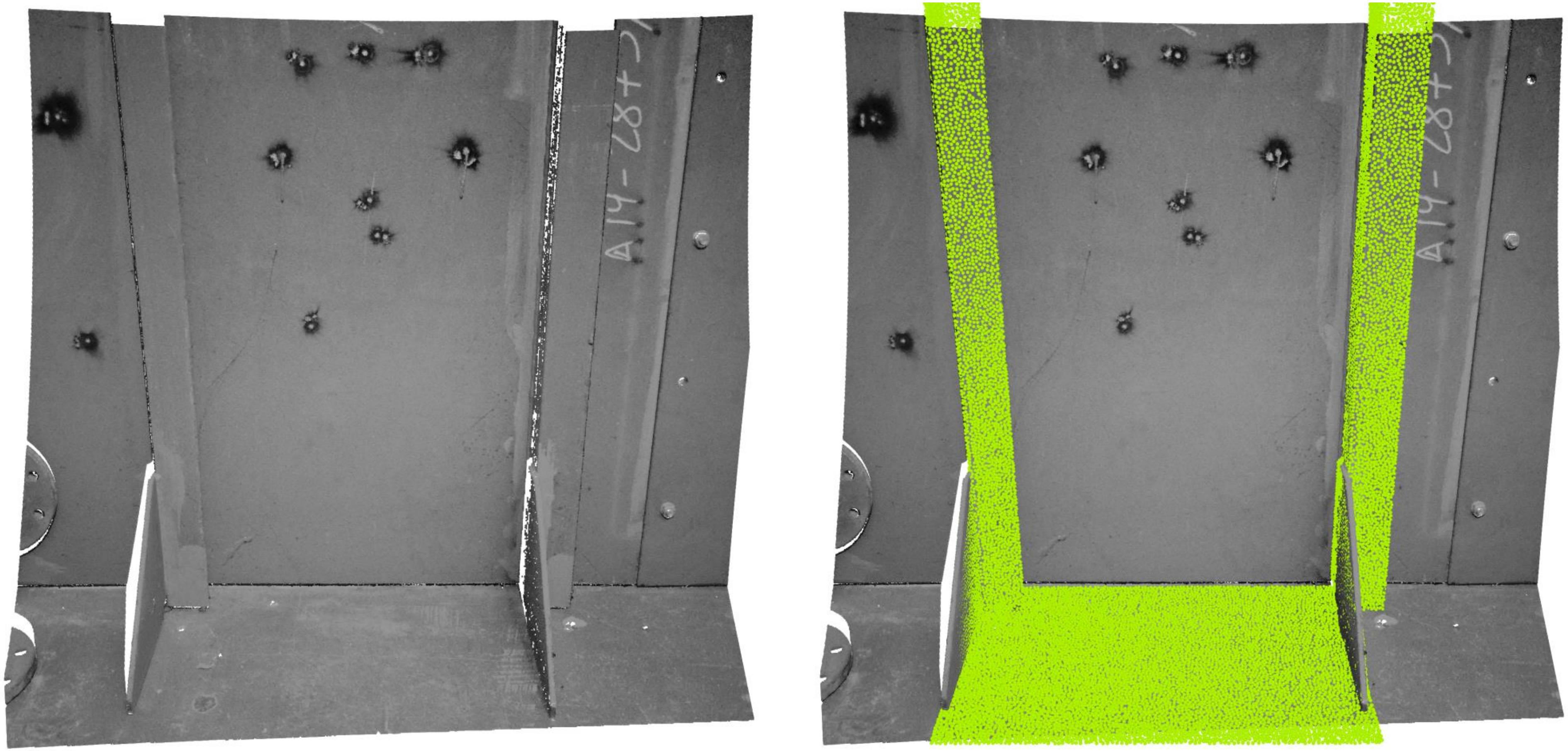
6 DoF pose estimation – Photoneo PhoXi XL



Example of alignment of the reference point cloud (shown as green circles) for the bottom section of the ship wall using the Photoneo PhoXi XL 3D sensor.

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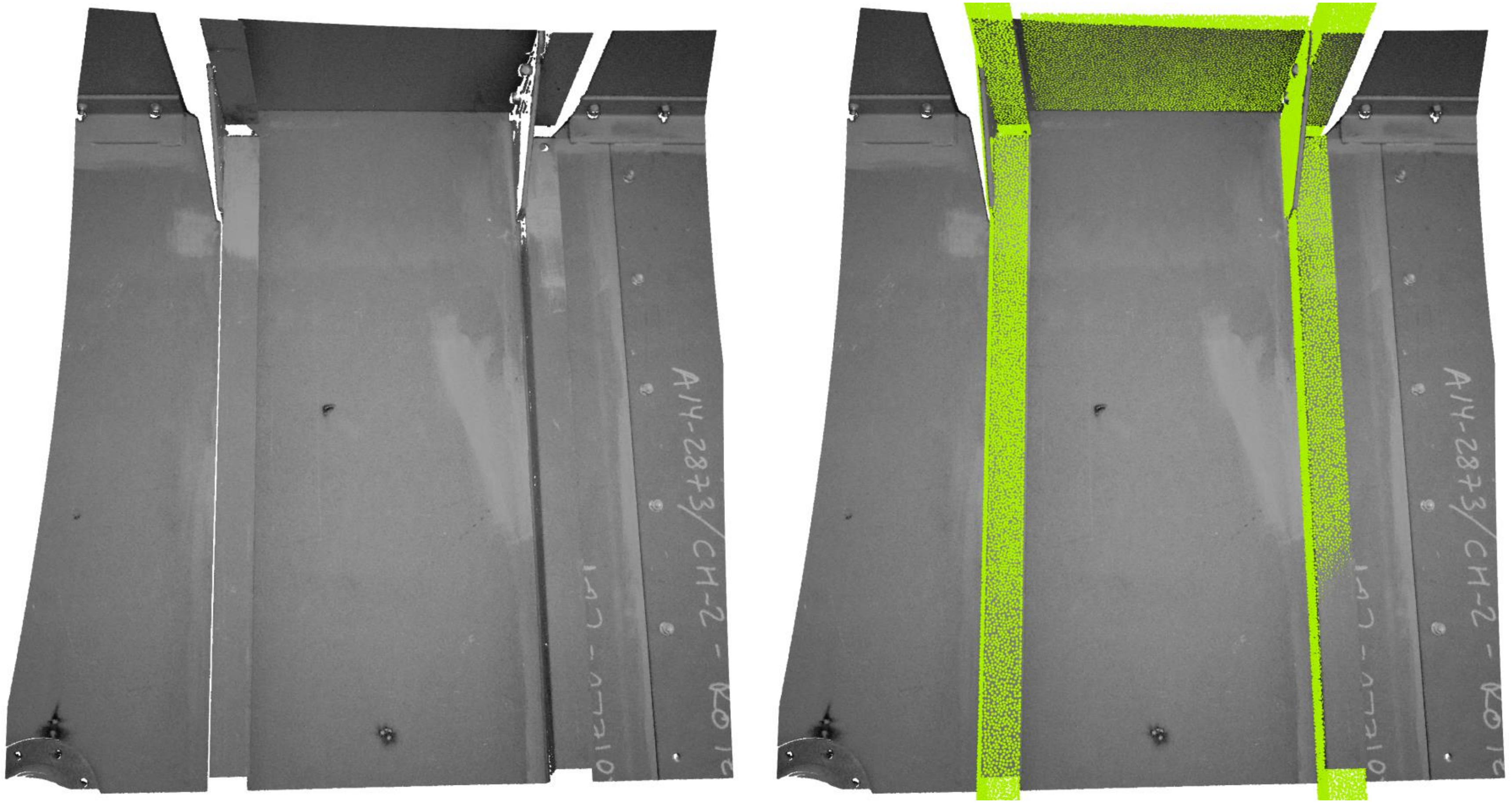
6 DoF pose estimation – Photoneo PhoXi XL



Example of alignment of the reference point cloud (shown as green circles) for the top section of the ship wall using the Photoneo PhoXi XL 3D sensor.

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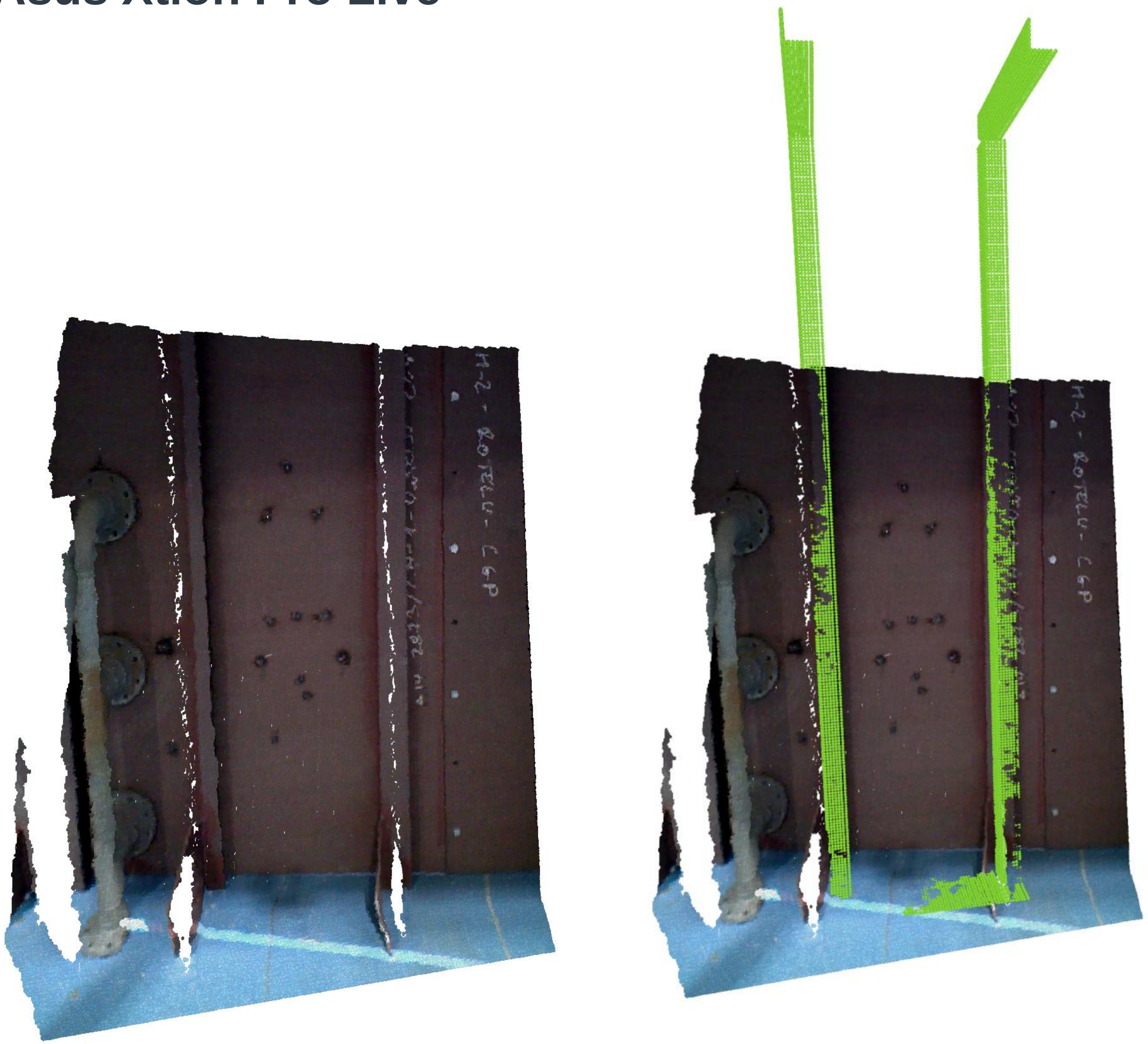
6 DoF pose estimation – Asus Xtion Pro Live

Example of alignment of the reference point cloud (shown as green circles) for the bottom section of the ship wall using the Asus Xtion Pro Live 3D sensor.



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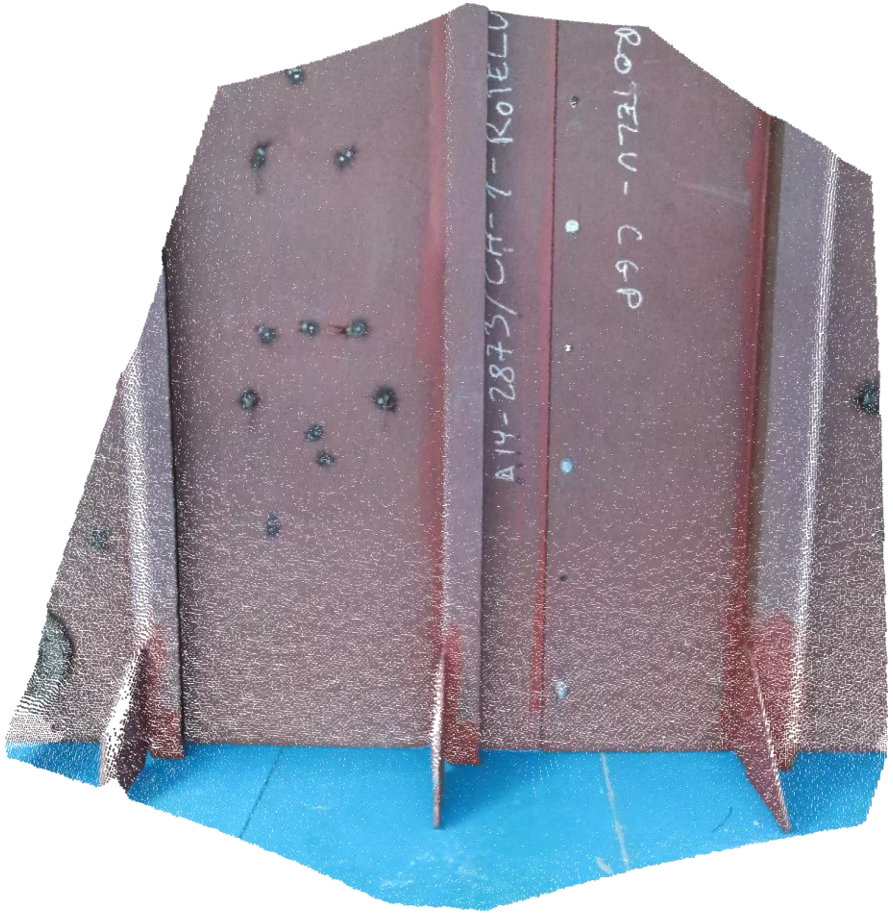
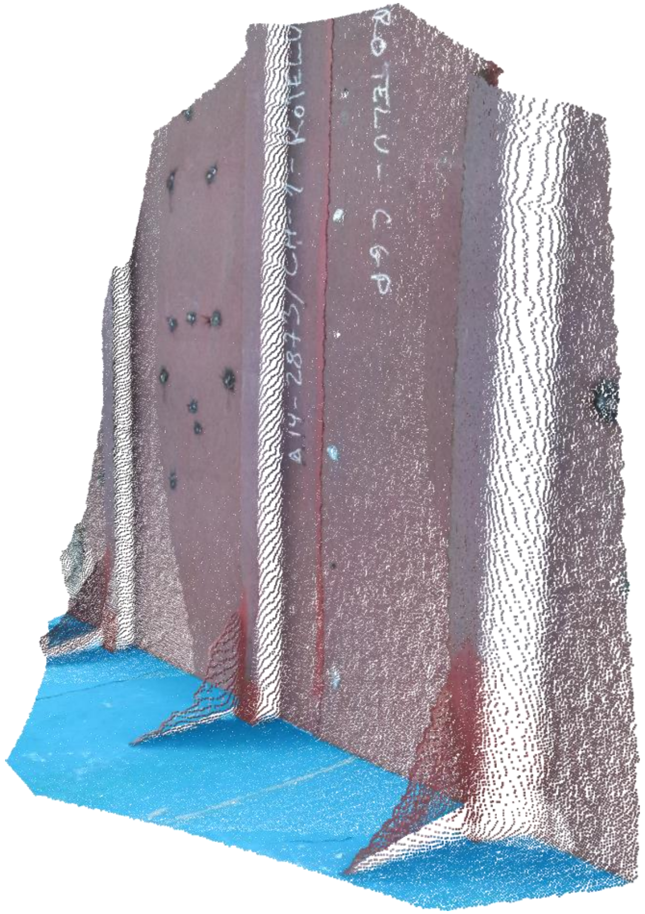
Test of other 3D sensors – Kinect Azure (ToF)





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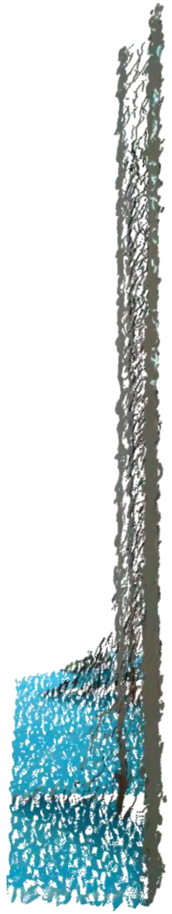
Test of other 3D sensors – Intel RealSense L515 (Lidar)



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Test of other 3D sensors – Intel RealSense D455 (stereo structured light - default preset)

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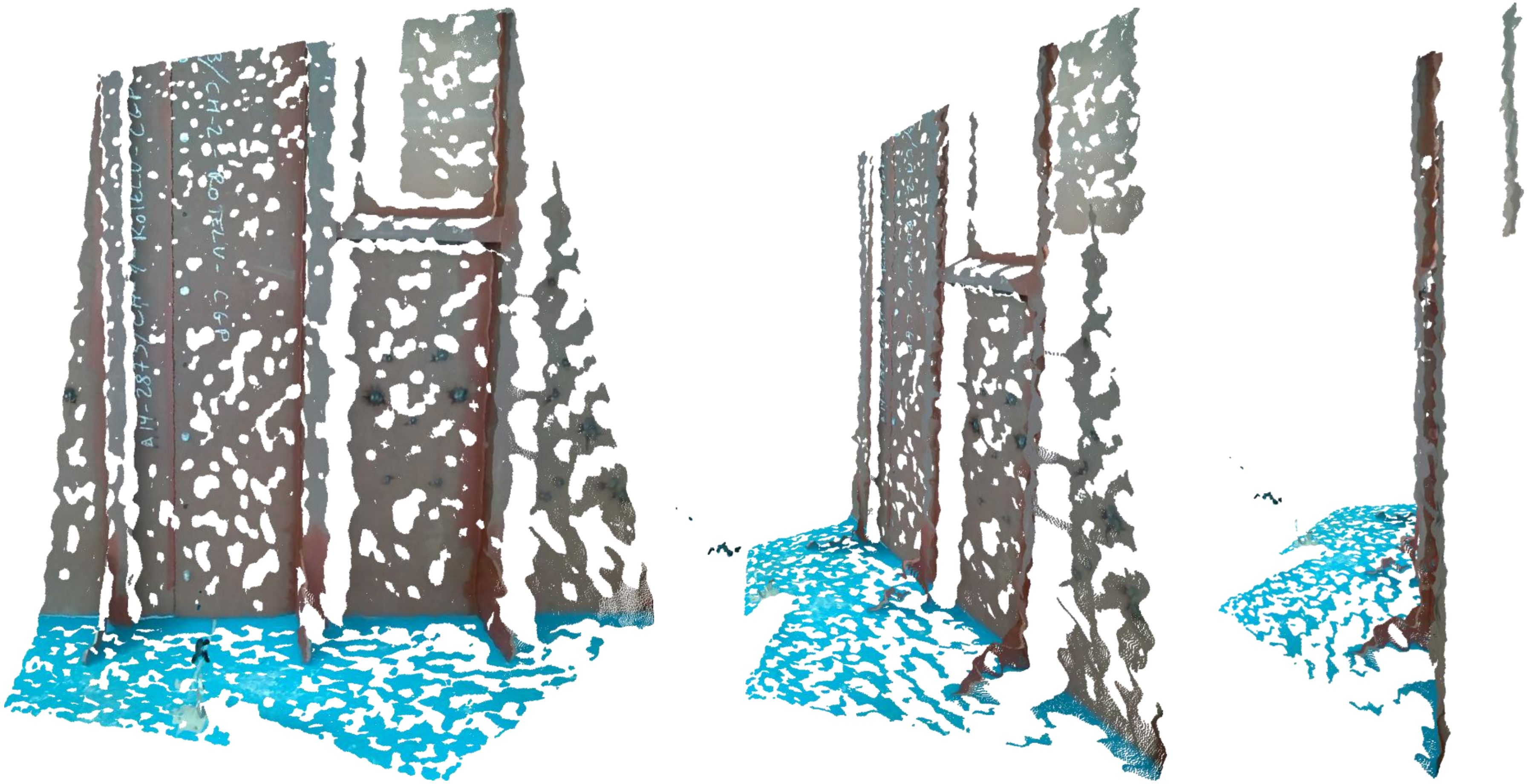
Test of other 3D sensors – Intel RealSense D455 (stereo structured light - accuracy preset)



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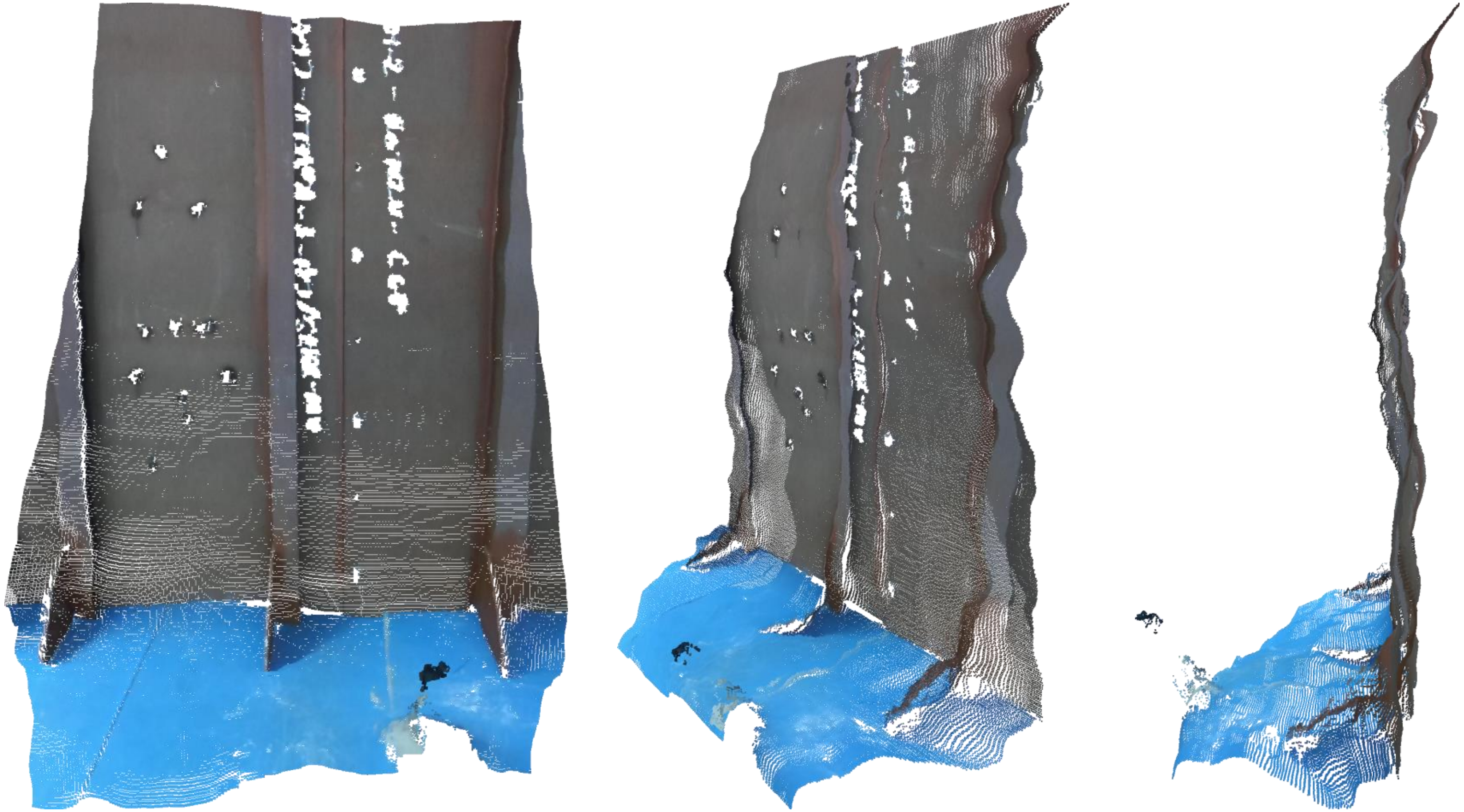
Test of other 3D sensors – Zed Mini (stereo)



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Rendering and projection

The last stage of a projection mapping system is the rendering of the CAD model using a virtual camera modelled with the calibrated intrinsic and extrinsic parameters, followed by the projection of the raster image into the environment.

The rendering is done using a graphics engine (Direct3D or OpenGL), for having hardware acceleration using a GPU to generate the raster images quickly.

In the Mari4yard project we used the devdept Eyeshot SDK. In other projects we also used the gazebo simulator.

Example of rendered images (top row) and the respective projection (bottom row)

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Thank you for your attention!

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