Human-Machine Interface for Real-Time Interaction Focused on LiDAR SLAM Feature Extraction

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NATALIA PRIETO FERNÁNDEZ

Natalia Prieto Fernández received the B.S. degree in industrial, electronic and automation and the M.S. degree in industrial engineering in 2018 and 2020, respectively, from the Universidad de León, León, Spain, where she is currently working toward the Ph.D. degree in 2-D LiDAR SLAM with the SECOMUCI Research Group, Department of Electric, Systems and Automatics Engineering.

From 2019 to 2020, she was a Pre-Doctoral Researcher in the Research and Development Department of TRESCA Ingeniería S.A., León. Since 2020, she has been Teaching Assistant with Universidad de León.

TOPICS OF RESEARCH INTEREST

- Feature extraction in 2D LiDAR mapping
- 2D LiDAR SLAM
- Measurement uncertainty with 2D LiDAR sensors

INTRODUCTION

- Design and development of an Human-Machine Interface (HMI) capable of controlling a LiDAR SLAM robotic system in real time.
- Seamless communication between ROS and MATLAB.
- Simple and intuitive HMI for the user compacting the visualisation of the raw data from sensors, the data processed in ROS as well as the data processed in MATLAB.

ROS

ROBOTIC SYSTEM

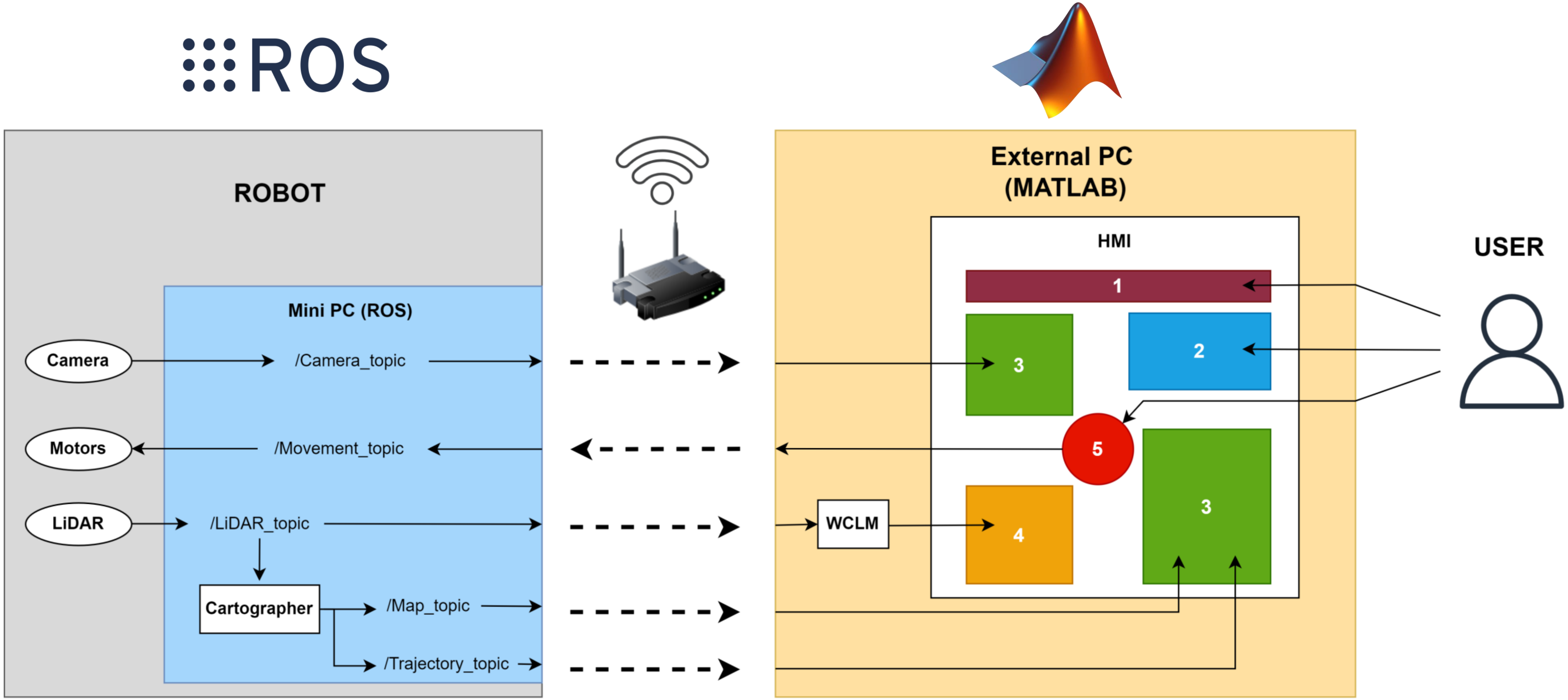
Intel NUC10i

RPLiDAR S2

4WD Rover Zero 3

Intel® RealSense™ D435i

ROBOTIC SYSTEM



1) Toolbar
2) System Communication
3) Visualisation of Sensor Data and ROS Data
4) Visualisation of LiDAR Data Processed
5) Remote Control

SLAM TECHNOLOGY

- **LiDAR SLAM:** *Google’s Cartographer*

The Google’s *Cartographer* algorithm was used to reconstruct the map and the trajectory followed by the robot.

This algorithm operates within the ROS environment of the robotic system's mini PC. Based on sub-mapping, it optimises the processing of the data. As the robot moves forward, the *Cartographer* algorithm progressively incorporates the LiDAR sensor readings into the most recent sub-map, allowing for continuous updating of the mapping information.

SLAM TECHNOLOGY

- **Feature Extraction:** Weighted Conformal LiDAR-Mapping (WCLM)

Straight line

$$\boldsymbol{x_Q} \cdot x_i - \boldsymbol{y_Q} \cdot y_i = 1$$

$$\widehat{\boldsymbol{x_Q}} = \frac{\left(\sum_i \omega_i \cdot x_i\right) \cdot \left(\sum_i \omega_i \cdot y_i^2\right) - \left(\sum_i \omega_i \cdot y_i\right) \cdot \left(\sum_i \omega_i \cdot x_i \cdot y_i\right)}{\left(\sum_i \omega_i \cdot x_i^2\right) \cdot \left(\sum_i \omega_i \cdot y_i^2\right) - \left(\sum_i \omega_i \cdot x_i \cdot y_i\right)^2}$$

$$\widehat{\boldsymbol{y_Q}} = \frac{\left(\sum_i \omega_i \cdot x_i\right) \cdot \left(\sum_i \omega_i \cdot x_i \cdot y_i\right) - \left(\sum_i \omega_i \cdot y_i\right) \cdot \left(\sum_i \omega_i \cdot x_i^2\right)}{\left(\sum_i \omega_i \cdot x_i^2\right) \cdot \left(\sum_i \omega_i \cdot y_i^2\right) - \left(\sum_i \omega_i \cdot x_i \cdot y_i\right)^2}$$

$$\boldsymbol{C_Q} = \begin{bmatrix} V_{\widehat{x_Q}} & C_{\widehat{x_Q}\widehat{y_Q}} \\ C_{\widehat{x_Q}\widehat{y_Q}} & V_{\widehat{y_Q}} \end{bmatrix}$$

Corner

$$x_Q \cdot \boldsymbol{x_c} - y_Q \cdot \boldsymbol{y_c} = 1$$

$$\boldsymbol{x_c} = \frac{y_{Q_{i+1}} - y_{Q_i}}{x_{Q_i} \cdot y_{Q_{I+1}} - y_{Q_i} \cdot x_{Q_{i+1}}}$$

$$\boldsymbol{y_c} = \frac{x_{Q_{i+1}} - x_{Q_i}}{x_{Q_i} \cdot y_{Q_{I+1}} - y_{Q_i} \cdot x_{Q_{i+1}}}$$

$$\boldsymbol{C_c} = J_c \cdot \begin{bmatrix} V_{x_{Q_i}} & C_{xy_{Q_i}} & 0 & 0 \\ C_{xy_{Q_i}} & V_{y_{Q_i}} & 0 & 0 \\ 0 & 0 & V_{x_{Q_{i+1}}} & C_{xy_{Q_{i+1}}} \\ 0 & 0 & C_{xy_{Q_{i+1}}} & V_{y_{Q_{i+1}}} \end{bmatrix} \cdot J_c^T$$

HMI MODEL

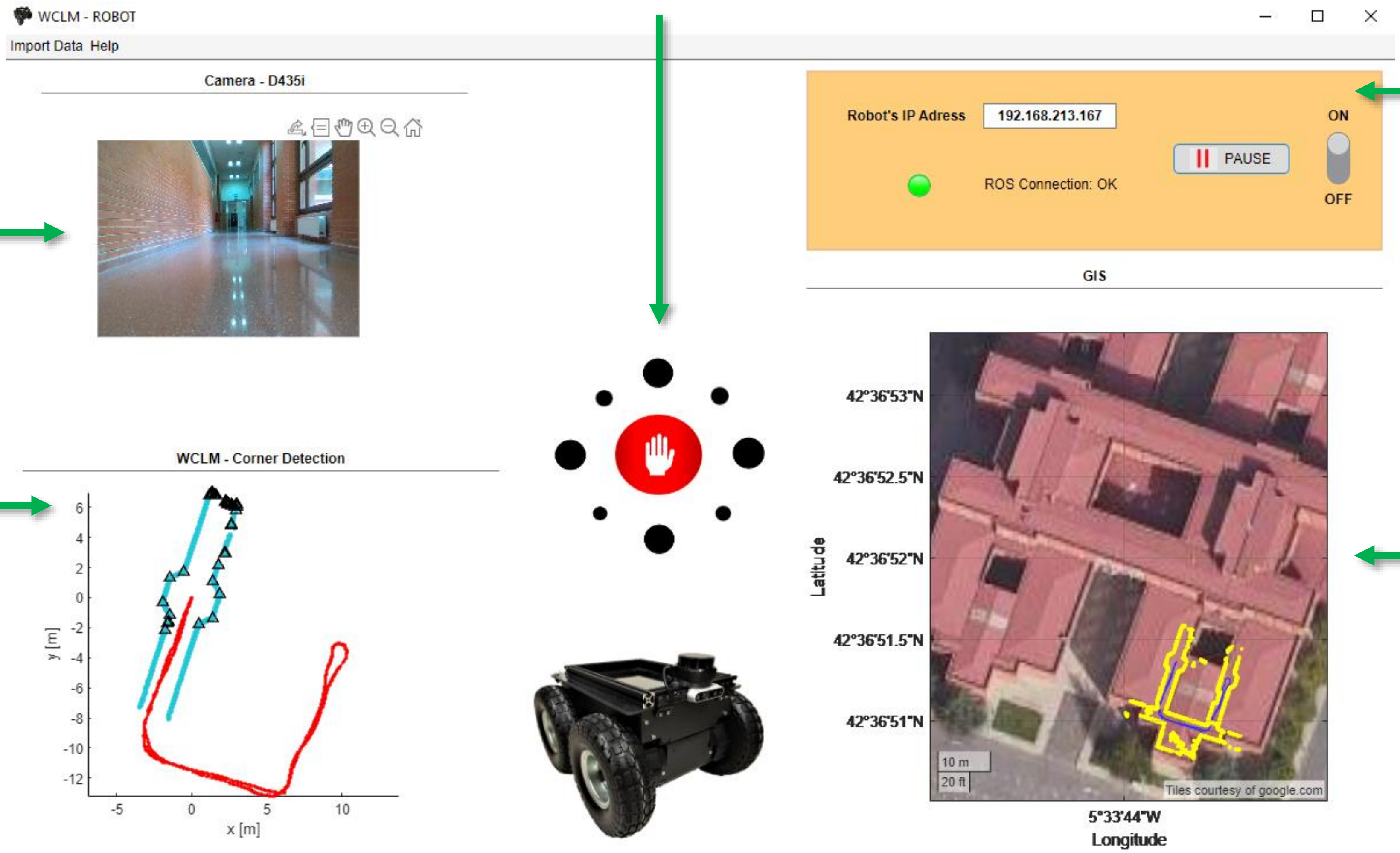
5) Remote Control

1) Toolbar

2) System Communication

3) Visualisation of Sensor Data and ROS Data

4) Visualisation of LiDAR Data Processed



3) Visualisation of Sensor Data and ROS Data

HMI MODEL

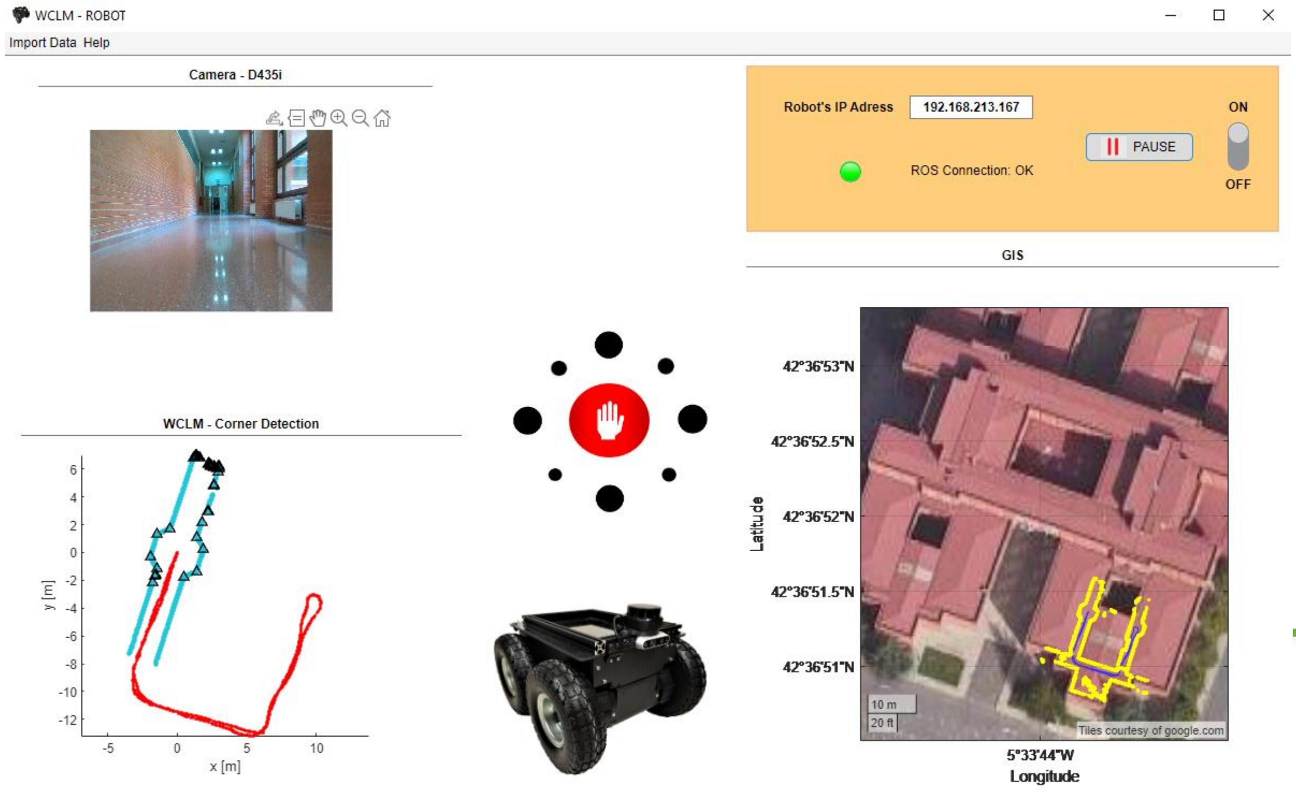
- **Signal Processing.** One of the main milestones of this work is the ability to process data from the sensors and send instructions to the robot in real time.

ROS

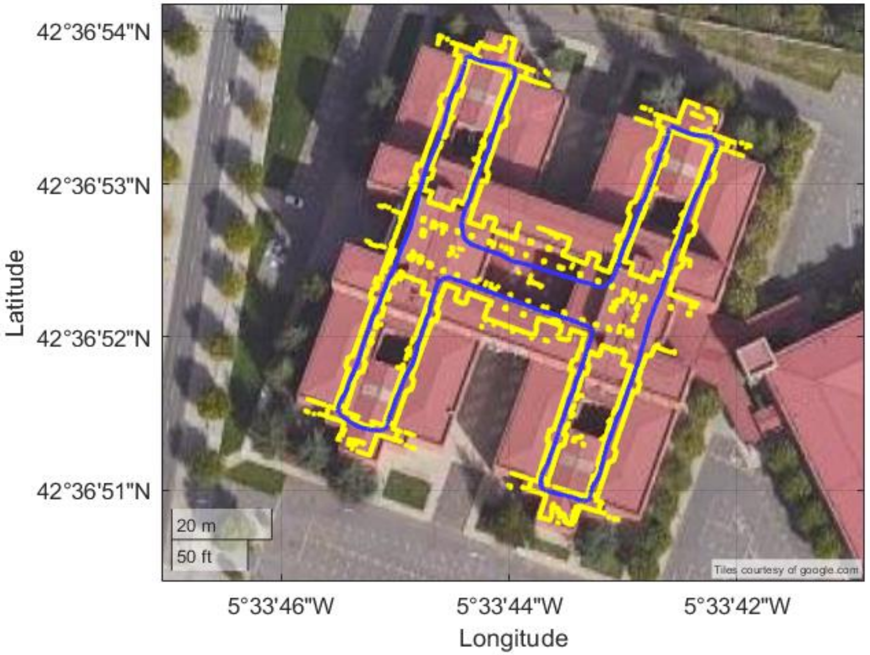
MATLAB's ROS Toolbox

- ✓ Initiate communication with ROS.
- ✓ Subscribe to the sensors and Cartographer *topics*.
- ✓ Publish to the *topics* related to actuator control.
- ✓ Close the communication.

EXPERIMENTAL RESULTS



HMI Operation



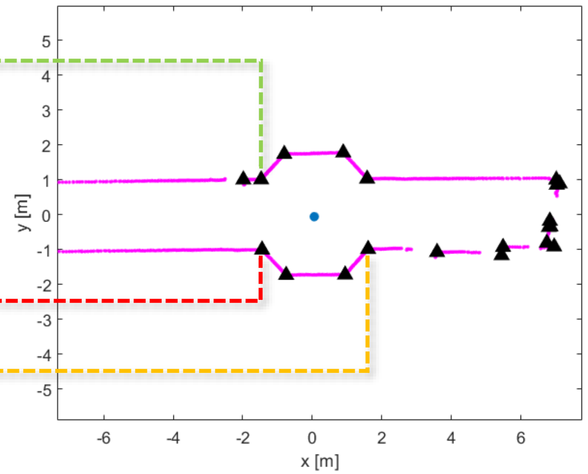
EXPERIMENTAL RESULTS

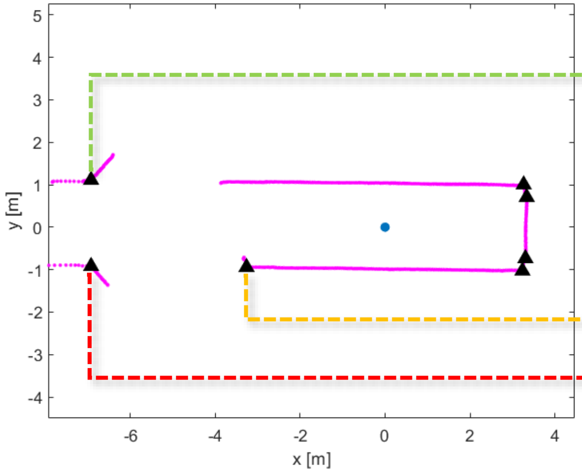
Corner Extraction: WCLM

$\sigma_{x_c} = 21.03\ mm;\ \sigma_{y_c} = 10.48\ mm$

$\sigma_{x_c} = 18.04\ mm;\ \sigma_{y_c} = 3.82\ mm$

$\sigma_{x_c} = 19.58\ mm;\ \sigma_{y_c} = 8.24\ mm$

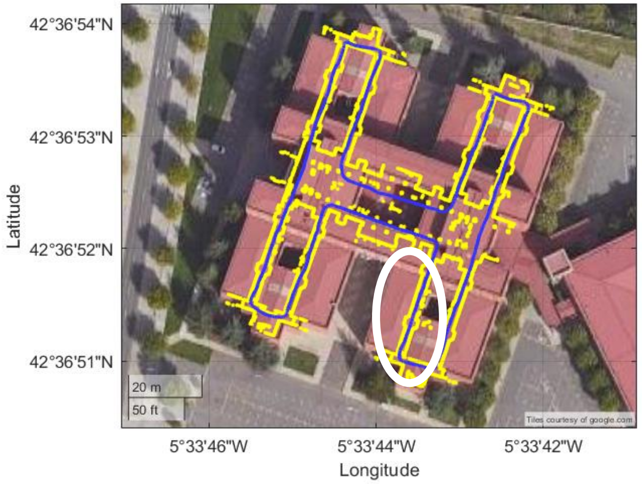


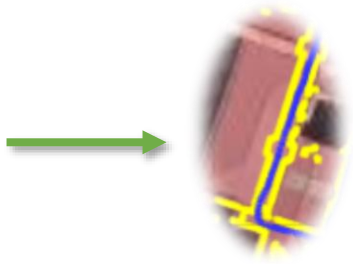


$\sigma_{x_c} = 26.83\ mm;\ \sigma_{y_c} = 12.25\ mm$

$\sigma_{x_c} = 19.22\ mm;\ \sigma_{y_c} = 2.34\ mm$

$\sigma_{x_c} = 29.24\ mm;\ \sigma_{y_c} = 13.65\ mm$





CONCLUSION

- ✓ The developed graphical user interface enables remote analysis and bidirectional communication in real time with the robot.
- ✓ The main achievement of the HMI is its ability to control and monitor the robotic system both in real time and deferred scenarios while visualising the data processed in different environments, ROS and MATLAB.
- ✓ It is an intuitive and efficient interface, aimed at a wide range of users.
- ✓ Versatility is coupled with accessibility turning the resulting product into a plug-and-play commodity for any user.

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