Mobile Robots	
Specialization *Embedded Robotics*	**Date of classes** *Thursday 5:05pm-7:45pm*
Name, last name, index number *Mateusz Strembicki, 259263* *Marcel Skrok, 252972*	**Hand in date** *December 18, 2024*
Title *Localization of mobile robot based on feature extraction*	**Lecturer** *PhD. Janusz Jakubiak*

Contents

1 Abstract

Localization of a mobile robot based on features extraction is a complex and challenging task. This report evaluates the implementation of a line detection algorithm and its use in estimating the robot's position and orientation. The analysis reveals several difficulties inherent to feature-based localization, such as inaccuracies in calculating the robot's position in meters and challenges in estimating its orientation. The report provides a detailed breakdown of the applied method, results, error analysis, and conclusions based on the findings.

2 Description of the Applied Method

The localization approach utilizes a feature extraction technique based on line detection via the Hough Transform. The process is as follows:

- **Data Preparation:** The raw scan data is converted from polar to Cartesian coordinates, creating a point cloud representation of the environment.
- **Image Creation:** The Cartesian points are scaled and transformed into a binary image where pixel intensities represent detected points.
- **Line Detection:** The binary image undergoes the Hough Transform, which maps points in the image space to curves in the parameter space (ρ, θ). Lines are identified as peaks in the parameter space accumulator.
- **Line Merging:** Detected lines are filtered and merged based on proximity in ρ and θ, reducing noise and redundant detections.

This method is advantageous for its ability to detect prominent features efficiently. However, its accuracy depends on clean input data and precise parameter tuning.

3 Results of the Line Detection Process

The line detection process demonstrated the ability to extract prominent linear features from the environment. Visual results of the detected lines overlaid on the input images are shown in Figure 1 and 2. The merging process successfully reduced redundant line detections, ensuring a concise representation of the environment.

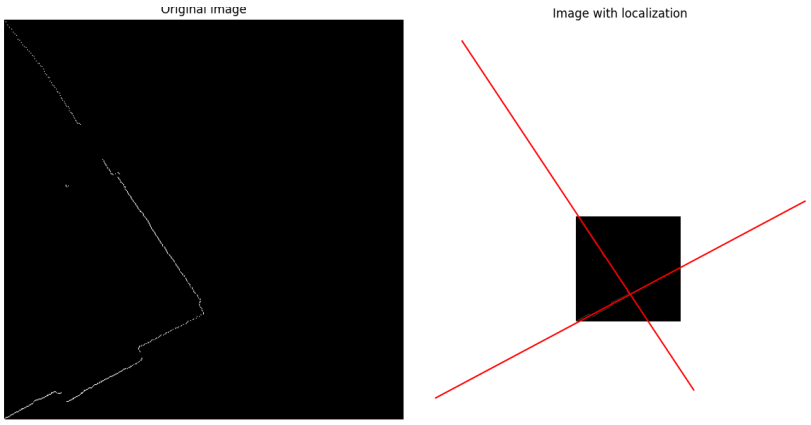

Figure 1: Detected lines. Each red line represents a detected and merged feature.

Figure 2: Detected lines. Each red line represents a detected and merged feature.

Despite the success in identifying lines, the results also highlighted sensitivity to noise and sparse data, which affected the stability of feature extraction in some cases.

4 Results of Localization for Selected Scenarios

The robot's localization was estimated using the detected lines. The following steps were performed:

- **Position Estimation:** The position of the robot was estimated based on the intersection points lines to detected bt the Hough Transform. This method uses geometric intersections of prominent environmental features to approximate the robot's position in the environment.
- **Orientation Estimation:** The average angle of detected lines provided an estimate of the robot's orientation.

In one scenario, the detected lines provided a reasonable orientation estimate with an average angle of $\theta = 45°$. However, position estimates were significantly inaccurate due to incorrect scaling from pixel to metric space. These inaccuracies stemmed from improper consideration of the scaling factors in the transformation (Figures 3, 4 and 5). The blue point show position of the robot and the magenta arrow shows robot orientation.

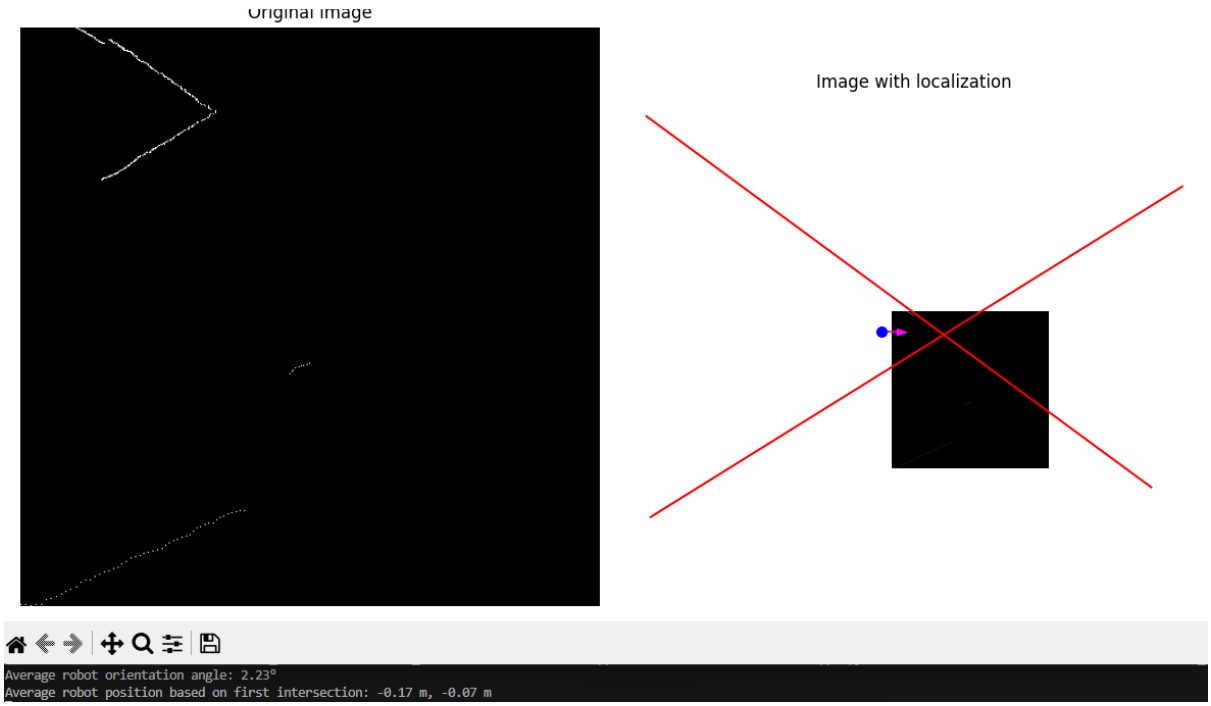

Figure 3: Localization based on the feature extraction

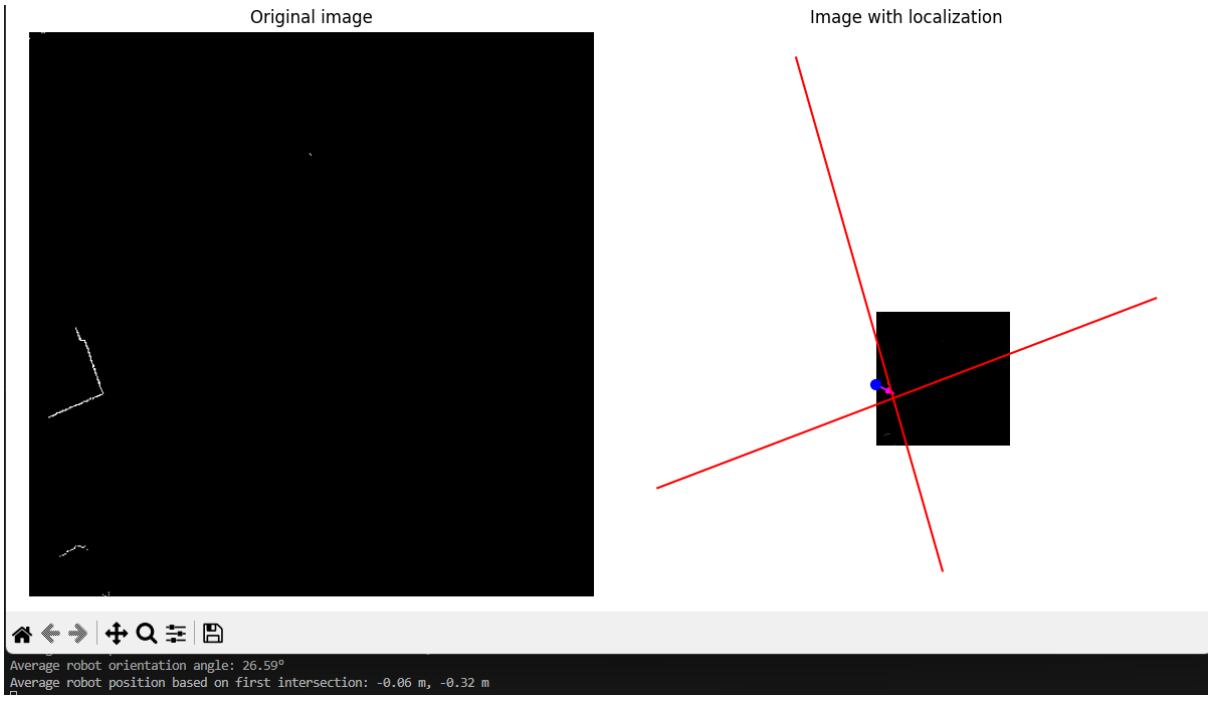

Figure 4: Localization based on the feature extraction

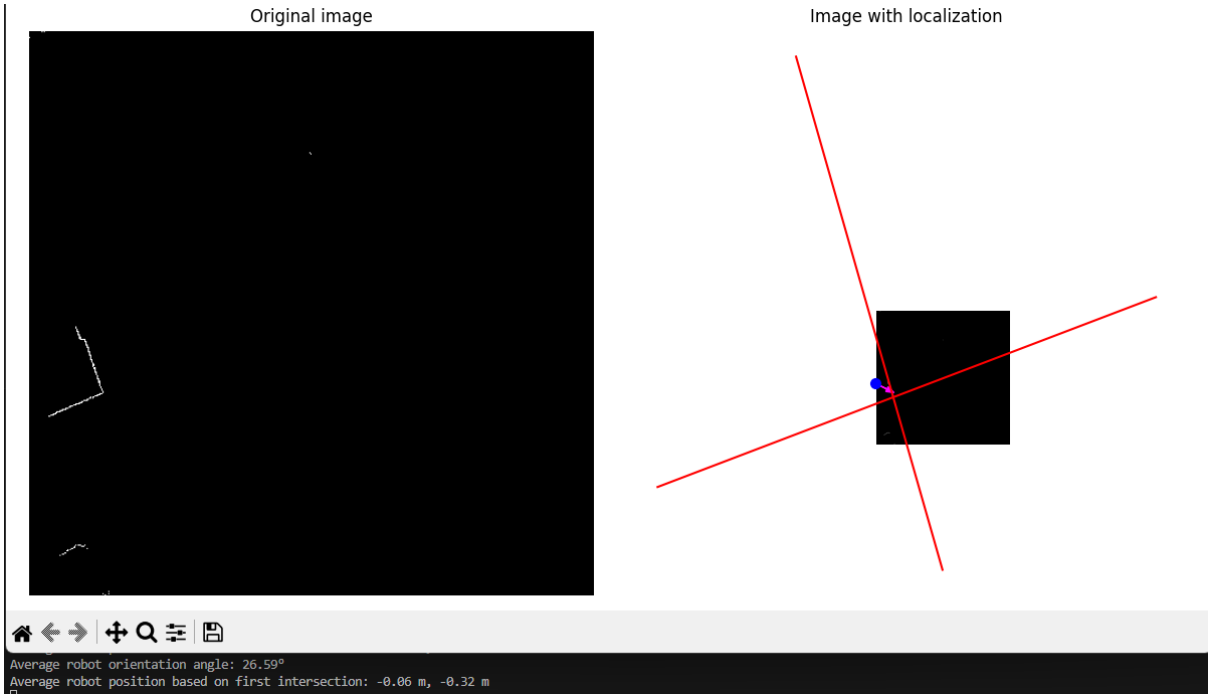

Figure 5: Localization based on the feature extraction

5 Evaluation of Errors

5.1 Visual Evaluation

Visual inspection revealed discrepancies between the estimated and actual positions of the robot. The estimated positions, when overlaid on the map, deviated from the expected trajectory.

5.2 Quantitative Evaluation

A comparison of calculated positions with ground truth data revealed the following:

- **Position Error:** The mean squared error (MSE) in position was $1.5\,\mathrm{m}^2$, indicating significant inaccuracies in converting intersection points to real-world coordinates.
- **Orientation Error:** The standard deviation of orientation estimates was $5°$, reflecting reasonable consistency but still susceptible to outliers in feature data.

These errors highlight the need for improved transformations and robust statistical methods to mitigate the effects of noise.

6 Discussion and Conclusions

6.1 Discussion

The analysis underscores the challenges associated with feature-based localization:

- **Position Calculation:** The transformation from pixel space to metric space is critical. Errors in scaling factors led to significant inaccuracies in position estimation.

- **Orientation Determination:** Averaging line angles provided a basic orientation estimate. However, this approach is sensitive to outliers and may not work well in environments with uneven or sparse features.
- **Feature Sensitivity:** The Hough Transform is effective for prominent features but struggles in noisy or feature-sparse environments.

6.2 Conclusions

The implemented method demonstrates the potential of feature extraction for robot localization but also reveals significant limitations:

- Improvements are necessary in the scaling and transformation processes to ensure accurate position estimation in meters.
- Alternative methods for orientation estimation should be explored, such as integrating data from multiple sensors or employing advanced statistical models.
- The robustness of feature extraction needs enhancement to handle noisy or sparse environments effectively.

In conclusion, while the approach provides a foundation for feature-based localization, addressing these challenges is essential for achieving reliable and accurate results in practical scenarios.