AMR TEAM 03

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***Abstract*—This project explores the implementation of autonomous navigation on the Robile platform. We focus on path and motion planning, localization, and environment exploration. A* is used as the global path planner, while the potential-field method is used for local obstacle avoidance. Monte Carlo Localization (MCL) will be implemented for accurate localization, and a frontier-based exploration approach will be integrated for environment discovery. The system is first tested on simulation and eventually in real-world scenarios, using ROS2 for execution and deployment.**

***Index Terms*—A* Potential Field Method Particle Filter Monte Carlo Localization (MCL) Environment Exploration**

I. Introduction

Robotic systems have become increasingly vital in autonomous navigation, mapping, and exploration tasks across various domains, from industrial settings to search and rescue missions. For a robot to operate efficiently in an unknown environment, it must be able to map its surroundings, localize its position within the map, navigate through the environment, and explore unmapped regions. This project leverages the Robot Operating System 2 (ROS2) to implement a series of processes that enable a robot to progressively map and navigate a partially known environment while autonomously exploring unexplored areas. The project is organized into four milestones, each focusing on a critical aspect of robotic exploration: mapping, navigation, localization, and exploration. This report details our implementation process, highlighting the techniques used for each milestone, the challenges encountered, and the solutions employed to ensure successful execution in a real- world scenario.

II. Mapping

The project is structured around four key milestones—**Mapping, Navigation, Localization, and Exploration**—to enable autonomous robotic operation in a partially known environment.

The first step is generating an occupancy grid map in ROS2, where the environment is represented as a grid of cells classified as free, occupied, or unknown. This serves as the foundation for navigation and exploration.

For seamless communication between the robot and the computer, we configured ROS2's DDS middleware. The network interface was identified using:

```
ip a
```

*Submitted to the Department of Computer Science at Hochschule Bonn-Rhein-Sieg in partial fulfilment of the requirements for the degree of Master of Science in Autonomous Systems

†Supervised by Supervisor 1 (Affiliation) and Supervisor 2 (Affiliation)

‡Submitted in Month 20XX

We updated the ROS2 configuration file to ensure data exchange across devices, then modified the '.bashrc' file with:

```
export FASTRTPS_DEFAULT_PROFILES_FILE=~/
    ros2_network_config.xml
export RMW_IMPLEMENTATION=
    rmw_fastrtps_cpp
```

The robot was accessed remotely via **SSH**:

```
ssh -x studentkelo@192.168.0.103
```

To manually guide the robot during mapping, we connected a **joystick controller**, enabling precise movements to collect environment data. For real-time **visualization**, we used **Rviz2**, setting the ROS domain ID to match our robot's ID:

```
export ROS_DOMAIN_ID=3
```

Rviz2 was then launched with the appropriate configuration file:

```
robile_gazebo/config/robile.rviz
```

This allowed us to track the robot's movement and monitor the generated map dynamically.

Once a sufficient portion of the environment was mapped, the data was saved using the **mapserver package** and transferred to a local server for later use in navigation and exploration:

```
scp studentkelo@192.168.0.103:/path/to/
    map /local/path
```

This stored map will be crucial in later stages, enabling autonomous path planning, localization, and efficient environment exploration.

III. Path and Motion Planning

In this milestone, we focused on enabling the robot to navigate efficiently through a known environment using a combination of global and local planning methods. To achieve this, we used the A* algorithm for global path planning and integrated it with a potential field method for local motion planning. The global path planning was responsible for generating an optimal path from the robot's current position to the desired goal, taking into account obstacles and free spaces on the map. The map, which was created in an earlier milestone, was processed using image dilation techniques to inflate obstacles, ensuring the robot maintained a safe distance from them. This path generation process involved transforming the robot's position and the goal's position from real-world coordinates to grid indices, which the A* algorithm then used to find the shortest path. Once the global path was generated, we realized that the raw path often contained unnecessary waypoints, leading to inefficient movements. To resolve this, we implemented a path simplification process where we removed collinear points and reduced the number of waypoints by selecting every nth point in the path. This simplified path allowed the robot to move more smoothly and reduced computational load. For local motion planning, we implemented the potential field method. This method involved calculating attractive forces pulling the robot towards the next waypoint, and repulsive forces pushing it away from nearby obstacles. The robot used real-time laser scan data to detect obstacles and adjust its movement dynamically. These forces dictated the robot's linear and angular velocities, enabling it to move towards the goal while avoiding collisions. During the early stages, the robot encountered challenges with getting stuck in local minima due to the nature of potential fields. We addressed this by adjusting the force parameters and introducing some randomness in the robot's motion when it detected stagnation. We also had to fine-tune the balance between attractive and repulsive forces, as initial settings either made the robot too sluggish or caused it to react too aggressively to obstacles. After several iterations, we found optimal values that ensured smooth and responsive navigation. In the end, we successfully integrated the global A* path planner with the local potential field motion planner. The robot was able to navigate through complex environments, avoiding obstacles and efficiently reaching its goal. The path simplification process played a crucial role in improving the robot's movement, ensuring it followed the planned route without unnecessary deviations.

IV. Localization

V. Environment Exploration

A. Problem Statement

Describe the problem you are addressing in the work.

B. Proposed Approach

Write a short summary of your proposed approach.

VI. Related Work

Summarise the relevant related work in this section and position your work with respect to the related work.

VII. Background

This is an optional section in which you can introduce concepts, terms, or methods that are important for understanding your approach and that would not directly fit in Sec. VIII. If you do not need this section, comment out the respective line in *report.tex*.

VIII. Methodology

Describe all conceptual details about your approach in this section. Add any necessary subsections to improve the presentation.

Feel free to rename this section to better reflect the concrete topic you are discussing.

IX. Evaluation

If your work involved experiments, describe the experimental setup and the results in this section.

X. Conclusions

A. Summary

B. Contributions

C. Future Work

References

ACKNOWLEDGMENT

Write your acknowledgments here.

STATEMENT OF ORIGINALITY

[If AI assistants have not been used, use this sentence] I, the undersigned below, declare that this work has not previously been submitted to this or any other university and that it is, unless otherwise stated, entirely my own work.

[If an AI assistant has been used, use this sentence] I, the undersigned below, declare that this work has not previously been submitted to this or any other university and that it is, unless otherwise stated, entirely my own work. The report was, in part, written with the help of the AI assistant [AI assistant name] as described in the appendix. I am aware that content generated by AI systems is no substitute for careful scientific work, which is why all AI-generated content has been critically reviewed by me, and I take full responsibility for it.

Date	Signature

Appendix

Please limit the main part of the report to 20 pages (not including the references, the statement of originality, and the appendix).

In your appendix, you can add any additional details about your work, such as:

- extra results that do not necessarily belong in Sec. IX
- more detailed justifications of certain algorithm design decisions
- algorithm proofs

Additionally, in the case of using AI assistants, describe in detail what content was generated using an AI assistant. In particular, name the AI assistant(s) that you used and how they were used (e.g. which prompts were used, and for which parts of the project).