Path Planning of a Mobile Robot with Real-Time Feedback from Mounted Camera and Lidar Sensors

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***Abstract*—This project tackles the challenge of dynamic path planning for mobile robots navigating alongside humans in shared environments. It proposes a novel method that leverages real-time sensor fusion from mounted camera and LiDAR sensors to create a dynamic potential field for safe and efficient robot motion. This approach builds upon existing potential field methods (PFMs) while addressing their limitations in dynamic environments through sensor fusion techniques. By incorporating high-fidelity 3D information from LiDAR for the static environment and real-time human detection capabilities from a camera, the system creates a comprehensive and dynamic environmental representation. This fused sensor data is then utilized to update the potential field in real-time, enabling the robot to navigate safely and efficiently around both static and dynamic obstacles, particularly humans. The project will be conducted in four phases, focusing on sensor integration and data fusion, dynamic potential field adaptation, path planning with robot control, and finally, evaluation and refinement in both simulated and real-world environments. The successful development of this system has the potential to significantly improve mobile robot navigation in dynamic human-shared spaces, paving the way for broader applications in various domains.**

I. Introduction

The revolution in mobile robotics demands a paradigm shift in navigation. We need robust and adaptable strategies to navigate the complex and dynamic world around us. These robots increasingly operate alongside humans in workplaces, hospitals, and even homes, presenting a significant challenge for traditional path planning methods. Algorithms like Dijkstra's algorithm and A* rely on pre-built static maps, rendering them ineffective when faced with moving obstacles such as people [1].

Potential field methods (PFMs) offer an attractive alternative due to their simplicity and computational efficiency. However, classic PFMs suffer limitations in dynamic environments because they pre-compute a potential field based on a static map, essentially treating the environment as unchanging [2]. This static representation fails to capture the real-time nature of human movement, potentially leading to collisions or inefficient navigation.

Researchers have explored advancements to address this limitation. One approach utilizes LiDAR sensors for real-time obstacle detection, allowing for dynamic updates to the potential field based on the changing environment [3]. Additionally, camera-based methods for human detection and path adaptation have been proposed, further enhancing robot navigation in dynamic situations.

This project builds upon these efforts by proposing a novel approach to dynamic path planning for mobile robots. It leverages a hybrid sensor fusion technique that combines the strengths of both LiDAR and camera data. LiDAR offers high-precision 3D information of the static environment, while cameras excel at real-time object recognition, particularly humans. By fusing this sensor data, the project aims to create a comprehensive and dynamic environmental representation that adapts to the presence of moving obstacles. This real-time sensor feedback will be utilized to update the potential field dynamically, enabling the robot to navigate safely and efficiently alongside humans in shared environments.

Citations:

- Khatib, O. (1986). Real-time obstacle avoidance for manipulators and mobile robots. The International Journal of Robotics Research, 5(1), 90-98.
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Key components of the project includes:

- **Sensor Fusion:** We combine data from multiple sensors (camera and LiDAR) to create a comprehensive representation of the robot's surroundings. Sensor fusion techniques enhance the accuracy of obstacle detection and localization.
- **Dynamic Path Planning:** Our system continuously updates the robot's path based on real-time sensor feedback. As the robot moves, it reevaluates its route, considering obstacles, terrain, and other dynamic factors.
- **Obstacle Avoidance:** The robot actively avoids collisions with obstacles by adjusting its path. When an obstacle is detected, the planner recalculates a safe trajectory, ensuring smooth navigation.
- **Goal-Driven Navigation:** We define clear goals for the robot, such as reaching a specific location or following a predefined path. The path planner optimizes the route while adhering to these goals.
- **Real-Time Execution:** Our system operates in real-time, allowing the robot to adapt swiftly to changes in the

environment. The combination of sensor feedback and path planning ensures efficient and safe navigation.

II. Work Done

A. Simulation Environment Setup

A simulated 3D environment constructed in MATLAB featuring a floor and walls to simulate a robot's operating environment. The environment is represented as a binary occupancy map, with occupied regions marked as 1 and unoccupied areas as 0. Additionally, the map is inflated to accommodate the robot's dimensions, ensuring conservative collision avoidance. This setup is a foundational step for environment setup, subsequent path planning, and navigation algorithms.

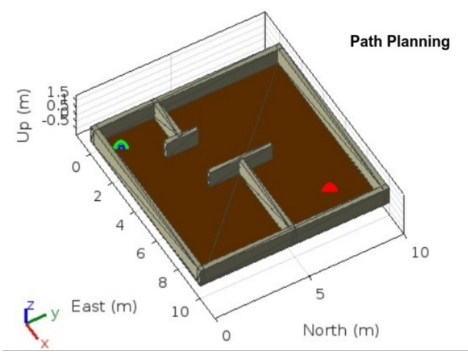

Fig. 1. Enviroment creation in MATLAB

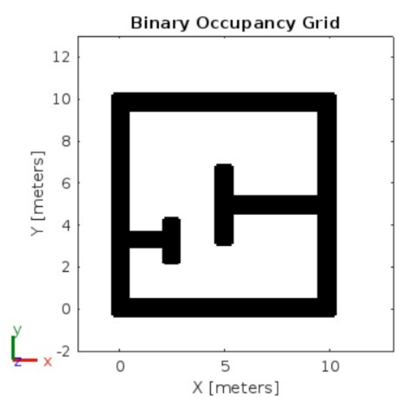

Fig. 2. Occupancy grid of enviroment

B. Literature review of Sensor Integration and Data Fusion Algorithm Design

SLAM framework for autonomous vehicles using 2D LiDAR and depth vision sensors aims to improve obstacle detection in complex environments by fusing data from both sensors.The overall process of the algorithm is mainly divided into the following parts

1) **Sensor calibration and Data processing:** The depth camera data is processed to convert into laser data for sensor data fusion. This conversion involves several steps: screening the depth image for the effective area to be processed, obtaining the position coordinates of each pixel in the world coordinate system, and projecting the spatial point cloud into the corresponding laser scanning range. The converted laser data is represented by dividing the laser beam into N parts and calculating the distance from the camera's light spot center to the point on the x-axis.

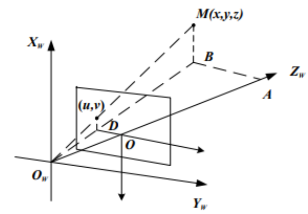

Fig. 3. Depth to laser conversion

2) **EKF Data Fusion:** Data fusion based on Extended Kalman Filter (EKF) is employed to improve mapping accuracy by combining depth camera and LiDAR data. The EKF process involves forecasting the next moment's pose using current data, associating data from both sensors to prevent mismatching, and updating the predicted pose using measurements from both sensors.

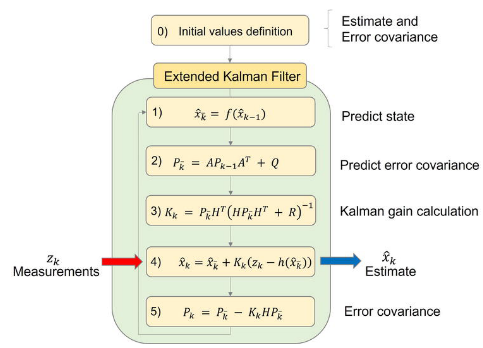

Fig. 4. Representation of the extended Kalman filter algorithm

3) **Map construction:** Map construction and loop closure detection utilize graph optimization algorithms. Loop closure detection involves matching current laser point cloud information with the sub-map using the Iterative Closest Point (ICP) algorithm to detect loop closures. The detection process involves judging the similarity between the relative positions of the robot in the laser point cloud and the carrier in the sub-map. Detected loop closures are then optimized and corrected to complete the loop closure detection process.

C. Potential field Algorithm development

The Potential Field algorithm is used in the path-planning method that operates by creating an artificial potential field. The goal location exerts an attractive force on the robot, and obstacles exert a repulsive force. The robot navigates by following the gradient of the potential field. Here are the equations used in the algorithm:

1) **Attractive Potential:** The attractive potential pulls the robot towards the goal. It is calculated using the equation:

$$U_{\text{att}}(x, y) = -\frac{1}{2} \times KP \times \sqrt{(x - x_{\text{goal}})^2 + (y - y_{\text{goal}})^2}$$

where KP is the attractive potential gain.

2) **Repulsive Potential:** The repulsive potential pushes the robot away from obstacles. It is calculated using the equation: where ETA is the repulsive potential gain, and

$$U_{\text{rep}}(x, y) = \begin{cases} \frac{1}{2} \times ETA \times \left(\frac{1}{\sqrt{(x - x_{\text{obs}})^2 + (y - y_{\text{obs}})^2}} - \frac{1}{RR} \right)^2 & \text{if } d \leq RR \\ 0 & \text{otherwise} \end{cases}$$

rr is the robot's radius

3) **Total Potential:** The total potential at a position is the sum of the attractive and repulsive potentials. The robot moves to the position with the lowest potential
4) **Path Planning:** The robot iteratively moves to the neighboring position with the lowest potential until it reaches the goal

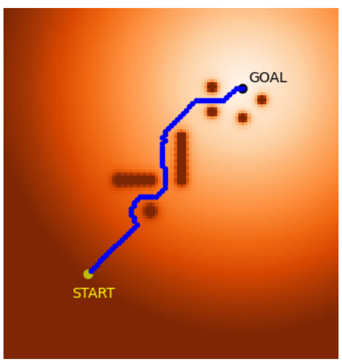

Fig. 5. Obstacle avoidance using Potential field

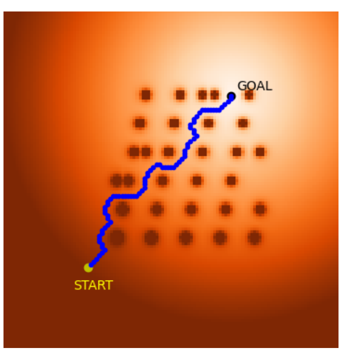

Fig. 6. Obstacle avoidance using Potential field in Complex environment

5) **Oscillation Detection:** The algorithm includes a mechanism to detect oscillations (when the robot gets stuck moving back and forth between positions). If an oscillation is detected, the algorithm breaks the loop.

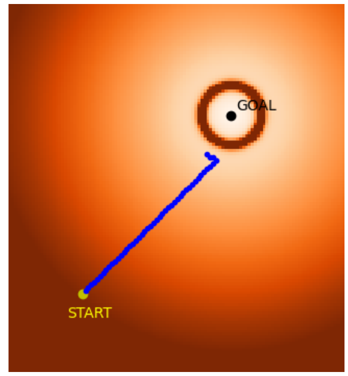

Fig. 7. Oscillation Detection

III. Future Work

1) Construction of dynamic environment in MATLAB
2) Implementation of current path planning algorithm developed in a dynamic environment
3) Extend literature review of sensor integration and data fusion to implementation using MATLAB's Robotics System Toolbox.
4) Evaluate the performance of the proposed system extensively in the simulated environment with varying configurations of dynamic obstacles
5) Identify potential issues for improvement before transitioning to real-world testing

IV. Contributions

- Abhishek Kumar:
  - Literature review of data fusion algorithm design, focusing on sensor integration and occupancy grid fusion for dynamic obstacle detection.
  - Potential field path planning algorithm development for static environment.
  - Exploring different potential field algorithm which can perform better.
- Aditya Kumar:
  - Exploring the design of a dynamic potential field algorithm, focusing on virtual force fields for robot navigation in dynamic environments.
  - Planned to implement algorithms that leverage camera data to create repulsive forces around humans, ensuring safe robot navigation in shared spaces.
- Ravi Joshi:
  - Crated Environment in MATLAB featuring floor and walls.
  - Exploring path planning and robot control algorithms using the dynamic potential field for optimal robot navigation.

- Planned to implement path planning algorithms (e.g., RRT*) in MATLAB Robotics System Toolbox to translate dynamic potential fields into robot motion commands.
- All Members:
  - Collaborating on simulation testing and evaluation, working together to evaluate the performance of the proposed system in simulated environments with varying configurations of dynamic obstacles and movement patterns.

V. Conclusion

During the mid-term period, significant progress has been made towards developing a path-planning system for a mobile robot that integrates real-time feedback from mounted cameras and LiDAR sensors. The project has successfully achieved several key milestones, including the construction of a virtual environment in MATLAB. The next steps are the integration of simulated LiDAR and camera sensors, as well as the development of sensor fusion and dynamic potential field adaptation algorithms. Currently, work has been started to develop the dynamic potential field adaptation algorithm which effectively guides the robot's path, considering both attractive and repulsive forces, based on the sensor data.

The next steps in the project will also include further refining the algorithms, integrating them with the robot's control system, and conducting extensive simulation testing and evaluation. The final system will be evaluated based on metrics such as path optimality, efficiency, collision avoidance, and human-robot interaction to assess its effectiveness in handling dynamic environments.

The significance of this project lies in its potential impact on the field of mobile robotics. By developing a path planning system that can adapt to dynamic environments in real-time, the project aims to advance the capabilities of mobile robots in various applications, including surveillance, search and rescue operations, and autonomous transportation. T

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