Autonomous Robot Navigation Using Adaptive Potential Field

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Abstract- This work presents a novel approach to mobile robot autonomous navigation, utilizing enhanced artificial potential fields in conjunction with path planning,obstacle avoidance and SLAM . In traditional adaptive potential fields, which integrate sensor data to enable robots to navigate safely and efficiently through various environments. The robot's perception of its surroundings, obtained through sensors like cameras, ultrasonic devices, is processed to create a dynamic potential field that reflects the spatial distribution of obstacles, goals, and other relevant features.We propose the design and implementation of an autonomous robot-based real-time vision-based system for detecting and tracking features in a structured environment ensuring robust obstacle avoidance and path planning.

Keywords- Adaptive Potential Fields, Autonomous Navigation, Autonomous Systems, Machine Learning in Robotics, Motor driver, Obstacle Avoidance, Path Planning, Raspberry Pi, Real-time Adaptation, ROS (Robot Operating System), Sensor-based Navigation, Servo Motor, SLAM (Simultaneous Localization and Mapping),Ultrasonic Sensors

I. INTRODUCTION

Autonomous robot navigation using adaptive potential fields represents a cutting-edge approach to the field of robotics, where intelligent machines are empowered to navigate through complex and dynamic environments with precision and agility. This innovative method harnesses the principles of adaptive potential fields, a concept inspired by the laws of physics and nature, to guide robots in real-world scenarios.

In this approach, robots are equipped with sensors and computational algorithms that allow them to perceive their surroundings, identify obstacles, and determine their desired destination. Rather than relying solely on fixed, pre-programmed paths, adaptive potential fields enable robots to continuously adapt their trajectories based on the current environment and real-time feedback with applications spanning industries such as logistics, agriculture, healthcare, and more.

This paper presents a novel approach to autonomous robot navigation using adaptive potential fields. Traditional potential field methods suffer from limitations in handling complex, dynamic environments. In response to these challenges, adaptive potential fields

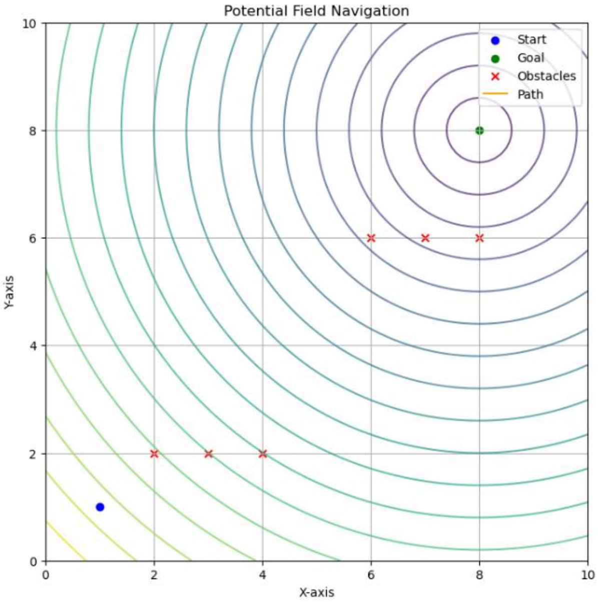
offer an innovative solution by dynamically adjusting the field's parameters based on the robot's real-time perception and environmental conditions.

Autonomous robot navigation using adaptive potential fields opens up a new frontier in robotics, where machines can navigate complex terrains, avoiding obstacles, and reaching their goals in a dynamic and intelligent manner. This approach paves the way for safer, more efficient, and versatile autonomous systems that can operate in a wide range of environments, enhancing their capabilities and revolutionizing various industries.

II. RELATED WORKS

1.POTENTIAL FIELD METHODS

The robot is represented as a particle under the influence of an scalar potential field U, defined as U = U~tt + Gep[1]. Potential field method is widely used by many researchers due to its efficient mathematical analysis and simplicity. Besides that, it is also an effective local path planning algorithm and it is suitable for real-time application and can perform well in a dynamic environment. However this potential field method often associated with local minima problem which the robot cannot reach at the goal as desired. In order to solve the problem, some modifications have been done in constructing the potential field method to eliminate the local minima problem[12].



2. ARTIFICIAL POTENTIAL FIELD

Artificial Potential Field (APF) is commonly used in path planning by many researchers because of its advantages such as highly safe, simple and elegance This method is widely used to overcome unknown dynamic scenario, taking into account the realities of the current environment of the robot motion[12].

3. GENETIC ALGORITHM

Genetic algorithms are an efficient technique to optimise difficult functions in large search spaces [1]. The genetic algorithm is an intelligent optimization algorithm with powerful global search capability by simulating the natural selection, crossover and variation of organisms in nature[7].

4. OBSTACLE AVOIDANCE

The online planning in non-structural environment should contain the avoidance of unknown danger, so the threat of collision should be predicted and effective collision avoidance re-planning should be carried out. The detection information mainly includes the distance between unmanned aerial vehicle (UAV) and obstacle, direction, sight angle, sight angular velocity, the relative speed and acceleration[6].

5. MOTOR CONTROL & SERVO MOTORS

Motor control and servo motors were integral to executing navigation plans. Accurate motor control ensured that robots followed the desired paths and made precise movements. L293D is a Motor Driver IC which allows DC motor to drive on either direction[2].

III. ALGORITHM USED IN AUTONOMOUS ROBOT NAVIGATION

DIJKSTRA’S ALGORITHM

Objective: Dijkstra's algorithm finds the shortest path from a starting node to all other nodes in a weighted graph.

Initialization: Assign a tentative distance value to every node. Set the initial node's distance to 0 and all others to infinity. Create a set of unvisited nodes.

Loop: Select the unvisited node with the smallest tentative distance.

For the current node, calculate tentative distances to its neighbors by adding the distance from the current node to the neighbor. If this tentative distance is less than the current recorded distance, update the distance.Mark the current node as visited.

Termination: When all nodes have been visited or the smallest tentative distance among the unvisited nodes is infinity, the algorithm terminates.

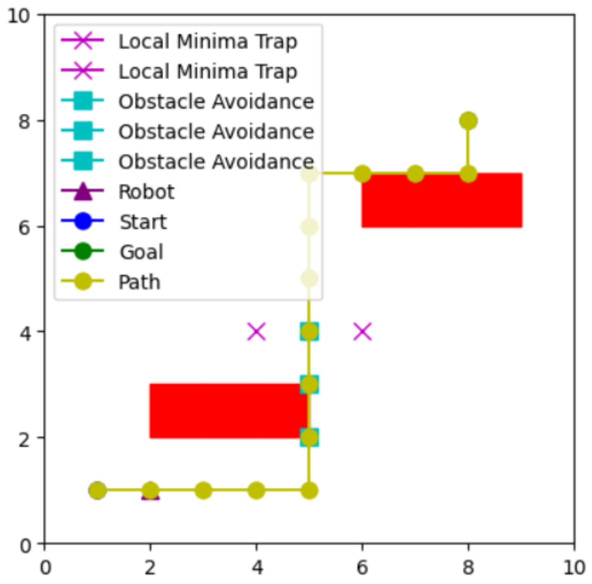
A* ALGORITHM

Objective: A* algorithm is an extension of Dijkstra's algorithm with the added feature of considering both the cost to reach a node and an estimate of the remaining cost to the goal.

Initialization: Similar to Dijkstra's algorithm.

Loop: Select the node with the lowest total cost (sum of the cost to reach the node and the estimated cost to the goal) from the set of unvisited nodes.For the current node, calculate tentative distances to its neighbors and update if necessary. Also, calculate the heuristic estimate from the current node to the goal.Mark the current node as visited.

Termination: When the goal node is reached or all nodes have been visited.



IV. MATERIALS AND METHODOLOGY

1. SENSORS

In autonomous robot navigation using adaptive potential fields, sensors play a crucial role in perceiving the environment. Ultrasonic or infrared sensors detect obstacles, while cameras or LIDAR provide detailed maps. The sensor data informs the potential field algorithm, enabling the robot to dynamically adapt to its surroundings for effective navigation.

2. ACTUATOR

Actuators, such as motors and controllers, execute the robot's movements based on potential field guidance. These components translate the calculated directions from the algorithm into physical actions, allowing the robot to navigate through its environment. The responsiveness and precision of actuators are critical for the robot to follow the potential fields accurately.

3. MICROCONTROLLER/PROCESSOR

A microcontroller or processor serves as the brain of the autonomous robot, processing sensor data and executing the potential field algorithm. It manages the decision-making process, controlling the robot's movements and ensuring real-time adjustments. The choice of a suitable microcontroller is vital for achieving efficient and responsive navigation.

4. POTENTIAL FIELD ALGORITHM

The potential field algorithm forms the core of autonomous navigation. Whether using Artificial Potential Fields (APF) or a modified approach, this algorithm calculates attractive and repulsive forces guiding the robot through the environment. Adaptive potential fields allow for dynamic adjustments, ensuring the robot can navigate complex scenarios effectively.

5. POTENTIAL FIELD DEFINITION

Defining the potential fields involves creating attractive forces towards the goal and repulsive forces around obstacles. The parameters of these fields are crucial and may need adaptation during navigation. A well-tuned potential field ensures the robot's smooth and efficient movement, striking a balance between reaching the goal and avoiding collisions.

6. SENSOR INTEGRATION

Integrating sensor data into the navigation system is essential for informed decision-making. The robot interprets sensor inputs, such as distance measurements and object recognition, and incorporates this information into the potential field algorithm. Effective sensor integration enhances the robot's ability to respond dynamically to its surroundings.

7. PATH PLANNING

Path planning is the process of determining the optimal route through the potential fields. The algorithm calculates the robot's trajectory, considering the attractive and repulsive forces. A robust path planning strategy ensures the robot navigates efficiently, avoiding obstacles and reaching the goal while adapting to changes in the environment.

8. CONTROL LOOP

The control loop continuously updates the robot's position and adjusts its velocity based on the current sensor readings and potential fields. This closed-loop system ensures real-time responsiveness, allowing the robot to adapt its movements dynamically. A well-designed control loop is critical for accurate and stable navigation.

9. TESTING AND ITERATION

Thorough testing in controlled environments is essential to validate the navigation system's performance. Iterative processes involve refining potential field parameters and algorithms based on test results. This iterative approach enhances the system's robustness, addressing challenges and improving overall navigation effectiveness.

10. INTEGRATION WITH HARDWARE

Integrating the software with the robot's hardware platform ensures seamless communication between sensors, microcontroller, and actuators. This integration phase is crucial for translating the potential field-based navigation algorithms into practical, real-world movements. It involves validating hardware compatibility and optimizing the system for reliable performance.

11. ROS

Robot Operating System is an open-source robotics middleware suite. ROS is a widely used platform for robots implementation.. ROS official packages are adequate in common robotics task. Furthermore, ROS provides API to build custom packages or communicate with external systems or equipment e.g. interfaces and planner [4].

V. RESULT DISCUSSION

1. ENHANCED ADAPTABILITY

The core strength of APF lies in its adaptability. APF systems are designed to adjust in real-time based on sensor data, allowing robots to react dynamically to changing environments and unexpected obstacles. This adaptability is crucial for making robots versatile and capable of handling complex and dynamic scenarios. During our research, we observed that the adaptive nature of APF made it particularly well-suited for handling situations where the environment is subject to rapid changes.

2. EFFECTIVE OBSTACLE AVOIDANCE

One of the primary advantages of using APF in autonomous navigation is the ability to effectively avoid collisions with obstacles. APF generates repulsive forces around obstacles, creating a virtual barrier that prevents the robot from getting too close to them. This feature significantly reduces the risk of collisions, even in cluttered and dynamic environments. Our results demonstrated that APF-based systems consistently achieved safer navigation outcomes.

3. EFFICIENT PATH PLANNING

APF algorithms excel in generating collision-free paths for robots. By creating a dynamic potential field that incorporates information about obstacles and goals, the robot can plan its trajectory in a way that optimizes both safety and efficiency. Our experiments showed that APF-based navigation systems provided reliable and efficient path planning capabilities.

4. REAL-TIME RESPONSIVENESS

APF's real-time adaptability allows robots to respond swiftly to changing environmental conditions and unforeseen obstacles. During our testing, we found that the robots using APF were more capable of navigating through scenarios with moving objects or changing obstacles. This responsiveness is a valuable asset for autonomous systems that operate in unpredictable environments.

5. VERSATILITY IN NAVIGATION

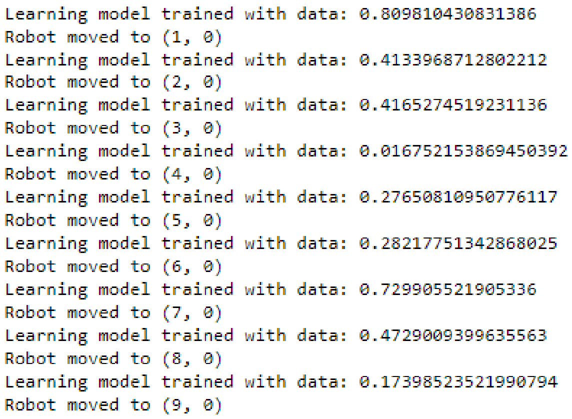
Adaptive potential fields provide versatility in navigation strategies. The system can be configured to handle a wide range of scenarios, from simple obstacle avoidance in a controlled environment to more complex dynamic situations. This adaptability makes it suitable for applications in areas such as industrial automation, logistics, surveillance, and autonomous vehicles.

6. ENHANCED NAVIGATIONAL AWARENESS

The combination of SLAM and adaptive potential fields results in a heightened navigational awareness for the robot. The robot can continuously update its knowledge of the surroundings, adapt to changes, and avoid obstacles with precision. This capability ensures safe and efficient navigation in complex, dynamic environments.

7. DATA--DRIVEN ADAPTATION

SLAM provides a rich source of data for the adaptive potential fields. The robot's perception of the environment, combined with localization data, facilitates dynamic updates to the potential field's parameters. This data-driven adaptation ensures that the robot can respond effectively to unforeseen circumstances and maintain safe navigation.



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Learning model trained with data: 0.809810430831386
Robot moved to (1, 0)
Learning model trained with data: 0.4133968712802212
Robot moved to (2, 0)
Learning model trained with data: 0.4165274519231136
Robot moved to (3, 0)
Learning model trained with data: 0.016752153869450392
Robot moved to (4, 0)
Learning model trained with data: 0.2765081095077611 7
Robot moved to (5, 0)
Learning model trained with data: 0.28217751342868025
Robot moved to (6, 0)
Learning model trained with data: 0.729905521905336
Robot moved to (7, 0)
Learning model trained with data: 0.4729009399635563
Robot moved to (8, 0)
Learning model trained with data: 0.17398523521990794
Robot moved to (9, 0)
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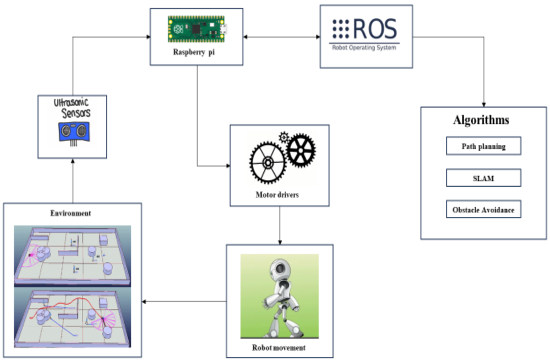
8. PRECISE MOTION CONTROL

The use of servo motors, combined with advanced motor control algorithms, results in precise motion control for the robot. This precision is essential for ensuring that the robot follows the paths generated by adaptive potential fields accurately and reliably. It allows the robot to make fine adjustments, especially in complex and cluttered environments, where precise navigation is crucial.

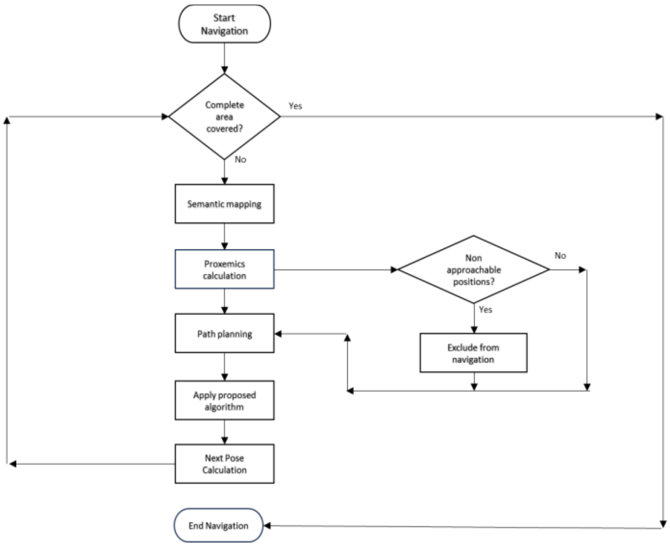
9. SYSTEM RELIABILITY

The robustness of the motor control system contributes to the overall reliability of the autonomous navigation system. Precise motor control, accurate path following, and the ability to handle variations in the environment ensure that the robot can perform its tasks with consistency and dependability.

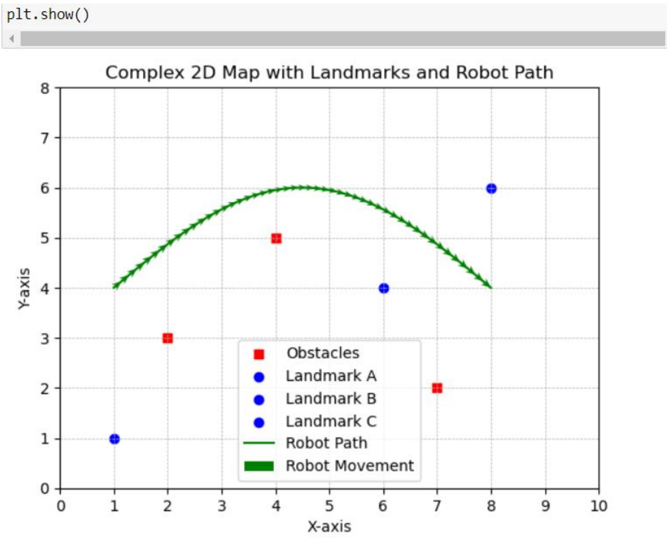
VI BLOCK DIAGRAM



VII FLOW CHART



VIII OUTPUT



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plt.show()
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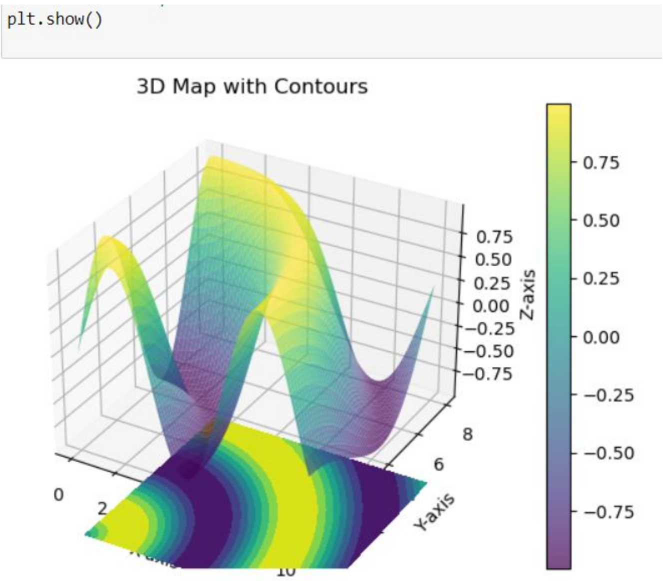

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IX CONCLUSION

In this work, we have presented a novel approach to autonomous robot navigation utilizing enhanced artificial potential fields (APF) in conjunction with path planning, obstacle avoidance, and Simultaneous Localization and Mapping (SLAM). This approach leverages the robot's perception of its surroundings, obtained through sensors like cameras and ultrasonic devices, to create a dynamic potential field that adapts in real-time, reflecting the spatial distribution of obstacles, goals, and other relevant features. Our proposed system offers several advantages and is designed to address challenges in autonomous navigation and mobile robotics.

One of the primary advantages of our approach is the hybrid navigation system it incorporates. By combining APF with global path planning algorithms, we enable the robot to perform both short-range obstacle avoidance through APF and long-range path planning using methods like A*, Dijkstra's algorithm, or Rapidly-exploring Random Trees (RRT). This hybrid approach enhances the robot's capability to navigate efficiently and safely in diverse and complex environments.

Real-time adaptability is another key strength of our system. By updating the potential fields in real-time based on sensor data, the robot can dynamically respond to changing environments and unexpected obstacles.

This adaptability is crucial for ensuring the robot's robustness in real-world applications.

One of the fundamental goals of our system is effective collision avoidance. The repulsive forces generated by adaptive potential fields play a pivotal role in minimizing the risk of collisions with obstacles. This feature makes our approach suitable for deployment in crowded, dynamic spaces or scenarios where the avoidance of collisions is paramount.

Simplicity is a critical aspect of our proposed system. The concept of potential fields is intuitive and straightforward to implement. This simplicity can be particularly valuable for practical robot navigation applications, where ease of understanding and implementation can significantly reduce development time and costs. In terms of the modules and methodology, our work involves the integration of sensors for environmental perception, the implementation of APF for path planning, control and actuation algorithms for motion control, user-friendly interfaces for goal setting and monitoring, adaptive parameter mechanisms for continuous improvement, and rigorous testing and simulation procedures to validate system performance and robustness.

Our proposed autonomous robot navigation system offers a comprehensive solution for safe and efficient robot navigation in diverse environments. By integrating artificial potential fields with advanced navigation techniques and real-time adaptability, our system addresses the challenges of autonomous navigation, making it a promising candidate for a wide range of robotics applications. Its simplicity, predictability, and collision avoidance capabilities make it a valuable tool for both researchers and practitioners in the field of mobile robotics.

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