A CONCISE EXPLORATION OF MOBILE ROBOT NAVIGATION USING VISUAL DATA

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ABSTRACT

This study provides a comprehensive review of mobile robot navigation with a focus on visual data. In the sections that follow, we'll examine the most common methods used for mobile robot navigation and highlight the noteworthy benefits of approaches that rely on visual information. Our main objective is to offer a new viewpoint on mobile robot navigation by contrasting and evaluating many techniques now in use in order to identify the most successful visual-based navigation strategy. We'll start by giving a full explanation of the core ideas guiding autonomous robots and path planning in order to accomplish these goals. Then, after thoroughly classifying these tactics, we will go into navigation strategies designed exclusively for autonomous mobile robots. In addition, we will thoroughly evaluate the strengths and shortcomings of these primary methodologies through a thorough comparison study. We shall choose the approaches that will work best in our particular setting after all.

Keywords: Visual Robotics Navigation, Adaptive Robot Guidance, Visual Autonomy, Command Adaptation, Dynamic Navigation.

I.INTRODUCTION

Robots, which are mechanical contraptions, possess the ability to perform tasks typically undertaken by humans, such as traversing to fulfill specific obligations or manipulating various objects. This eliminates the necessity for human interaction. As time has progressed, the definition of the term "robot" has evolved. Particularly, it was initially introduced in science fiction through the works of Josef and Karel Apek. A contemporary robot is characterized as a self-sufficient system capable of perceiving its surroundings, executing actions, making decisions, and communicating. It consists of a mechanical framework that governs its allowable shapes and movements, as well as sensors and actuators for interacting with its environment. Additionally, it incorporates a control system that analyzes sensor data and strategizes the robot's movements.

Intelligent autonomous robots are indispensable across a multitude of domains, encompassing space exploration, transportation, business operations, and military applications, among others. An autonomous robot must possess the capability to navigate both static and dynamic settings with freedom. The primary objective of mobile robot navigation is to achieve smooth and secure traversal in such environments.

The navigation process of a mobile robot typically comprises five stages: self-localization, path planning, environmental sensing and load assessment, and the execution of predetermined motions. Due to its significance in industrial robot applications, the field of route planning has been extensively explored prior to the widespread availability of mobile robots. It is noteworthy that the challenge of route planning for industrial robots is considerably more complex compared to that encountered by autonomous robots in generally flat terrains. This is primarily due to the increased degrees of freedom possessed by industrial robots.The techniques employed by self-governing robots for path planning are based on those used by industrial robots. It is important to note that autonomous robots are not constrained by the same speed limitations as industrial robots, which often move at high speeds for efficiency and cost-effectiveness. Since many mobile robots move at much slower speeds, route planning can be simplified by disregarding dynamic elements. This simplification has led researchers to explore different navigation planning approaches, as evidenced by an in-depth analysis of navigation strategies suitable for both static and dynamic scenarios in [1]. Real-time navigation scenarios for mobile robots can benefit from the straightforward implementation of these tactics. This study presents a comprehensive review of mobile robot navigation with an emphasis on visual data. In the subsequent sections, we will examine the most commonly used methods for mobile robot navigation and highlight the notable advantages of visual-based approaches. Our primary aim is to provide a fresh perspective on mobile robot navigation by contrasting and assessing the various techniques currently in use, in order to determine the most effective visual-based navigation strategy. We will begin by providing a thorough explanation of the fundamental concepts that guide autonomous robots and path planning, in order to achieve these objectives. Then, after a comprehensive classification of these strategies, we will delve into navigation approaches specifically designed for autonomous mobile robots.

II. BRIEF SUMMARY OF NAVIGATION TECHNIQUES

The existing literature provides a wide range of methods and strategies for guiding independent mobile robots. These navigation techniques can be broadly classified into three main groups: 1. Global methods; 2. Local approaches; 3. Hybrid approaches.

1. Global Methods: These methods are used when we have a thorough understanding of the spatial layout of the travel environment through a map. Starting from an initial point, we plan the most efficient route to the final destination while avoiding obstacles. This offline route planning mode is commonly known as the classical method, as explained in [2].

The most commonly used global navigation methods for mobile robots are [1], [2]:

1.1. Artificial Potential Field (APF) - This technique takes inspiration from nature. It creates an artificial potential field that includes both attractive and repulsive forces. Obstacles are repelled by the repulsive force, while the attractive force guides the robot towards its destination. At each time step, the potential field is calculated at the robot's current position. The main challenge here is the local/global minimum dilemma, where the robot may get stuck at a point where these forces balance each other, hindering further progress.

1.2. Cell Decomposition (CD) - In this method, the navigation environment is divided into non-overlapping cells, and connectivity graphs enable transitions between these cells. The path follows clear cells without obstacles, and if a cell becomes obstructed, it is divided into two new cells - one clear and one obstructed. The clear cell is included in the sequence when determining the optimal route from the starting point to the target. This sequence of clear cells determines the path. There are three variations of this approach: exact, approximate, and adaptive decomposition.

1.3. Roadmap Approach (RA), also known as the highway approach, involves moving from one location to another using one-dimensional curves that connect open spaces. A map guides the route planning process, with nodes playing a crucial role in determining the desired path for the robot. Voronoi diagrams and visibility graphs are used in developing the roadmap approach.

1.4. A* Algorithm (A-star) - This approach represents the route as a graph, where locations are explored until the target location is reached. If the target is not reached, neighboring locations are explored to identify the shortest route. This method has various adaptations and is particularly popular in game pathfinding.

1.5. Dijkstra Algorithm - This technique is used to find the shortest route between any two beginning nodes in a network, making it easier for the robot to plan its routes. The approach is often used to find the shortest path via weighted, directed graphs, where the arcs denote particular costs taken into consideration. In unweighted graphs, when arcs don't have associated costs, the shortest path between two nodes is the one with the fewest arcs.

2. Local Strategies: These strategies operate in an online manner for route planning and use sensory input to navigate when the contextual structure is unknown. In this method, the trajectory is progressively built without

taking a broad view from the beginning to the goal, based on a "local" map inside the sensor's range. These techniques are known as the reactive approach in [2].

The two local navigation methods for mobile robots that are most often used are [1] and [2]:

2.1. Genetic Algorithm (GA) - This technique is used to tackle optimization issues and is modeled after biological evolution. According to their goals, each population member is given coefficients, and individuals are then chosen based on these coefficients, passing on their genetic features to the following generation. Mutation keeps variety intact and prevents early convergence.

2.2. Fuzzy Logic (FL) is a concept that was initially developed by Zadeh in 1965 and is frequently used in circumstances characterized by high levels of complexity, nonlinearity, and uncertainty. It is suitable for managing mobile robots because it uses mathematical counterparts of human-defined rules (If-Then).

Neural Networks (NN), sections:

2.3 This intelligent system is made up of interconnected processing components that mimic organic nerve systems, including the brain. It is made up of synthetic neurons that are linked together to create certain results. Neural networks are particularly appropriate for dynamic situations since they are built to learn from experience, adapt to received information, and do so.

2.4. Firefly Algorithm (FA): This algorithm, which is based on the behavior of fireflies, uses random trials and error measurement to operate and finds use as an optimization tool for mobile robot navigation.

2.5. Particle Swarm Optimization (PSO) is an algorithm that draws its inspiration from natural phenomena like fish schools and bird flocks. Particles that indicate potential solutions are involved.

Ant Colony Optimization Algorithm (ACO): This algorithm was also influenced by nature and is based on how ants mark their paths using pheromones. For optimum navigation, they use pheromones to indicate the pathways.

2.7. Vector Field Histogram (VFH) - Based on sensor-derived information, this technique uses a safety grid radar screen to identify obstacles and delivers repulsive or attractive forces to the robot. It is appropriate for slow-moving traffic.

2.8. Additional Algorithms - To tackle the problem of robot trajectory optimization, several researchers have presented nature-based metaheuristic algorithms, such as Harmony Search, Cuckoo Search, Simulated Recovery, collision avoidance based on geometric principles, and numerous hybrid techniques. Sensors play a crucial role in gathering environmental input in the context of local approaches. Ultrasonic, laser, and visual sensors are the most widely used types of navigational sensors.

LIDAR, which uses laser-based remote sensing, measures distances, speeds, and signal amplitudes with a resolution of 0 to 40 meters. LIDAR may be used with a camera to improve mapping, localization, and landmark location (SLAM), and it functions independently of GPS.Whether they are global or local, each of these tactics has pros and cons of its own. Hybrid strategies are created as a result of the combination of both approaches in order to achieve optimal navigation. Robot control in hybrid strategies is divided into two hierarchical levels: the higher level is in charge of managing the overall route (using global techniques), and the lower level is in charge of managing the obstacle avoidance and stalemate resolution (using local methods).

When dealing with numerous objectives, hybrid algorithms are extremely helpful. However, it's critical to understand that not all approaches naturally complement one another, and their integration might present fresh difficulties and ambiguities. Performance may be affected as a result, and undesirable outcomes may be obtained.

III. AN IN-DEPTH COMPARATIVE ANALYSIS

A detailed analysis of the main approaches used in robot route planning was carried out, and the results showed a common research focus on reducing computing complexity and speeding up processing times. Researchers carefully analyzed a number of important aspects, including route length, stability, efficiency, and, most importantly, safety, in their quest of the best possible route planning. At first, it was attempted to simplify the complexity by focusing on a single algorithm, but it soon became clear that no one algorithm had the perfect mix of qualities. Hybrid algorithm usage became crucial for achieving top performance. This method improved accuracy, reliability, and system efficiency overall while also reducing reaction times. It is important to remember that hybrid systems may not automatically promise greater outcomes or performance. As a result, scientists are actively looking for a balanced answer that guarantees the best overall performance.

Below is a brief summary of the findings from this in-depth investigation [1], [2], [7], [8], [9], and [10]. This is a succinct summary of the benefits and drawbacks present in some of the algorithms under consideration:

The characteristics:

A* algorithm includes:

- Completeness and determinism.
- Memory-intensive as a result of heavy list usage.
- Best-first search that is not methodical.

Artificial Potential Field (APF) include:

- low computational complexity.
- Adaptability.
- Simplicity of application.
- Ineffectiveness in incredibly restricted settings
- Propensity to become trapped in local minima.

Fuzzy logic's include:

- effectiveness when combined with other algorithms.
- The capacity to simulate control logic used by humans.Creating rules for membership in unstructured contexts may be difficult.

Neural Network include:

- the ability to conduct experiments and simulations in real time.
- The ability to generalize and learn.
- Complexity in controlling several brain layers is a weakness.
- Increasing computational complexity as layer count rises.
- A slower rate of convergence.

Particle swarm optimization's include:

- favorable simulation outcomes.
- Simultaneous implementation is simple owing to low processing complexity.
- Rapid convergence that outperforms fuzzy logic.
- Complex maps' propensity for trapping users in local minima is one of its weaknesses.
- Performance analysis is hampered by the complexity that polygonal object shapes introduce.

Genetic Algorithm includes:

- Produces positive simulation outcomes.
- Exhibits remarkable optimization ability.
- Simple implementation with acceptable results when combined with other methods.
- Dealing with changing situations is difficult.
- Exposure to possible oscillations and local minima issues.

Ant Colony Optimization

- Positive simulation outcomes
- A more straightforward approach that needs fewer control parameters.
- The possibility for synergistic integration with other algorithms.
- Convergence is slower, which is a weakness.

The study draws the following conclusions in [2]:

- Reactive techniques have an advantage over conventional ones due to their improved flexibility in controlling environmental uncertainties.

- Reactive methods should be used to solve problems with real-time navigation.

- When opposed to static environments, investigations on dynamic environments are far less common.

- The bulk of papers generally present simulation-based outcomes, with little real-time research being done.

- The number of publications highlighting hybrid algorithms is significantly lower than that of autonomous algorithms.

CONCLUSION

It's important to note that almost all of the techniques we've already examined and those mentioned in the literature have largely been tested in certain contexts and applications. when a result, when we consider our own applications in the future, we'll need to modify one of these outlined ways to meet our unique requirements. Almost all of the algorithms discussed in parts above use or may be modified to incorporate visual input.

Industrial applications, which are frequently defined by static surroundings, is one area in particular we're thinking about for future growth. Given this situation, it is reasonable to conclude that the Genetic Algorithm is the best technique for our needs. This strategy promises to provide us with the benefits of efficient optimization capabilities and simple implementation, producing favorable outcomes when merged with other algorithms.

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