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A Hybrid Path Planning Strategy for Mobile Robot Navigation Using A* and the Dynamic Window Approach

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INTRODUCTION & AIM

Autonomous navigation of mobile robots has become a key component in various domains such as logistics, agriculture, and industry. Robot autonomy relies on a combination of efficient path planning, obstacle avoidance, and real-time adaptation, even in dynamic and complex environments. Path planning aims to enable a mobile robot to move from a starting point to a target by navigating through an environment containing both static and dynamic obstacles.

Depending on the amount of information available about the environment, path planning can be divided into two categories: global planning and local planning. Global planning assumes full knowledge of the environment, providing the robot with all necessary data to anticipate its trajectory. In contrast, local planning is based on partial or no prior knowledge of the environment and requires real-time adaptation to unforeseen obstacles [1].

With regard to local planning, the Dynamic Window Approach (DWA) offers good performance in real-time obstacle avoidance. However, it may fail to generate optimal paths in complex environments. In particular, DWA tends to fall into local minima, which can reduce the success rate of reaching the target [2].

In this context, this paper proposes a hybrid navigation method that combines the A* algorithm for global planning and the DWA algorithm for local control. This fusion aims to overcome both the limitations related to local optimality and the inability to handle unknown obstacles. Simulation results demonstrate that this approach significantly reduces travel time and collision risks, highlighting the benefits of combining global and local strategies to enhance autonomous navigation for mobile robots.

METHOD

The simulations were performed on an Acer computer running Windows 10, equipped with a 500 GB hard drive and 4 GB RAM, using Python 3.10.11 with numpy 1.26.4 and matplotlib 3.9.2 in the Anaconda environment and Spyder 5.5.1. The simulation environment consists of a 50×50 grid with a differential drive robot navigating among static obstacles, including walls and isolated blocks, with multiple start and goal pairs to create complex scenarios.

The A* algorithm is employed for global path planning, combining the accumulated cost (g(n)) and heuristic estimate (h(n)) to minimize the total cost:

$$f(n) = g(n) + h(n) \qquad (1)$$

where the heuristic (h(n)) is computed as the Manhattan distance:

$$h(n) = |x_{goal} - x_n| + |y_{goal} - y_n| \qquad (2)$$

A* selects the node with the lowest (f(n)) at each step to generate an optimal trajectory while avoiding obstacles in static environments.

For local navigation, the Dynamic Window Approach (DWA) is used, which generates trajectories reactively based on the robot's current state and nearby obstacles. Candidate positions are evaluated using:

$$E(q) = \alpha\, D_{goal}(q) + \beta\, V(q) - \gamma\, D_{obs}(q) \qquad (3)$$

where $D_{goal}(q)$is the distance from the candidate position (q) to the goal, V(q) is the candidate speed, and $D_{obs}(q)$is the distance to the nearest obstacle. Coefficients alpha, beta, and gamma weight the relative importance of these factors.

The hybrid approach integrates A* and DWA to exploit the strengths of both methods. A* computes a global path considering static obstacles, serving as a reference for general movement. DWA locally adjusts the trajectory if unexpected obstacles appear, using its evaluation function to find alternative positions while remaining aligned with the global path. The hybrid cost function is defined as:

$$E_{hybrid}(q) = \alpha\, f(n) + \beta V(q) - \gamma D_{obs}(q) \qquad (4)$$

where f(n) is the A* cost up to the current point. This combination ensures efficient global path navigation with dynamic flexibility, allowing the robot to adapt locally without recomputing the full path, improving both travel efficiency and robustness in complex environments.

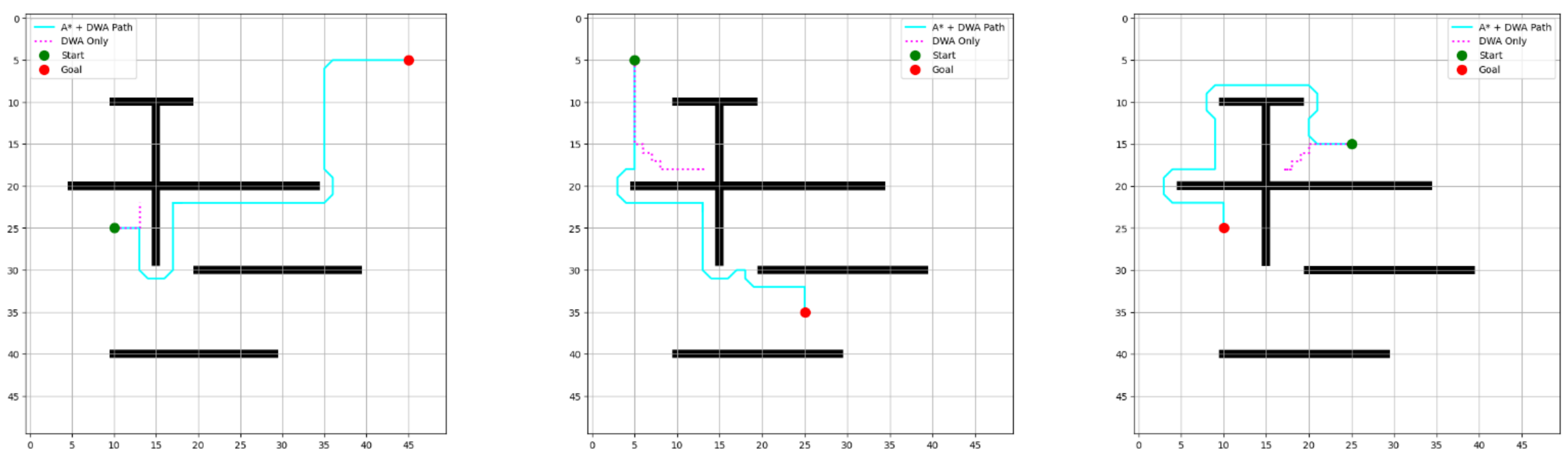
RESULTS & DISCUSSION

Simulations were carried out in a fixed environment containing obstacles (walls). Two scenarios were defined by only changing the start and goal positions in order to fairly compare the performance of the two approaches: DWA alone and the hybrid A* - DWA technique.

Scenario 1: Comparative Performance in a High Risk of Blockage Environment

In this scenario, the start and goal points were deliberately placed in an area with a high risk of blockage, characterized by dead ends and narrow passages likely to induce local traps. The aim is to evaluate each method's ability to avoid these problematic situations and successfully reach the target.

Figure 1 illustrates the trajectories generated by the hybrid method (A* for global planning and DWA for local control) and by DWA alone, in three different configurations:



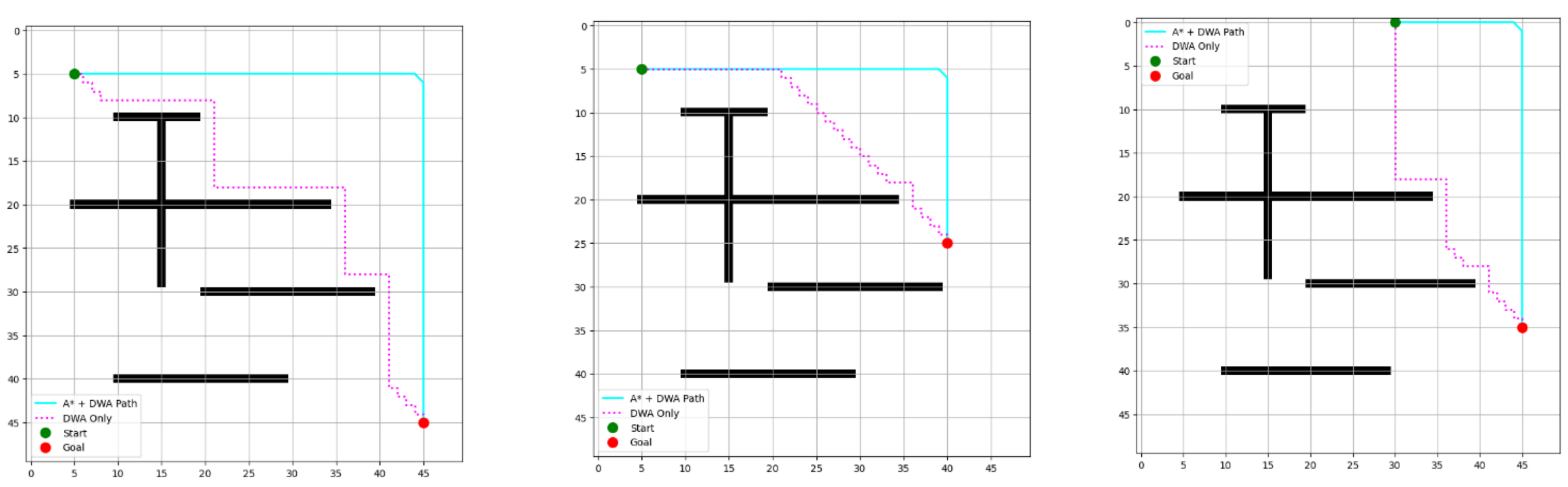
(a) (b) (c)

Figure 1. Trajectory Comparison in a Constrained Environment Using DWA Alone and the Hybrid Method (A*+DWA)

Scenario 2: Trajectory Quality Analysis in a Favorable Case

In this scenario, the start and goal points were repositioned within the same environment as before, but avoiding narrow or trap-prone areas. The objective here is to evaluate the performance of both methods (hybrid and DWA alone) in a simpler context where the risk of blockage is low.

Figure 2 illustrates the different trajectories generated in three favorable configurations:



(a) (b) (c)

Figure 2. Comparative Analysis of Path Planning in an Open Configuration: Hybrid Method (A*+ DWA) vs. DWA Alone

Scenario	Method	Distance (m)	Time (s)
(A)	Hybrid method	79.41	80
	DWA alone	80.11	81.05
(B)	Hybrid method	54.23	54.52
	DWA alone	55.06	55.12
(C)	Hybrid method	49.37	49.96
	DWA alone	49.97	50.94

CONCLUSION

The study demonstrates that a hybrid navigation method, combining A* for global path planning with DWA for local control, outperforms DWA alone. In complex environments, where DWA risks getting trapped, the hybrid approach enables the robot to plan safer and more efficient routes from the start. Even in simpler scenarios, it produces shorter trajectories and reduced travel times. These results highlight the benefit of integrating global planning with local reactivity, improving reliability, speed, and adaptability of mobile robot navigation in semi-structured or cluttered environments, thus enhancing overall autonomy and performance.

FUTURE WORK / REFERENCES

These simulation results suggest promising real-world applications, including implementation on physical robots, adaptive parameter tuning, and multi-robot scenarios with shared global planning and decentralized local control.

[1] SHI, Yongliang, HUANG, Shucheng, et LI, Mingxing. An Improved Global and Local Fusion Path-Planning Algorithm for Mobile Robots. *Sensors*, 2024, vol. 24, no 24, p. 7950.
[2] Prasad, A., Chaudhary, K., Sharma, B., & Ali, A. S. (2024). Robot Path Planning and Motion Control: A Systematic Review. *Engineered Science*, *33*, 1354.