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PRE-FILTERING OF GRID MAPS WITH SKELETONIZATION AND MORPHOLOGY METHOD FOR EFFICIENT PATH PLANNING FOR MOBILE ROBOTICS

Abstract. SLAM-based occupancy grid maps are widely used for indoor mobile robots, but their noise, jagged obstacle borders, and spurious narrow gaps can mislead the classical grid-based path planners, e.g. A* algorithm, causing unstable routes, edge-hugging behavior, and increased computation. This manuscript proposes a lightweight pipeline to improve global path planning robustness and speed in warehouse-like environments. The approach first converts the SLAM map into a conservative binary representation and applies morphological refinement to remove small artifacts and smooth free-space connectivity. Next, the free space is skeletonized and transformed into a graph that captures the topology of navigable corridors. Global path planning is then performed using a hybrid strategy: a local grid search connects the start and goal regions to the skeleton, while the main route is computed on the skeleton graph. Experiments in two warehouse scenarios show that the proposed method substantially reduces node expansions and path planning time compared to full-grid A* algorithm, while producing more physically plausible paths that avoid false passages in noisy maps. These results indicate that morphological and skeleton-based global path planning can serve as a practical solution to enhance efficiency for robust navigation in realistic SLAM based path planning.

Keywords: Warehouse Robotics, SLAM, Occupancy Grid Map, Morphological Filtering, Skeletonization, Graph-Based Path Planning, A* Search.

1. Introduction

Autonomous mobile robots (AMRs) and mobile manipulators are becoming core components of warehouse intralogistics, where robots must navigate narrow aisles efficiently and reliably under limited onboard computation. Recent surveys and industry-oriented studies highlight that, beyond the choice of controller, the quality of the environmental representation and the efficiency of global path planning strongly influence overall system robustness and throughput in real warehouse deployments [1]–[4].

In many ROS-based indoor systems, SLAM-generated 2D occupancy grids remain a practical standard, but they often contain artifacts such as jagged obstacle borders, small spurious gaps, and isolated noisy cells [5]–[7]. These defects are problematic for classical grid-based A* path planning: the search may exploit false connectivity through one-cell passages, generate edge-hugging or irregular routes, and expand many unnecessary nodes, increasing planning time—especially in larger maps or higher resolutions. To address this, this paper proposes a lightweight path planning pipeline for warehouse maps: (i) conservative binarization of the occupancy grid followed by morphological refinement to remove small defects and enforce safe clearance, inspired by morphology-based planning practices [8]; (ii) skeletonization of refined free space and conversion to a compact graph representation for corridor-centered routing [9], [10]; and (iii) a hybrid planning strategy that connects start/goal locally on the grid while computing the main route on the skeleton graph. The goal is to reduce search effort and improve path plausibility in the presence of typical SLAM map noise.

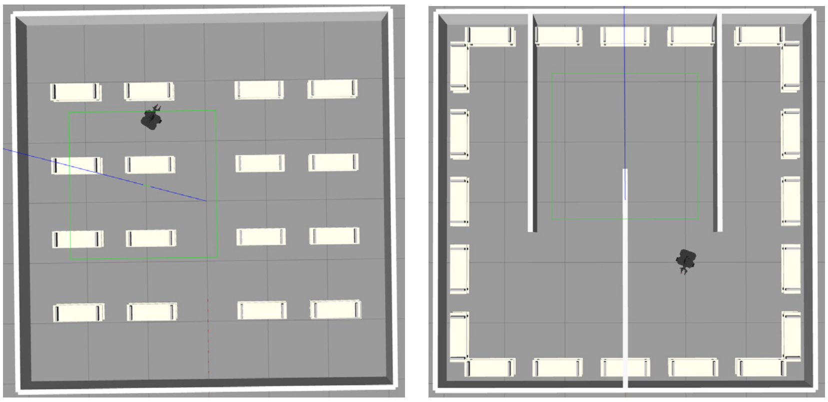
2. Materials and methods

2.1 Experimental Design and Setup

The study compares two global path planning approaches on 2D SLAM occupancy maps: (i) baseline full grid A* and (ii) the proposed hybrid grid–skeleton planner. Experiments were executed in a reproducible ROS/Gazebo simulation pipeline, using standard ROS map messages and a fixed start–goal configuration per scenario [11],

[12], [13]. Experiment will consider 2 cases, where Case 1 without any walls, only shelves and Case 2, where walls included in map A* was selected as the baseline due to its widespread use in robotics navigation as an optimal heuristic search on graphs [14].

Figure 1
Two compared scenario: (a) Case 1; (b) Case 2



(a) (b)

2.2 Map Input and Conservative Binarization

The input map is a SLAM-produced 2D occupancy grid, a common representation for indoor navigation and path planning [5], [8]–[10]. Each cell is assigned to free, occupied, or unknown. To prevent path planning through uncertain "micro-gaps" and partially observed regions, the grid is converted into a conservative binary map: only confidently free cells are kept as traversable, while occupied and unknown cells are treated as obstacles. This choice prioritizes physical feasibility over optimistic connectivity, which is important when SLAM artifacts are present [5], [8].

2.3 Morphological Refinement of the Binary Map

To reduce the impact of jagged borders, isolated noisy pixels, and spurious narrow connections, the binary map is refined using morphological operators. Specifically:

a) Closing is applied to remove small holes and bridge tiny gaps that are not reliably traversable.

b) Dilation is then applied to introduce a safety margin approximating the robot footprint in grid cells.

Morphological preprocessing is a practical technique for improving the robustness of path planning on occupancy maps without modifying the SLAM backend [15]. Structuring element sizes are selected in grid cells according to map resolution and robot dimensions (i.e., the dilation radius corresponds to the desired obstacle clearance).

2.4 Skeletonization and Skeleton Graph Construction

From the refined free-space mask, a 1-cell-wide skeleton is extracted via thinning/skeletonization to approximate corridor centerlines and preserve the topology of navigable space [16], [17]. Thinning can be implemented using classic fast parallel methods (e.g., Zhang–Suen-type thinning), which are commonly used for skeleton extraction [18].

The skeleton image is converted into a weighted graph G=(V,E):

a) Vertices correspond to junctions and endpoints (pixels with degree ≠2 in 8-neighborhood connectivity).

b) Edges are formed by chains of degree-2 pixels between vertices, with edge weights equal to the geometric length of the chain.

To reduce redundancy, intermediate degree-2 points are compressed into single edges, producing a compact graph suitable for efficient global search [16], [17].

2.5 Path Planning Methods

Baseline (Full grid A*):

A* searches directly on the (refined) binary grid, using 8-connected moves and edge costs proportional to Euclidean step length. The heuristic is the

Euclidean distance to the goal, ensuring admissibility under standard conditions [14].

Proposed (Hybrid grid–skeleton planning):

Planning is performed in three stages:

a) Local grid A* from start to the nearest reachable skeleton vertex,

b) Graph A* on the skeleton graph between skeleton vertices,

c) Local grid A* from the skeleton to the goal.

This design keeps endpoint flexibility (grid search near start/goal) while leveraging a compact topological representation for the main route to reduce the explored state space [16], [17]. The final path is assembled by concatenating the three segments; optional post-processing (e.g., simple shortcutting) can be applied if needed, but the reported results use the direct concatenation to keep comparisons consistent.

2.6 Evaluation Metrics

For each scenario, the following metrics are recorded:

a) Expanded nodes (search effort) for both the grid and graph searches,

b) Planning runtime (ms) measured as wall-clock time for the planning call,

c) Path length (in grid units/pixels) and number of path nodes to characterize the resulting route.

These metrics are standard and directly reflect computational efficiency and route geometry in graph-search path planning on occupancy maps [14], [16].

2.7 Replicability Notes

The full pipeline is reproducible given: (i) an occupancy grid map (ROS nav_ msgs/OccupancyGrid), (ii) robot footprint parameters to set the dilation/clearance, (iii) start and goal coordinates in map frame, and (iv) fixed neighborhood/cost definitions for A*. The morphology and skeleton steps are deterministic for fixed parameters, and the hybrid planner uses the same A* implementation as the baseline for fair comparison.

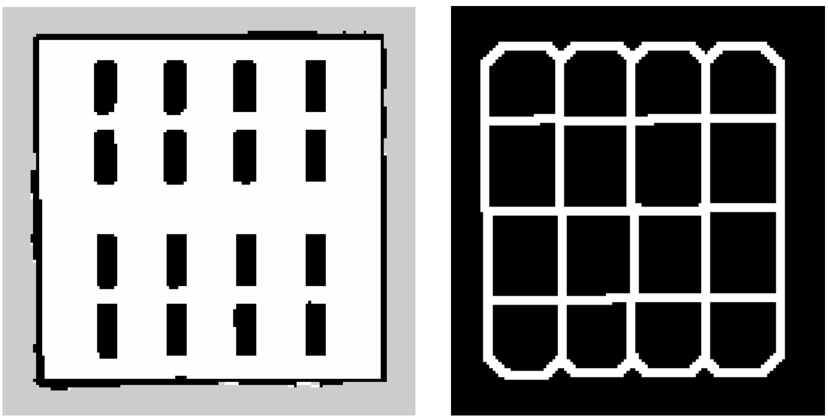
3. Results

The proposed pipeline was evaluated on two tested maps: Case 1 and Case 2. For each case, we first considered the original occupancy representation (without skeletonization) and then the corresponding skeleton representation used for graph-based routing (Figures 2 and 3). In both cases, the skeleton captures the main navigable corridors as a compact structure for global path planning.

Figure 1 presents the overall real cases that were used in experiments. Figures 4 and 5 show example planned routes for the baseline full grid A* and the proposed hybrid method in Case 1 and Case 2, respectively.

Figure 2

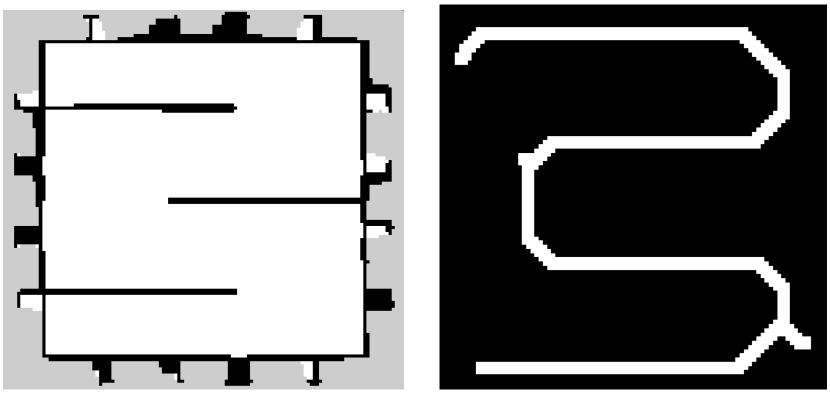
Tested map Case 1: (a) Without Skeletonization; (b) After Skeletonization



(a) (b)

Figure 3

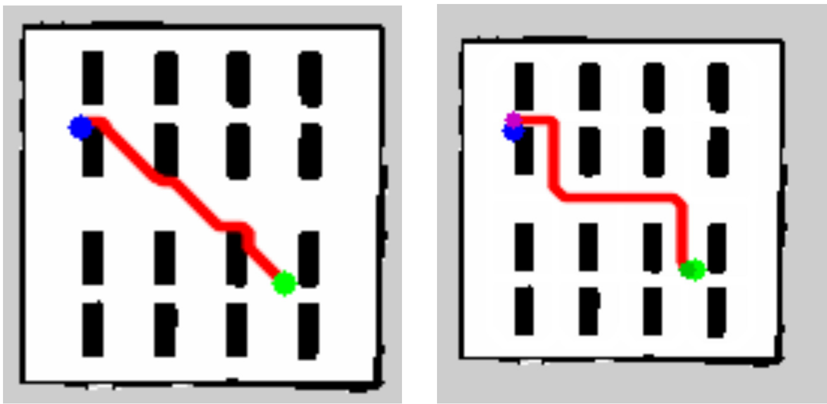
Tested map Case 2: (a) Without Skeletonization; (b) After Skeletonization



(a) (b)

Figure 4

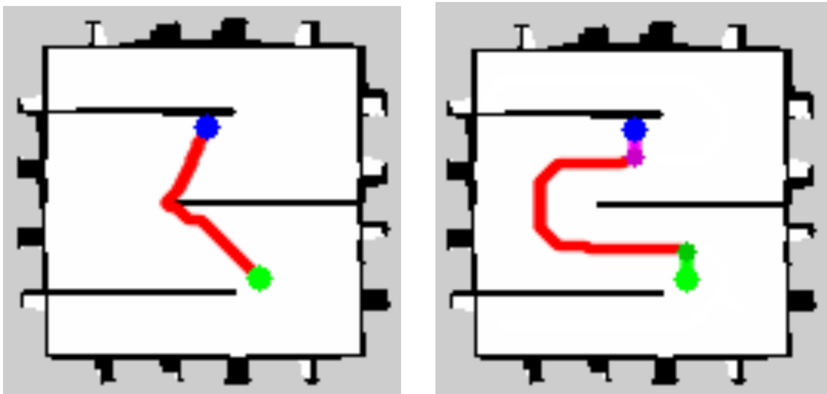
Tested map Case 1: (a) A without skeletonization; (b) A* with skeletonization*



(a) (b)

Figure 5

Tested map Case 2: (a) A without skeletonization; (b) A* with skeletonization*



(a) (b)

Quantitative results are summarized in Table 1. For Case 1, the baseline full grid A* expanded 1840 nodes with a planning time of 23.12 ms, while the hybrid method expanded 1005 nodes with 3.75 ms runtime. The resulting path length was 95.3 px (baseline) and 122.1 px (hybrid), with 76 and 119 path nodes, respectively.

For Case 2, the baseline full grid A* expanded 1365 nodes with a planning time of 16.19 ms, while the hybrid method expanded 498 nodes with 1.70 ms runtime. The resulting path length was 70.3 px (baseline) and 118.6 px (hybrid), with 56 and 113 path nodes, respectively.

Table 1

Comparison of full grid-based A and hybrid skeleton-based path planning (Cases 1 and 2)*

Metric	Case 1 – Full A*	Case 1 – Hybrid	Case 2 – Full A*	Case 2 – Hybrid
Expanded nodes	1840	1005	1365	498
Runtime (ms)	23.12	3.75	16.19	1.70
Path length (pixels)	95.3	122.1	70.3	118.6
Number of path nodes	76	119	56	113

4. Discussion

The results demonstrate that the proposed hybrid grid–skeleton approach consistently improves path planning efficiency compared to full grid A*. In both scenarios, the hybrid method reduces expanded nodes and runtime, indicating that most of the search is shifted from the dense grid to a compact topological representation of free space. This behavior is aligned with the motivation of using skeleton/graph structures to decrease the number of explored states while preserving connectivity for global routing [16], [17].

A key practical benefit is robustness to typical SLAM occupancy-grid artifacts. Occupancy grids frequently contain jagged borders, isolated noisy cells, and thin "false" passages created by sensor noise or partial observations [5], [8]–[10]. The conservative binarization and morphological refinement step reduces these defects, and the skeleton then captures the dominant corridor structure of the refined free space. In Case 2, where artifacts and complex connectivity are more likely, the hybrid method achieves the strongest reduction in expanded nodes, suggesting that the pipeline is particularly helpful when raw grid connectivity is unreliable.

The observed trade-off is an increase in path length (in pixels) for the hybrid method in both cases. This increase is expected for two reasons. First, morphological dilation introduces safety clearance that removes narrow shortcuts and pushes routes away from obstacle boundaries, favoring physically feasible trajectories over optimistic grid connectivity [15]. Second, skeleton-based routing tends to follow corridor centerlines, which may be slightly longer than a shortest path that cuts corners or uses marginal gaps. For warehouse navigation, this trade-off can be acceptable or even desirable because centerline routes improve clearance and reduce collision risk in narrow aisles, supporting stable execution by downstream local controllers.

Several limitations should be noted. The quality of the final route depends on parameter choices for morphological refinement (e.g., structuring element radius). If the dilation is too aggressive, it may over-constrain free space and unnecessarily lengthen paths or disconnect corridors; if too small, spurious gaps may remain. In addition, the current evaluation focuses on static maps and fixed start–goal pairs; dynamic obstacles and frequent map updates are handled primarily by local planners in standard navigation stacks rather than by the global planner. Future work can therefore include automated parameter tuning based on robot footprint and map resolution, incremental skeleton updates as the map changes, and evaluation on a larger set of start–goal pairs and more diverse warehouse layouts.

Overall, the findings indicate that combining lightweight morphological preprocessing with skeleton-graph routing is an effective and practical enhancement for global path planning on SLAM occupancy grids, especially in environments where grid artifacts can mislead full-grid A* search.

5. Conclusions

This paper presented a lightweight global path planning pipeline for warehouse-like SLAM occupancy grid maps that combines conservative binarization, morphological map refinement, free-space skeletonization, and a hybrid grid–skeleton A* strategy. Across two scenarios, the hybrid approach reduced search effort (expanded nodes) and planning runtime compared to full grid A*, indicating more efficient global path planning on noisy or artifact-prone maps. Although the resulting routes were longer in pixel length, they were biased toward corridor-centered, clearance-aware paths, which are typically more physically plausible for navigation in narrow aisles. Future work will focus on automatic selection of morphological parameters for different map resolutions and robot footprints, incremental skeleton updates for online mapping, and evaluation on larger sets of start–goal pairs and dynamic warehouse conditions.

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Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, A.S. and M.I.; Methodology, A.S.; Software, A.S.; Validation, A.S., K.A. and M.I.; Formal Analysis, K.A.; Investigation, A.S.; Resources, M.I.; Data Curation, K.A.; Writing – Original Draft Preparation, A.S.; Writing – Review & Editing, K.A. and M.I.; Visualization, A.S.; Supervision, M.I.; Project Administration, M.I.

All authors have read and agreed to the published version of the manuscript.

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