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Multi Robot Route Planning for ROS2

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***Abstract*— This work presents the implementation of a multi robot route planner based on the prioritized planning approach as well as its integration into ROS2 and the well-known Nav2 stack. Further, a method to increase the resilience towards uncertainty and unpredictability in timing during the execution of found routes is introduced. These so-called routing preconditions are shown to be effective on a subset of routing scenarios and offer significant opportunity for further exploration.**

***Index Terms*— multi robot system, path planning, ROS2, Nav2**

I. INTRODUCTION

To leverage the advantages of a multi-robot system (MRS), large fleets of mobile robots must be able to effectively compute routes from one point in the environment to another without risking collision. This makes multi-robot-route-planning a fundamental problem for MRS, as it lays the groundwork for more complex behavior [3]. Many approaches to solving this problem have been discussed in the literature, with so-called ”prioritized planning” appearing in a significant number of publications [2]. However, up to current knowledge, no publicly available ROS2-compatible software packages provides an easy integration of such functionality. This work aims to close the identified gap, similar to the previous work of [1] on ROS, but by taking advantage of the advanced capabilities offered by the well-known Nav2 stack. Results are presented by using a simulated environment as shown in Fig. 1.

II. PRIORITIZED PLANNING

Prioritized Planning refers to the practice of decomposing the multi-robot-route-planning problem into a series of single-robot-route-planning (SRRP) problems. Each of the SRRP-problems concerns itself with finding a collision-free route for an individual robot and must take static obstacles as well as robots for which a route has already been found into consideration. Since routes are planned in descending order according to some priority metric, higher-priority robots represent dynamic obstacles in the planning space of low priority robots.

III. IMPLEMENTED PLANNING ALGORITHM

To realize this specification of a Prioritized Planner, some considerations need to be made: First, a planning algorithm which is able to handle dynamic obstacles is required to solve the individual SRRP-problems. Second, the routes generated by the prioritized planner need to be suited for execution by a real MRS.

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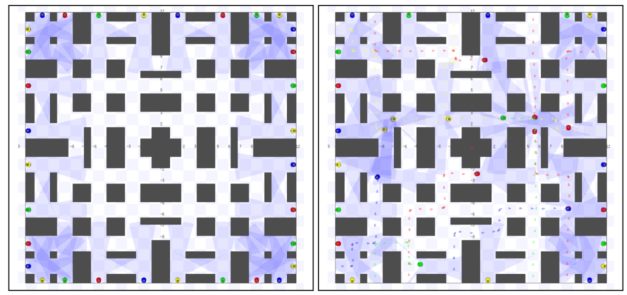

(a) Initial position (b) During navigation with Nav2

Fig. 1: Stage-simulation of a 32-robot MRS.

A. Sequential Planner

The chosen planning algorithm can be described as a variant of the spatio-temporal A*-Algorithm introduced in [4] operating on a graph-based abstraction of the environment. This abstraction is able to emulate 4/8-connected grid maps, as well as higher level concepts such as voronoi graphs with multi-edges. The key difference to the well-known A*-Algorithm is given by additional occupancy checks whenever a graph vertex is explored and added to the frontier: should it be occupied by another robot at the point in time in which the planning robot expects to enter, time must be spent waiting earlier along the currently considered route. If it is impossible to insert this waiting time at some point along the path without risking collisions, the proposed node is not marked for further exploration. These iterative planning processes result in a detailed record describing at which points in time any particular graph vertex is expected to be occupied by a robot if no unexpected delays occur.

B. Route Representation

After planning an ideal path for a robot in the system, post-processing is done to create a route suited for execution by a real MRS. Routes consist of a series of indexed route segments, each describing a move from one vertex of the graph to one of its neighbors. In addition to the timestamps during which this move is expected to take place, a set of preconditions for the segment is generated by considering all other robots scheduled to pass the destination of the move before it occurs. A precondition is considered to be satisfied as soon as the robot it is referencing has completed the noted segment of its own route (i.e. it has passed through the vertex at which both routes cross). This creates clear precedence relations, which serve to improve the systems resilience towards neglected or unexpected delays during navigation.

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IV. ROS2 Integration

The ROS2 integration of the implemented planner is split between multiple communicating system components, pictured in Fig. 2.

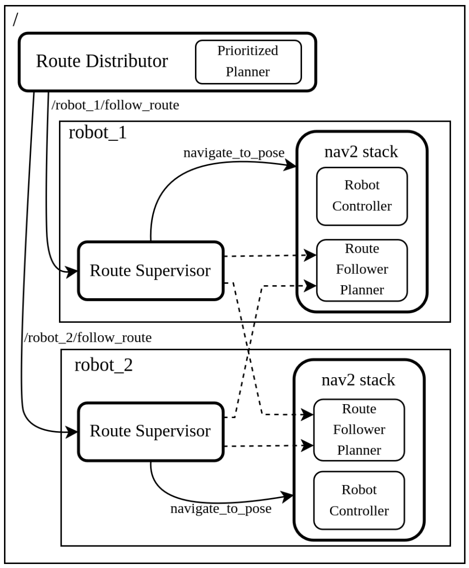

Fig. 2: Architecture of the ROS2 integration.

A. Route Distributor

The Route Distributor node acts as the central coordinator of the MRS. It is responsible for initializing navigation by generating each robots route using the implemented prioritized planning algorithm and distributing them among the MRS using ROS actions. During route execution, it monitors the received feedback and aborts navigation should unexpected issues arise.

B. Route Supervisor

The communication between robots and the Route Distributor is handled by an individual Route Supervisor node for every robot. Each of these nodes also monitors the robots progress along its own route and publishes this information for consumption by all the Route Followers in the system. This enables robots to wait on unsatisfied preconditions to in order to avoid situations not considered during planning.

C. Route Follower

To enable the use of the wide variety of localization strategies, local planners and other software components available within Nav2, the system integrates with a Nav2-planner-plugin known as the Route Follower.

V. Evaluation

The implemented planning algorithm was tested on randomly generated routing problems featuring 8-32 robots concurrently attempting to find a route through a heavily restricted warehouse-like environment. Through varying the order in which routes are planned, a solution to each of these routing problems was found. The systems capability of executing these found routes was then evaluated by simulating navigation using the Stage simulator.

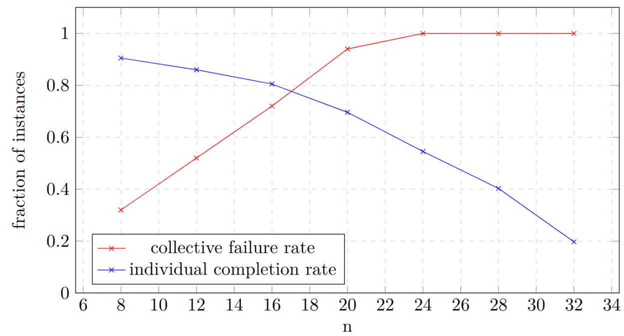

Fig. 3: Routing success in a highly constrained environment.

Fig. 3 depicts the ratio of individual robots which were able to reach their goals as well as the chance of any robot failing to finish its route due to an emergency stop, a collision or similar reasons. Both metrics behave in a roughly linear fashion, resulting in sharply degrading reliability as more concurrently navigating robots are added to the system.

Two central causes for these failures were identified:

1) Off-the-shelf Nav2 local planner solutions navigating based on a generic path representation deviating from the strictly defined pre-planned routes.
2) Endless waiting on an unsatisfied precondition referring to a stuck robot causing cascading failure in the system.

VI. Summary and Outlook

Collision-free routes for members of a multi-robot systems can be found by the implemented algorithm, but it is evident that this does not guarantee that these routes can be executed without issue in realistic conditions. While routing preconditions were introduced to counteract timing-related failures, they have proven insufficient to avoid them entirely without addressing flaws in the systems architecture and implementation. Introducing additional mechanisms to increase robustness such as on-line re-planning in case of a detected deadlock represents another avenue for future work.

VII. Acknowledgment

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