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An Architecture for Navigation of Service Robots in Human-Populated Office-like Environments [⋆]

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Abstract: This paper proposes a simple and efficient solution for robot navigation in office-like, indoor environments. The proposed methodology does not rely on metric localization and uses a laser range finder to detect the transitions among the nodes of a topological map of the environment, which is represented by a directed graph. The navigation between two nodes of the topological map is performed by using a vector field that is computed on the fly in function of the detected walls of the corridors, which are common in office-like environments, and of the people and other obstacles encountered in the robot's path. This vector field is computed independently of the robot's global path and is designed in a way that the robot's behavior is socially accepted by the humans of the environment. Because metric localization is not necessary and the vector field computation is very simple, the method is computationally efficient, and this allows the robot to navigate at high speeds. In this paper we illustrate the methodology through real world experiments with a nonholonomic service robot navigating in an office-like environment.

Keywords: Service Robotics, Human-Aware Navigation, Autonomous Mobile Robots, Robot Navigation.

1. INTRODUCTION

Recently, multiple advances in the development of mobile robots have emerged with the purpose of replacing humans in basic activities. Themes such as navigation, human interaction, localization, and mapping have been researched for both industrial and domestic use. Among the different applications, service mobile robots have become quite common, as scientists have started to focus on how technology can help the human being on some of their daily problems.

In general, similar to most mobile robots, a service robot depends on three basic pieces of information to carry out any activity: its actual position in the environment, the goal position where the requested service is to be performed, and data that will help the robot on planning how it is going to travel from where it is to where it should go. To determine the robot's position, a localization procedure is usually executed, based on the usage of on-board sensors, which may include odometry, inertial units, sonars, lasers, and cameras. Although there are several methods that integrate those sensors to compute the metric position of the robot in a map, including well known simultaneous localization and mapping (SLAM) algorithms (Thrun et al., 2005), it can be noticed that most strategies are very time consuming, requiring slow movements of the robots, especially in dynamic environments. Moreover, in office-like environments, which usually present several similar and symmetrical places and rooms, the current methods may not perform well. Thus, alternative solutions, robust to these problems, must be developed. The methodology proposed in this paper falls as one of these solutions, since it does not require metric global localization and works even if the locations have symmetry.

As will be detailed in the paper, given its approximate initial localization, the robot is able to keep track of its position in a topological map represented by a graph, where each node is a large portion of the environment, generally a corridor. This topological localization strategy is very efficient, allowing for fast movements for the robot. As the goal position is also represented by a node in a graph, we are not allowed to use standard path planning approaches based on metric maps (Choset et al., 2005). With such a simple discretization approach, few nodes are necessary, in contrast to other algorithms, such as grid search and RRT, in which, depending on the discretization, thousands of nodes will be necessary to represent a simple portion of an environment instead of the single node in the topological map. The reduced number of nodes drastically decreases the computational time of the searching algorithm.

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To move from the current position (node) to the final destination we introduce a strategy that is inspired by the way humans give instructions to other humans. In an office-like environment, when one is asked for the location of a certain room, for example, the indicated path is generally based on simple instructions such as "turn the first corridor to the right" or "turn the second one to the left". To simplify navigation, we used this idea in our topological map. In the graph that represents the environment, while each node is a portion of the environment, each edge connecting the nodes is a simple instruction such as "right", "left", or "forward". Using common graph search algorithms, it is then possible to find the best path from one node to another and transform it into a small set of instructions.

Once a path is found, the last problem is to order the robot to follow it. When a standard path with a continuous set of way-points is computed, a path-following approach that relies on the robot's localization can be used (d'Andréa Novel et al., 1995). However, in the solution proposed here, no explicit path is considered. Assuming that the environment is assembled by a series of interconnected corridors, we use sensor-based reactive controllers to perform the simple instructions given by the graph search planner. These reactive controllers are based on vector fields, which may consider obstacle avoidance and can be computed so that the robot presents socially acceptable behavior when interacting with humans (Kruse et al., 2012). This is an important point that is usually overlooked during the development of service robots. In an environment populated by humans, the behavior of the robot must respect the same rules that humans respect when interacting with each other, as pointed by Dautenhahn (2007). The robot should never cause discomfort for the humans (Fong et al., 2003).

The main contribution of this paper is, then, a hybrid (deliberative+reactive) architecture for a human-friendly service robot. Although some architectures present principles similar to the ones used here, such as (Shah and Campbell, 2013) and (Lam et al., 2011), the authors believe that the complete solution presented in this paper is unique. The problem it will solve will be described in Section 2 and then the architecture, including navigation, motion planning, and human awareness will be detailed in Section 3. To evaluate the architecture, we present, in Section 4, experimental results with a service robot called MARIA, which is based on a Pioneer 3-AT robot. Finally, conclusions and future works are presented in Section 5.

2. PROBLEM DEFINITION

In this work we consider the problem of navigating a nonholonomic mobile robot in an indoor environment. Instead of trying to solve the navigation problem for every possible indoor environment, which would generate a very complex system with several capabilities including mapping, localization and dynamic planning, we will focus on a particular kind of environment in order to develop a very simple and robust navigation architecture. In this line, we assume that the robot must navigate in an environment which may be described as highly dynamic (due to the presence of people) and formed from many corridors connected through intersections of up to four incoming corridors.

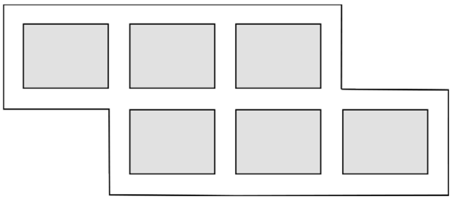

Fig. 1. Example of floor plan considered in this work, formed by intersecting corridors. The inner rooms (gray boxes) are not reachable by the robot.

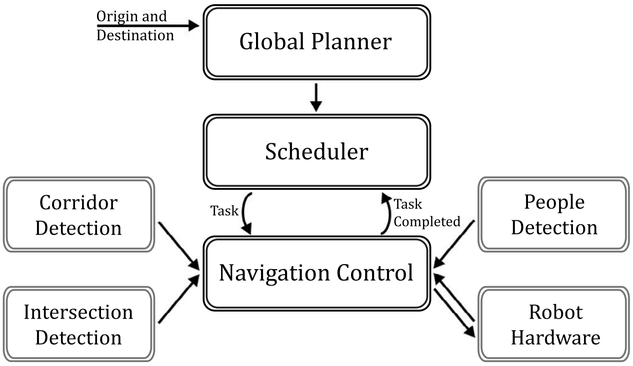

Fig. 2. Block showing the architecture's main flow of execution.

This sort of environment is very common, characterizing, for example, office buildings, hospitals, supermarkets, and schools. Figure 1 is a floor plan of a sample environment. In this figure, the darker regions are rooms that cannot be visited by the robot, which will navigate only in the white corridors. A service robot that can quickly navigate through this kind of workspace might be used to make deliveries, to guide visitors, or even to guard the building.

To navigate in these environments, we assume the presence of a planar laser range finder with a field of view equal or larger than 180 degrees. This range sensor will be used to detect the walls of the corridor, people, and other obstacles in the environment. Please notice that we do not assume the presence of odometers or inertial sensors, although these can facilitate the implementation of the robot control.

3. NAVIGATION ARCHITECTURE

To integrate navigation, human interaction, and control for a service robot, a three-layer architecture was developed. Figure 2 shows the basic execution flow of this architecture. The environment is first described using a topological map represented by a graph. Given origin and destination, motion is planned based on graph search and the robot objectives are turned into scripted actions, defined by words. This first layer is executed off-line, before the robot starts its motion. The script file computed by the first layer indicates the actions the robot has to execute in a predetermined order, simplifying its on-line decisions. The second layer is basically a simple scheduler that gives to the third layer the task to be accomplished next by the robot. Each task is then performed by the third layer, which is, in fact, a set of local controllers, used differently depending on the task. The next subsections will cover the details of this architecture.