Research Statement

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1 Introduction

The main topic of my doctoral research is the development of inexpensive, intelligent, and safe techniques for mobile robot navigation. We designed algorithms and data structures, developed software, and performed hardware experiments using mobile robots. My current work is extending our methods for single robots to multiple robots. We are also applying them in a web–based route planner for navigating the Texas A&M campus.

My research interests potentially extend to essentially any robotics-related area. Mobile robotics has been a perfect topic for me because it builds on two disciplines that I have studied — mechanics and computer science. In addition to mobile robotics, I am interested in exploring other topics that can utilize my multi-disciplinary background such as unmanned flying vehicles, underwater survey vehicles, virtual reality, and computer animation.

2 Autonomous Mobile Robot Navigation

The mobile robot navigation problem is to compute a route and safely moving the robot to its destination while interacting with other objects. Among many issues for autonomous application, I have focused on two main computational issues. The first issue is *path planning* whose basic objective is to find a collision–free path between given start and goal positions. Our contribution is to improve the process of selecting a path from roadmap of the environment. The second issue is *path following* which requires accurate and efficient techniques for *localization*. Localization, or the precise determintation of position, is required to correct for odometer errors caused by wheel slippage, change of tire radius, uneven floor, etc.

Our navigation system coordinates the path planning and localization modules in such a way that they aid each other [4]. Our path planner optimizes the path to make subsequent localization easier.

Roadmap–Based Path Planner Our path planner is based on probabilistic roadmap methods (PRMs) [3] which efficiently provide feasible solutions for many problems with large search spaces (e.g., high degrees of freedom). We developed a method that considers one or more optimization criteria and extracts the optimal path among all paths contained in the roadmap [6]. For example, in autonomous navigation of mobile robots, a planned path has to be safe as well as short–distanced. One measure of safety is clearance, and maximum safety in this sense is achieved by maximizing path clearance. Such path is computed by our augmented version of Dijkstra's shortest path algorithm [6] that computes edge weights relative to the current path. In addition to maximizing path clearance, our system enables any combination of optimization criteria such as minimum energy consumption, minimum localization effort, and kinematic/dynamic constraints. Also, we relaxed the definition of goal state, which is often specified as a particular position or vertex in the roadmap. Our *goal set* is composed of the nodes that satisfy final condition, and enables further improving path quality.

Geometric Feature-Based Localizer In its most general form, the localization problem uses information sensed about the environment to reduce uncertainty about the robot's position and orientation. Many different approaches have been suggested for various sensors, and we focus on inexpensive range sensors such as sonar and IR sensors. Those sensors have physical limitations in range (maximum and minimum) and incidence angle to the sensed object. So, depending on the position of the robot, the robot can measure only a certain part of the environment.

Our methods for localization are based on geometric *features* of the environment, which we define as a part of the environment that can be scanned and used for localization. Our premise is that we begin with some partial, possibly incorrect, information about the environment, e.g., the blue prints for a building. Our approach preprocesses the environment by subdividing it into sectors and computing and storing features for each sector. During localization, the robot scans the environment and extracts features that are compared with features in the sectors the robot may be in. Our sector–based localization does not require complete information and uses less storage when compared to grid-based methods. In particular, we proposed data structures called *relaxed sectors* [5] and *scannable sectors* [7], that are improvements over previous visibility–based methods [2]. Our proposed framework includes localization algorithms based on these sectors. We experimented with an AmigoBot robot that is equipped with eight sonar range sensors (see Figure 1(a) and Figure 2).

3 Campus Navigator Application

Our techniques for extracting an optimal path are being applied to a web–based route planner. Our *campus navigator* [1] for the Texas A&M University campus is similar to Yahoo Map and MapQuest but supports more sophisticated queries.

- It supports several modes of transportation. Currently we have implemented pedestrian (walking and wheelchair), individual vehicle (bicycle, motorcycle and automobile), and bus. Paths utilizing multiple modes are considered to obtain the best result. For example, most paths will start and/or end with walking but they might use a bus in the middle to minimize time.

- The path can be optimized with respect to several criteria such as shortest time, shortest distance, shortest walking distance, avoiding heavy traffic areas, or poorly lit areas. Furthermore, the path can be customized for personal situations such as the parking lots valid for a particular parking permit or a bike parked at a specific location.

4 Feedback Control of Real-Time Systems

Validation of theory through experiment has been an important part of my academic career. For my master's research, a two-link robotic manipulator has been constructed (Figure 1(b)). For real-time data acquisition, Matlab Real-time Workshop toolbox was used under MS-DOS, and the motor was controlled using Matlab Simulink with a customized S-function.

For my doctoral research, controlling a mobile robot was relatively simple because the robot stops moving and localizes at times selected by our path planner to avoid collision. However, several issues had to be considered for safe experiments. For example, if an unknown or moving obstacle emerges in the robot's path, then the robot has to stop and wait until its route is clear or select a new route.

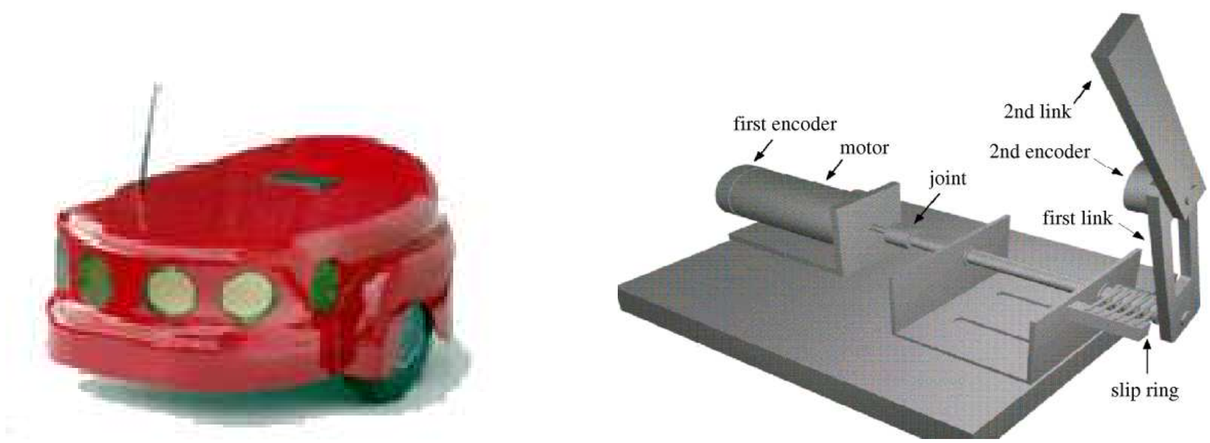
5 Directions for Current and Future Research

Our proposed methods of navigating for a single mobile robot can be extended to multiple robots. Multi–robot path planning has often been focused on collision avoidance among the robots. Another important topic is coordinating a group of robots that move together. These kinds of movements are called *flocking* in graphics. Although these behaviors might be expressed with a single cost function in our augmented Dijkstra's algorithm, there are several issues that must be addressed. For example, we need a roadmap suitable for multiple robots and a method to find shortest paths for multiple agents in this roadmap.

When multiple robots are localizing, one robot may reduce its position and orientation uncertainty by scanning other robots. This is sometimes called cooperative localization. Our current work for this problem is investigating methods to determine the sequence of localization so that the localization time is minimized. We have shown that this problem is NP complete, and the next step is to design heuristic or approximate methods for efficiently localizing groups of robots and then testing them in simulated or actual scenarios.

Our techniques for extracting optimal paths from the roadmap can be extended for the intelligent navigation of automobile or aircraft. Our previous results with mobile robots used very simple kinematic and dynamic constraints, and were valid only if the robot was holonomic and moved slowly. Vehicle trajectory planning requires precise formulating of such physical constraints. In the real world where the efficiency of transportation is heavily affected by circumstances, such as speed limit of the road, traffic, road surface condition, etc., finding the best path might not be possible. Our campus navigator can be extended for a broader range of applications that would incorporate a broader range of optimization criteria and physical constraints.

In computer animation, games, or virtual reality, the quality of solution is often measured by the degree of realism. One requirement for this is real–time processing. Thus, computational efficiency is extremely important. Fortunately, for many simulation purposes, the physical constraints can be relaxed and environmental factors can be simplified. Roadmap–based methods are well–suited for these applications, and we are interested in applying out intelligent navigation framework to such more realistic scenarios.



(a) (b)

Figure 1: Hardware experiments, (a) AmigoBot, (b) Two–link testbed.

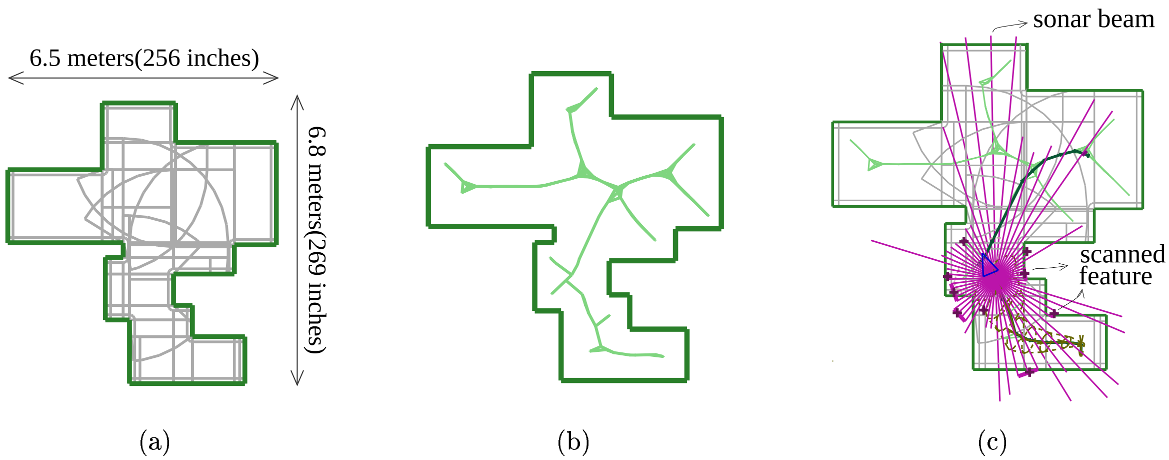


Figure 2: Hardware experimental results (a) lab environment and scannable sector boundaries, (b) medial–axis based roadmap, (c) real scanning and identified features for localization.

References

[1] Campus Navigator Research Webpage, `http://parasol.tamu.edu/groups/amatogroup/research/campus-nav/`.

[2] Leonidas J. Guibas, R. Motwani, and P. Raghavan. The robot localization problem. *SIAM J. Comput.*, 26(4):1120–1138, August 1997.

[3] L. Kavraki, M. Kolountzakis, and J.-C. Latombe. Analysis of probabilistic roadmaps for path planning. In *IEEE Trans. Robot. Automat.*, volume 14, pages 166–171, 1998.

[4] J. Kim, N.M. Amato, and S. Lee. An integrated mobile robot path (re)planner and localizer for personal robots. In *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, pages 3789–3794, 2001.

[5] J. Kim, R.A. Pearce, and N.M. Amato. Robust geometric–based localization in indoor environments using sonar range sensors. In *Proc. IEEE Int. Conf. Intel. Rob. Syst. (IROS)*, 2002.

[6] J. Kim, R.A. Pearce, and N.M. Amato. Extracting optimal paths from roadmaps for motion planning. In *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, 2003.

[7] J. Kim, R.A. Pearce, and N.M. Amato. Feature-based localization using scannable visibility sectors. In *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, 2003.