Robust Navigation for Autonomous Mobile Robots

Abstract of Ph.D. Thesis

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Navigation can be defined as finding the answers to the three questions ”Where am I?”, ”Where do I go?”, and ”How do I get there?”. For an autonomous mobile robot these questions refer to the tasks of *self-localization*, *map-building*, and *path-planning*. In this thesis all of the three problems are addressed and solutions and new scientific results are provided. Especially the first two problems are investigated thoroughly with significant new results obtained. Furthermore, the application of all three navigation tasks in a team of robotic soccer players is developed resulting in the most successful robotic soccer team as of to date.

Self-Localization

Almost all navigation tasks in mobile robotics require the robot to have some idea about where it is in the environment. Today's methods can roughly be divided into behavior based systems (i.e. no global position is available), landmark-based navigation, and dense sensor matching. Especially the last one employing accurate sensors such as laser range finders (LRFs) can yield very reliable and accurate results in global position estimation.

The thesis experimentally compares different methods for matching range information from LRFs and proposes a new method that combines the scan-matching approach proposed by Cox with the IDC algorithm proposed by Lu and Milios. The new combined method (CSM) inherits the advantages of both approaches while avoiding their drawbacks [1][1].

The CSM method has been extensively tested on a *Pioneer I* robot equipped with a *SICK* LRF and with data obtained from experiments of the mobile robot RHINO in the *Deutsche Museum* in Bonn and the Department of Computer Science at the University of Bonn. The result is that scan-matching is a powerful, accurate, and robust method for tracking the position of a mobile robot [17]. Fig. 1 (a) displays the trail of the robot obtained by scan-matching during a 4.5 hours run in the museum.

Furthermore, the scan-matching techniques have been experimentally compared with a grid-based Markov Localization method which maintains a probability value for each cell in a 3 dimensional grid covering the entire environment. The results are that scan matching is more accurate than Markov Localization while the latter is more robust than the former. This is the first publication that experimentally compared two significant different methods for mobile robot self-localization. The comparison concludes with a combination of Markov Localization and scan matching that inherits the advantages of both methods [17]. This work won the best paper award at IROS 98.

Map-Building

In order to be able to localize itself in an environment, the autonomous agent needs a representation or map of the environment. Obtaining maps from CAD models or measuring them by humans can be time consuming and inaccurate. The robot should obtain a map by its own.

The thesis presents previous work done in map building including the method of consistent pose estimation by Lu and Milios and an approach using an expectation and maximization algorithm proposed by Thrun *et al.* A combination of these two methods has been developed that is able to generate accurate maps but requires off-line processing due to high computational complexity [18].

[1]The citation numbers refer to the publications as listed in the document describing the effective results of the PhD.

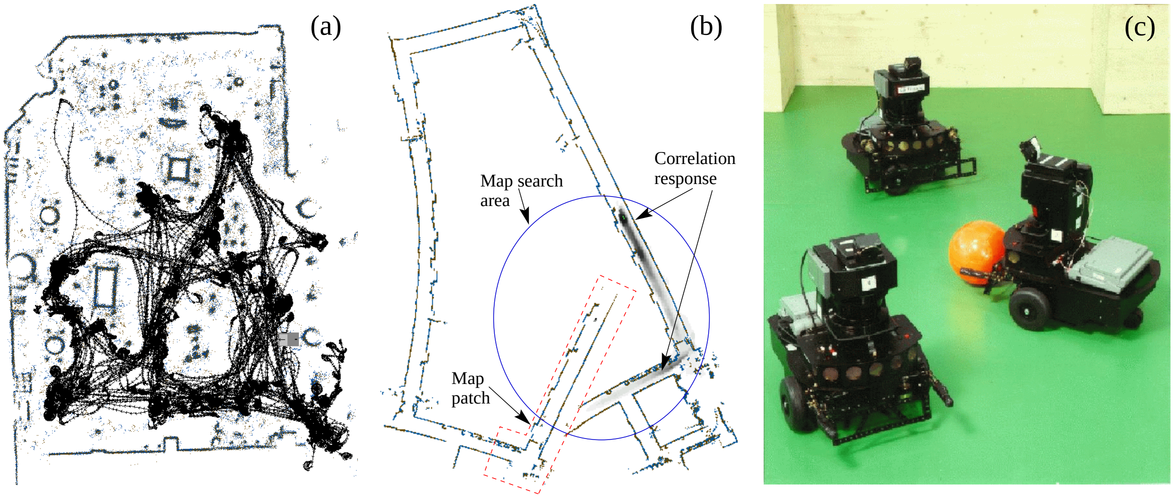

Fig. 1. Major contributions of the PhD thesis: (a) experimental comparison of localization methods (here: data from RHINO in a long term localization experiment in the *Deutsche Museum* in Bonn), (b) incremental mapping of large cyclic environments (here: correlation response of mapping algorithm with LRF data obtained in Carnegie Mellon's Wean hall), (c) CS Freiburg robotic soccer team (here: two field players and the goalkeeper).

Using a recently proposed new method in global mobile robot localization, the thesis develops a new mapping algorithm (LRGC) that creates maps of large cyclic environments on-line without relying on features or operator interactions. LRGC uses scan matching (local registration), map correlation (global correlation) and consistent pose estimation for creating accurate maps with a run time close to real-time [10,13]. Fig. 1 (b) displays the result of correlating the last few scans obtained by the robot with the previously obtained map. From this correlation response the robot can detect its true position in the corridor and close the loop. This is the first method published that is able to map large cyclic environments on-line.

Robotic Soccer Playing

The Robot World Cup Initiative (RoboCup) is an attempt to foster research in AI, robotics, multi-agent systems, and real-time planning and execution by providing a standard problem where a wide range of technologies can be integrated and examined.

In this thesis, the development of the CS Freiburg robotic soccer team is presented with a deeper focus on the self-localization and perception module of the robots and their basic navigation and coordination mechanisms [8,9,11,14]. Fig. 1 (c) shows 3 of the 5 CS Freiburg robot players.

The idea of the development of the CS Freiburg team was based on the assumption that it would be of great advantage if the robots know their position in the field (at the first competition in 1997 none of the robots in middle size league was capable of this). A new scan-matching method has been developed that exploits the polygonal RoboCup soccer environment. In a comparison of this method with competing methods the thesis shows that the new method is faster and more robust than its competitors while still retaining their accuracy [6,12,15].

Given the absolute position on the field, the integration of other sensor information for localizing players and the ball is straight-forward and the local information about the world can be exchanged and fused with the team mates [2,3].

The CS Freiburg team is the most successful team in the middle size league and won 3 times first place and one time 3rd place [1,4,5,14]. In the first year of its participation, its success could be clearly attributed to the capability of the robots being able to localize themselves on the field [19]. The localization module since then basically remained unchanged enabling the development of further and more sophisticated skills such as dribbling around the opponent, rebound shots using the walls, and ball passing in front of the opponent's goal [4,5].