別紙４－１（課程博士（英文））

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Abstract (Doctor)

Title of Thesis	Optimal Coverage and Probabilistic Robust Path Planning for Nonholonomic Mobile Robots

Approx. 800 words

In recent years, much attention is given to autonomous vehicles and mobile robots. In industry and households, mobile robots are deployed for a variety of tasks. A growing interest is in mobile robots in households, where it is used for lawn mowing and vacuum cleaning. Mobile robots are also commonly used for space exploration, specifically on Mars, Mars rovers like curiosity are used to explore the environment, and for cleaning train stations and industrial facilities. The above mentioned mobile robots are using path planning algorithms to fulfill their tasks. In general, these path planning tasks are divided into coverage path planning (CPP) and point-to-point (PTP) path planning. The former generates paths with an objective of moving everywhere in a preassigned area and the latter generates paths from a starting position to a goal position while avoiding obstacles. Challenges in these areas differ, CPP is in general used in known bounded environments, while PTP is often used in unknown, uncertain, dynamic environments.
Generally, mobile robots have a limit power supply due to the fact that they have to carry their own batteries. Thus, CPP is a power demanding problem for mobile robots. Therefore, one of the objectives of this dissertation is an algorithm that generates optimal CPP paths in known bounded environments, where the objective of the cost function is either traveling time, repetitive visits or energy consumption. The second objective of this dissertation is a probabilistic robust PTP path planner that generates probabilistic safe paths in real-time under state and environment uncertainties.

Part I of this dissertation presents new optimal offline approaches to solve the CPP problem. A novel hybrid genetic algorithm (HGA), which uses the turn-away starting point (TASP) and backtracking spiral algorithms (BSA) for performing local searches, is proposed for grid-based environmental representations. Three different variations of the HGA are proposed based on the underlying local search algorithm: HGA/BSA using the BSA for local search, HGA/TASP using the TASP algorithm and HGA/Both which uses both algorithms for the local search procedure. The HGA algorithms are validated using the following three different fitness functions: the number of cell visits, traveling time, and a new energy fitness function based one experimentally acquired energy values of fundamental motions. Computational results show that compared to conventional methods, HGA improves paths up to 38 %; moreover, HGAs have a consistent fitness for different starting positions in an environment. Furthermore, experimental results prove the validity of the fitness function. It was shown, that the HGA/BSA finds good solutions for the number of visited cells, whereas the HGA/TASP provides better solutions for the traveling time. Both variations showed good results using energy consumption as fitness function. Furthermore, HGA/TASP has the fastest computation time among the HGAs.

Part II of the dissertation focuses on control approaches for parking and generating paths to a specific goal pose, where the focus is in particular on probabilistic robust path

planning.
A hybrid systems approach to garage parking of a differential drive mobile robot is proposed in this dissertation. The proposed system consists of three system states, in which each system state converges to its desired control value and then switches to the next state. Two system states use input-output linearization for multiple input multiple output (MIMO) systems to conduct exact linearization of the plant, which can then be controlled by a linear controller. Simulation and experimental results show that the robot converges to its desired states and safely parks at the final position in a reasonable time.
To guarantee safe motion planning, the underlying path planning algorithm must consider motion uncertainties and uncertain state information related to static, and dynamic obstacles. This dissertation proposes novel hybrid A* (HA*) algorithms that consider the uncertainty in the motion of a mobile robot, position uncertainty of static obstacles, and position and velocity uncertainty of dynamic obstacles. A variant of the HA* algorithm is proposed in this dissertation that uses a soft constraint in the cost function instead of chance constraints for probability guarantees, this algorithm offers a trade-off between the traveling distance and safety of the path without pruning any additional nodes. Furthermore, this dissertation introduces a method for considering the shape of a mobile robot for probabilistic safe path planning. The performance of the algorithms was evaluated using the Monte Carlo simulation. The results showed that safety can be improved without significantly increasing travel distance. The results also showed that dynamic obstacles were safely avoided, which is in contrast to the conventional HA* algorithm that has a high probability of collision. Furthermore, considering the shape of the robot in the proposed probabilistic approach led to safer paths overall. Additionally, the HA* algorithm that used the chance constraints was very conservative as such, exhibited a very low probability of collision. However, with an increasing number of obstacles, the algorithm may fail to find a solution due to pruning all the expanded nodes. In addition, a probabilistic robust planner that avoids the use of the Gaussian error function or inverse Gaussian error function is proposed. The resulting planner generates a confidence ellipse of the current state and covers the resulting ellipse with two circles of equal radius. The radius of the circles is used to inflate the obstacles and collision with obstacles can be detected with deterministic approaches. The planner was able to find probabilistic robust paths with a smaller computation time than existing probabilistic robust path planners. Lastly, a planner is proposed that receives measurement feedback from the environment and selects the linear velocity at each node according to the current probability of collision. The resulting paths successfully avoid static and dynamic obstacles and had a shorter travelling time than existing planners.