REMOTE LABORATORY EXPERIMENTS ADDRESSING PATH PLANNING FOR MOBILE ROBOTS

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Abstract: This paper describes an educational remote experiment for path planning with mobile robot hardware which is accessible via the internet. The experiment uses a nonholonomic car-like mobile robot with an Ackerman-steering and demonstrates the problems of the inverse kinematics of this kind of mobile robot. It emphasizes the educational aspects, shows how to combine primitive manoeuvres in order to solve the inverse kinematics problem, and gives a detailed description of these manoeuvres.

1 INTRODUCTION

Introducing the new media and the internet provides new possibilities for eLearning. In the last years, remote laboratories and tele-experiments were created in order to improve the quality of education. Many of these remote-experiments are related to control methods like PI-Controller or the control of other processes. Providing remote experiments with mobile robots and especially real hardware experiments with mobile robots are not so popular.

There are few remote-laboratories working with real mobile robots (cf. 0/2003a/2003b and 0). (0) uses a Path Following algorithm, but the experiment is based on a tracked robot. The experiments in (0 and 2003a are related to the inverse kinematics problem of a differential drive robot and the PI-Control of the robot's velocity. These kinds of nonholonomic mobile robots require less space and the control methods are easier compared to car-like mobile robots with an Ackerman steering. 0 presents an experiment to a nonholonomic motion planner (NHMP), but this experiment does not use a real car-like mobile robot. Instead a movable platform to simulate the nonholonomic behavior of the robot is use. On that account, this experiment does not provide the same problems like friction, deviations because of the mechanical construction, and slippage like using real car-like mobile robot hardware.

This work presents an experiment of a remote laboratory which is focused on real hardware experiments with nonholonomic car-like mobile robots. The students are starting with experiments of the forward kinematics where a kinematics model of the car-like mobile robot is introduced. The students' task is to find several variables which are necessary do build the model e. g. systematic errors for encoders and gyro, deviations of the mechanical driving mechanism and accuracy of a fuzzy distance controller (cf. 0/2004b).Then dynamic and control aspects are presented in a PI-Controller experiment (cf. 0/2004b).

The present experiment is a first approach to build a remote exercise related to Path Planning methods for nonholonomic car like mobile robots with Ackerman steering. This Experiment is an "interface" between an existing forward kinematics exercise and a new one related to Path planning. Presented exercise give students the opportunity to check validity of the created model. The obtained variables are used to estimate the position of the robot, after simple or complex motions.

2 EXPERIMENT OUTLINE

The presented remote experiment uses the experiment area and infrastructure (cf. Fig. 1) of the remote laboratory for car like mobile robots of the University of Würzburg shown in 0 and 0. Performing a remote experiment consists of three steps. At first, the students get a tutorial. This

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tutorial describes several sub-experiments and gives basic information to the subject. After students finished this tutorial, they can pass an online exam with test questions. Finally the control GUI for the robot can be accessed and the hardware experiment described in the tutorial can be performed with our MERLIN robot (cf. Fig. 3). The design of these online-experiments is well tested and was evaluated in previous projects.

The experiment described in this paper consists of 3 steps, a simulation of different methods of motion, a test of the simulation results on real hardware, and finally a demonstration and analysis of three different path planning approaches.

At first, the students are introduced to the basic motion of a car-like mobile robot. Afterwards the students are able to combine basic motions to primitive maneuvers, like three-point-turn and sidewise shifting (cf. Section IV). The next step introduces the students to the combination of primitive maneuvers to complex maneuvers for achieving a certain configuration. In order to highlight issues related to robot maneuverability and robot control, we assume that obstacle avoidance is solved by path planning comparisons, and string concatenations.

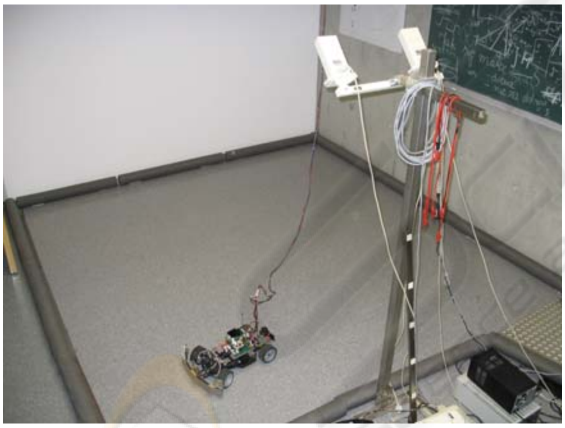

Figure 1: Area for the experiments with MERLIN

After the students are familiarized with the primitive maneuvers (cf. Section IV), a simulation is provided. Here the inaccuracy of the distance controller and the influence of this deviation on the finally achieved pose are demonstrated. These simulation results are now tested on our real MERLIN hardware and the students experience the difference between simulations and the real hardware. Here students can see the influence of a deviation of the distance controller in open loop control and they can analyze the effects of an orientation error while performing complex maneuvers. They compare these different maneuvers with respect to environmental influences and parameters like the available free space, the required accuracy, and the traveled distance.

Finally, several path planning algorithms (cf. 0) like the Road Map, the Potential Fields, and the Distance Transform methods are presented. The experiment provides a GUI to the students where they can examine these three methods and analyze their usability for different maps. These methods always return a path that has to be transformed into segments which are navigable by the used mobile robots. Therefore we derive a path which consists of primitive maneuvers. Now, the students can learn how to combine the methods of path planning and the different primitive maneuvers in order to move the robot to a certain configuration.

3 INVERSE KINEMATICS OF CAR-LIKE MOBILE ROBOTS

Inverse kinematics for nonholonomic mobile robots with Ackerman-steering is a complex problem due to the constraints described in Latombe, 1993. A solution (path) can not be represented by a single motion or mathematical equation. It was proven 0 that, despite this limitation, the robot remain fully controllable. For these purposes a combination of several primitive maneuvers were created. The experiment provides these maneuvers to the students for theoretical analysis and tests with real hardware.

1) Primitive Maneuvers: For car-like mobile robots 0 introduced primitive maneuvers for rotation and shifting. For the rotation, we use the three-point-rotation as described in 0 (cf. Fig.3). Here, the path of the robot consists of two circular arcs of a given length, a given radius, and a tangential connection between them. This primitive maneuver enables the robot to perform clockwise or counter-clockwise rotations.

For performing a sidewise motion of the robot, we present the students the typical maneuver for shifting as it is described in 0. Due to the kinematics constraints of a mobile robot with an Ackerman-steering, this maneuver is based on performing motions on a circle arc with a suitable radius and a suitable length and moving on a tangential line from one circle arc to another circle arc (cf. Fig.2).

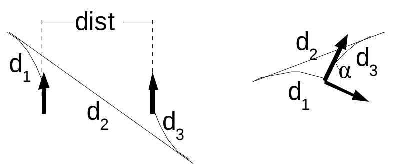

Figure 2: Shifting maneuver (left side) and rotation maneuver (right side).

One of the common problems of the inverse kinematics of nonholonomic mobile robots is the required space. Usually, experiments of inverse kinematics of mobile robots require a large experiment area. In Fig.2 we see that the typical maneuver presented in 0 requires enough space in each direction of the robot. In a small experiment area, it could be necessary to modify this maneuver in a slight way because of the limited space on at least one side of the robot. Fig. 3 presents two alternative maneuvers for shifting.

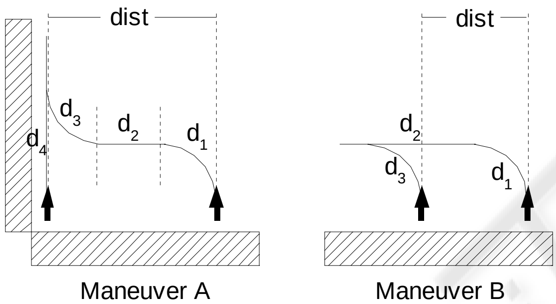

Figure 3: Alternative methods to shift a nonholonomic mobile robot

If the robot's starting configuration is located too close to a wall it is impossible to perform a circular motion in the direction of the wall. In this case, we have two possibilities to shift MERLIN.

Maneuvers A and B are still applicable if the robot is placed close to some obstacles. For the mathematical representation let R be the minimum turning radius, d be the wheelbase, and dist be the distance the robot should be moved sidewise.

2) *Complex Maneuvers*: To familiarize students to the problems of the inverse kinematics, we present two more complex maneuvers to reach a given configuration.

At first we use the same two primitive maneuvers like introduced for the differential drive mobile robot: two rotations and a straight-line movement. At first the robot performs a three-point rotation (see Fig. 4b) to the direction of the target position. Then it moves to the position where the second rotation should take place (Fig. 4c). After the second rotation (cf. Fig. 4d), the target pose ptarget is reached. This approach can use up to seven basic movements: the rotations consist of three movements on circle arcs each and the straight-line movement.

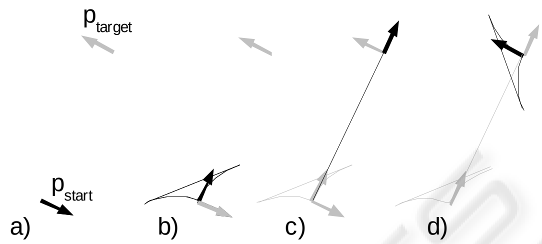

Figure 4: Rotate-move-rotate maneuver for a nonholonimic car-like mobile robot

The second approach consists of driving on two segments of circle arcs and one tangential connection between them (cf. Fig.5). Using this method we need a maximum of three basic motions to reach any target configuration.

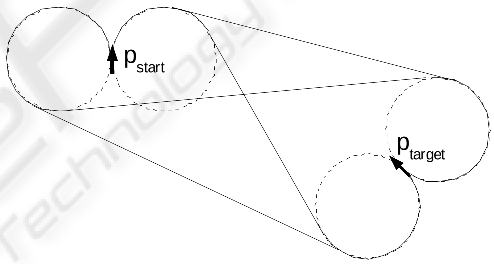

Figure 5: Driving on two circle arcs and their tangential connections as complex maneuver for navigating to a target pose

Fig.5 presents only some possible traces from the start configuration to the end configuration. Connecting these two pairs of circles with tangential lines results, always in nine traces to the new position. Then the most suitable trace can be chosen with respect to the environmental parameters

4 PATH PLANNING

The hardware experiments are concluded by a simulation of three basic path planning approaches. The students are introduced to the Road Map, the Potential Field, and the Distance Transform method. The students examine the performance and usability of these methods with different environmental maps with varying obstacle arrangements.

So they can decide which path planning method is the most applicable for the different situations.

After the usability of the path planning methods is analyzed, the students have to combine their knowledge gained in previous experiments. The provided simulation tool considers a point-robot. Thus, kinematics constraints are not included and the resulting path of this path planning method will not be navigable by MERLIN.

Now students learned the necessary basic knowledge about path planning and the basics about the inverse kinematics of a car-like mobile robot. In a next experiment they are able to combine this knowledge to perform experiments related to docking or the parking problem.

5 CONCLUSIONS AND FUTURE WORK

According to our knowledge, we present the first remote experiment related to the inverse kinematics and the path planning for nonholonomic car-like mobile robots, which is accessible via the internet. The experiment starts from the basic motions of nonholonomic mobile robots and demonstrates the students how to combine these basic motions to get some complex maneuvers. The students compare several dedicated maneuvers for moving MERLIN to a certain configuration. They are introduced to sources of deviations (cf. 0, Zysko, 2004b) and the effect of these deviations on the final configuration. The students learn to estimate the expected deviations when these maneuvers are performed with the real hardware and they can choose the appropriate maneuver for the individual needs.

In the end, our experiment provides some path planning approaches (cf. 0) to give the students an idea how they can use the gained knowledge about inverse kinematics and introduces them to the following experiment for the docking or parking problem.

In the future we intend to extend the existing experiments with algorithms using feedback in order to achieve better accuracy.

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