Experiments with Mobile Robots in Tele-Education

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Abstract: This work describes learning units, experiments, and infrastructure of a remote laboratory with mobile robots in tele-education. Remote experiments with real hardware are an important issue in the education of engineers and students of natural sciences. The presented infrastructure is based on JAVA applets in a server/client architecture to accommodate several self-contained learning units with interactive components. The content is related to the kinematics, control, and path planning for non-holonomic mobile robots, which can be integrated into the curricula of robotics, mathematical modelling and control engineering. Experiences in using these learning units in class are addressed.

1 Introduction

Experiments with hardware are a key element in engineering education 0. Modern telematic techniques enable to access remote equipment via internet and to offer experiments with remote equipment in a tele-education context. While first the techniques to teleoperate hardware were investigated 00 only nowadays whole educational units are developed 00. At the University of Würzburg experiments with mobile robots have been implemented and introduced into standard classes for local, as well as for remote students. The experiments in Würzburg provide traditional e-learning content like tutorials, experiment descriptions and simulations. On the other hand, the remote control of real mobile robots is included to the learning process. Thus, the theoretical knowledge gained from tutorials and simulation results can immediately be applied to the real hardware to examine its behavior under real world conditions. Analyzing the deviations between idealized models and the robot hardware

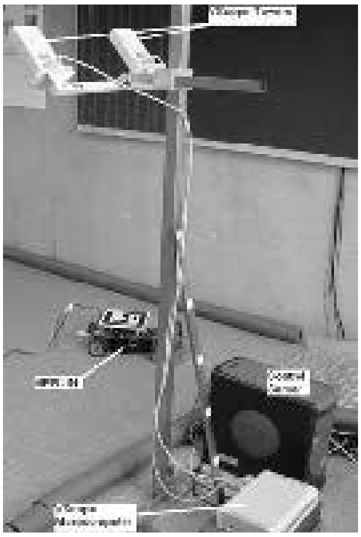

Fig. 1: Experiment Area

implementation is a major objective of a practical and application-oriented education and can be considered as key qualification of students in engineering and natural sciences. The following sections give an overview of the software and hardware architecture, the used mobile robots and the content of the experiments provided by the University of Würzburg.

2 System Architecture

2.1 Software Architecture

The System architecture is based on the classical server-client model 0 (cf. Fig. 2) and consists of different components: JAVA applets on the client side, the control servers, a database system, and the web portal. The control clients send different requests and control commands via the internet to a robot control server. Furthermore, the current sensor data values and a video stream of the experiment area are displayed. The robot control server is directly connected to the mobile robot and answers the requests and executes the received commands. Furthermore, the robot sensor data is processed and sent to the client. Besides these tasks, the control server also analyzes the data of the positioning system (VScope) and takes care of a user authentication.

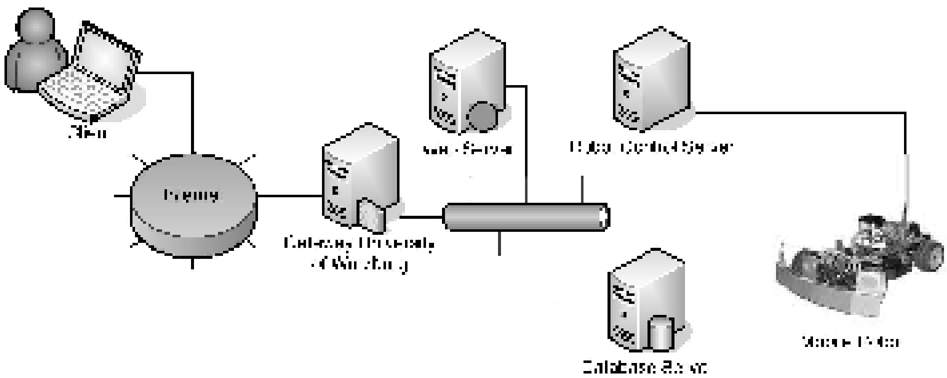

Fig. 2: System Architecture

The tele-lab architecture has to accomplish objectives like platform independence, efficient use of the available bandwidth, intuitive usable GUI for displaying sensor data and sending control commands, and security issues. Therefore, all remote experiments are hosted in a PHP based web portal. This web portal consists of different modules: the resource management, the user management, a module which provides the tutorials for each experiment, a control question module, a module for uploading experiment reports, and finally a module for each supported control server (cf. Fig. 3). The information required for the user and resource management is stored in a standard MySQL database and minimizes the administrative effort. Furthermore, the connected database system allows a dynamical web page construction. Each user can access a personalized experiment environment for downloading detailed tutorials with the required theoretical knowledge for each experiment as well as an experiment description. The control question module allows a monitoring of the learning progress of each learning unit as the students have to answer interactive control questions to proceed with the experiment. After passing this interactive test, the student can book timeslots for the corresponding experiment using the resource management module and afterwards start the control client. Based on the experience of former projects related to tele-education 0000, requirements like platform independence of the client, efficient use of the available bandwidth, displaying continuously updated sensor data and a user and resource management system which needs a minimum of maintenance effort were set up. To enable continuous updates of the sensor data and video image the control clients are implemented as JAVA applets. In addition, these JAVA applets have the advantage of being platform independent as they only require a web browser and a JAVA virtual machine installed. For the communication channel between the control server and the JAVA clients standard TCP/IP and UDP/IP is used. The control servers have a camera module which sends a video stream to the control client and a control module. This control module is responsible for the client communication, access control, database communication, sensor data processing, the robot control and communication, and optional the communication with external localization systems. The access control monitors the reserved timeslots for the users and registers the login requests of the client. The robot control module translates and forwards the control commands from the user to control commands for the robot via the robot communication module which is connected to the serial port of the server. The module for external localization systems handles the data exchange via RS232 or Ethernet interface. The server supports several external localization systems whereas now, only a VScope (described in the hardware section) is used.

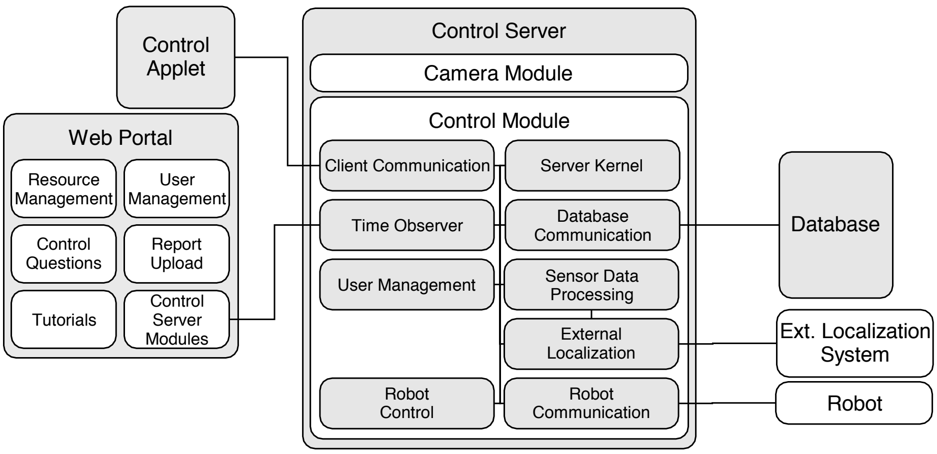

Fig. 3: Modularized Design

2.2 Hardware

The Tele-Experiments are using two different types of mobile robot. The TOM robot is a simple differential drive mobile robot (cf. Fig. 5), whereas MERLIN (Mobile Experimental Rover for Locomotion and Intelligent Navigation) is a car like mobile robot with an Ackerman steering (cf. Fig. 4).

MERLIN is a four wheel mobile robot with an Ackerman steering and two powered rear wheels. The wheelbase is about 30cm and the track width is 21.5cm. MERLIN is equipped with Hall-sensors at each frontal wheel with a resolution of 8 pulses per wheel turn. In addition to these Hall-sensors, a wheel encoder with a resolution of 100 pulses per wheel turn is installed at the right frontal wheel. Furthermore MERLIN has a gyroscope, three ultrasonic sensors at the frontal bumper, one ultrasonic sensor at the rear bumper and two markers for the external tracking system VScope. The onboard data processing and the low-level operations for steering and motor control are done by a C167 micro processor. Due to the 24 hour availability of these experiments, MERLIN's power supply is realized with a cable.

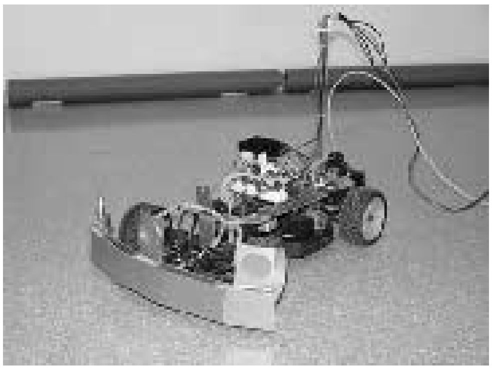

Fig. 4: Mobile Robot MERLIN

The experiment area for MERLIN consists of several hardware components:

- The MERLIN robot;
- An external tracking system, VScope;
- A web-camera and a camera server;
- The MERLIN control PC;

For the localization of MERLIN, the VScope is used as external localization and tracking system. It is based on infrared and ultrasonic signals and capable of tracking up to three VScope markers in a 2D or 3D environment. The VScope system consists of three components: the VScope buttons, the VScope towers, and the VScope microcomputer. A VScope button has an infrared receiver and an ultrasonic transmitter. Each button sends a unique identification. Thus this localization system can determine the x-, y-, and z-position of three different buttons simultaneously. After a VScope button is activated by the infrared signal of the VScope towers, it starts sending an ultrasonic signal to the towers. Then the VScope microcontroller can calculate the position of each button based on the signal propagation delay. To support the user with an overview of the experiment area a web-cam is mounted above. In case of the MERLIN experiments the camera will follow automatically the robot.

TOM is a mobile robot with a differential drive (cf. Fig. 5). Both motors are equipped with an encoder of a resolution of 8400 pulses per wheel turn. The onboard data handling, the motor control, and the communication to the control server are done by a C167 microcontroller. To control the robot, the students are sending the voltage for the left and right motor, the duration of the movement, and parameters for the PI-Controller to the robot. TOM returns the current wheel encoder values of the left and right encoder.

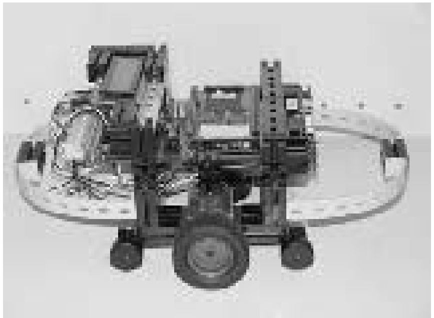

Fig. 5: Mobile Robot TOM

The experiment area for TOM uses three hardware components:

- The control server;
- The web-camera;
- The TOM robot;

Both robots are connected to the internet via different control servers whose functionality is described in the above software chapter

3 The Remote Experiments

The experiments combine the application of telematcis methods in parallel to the knowledge learned for performing the experiments and thus extend the education of engineers as well as students of natural sciences with a qualified practical education 0. The remote experiments described in this work are using two different designs of mobile robots: the differential drive robot TOM, and the car-like robot MERLIN. Mobile robots are an appropriate test object to analyze the kinematics constraints of a mechanical construction or the deviations and errors caused by slipping, friction and inertia. As well, they are very useful to demonstrate the basics of control engineering with the tuning of a PID controller. In contrast to many other remote controlled robots in the internet, the University of Würzburg provides seven interactive learning units related to mobile robots.

The experiments related to the kinematics of mobile robots introduce the students to the basics of the holonomic and non-holonomic mobile robots. The focus of these experiments is set on the problems experienced during the work with real hardware. In contrast to ideal simulation models, real hardware and real sensor measurement data always influenced by external sources of error like friction, inertia, sensor or actuator deviations. Furthermore the students are introduced to the differential drive mobile robot TOM and the car-like mobile robot MERLIN to analyze the different kinematics constraints caused by the different mechanical constructions. For the TOM robot the kinematics and inverse kinematics (calculate the control commands to move the robot from pose A to pose B.) is covered with an experiment. MERLIN explains the functionality of the commonly used steering mechanism in automobiles - the Ackerman steering. Furthermore, the students learn how to handle the behavior of the robot in a mathematical way and how to deal with the inverse kinematics problem for this non-holonomic robot. Finally, these experiments explain some basic procedures to deal with real sensor data and systematic errors. Therefore, a simulation of an idealized model is given to the students. After important hardware parameters are determined, the ideal simulation of a movement is compared to the real path traveled by the MERLIN robot to analyze sources for the deviations like friction, inertia, or systematic errors.

The second main topic of the remote experiments is the motor-controller synthesis for mobile robots 0. Usually, mobile robots are driven by dc electrical motors. Thus, the control of dc-motors is a key issue while analyzing the dynamics and kinematics of mobile robots. The experiments in this topic are dealing with the basics of dc-motors, the PWM (pulse-width modulation), and the mechanical and driving system of MERLIN and TOM. Furthermore, an introduction to control theory is given including the theory and methods for control system analysis and synthesis. The focus of the TOM experiments is set on the control of both electrical motors and the objective is determination of the transfer function of an open-loop controller, a closed loop controller and the step response of the system. Finally, the designed PID controllers for both robots are tuned using the Ziegler-Nichols rules.

Finally an experiment related to path planning algorithms for mobile robots is available. Different methods of finding a suitable path between a start configuration and a given end configuration of the robot are presented. The planning algorithm is responsible for providing a collision free path that complies with the kinematics constraints of the robot. The experiment describes the fundamentals of the path planning problem using three different path planning algorithms: the Roadmap - Visibility Graph, the Potential Fields, and the Distance Transform method. For this experiment, a simulation interface is provided. Different environment maps are used to apply and compare the usability of the different methods. The focus of this learning unit is set to the identification of some basic problems of path planning and on applying a suitable algorithm for the given requirements. For the final report a detailed analysis of the different parameters of each path planning algorithm should be given.

4 Conclusions

The tele-experiments described in this work are using a non-holonomic car-like mobile robot which is very unusual in the e-learning context. With respect to the mechanical and electronic construction, non-holonomic mobile robots are relatively complex and their operation requires a lot of space. Due to the non-stop availability of the whole system, the robot-hardware as well as the infrastructure has to be well tested and reliable. Therefore, the robots have self-tests and protection routines to avoid damages. In future, emphasis will be set on improvements to decrease the required bandwidth and to increase the usability of the control interface. Therefore, a student survey of in a practical course of computer science students at the University of Würzburg was evaluated. Since the summer semester 2005 all experiments are available at the vhb (Virtuelle Hochschule Bayern) and they are integrated into the curriculum of some of the partner Universities.

5 Acknowledgements

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