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Mobile Mini-Robots for Engineering Education*

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Mobile robots provide a motivating and interesting tool to perform laboratory experiments within the context of mechatronics, microelectronics and control. Students study this particular example in system design and integration tasks at different levels of complexity. This paper describes a set of workshops in which mobile robots were constructed in order to introduce students by hands-on experiments to mechatronic systems and control system design. This was tackled in combination with a teleoperations environment for rovers. Such tele-education experiments in the area of telematics are addressed in the paper, as well as describing typical objectives, the mobile robot hardware and the exercises performed within such robotics workshops.

INTRODUCTION

In industry, engineers usually design equipment to perform given tasks, while the particular technologies employed for the solution do not matter greatly. In contrast, traditional university courses are related to the training of specific techniques. In order to bridge this gap, a *robotics workshop* has been introduced into the final year curriculum of the Master course *Mechatronics* at the Fachhochschule Ravensburg-Weingarten - University of Applied Sciences (FHR-W) in Weingarten, Germany.

In response to the given tasks, students have to develop a related system design of a mobile robot. The control system, consisting of sensors, actuators, microprocessors and software, is one key component. The students can select from different prefabricated electronic and mechanical components to generate their robots.

Mobile robots find a broad range of applications in the context of material transport as well as in monitoring, reconnaissance and exploration. Beyond the direct application of these robots, which range from space exploration to industrial production, there are also significant spin-offs towards cars in order to increase safety and comfort.

Small mobile robots also provide an interesting method in education as a system of limited complexity, which nevertheless allows the students to perform interesting experiments. For several years, FHR-W has organised robot-building workshops for pupils and students, which are very well perceived. The workshop activities are usually performed in teams of up to four students, with a tight schedule and a competition between the different robots at the end. Thus, a typical framework for engineering work is provided that extends beyond the technical aspects. This includes:

- Cooperation in multidisciplinary teams.
- Coordination of parallel work between the team members.
- Finding engineering solutions under time pressures.
- Applying the theory learned to solve practical problems.

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- Learning from failures to finally achieve working solutions.

Thus, the usual courses are complemented by additional experiences in the areas of work management and social team dynamics.

This paper places its emphasis on the control hardware and software, as well as on the control-oriented tasks addressed in the experiments.

THE ROBOTICS INFRASTRUCTURE

At different levels of complexity, suitable robots, sensors and sensor data processing components are provided for the control tasks. Here, in particular, the aspects related to navigation are addressed.

Basic Level Components

For introductory courses, a low-cost control system is used. This allows for interesting and engaging experiments related to:

- Navigation in maze parcours.
- Obstacle avoidance.
- The acquisition and collection of objects.

A small dimension mainboard has been developed, based on the low-cost microcontroller BASIC stamp II, allowing to control two motors and the use of up to four sensor interfaces. Via a serial RS232-port, communication with a PC can be performed, either for remote operations via a terminal program or for downloading a compiled BASIC-program to the microcontroller for autonomous control reactions.

Limitations of this low-cost approach include:

- Maximum executable program length of about 500 instructions.
- The sensors must provide inputs at the appropriate microcontroller level.
- Input/output of pulse sequences are difficult to process due to delays occurring that are related to the processor load.

Thus, decentralised motor controllers were used, which receive the control action plan from the central microprocessor and then autonomously control the motors.

According to the envisaged tasks different sensor configurations can be used, such as:

- Line detection system, based on infrared diodes used to follow optical guidelines.
- Light detection system, used to approach towards light sources.
- Obstacle detection system, based on infrared diodes.
- Collision avoidance system, based on tactile bumpers.

The students can employ these building blocks to appropriately equip their robot for the given task. An example program containing all drivers for sensor/actuator control is made available; nevertheless, specific code related to the given control task is still to be programmed by the students. These boards are usually used in combination with mechanical building blocks from fischertechnik™ construction kits (see Figure 1) providing components like chassis, transmissions, gears, handling equipment, etc, which allow for very flexible implementations.

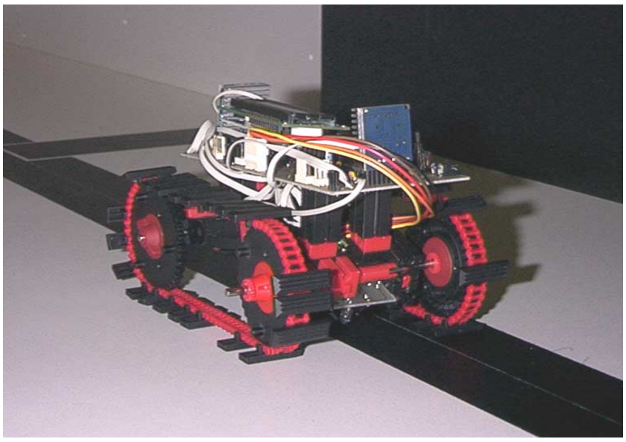

Figure 1: Example of a tracked robot for autonomous line-following tasks that has been equipped with the BASIC stamp microcontroller board.

Advanced Level Components

For more complex control tasks in the educational context, FHR-W has developed, together with the Steinbeis Transferzentrum ARS, the MERLIN (Mobile Experimental Robots for Locomotion and Intelligent Navigation) vehicles (see Figure 2). Here, the control is based on a modular multi-processor system adapted to the sensor sytem requirements.

In the basic version, one 80C167 microprocessor is employed for:

- Sensor data acquisition via CAN-bus, serial interface or special interfaces from processor ports.
- Sensor data pre-processing.
- Pulse-width modulated control of steering and driving motors.
- Calculation of reactions from the control algorithms.
- Telecommunication with a remote control and monitoring station.

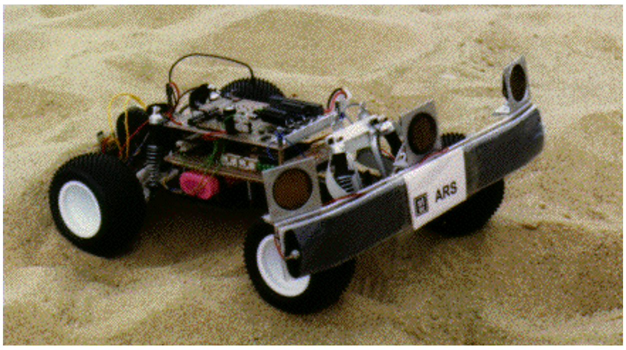

Figure 2: The wheeled and the tracked variants of the MERLIN vehicle.

The most sophisticated processor system used so far consists of three processors, shown in Figure 3. This system is used:

- For control of (several) drive motors and the steering motor of an 80C592 micro-controller.
- For sensor data acquisition and pre-processing in which the 8-bit processor 80C592 or the 16-bit processor 80C167 (both including a CAN-bus interface) is used according to sensor system needs.
- As the main controller, the 80C167 processor provides the telecommunication link, which, via the serial port, executes the control algorithms.

For complex algorithms that require huge computational effort, a development based on the digital signal processor TMS320F243 has been initiated. The interprocess communication is always based on the CAN-bus.

The 80C167 CR 16 bit-processor offers performance characteristics to deal with challenging sensor data processing and control tasks, including:

- 16 A/D-ports with a resolution of 10 bits.
- An integrated CAN bus interface.
- A 100 ns processing cycle.
- An external bus interface capable to address a storage area up to 16 Mb.

Additional, more sophisticated sensor modules can be employed in combination with the dedicated sensor board of MERLIN, such as:

- Obstacle avoidance system based on multiple ultrasonic sensors [1]. Another system utilises active laser marking [2][3].
- Outdoor navigation based on (differential) GPS [4].
- Navigation support from gyros and odometry.
- Attitude determination by 2-axis inclinometers and 3-axis magnetometers.
- Localisation according to ultrasonic range profiles [5].

Through this, interesting experiments that relate to environment perception, navigation in less structured environments and autonomous control strategies can be carried out indoors as well as outdoors.

Professional Demonstration Equipment

The problems to be solved during the workshop are focused on tasks for inspection robots in planetary exploration (see Figure 4), as well as industrial transport robots (see Figure 5). Due to earlier R&D projects in cooperation with industrial partners, performance demonstrations with related professional robots can be included.

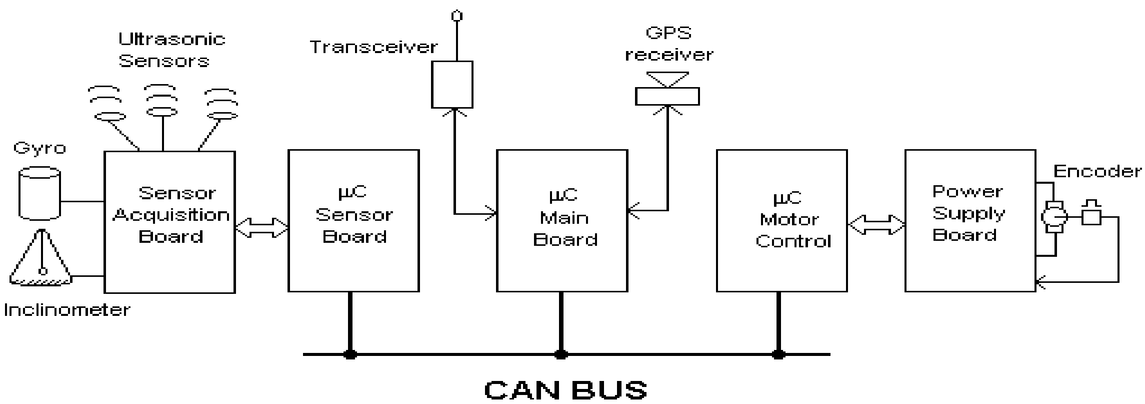

Figure 3: The electrical architecture of the MERLIN vehicles.

The robot systems available include:

- Several industrial transport robots based on guidance by:
  - Induction wires.
  - Optical guidelines.
  - Free navigation.
- Robots for sewage pipe inspection and repair.
- Electrical wheelchairs for disabled people.
- The Mobile Instrument Deployment Device (MIDD), developed for Mars exploration in contract for the European Space Agency (ESA), shown in Figure 5.

Beyond the demonstrations that accompany lectures, these vehicles are also employed as test platforms for thesis work and actual research projects.

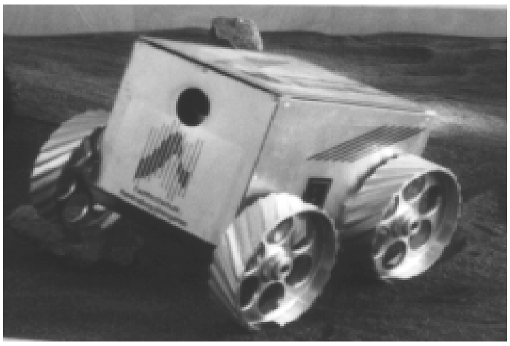

Figure 4: The European Mars rover MIDD, developed within an international team by the Steinbeis Transferzentrum ARS for the European Space Agency (ESA).

Figure 5: Typical industrial Autonomously Guided Vehicle (AGV) used for demonstrations of a forklift handling device and optical line following system.

THE TELEMATICS TESTBED

To train the students in telematics, techniques of the rapidly growing teleservicing market has been incorporated utilising an infrastructure to remotely control the mobile robots via the Internet [6]. This is based on the testbed for remote control and teleoperation aspects of the Mars rover MIDD [2]. The MIDD is also participating in the educational *Red Rover* project of the Planetary Society and the Utah State University [7].

The testbed consists of three prime elements:

- A rock and sand landscape similar to Mars, including facilities for a tether link to power and control rovers.
- A rover operator workplace (out of sight from the Mars-landscape), a computer processing rover sensor data according to the selected test scenario (adding noise, delays, etc) and hosting the video framegrabber for the monitoring cameras.
- A WWW-server that interfaces with clients and handles over the Internet the transfer of sensor data from the operator workplace and commands to the rover.

The WWW-server and the operator workplace exchange data via sockets. From 1995 on, a distributed control system based on a CGI script manages the control access.

As part of the *Virtual Laboratory* within Baden-Württemberg's programme, *Virtual University*, this testbed has been further improved to allow remote partner universities to use these experiments in their courses. In this context, an alternative access based on JAVA applets has been implemented, as demonstrated in Figure 6.

These facilities allow the students to analyse robustness and safety aspects of information process-

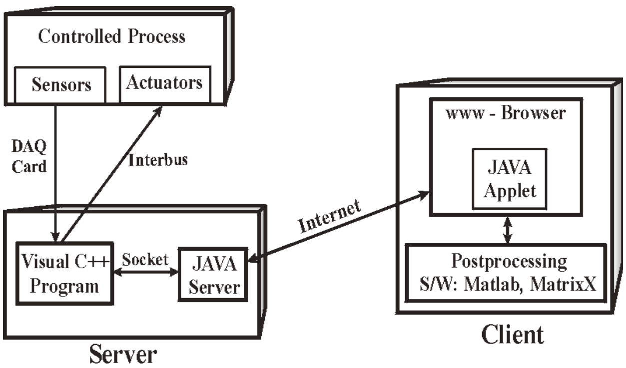

Figure 6: Typical information flow of a JAVA implementation between the remote equipment, including smart sensors and actuators, and the remote student at the client site.

ing methods related to data compression, packetising and sensor data processing. In control engineering the topics addressed relate to controls with delays, distributed control schemes and remote controls. The tele-education use of these experiments has been undertaken together with 11 partner universities from Europe, the USA and Canada and is further explored in the international projects TEAM (http://www.ars.fh-weingarten.de/team) and IECAT (http://www.ars.fh-weingarten.de/iecat) [8].

EXAMPLES OF EXPERIMENTS

During the workshop, the students have to implement different control functionalities in successive steps of increasing complexity, such as:

- Modelling and controlling the vehicle with the following aims:
  - Modelling of the vehicle.
  - Identification of related control parameters.
  - Development of PID-control algorithms for steering and adapting the vehicle's speed.
- Avoiding obstacles with the following aims:
  - Detection of obstacles by tactile and range sensors.
  - Design of collision avoidance schemes.
  - Programming of efficient autonomous detour manoeuvres towards the target.
- Following a line marked on the floor, with the following aims:
  - Line detection with infrared diodes.
  - Control schemes to follow the line from a fixed starting location.
  - Development of strategies to find the guidance line from any starting location.
  - Implementation of methods to follow the lines in a known environment towards the target, despite line crossings and a random starting point.
  - Tuning of the controller to avoid unwanted oscillations.
- Crossing of a maze parcours by remote control, with the following aims:
  - Design of a user interface for remote control.
  - Transmission of camera data to the remote operator.
  - Identification of problems due to limited sensor characterisation of the environment.
  - Combination of remote control with autonomous obstacle avoidance.
- Collection of samples via remote control in an outdoor environment, with the following aims:
  - Design of a sampling device.
  - Development of a method to dock at the target with sufficient accuracy.
  - Coordination of motion with sampling control.
- Autonomous navigation towards a target, with the following aims:
  - Selection of an appropriate sensor system.
  - Identification of passive objects by sensors.
  - Path planning to a target.
  - Autonomous docking at the target.
- Autonomous collection of multiple samples with the following aims:
  - System integration of previous autonomous sampling and navigation functionalities.
  - Mission planning for the efficient collection of distributed samples.

Each experiment consists of typical steps like:

- Development of a control process model.
- Design and programming of a first simple control.
- Calibration of sensors and actuators.
- Conception of performance tests and their documentation.
- Adaptation and fine-tuning of the sensor and control system.

Advanced students have to compare the performance of different control approaches in hardware tests, eg using adaptive control, fuzzy logic or neural networks. In particular, analysis incorporates robustness to varying ground contact friction parameters, changing payload mass and moving obstacles. With respect to sensor data processing, Kalman-filters for sensor data pre-processing and sensor data fusion are studied.

Thus, a broad spectrum of problems is offered, with the solutions always requiring a mix of contributions from mechanics, electronics, informatics and control. The technical approach to achieve a specified design objective is intentionally kept open to creative solutions. The broad variety of robot solutions is displayed at the FHR-W Web-site [9].

CONCLUSIONS

The implementation of mobile robots offers interesting practical experiments for education in system engineering topics, motivated by industrial applications.

Within the framework and resources of a standard university course, students thus learn to design creative solutions to given problems in an interdisciplinary approach with emphasis on mechatronics, sensorics and control. By taking advantage of a telematics testbed, modern teleservicing techniques related to telediagnosis and remote control are also trained.

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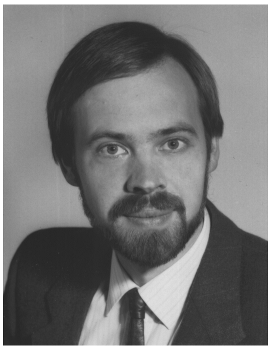
BIOGRAPHIES



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