Remote Experimentation in Distance Education for Control Engineers

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Abstract

In the past few years, „Virtual labs“ have been meaningful and very popular in distance education in engineering-oriented fields of study, since they allow to perform interesting experiments with the equipment in the labs remotely through Internet. Thereby, the students can gather experiences with practical experiments and prove the theoretical knowledge contained in courses.
In our paper, we discuss utilization and the technical structure of two of our virtual laboratories, which were developed to support the distance education for control engineers.

1. Introduction

The FernUniversität in Hagen is the only distance teaching university in Germany and an integral part of the regular public higher education system. At present, a comprehensive environment „Virtual University“ is developed in which all courses and services of the FernUniversität can be accessed and used via electronic communication and multimedia.
Significant role in this concept play various virtual laboratories, especially in engineering-oriented fields of study, because they contribute to extension of the courses by practical experimentation and „touch with reality“, which is very important for expectant engineers. Other benefit of the virtual laboratory is, that it saves students‘ travel and accommodation costs, which would be needed to come to make the practical training at our university. Moreover, the virtual lab is one possible technique to share usually expensive equipment among several universities or education centres.
At our research group, several such laboratories were established in several past years. They are used in distance education for control engineers and including a laboratory for remote control of a mobile robot with omnidirectional wheels [1], [2], [3] and for Internet-based testing and programming of industrial PLC controllers (Simatic S7 from Siemens) [4]. Our last developed virtual labs, which will be presented below in detail, are dedicated to inverted pendulum/gantry crane control and teleoperation and advanced control of a mobile robot.

2. Virtual laboratory for inverted pendulum/gantry crane system

The virtual laboratory for real-time control of an inverted pendulum and a gantry crane system was developed in past three years within the project „LearNet“ (Learning and Experimentation in Network) [5]. In this project, which was supported by a grant of the German Federal Ministry for Education and Research, several German universities collaborated in order to set-up a common platform for on-line learning and experimentation in control-engineering education. Now, a network of on-line experiments is available to students from all over Germany to support them by study of control theory and process automation.
Because of its configuration flexibility and wide range of executable experiments with various complexities, this laboratory is used as a main platform for practical experimentation in several courses concerning control theory on both master and bachelor level. The inverted pendulum/gantry crane system was chosen because it represents one of the most commonly used non-linear systems in control theory at the undergraduate level. The ability of this system to provide interesting and challenging experiments makes it very attractive for students. The spectrum of the experiments ranges from the position/speed control of the single axis to the control of the pendulum (alternatively 2D-pendulum) in its stable/unstable position by several types of controllers (PID, state-space feedback, fuzzy controller, etc.).

2.1. Virtual laboratory components

The basic idea of the virtual laboratory is to allow the remote access to an experiment via Internet (teleoperation) and to mediate the actual state of the experiment to the user (telepresence) at the same time.
For realistic presentation of the experiment via the Internet, several visualization methods are used. The students choose from video- and audiostreams, 3D animated graphics or conventional curve plotting, depending on the speed of their data connection to our lab. Only standard Web-browsers (optional with VRML Plug-In and Java Media Framework) are required as an interface to the laboratory.

Real-time control of the inverted pendulum/gantry crane system is based on using of MATLAB/Simulink with xPC Target Toolbox. In this case, the system is controlled by xPC Target. The communication between client and xPC Target carries out the xPC Server, which also controls the remote access to the lab.

For the remote operation of the experiment, Java-applet based user interface called Control Applet is used.
The main components of the virtual laboratory for inverted pendulum/gantry crane control and their interconnections are depicted in Fig. 1.

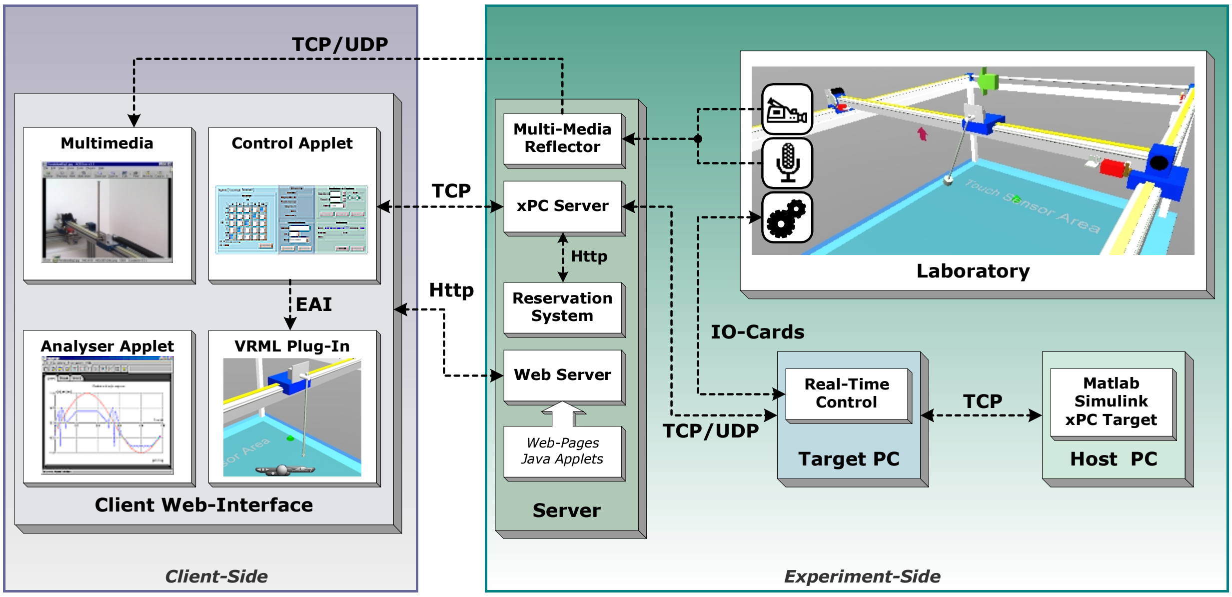

Fig. 1. Components of virtual laboratory for inverted pendulum/gantry crane control

2.2. Experiment set-up

The essential part of the laboratory, the inverted pendulum/gantry crane system, is a triaxial system, which consists of the gantry movable along an x-axis and pendulum/crane system also movable along y-axis placed on it. The DC motors drive both the gantry and the cart. For control purpose, a standard PC with input/output cards is used. These cards convert the signals from the sensors (optical encoders for measurement of the axes positions; contactless proximity sensors) and control the drives for the axes.
The control algorithms were designed and implemented by the Matlab/Simulink software package (Release 12) with Real-Time Workshop and xPC Target Toolbox. These tools are able to automatically generate stand-alone real-time applications from the Simulink models that run on the so-called *Target PC*, while their development is carried out on separate host computer (*Host PC*). The Target PC is based on a special real-time operating system (Real-Time Kernel) and it communicates with the Host PC through serial link or network connection. Through this connection, it is possible to operate the Target PC (load/start/stop application, change algorithm parameters, trace signals) completely by the Host PC (from the Matlab command line or directly from the Simulink model). The major advantages of this experimentation platform are:

- short development times for the control algorithms,
- only standard PC-hardware requested for the Target PC (486/8MB PC is often suitable minimum, we used a Pentium MMX/200MHz/32MB),
- high stability and reliability of the Target PC, since it works with an optimised operating system (reduces to necessary functionality).

2.3. xPC Server

Even though the Target PC is fully controllable from the Host PC, this feature has been used only in the development and testing phase of the lab. For the teleoperation of the lab, some type of remote control of the Target PC via Internet is necessary. With the xPC Target Toolbox, a simple interface to the xPC Target through Web-browser is provided too. Since it was not possible to implement all required functionality with this interface, we decided to use C-API functions from the supplied library *xpcapi.dll* to build our own server application in order to manage the Target PC, called *xPC Server*. These functions serve to establish a basic control for the Target PC (restart, opening/closing of the communication port), downloading of any real-time applications and control of its functional flow (load/unload, start/stop, stop time and sample time setting), adjustment of the control algorithms and signal tracing. Moreover, the xPC Server communicates with the client components, enables the control of the lab cameras and supervises the access to the lab.

One of the main advantages of the realized xPC Server is its easy adaptability to new experiments and other lab equipment. Namely, each experiment is implemented by a Simulink model. This model contains the particular control algorithm as well as some special blocks that are required for operation with the xPC Server. These blocks are designed for:

- initialisation of the experimental plant,
- turning on/off of the control algorithm,
- acquisition and transmission of the experimental data,
- camera control.

However, all these requirements are easy to accomplish, as the necessary blocks and subsystems are for the disposal in advance.
A further condition for the compatibility with the xPC Server, is the initialisation file created for a specific Simulink model. This file includes information about the model, the list of the adjustable parameters with their boundary values, the numbers of the captured signals, etc. The xPC Server reads this file before loading the model on the xPC Target and sets the parameters of the communication with the client accordingly.
In the xPC Server, two techniques for data logging are implemented. For data acquisition during the execution of the lab experiment, the fast (but unreliable) UDP protocol is used. This type of communication is supported directly by the xPC Target Toolbox. Therefore, only dedicated blocks must be added into the Simulink model with the tested algorithm. The xPC Target sends data during running of the application through its UDP port to the xPC Server, which transfers them further to the client. In this manner received data are used on the client-side for the animation of the 3D-model and on-line monitoring tools.
For any more precise analysis of the experiment, another method for data storage is used. Since the data for analysis must be uniformly sampled, we used special blocks from the xPC Target Toolbox in Simulink models – *xPC Scopes*. These data are logged for a desired time on the xPC Target first and then they are sent to xPC Server all at once. On the server side, these data are saved in files, which are available for download by the student.

The last function of the xPC Server is the remote operation of the cameras in the lab. In our lab, several cameras are placed that present a view on the experiment from various viewing angles. The user can teleoperate the cameras (rotating and zooming) and thereby adjust them according to his needs. Besides the videostream from the cameras, the xPC Target screen is transmitted to the client, who can thereby observe its operating condition.

2.4. Multimedia Reflector

The *Multimedia Reflector* (MMR) is a server component developed during the LearNet project (Ruhr-Universität Bochum). It is designed for real-time processing of video-, audio- and data-streams from the laboratory and for their live transmission (synchronously) to the client. MMR simultaneously transmits streams to several clients with various transfer rates.

2.5. Reservation System

A new reservation system for distributed labs has been developed during this project and it is now used for booking of time quota with respect to each experiment in charge. This system is accessible through Web-browser interface and offers information about occupation of particular experiment. The sample reservation interface is presented in Fig. 2.

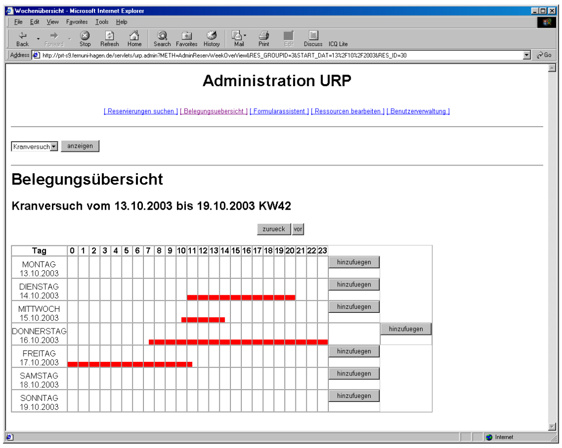

Fig. 2. Interface to the reservation system

Before accessing any lab experiment, every user has to identify by his user name and password that has been distributed to him by the reservation system. These data are checked by the xPC Server, which communicates with the reservation system server via HTTP protocol. The response of the reservation system is an XML-document with allowed duration time for teleoperation of the experiment and acknowledgement of the access to the lab. The xPC Server executes this checkout in regular time intervals during experimentation in order to assure the access to the laboratory for the next client.

2.6. Client interface to the lab

Client components are dedicated to experiment control and data visualisation. The communication with all servers involved is based on the TCP protocol and can be handled by standard Web-Browsers. All client components are implemented as JAVA-applets. Thereby, a comfortable and easy to operate user interface is created. The main requirement on the clients side can thus be reduces standard Web-browser without additional software.
Because of several types of available web-browsers and varied transfer rate of the Internet connection, a number of different equipped interfaces to the lab (full version for the students with the fast connection, the version with only VRML-model animation for the clients with slow

connection, etc.) were designed. The Web-interface to the gantry crane controlled by a fuzzy controller is shown in Fig. 3.

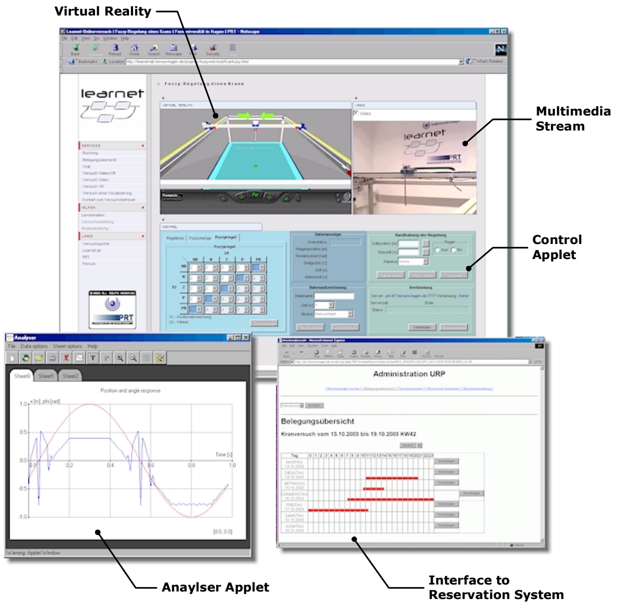

Fig. 3. Web-browser with user interface to the lab

2.7. Control Applet

The main component for teleoperation of the virtual lab is the *Control Applet.* A version for gantry crane control is shown in Fig. 4. The tasks performed by the Control Applet are:

- Verification of the access to the lab
- Opening/closing connection with the xPC Server
- Transmitting the commands to the server in defined protocol (start/stop application, get/set parameters, etc.)
- Displaying experiment state (elapsed time, server response, etc.) and signal values
- Controlling of the communication status and user activity (when no activity occurs, it aborts the experiment and closes the communication)
- Communication with VRML Plug-In

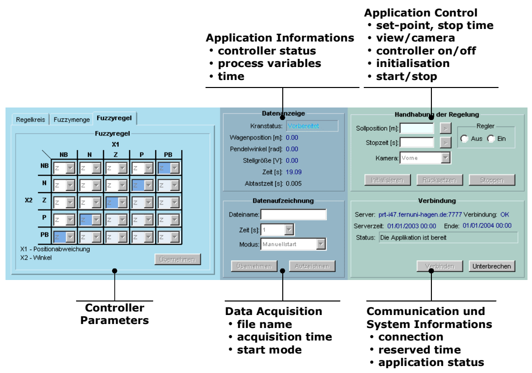

Fig. 4. Control Applet

2.8. VRML Plug-In

A VRML Plug-In is used for visualization of the experiment by means of its virtual 3D model. This option is used because it allows realistic presentation of the lab scenery in virtual reality. Moreover, it works even with low-bandwidth Internet connections, because of the small amount of transmitted data. Furthermore, the virtual reality model enables to visualise miscellaneous physical and process quantities like acting forces, set-points, control signals, etc., and to interactively handle the lab by various switches and sliders. The animation of the virtual scene is implemented by using the External Authoring Interface (EAI). The 3D model of the pendulum/crane system is shown in Fig. 5.

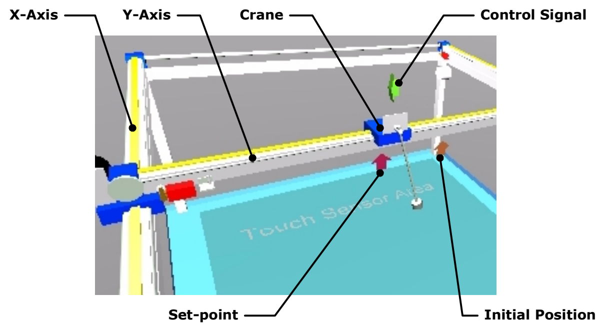

Fig. 5. VRML 3D model of the pendulum/gantry crane system

2.9. Analyser Applet

This applet has been developed for the on-line experiment evaluation; it is useable for plotting of the experimental data saved on the server. The data are received by the 'Control Applet' from the xPC Server and saved in the user's local file system. The user can plot several curves, zoom-in/out the graph, etc. It is shown in Fig. 6.

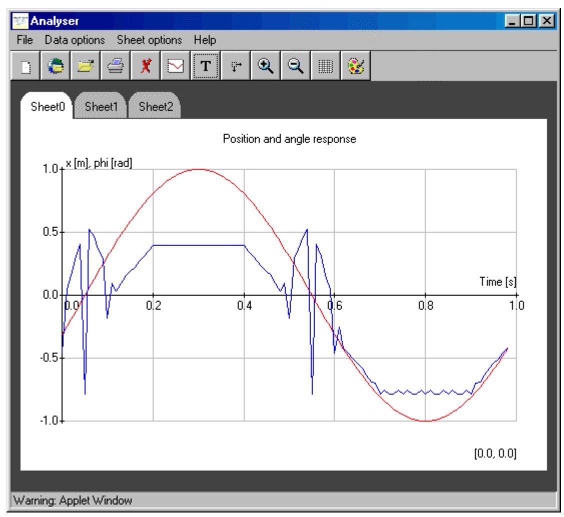

Fig. 6. Analyser Applet

2.10. Multimedia Applet

An additional 'Multimedia Applet' (Ruhr-Uni-Bochum: in combination with MMR server) displays streaming video from the virtual lab, plays sound and roughly plots the process data. It is a hybrid Java-class that can be started either as Java applet or as stand-alone application. It exploits JMF, which must be installed on the client computer. On the start-up, the user can chose from the set of available media (video, sound, data) as well as transfer rate for the video stream. This 'Multimedia Applet' receives the data directly from the MMR server. Examples of video streams from several cameras located in our lab as well as transmitted xPC Target screen are given in Fig. 7.

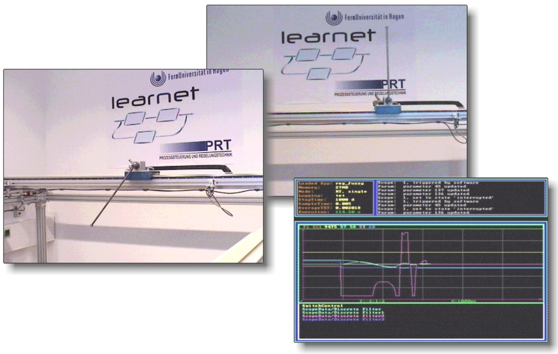

Fig. 7. Video streams from the lab

2.11. Utilization of the laboratory for inverted pendulum/gantry crane control

The laboratory was completed during the summer term of 2003 and thenceforward it is a part of several courses concerning control theory and mechatronics. The students can performed their experiments through both LAN and modem connection. However, the tests shown, that the minimal baud rate for streaming video from the lab is 56 kBit/s. With the slower connection, only restricted telepresence (VRML-model and graphs) is available.

3. Virtual laboratory for mobile robot control

The virtual laboratories for the robot control are developed and used in education process on FernUniversität in Hagen since 1997. The first laboratory served to experimentation with omni-directional mobile platform [1], [2]. This vehicle is equipped with Mecanum wheels, which provide three degree-of-freedom motion in Cartesian space. The students task was design of a speed controller for the robot wheels. During experiments, the robot moved along an in advance defined trajectory and the students evaluated the influence of speed controller parameters on its performance. A sample user interface for teleoperation of the mobile platform is shown in Fig. 8.

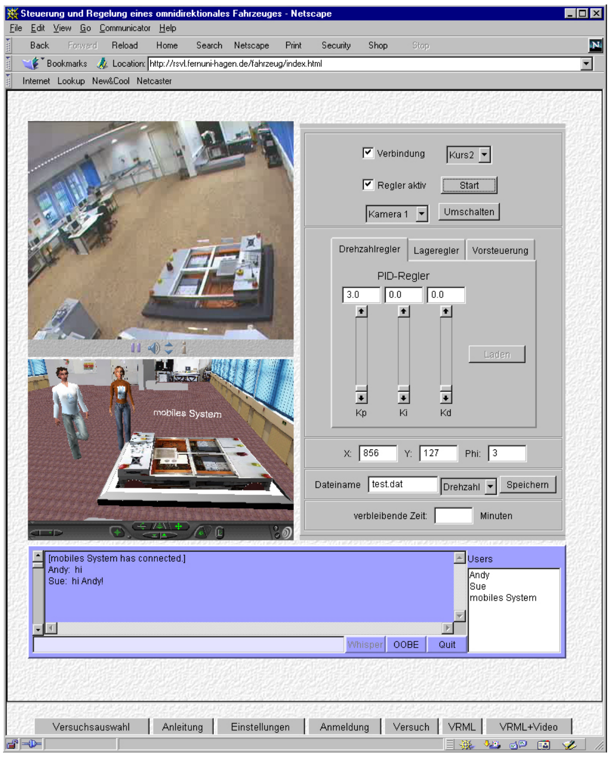

Fig. 8. User interface for remote control of the omnidirectional platform

To extend the range of existing labs by advanced experiments typical for mobile robot missions like "labyrinth crossing" or "room exploring and mapping", we are developing a new virtual laboratory for teleoperation and remote control of a mobile robot PIONEER 3-AT from ActiveMedia. In this lab, the students will be able to develop and evaluate algorithms for robot path planning, reactive control, data processing from various sensor, map generation, etc.

3.1. Mobile robot PIONEER 3-AT

PIONEER 3-AT is a wheeled all-terrain experimental mobile robot. It can be equipped by various types of sensors, including front and rear sonar, laser rangefinder, bumpers, pan-tilt-zoom colour camera and GPS receiver. Robot motion is controlled by embedded microprocessor, which communicates with a PC client. This communication is used for sending motion commands to the microcontroller and data transfer between microcontroller and PC client. The PC client is placed in our case on the robot and running under Linux OS. It is equipped by wireless radio modem and thereby accessible through our network, which makes it an ideal platform for remote control. Delivered software enables to program the robot on various levels, ranging from simply microcontroller commands to complex actions. The PIONEER 3-AT mobile robot is in Fig. 9.

Fig. 9. Mobile robot PIONEER 3-AT in laboratory

3.2. Utilization of the laboratory for mobile robot control

As mentioned above, this lab will be used for development and verification of sophisticated control strategies and algorithms for mobile robots. Because such types of experiments require high level of students' skills and more time to practice, the operation of the lab will be different from the one used by the inverted pendulum/gantry crane experiments. The students get their problems to solve at the beginning of the term in order to prepare their partial solutions. For this purpose, they will be able to use a mobile robot simulator with specific data (map of the laboratory with various objects) at home to develop their algorithms. Robot simulator is shown in Fig. 10.

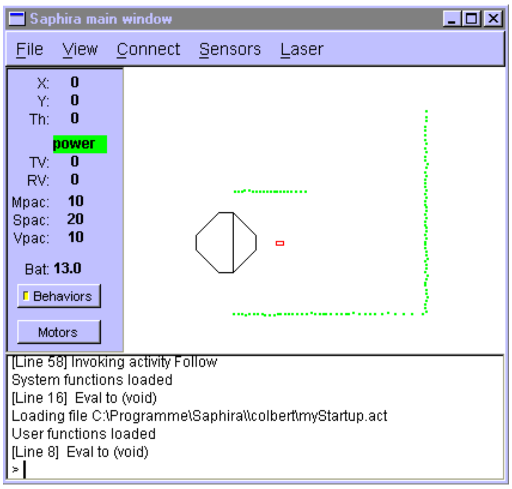

Fig. 10. Using of the robot simulator during development

At the end of term, the students will test and evaluate designed strategies in the virtual laboratory. The algorithms will be loaded on the real mobile robot and the student will observe it remotely. He will also be able to adapt the robot control program according to its behaviour in the real world. For the remote control of the robot, including downloading of the user programs, Web-browser with a user interface similar to the one shown in Fig. 11 will be used. The components for multimedia stream processing, reservation system and remote access control will be the same as in the pendulum/gantry crane virtual lab.

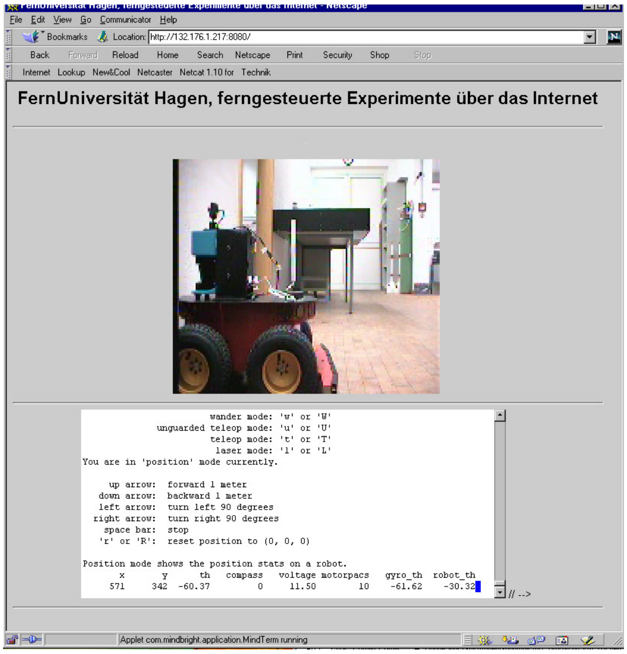

Fig. 11. User interface for remote control of the PIONEER 3-AT mobile robot

4. Conclusion

In our paper, we presented two of our virtual laboratories designed for use in distance education for control engineers. Both of them can considerably enrich the content of the courses by addition of practical experimentation with minimum requirements on the student side. The presented structure of the labs provides a possible framework for future laboratories.

5. References

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