

# Practical Education of Control Systems Engineers in a Virtual University

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## Abstract

*This contribution presents a Web-based on-line learning environment for Control Systems Engineers in a Virtual University.*

*It outlines the on-line environment in general, but is especially focussed on advanced VU features like mobile learning, on-line practise and audio-/video-conferencing for seminars and oral examinations.*

*Engineering students are confronted with problem solving in the field on controller design and robotic applications.*

## 1. Introduction

The concept of a Virtual University has been arisen almost a decade ago. Starting with simple communication tools such as 'Email' and 'Newsgroups', this concept has been enhanced with many different ideas and applications. Learning platforms as a framework for Internet universities have been developed providing various helpful tools and instruments to build a consistent system of information sharing and electronic courseware distribution. Content management systems have been integrated to enable a user-friendly input of information. Computer supported collaboration re-introduces groupwork into a Virtual University environment. Remote laboratory infrastructures provide access to Internet-based experiments especially for students in engineering, natural and computer sciences. Virtual seminars can be carried out via video and audio conferencing on a personal computer. Virtual Reality techniques are also applied to many different learning scenarios.

Mobile learning is one of the more advanced features of a virtual learning environment, making the learning process time- and location independent. Assuming, that at least a minimum communication infrastructure is available, the learner can connect to any educational service provided by the virtual university, if services have been adapted to the requirements of a mobile learner (restricted bandwidth, specific wearable computers with reduced hardware).

This paper is organized as follows:

It briefly outlines the platform requirements of a Virtual University environment.

Then, it introduces specific on-line tools for engineering education, such as 'virtual laboratories' and 'virtual seminars'.

## 2. The Virtual University environment

Any Virtual University requires some basic platform features in order to provide its services in an appropriate manner.

Typical learning platforms administrate on-line access to all teaching material, offer integrated synchronous and asynchronous communication tools, contain exercise and assignment areas, and include databases for student and examination management.

Content management systems are linked to these platforms to integrate a comfortable environment for authors, designers and technicians in order to efficiently create courseware material. Here, a strict separation of content and design is necessary.

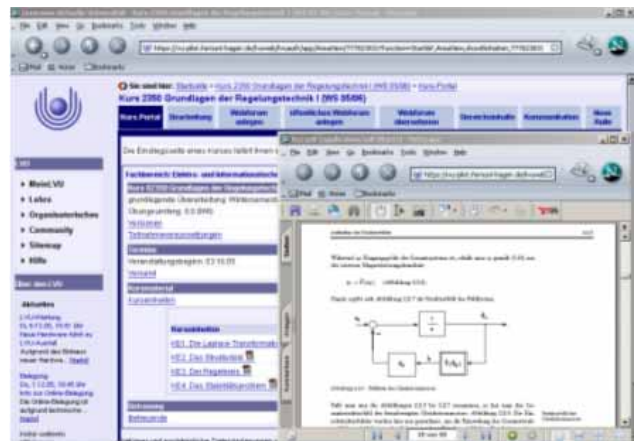


Figure 1: Courseware in the VU platform (students view)

With respect to Engineering education in the field of robotics and control, some more detailed requirements can be formulated to enhance the learning process and provide a deeper understanding about control systems and their closed-loop behavior.

Advanced multimedia animation and simulation tools have to be considered, as well as Internet based remotely controllable labs.

On-line seminars, electronic learners workgroups, Internet contests in robotics and control, and world-wide

access are features and learning scenarios currently under development in our research group.

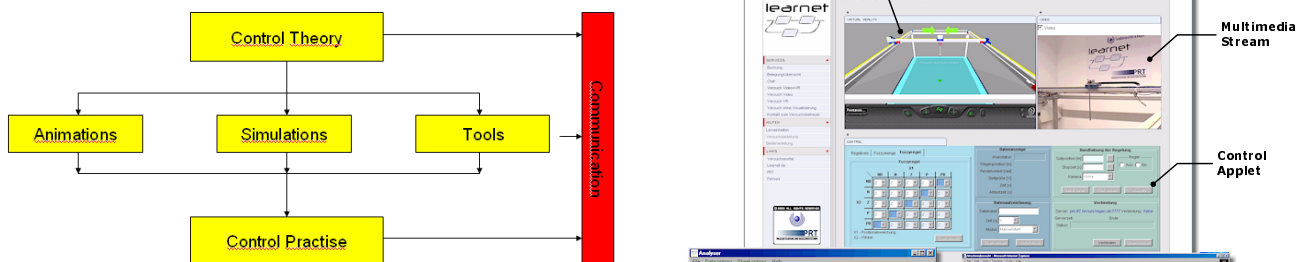


Figure 2: Control courseware in the VU environment

A description of our on-going research in these fields of engineering education is subject of this contribution.

### 3. Virtual laboratories

Virtual laboratories play significant role in the concept of virtual university, especially in engineering-oriented fields of study. 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.

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.

As a controlled system for one of our virtual labs, the inverted pendulum/gantry crane 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.).

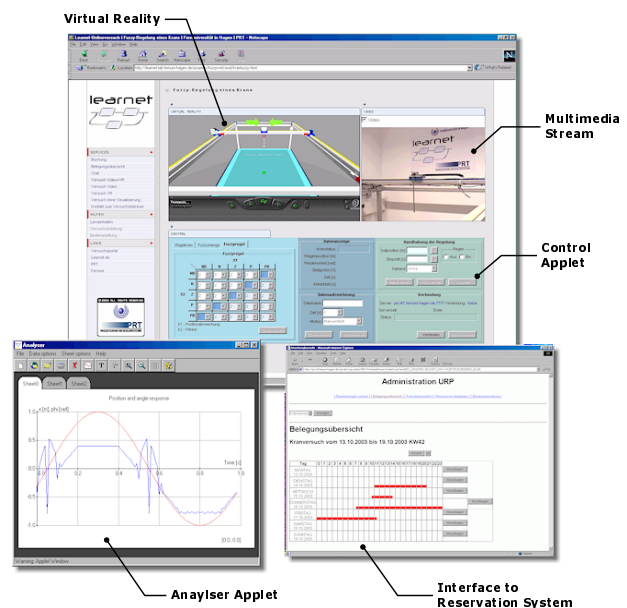


Figure 3: Components of the virtual laboratory for inverted pendulum/gantry crane control

The inverted pendulum/gantry crane 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 with Real-Time Workshop and xPC Target Toolbox. The major advantages of such solution 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),
- easy and quickly adaptability to another experiments.

As mentioned above, the presented virtual laboratory is used for experimentation with various types of controllers. In the practice, the students should optimize controller parameters with predetermined structure (fuzzy controller, state-space controller). It is not allowed to students to change the controller structure because of the possible risk of mechanical damage caused by using of an unsuitable controller.

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 perform their experiments through both LAN and modem connection. However, the tests show 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.

#### 4. Virtual seminars

Although the University of Hagen is a distance teaching university, the typical on-site seminar event is still a synchronous event. Usually the students have to travel to Hagen for these kind of events. To avoid the effort of time and money for the students a synchronous communication feature is highly desirable. As a future perspective of a distance teaching university, even a development towards a 'Virtual University' is imaginable, which should be completely Internet-based. Asynchronous virtual workshops (seminars) are taking place at the University of Hagen since 1996 [4]. But asynchronous events have some disadvantages regarding collaboration in a group. To provide a synchronous seminar-like environment to a group of students, typical synchronous communication techniques like video-conferencing are not suitable because of bandwidth limitations. Since not all of our students are equipped with high speed internet access and the seminar is part of the curriculum for all students, we still have to take care of bandwidth limitations of modem users (e.g. last online seminar event summer 2007: 25% of the participants). A video-conference with more than two communication partners is a typical point-to-multipoint application. If a true collaboration of all partners is desired, the partner with the smallest bandwidth limits the communication.

Another important topic is platform independence. Up to 17% of the participants (last online seminar event summer 2007) were using alternative operating systems like Linux and MacOS X. To overcome these restrictions the online seminar environment is based on two components. An audio based communication tool and a collaborative remotely usable computer desktop.

To provide the users with a kind of a white-board an universal solution was chosen. Not only Presentation-software like PowerPoint is frequently used to explain topics to a group of users. In different disciplines user-groups need different software-tools, or operating systems during seminar events. A universal solution is a shared PC, simultaneously useable to all participants (Fig. 3). A platform independent solution for simultaneously remote control of computers is the open-source 'Virtual Network Computing' tool initially developed by the AT&T Laboratories in Cambridge [5]. A wider developed branch of this tool with collaboration support and better

compression algorithms for bandwidth saving is UltraVNC [6].

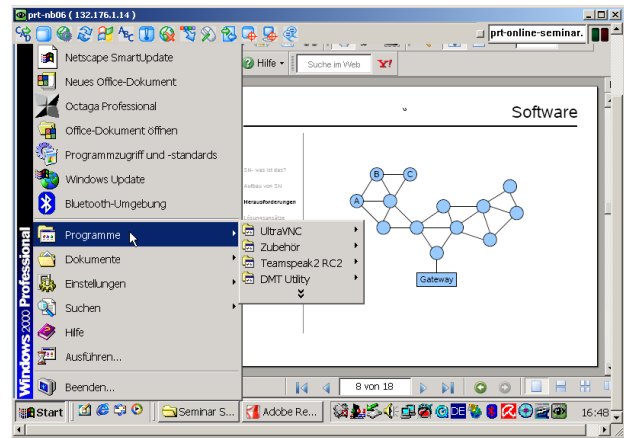


Figure 4: A collaborative remote controlled desktop inside of a window

The VNC-server utility is running on the shared seminar computer, which provides the desktop content of the shared computer to all connected VNC clients. Connected and authenticated users are able to control all installed applications remotely. The screen resolution of the shared computer and color depth should be reduced to 800x600 with 16 bit colors due to bandwidth limitations of remote modem users.

Audio is the most important means of communication in seminars. Most of ADSL users today are connected via NAT (Network Address Translation) routers which unfortunately limits UDP (User Datagram Protocol) based real time communication. Network Address Translation provides a local network with private non-routable IP addresses. For outgoing connections NAT translates all local to public addresses. For incoming requests NAT is often a problem. Users of audio conferencing tools behind a NAT router have to open ports for incoming connection manually. Open UDP ports are often required by VoIP (voice over ip) applications.

To avoid any effort for our students we have integrated the free (for non commercial use) and platform independent (available for Windows, Linux and MacOS X) Teamspeak client/server (VoIP) software [7] into our online seminar environment. This solution was chosen because of its good usability, bandwidth scalability and robustness in NAT routers environments. Since the server is also free for non commercial use, the university is able to host the service. No sign up to external service providers like for Skype or Google talk is required. The Teamspeak solution provides interfaces to university based directory services like LDAP (Lightweight Directory Access Protocol) for user authentication.

Teamspeak was originally designed as an easy to use tool for online gaming communities. Therefore just a small amount of time (usually 15 minutes) is enough for individual training and adjusting audio settings. This training happens online with all the students individually. Teamspeak provides quite understandable audio conferences with different compression codecs down to a data rate of 5.1 Kbit/s (CELP codec), which is only 10% of maximum modem data rate.



Figure 5: Teamspeak client during online seminar audio conference

As a backup solution a Teamspeak client is connected via a virtual audio device to a SIP Softphone (SIP, Session Initiation Protocol, RFC 3261) [8]. This modified client is used as a backup to access the audio conference over the conventional telephone network. In case of a broken internet connection the students are able to use a standard or a mobile phone to reconnect to the audio conference and continue their seminar presentations.

## 5. Virtual robot contest

As the mobile robots and various robot contests became very popular in several past years, we decided to organize a novel event for the students of mechatronics and robotics – a virtual robot contest [14]. The main idea was to allow them to participate on a robot contest and to design control strategies for various robot tasks without having a real robot. Instead, they can use a simulation and a virtual model of a mobile robot F.A.A.K., which was designed at our department. Typical objectives of the competition are line following or path finding in a labyrinth.

The virtual robot contest consists of an asynchronous and a synchronous phase and is organized as follows. At the beginning of the contest, the participants get the

simulation model of the robot and development tools. The robot is programmed and simulated using comprehensive integrated environment based on MATLAB/Simulink software package [13]. This developing tool includes models of all robot subsystems (drives, sensors, visual system, etc.) and also of its environment. Thereby, complex simulations of the robot interacting with the surround can be performed and visualized by 3D robot model.

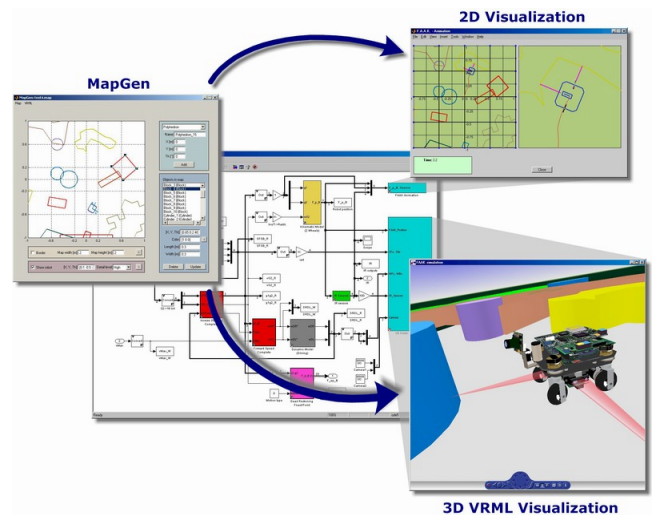


Figure 6: Virtual robot simulation

In the asynchronous phase of the contest, the students work alone or in small teams on their solution of the given problem. During a term, they get some introductions from the lecturer and can exchange their experiences. After this phase, the robot contest is organized as a synchronous event in like manner as the virtual seminar described above, i.e. the students use VNC-client to watch the simulation of the competing mobile robot and use Teamspeak for voice communication during contest.

On the contest day, the students get the final map for the particular task and send their algorithms for robot control. Then, the robot is simulated on the server in Hagen and the participants can follow the results. After first round of the competition, the students become some time to change/adapt their algorithms to achieve better results. Afterwards, the final round decides about winner.

The online simulation robot contest was organized for the first time in winter term 2006. Because of the very positive response from the students, we continue with this event with several improvements. By the next contest, the real robot will be programmed with the best algorithms and used for the same task as used in contest. The

participants will be then able to see the robot performance via video stream from the lab.

## 6. Mobile learning

Mobile devices such as notebooks and PDA's are very interesting tools for web-based teaching and distant teaching today. By the development of wireless communication networks like portable mobile phone networks (GSM, GPRS, EDGE, UMTS) and local wireless networks (WLAN), electronic teaching material can be accessed from any location. Since the typical students of distant teaching universities are professionals, mobile learning will give them the opportunity to effectively use also small amounts of spare time. Web based remote laboratory environments have been adapted to mobile devices like PDAs and smartphones [9]. Since not all implementations of PocketPCs are supporting the Java integration to a web page without of installation of commercial software an alternative solution is required for student usage with their own devices. An environment that works 'out of the box' with common Windows Mobile devices is needed.

As an example of online mobile remote experimentation a robot remote control application which demonstrate the features of a PIONEER 3 -AT mobile robot was chosen. The PIONEER 3-AT is a wheeled all-terrain experimental mobile robot. It can be equipped with various types of sensors, including front and rear sonar, a laser rangefinder, bumpers, a pan-tilt-zoom colour camera and GPS receiver. Robot motion is controlled by an embedded microprocessor, which communicates with a PC client. This communication is used for sending motion commands to the microcontroller and for data transfer between microcontroller and a PC client. The PC client is mounted on the robot and running under Linux OS. It is equipped with a wireless radio modem and thereby accessible through our network, which makes it an ideal platform for remote control. The onboard PC is able to communicate via wireless LAN (WLAN) with connected computers over the Internet. Delivered software enables to program the robot on various levels, ranging from simple microcontroller commands to complex actions.

The robots software was supplemented by a Linux based streaming server (ffmpeg/ffserver) with MPEG4 support and a self developed Java server application to realize a web-based remote control with real time video stream feedback. In a first step a PC client based on Java Media Framework and a Java control applet was developed at the university.

To provide the same functionality to a mobile device more effort is required, because no native Java Media

Framework support for PDA platforms is available. The bundled Windows Media Player in common Windows Mobile and PocketPC variants (PPC2002, WM2003, WM5, WM6) is capable to playback MPEG4 compressed video streams in full screen mode. Since Windows CE NET 4.1 and Windows Mobile 2003 (WM2003) it is possible to embed the Windows Media Player in a web page of the Pocket Internet Explorer. Some Windows CE NET 4.1 based devices, like the bSquare Maui are supporting a Java variant (Personaljava) 'out of the box' (included in ROM), but are not available on the market anymore. These devices are suitable to run an adapted PC control applet [9]. To overcome these restrictions a new approach based on asynchronous Javascript was realized. This asynchronous Javascript client sends user requests (button events) to the server *without* a reload of the web page. Each reload will stop the video stream initially and has to be avoided. With asynchronous Javascript an application like behaviour like a Java or a Flash can be established. In combination with the exchange of XML based messages between client and server these techniques is well known under the term 'AJAX'. Windows Mobile does not support an AJAX framework directly, but asynchronous HTTP requests are possible in Javascript. The new asynchronous web client operates on with each Windows Mobile device without any additional installed software (Fig. 5).



Figure 7: Pioneer 3AT mobile robot controlled by Windows Mobile smartphone

To support the mobile student in their experimentation practice a podcast variant of the required teaching material was derived automatically out of text based e-learning material by the use of text to speech techniques [10].



Figure 8: Screenshot of mobile application, video stream and asynchronous Javascript (similar to AJAX) integrated in mobile IE

Nevertheless a Windows Mobile device is required for this mobile experimentation practice. To establish an alternative interface for any cell phone a speech recognition based remote control was also realized. The mobile robot is equipped with an Asterisk VoIP SIP telephony software [11] in this case. Since the SIP protocol is IP based no extra connection to a phone is necessary, an SIP service provider account is sufficient. The Asterisk speech recognition module ASR [12] was coupled to the robots low level control API to send movement commands directly to the underlying microcontroller. The speech recognition robot user interface can be reached from every phone worldwide by a land line phone number.



Figure 9: Pioneer 3AT mobile robot controlled by speech via cell phone

## 6. Conclusions and Remarks

Web-based tools are an important learning add-on and a benefit not only for trainees and students of 'Virtual Universities', but also for students of conventional universities and schools. All these people have to learn at home in order to get a deeper insight and a more practical understanding of the usually more theoretically oriented lessons taught in classrooms (or provided by electronic courseware). Some of these learners use such tools for exam preparation.

But also practitioners have a benefit from Web-based tools, that address their field of expertise and probably these tools can support them during problem solving. To focus on control systems engineering education, it is quiet obvious to understand, that some sort of experimental environment is urgently necessary for students to find out and explore what happens, if system dynamics change or if controller parameters are altered. This can only be learnt by doing.

It is due to this fact, that tools like ours are under development in many universities. Most times, these tools are distributed with commercial books or offered to a restricted user group only.

Still often, these tools are accessible via Web-pages of university institutes, but they remain unrelated to the teaching programs of the faculty.

However, sometimes these tools are really integrated into learning platforms, so-called 'Virtual University' environments. Here they are in close conjunction with the courseware itself, e.g. via links from examples introduced in the theoretical fundamentals of the course. Libraries of solved examples can enhance these environments.

In our case, the Web-based tools presented here have become features of our 'Virtual University' (FernUniversität in Hagen is the only German university based on the principles of distance education).

Moreover, we have implemented a consequent learning environment for control systems teaching:

1. Electronic courseware to introduce the theoretical fundamentals of control theory and into robotic applications.
2. A closely related system of exercises to be solved 'by hand' in order to learn the basics of problem solving in control systems engineering.
3. A Web-based environment for control problems to become familiar with computer-based problem solving. Interfaces to MATLAB/Simulink<sup>®</sup> are available.
4. An Internet-based 'remote lab' for carrying out real experiments in our lab from the user host computer at home.
5. Student workspaces for cooperation, collaboration and application contests.

6. Mobile learning techniques to provide access to all types and features of our control education.

We believe that all these different methods and tools are necessary to establish an environment for the education of control systems engineering students in a 'Virtual University'.

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