

# The Development of Remote Access Computer-Aided Laboratories and their Use at Technical Universities

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**Abstract** - Laboratory practical works are the most important component in training the polytechnic specialists. Using the global Internet system enables an engineering university to have an access both to the facilities of the leading universities and to the unique equipment of research institutions. To raise the role of information technologies in the educational process, a Laboratory for a software and hardware securing the remote practical works was established at Bauman Moscow State Technical University (BMSTU). A remote interactive dialogue system has been developed at BMSTU to provide a thorough support for remotely accessing laboratory practical work. BMSTU has created a Web-site to run computer-aided online remotely accessing the lab real practical works (<http://lud.bmstu.ru>). It includes demo versions and some methodical parts to conduct the lab real practical works developed by the University. There are also three Internet-based laboratories: for material testing, plasma diagnostics and radio-physics. It is possible to get acquainted with electronic descriptions of the lab real practical works in advance, to perfect the facility control technique on a simulator and then upon having exchanged E-mail messages to enable an access to the server and conduct a lab real practical or research work according to an individual scenario.

*Index Terms* – Engineering education, Remote laboratories, Accessing real devices, Practical works.

## INTRODUCTION

Laboratory practical training, being a major tool for the development of students' practical skills, is one of the vital parts of the engineering education at technical universities (and of the study of natural sciences – at “classical universities”).

With the distance learning concept now being actively developed, the Remote Access Computer-Aided Laboratory (RACAL) development is becoming increasingly important. RACAL can be used not only in Open and Distance Education, but in traditional internal education as well. In the latter case, RACAL helps to expand the list of equipment used for practical training due to the latest experimentation techniques and unique experimental stands available at major universities.

RACAL development and further use of their resource-sharing capabilities will essentially raise the level of practical training, which is highly topical for the universities of Russia, and other countries. Due to ever-expanding use of the Internet, educational institutions are acquiring new access capabilities not only to the laboratory equipment of major universities, but also to the unique stands of academic and applied research institutes.

## THE STRUCTURE OF THE REMOTE ACCESS COMPUTER-AIDED LABORATORY

The Computer-Aided Laboratory system is understood to be a set of hardware, software and methodological tools for laboratory research and experimentation directly with physical objects and/or mathematical models. The laboratory systems we are going to discuss in the present report do not use the mathematical simulation of an object to be investigated (such laboratory systems are often called “virtual laboratories”). Here we present the laboratories involving real stands for real experimentation. Along with the name “RACAL” these laboratories are also referred to in literature as “Internet laboratories”, but the latter term is mainly applied when a single Web-server is used for several laboratories or experimental stands.

The remote access is the mode of CAL system operation when a physical object is operated with from a computer terminal located however far away from the object.

RACAL development requires, first, special technical tools both for the automation of the experimental stand, and for the interaction of the controlling computer with a remote user; second, specialized software development and, third, methodological support of the laboratory experimentation.

The experimental stand can be equipped with specific types of sensors and actuators, but the set of standards for measuring and controlling devices and systems is limited. The choice of standard for a particular RACAL depends on the available equipment. Naturally, the selection of a particular standard leads to the specificity of software for some of the Computer-Aided Laboratory subsystems. This applies, in the first place, to the measuring and controlling subsystems. In RACAL construction one can use both the interface cards built into the computer or measuring devices (GPIB, Plug-in-card) and individual devices like programmable logic controllers, backbone modular systems, combined multi-level hierarchical systems, etc.

The communication between a remote user and the computer-aided stand goes through a network. The client and controlling computers are connected to the network via network adapters. However, when we use the Internet, the communication arrangement can be of different types:

- The computer controlling the stand contains the web-server. In this case some applications used in a laboratory experiment may affect the performance rate of other applications. Then the time needed for the main task of the experiment may become unpredictable. Specifically, this may happen if some of the stand subsystems are controlled by DOS applications. Therefore, this type of communication arrangement requires a thorough analysis of various functional applications and organizing the corresponding priority queue for their performance. Besides, in case of network faults and computer “hang-up”, the stand may become uncontrollable and its state unpredictable.
- The controlling computer and the web server are separated. The data and command flows for this type of communication arrangement are presented in Fig.1.

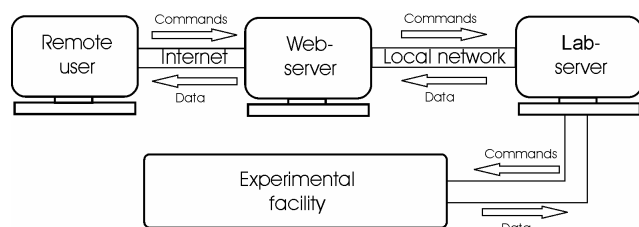


FIGURE 1

THE DATA AND COMMAND FLOWS FOR THE CONTROLLING COMPUTER AND WEB SERVER SEPARATED

Here the web server carries the telecommunication subsystem, and communication with a remote user goes through the Internet/Intranet, using TCP/IP protocol. The controlling computer is linked with the web server through a local network, typically, with another protocol being used. This type of communication technology is more flexible and efficient, and ensures that the time for the main task performance (control and measurement) is practically independent from the server workload and the number of users. In case of an accidental communication breakdown between a remote user and the server, the controlling computer continues the experiment according to the conditions set by the user, with the mode of stand performance unaffected.

The RACAL software is supposed, on the one hand, to maintain the interactive dialogue between a remote user and the web-server when setting up experiment conditions, and on the other hand, to ensure the stand operation in the set mode and transmit the results of the experiment to the remote computer or RACAL web-site. Obviously, the major part of software must be specifically developed for a particular Laboratory, though some standard environments can be involved, e.g., graphics programming tools, among which the most worth mentioning are the software products created by the National Instruments Corporation (LabVIEW, BridgeVIEW, etc.)

The specialized software developed for the presented Laboratory system also provides methodological support for laboratory experiments, i.e. contains different reference materials, the description of the laboratory stand and measurement procedures, etc.

#### USING RACAL IN THE TRAINING PROCESS WITH THE TRADITIONAL EDUCATIONAL TECHNOLOGY

An a priori disadvantage of the remote laboratory training is that a student does not have a direct contact with the instrumentation and stand control tools. Therefore, if we are to achieve the highest possible training results while using RACAL, it must offer new opportunities that are out of reach for traditional forms of laboratory training, and of course, the remote laboratory training must be well grounded methodologically.

Here we would like to point out the following basic considerations:

First, the students, who are about to start the remote training session, are supposed to have gone through traditional internal laboratory training and to have basic knowledge on the theme of the experiment, and necessary practical skills.

Second, the remote laboratory training is reasonable if we deal with sophisticated, and often unique computer-aided stands, where students are normally not admitted to real experimental work because of a possible damage to expensive equipment, short stand start-up time, adverse conditions in the control room (e.g., noise), etc.

Therefore, the laboratory training on such installations is mainly restricted to observations, and methodologically, it is rather connected with data analysis procedures than with the investigated object, performance control and diagnostics.

The remote access enables students to actively participate in conducting experiments. To provide for this, the communication programs must allow for the verification of feasibility of the modes set up by students for the experiment. Students should have the possibility to try and master the stand control techniques in advance, in the emulation mode, not to waste time while conducting real experiments. Besides, the remote laboratory training is conducted in favorable conditions, without any disturbing factors, and students can have immediate access to any needed reference material and visual methodological aids created with the use of modern Internet technologies.

Third, during the remote laboratory training session the student carrying out the experiment is supposed to be controlled by a tutor, who is at the remote workplace together with the student. The tutor should have special service facilities to check the results of the experiments obtained by the student.

#### THE REMOTE INTERACTIVE DIALOGUE SYSTEM

The Remote Interactive Dialogue System (RIDS) was developed under the direction of the author of the present report to support the network-based Remote Access Computer-Aided Laboratory experimentation. From the very beginning of the system development the task was set for a

remote user not only to be able to obtain the experimental data, but also to change the experiment conditions, and to use individual experiment modes. Provision was also made for user testing before admitting him to the remote stand control panel, and for the tutor located at a remote user workplace together with the student to be able to check the correctness of the experimental data analysis performed by the student.

The RIDS includes visual and easily understandable methodological aids necessary both for the preparation to the training session, and for writing the report on the results of the experiment and their analysis.

On the basis of the above considerations, the Computer-Aided Laboratory working within the RIDS system includes some subsystems (Fig.2).

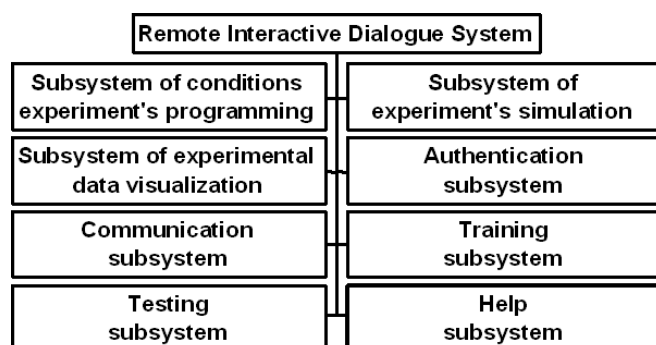


FIGURE 2

THE STRUCTURE OF THE COMPUTER-AIDED LABORATORY WORKING WITHIN THE RIDS SYSTEM

Now let us dwell briefly on the functions of the subsystems listed above:

- The communication subsystem provides communication of a remote user with the web-server, and the latter with the controlling computer. Different protocols can be used here depending on the equipment and system software.
- The training subsystem contains overall information on the experimental stand (equipment, instrumentation, etc.), brief theoretical provisions, measurement procedures, etc., which allows a student to prepare for the laboratory session and write the report.
- The testing subsystem checks the student's knowledge about the stand, physical principles of the experiment and experimental techniques. The student is not admitted to the experiment until he passes the test.
- The help subsystem contains textual, tabular and graphic information necessary for the analysis of experiment results.
- The authentication subsystem verifies if the user is entitled to operate the stand at the moment, and ensures that only one single user carries out the experiment at a given time.
- The subsystem of conditions experiment's programming allows the students to set the stand parameters according to the desired experiment conditions, and to do it in the interactive mode. The subsystem also performs the monitoring of parameter tolerance.
- The subsystem of experiment's simulation allows the students to familiarize themselves with the stand control

panel and imitate the basic operations on entering the experiment conditions before starting the real experiment to reduce the time for the real experiment.

- The subsystem of experiment visualization makes it possible to present the experiment results in a visual form suitable for further analysis.

The control and measurement systems are responsible for the reset of the laboratory stand, control of its operation in the mode selected by the user, and measurement of the necessary parameters. The object and measurement systems are parts of the laboratory stand.

RIDS enables students and researchers:

- to get familiarized with theoretical basis of the laboratory, as well as with every piece of experimental equipment, and with measuring method;
- to simulate an experiment in order to get practical skills in lab facilities control;
- to test acquired knowledge;
- to ensure access to lab facilities and secure privilege of control operations to remote user;
- to interactively program experiment conditions and to verify their feasibility;
- to report results of experiments in coherent and process able terms;
- to widen professors' testing means.

The methodological support in RIDS is provided by the training subsystem, and the testing system checks the knowledge of theoretical material, stand elements, and experimental techniques. While creating the training subsystem, we kept in mind a number of principles aimed at better perception through the Internet of the methodological materials:

- Comprehensiveness of the material needed for a particular laboratory session.
- Brief presentation of theoretical material for students to be able to comprehend it from the display screen, without using the printed copy.
- Detailed description of the laboratory stand using the HTML graphics technology (image card with graphic hyperlinks, pictures in GIF/JPEG format, diagrams, etc.), including the operation principle for every device, its schematic diagram and basic parameters.
- Using hypertext and split-screen approach which provides fast selection of the needed section and simultaneous presentation on the display screen of the intertwined fragments of the training subsystem.
- The possibility to use methodological materials after the test check at further stages: while conducting the experiment and analyzing the results.
- Simple navigation, i.e. selecting needed subsystems through visual menus and fast return to the initial page.
- User-friendly interface for easy perception of textual and graphic information.

The training subsystem is based on modern Web-technologies and is implemented in the form of interconnected HTML-documents compiled thematically.

The testing subsystem plays a very important part in the laboratory training. It is designed to check the student's knowledge about the stand and experimental techniques.

Until the user passes the test he is not admitted to the stand control panel and cannot start the experiment.

Individual users can pass the test simultaneously and independently of one another. The number of users is only limited by the server capacity and communication channel capacity. Thus, the system provides multi-user service with different texts for each remote computer.

The questions (with the corresponding answer options) are selected at random from the server database, which should eliminate the chance for a student to mechanically memorize correct answers in case of multiple launch of the testing program. The database for the Laboratory system developed contains up to 100 questions on all the topics included into the training system. There is a special program designed to fill and change the database content.

The student can start the experiment if he gives correct answers to at least 4 questions out of 5. If he gives less than 4 correct answers, he is offered to review the theoretical material and laboratory stand description by automatic selection of the training subsystem.

### THE RACAL DEVELOPED AT THE BAUMAN UNIVERSITY

There are now more than 50 Remote Computer-Aided Laboratories in Russia for students training in natural and technical sciences. The unified all-Russia specialized RACAL-server has created at the 2006 by the leading developers: the Bauman Moscow State Technical University and the Moscow Power Engineering Institute. It has URL: <http://www.alpud.ru>.

The list of the existing in BMSTU Internet-laboratories and their developers, and information on the capabilities of RACAL created for laboratory training and research for all years of study is published on the RACAL BMSTU web-site (<http://lud.bmstu.ru> - Fig.3).



FIGURE 3  
THE BMSTU RACAL WEB-SITE

The Bauman University site is a prototype of RACAL portal. It contains information on the standards for laboratory courses, definitions and methodological issues. Every course located on the site has a brief description and a demo-

version, and some courses have beta-versions in several languages. One can find here the detailed information on: 4 laboratory courses for different branches of physics (mechanics, electromagnetism and quantum physics) and three Internet-Laboratories "Plasma diagnostics" (Fig. 4), "Materials testing", "Radio-Physics". Several years, during which the above listed remote laboratory courses have been used in the education process, showed students' interest in this form of training and the resulting shift toward the individualization of the training process.

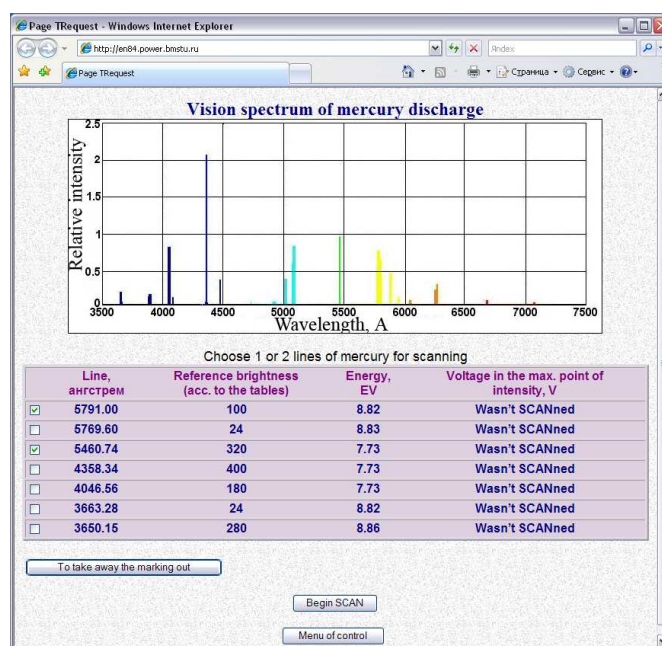


FIGURE 4  
ONE OF WEB-PAGE OF "PLASMA DIAGNOSTICS" INTERNET-LABORATORY

At the 2005 the multi-profile Internet laboratory "Radio-Physics" was launched. It is based on the network-based use of the unique equipment – one of the largest in Europe radio telescope of some mm wavelength range (Fig. 5). It belongs to the Bauman University and is located 90 km from Moscow.

The radio telescope Web-site (<http://ilrt.bmstu.ru>) contains the pilot Remote Computer-Aided Laboratory course on the instrumentation and scanning methods for astrophysical objects. A block-diagram for the remote controls through the global network and structure of the software are presented. An application of a computer-aided hardware for laboratory as well as teaching and research student works is considered. A computer-based network laboratory workshop with remote access to apparatus and remote technique of radio-engineering subject of inquiry scanning is described.

The results of the experiment are registered in the database and can be visualized with the help of specially developed net media (Fig. 6).

In future, the list of RACAL will be expanded, which will enable technical and classical universities to carry out their training and research activities in the following fields:

- Radio receivers;
- Antennas and microwave devices;



- Radar and optical location;
- Radio communication and navigation systems;
- Antenna systems of radar and communication complexes;
- Radio physics, electrodynamics and radio-wave propagation;
- Radio astronomy;
- Solar and space plasma physics;
- Space meteorology, etc.



FIGURE 5

THE GENERAL VIEW OF THE ANTENNA OF THE BMSTU RADIO-TELESCOPE

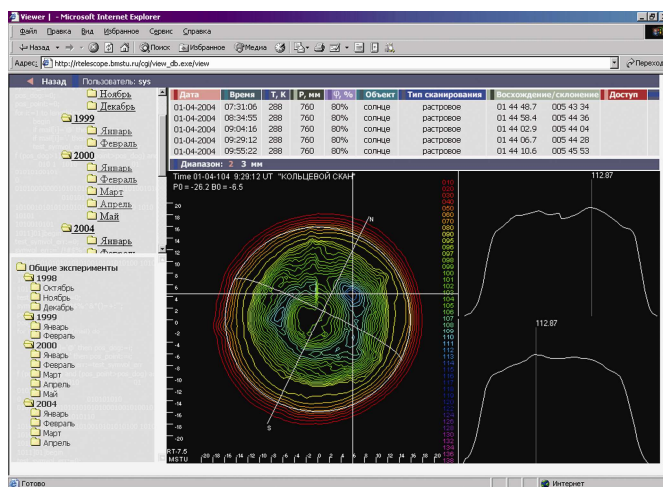


FIGURE 6

THE SUN MAP MADE BY BMSTU RADIO-TELESCOPE SCANNING

The Remote-Access Computer-Aided Laboratory systems developed in the Bauman University conform to the RF and international standards.

In future, there are plans to integrate the developed training resources into a number of international programs, in particular into the WWSL program (World Wide Student Laboratory) [2].

## CONCLUSION

Laboratory practical works are the most important component in training the polytechnic specialists. Using the global Internet system enables an engineering university to have an access both to the facilities of the leading universities and to the unique equipment of research institutions.

The remote access computer-aided laboratory courses help to essentially extend the list of experimental stands available for training and research experiments. They can be used both for distance learning, and for traditional training.

BMSTU has created a Web-site to run computer-aided online remotely accessing the lab real practical works. It includes demo versions and some methodical parts to conduct the lab real practical works developed by the University. There are also three Internet-based Laboratories: for material testing, plasma diagnostics and radio-physics.

An objective to develop and then to use collectively computer-aided remotely accessing laboratory practical works is very topical both in the Russia and all over the world.

The international cooperation and organization of the shared use of the unique experimental stands can give a powerful impulse to the development of this field.

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