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Experimenting from a Distance - Remotely Controlled Laboratory (RCL)

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Abstract

The use of computers and multimedia, as well as the World Wide Web and new communication technologies, allows new forms of teaching and learning like distance learning, blended learning, use of virtual libraries and many more. The herewith discussed RCL project shall offer an additional contribution. The basic idea is for a user to connect via the Internet with a computer from place A, to a real experiment carried out in place B. An overview of our technical and didactical developments as well as an outlook on future plans are presented.

Currently, about 10 RCLs have been implemented. The essential characteristics of an RCL are the intuitive use and interactivity (operating the technical parameters), the possibility of different points of view of the ongoing experiment thanks to web cams, and the quickest possible transfer of the data measured by the user. A reasonable use of sensibly chosen real experiments as remote labs allows a new form of homework and exercises, as well as project work and the execution of experiments, which usually would a teacher’s prerogative only.

1. Introduction

Real experiments are central in the teaching of physics in schools and universities. Moreover, the sensible use of computers (since approx. 1970) and of multimedia (since approx. 1990) has enriched the importance of experiments: animation of complex procedures, interactive simulation to deepen knowledge [1], interactive on-screen experiments for self-learning [2], video analysis of motion (interactive video) [3] and videos for the quantitative analysis of an experiment as an alternative for homework [4]. The question is: beyond that, how can the Internet be integrated in a meaningful way. There are known examples of lectures video broadcast to different locations [5], of virtual libraries and access to data of research instruments [6], of databases and education servers being used [7]. In addition, the proportion of distance learning will increase; this raises problems especially for subjects focusing on experiments in natural sciences (physics, chemistry, biology), if it is to be avoided to have only lecture notes distributed electronically [8]. The benefits of a remote control experiment over simulations or virtual laboratories have been thoroughly discussed in literature [9, 10].

Fig. 1

The concept of a remote lab is for a user with a computer from a distant location to remotely control an experiment set up at a specific location (Fig. 1). This principle has been known for years in research and technology, one only has to think about the control of complex conveyer belts in factories or about space telescopes and space probes. The first application of telemanipulation over the Internet was, to the best of our knowledge, in the field of robotics and dates back more than one decade [11]. After these pioneering works remote control of lab experiments for the public through the World Wide Web developed to a growing field, in particular in robotics and engineering.

When implementing remote labs, it is important that the user is able to follow the real experiment via a web cam, to follow the variation of parameters with another web cam, and to gather his or her own measurement data online. Operating the experiment should be as authentic and transparent as possible for the user, *i.e.* the experiment should come across as a common real experiment carried out in lessons or in lab courses. Further requirements for remote labs are easy access and intuitive operating. Measurements and observations need to be quickly available. Moreover, the user needs to find all necessary information (be it background knowledge and theory, technical specifications of the equipment etc.) directly in the accompanying text published on the web site, without having to rely on looking it up on other sources. These features of a remote lab are often described in literature, although suggestions were made with emphasis on particular issues like *e.g.* usability or technical features [10, 12, 13].

There is by all means a need for remote labs, though it must be critically observed whether the user operates the remote experiment to play, to learn, or even to explore. So far, we have considered three relevant target groups concerning our RCLs. First group: Schools and universities should be given access to a network of RCLs to promote self-learning (*e.g.* for homework and exercises via Internet). A long-term advantage will be a collection of remote experiments accessible for use in physics teaching at schools while sharing resources of each contributing school. Second group: RCLs should allow interested lay people or visitors to exhibitions to further dwell into a subject (*e.g.* understanding principles of computer tomography). Third group: a network of RCLs could overcome the problem of lacking experimental labs for educational purposes in particular for distance education and for students of the so-called development countries. To take into consideration those target groups requires having the opportunity of different modes of interactivity and/or to provide different didactic material accompanying the RCL, for example.

2. Worldwide Inventory

We carried out detailed enquiries at worldwide level in May 2004 and again in April 2006.[1] In 2004 we found roughly 70 remote labs, of which only about 50 were free to access, while some required a user account, some required payment or were only accessible to a closed circle of users. Only about ten of these remote labs worked flawlessly; all others had either broken links, or the experiment was „out of order“, or it was not a proper remote lab in the way we understand it, or the controls did not react. The result of the 2006 research was quite similar (table 1): We found about 60 projects offering about 120 remote experiments. More than half of these projects were located in USA and Germany, and some projects were joint ventures of universities from different countries. In the 2004 enquiry about 90% of the remote labs were related to engineering techniques like steering and controlling, electronics, robotics or mechatronics (*e.g.* moving building blocks with a robotic arm [14]), whereas in 2006 we found about one third of remote labs dealing with physics and about two third dealing with engineering techniques as aforementioned. Only a few remote experiments were related to other disciplines like chemistry, for example. Of the physics experiments many were dealing with electronics, too. Only 20% of the projects allowed free access to their remote experiments and which worked without problems. In fact, the major fraction of remote labs that was found in engineering education is reflected by the large amount of publications in this field [15]. On the other hand, literature research on this topic is very time consuming and laborious since many publications are ‘hidden’ in conference proceedings which are not available in many cases.

[1] The enquiries were performed by means of Internet search engines, like *e.g.* Google, and several listings, like those cited in [17]. Since many projects have uncommon names like “virtual lab” or “Internet assisted lab” we used different phrases and their permutation in the search. We neglected those remote operations which were offered by specialized companies for training purposes, that is remote programming and network administration, for example.

Table 1

Most developers underestimate the required efforts and financial resources needed to build and in particular to maintain a remote lab. Missing standards (experiment – computer interface, website - control software interface etc.) lead to many individual solutions, and therefore to unnecessary hurdles for hosts and users. Moreover, the focus is more on technical problems (*e.g.* client-server communication, server architecture and programming, data transmission) [15] rather than on didactical efforts (*e.g.* to analyze how a remote lab can be implemented in different teaching and learning environments) [16].
It would be going beyond this article to describe some of the most striking projects, therefore, we only give reference to resources on the Internet [17]. These collections present to some extent a representative collection of remote labs available on a worldwide level.

3. Initial Developments (2002-2005)

We started in 2002 by building a prototype for the diffraction of electrons by a graphite sheet (electron diffraction tube and CASSY interface from the company Leybold Didactic [18, 19]), in order to test, to assess feasibility, and to gather errors and experience. This experiment so central to physics lessons allows one to determine the lattice parameters of graphite by varying the velocity (~ wavelength) of electrons which are accelerated by an electric field (Fig. 2).

Fig. 2

The user can change the acceleration voltage, he or she can measure the diameter of the diffraction rings by observing the streaming images of a web cam or by saving those images locally on his or her computer, and then the user can evaluate his or her measurements. The web site was initially organized as follows (in order of menu options):

1. Setup: A photograph of the experiment was presented, in which each component of the set up was explained when touching it with the mouse;
2. Theory: This site contained background knowledge and the manufacturer's specifications of the electron tube and of the power supply;
3. Analysis: A sample evaluation with discussion of measurement errors as well as a list of images to compare with previous measurements was presented. Hence, the user could recognize how the result should look.
4. Discussion: Questions concerning the experiment rounded off the remote lab site.

As for the execution of the real experiment, *e.g.* a demonstration during lessons, things can go ‘wrong’ for the user (fluorescence fading in the tube: ageing of tube; diffraction rings are not in centre: misalignment of web cam and/or tube; voltage cannot be further increased since it has already reached maximum value: protection of the tube). With the exception that the tube had to be replaced, the experiment has now been running without problems for the past four years. The benefits here are obvious. The remote lab can replace the real experiment in school if the tube is not working or if the equipment is not available. Moreover, even if working in the lesson, this traditional demonstration experiment can be performed by the students having the opportunity to get their own measuring data. Thus the experiment yields a larger database for evaluation than if performed only by the teacher during the lesson.

After building this first prototype three more remote labs have been set-up in the framework of an exhibition on the topic „Climate“ at the ‘Deutsches Museum’ in Munich:

- Robot in a Maze (Fig. 3),
- Thermal Imaging Camera,
- Optical Tweezers.

These experiments were running for about one year at the ‘Deutsches Museum’ (autumn 2002 – autumn 2003) and there were about 20,000 users during this period. The remote labs ‘Robot in a Maze’ and ‘Optical Tweezers’ are now installed at our physics department in Kaiserslautern and still accessible online [20].

Fig. 3

Herewith we will briefly present the remote experiment ‘Optical Tweezers’; this experiment represents our intention to allow interested lay people to conduct a ‘mini-research’, in this case on the topic of “Telemanipulation with Light” [21]. Tiny glass balls (1-10 μm diameter) are suspended on an object carrier and observed by means of a CCD camera mounted on a microscope with oil immersion lens (total magnification 1000x). In addition to observing the Brownian motion of the spheres, a sphere can be captured by the electric field of laser light, it can then be moved in relation to the object carrier to a pre-defined position by switching off the laser (Fig. 4).

Fig. 4

This experiment is a very ambitious remote lab alternative, since it utilizes a current research tool from biophysics. The experience shows that there are no problems with either the tools or the remote lab components, but there are some problems preparing and keeping the sample (suitable solution, adhesion of the spheres, etc.). In addition, the lifetime of the diode laser is limited, in particular because of many turn-on/turn-off cycles, for which reason the laser had to be replaced after three years working.[2] To make available such an experiment to schools and its ease to be conducted give this remote lab an added value.

Two further experiments were realized in 2004:

- ‘Diffraction and Interference of Light’ (Fig. 5) for physics lessons or homework,
- ‘Hot Wire Game’ as a prototype for students’ project with Fischer Technik© robot construction set (Fig. 6).

‘Diffraction and Interference’ is a central experiment in teaching wave optics (demonstration of the phenomena, model of light as a wave comparing the experiment to a simulation, challenging mathematical derivation of the formula). Usually, when building the experiment for teaching purposes a series of problems may arise: availability of a number of lasers for teamwork, security concerns, choice of suitable sets of diffraction objects, mainly qualitative implementation in lessons, quantitative evaluations and systematic variations of technical parameters too time consuming.

Fig. 5

A possible implementation could envisage having the teacher explaining the theory and carrying out a qualitative demonstration experiment during lessons; the students are then split into groups and are given the task to carry out the experiment via Internet as homework. Each group is assigned an object to measure (varying parameters: slit width, slit distance) and to evaluate their measurements. Finally, the groups have to present their results during subsequent lessons as a homework discussion.

In 2005 we realized ‘Photoelectrical Effect’, ‘Speed of Light’, an alternative of the ‘Hot-Wire Game’ and a model of the ‘German Toll System’ as remote experiments. These RCLs were set up by students (age 16-18) as prototypes in a project during one week (‘Summer Camp’) and later improved by us for online use to the public. However, such successful project work was

[2] Moreover, this experiment is part of the advanced laboratory courses at our department held twice a year for on-campus students.

only possible since all material necessary to set up the experiment and to build the RCL has been carefully prepared prior to the project run.

4. Improvements (2005-2006)

Initially, the first technical solutions of our remote experiments made use of commercially available interfaces (*e.g.* from Leybold Didactic [18]) and of specially developed computer (web server) programs for controlling the experiment parameters (*e.g.* laser on/off, moving of motors) [22]. Attempts to implement low-cost interfaces, such as 'Intelligent Interface' from Fischer Technik © [23], were not satisfactory, since these kind of interfaces are limited when used to transfer data (I/O-channels) or of minor precision to control electromechanical devices. On the other hand, our philosophy to realize RCL experiments follows several lines:

a) At the user side (client) the usage of a remote lab should be – almost – independent from operating system or browser type. In addition, the user should not be forced to install plug-ins or special viewer software (like it is necessary in the case of remote labs based on LabView © technology [24, 25]) and to update them regularly. The only requirements for a user is to have a Java enabled browser installed and standard ports opened for Internet connection.

b) The interface between web server and experiment must have a maximum of flexibility and universality in order to adopt quite different equipments as a remote experiment. For example, some experiments simply require to turn on/off a power supply while others require to control stepper motors, to allow voltages to be changed, to start or to reset a counter. Furthermore, the interface should act as a wall against abuse, *i.e.* to avoid destruction of an experiment via Internet. Therefore, we implemented a microcontroller as a basic unit of the interface which provides for communication of web server and experiment via RS232. Once the microcontroller has been programmed (which is very easy), a set of PHP modules running on the web server provide for the graphical user interface (*e.g.* control panel, I/O channels) and allows the user to control the experiment by exchange of data between client and web server. These modules provide also for user management, easy implementation of different languages, and more. They are running in the background, although they are activated by requests of the client, such that the user is neither bothered by programming tasks nor by technical demands. Streaming video from web cams is enabled by a video server program.[3]

[3] Typical frame rates are 1-3 images per second (resolution 329x240, JPEG compression), which – of course – depends on the Internet connection of the client computer. However, lower frame rates caused by 56k modem

c) We use consequently Open Source software (*e.g.* Apache web server with PHP, video server) as well as common standard hardware components (*e.g.* ATmega16 microcontroller from ATMEL). One of the most important reasons for this decision was to enable teachers and students to build their own RCL at school. Therefore, we support those people interested in an RCL project with a detailed tutorial “How-To” [26]. The overall costs to build an own interface is of the order of 50 €.

More details about technical realization and requirements for building an RCL will be published elsewhere.

5. Didactic Considerations

Different target audiences (interested lay people, pupils, students and teachers) require different documentation. The web site for the remote labs at the museum exhibition has been structured on the basis of “Play – Learn – Research” [27] to suit interested lay people; for the use in lessons, we have chosen the usual scheme of “Introduction – Theory – Experiment – Evaluation – Discussion” [20]. In addition, each RCL obviously contains its particular facets with respect to a given topic.

It is however our opinion that following elements are indispensable: provision of the physics background knowledge (it cannot be expected that the user interrupts the remote experiment to retrieve information from the library), sufficient description of the tools being used (*e.g.* data sheets from the manufacturers); sample measurements, to enable the users to properly class their own result (*e.g.* representative web cam images or typical measurement data); evaluation example with discussion of quantitative results and measurement errors (*e.g.* comparison with values from text books, sources of errors) as well as knowledge questions.

Since secondary school physics curriculum covers about 300 experiments for teaching, a selection has to be made based on criteria useful for development of an RCL and meaningful concerning educational impact. We can differentiate three main categories in accordance with previous literature [28, 25, 13], namely pedagogical, experimental and technical issues. Criteria essential for implementing a physics experiment in an RCL are – in our opinion – questions like as follows:

- How central and meaningful is the experiment to the physics lesson?

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connection, for example, are sufficient for experiments where time is not a critical parameter. For the RCLs “Millikan’s Experiment” and “Toll System” higher frame rates are necessary, and this is realized by means of a Java script continuously requesting the web cam images as fast as possible through the Internet connection.

- What is the priority of the experiment in the lesson plan (not just in relation to curriculum topics)?
- What are the difficulties in learning and understanding of the students?
- What interactivity makes sense to offer via RCL (*e.g.* choice of variables, controls)?
- Which media could be implemented concurrently or alternatively?
- How difficult or easy is it to carry out the real experiment?
- Does the students have access to perform the real experiment in school/university?
- Is the technical effort justified?
- How can data be quickly processed and/or transferred?
- How solid is the real experiment, including control over personal computer (maintenance effort)?

6. Current State of RCLs

Up to now we are offering 12 RCLs online which have – at least partially – been selected by application of the criteria mentioned above. We categorize them according to our different approaches (target groups) described in the Introduction:

Topics of physics curriculum

- Electron Diffraction (wave nature of electrons, example for structure determination by diffraction),
- Photoelectric Effect (model of light as particle, determination of Planck's constant and work function),
- Radioactivity (exploring different kinds of radioactive radiation, absorption of radiation, statistical nature of nuclear decay),
- Diffraction and Interference of Light (various diffraction objects can be studied systematically),
- Voltage-Current Characteristics of Semiconductor Devices (introductory electronics),
- Oscilloscope (how does it work, preparation for lab work),
- Millikan's Oil-Drop Experiment (proving and determining elementary charge).

Examples for students' projects

- Toll System (model, how does it work, methods to identify moving vehicles, exploring alternative techniques),
- "Hot-Wire" Game (how to build and to control a robot).

Motivational and lay-people oriented

- Wind Tunnel (air friction of different cars, impact on gasoline consumption),
- Optical Tweezers (moving particles with laser light, introduction to front-edge research instrument),
- Robot in a Maze (playful approach to remote operation).

To describe all the above mentioned RCLs in closer detail would go beyond the intentions of this paper. The reader is invited to have a closer look at the web site of the project [20].

As an example, the added value of these experiments as an RCL alternative will be briefly discussed in the case of "Millikan's Experiment". The use of this experiment in school lessons is similar like in the case of diffraction and interference: mostly qualitative since very time consuming, mostly demonstration since equipment exists only one time per school, if at all. On the other hand, the RCL experiment can be performed by all students, it allows to gather a collection of data (let's say 25 students times 10-15 measurements) providing a 'good' statistics necessary for a quantitative analysis of this experiment.

We will offer each RCL in German and English language. In addition, we translated the web portal and two RCLs in French and Italian language. If someone wants to realize his or her native language, feel free to translate and with our help it is possible to implement those pages in the portal.

Pupils should make use of remote labs not only for demonstration experiments or homework for physics lessons, they should be put in a position to build their own RCL as a school project. Fig. 6 shows an example of how we picture this alternative with the help of Fischer Technik © robotic construction kit [23]. As already mentioned, a first application, "Summer Camp" for pupils at Munich in 2005 as a workshop to build and set-up RCLs, was very successful and promising for future projects.

Fig. 6

7. Experience

We have installed tracking and monitoring devices in some RCLs; *i.e.* we are able to capture all relevant data of a user by identifying the IP address and information provided by the user: user name, institution, country, which parameters have been changed in what way (playing or purposeful work), duration of use, and more. This is obviously done in observance of the privacy laws.

Access rates to remote labs during the exhibition at the 'Deutsches Museum' and to the RCLs in Kaiserslautern have been captured over some periods of time (table 2). According to this, RCL experiments have been accessed worldwide several times a day; this is in comparison to the average teacher who once a year carries out such an experiment during lessons. In addition, we got individual feedback from RCL users at exhibitions and from teachers at conferences and workshops.

Table 2

The higher financial commitment (compared to the real experiment) includes hardware (interface, computer, web cams) as well as programming costs (typically 1-2 months worth of work per experiment during the initial phase, *i.e.* until the software modules can be transferred).[4] Higher development costs for some projects can arise due to missing standards and due to necessary re-development (*e.g.* installing several web cams for an experiment in conflict with MS Windows© operating system). The maintenance of the real experiment contains usual tasks.

8. Future Developments

Currently, we are in progress to organize in-service teacher training courses together with our sponsors. We focus here on two target groups: First, teachers who want to make use of our RCLs in teaching (in lessons, for students' homework). Central here is a didactical point of view, for example: discussion of new ways of teaching like 'learning at stations' and project-like studies of a topic. Second, teachers who are interested to use our RCL technology in students' projects, that is to set-up an own RCL at their school. These courses will be held in cooperation with the "Association of Mathematical and Scientific Excellence Centres at Schools" [29] and our sponsors. Those readers interested are requested to contact the authors.

In the next future we want to evaluate the use of RCLs in physics teaching covering questions like application in physics lessons as well as in homework assignments, since reports about analysis of learning outcomes in literature are sparse. Such evaluation makes necessary a user management with a booking system to guarantee online use of a given RCL for reserved time intervals. This system is still in development. Moreover, tracking of user operation will be extended to gain insight in what the users are doing when visiting an RCL: playing, systematic choice of parameters, sequence of visited websites, how well the basic documentation is read and so on.

[4] Now we are at a stage where we can easily transfer those modules by 'copy and paste'. Only the graphical user interface has to be adapted to the actual experiment and the control commands have to be implemented into the PHP module.

In addition to the RCLs already online, a further set of six RCLs are currently being under construction.[5]

Up to now we handed over three RCLs to partners of the project "Intel © teach to the future" [30]: Diffraction and Interference of Light (Academy for Teacher Advanced Training and Personnel Management, Dillingen, Bavaria), Wind Tunnel (Centre for Technology and Foundation, Kaisersesch, Rhineland-Palatinate) and Photoelectric Effect (Gymnasium Isernhagen/Hannover, Lower Saxony). Some more of our RCLs will follow.

A worldwide network of clusters of remote labs should be the long term outcome, offering various experiments. The advantages are obvious: the maintenance of real experiments is not borne by just one institution; everyone can learn from each others' experiences; synergies can be used to solve technical problems; different cultural approaches to install, implement and test a remote lab in learning environments will evolve.

9. Conclusions

- We are trying to increase the use of modern communication technologies and Internet for teaching purposes through our RCL project.
- We want to make distance studies more interesting and appealing: moving away from paper-based studies, towards Internet-based degrees, especially in science disciplines focusing on experiments.
- There is a need to highlight the importance of real and real-time experiments compared to simulations or digitally conserved experiments.
- Young people on the Internet should be attracted to technology and education in play mode.

10. Acknowledgements

As a closing statement, we would like to thank the sponsors of the project(s), who have always believed in the potential of RCLs: the 'Eberhard von Kuenheim Foundation' of BMW Germany, the German Employers' Association 'Gesamtmetall' (Think Ing initiative), the 'Deutsches Museum' in Munich, and more recently Intel © Germany – Education Group. We appreciate sponsoring of the RCL 'Oscilloscope' by Hameg Instruments Germany and of the RCL

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Millikan's Experiment by Xplora (European Schoolnet, EU). The collaboration with Netzmedien Association during the initial stage, represented by D. Roth and S. Maus, was extremely important. Last not least, we thank our students involved in the project for their outstanding achievements.

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[19] In this remote experiment we replaced the CASSY interface from Leybold Didactic by a microprocessor based interface as a result of our technical improvements. It is worth to note that this modification took not more than one day – including building and programming the interface, adoption of the web server (*i.e.* installing PHP modules). Redesigning the web sites (content like text and figures) took more time!

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[22] The techniques utilized for these RCL experiments are described at the homepage of the 2002 project: http://www.remote-lab.de/en/profil/technik.html (in English)

[23] Fischer Technik © Company: http://www.fischertechnik.de/english/index.html

[24] LabView © is a standard application in research, in particular in engineering research and education. Since many remote experiments are realized at faculties of engineering, it is not surprising that this application has been used so widely. Furthermore, some of the remote engineering experiments are devoted to train the students in the use of LabView software (*e.g.* programming tasks, use of graphical interface software).

[25] J. García-Zubia, D. López-de-Ipiña, P. Orduña, U. Hernández, I. Trueba, Questions and Answers for Designing Useful WebLabs, Int. J. Online Engineering **2**/3 (2006).

[26] Tutorial online available through http://rcl.physik.uni-kl.de/docs/Tutorial_RCL.pdf (in German). The tutorial contains detailed instructions on how to build a microcontroller based interface including circuit diagrams and wiring, necessary electronic devices (e.g. resistors) and mounting, how to program the microcontroller, how to install the web server, detailed

procedure to set up a simple RCL as sample, comments on extension devices (relays, motors, switches etc.).

[27] remote_lab: http://www.remote-lab.de/ also available through [11]

[28] B. Dabrowski, L. Nock, T. Kniss, M. Godfrey, B. Stockhausen, Creating Remote Experiments, ALCOM Education Project, Liquid Crystal Institute at Kent State University, Ohio, ca. 2000. Online available through Google Cache http://72.14.205.104/search?q=cache:Dw2z6N1XDhoJ:olbers.kent.edu/alcomed/Remote/Manual/Manual2d.htm or through Web Archive http://web.archive.org/web/20041012222933/olbers.kent.edu/alcomed/Remote/Manual/Manual2d.htm

[29] Verein mathematisch-naturwissenschaftlicher Excellence-Center an Schulen e.V. (Verein MINT-EC), http://www.mint-ec.de/

[30] Intel © Teach to the Future: http://aufbaukurs.intel-lehren.de/index

[31] S. Gröber, M. Vetter, B. Eckert, H. J. Jodl, World Pendulum – A distributed Remotely Controlled Laboratory (RCL) to measure the earth's gravitational acceleration depending on latitude, in preparation.

[32] S. Gröber, M. Vetter, B. Eckert, H. J. Jodl, Modelling transitions between order and disorder in a Remotely Controlled Laboratory (RCL), Proc. GIREP Conf. August 20-25, 2006, Amsterdam, The Netherlands. (in print)

(web sites accessed September 26, 2006)

Table 1: Summary of the enquiries on world-wide remote labs.

Year	Total number of remote labs	Free to access *	Worked without problems *	Subjects *
2004	~ 70	~ 70 %	~ 15 %	~ 90 % engineering
2006	~ 120 (~ 60 projects)	~ 20 %	~ 20 %	~ 60-70 % engineering ~ 30 % physics *** < 10 % other disciplines

* In percent of total number.

** Only the 20 % with free access are counted here, although a few other remote labs were operable after receiving access data to test them.

*** Including such remote labs dealing with electronics.

Table 2: Access rates to RCLs

a) At the “Deutsches Museum” as part of an exhibition (evaluation period January – March 2003)

	Total Access	Locally at the museum	Via Internet
Optical Tweezers	4509	4115	394
Thermal Imaging Camera	7744	7244	500
Robot in a Maze	5060	4567	493

i.e. about 50 users per experiment and per day in the museum, about 5 users per experiment and per day via Internet.

b) **Electron Diffraction** in Kaiserslautern via Internet, exemplary

July 2002 - October 2002	2-3 a day
July 2003 - December 2003	1-2 a day
Mid December 2004 - Mid January 2005	4-5 a day
January 2006 – February 2006 *	14-15 a day

* Usage: variation of voltage ca. 4-6 times per session
Visitor’s country: Germany, Czechia, India, Ireland, Greece, Belgium, Austria and others (frequency of usage in this order)

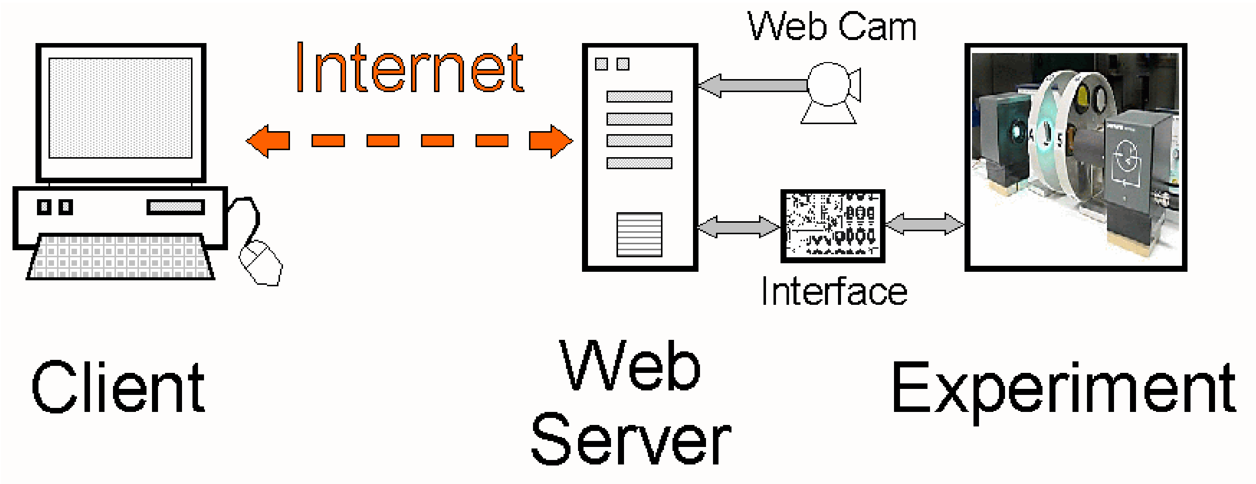


Fig. 1: Principle of a remote lab: A user with client computer controls a real experiment at a remote location via Internet. The experiment is controlled by the user through a web server and an interface; at least one web cam allows the user to observe the experiment and to take data.

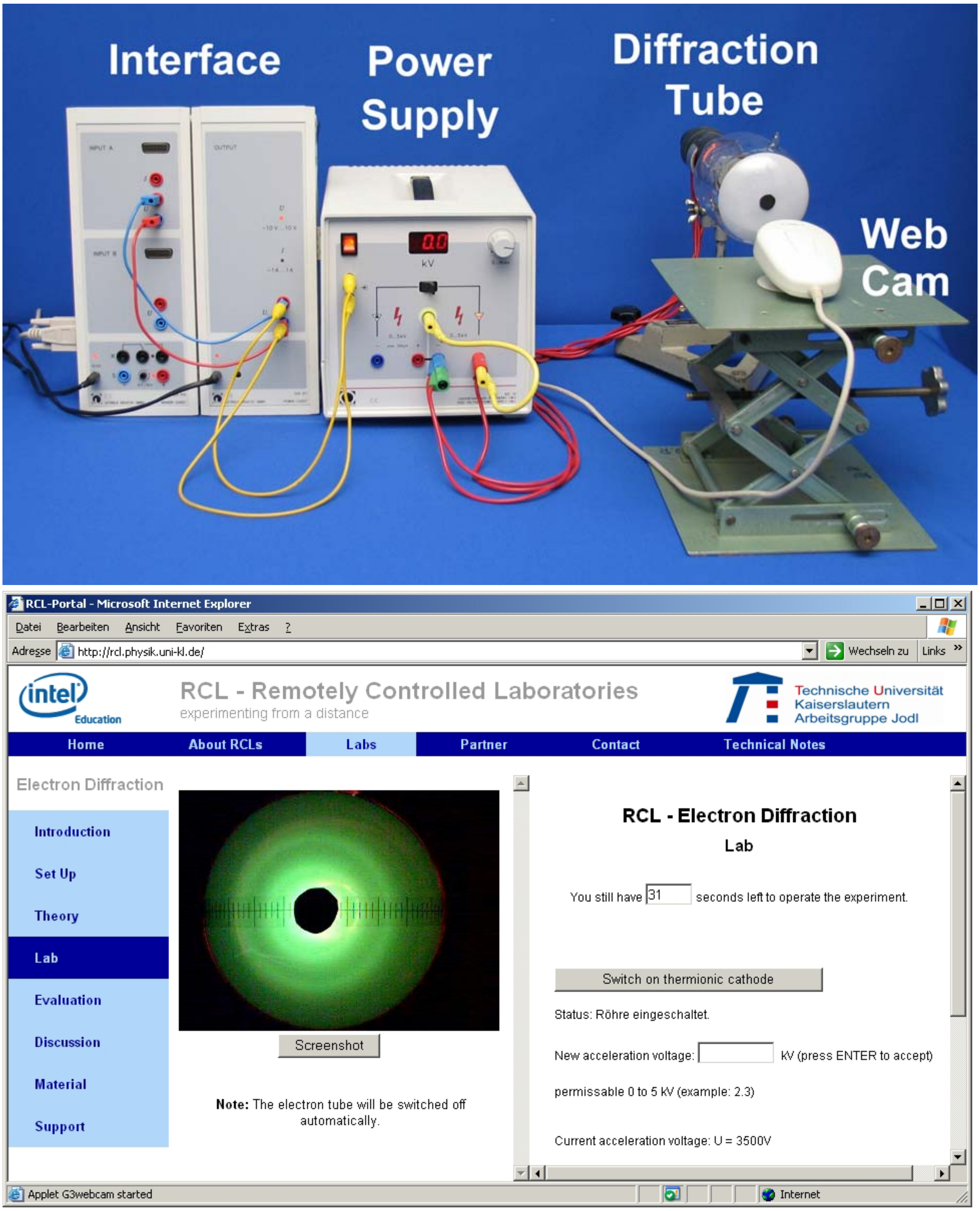


Fig. 2: RCL „Electron Diffraction": experimental set up with CASSY-interface [18, 19], power supply, electron tube and web cam (top). Screenshot of the website under menu option „Lab": live video stream (the diffraction order 0 is blocked to avoid supersaturation of web cam) as well as chosen acceleration voltage and some other data (bottom).

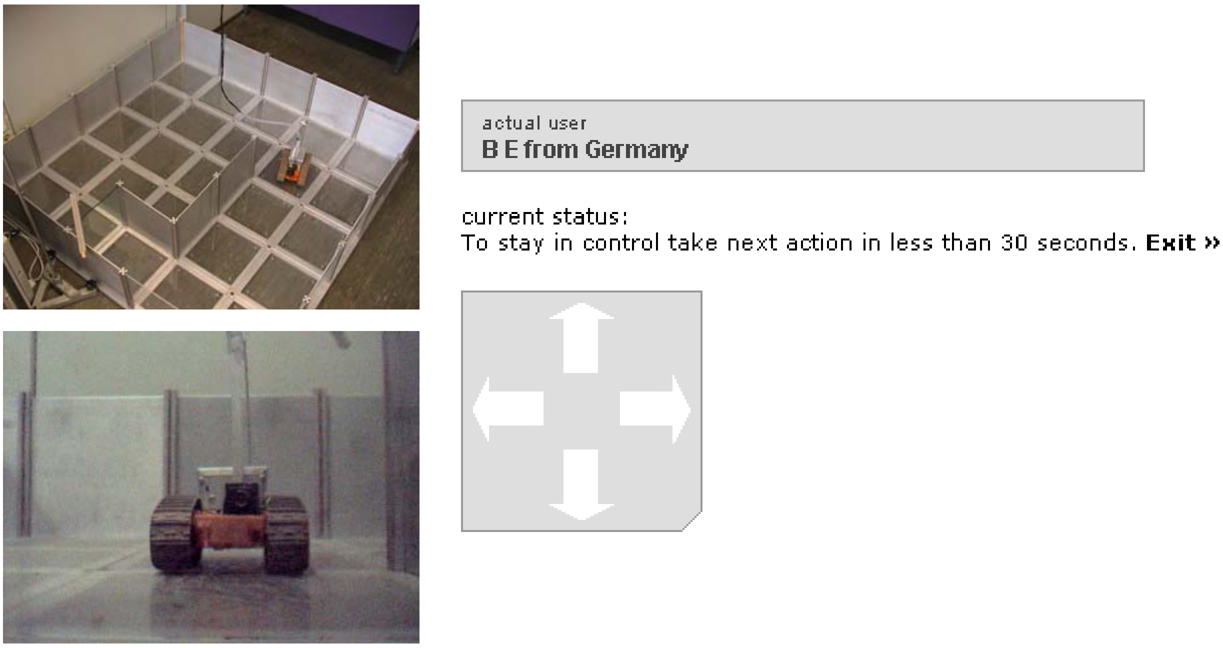
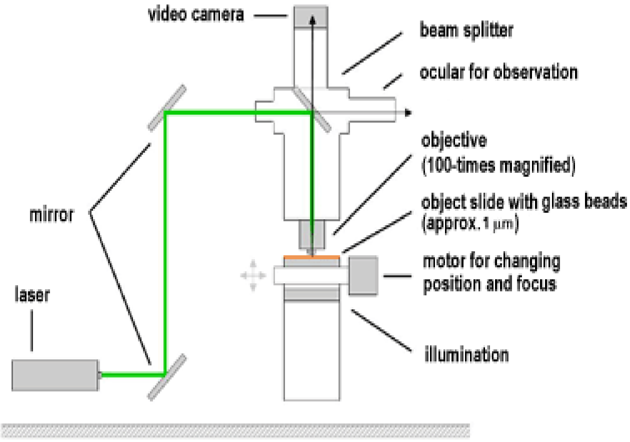
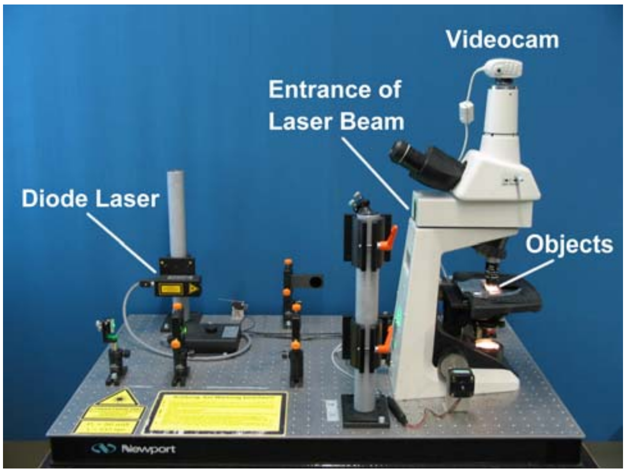


Fig. 3: RCL „Robot in a Maze“: the variable maze and the robot vehicle are seen on the left. Two viewing modes are possible: tilted laboratory view from above (top left) and robot view (bottom left, a web cam placed on the robot enables this feature). The relatively simple controls of the robot and the status display are shown on the right hand side. A sample task for the user is to find the place in the maze where – in the robot view – one can see the robot itself at a mirror wall. This RCL is thought to excite curiosity and to create interest in remote operation.





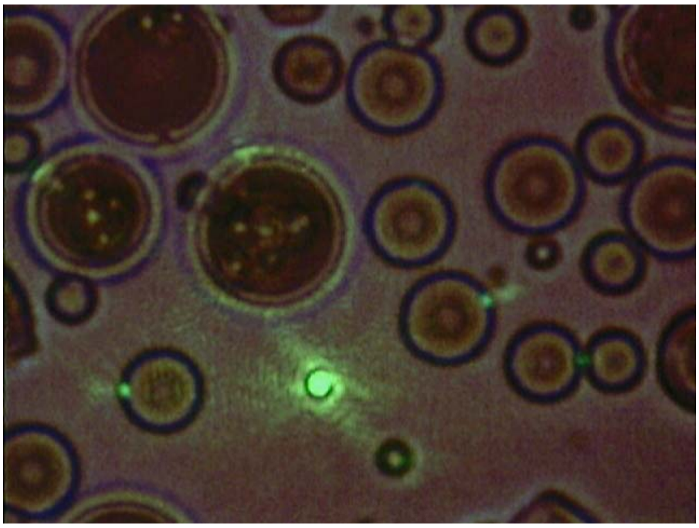


Fig. 4: RCL „Optical Tweezers“: simplified scheme (top left) and photo of the real set up (top right). The user can switch the laser on and off, align the focus (vertical *z*-axis) and move the object carrier and therefore the relative position of the laser focus in the *x*-*y* plane. The image below shows a representative still photo of the live video stream of the microscope camera, where the laser has just captured a particle (the height of the image corresponds to ca. 20 µm).

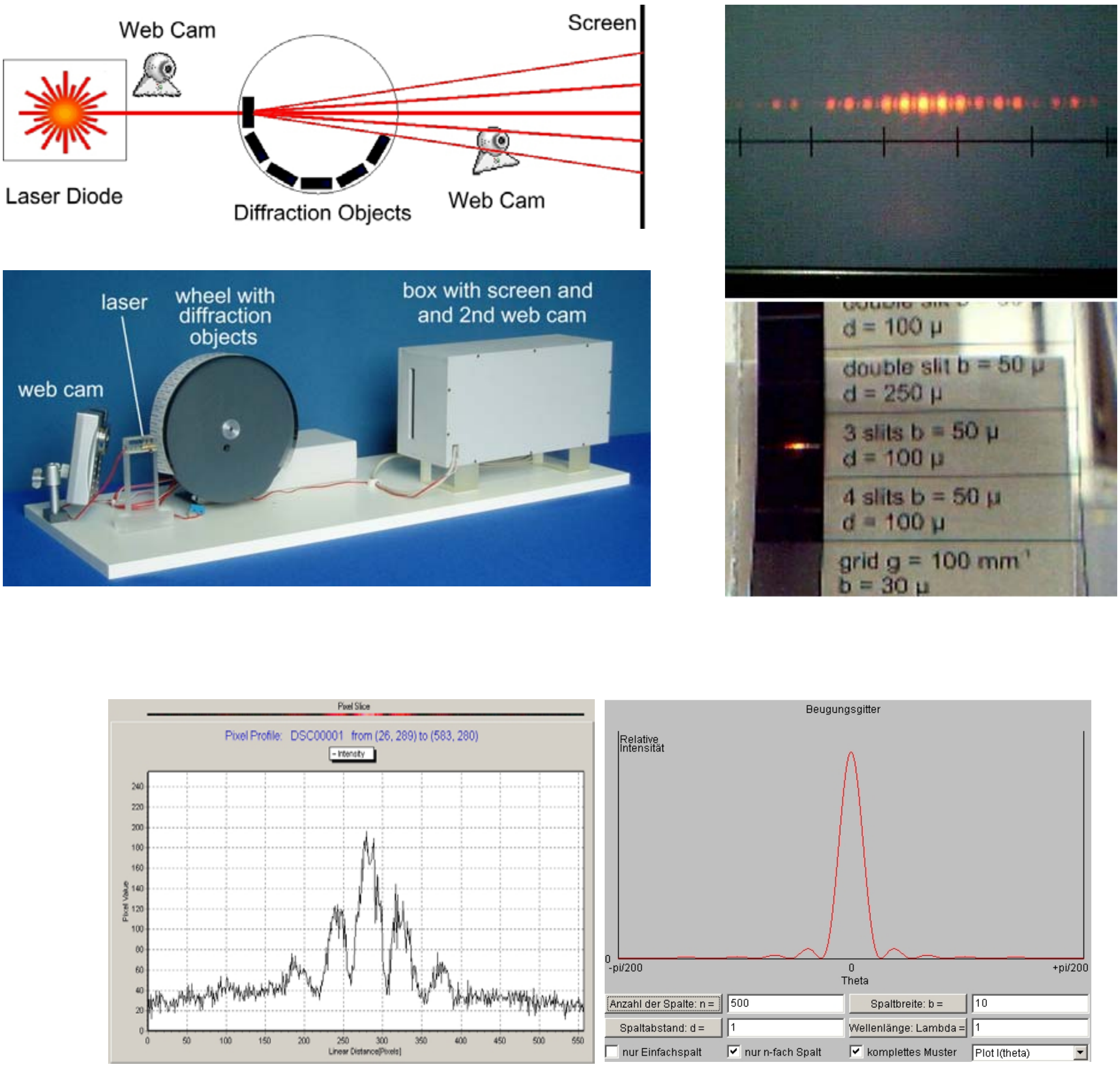
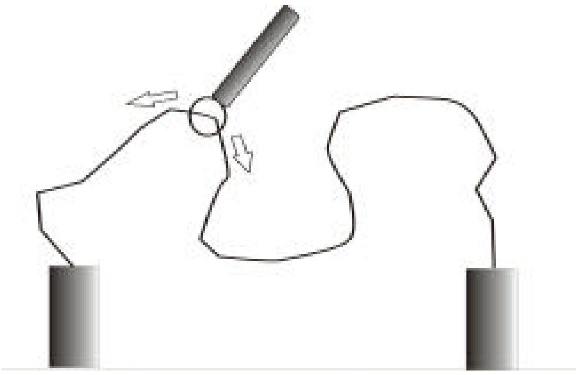


Fig. 5: RCL „Diffraction and Interference“: The user can choose between various single slits, double slits and gratings (website currently only in German). One web cam shows the rotary disk, on which the objects are positioned, a second web cam shows the diffraction pattern on the screen (simplified scheme and real set up upper part left). On the right hand side the view of both web cams is shown: a diffraction pattern with scale (top) of the chosen object (below). The user can take a screenshot of the intensity pattern and then he or she can store it; following on, with the help of a simple tool the intensity distribution can be evaluated (bottom left) and the result can be modelled by means of a Java applet (bottom right).



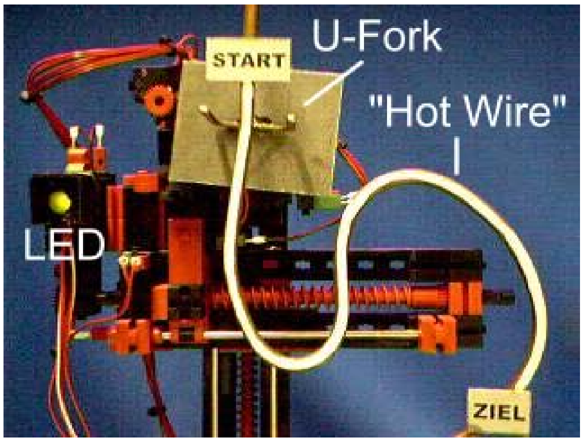


Fig. 6: Students' project example: based on a construction set by Fischer Technik © students can independently build their own robot as an RCL as part of a project for self-defined purposes, *e.g.* to steer and regulate, as an assembly line robot. The scheme left shows the idea of the "Hot Wire" game. On the right is shown the web cam view on the movable part of the toy robot. Instead of the ring-shaped noose, in the RCL an U-shaped fork is utilized, which can be moved up and down, left and right and screwed clockwise and counter clockwise. In the course of the game the user has to move the robotic arm with the U-fork along a wire as quickly as possible, without touching the wire (an LED lights green, touching the wire causes a short circuit and the LED lights red, the game is over).