Remotely Controlled Laboratory (RCL): Experimenting from a Distance

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Abstract. The use of computers and multimedia, as well as internet and communication technologies, allows for new forms of teaching and learning: 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 physics experiment carried out in place B. Currently, about ten RCLs have been implemented, an additional ten are being built or tested. A reasonable deployment of sensibly chosen real experiments in RCL allows a new form of home-work and exercises, as well as project work and the execution of experiments, which usually would a teachers' prerogative only.

Introduction. Real experiments are central in the teaching of physics in schools and universities. Moreover, the sensible use of computers (since ~1970) and of multimedia (since ~1990) has enriched the importance of the experiments: animation of complex procedures, interactive simulation to deepen knowledge [1], interactive on-screen experiments for self-learning [2], and measurement videos as an alternative for home-work [3].

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 [4], of virtual libraries, of databases and education servers being used [5]. In addition, the proportion of distance learning will increase; this poses problems especially for subjects focusing on experiments (physics, chemistry, biology), if it is to be avoided to have only lecture notes distributed electronically [6].

The principle of an RCL is shown in Fig. 1. This technique has been known for years in research and technology (e.g. control of complex conveyer belts in factories or space probes). When implementing RCLs, it is important that the user is able to follow the real experiment via a web cam, to follow the changes of parameters with another web cam, and to gather the measured 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. To convey this procedure, we have therefore added a playful approach through a maze-robot in RCLs (Fig. 2). Further requirements for RCLs 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, technical specifications of the equipment, etc.) directly in the accompanying web site, without having to rely on looking it up on other sources.

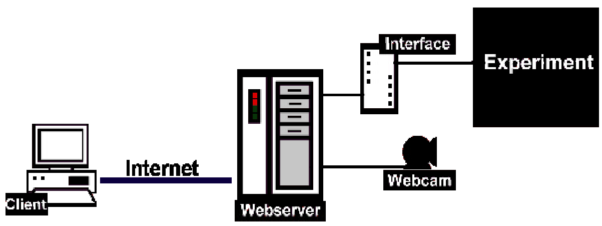

Fig. 1. *Principle of RCL*

There is by all means a need for RCLs, though it must be critically observed whether the user operates the RCL to play, to learn, or even to research.

Worldwide Inventory. We carried out a detailed research in 2004 and we found ca. 70 RCLs, of which only about 50 were free to access, while some require a user account,

Fig. 2. *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 (image left) and robot view (web cam placed on the robot). The relatively simple controls of the robot and the status display are visible on the right hand side.*

some require payment or are only accessible to a close circle of users. Only about ten of these RCLs worked flawlessly; all others had either broken links, or the experiment was out of order, or it was not a proper RCL in the way we understand it. Most experiments referred to either control engineering or games (e.g. moving building blocks with a robotic arm [7]).

Obviously, most of the RCLs are related to engineering techniques like steering and controlling (~ 90%), only a few percent are dealing with physics experiments [8]. Of the various projects we mention only two joint projects which are of large scale and of relevance according to our purposes: PEARL (Practical Experimentation by Accessible Remote Learning) [9], and I-Labs (Internet Assisted Laboratories) [10].

Most developers underestimate the required efforts and financial resources needed to build and in particular to maintain an RCL. 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 currently on technical problems which leaves little time for the necessary didactical efforts.

Our Development. We started in 2002 by building a prototype in Kaiserslautern for the diffraction of electrons at graphite [10], in order to test, to assess feasibility, and to gather errors and experience. This experiment so central to physics lessons allows one to measure the lattice parameters of graphite by varying the velocity (~ wavelength) of electrons which are accelerated by an electric field (Fig. 3).

The user can change the acceleration voltage, measure the diameter of the diffraction rings through web cam, save the images, and evaluate the measurements. Option 'Setup' presents a photo of the experiment, in which each component of the set up is explained; a further option contains background knowledge and the manufacturer's specifications of the tube; 'Analysis' presents a sample evaluation with discussion of measurement errors as well as images to compare with previous measurements. Questions around the experiment round off the discussion. With the exclusion of the replacement of a tube, the experiment has now been running without problems for the past three years.

The following RCLs were built, activated and kept constantly tested for about one year for an exhibition at the 'Deutsches Museum' in Munich (2002 – 2003 on the topic „Climate"): "Robot in a Maze" (Fig. 2), "Thermal Imaging Camera", "Optical Tweezers", "Fuel Cell". Three more experiments were realized for physics lessons in 2004, which are successively released [10]: "Diffraction and Interference of Light" (Fig. 4), "Optical Analogy to a Computer Tomograph", "Hot Wire" as a prototype for students' projects.

Didactics. Different target groups (interested lay people, pupils, students, and teachers) require different documentation. The web site has been structured on the basis of “Play – Learn – Research” to suit interested lay people; for use in lessons, we have chosen the usual scheme of “Introduction – Theory – Experiment – Evaluation – Discussion”. 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 RCL experiment to retrieve information from the library), sufficient description of the tools being used; example measurements and evaluation with discussion of results and errors as well as knowledge questions.

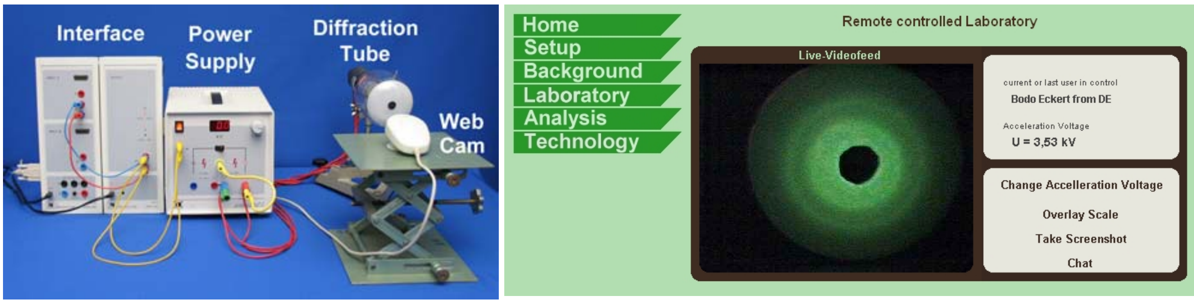

Fig. 3. *RCL „Electron Diffraction Tube“: set up of the experiment with CASSY-interface, power supply, electron tube and web cam (left). Part of the website under option „Laboratory“: live video stream (the diffraction order 0 is blocked) as well as chosen acceleration voltage and voluntary user data (right).*

Outlook. We are planning to build ten further RCLs in the near future (2005-2006), in collaboration with Intel® Germany for their teaching and learning platform [12] and with support from the Eberhard von Kuenheim Foundation (BMW Germany), as well as with the Employers’ Association ‘Gesamtmetall’. To this end, we have pre-selected ca. 30 experiments from a list of about 300 school experiments of secondary school curriculum, based on the following criteria:

How central and meaningful is the experiment to the physics lessons?	How can data be quickly processed?
What is the priority of the experiment in the lesson plan (not just topic related)?	How solid is the real experiment, including control over personal computer (maintenance effort)?
What are the difficulties in learning and understanding of the students?	Is the technical effort justified?
How difficult or easy is it to carry out the real experiment?	Which media could be implemented concurrently or alternatively?
What interactivity makes sense to offer via RCL?	

The following experiments are currently being developed: voltage-current characteristics of building blocks in electronics; charging and discharging a capacitor; electric resonant circuits; wind tunnel; radioactivity; Lorentz force on electron beam (determination of e/m); measuring the speed of light; photoelectrical effect (Planck’s constant).

Once we have realized RCLs, they will be handed over to “Intel Virtual School“ [12] and the supervising teachers will be inducted. A network of RCLs in schools should be the result. Pupils should make use of RCLs not only for demonstration experiments or homework for physics lessons, they should be put in a position to build their own RCL project.

A worldwide network of RCL clusters should be the long term outcome, offering different RCLs. 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 of RCLs in learning environments will exist.

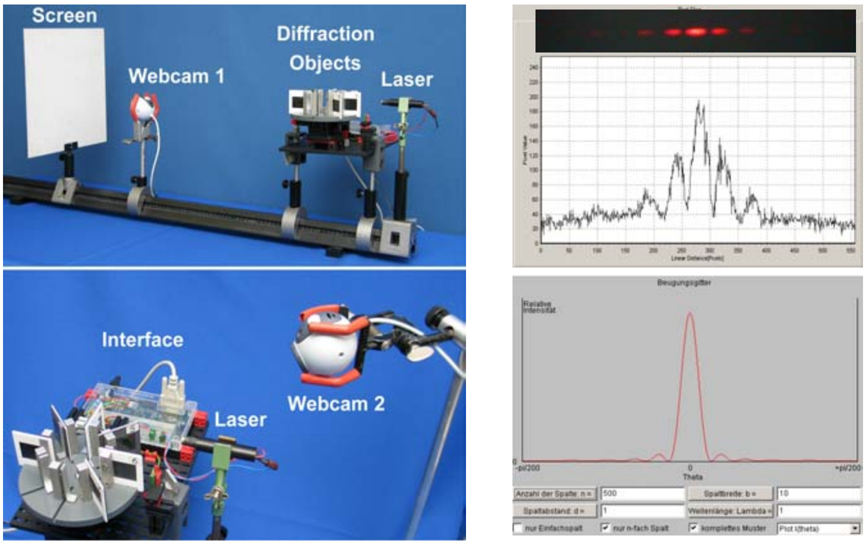

Fig. 4. *RCL „Diffraction and Interference ": Web cam 2 shows the rotary disk with the objects, web cam 1 shows the diffraction on the screen (left). The user can take an image of the intensity pattern; then, with the help of a tool the user can evaluate the intensity distribution and model the result with a Java applet (right).*

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[1] The Physlets® of W. Christian and colleagues are mentioned here, representing many developments in the implementation of simulations and animations in physics lessons: W. Christian, M. Belloni, *Physlet® Physics – Interactive Illustrations, Explorations, and Problems for Introductory Physics* (Pearson Education, Upper Saddle River, NJ, 2004). http://webphysics.davidson.edu/applets/applets.html
[2] J. Kirstein, "Interactive Screen Experiments: Documentation and Presentation of Real Experiments in Physics with Standard Multimedia Technology", Proc. MPTL 4, November 22-23, 1999, Amsterdam. http://www.ifpl.tu-berlin.de/ and http://pen.physik.uni-kl.de/w_jodl/MPTL/docs/CONTAMST.pdf
[3] A. Wagner, S. Altherr, B. Eckert, H. J. Jodl: "Multimedia in physics education: a video for the quantitative analysis of the Reynolds number", Eur. J. Phys. **24**, 297-300 (2003). http://pen.physik.uni-kl.de/medien/MM_Videos/index_eng.html
[4] In this paper we do not discuss whether it makes sense didactically to broadcast lessons over the internet.
[5] For comparison see the compilation in: S. Altherr, A. Wagner, B. Eckert, H. J. Jodl: "Multimedia material for teaching physics (search, evaluation, and examples)", Eur. J. Phys. **25**, 7-14 (2004).
[6] For example, we mention here a multimedia based university physics teaching distance course: early entrance in physics study ("Früheinstieg ins Physikstudium", FiPS). http://www.fernstudium-physik.de
[7] K. Taylor, B. Dalton, University of Western Australia: http://telerobot.mech.uwa.edu.au/
[8] The following web sites will allow a closer look at the current status of RCLs; they present to some extent a complete listing of RCLs available on a worldwide level: 1. http://telerobot.mech.uwa.edu.au/links.html
2. http://prolearn-oe.org/bin/view/OE/ExperimentDescriptions
3. http://www.learninglab.de/i_labs/docs/Uebers_Fernlabore/uebersicht_fernlabore.html
[9] M. Cooper, A. Donnelly, J. Ferreira, "Remote Controlled Experiments for Teaching over the Internet: A Comparison of Approaches developed in the PEARL Project", ASCILITE Conf. Proc., Auckland, December 8-11, 2002. See also: http://iet.open.ac.uk/pearl/
[10] Wallenburg Global Learning Network (ed.), "Achievement Report 2003-2004", pp. 16-18. See also: http://www.wgln.org and http://www.l3s.de/i_labs/
[11] http://pen.physik.uni-kl.de/w_jodl/RCLhome.htm
[12] Intel® Teach to the Future: http://aufbaukurs.intel-lehren.de/index