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An easy-to-build remote laboratory with data transfer using the Internet School Experimental System

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Abstract
The present state of information communication technology makes it possible to devise and run computer-based e-laboratories accessible to any user with a connection to the Internet, equipped with very simple technical means and making full use of web services. Thus, the way is open for a new strategy of physics education with strongly global features, based on experiment and experimentation. We name this strategy integrated e-learning, and remote experiments across the Internet are the foundation for this strategy. We present both pedagogical and technical reasoning for the remote experiments and outline a simple system based on a server–client approach, and on web services and Java applets. We give here an outline of the prospective remote laboratory system with data transfer using the Internet School Experimental System (ISES) as hardware and ISES WEB Control kit as software. This approach enables the simple construction of remote experiments without building any hardware and virtually no programming, using a paste and copy approach with typical prebuilt blocks such as a camera view, controls, graphs, displays, etc. We have set up and operate at present seven experiments, running round the clock, with more than 12 000 connections since 2005. The experiments are widely used in practical teaching of both university and secondary level physics. The recording of the detailed steps the experimentor takes during the measurement enables detailed study of the psychological aspects of running the experiments. The system is ready for a network of universities to start covering the basic set of physics experiments. In conclusion we summarize the results achieved and experiences of using remote experiments built on the ISES hardware system.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Many students perceive physics as a difficult subject which deals with abstract laws and models that do not describe the real world and so is not much help for future careers in engineering and natural sciences. The classical physics teaching strategy of lecture–seminar–laboratory exercises based on the accumulation of basic models and laws, cumulatively speaking 'the rules' of the subject, is undergoing a crisis [1]. The other, more compatible strategy to the present state of the society is that used in the scientific method of cognition of the real world [2] or the method of e-LTR (e-learning, e-teaching and e-research) [3]. The main features of these methods are observations, the search for proper information, its processing and storage, the organization and planning of work, and data and results presentation. In this method, experiment and experimentation plays a decisive role [4]. Traditional laboratory courses do not comply with these trends; therefore it is necessary to redefine learning targets and to reconsider learning methods. Project work based on the theory of constructivism [5] and blended learning [6] will play a decisive role in laboratories and the idea that project laboratories will be the typical learning environment for physics and engineering students for the next generation is very probable [7]. In experimental laboratories a silent revolution has taken place due to the massive invasion of personal computers and information communication technologies (ICT). Experimental workplaces for teaching purposes provide real experiments using the nowadays omnipotent computer for data collection, processing and evaluation. The second, fast developing area of physics experimentation in teaching is remote e-laboratories with remote experiments (RE). Many real remote e-laboratories across the Internet have been published that provide experiments on real-world objects, supplying the client with a view of the experiment, an interactive environment for experiment control and resulting data for evaluation. Recently, two European projects have promoted interest in remote physics laboratories: the 'Practical Experimentation by Accessible Remote Learning' (PEARL) [8] and 'Remotely Controlled Laboratory' [9]. The experience gathered, a description of the state of the art and corresponding references from Europe and the United States are to be found there.

In the present paper we want to add to these activities in a constructive way. We know, from our own long experience, that once the university or the department and/or their teachers decide to build an RE, the main obstacle is often not the financial requirements of the RE, but the technical know-how of ICT, client–server communication and its establishment.

In this paper we intend to offer a remedy to this situation and provide help with available hardware and software solutions, enabling easy building of computer-based real experiments and their straightforward transformation to real RE across the Internet. We base this on a scalable building set for the construction of natural science experiments, including for physics, Internet School Experimental System (ISES) [10] and ready-for-use software for easy and simple creation of remote experiments, ISES WEB Control [11]. Further, we give an overview of the two-decade-long activity in real physics experiments with computers, and the present state of the remote experiments e-laboratory, with data transfer using only web services with common web browser and active Java support on the side of the remote experimentor. The potential and future possibilities for the ISES systems in connection with the RE are also discussed.

2. Reasoning for remote laboratories

There is general consensus among academic staff and the authorities of universities about the weight and importance of laboratory work in science and engineering in general, and in physics in particular. In reality, due to many reasons including the need for new instrumentation, new techniques and methods and the resulting costs, the quality and the role (expressed in teaching hours) of the laboratories may start to diminish. Besides, the laboratory work is usually only loosely bound to the time schedule of the lectures and seminars and, at the majority of universities, consists of lists of experiments with more or less given recipes, and strict objectives and goals to be achieved by the student within the planned teaching hours. It is then a common habit to have fixed, prepared laboratory working places with experiments set up for the whole term and students 'circulating' individual experiments in an arbitrary way. In this way the access of the students to the laboratories for independent work and self-study is not included in the planning. The same goes for distance-learning students and students, who, for a variety of reasons, are excluded from the laboratory work.

The general and most decisive criterion for the introduction of remote laboratories in our case was the need to draw students more into practical experimental work and to remove the barriers against independent laboratory work. The provision of remotely controlled real experiments accessible over the Internet can potentially address all these issues.

- Remote real experiments in most cases work round the clock. Students and those interested may choose a time that is optimal for them and work at their own speed. If the instructor's presence is required, a reservation system for the experiment is needed.
- Access to costly and potentially unsafe experiments is feasible.
- The introduction of the students in a natural way to the real contemporary world of science and scientific techniques, with the team work mediated through computers and the web, so building correspondance skills.
- University premises do not limit access to the RE, but a computer and the Internet mediate them. Distance-learning students may profit from RE. In the more traditional scheme of organization, they work in laboratories in blocks covering more than one laboratory experiment, completely independent of lectures. RE positively influences the large group of people who, for different reasons, are excluded from laboratory work.
- Remote experiments support the idea of globalization and delivery of experiments to underdeveloped countries.

When RE are introduced, provision for a high quality educationally effective interface design, instructions for the experiment, questions and problems connected to the experiment, further reading texts, and a means of communication with the instructor and help system is required. These all are of paramount importance. Students should concentrate, during the measurement and subsequent data processing, on the examined phenomena and not on the instrumentation and its function. Also, they should from the very beginning of the RE know what to measure and what to observe and thus the communication page on their computer should be as simple and self-explanatory as possible. The focus in the RE should be data processing and evaluation after their transfer to the client (experimentor) computer.

3. Pedagogical issues

In searching for pedagogical reasons to introduce remote laboratories it is valuable to summarize the skills and benefits of the laboratory work that may be acquired [12, 13]. The requirements for all these skills and benefits should be taken into account when building a remote experiment. On top of this, without the claim of being exhaustive, present students should learn and make full use of the advantages the ICT and Internet bring to laboratory work. In the majority of progressive university laboratories the computer has found its way into experiment in various ways, from data collecting (replacing, e.g., analogue and digital oscilloscopes), through to filtering noise, simple processing and exporting to graphical processors for the presentation of results. Our own experience and the golden rule in introducing computers into the student laboratory is that the computer should remove the routine work, and not encroach on the physics principles and laws of the examined phenomenon. The Internet itself opens the possibility for searching for information and supporting material, enabling the student to compare his/her results with others.

The potential and the assets of RE described above are good reasons for their introduction; let us specify the most important in more detail below.

3.1. To substitute 'recipe labs' [14] by research laboratories

Laboratory classes in traditional laboratories typically involve students performing teacher-structured laboratory exercises or experiments. Each step of a procedure is carefully prescribed and students are expected to follow the procedures exactly. Usually, little is left to the student's own thought or ingenuity. This requires little student engagement with the content, and as it is commented in [15], 'students can be successful in their laboratory class even with little understanding of what they are actually doing'. In [16] the authors suggested that the recipe lab 'omits the stages of planning and design' and it encourages 'data processing' rather than 'data interpretation'. In [17] the authors developed this further by commenting on the various steps a research scientist would take before actually getting to the practical aspect of the experiment by asking: what questions are we trying to answer? What observations would provide an answer to the questions? How can we best create conditions for making the desired observations? How will we process and evaluate the observations? What will we do next?

RE provide more scope for skills development and understanding of concepts and of the experimental process. The students get experience of the whole scientific process in a relevant and stimulating format. Furthermore, they seem to enjoy the experience of working by trial and error, hypothesis formulation and their proving or disproving ideas; at the same time this is the main objection against the introduction of virtual e-laboratories [8].

3.2. Project work by RE

Once we have introduced research laboratories using RE, we can also start to think about project education [18]. The problem solving students encounter in their projects with RE help them to learn a set of important concepts, ideas, skills and techniques that will be required in subsequent subjects and their future careers. This form of education constitutes an enormous change; students must be willing to take charge of their own learning and to cope positively with the attitude shifts that are required. The enormous advantage of this approach is the possibility of working at any time; students can work from any destination they choose and at their own rate.

3.3. Skills students acquire

The question of additional acquired skills is very obvious in RE work. On the one hand students are forced to measure independently and, on the other hand, they can easily share experiences. On top of this, the tutor, or other sources of information on the RE, is easily available. This forces students to exchange information, knowledge and know how in the team work. This supports self-awareness as planning work, selecting appropriate techniques and procedures, and understanding errors are all necessary. Further, the main feature of project work forces students to analyse and evaluate the data obtained. Project work using RE strengthens the possibility of measuring and observing events of the real world and its peculiarities and thus serves to introduce and generate interest in general science issues, and to teach presentation of the results gained.

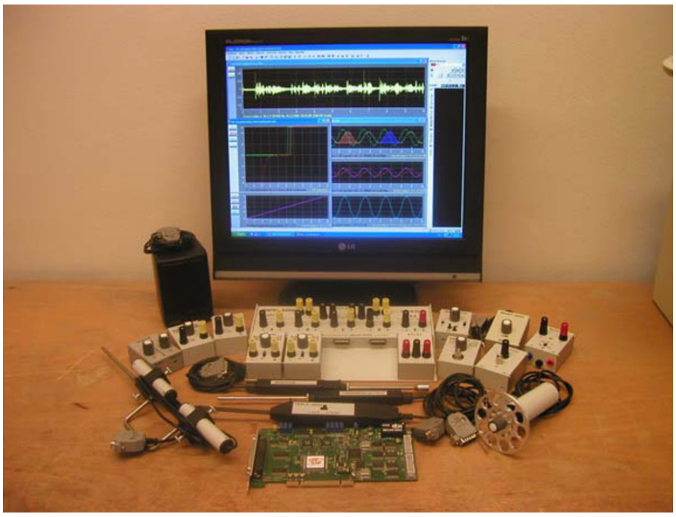


Figure 1. ISES—Internet School Experimental System [20].

The additional skills gained in ICT and Internet are quite important and obvious, but above all it is the endeavour of university teachers to challenge the deeply seated student notion of the Internet as an ICT environment for chatting, playing and surfing, and not appropriate for serious, especially scientific, work.

To optimize the pedagogical and educational goals of RE constant feedback on its effectiveness and operation should be provided. Statistics on the number of visits to individual experiments with detailed recording of activity split into individual steps and corresponding times spent are imperative for both pedagogical research and constant improvement of the hardware and software of RE, similar to the pedagogical research on the efficiency of applets [19].

4. Technological aspects of remote real experiments—ISES and ISES WEB Control

The present state of ICT in the area of measurement, data collection and transfer using web services is rather complicated and not clearly arranged for the physics teacher to build remote real physics experiments. Missing standards lead to many individual solutions, and therefore to unnecessary hurdles for hosts and users [9].

To build remote real physics experiments requires as the first step setting up the computer controlled experiment. In our laboratory, a user-friendly hardware and software system for easy building of physics experiments—Internet School Experimental System (ISES)—has been constructed [20]. It forms the basis of our approach to the simple and prospective building of remote experiments. Its detailed description and philosophy is reported elsewhere [20]. Here we will mention only a few simple facts important in relation to RE construction. ISES is an open system working under the Windows operating system with all its advantages (OLE and multitasking). The system is composed of an interface card, a set of variable modules and sensing elements, and the service graphical and evaluation software (see figure 1).

Once the computer-oriented experiment using the ISES system is built, the second step is to build the real RE across the Internet, i.e. to establish a classical server–client connection

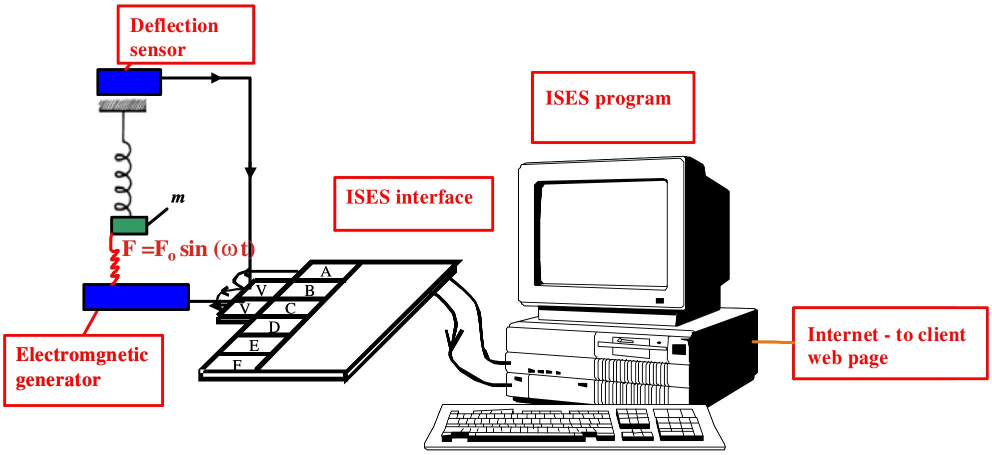


Figure 2. A schematic representation of the server of the remote experiment 'Natural and driven oscillations' with mass and spring using the ISES.

with data transfer from the server to the client and in the reverse direction for the control of the experiment by the client (experimentor). For this purpose, we built the software kit ISES WEB Control [23] for the easy transformation of the computer-oriented experiment based on the ISES system to the RE (with server–client approach), using only web services, web pages and Java support on the client side based on a copy–paste approach, prefabricated building blocks, and limited knowledge of the rules of web page creation and suitable editor. A schematical representation of the RE 'Natural and driven oscillations' using ISES hardware and ISES WEB Control software is shown in figure 2.

In figure 3 there are examples of the typical prefabricated controls for the set-up of a client web page. The present ISES WEB Control kit consists of 15 typical Java applets with great flexibility and adjustable parameters enabling us to build web pages for controlling the majority of physics experiments on the client side. Figure 4 shows the control web page for the RE 'Natural and driven oscillations' (with live web camera view, frequency controls, and graph of the measured data). Figure 5 shows the data transfer to the client computer for further plotting, processing and evaluation.

5. Discussion—past, present and outlook for remote experiments using ISES

The present state of the remote experiments in our e-laboratory project can be seen via our new web pages (see www.ises.info): they are water-level control, a meteorological station in Prague, electromagnetic induction, natural and driven oscillations, diffraction on microobjects, solar energy conversion and the Heisenberg uncertainty principle. In the following we want to state the reasons why exactly these pilot individual experiments were chosen. We give the variable parameters and the outputs, and hints for their operation. We also give some of the leading didactical aims for each of the experiments. All the detailed instructions for each experiment (motivation, introduction, physical background, experimental setup, experiment and assignments) are given on the website (www.ises.info). We will next only comment on the specifics of each experiment.

The motivation for the choice of the experiments was the need to have one introductory experiment, one experiment featuring manual control, one experiment featuring a data logger and then which experiments cover step by step the basic course of physics at universities.

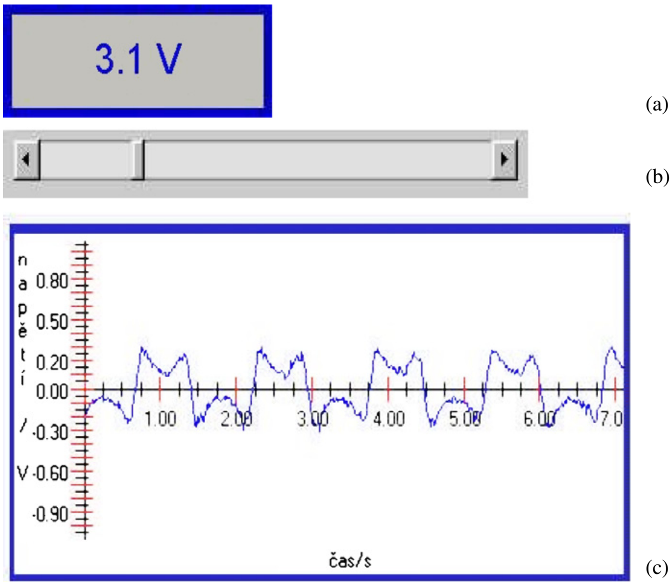


Figure 3. Examples of modular Java applets from the ISES WEB Control kit [23] as building tools and blocks for RE web control pages (a) display, (b) control slide, (c) graph for data presentation.

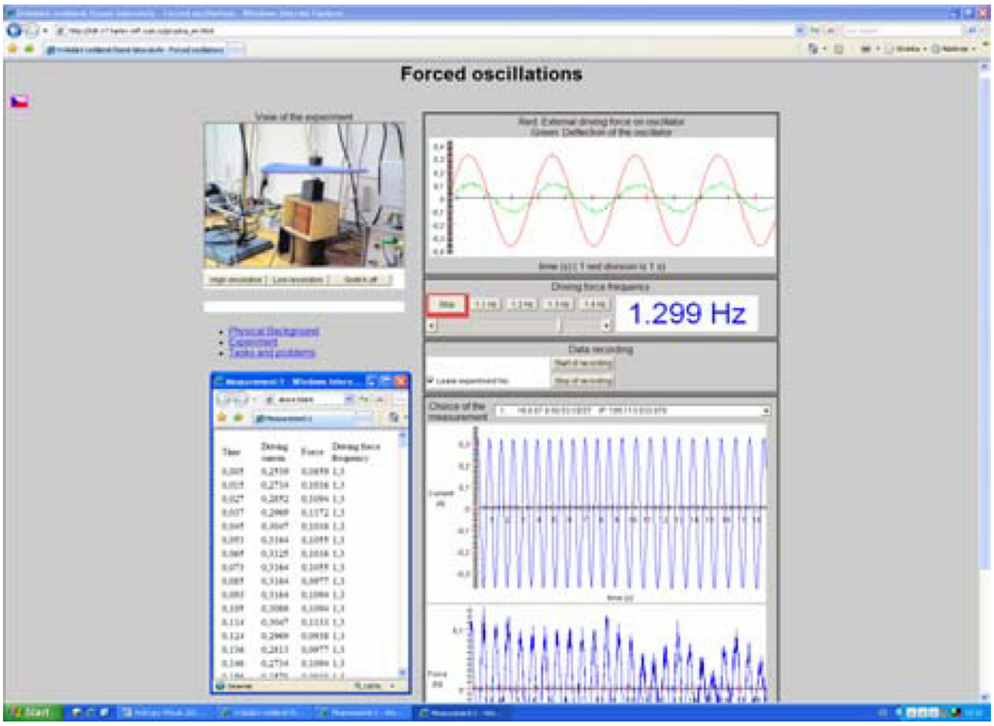
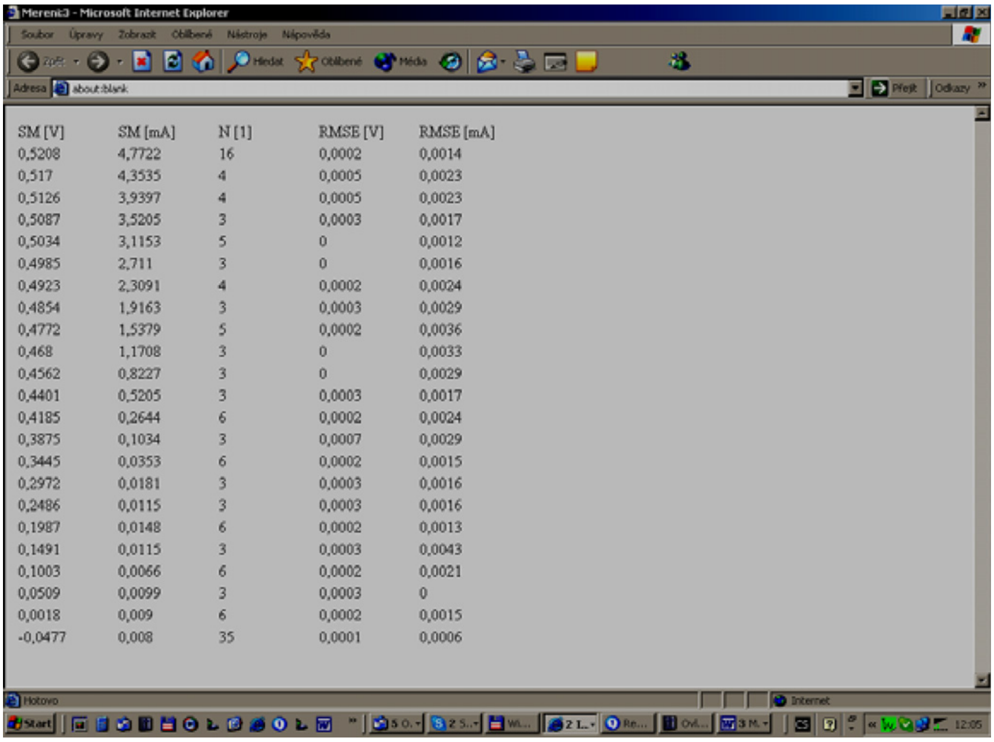


Figure 4. The web page on the client computer of the real remote experiment 'Natural and driven oscillations' with live web camera view, frequency controls and graph of the measured data.



SM [V]	SM [mA]	N [1]	RMSE [V]	RMSE [mA]
0,5208	4,7722	16	0,0002	0,0014
0,517	4,3535	4	0,0005	0,0023
0,5126	3,9397	4	0,0005	0,0023
0,5087	3,5205	3	0,0003	0,0017
0,5034	3,1153	5	0	0,0012
0,4985	2,711	3	0	0,0016
0,4923	2,3091	4	0,0002	0,0024
0,4854	1,9163	3	0,0003	0,0029
0,4772	1,5379	5	0,0002	0,0036
0,468	1,1708	3	0	0,0033
0,4562	0,8227	3	0	0,0029
0,4401	0,5205	3	0,0003	0,0017
0,4185	0,2644	6	0,0002	0,0024
0,3875	0,1034	3	0,0007	0,0029
0,3445	0,0353	6	0,0002	0,0015
0,2972	0,0181	3	0,0003	0,0016
0,2486	0,0115	3	0,0003	0,0016
0,1987	0,0148	6	0,0002	0,0013
0,1491	0,0115	3	0,0003	0,0043
0,1003	0,0066	6	0,0002	0,0021
0,0509	0,0099	3	0,0003	0
0,0018	0,009	6	0,0002	0,0015
-0,0477	0,008	35	0,0001	0,0006

Figure 5. Example of the transfer of the measured data in the remote experiment 'Solar energy conversion' [25].

We insisted from the very beginning of our activities in remote experiments that we should master data transfer to the remote experimentor to enable them to do further processing. We realized at the early stages of the construction of the e-laboratory that the suitability of any classical experiment for RE differs widely due to their steady or dynamic character, the level of the observed signals and the number of parameters necessary to study the phenomenon in question. We purposefully did not use complicated and sophisticated instrumentation for RE construction, because we wanted to persuade teachers to build similar experiments by themselves for their work.

5.1. Water level control

The introductory remote experiment 'Water level control' is an experiment with manual control of the type on/off. Water level is controlled interactively and manually via the web page without data transfer to the user. The controls are 'Run Experiment', 'Pump control', 'Start–Stop', 'Overflow checking' and 'Enable–Disable'. Further, the messages 'Probe 1 status' and 'Probe 2 status' signal the height of the water level. The tasks and questions are oriented on the coloured water pumping dynamics and monitoring.

5.2. Meteorological station in Prague

The experiment 'Meteorological station in Prague' is a remote laboratory experiment monitoring the temperature, pressure and intensity of sunshine at the Faculty of Mathematics

Table 1. Number of connections to remote experiments.

Total number of online connections to RE from start of monitoring till February 2008						
Water level IV /2004	Meteorology in Prague XII /2005	Electromag. induction X/2006	Natural and driven oscillations X /2006	Solar energy conversion X /2006	Diffraction microobject VI /2007	Σ
3573	2401	2748	1282	1515	862	12 381

and Physics, Charles University in Prague at Klarov. The built experiment shows the possibility of monitoring different physical variables with simple technical hardware and software across the Internet. It is a typical task of remote sensing, where the selected variables are only sampled at certain time intervals, and are measured and stored without any remote control of the process. The experiment has been running since 2002. More users may be connected to this experiment at any time. The task is accessible round the clock and is free to access without any password or registration. The tasks and questions are oriented on the evaluation of quantities related to the weather and environment, their presentation, evaluation and their relation to human mood and body fitness.

5.3. Electromagnetic induction

This phenomenon is presented in a remote experiment using a rotating coil in a homogeneous magnetic field. The goal of the experiment is to show the phenomenon and how it compares with Faraday's law of electromagnetic induction. The only parameter is the voltage for the driving motor influencing the frequency of the rotation of the coil; the data collected are the voltage picked up from the coil. The tasks and questions are oriented on Faraday's theory.

5.4. Natural and driven oscillations

The experiment from mechanics covers oscillations, an important part of the physics course, forming the basis of many phenomena and technical applications, ranging from UV absorption in the atmosphere to telecommunications, and molecular, atomic or nuclear physics. The remote experiment 'Natural and driven oscillations' is built as a simple mechanical oscillator with a mass and spring, externally driven by an electromagnetic generator of variable frequency. The parameter is the driving force frequency and the data transferred are the instantaneous driving force and the deflection. The wide range of tasks and questions are oriented on the study of natural oscillations and their damping, amplitude and phase characteristics, resonance phenomena and energy transfer.

5.5. Diffraction on microobjects

The experiment from physical optics shows diffraction phenomena on microobjects and how they change with the dimensions of the microobjects and wavelengths of the coherent sources of light. The variable parameters are the microobject dimension and the laser wavelength. The transferred data are the spatial distribution of the diffraction intensity. The goal is to determine the geometrical dimensions with their corresponding errors and the impact of the errors of the individual quantities, entering the calculation of the resulting quantity.

Table 2. Activities recorded in the experiment 'Diffraction on microobjects'.

Activity no	Activity
1	User connection
2	Auto measurement start
3	Manual measurement
4	Wider slit on
5	Narrow slit on
6	Green laser on
7	Red laser on
8	Start recording data
9	Stop recording data
10	Data transfer
11	User disconnected

5.6. Solar energy conversion

This remote experiment may be used in relation to circuits, solid state and the environment, stressing the respective teaching goals. It consists of a solar cell illuminated with a light source of variable intensity and voltage applied to the cell. The *I–U* characteristics in the dark and under illumination give a great deal of information, ranging from the equivalent circuit, solar to electric energy transformation efficiency and fill factor, optimum load for maximum power transfer, etc. The transferred data are the averaged *I–U* characteristics, the number of measurements and the corresponding mean square deviations.

5.7. Heisenberg uncertainty principle

This remote experiment from quantum theory uses the hardware from the experiment diffraction on microobjects and differs only in its instructions and assignments. The goal is to verify the validity of the Heisenberg principle of uncertainty (crucial for the microworld) using the diffraction probability distribution of photons on a screen after passage through a slit, and/or to find the approximate value of Planck's constant.

We have recorded till now (February 2008) over 12 000 accesses to our RE. The number has been recently rising fast: the numbers of users (visitors) since in mid 2007 was about 7000 compared to the present 12 000.

The next important step in the development of the remote experiments and the study of their impact on the experimentors was to look at the pedagogical and psychological aspects of the RE. We started systematic recording on the server side of the detailed steps the experimentor on the client side takes during the measurements, with the time spent for each step. To give a more specific insight, in table 2 are summarized the types of activities recorded in the experiment 'Diffraction on microobjects' with time scale. The scope of the data is enormous and this information is currently being evaluated to assess the pedagogical impact of the experiment and its psychological improvement.

The last and most recent stage in our activities was a remote scientific experiment in solid-state physics, based on the characterization of a photovoltaic solid state cell [25].

To add to the general accessibility of the e-laboratory in Prague, access to any experiment is at present granted to anyone interested, without any checks or registration. The laboratory is operated round the clock, with experiments constantly monitored and maintained. All the experiments can be viewed via a live camera to enable the client/experimentor to make a choice about which data to transfer for processing (with the exception of 'Water level control').

In the near future, our activities will focus on ISES and ISES WEB Control and the building of remote laboratories at Charles University in Prague, Tomas Bata University in Zlin in the Czech Republic and several universities in Slovakia, with the centre at the Trnava University in Trnava. The main goal of this emerging e-laboratory network is to cover the syllabus of a university basic physics course by using experiments in the direction of integrated e-learning [26].

We have envisaged and started to build the following new remote experiments:

- 'Standing waves in the resonator'
- 'Driven mathematical pendulum'
- 'Oscillations in RCL circuits'
- 'Magnetic field generation and mapping'
- 'Electrochemical sources of energy' [28]
- 'Free fall in gasses and liquids'.

6. Conclusions

Remote real laboratories are a new phenomenon in the teaching of engineering and natural sciences subjects, where the classical method of teaching 'rules' still prevails. The new strategy, based on practical observations and personal involvement in the discovery of real-world phenomena, is urgently needed. If it were the strategy of blended [6] or project [18] learning stemming from the more general strategy of constructivism [5, 28] or other stream of new ideas, it is not obvious. We propose the idea of integrated e-learning [26] based on the scientific method of work, where observation and its rationale play the crucial role. This complies with the truism of Einstein 'Truth is what stands the test of experience' [27]. The idea of remote real experiments strongly supports these strivings for new teaching methods and so is worthy both of further development and of wider acknowledgment. We try with our results to contribute to this trend by devising the system ISES and ISES WEB Control, which will allow the possibility of unifying remote real experiments across the Internet.

On top of this, from the experience of the last two decades in the field, we may draw the following conclusions.

- Remote real experiments—interactive, real time, and with data outputs—bring the possibility of making the study of many engineering and science subjects more interesting and stimulating, ushering students to get involved in the elucidation of real-world phenomena.
- We are in favour of real experiments against the idea of the virtual world and virtual measurements, the indistinguishable nature of the real and virtual 'measurements' [8], stripped of the possibility of hypothesis formulation and thier proof or disproof.
- We hope to attract young people, used to using the Internet for playing, chatting and communication, to work with our programme, and to persuade them of the strength of information gained from remote experiments on the Internet.
- Finally, we hope to bring practical experimental work by remote real experiments to those currently not participating in laboratory work for different reasons—distance-learning students, disabled and handicapped students, and those from underdeveloped countries who cannot afford to enter real laboratories.

- For all these reasons we suggest building a network of e-laboratories, accessible without preconditions, to serve worldwide for the popularization and advancement of physics education.

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