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REAL INTERACTIVE FREE FALL EXPERIMENT WITH DATA COLLECTION AND TRANSFER ACROSS INTERNET

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Abstract
Within the strategy of Integrated e-Learning (INTe-L) in the discipline of mechanics we set up a set of remote interactive mechanics experiments across the Internet. The paper presents a new and sophisticated experiment free fall, based on the movement of a permanent magnet in a glass tube with induction pick up coils for position measurement (http://remotelab4.truni.sk). Besides the air the tube is supposes to be filled with various liquids to study damped motion and corresponding viscosities. To transform the hands-on experiment into a remote one, we have had to move the magnets to their starting position by the magnetic vessel, surrounding the tube. The experiment was used with success for the study of the basis of mechanics and for verifying Faradays' law.

1. Introduction
The information communication technologies development has made it possible to introduce remote experimentation as an indispensable and missing part of e-Learning. We proposed and realized the new technology of education - Integrated e-Learning (INTe-L) (Schauer 2008a, 2009). INTe-L is a new strategy of physics education based on the method sciences use for the cognition of the real world, starting from experiments. In this respect remote experiments will play a decisive role as described by Cooper in 2005. The teaching of mechanics is usually a starting point of any basic university physics course, where the support of experiments is decisive and remote experiments are generally missing. The reason is the difficulty in the technical implementation of any mechanical experiments, in the necessity to build the PC controlled actuators that are far beyond the abilities of most university educators. Here, potentially, remote experimentation may help, and we hope for a future network of remote experimentation, created and shared by interested universities (Ožvoldová, 2009).
In this article we take one step in the right direction and exploit the possibilities of remote experiments in mechanics. We chose two experiments: First, free fall in a tube, an experiment in the dynamic range of the fractions of seconds with the need of mechanical actuators for teaching of Newtonian mechanics and conservative and dissipative forces (this paper); Second, reconstructing the instantaneous deflection angle of a pendulum for teaching kinematics, dynamics and energetics of oscillatory motion (Schauer 2009) both of these available on http://kf.truni.sk/remotelab.

2. Experiment "Free fall of a body"

2.1. Hands-on laboratory experiment Free fall
A free fall experiment in a tube is a popular experiment. Based on the motion of a permanent magnet in a tube inducing electromotive force in the coils distributed along the tube and giving corresponding signals, it is one of the most frequently used experiment on free fall (Kingman 2002). It is used in many modifications from a simple recording of the signal to the most sophisticated applications such as the fall in conductive media. We have built and present the PC assisted experiment based on the system ISES (Internet School Experimental System (Schauer 2008a), enabling both hardware (hw) solutions (tube with coils ISES, signal V-meter module ISES) and software (sw) support (signal recording and data smoothing, processing - recording of chosen typical data, fitting, etc).
In Fig. 1 is the view of the hands on experiment used in the laboratory exercises with the data processing and evaluation: a - arrangement of the experiment, b - start of a free fall, c - a typical recorded signal in air, d – the magnetic flux $\Phi(t)$ of a falling magnet (up) and corresponding time dependences of the electromotive voltage $U(t)$ (down), and e - a typical signal in a liquid. The experiment was performed successfully in both mechanics (Ožvoldová 2009) and as a Faraday law experiment in an electromagnetic theory course (Schauer 2008b).

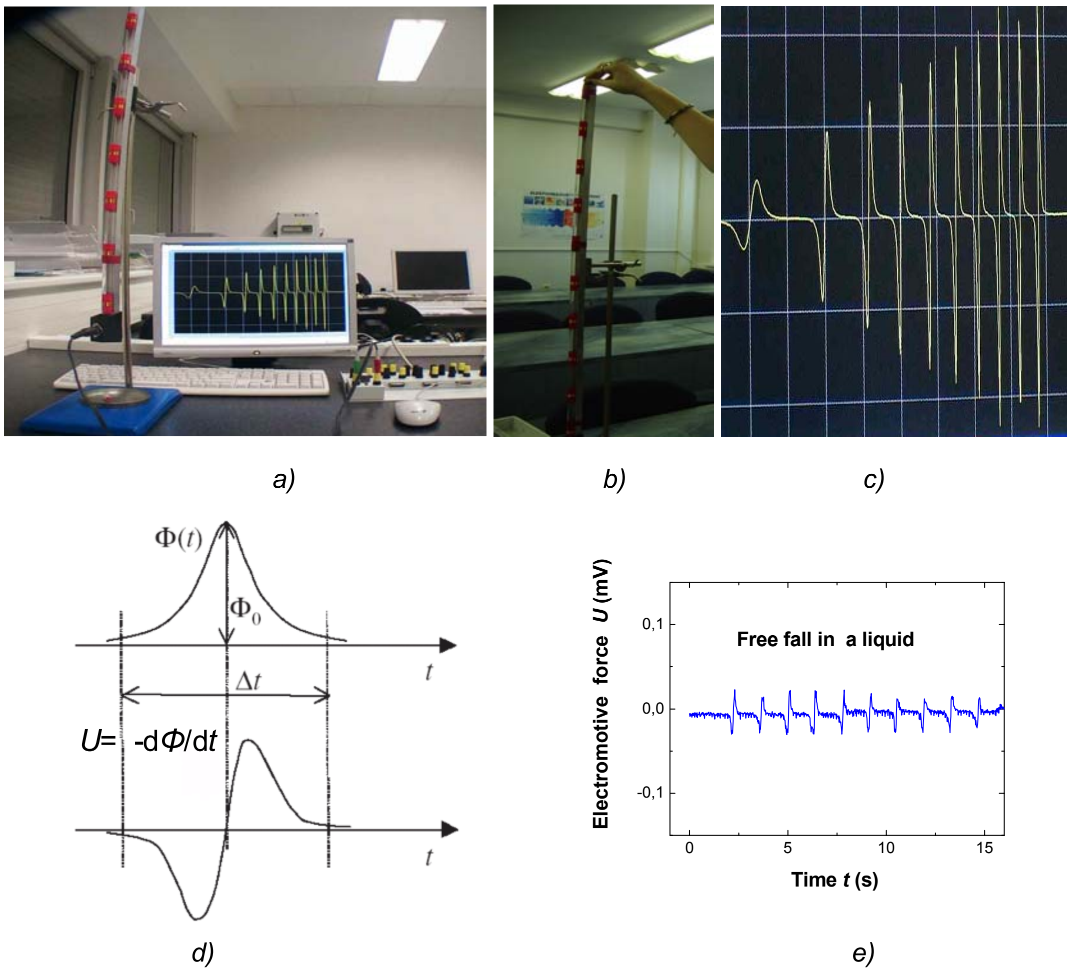


Figure 1: Arrangement of the experiment free fall (a), manual start of the magnet (b), a typical signal of the free fall in the air recorded by the ISES system (c), the magnetic flux Φ(t) of a falling magnet in a coil (up) and electromotive voltage U(t) time dependences (down) (d), a typical signal in a liquid (e)

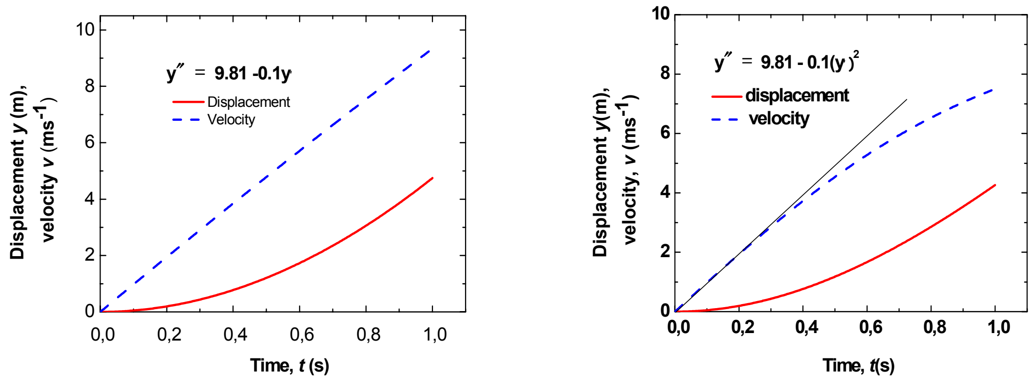
When we started the transformation of the hands-on experiment to the remote one, the detailed evaluation of the data of the experiment systematically produced differences between the results of other experiments on the free fall and the free fall in a tube, caused by the presence of dissipative forces. We decided to introduce these dissipative forces during the experiment artificially, and then control and measure them. The tube enables us to both eliminate and enhance the friction forces in controlled manner, changing the density of the gas in the tube. This is accomplished by both the rotary pump and controlled gas pressurizing of the tube. In the future the liquids introduced to the tube may serve for experimentation in viscous media.
The theory of the free fall in dissipative media is starting from the differential equation (assuming the positive direction for y is chosen to be upwards) with a general solution for the motion in low pressure gasses (neglecting the buoyancy force)

$$m\frac{\mathrm{d}^2 y}{\mathrm{d}t^2} = mg - \mathrm{k}_1 v \quad \Rightarrow \quad v(t) = \frac{mg}{\mathrm{k}_1}\left(1 - \mathrm{e}^{-\frac{k_1 t}{m}}\right) \tag{1}$$

and for the motion in viscose liquids

$$m\frac{\mathrm{d}^2 y}{\mathrm{d}t^2} = mg - \mathrm{k}_2 v^2 \quad \Rightarrow \quad v(t) = -\sqrt{\frac{k_2}{mg}}\,\mathrm{tgh}\left(\frac{\mathrm{k}_2 g}{m}t\right) \tag{2}$$

where *m* is the falling body mass, *t* is the time and *v* is the velocity, k_1 and k_2 are the corresponding coefficients of dynamical friction. The numerical solutions for arbitrarily chosen parameters k_1 and k_2 give displacement–time and velocity–time dependences in Fig. 2.



a) *b)*

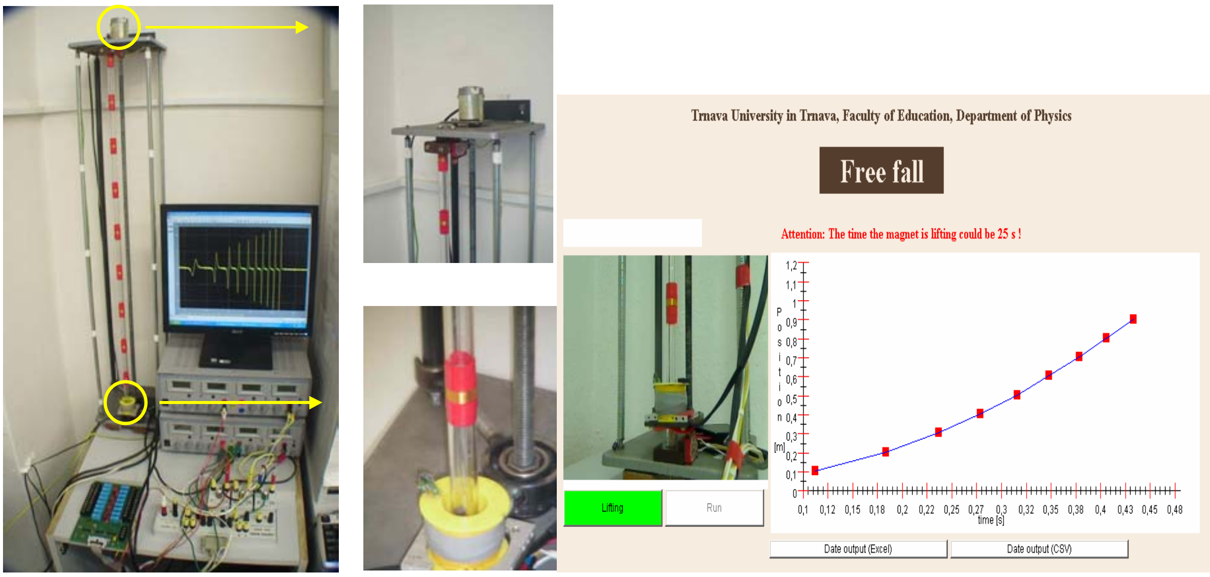
Figure 2: The modeling results of the eq. (1)(a) and (2)(b) – time dependencies of the displacement y(t) and velocities v(t)

2.2 Technical means of remote experiments

The basis of all our solutions for hands-on experiments is the system Internet School Experimental system (ISES) described elsewhere in detail (Schauer 2008a). It consists of sw and hw solution for the wide range of experiments in physics, chemistry and biology. It offers about 40 modules of sensors and outputs of typical analogues signals, program for data recording, storing and processing. The recent component part of the ISES system is the WEB CONTROL kit for easy building of the remote experiment, a detailed description of which can be found elsewhere (Schauer 2009). It enables the easy construction of remote experiments on the basis of ISES hw by inserting the pre-prepared building blocks into the html programme, formed by the compiled Java applets for typical controls and graphs and setting their parameters.

2.3 Remote experiment Free fall

Once the computer-based experiment using the ISES system is built, a second step in establishing the remote experiment is needed, i.e. the establishing of the classical server-client connection with data transfer from the server to the client and in the reverse direction for the control of the experiment by the client (experimenter). For this purpose, we built the sw kit ISES WEB Control (Schauer 2008b) for the easy transformation of the computer-oriented experiment (Fig. 3).
To transform the hands-on experiment to the remote one, the most demanding task was to repeatedly lift magnets to their starting position. For this purpose we devised and used the electromagnetic vessel, depicted in Fig. 3b, lifted by the screw driven by the step motor. To plan and programme the experiment, a detailed time and logic scheme of experiment is needed, serving for the proper functioning of the experiment. For this purpose a standard flow chart serves nicely, resulting in the corresponding programme and the final form of the experiment available on http://remotelab4.truni.sk.



a) *b)* *c)*

Figure 3: The remote experiment free fall. The total arrangement (a), two details: The magnetic vessel lifted by the screw (down), the step motor driving the screw (b), www page of the remote experiment with life camera view, time dependence of the displacement recorded by the experiment, see http://remotelab4.truni.sk (c)

2.4 Conclusions with implications for INTe-L

The main conclusions of the remote experiment free fall may be formulated as follows:

- The remote experiment from mechanics with mechanical actuators was devised and successfully implemented.
- The fast dynamic range in the fraction of a second for the whole experiment with the transfer rate across the Internet with 100 kHz sampling rate was successfully mastered.
- The dissipative forces were introduced into the experiment by the variable gas pressure from vacuum-like conditions to increase pressure above the atmospheric conditions. We intend to introduce liquids to test the motion in strongly viscous media.
- The remote experiment free fall was with the success used in education process via INTe-L strategy.
- The technical and financial requirements to build such experiments call for the establishing of a European university network of remote experiments, covering a basic course of physics, based on nearly identical syllabi.

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