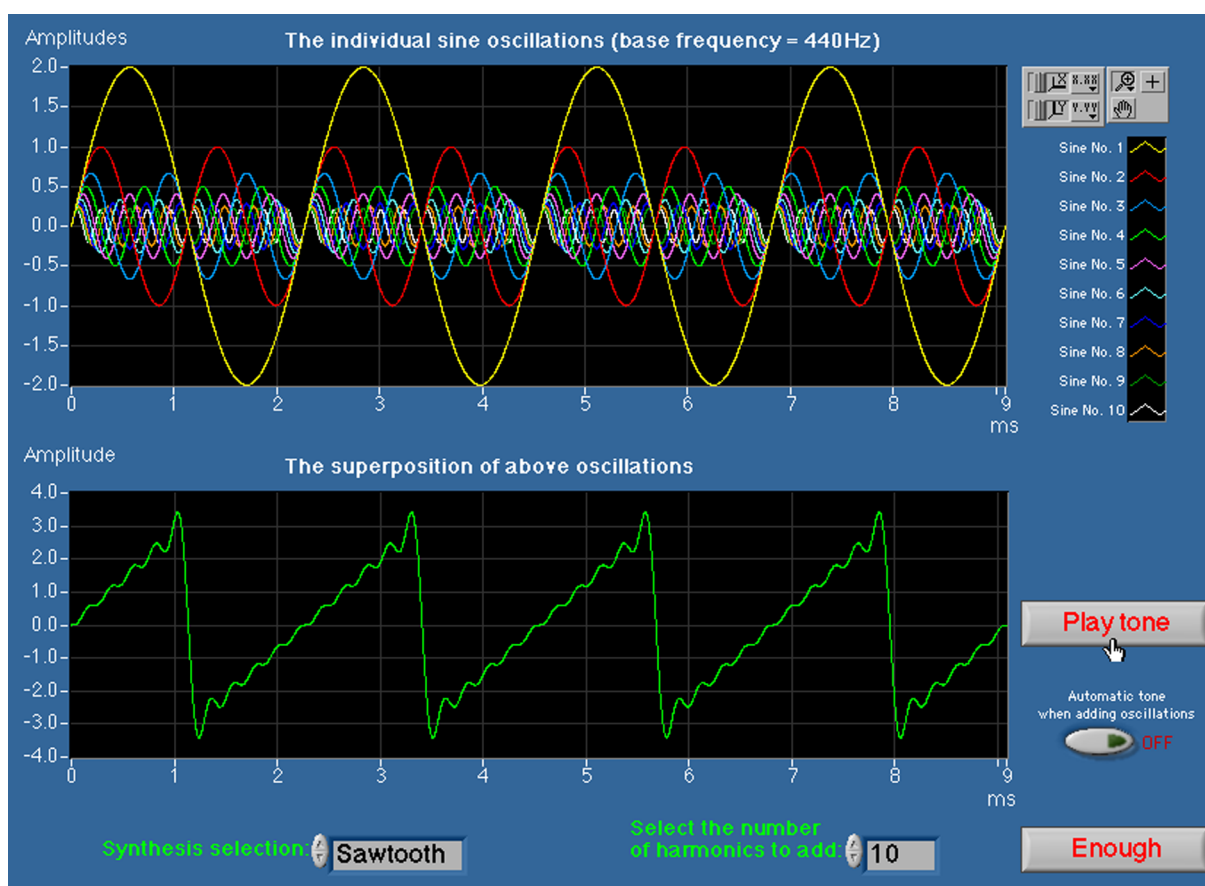


LabVIEW™ in Physics Education

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This “white paper” describes the experience to blend LabVIEW™-based data acquisition technologies with traditional apparatus for demonstration experiments and student labs in physics education. After explaining the advantages of using LabVIEW™ in physics education, a few selected examples, typical for the three main fields of application “Demonstration experiments”, “Student lab experiments” and “Simulation of physical phenomena”, will be discussed and illustrated. Finally, the conclusions will be listed.

Contents

Why LabVIEW in physics education?

Among other advantages, the three reasons listed below are the most important ones for applying LabVIEW:

- LabVIEW is a powerful, platform-independent, graphical programming development system which is ideally suited for data acquisition, storage, analysis, and presentation.
- LabVIEW is a programming environment which fulfills industry standards and is widely used for measurement and automation.
- LabVIEW helped us blend our existing educational hardware inventory with virtual instrumentation in an economical way and with reasonable funds.

Using LabVIEW in three domains of physics education

Demonstration experiments

In contemporary physics education, lecturing the basic concepts of physics is still a vital part of teaching. Because physics offers a fundamental understanding of the processes which govern nature, it is important to show real-world demonstration experiments as proofs that the main concepts, communicated verbally, are valid in the real world. In contrast to many other academic fields, in physics it is possible to reproducibly illustrate the precise and deterministic character of how nature behaves and structures the universe. Actual demonstration experiments are especially important in a world where it is increasingly difficult to distinguish the real from the virtual environment. We use LabVIEW as a helpful tool to enhance demonstration experiments in physics lectures for the following reasons:

- The quick implementation of measurements during demonstration experiments and the reduced need to build dedicated hardware.
- The easy modifications, the fast access and the practical storage on a PC disk make LabVIEW™ VIs intelligent and dedicated instruments for a strongly diversified inventory of demonstration equipment.

Student lab experiments

A very important part of physics education are student lab experiments, where students carry out their own experiments. The experience to make an experiment and

to observe, measure and acquire data is essential for a deep and thorough understanding of physical processes. Doing lab experiments, the students are learning experimental techniques and begin to understand the inherent limitations of precision in measuring relevant parameters. Different types of sensors are used to track and measure variables during a student lab experiment. We use LabVIEW in this domain for the following main reasons:

- The appropriate use of LabVIEW-based instrumentation to acquire signals gives the student more time for observation and investigation of physical processes.
- The possibility to modify and adapt, as well as the versatility of virtual instrumentation, saves time and funds, and allows to maintain a large number of dedicated to individual experiments.

Simulation of physics phenomena

The investigation of certain physical mechanisms by numerical modelling i.e., simulating nature by applying the laws of physics to virtual processes is becoming increasingly important. The method can lead to an understanding of the overall impact when specific parameters are selectively modified. If the parameters can be changed and adjusted interactively while their effect on a given system is visualized, a student may gain an understanding of the process by observing the effect of the changes. There is one great reason to use LabVIEW in this domain:

- LabVIEW™ allows us to produce interactive software for all major computer platforms (Windows, MacOS 9 and X, Linux and Sun UNIX).

Examples for using LabVIEW with demonstration experiments

Tracking of motions with a laser distance sensor

Newton's three principles are the basic pillars of mechanics: For demonstrating these principles we make use of a commercial laser distance sensor, made by Swiss manufacturer Erwin Sick, and shown in Fig. 1. The DME-3000 device is capable of measuring distances of up to 30 meter to an accuracy of 1mm without mechanically touching the tracked object.



Figure 1: DME-3000 laser distance sensor.

By aiming an emitted laser beam at a given target, the DME-3000 samples the distance with a phase correlation technique at a sampling rate of 100 readings per

second and transmits the numerical values as ASCII characters through an RS-422 interface to a receiver which in our case is a B&W Yosemite Macintosh G3 running LabVIEW 6.1. Connecting the DME-3000 by appropriately routing the wires to a Mini-DIN connector, we are able to acquire the distance values while a dedicated software either displays the values in realtime on LabVIEW front panel charts or allows for post-acquisition analysis of data.

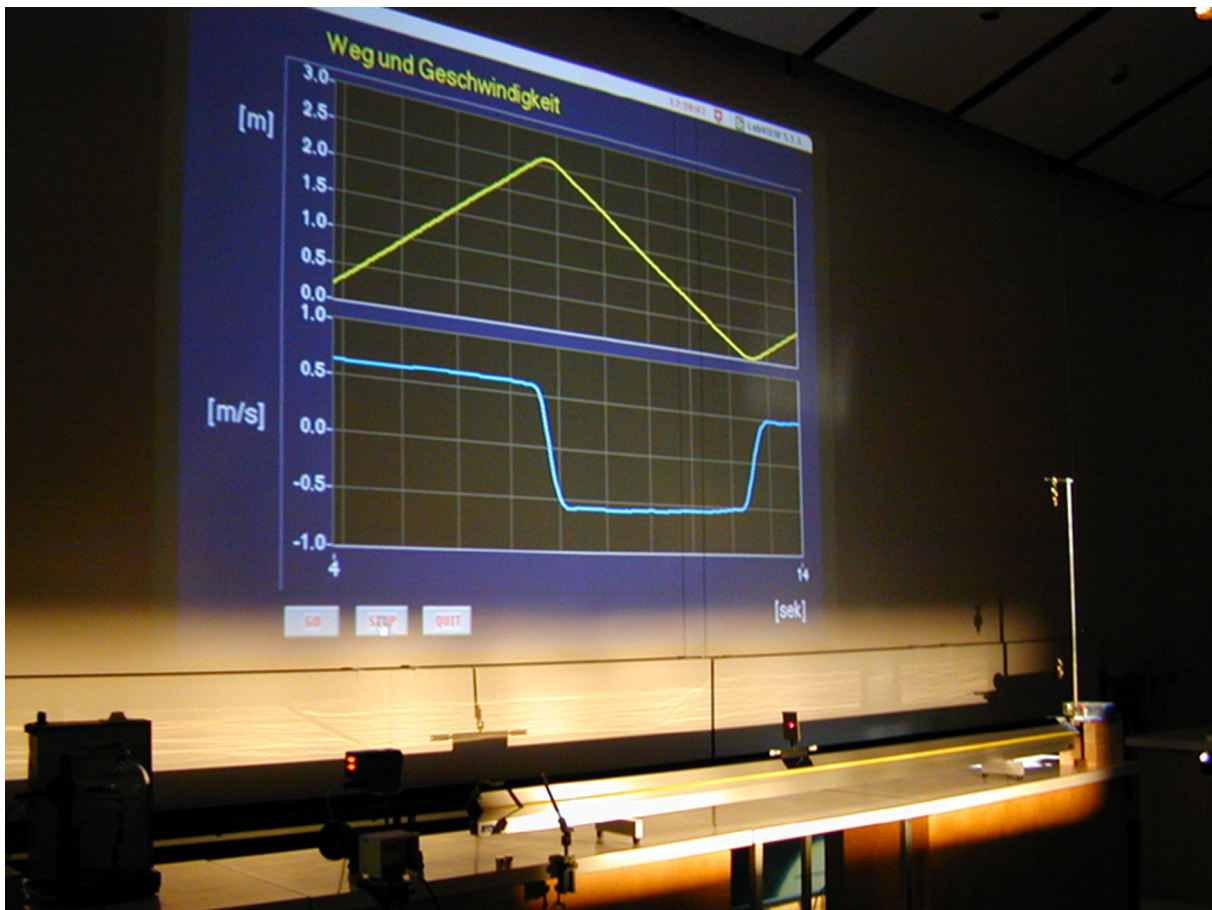


Figure 2: Demonstrating Newton's first principle with airtrack motion.

In order to demonstrate the fundamental properties of motion, thus primarily Newton's first principle, we track the displacement of a slider which moves practically frictionless along a 3 m airtrack. The LabVIEW display shows the displacement and a choice of derivatives which represent instantaneous speed or acceleration of the moving slider, as shown in Fig. 2. The sensor transmits the distance values through the serial link to the Mac, where they are continuously received and read by the LabVIEW program. The program displays the actual values on the computer display as well as on the large built-in data projector of the auditorium. The program allows for several display modes and it calculates online the 1st and 2nd time derivatives of the displacement data, representing the velocity and the acceleration, respectively. A typical LabVIEW front panel view for a simple forward-backward bouncing of the slider is shown in Fig. 3.

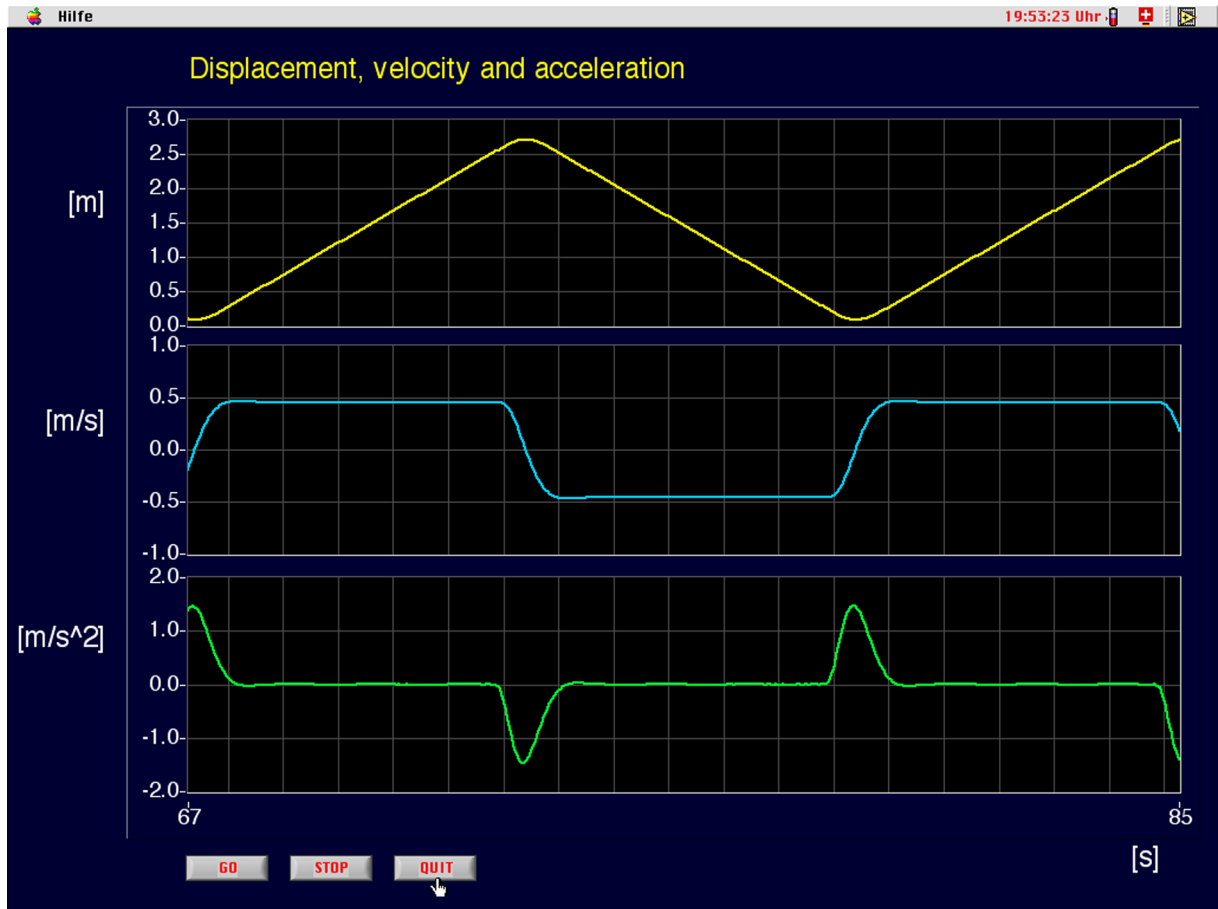


Figure 3: LabVIEW front panel display of a bouncing airtrack slider.

Motion tracking with image acquisition

Another way of motion tracking is achieved with image acquisition capabilities. This technique allows us to study the motion of objects in 2 dimensions. The most direct and simple way of transferring images into LabVIEW is to connect a common consumer product digital video camera to a Macintosh by its built-in Firewire IEEE1392 link. Then one can use the freeware tools of longtime expert of “LabVIEW on the Macintosh”, Christophe Salzmann of the Swiss Federal Institute of Technology in Lausanne to transfer the images into LabVIEW. QuickTime-based video camera drivers for the Macintosh platform can be found at <http://labview.epfl.ch/qt/QTVIs.html>. Fig. 4 shows the hardware setup.

Another, more sophisticated method of online processing of incoming video images is to use dedicated frame grabber hardware and appropriate software. An industrial monochrome frame grabber PCI-1408 from National instruments was used along with the IMAQVision software to program the image acquisition and the extraction of the moving balls. We placed a video surveillance camera on top of a small-size billiard table in order to study the collision parameters of the balls by measuring the deflection angle after an impact. IMAQVision software is programmed to distinguish the moving ball from the background and trace the position online in a separate display window. After each collision it is possible to read out the angle between the

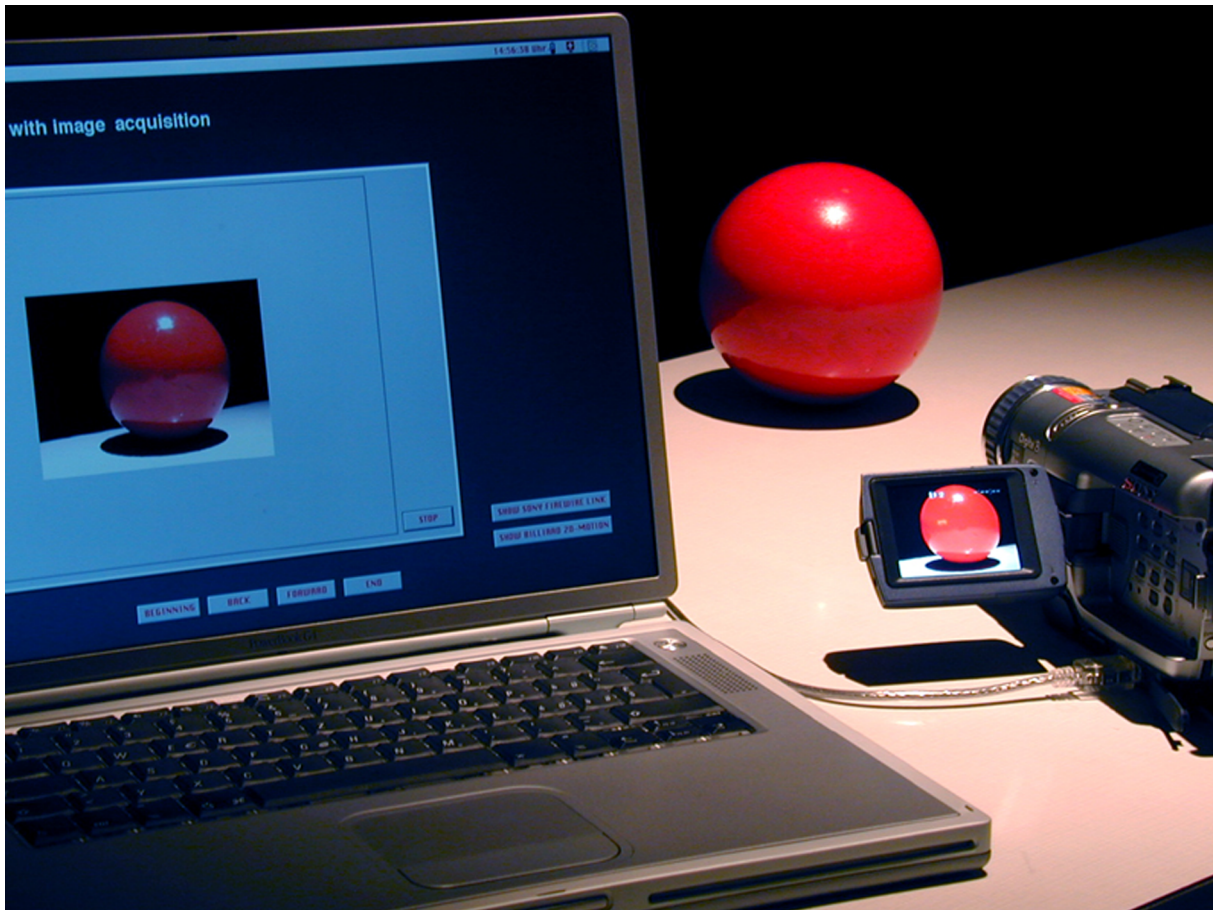


Figure 4: Use Chris Salzmann's QuickTime VIs to fetch images with Firewire into LabVIEW.

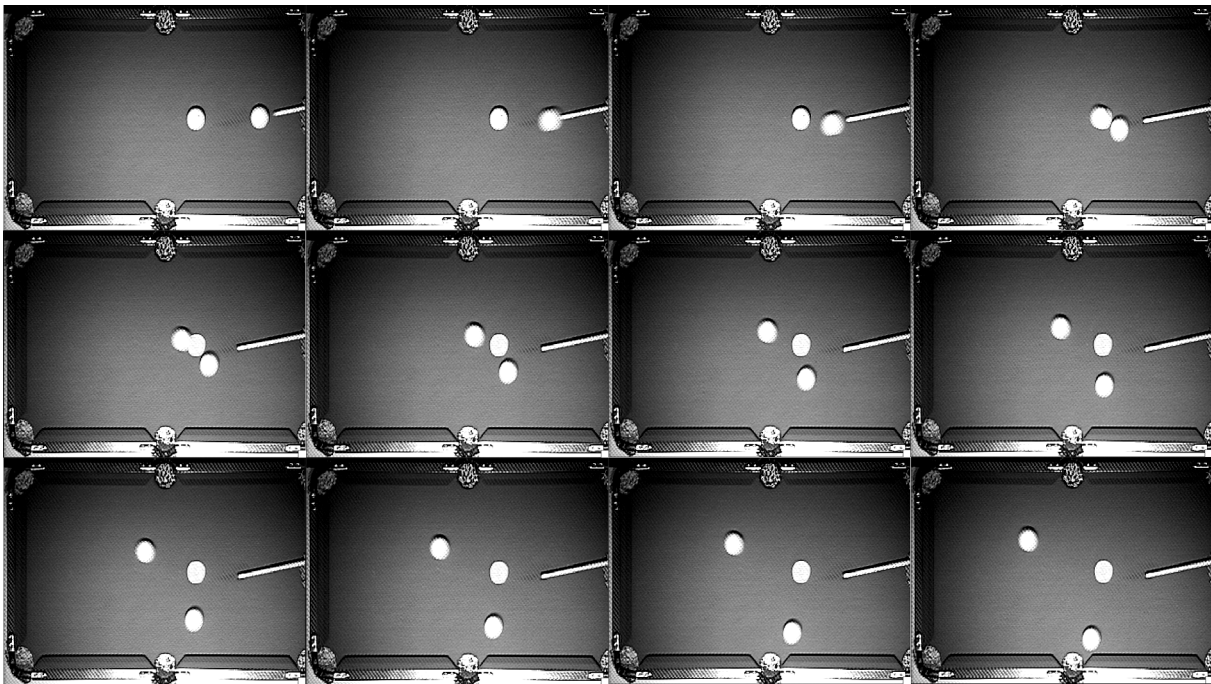


Figure 5: A typical video sequence of a collision between two billiard balls. Time proceeds from upper left to lower right. The position of the ball initially at rest is marked by a white circle on the table.

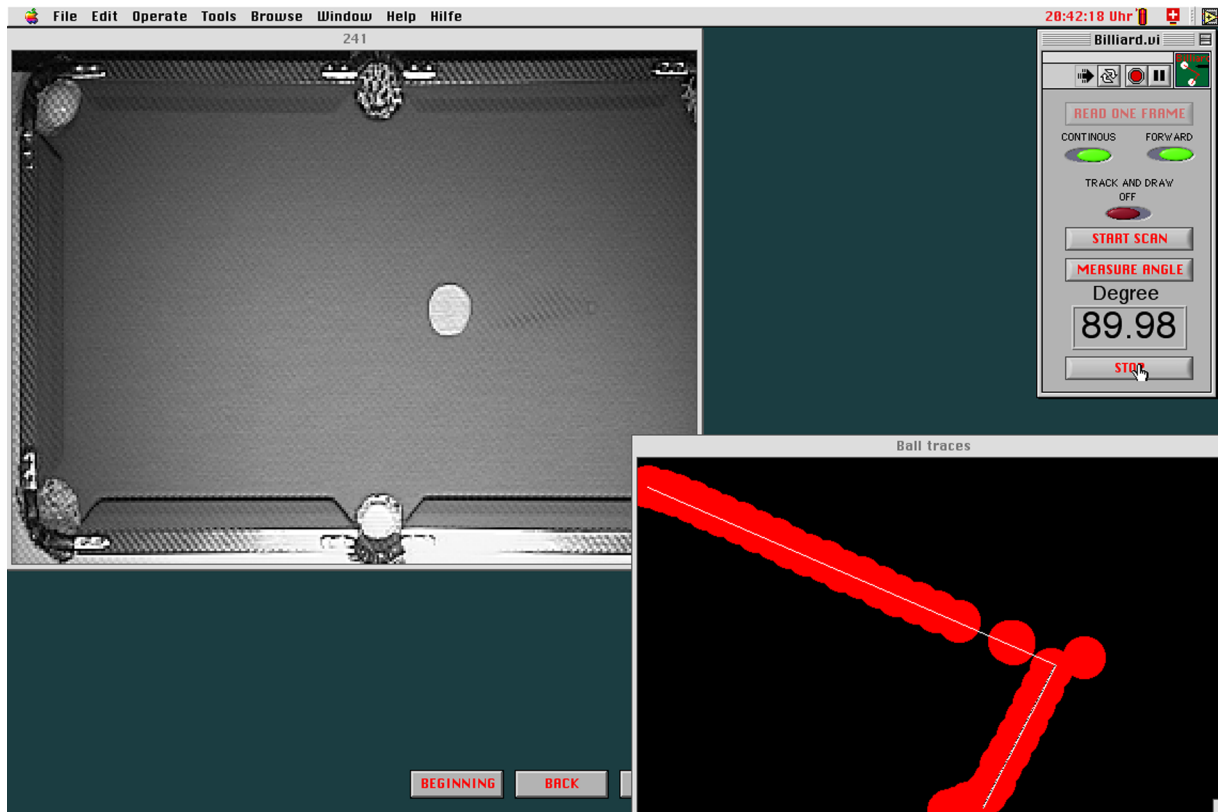


Figure 6: Measuring the angle after tracing the collision paths.

two paths of the billiard balls before and after the collision. Fig. 5 illustrates a sequence of video images for a typical collision. The acquired path information and angle readout are shown in Fig. 6.

Demonstration and analysis of heat conduction

Heat conduction is a fundamental process in nature and illustrates the physics of all diffusive processes. To illustrate the distribution of temperature in one dimension, 16 small holes were drilled at equal distances into a 5-mm-diameter solid copper rod. Special care was taken to stop drilling 2 mm before drilling completely through the rod. 16 high-temperature PT-100 resistors with heat-protected leads were placed in each hole and sealed with a heat-conductive paste. The ends of the leads were attached to a specially constructed stand which holds the thermally isolated copper rod and the leads to the PT-100 resistors. 4 to 20 mA transducers excite the PT-100 thermal resistors and modulate a voltage which is proportional to the actual temperature at each location on the rod. All 16 voltages are picked up by the computer for data acquisition and display. The experimental setup is shown in Fig. 7.

To perform the experiment, a Bunsen burner is lit at one distinct spot underneath the copper rod and the process of heat conduction is observed. Temperatures will quickly rise and as soon as the PT-100 sensor above the flame reaches a value of 200 °C, the flame is extinguished. Fig. 8 shows the LabVIEW display just before the flame is extinguished. Afterwards, the system will behave according to the law of heat conduction (one dimension, no sources). Four stages of the heat flow in the

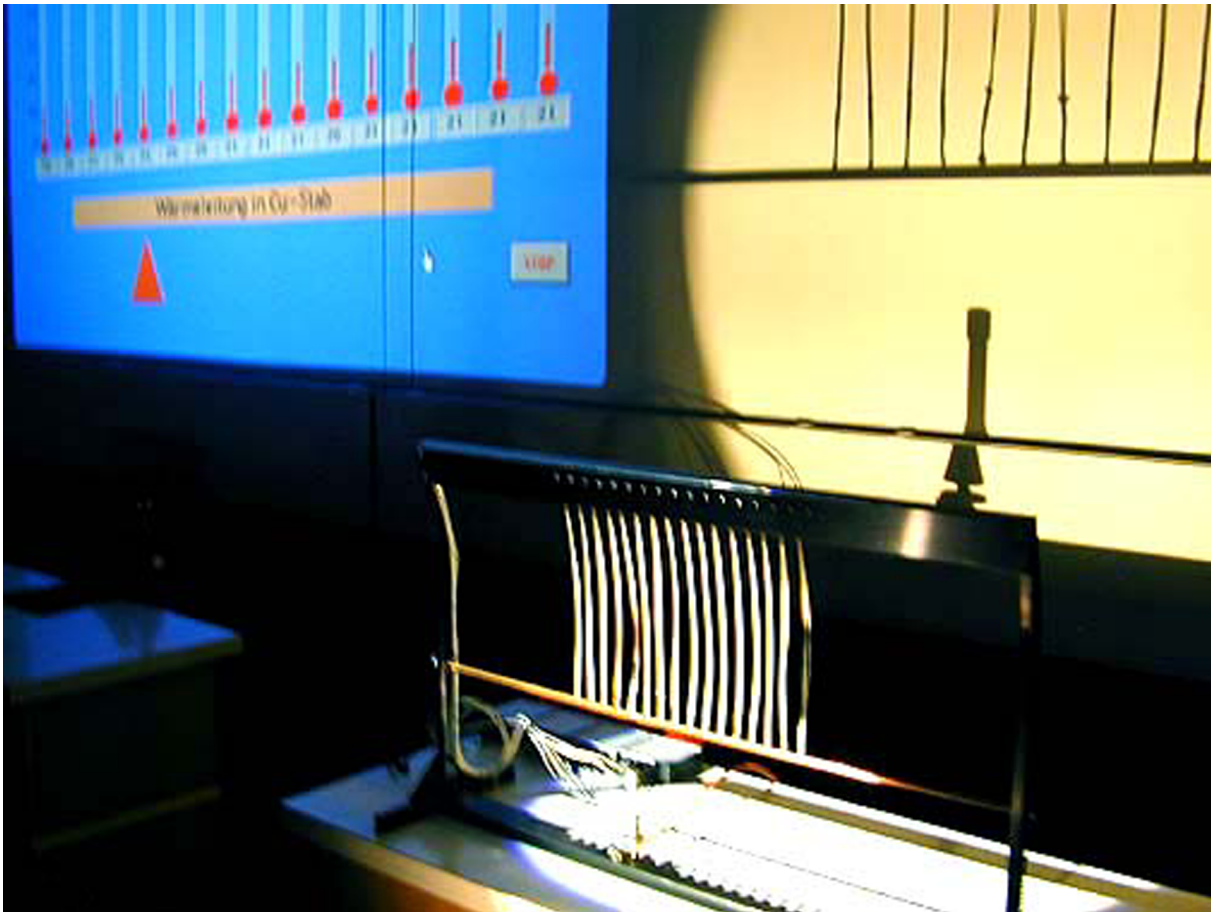


Figure 7: Copper rod suspension and temperature measurement.

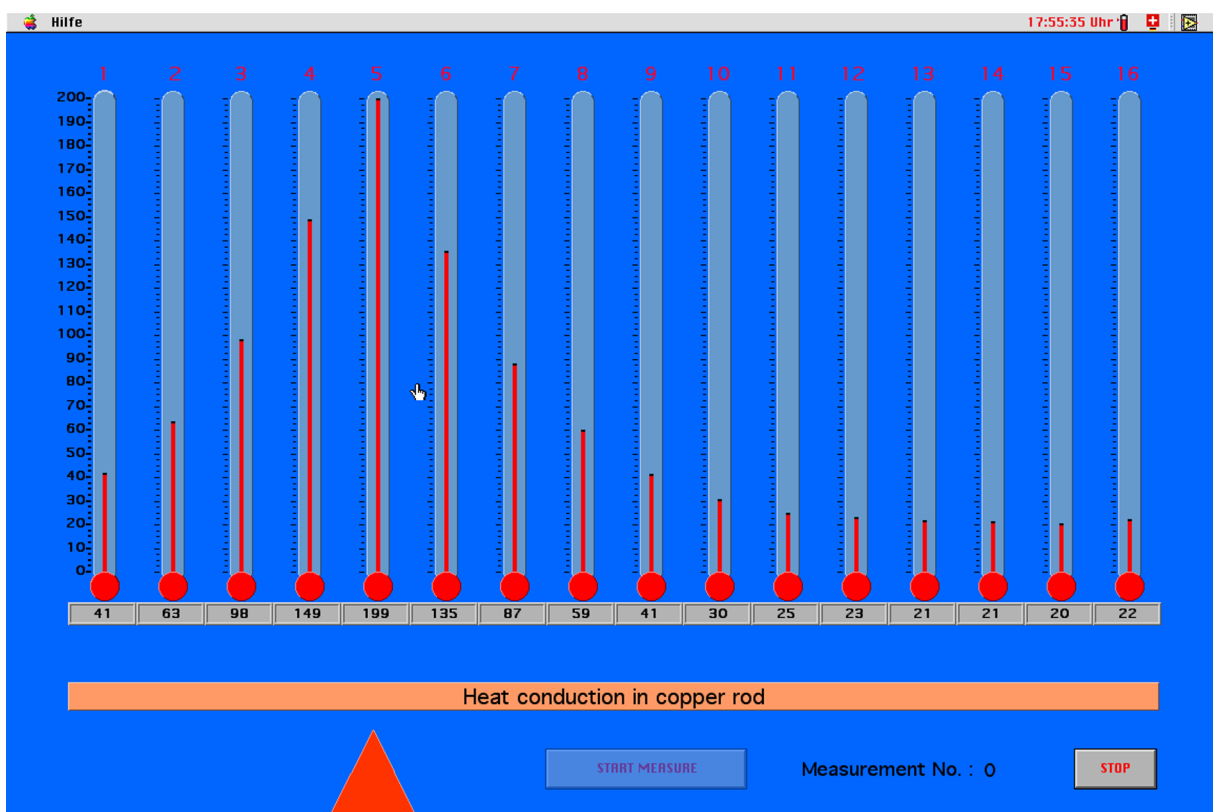


Figure 8: The temperature profile in the rod before the flame is extinguished. The heat source is marked by the orange triangle.

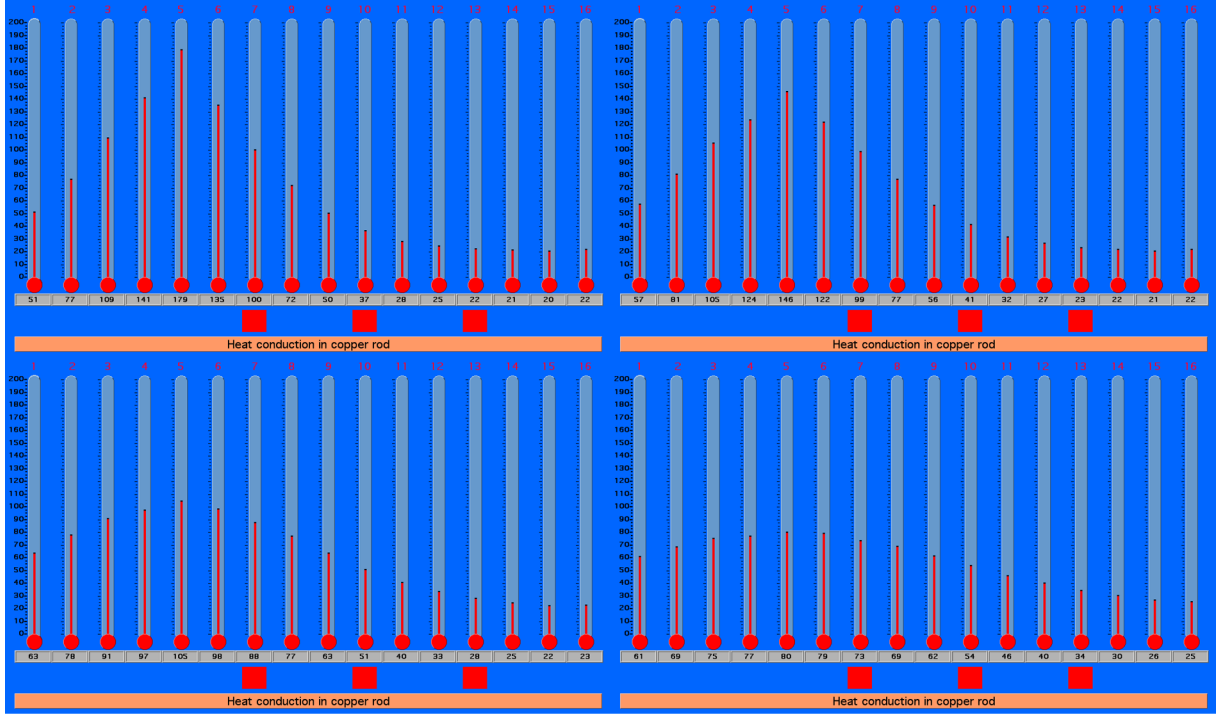


Figure 9: Four stages of the heat distribution after the flame is extinguished. The location of the PT-100 resistors whose values are used in the calculations are marked by a red square.

rod are illustrated in Fig. 9. It is very instructive to observe the time evolution of temperatures along the copper rod. The gradual broadening of the distribution is precisely visible, with the hot regions cooling while the temperatures farther away are still rising. The curvature and the evolution of its shape provide a visual understanding of the partial differential equation which describes heat conduction, and diffusion in general. During the demonstration, the program accumulates a series of temperature measurements from a selection of three equally spaced thermosensors every five seconds. Three red squares (Fig. 9) flash briefly to indicate where and when these temperatures are recorded. After collecting 10 sets of 3 temperature readings, the values are used to calculate the differentials, numerically approximating the differential equation:

$$j = -\lambda \frac{\partial T}{\partial x} \quad \text{and} \quad \frac{\partial T}{\partial t} = -\frac{1}{c\rho} \frac{\partial j}{\partial x} \quad (1)$$

or, combined

$$\frac{\partial T}{\partial t} = \frac{\lambda}{c\rho} \frac{\partial^2 T}{\partial x^2} \quad (2)$$

$$D_T \doteq \frac{\lambda}{c\rho} \quad \text{is called thermal diffusivity} \quad (3)$$

The top frame of Fig. 10 shows the first five triplets of the temperature readings. The frame underneath lists the calculated values for the first and second spatial derivative according to the formulae in the leftmost column. The last frame displays the values of two neighboring columns of the previous frame, thus representing the values of the second spatial derivative at the time points between the readings. The second

Measured temperatures in °C:					
	t= 5s	t= 10s	t= 15s	t= 20s	t= 25s
T1	97.8	99.8	96.7	92.9	89.1
T2	34.5	39.4	43.9	47.4	50.0
T3	21.9	22.8	24.0	25.5	27.1
Evaluation:					
	t= 5s	t= 10s	t= 15s	t= 20s	t= 25s
$(T2-T1)/\Delta x$	-843.9	-805.3	-703.7	-606.2	-521.9
$(T3-T2)/\Delta x$	-167.3	-220.8	-265.7	-292.9	-304.6
$(T3-2\cdot T2+T1)/(\Delta x)^2$	9021.5	7793.7	5840.8	4177.6	2896.7
Average					
$(T2(t+\Delta t) - T2)/\Delta t$	8407.6	6817.3	5009.2	3537.2	
	1.0	0.9	0.7	0.5	

Figure 10: Table of values and figures.

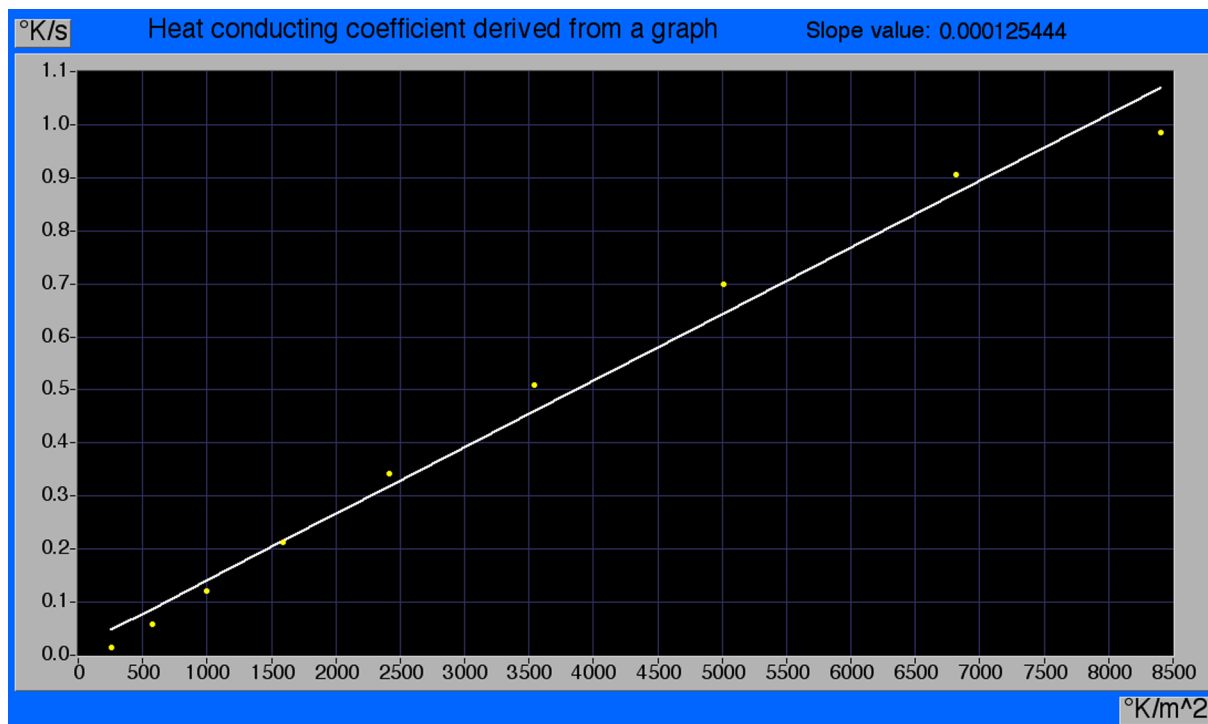


Figure 11: Graph and linear fit.

line in frame 3 of Fig. 10 gives the time derivative of the temperature. The ratios between the temporal derivatives and the second spatial derivatives at a specific location (the central sensor) and any specific time represent values for the thermal diffusivity D_T . Fig. 11 demonstrates that the ratio is approximately constant, and we find, by linear regression; a slope of $1.25 \cdot 10^{-4} \text{ m}^2/\text{s}$. According to (2) and (3) this is the thermal diffusivity of the rod, which compares well with that of copper ($1.14 \cdot 10^{-4} \text{ m}^2/\text{s}$).

Visible Acoustic Signals

The standard audio ports of a Mac or a PC equipped with a supplementary sound card can be used to acquire sound signals and to view them both in the time and in the frequency domain. More detailed analysis of the acquired sound signals with user-defined sampling rates can be done with an appropriate DAQ-board. The capability of LabVIEW to sample a signal continuously in time while numerically calculating the Fast Fourier Transform (FFT) permits online graphing in time of frequency spectra as a sonogram. To observe the evolution of a frequency content of an acoustic signal is probably the most comprehensive way to gain a fundamental understanding of analytically transforming signals into the other domain. Just looking at a signal changing in time is one thing, but if one is able to both listen to the signal in the time domain and observe the same signal in the frequency domain is very instructive. Additionally, the impossibility to increase both the resolution in frequency and in time can be demonstrated by performing sound analysis and by observing how the change of certain parameters affects the results.

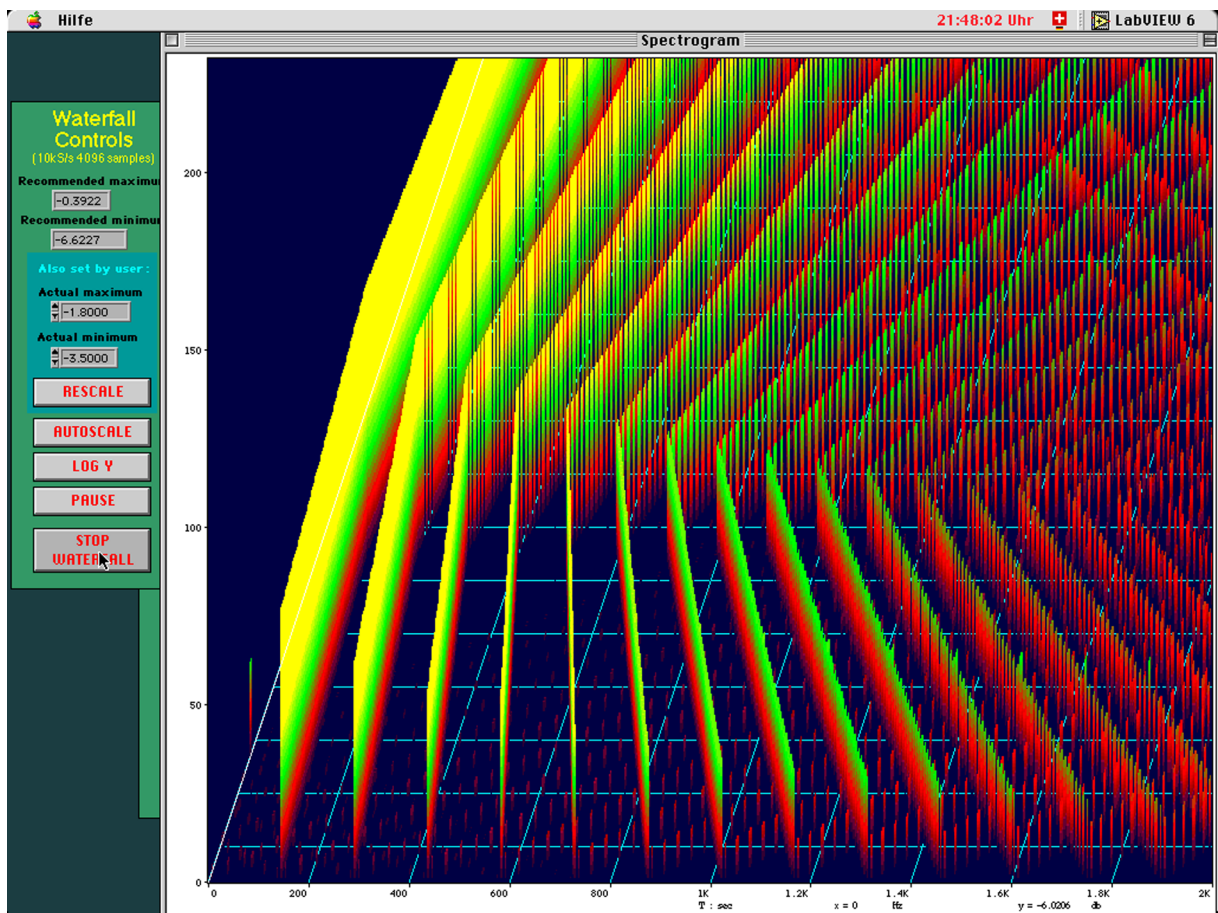


Figure 12: A sawtooth oscillation modulated with a triangular function in a sonogram.

To illustrate some of the aspects mentioned above, we project the computer display showing a real-time sonogram in a LabVIEW intensity chart. After some time of visual observation we then play the sound which generates the sonogram. We also produce synthesized signals which are periodic in time and simultaneously watch the

results in the frequency domain. An example of a triangular oscillation modulated with a sawtooth function is shown in Fig. 12.



Figure 13: The Euler Disk in its spinning state.

In another example we record the acoustic signal from the famous spinning Euler Disk at a moderate sampling rate. Fig. 13 shows the disk in action. The Euler Disk's spinning process bundles various aspects of rotational mechanics in a complex way, yet by recording the sound of the spinning disk and later transforming this signal in the frequency domain we are able to gain a better understanding of the energy and forces which make the disk mechanically spin for such a long time. The Euler's Disk is one of the few examples in mechanics where infinity is reached in finite time. One can show that the spinning frequency accelerates to infinity (H. K. Moffatt, *Nature* 404, 833 - 834 (20 Apr 2000)).

After we have manually started the disk, giving it a sideward kick when releasing it from its side position, we start acquiring the acoustic signal with a microphone. The entire spinning phase is recorded, giving us one single continuous signal which we store in a file. After the acquisition we can read the signal from the file, investigating its frequency behavior in time. The transformation is done by user-selected JTFA (Joint Time Frequency Analysis) algorithms by applying user defined parameters like sampling rate, window lengths and number of frequency bins. The goal is to derive a spectrogram with an optimal resolution in time and frequency. An example of a typical measurement the analytical result of a complete spinning event is shown in Fig. 14.

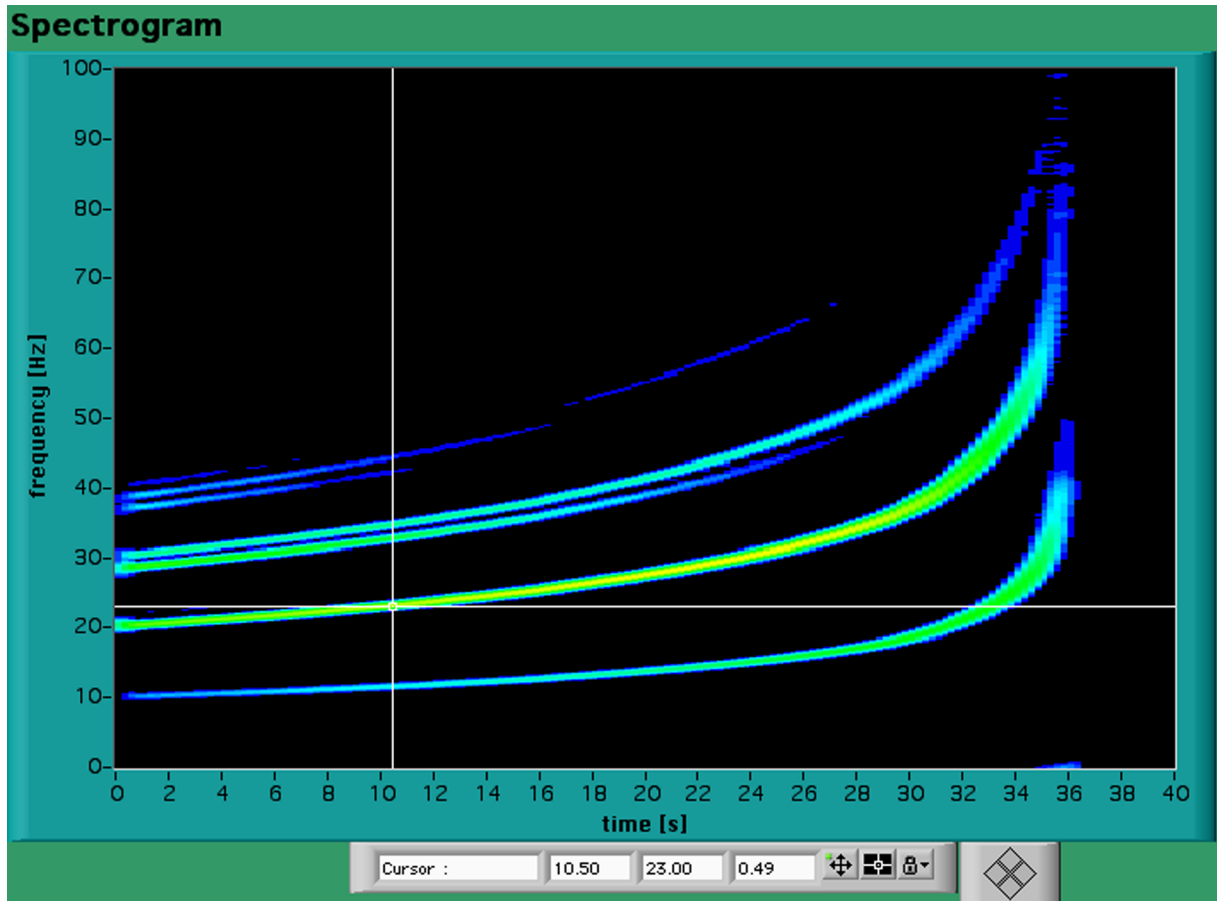


Figure 14: A typical spectrogram of a single Euler Disk spinning event showing the frequency acceleration to infinity in finite time.

Illustration of the mechanism of electrical conduction

The transport of electrons in a given material is approximately described by Ohm's law. In a semiconductor at a higher temperature, more free electrons are released and conductivity is increased. On the other hand, atoms vibrate more strongly and electrons are moving less freely, an effect which reduces conductivity. Conductivity is strongly affected by thermal effects in a given material. To clearly demonstrate the two extreme cases of charge transport in a conductor and the case of an approximately Ohmic conductor we trace the current versus volt characteristics for three different types of conductor materials. A resistor which is conditioned to show approximately linear characteristics in a specified voltage range, a carbon filament bulb and a metal filament bulb, both starting to glow when voltage is raised. The three types of resistors are shown in Fig. 15. The characteristics are displayed on a large projection screen right above the experiment enabling the students to clearly link the visible state of heating with the instantaneous tracing. The result of going through the three types of resistor characteristics can be compared easily and permits a concise explanation of the processes responsible for the two different conduction effects. From the chart it is clearly seen that the linear Ohm characteristics is just a special case. The LabVIEW output of this demonstration experiment is illustrated in Fig. 16.

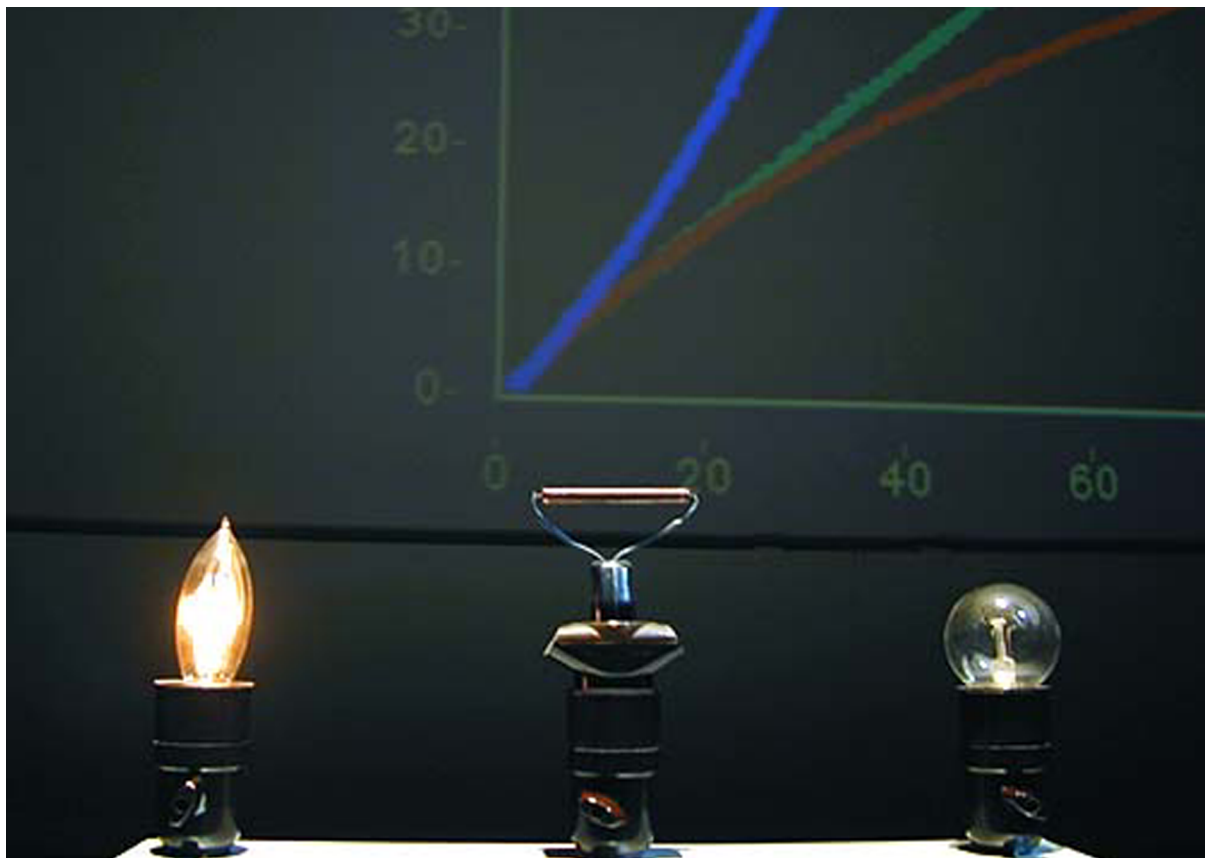


Figure 15: Three resistors: a carbon filament (left), an Ohmic resistor and a metal filament (right).

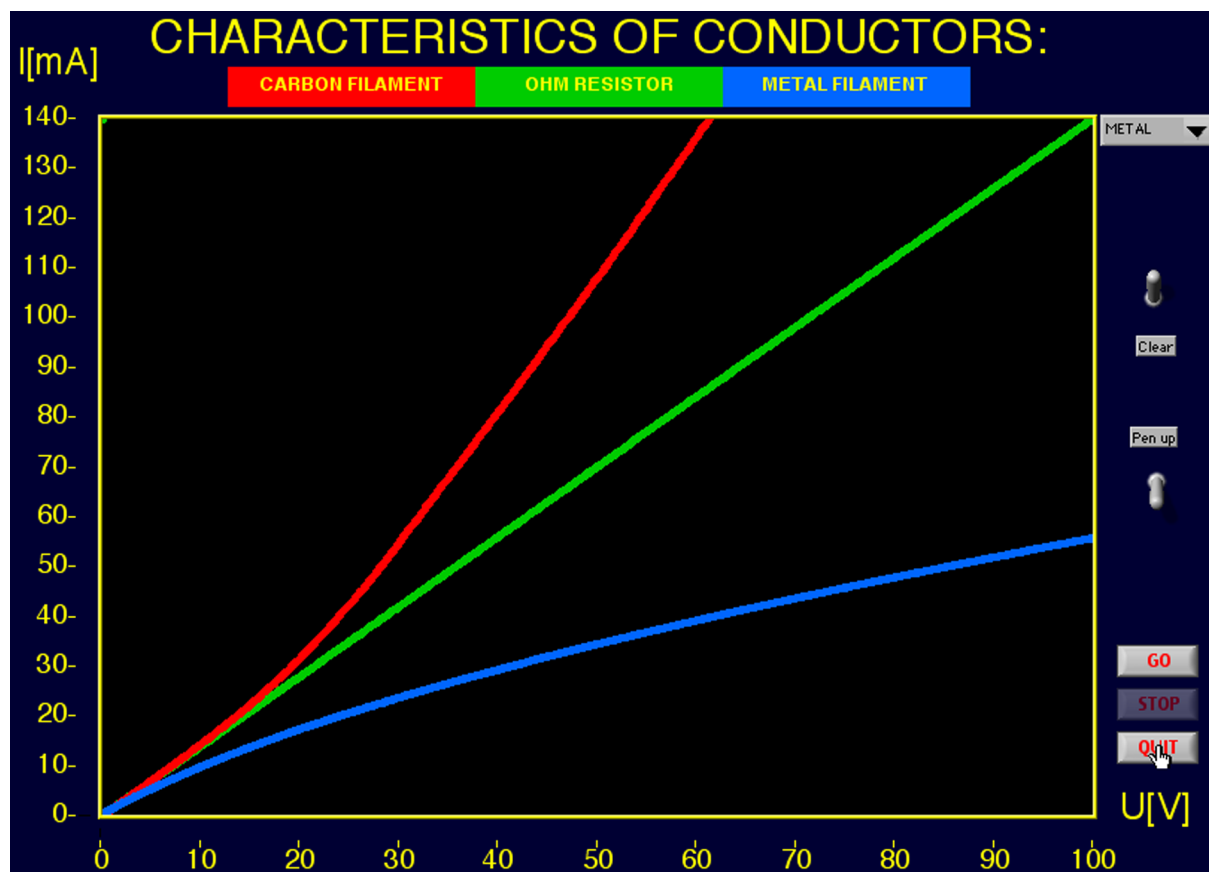


Figure 16: The three resistor characteristics after the online measurement.

Acquiring a Compton spectrum

One of the most important experiments that led to the understanding that electromagnetic waves also have particle properties, is the famous Compton scattering experiment. The experiment was first made in 1923 and strongly supported Einstein's hypothesis of quantum electromagnetic wave packets with the energy E_{ph} , the product of Planck's constant h and the frequency f . With Einstein's formula of the equivalence principle it is possible to assign to the photon a mass and thus a momentum. In Compton's experiment photons are scattered by electrons as if they had a mass. From this effect the characteristic Compton wavelength is derived.

To demonstrate this effect and to explain the concept of a multichannel analyzer we have built an arrangement of a ^{22}Na radioactive source and two diametrically positioned NaI scintillation counters. The counters are able to detect individual photons, indicating their energy. The photons interact with the NaI material to create weak flashes of light with an intensity proportional to the photon energy. The flashes are

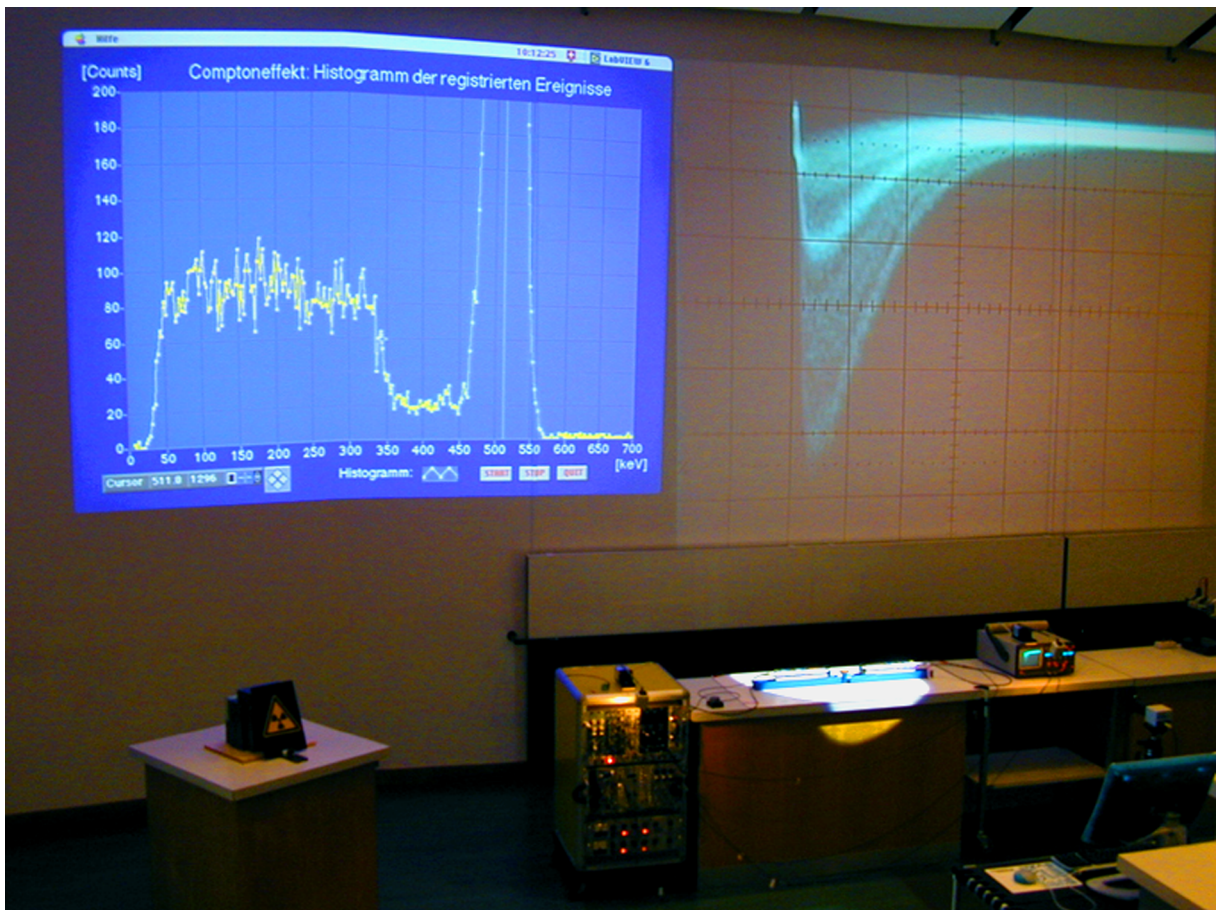


Figure 17: The Compton experiment: Two NaI counters and a ^{22}Na source between them.

detected and amplified by a photomultiplier tube and amplified. The ^{22}Na source emits positrons which annihilate with electrons of the surrounding material, each one creating two photons or gamma quanta which are emitted in exactly opposite directions. With the help of an electronic coincidence unit we select only those pho-

tons resulting from a positron-electron annihilation. The energy distribution of the pulses of one of the counters represents the characteristic Compton spectrum. To analyze the pulse heights we trigger the analog input channel of the DAQ-board with the coincidence pulses, via a delay circuit set with a delay to achieve one single data conversion at the top of each energy peak. For each new incoming pulse height value LabVIEW scales the amplifier voltage to energy in keV and updates an energy distribution histogram to show the spectrum as it develops and builds itself up. The experimental arrangement and the way the measurements are presented are shown in Fig. 17. Fig. 18 shows the LabVIEW multichannel analyzer output with the cursor set at the Compton edge.

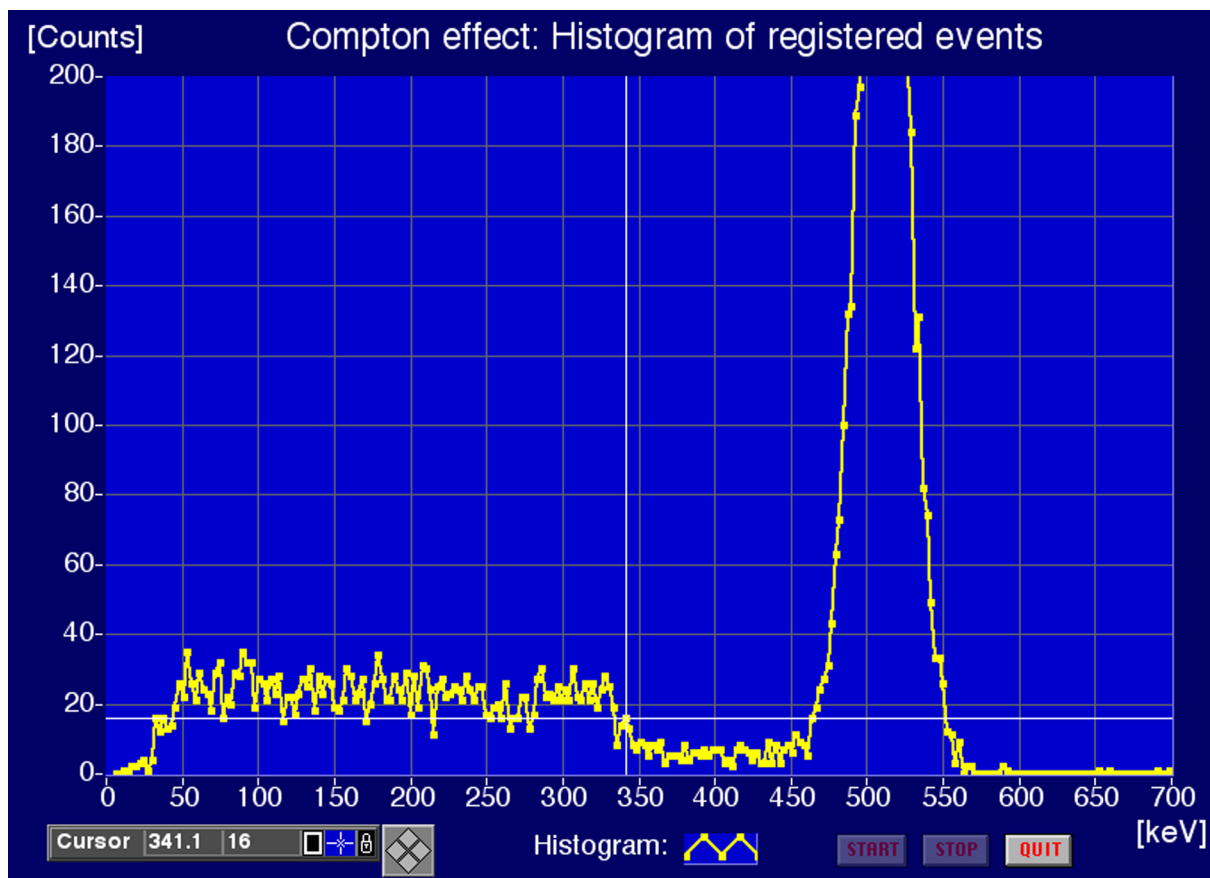


Figure 18: LabVIEW multichannel analyzer front panel display showing the energy distribution.

Examples for using LabVIEW with student lab experiments

Introduction to LabVIEW concepts by measuring the student's heart beat

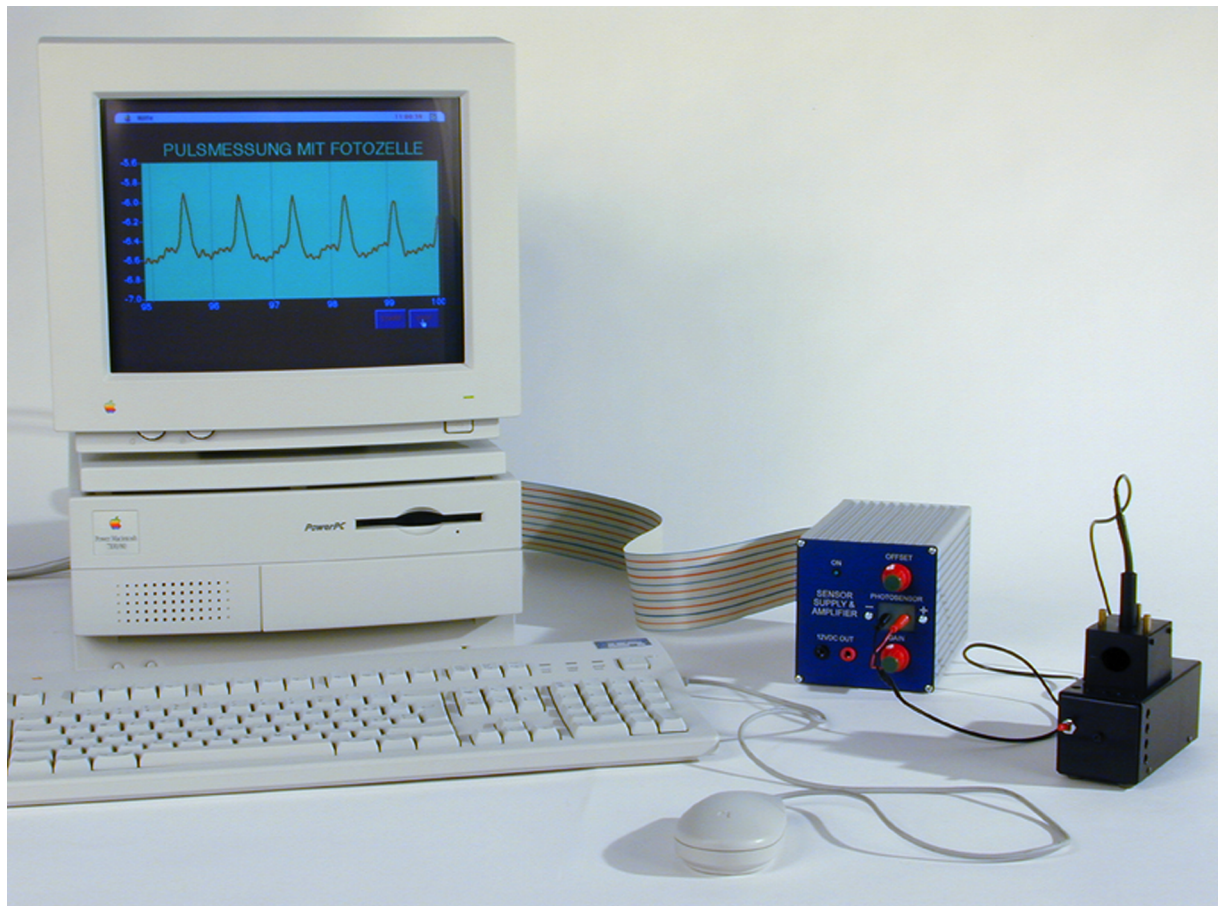


Figure 19: Student lab to get introduced to data acquisition with LabVIEW.

This student lab is targeted to give the students an idea of the power of LabVIEW by introducing the most basic way of performing a LabVIEW data acquisition of a given signal. The goal of the lab is to let the student program an appropriate DAQ vi to measure his own heart beat. For making this possible, a sensor device was specially designed. The student inserts a finger through an opening into the device. A strong light bulb which is cooled with a small ventilator shines through the inserted finger.

heart beats increase the amount of blood within the finger tip periodically and the light absorption is increased accordingly. A phototransistor on the opposite side of the finger detects the intensity of the remaining light. Fig. 19 shows the experimental arrangement. The acquisition of the signal is performed on a Macintosh with Nu-Bus DAQ boards. The sensor is the black device on the right side of Fig. 19, the blue box is the amplifier for the phototransistor signal.

The heart beat signal is suitable to go through all basic variations of LabVIEW driven data acquisition, from the immediate non-buffered DAQ to a circularly buffered continuous DAQ. Knowing about the various DAQ strategies with their advantages and disadvantages is essential for programming larger and more complex data acquisition systems in a research laboratory during a more advanced stage of the student education. Motivated students are capable to program a nice and user-friendly front panel display, some may venture into displaying the pulse rate or a graphic display of the heart beat signal in the frequency domain.

Interactive Fraunhofer diffraction analysis

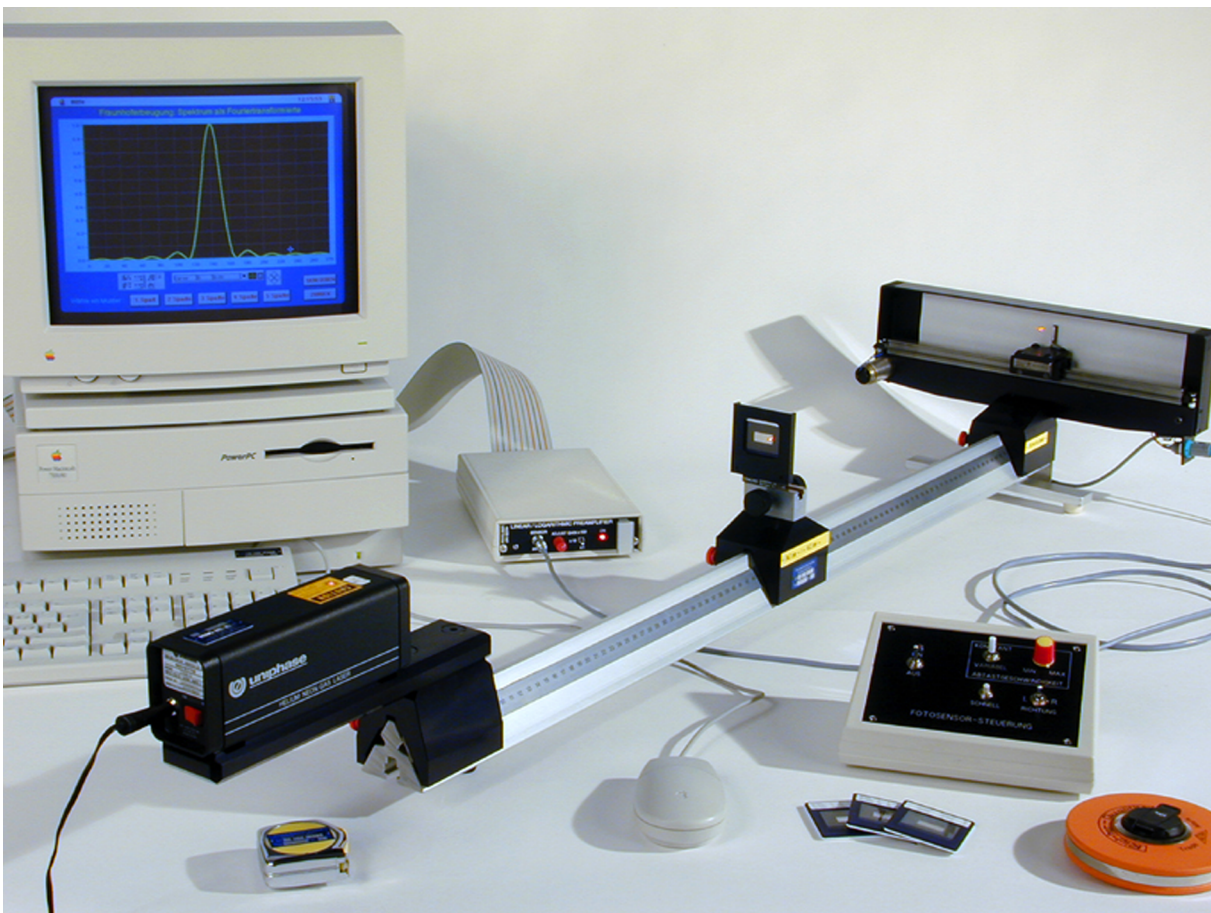


Figure 20: Student lab to learn about the wave properties of light.

This student lab experiment is for students to learn about the wave properties of light. Light from a red HeNe-laser is sent through diaphragms with various slit patterns, ranging from 1-slit patterns of different widths to multiple slit patterns.

The superposition of the electromagnetic waves after passing the slits, will generate a diffraction pattern of bright and dark areas behind the diaphragm. These patterns are analytically expressed by the Fraunhofer formula.

A sensor consisting of an array of photodiodes is moved by means of a tiny motor along a small rail to measure the intensity distribution for a selected number of slit patterns. The sensor is moved at a constant scan speed which is calibrated with a known slit geometry. The acquired and stored intensity distributions are scaled with the experimentally determined scan speed and compared with and tested against intensity distributions calculated with the Fraunhofer formula. The lab relies on a dedicated LabVIEW application which assists the student in performing the measurements as well as in solving the analytical problems. Fig. 20 shows the Fraunhofer diffraction experiment. The laser is seen mounted to the front end of the optical bench. Further along the bench the diaphragm holder can be seen, and at the end the screen on which the visible intensity patterns are seen. The light intensity is detected by the moving linear photodiode array which points towards the laser just in front of the screen. Some control electronics enable sensor movement adjustments, and a preamplifier conditions the sensor signal for input to the DAQ board of the computer. LabVIEW functions as a dedicated instrument for this particular student lab experiment. The application is distributed as an executable application, with the student acting as an operator of the user interface. The screen copy of an output of the program is shown in Fig. 21.

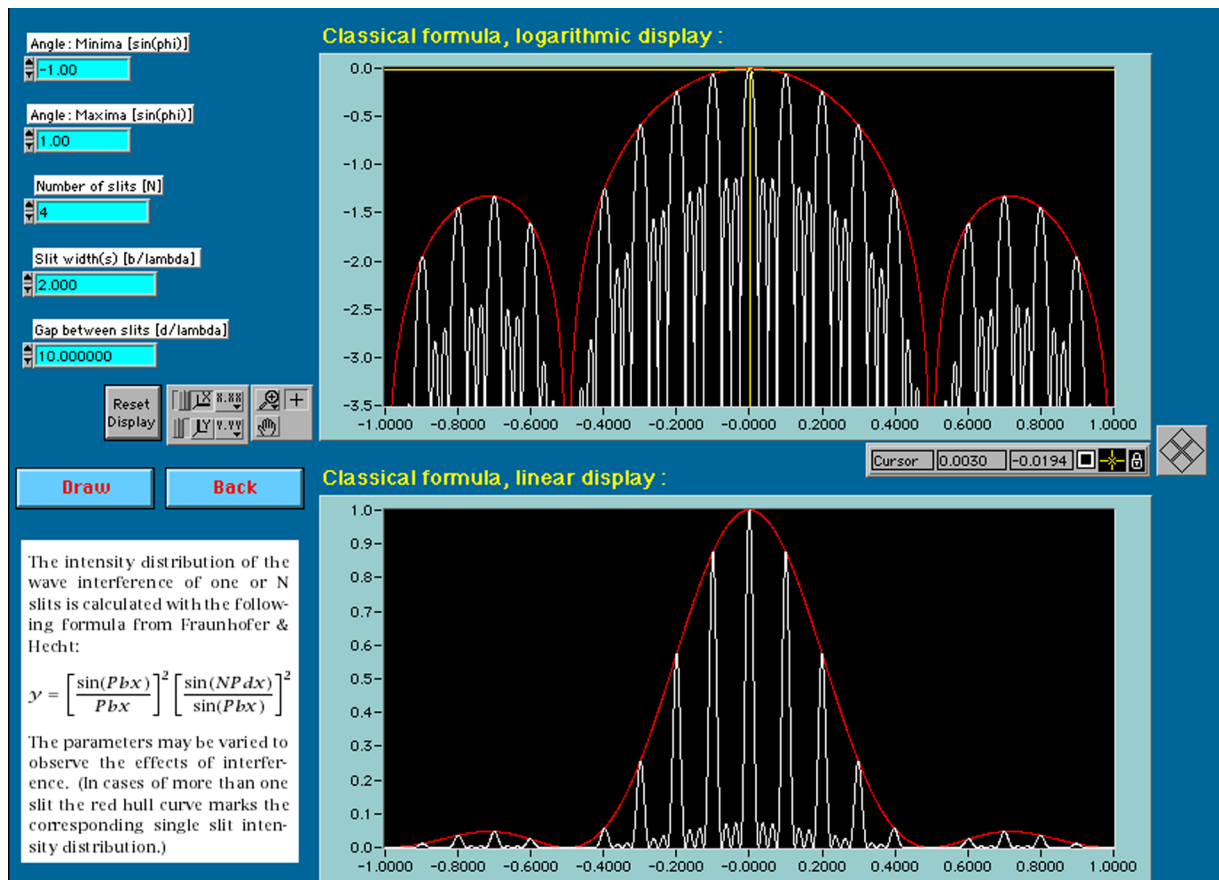


Figure 21: The measured intensity patterns are compared to a mathematical model as calculated by a LabVIEW program.

Interactive sound analysis

In this lab, the students will explore, acquire, analyze and observe the sounds produced by appropriate excitations of a large symphonic gong. The goal is to get students acquainted with various ways of sound measurement and digital sampling methods. The experiment and the needed equipment is illustrated in Fig. 22.

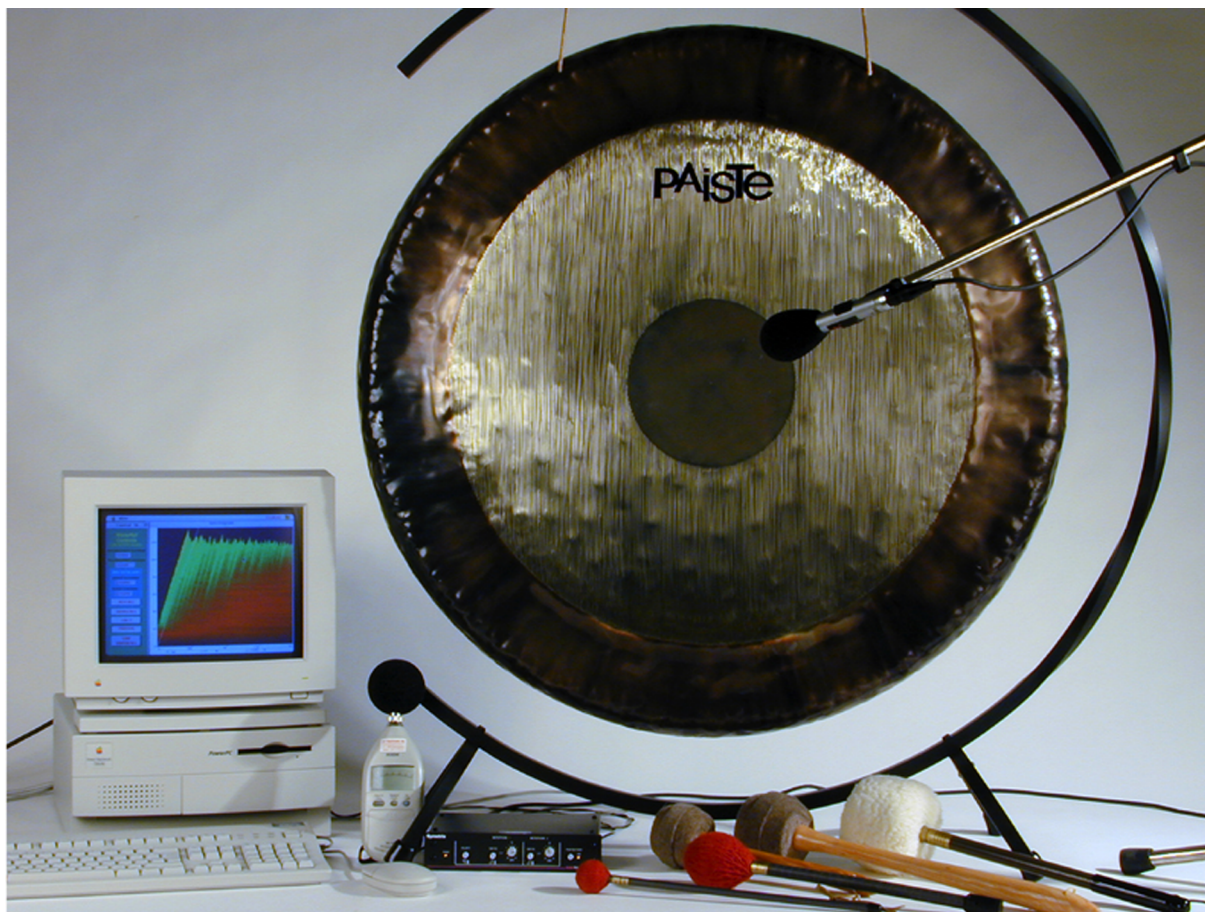


Figure 22: The acoustics lab investigates the sound of a symphonic gong.

Again, a dedicated LabVIEW software application guides the students through the different stages of the lab. Because the actual sound signals are picked up by a microphone, the students will first calibrate the microphone voltage signal against a sound pressure instrument. After calibration of the microphone the program enables the student to explore the sounds of the gong after conversion into the frequency domain. For the amplitude the choice is from volts, sound pressure, sound pressure in decibels, even the display of a physiologically weighted frequency spectrum is possible by calculating the physiological filter function according to the actual measured dB level. The first part of the program allows, in fact, an observation of the sound in the frequency domain helping to find a specially suitable way of gong excitation for further analysis. Fig. 23 shows a momentary frequency spectrum of a gong sound.

A second part of the LabVIEW acoustic application allows to record various sounds on a disk. The sound can be sampled at a chosen rate for the entire duration of the sound. A number of interesting signals can be saved to disk in a compact binary

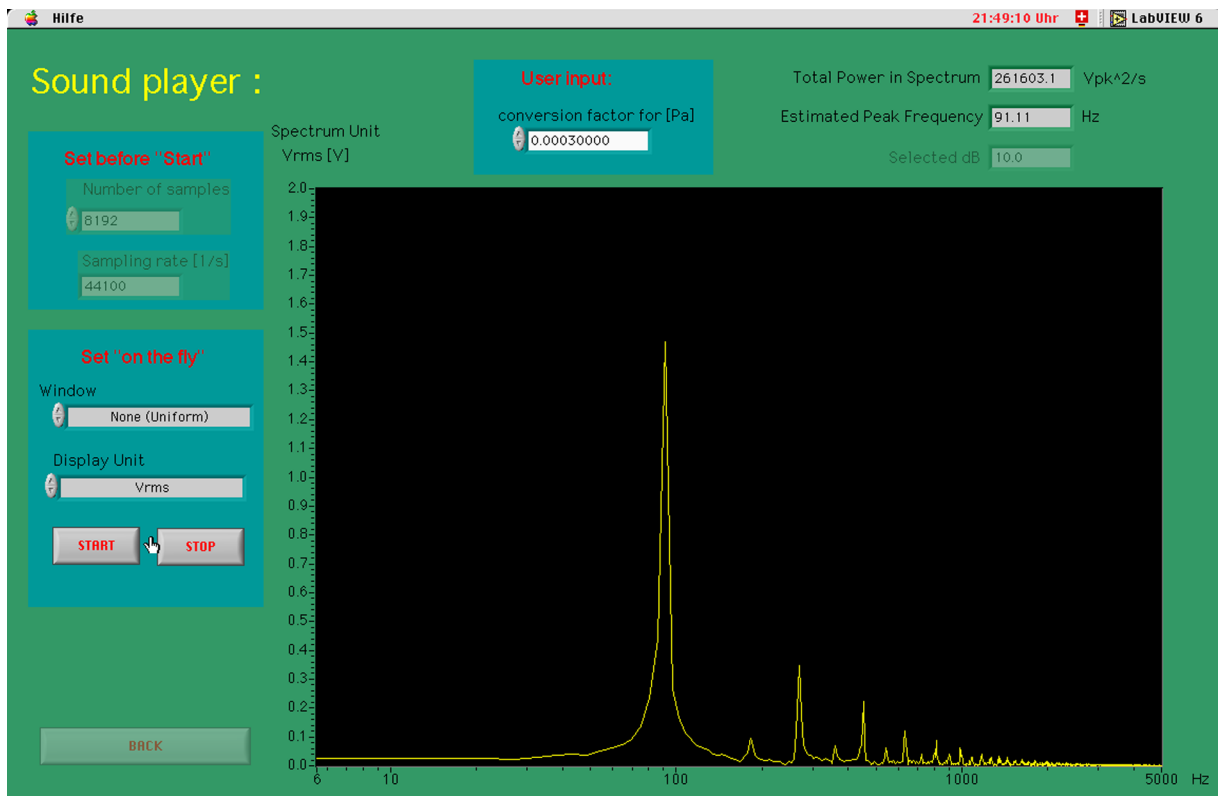


Figure 23: A instantaneous frequency spectrum of a gong sound.

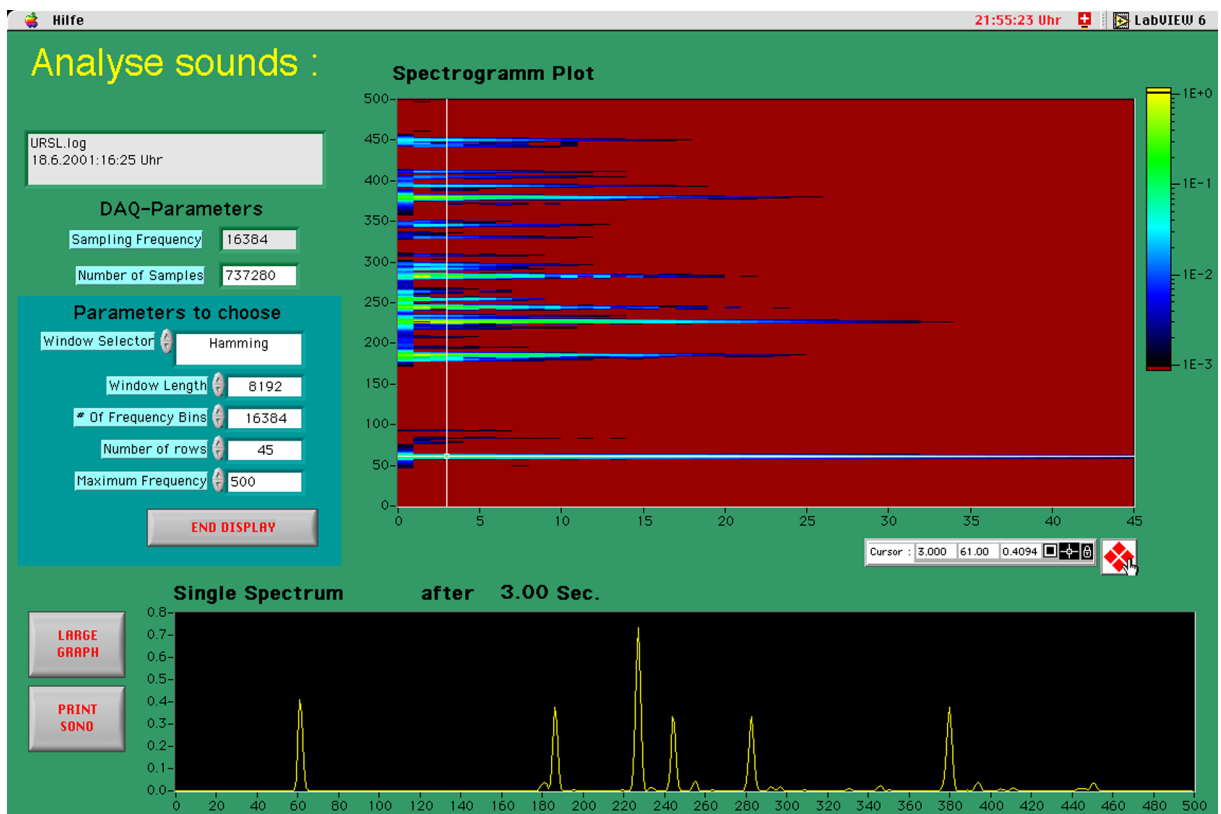


Figure 24: The sonogram output after calculating a JTFA analysis.

format.

The third part offers the possibility for a more detailed investigation of the frequency behavior over time of the acoustical signal. The experimenter has to select suitable parameters to optimize the analysis for the best possible time and frequency resolutions, while keeping the calculation load of the computer below a reasonable limit. JTFA (Joint Time Frequency Analysis) algorithms are used to transform the signal from the time domain into a 2D-spectrogram which shows how the frequency components vary in time. This kind of output is shown in Fig. 24

Simulations of physical phenomena

Even if simulations and computer models never replace or even come close to actual real-world experiments, there are several situations where a model makes sense. Four such cases are:

- Compare calculations using idealized conditions and approximations with experimental data
- Simulate hazardous demonstrations
- Simulate statistical processes
- Visualize fast processes
- Enable personal interactivity for students

Hazardous demonstration: Radioactive decay

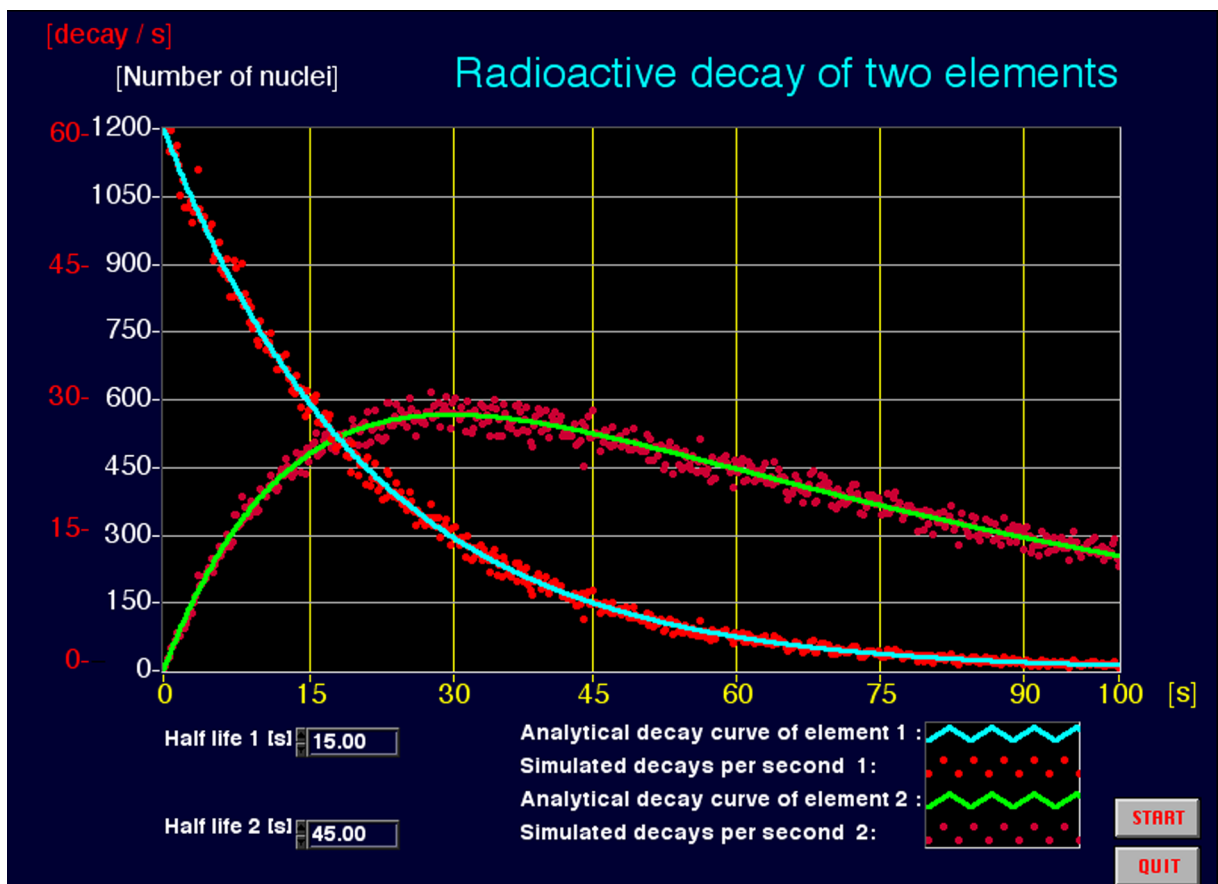


Figure 25: The simulation of radioactive decay.

Because handling even small quantities of radioactive material in front of a large number of students in a classroom should be avoided whenever possible, the simulation of radioactive decay processes is quite suitable.

A LabVIEW VI simulates the decay of an element which produces a secondary element with a longer half life as a daughter product of the original material. The simulation outputs a clicking sound to a loudspeaker for each decay, thus simulating a detector equipped with a Geiger-Müller tube. The curves are drawn while the simulation is in progress and the result is shown in Fig. 25.

Statistical behavior: Diffusion process

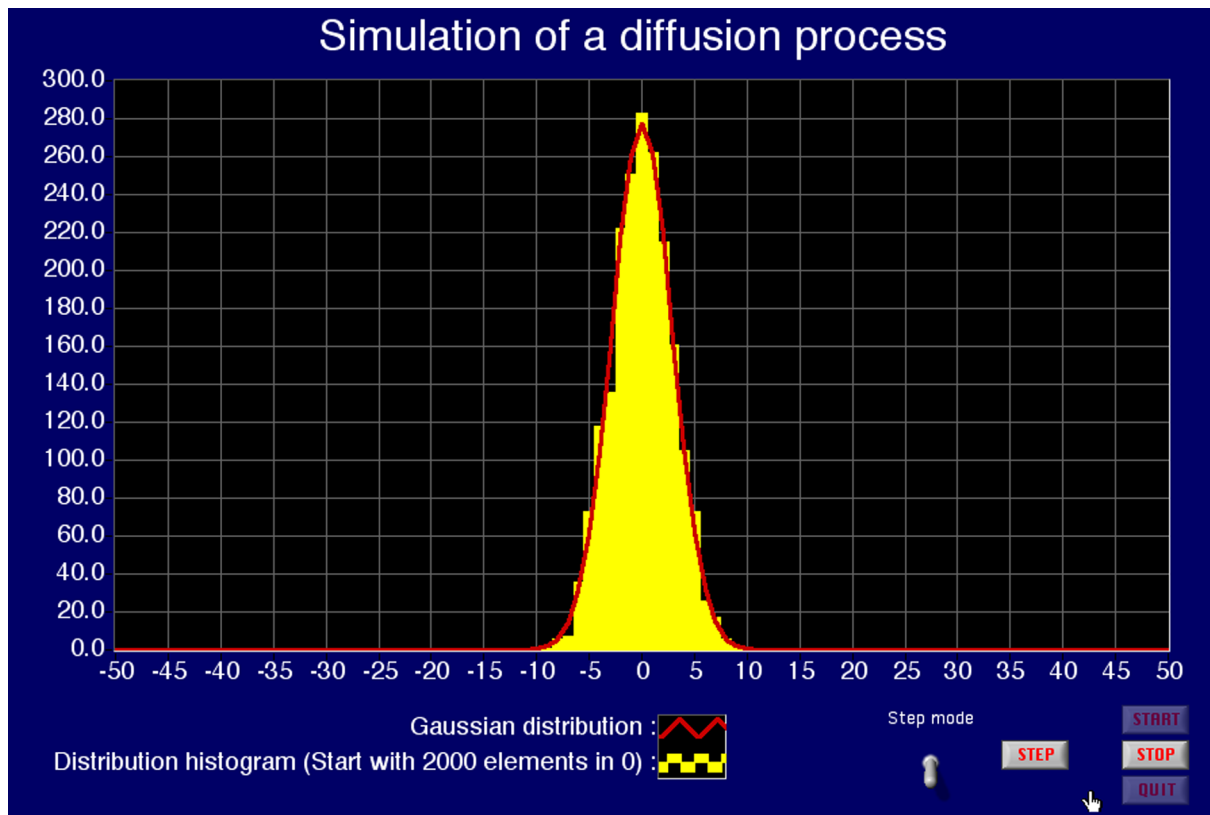


Figure 26: The simulation of a diffusion process.

Diffusion is a very fundamental mechanism in nature and is responsible for a great number of important phenomena, like heat conduction, gas and fluid behavior, and concentration variations effecting electrolytic signal propagation in organic cells. To show the essence of this mechanism, we simulate a diffusion process as a continuously updated histogram. We start with 2000 elements in the center bin, then process each element having three random possibilities: either staying, or dropping to the right or left neighbor bin. This simple property leads to a spreading distribution which is expressed analytically with a widening gaussian probability function. The LabVIEW simulation shows the result by calculating the positions for every one of the 2000 particles, graphing the result for every cycle. At the same time, the gaussian distribution function is superimposed on the result. The simulation allows to

enter a step mode in which each cycle can be evoked manually. The graph shown in Fig. 26 shows the distribution at an early stage.

Visualization of a fast process: The brachystochrone experiment



Figure 27: The experiment for demonstrating the brachystochrone.

On what trajectory will a steel ball roll in the shortest possible time from an elevated to a lower position? This prize-winning problem was already posed by Johann Bernoulli in the journal of “Acta Eruditorum” in 1696. Although apparently trivial, this was an open question for a long time, and was solved by Bernoulli himself with his variational method revolutionary at the time. It turns out that the fastest path describes half of a cycloid. To illustrate this fact we built an experiment with three different tracks (straight, cycloid, circular) where we can release three independent steel balls of equal size and weight simultaneously from a starting position. At the end of the slopes three markers indicate the arrival for each ball at the lower level. The experiment is shown in Fig. 27 with the cycloid as the middle one of the three tracks.

After releasing the balls by switching off the electronic magnets which hold them in place, the balls will accelerate down the tracks too fast to allow a precise visual observation. To investigate the arrival situation we video-tape the demonstration and play it back in slow motion afterwards. This way it is possible to show that the fastest track is the cycloid and the slowest one the straight line. To illustrate

what is happening while the balls are moving along the tracks, a LabVIEW simulation graphically visualizes the demonstration experiment. Calculating the new positions and the speed for every consecutive small time interval reveals a model that compares precisely with the actual observation of the experiment by the video camera. The LabVIEW model animation is shown in Fig. 28.

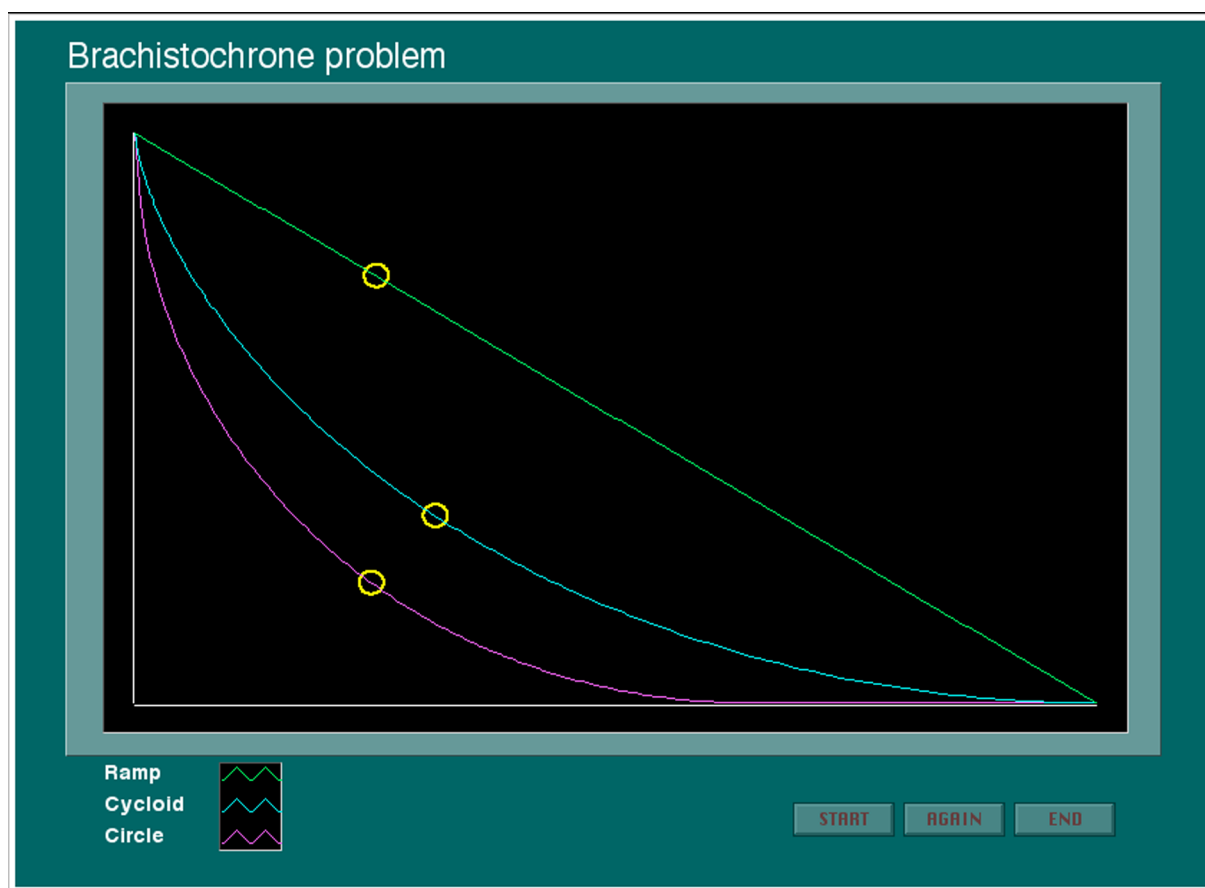


Figure 28: The LabVIEW animation of the brachistochrone slopes.

Student interaction:

A wave and oscillation simulation package

A good reason for software simulation or the modelling of physical properties as opposed to conducting a traditional experiment in physics is the possibility of interaction and parameter studies. It is a great benefit for a student if he can interactively explore a model which creates some graphical output, by changing parameters and observing how the changes affect the model. LabVIEW with all its elements enabling user interfaces is the ideal tool to produce this kind of software. This software can be distributed for downloading by the students as a supplement to classes. It enables them to gain a better understanding of the fundamental laws in physics. Fundamental concepts in physics are oscillations and waves. Their behavior is responsible for a great variety of phenomena in nature.

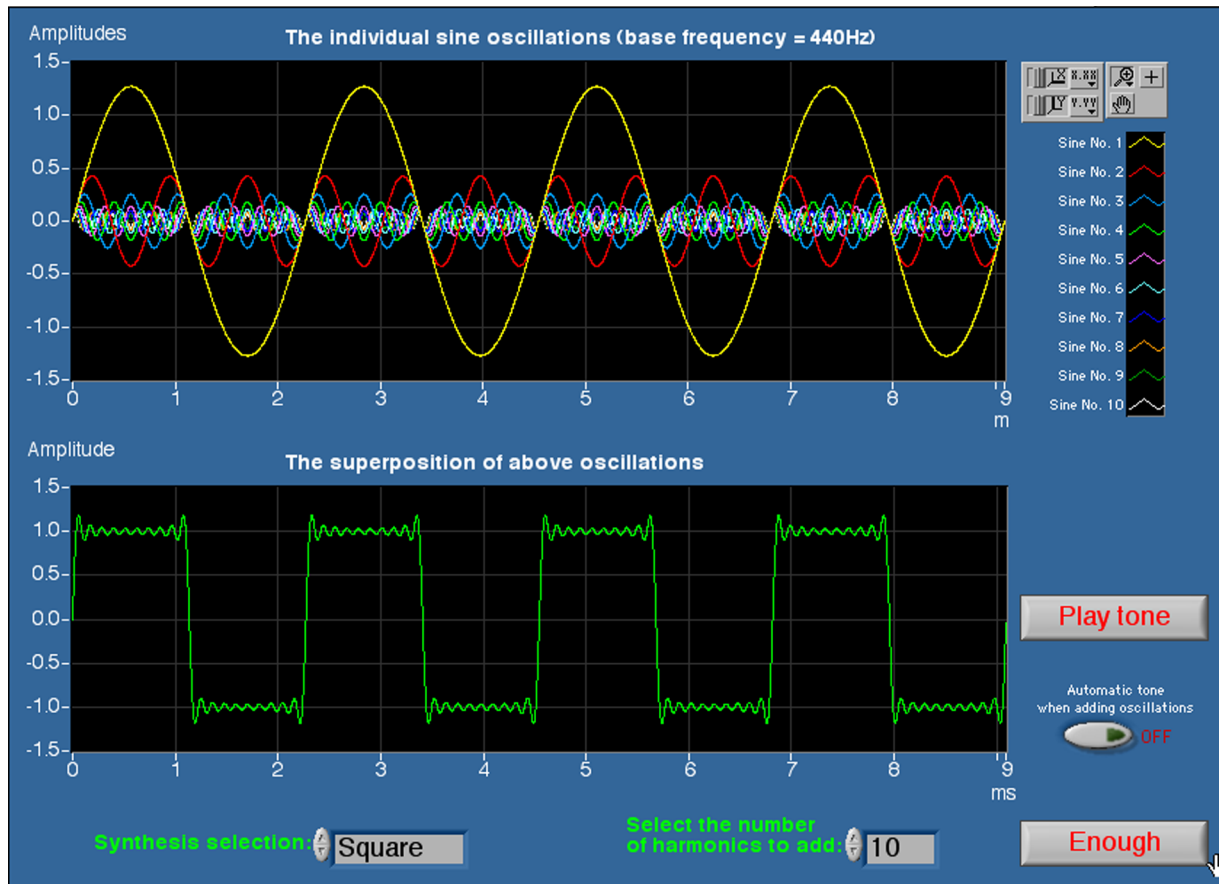


Figure 29: Superposition of harmonic oscillations "Fourier Synthesis".

An interactive software package is called "WaveAspects" which can be downloaded as a stand-alone executable for Macintosh and Windows systems from the teacher support site of the University of Bern at:

<http://www.lauterburg.ch/Software/WaveAspects>

It is the aim of the interactive software to get students acquainted with wave and oscillation properties in a joyful, esthetically pleasing, simple and concise way. Presently, six sections are available, covering the following topics:

- Oscillations in general: Animation of the motion of some harmonic oscillators.
- Sine oscillation: The three fundamental parameters which characterize harmonic oscillations: amplitude, frequency and phase.
- Superposition: Some examples of the effects caused by superposition of harmonic waves.
- Frequency analysis: Periodic oscillations in the time- and frequency domains (FFT: Fast Fourier Transform).
- Diffraction: Modelling of interference patterns which occur when light passes through diaphragms with one or several narrow slits.
- Reflection: Short interactive demonstration of the basic principle of total reflection.

Most sections offer a choice of typical examples of interactive simulation. Graphical displays show the animations and user interface components, such as knobs, sliders, numeric inputs, switches. Graphs permit the variation of the parameters while observing the effect on the display. The layouts are kept especially simple, thus the student is able to focus on the most important fundamental aspects of a particular topic. Fig. 29 shows the "Fourier Synthesis" panel in the "Superposition" section, where the fundamental sine and the superposition of higher order waves forms a rectangular function. Several basic functions can be synthesized. The sound of the resulting wave can be heard with the help of the computer loudspeaker whenever another frequency is added.

Interactive investigations of mathematical models are a very valuable resource for understanding the concepts of physics. They support the capability of a student to follow lectures, by better understanding the essential themes of physics.

Summary and conclusions

LabVIEW™ is a powerful environment for software development. It is widely used for instrument control, data acquisition and data analysis. It is a versatile tool to be used in physics education. LabVIEW's graphical way of programming allows fast and efficient developing of robust, user controlled applications for measurement, analysis, visualization of data, as follows:

- controlling demonstration experiments to acquire signals and display them on-line,
- helping to implement dedicated instrumentation for student lab experiments,
- enabling to produce interactive simulation programs in appropriate cases.

To sum up, our 10-year long engagement using the graphical programming environment LabVIEW™ as a standard tool to perform data acquisition, analysis and display was well worth the initial investment. We have saved several times the expenses which we would have spent otherwise on dedicated hardware.

Last but not least, programming in LabVIEW is fun, whereas traditional, line programming is more than often tedious labor.

About the author

Urs Lauterburg, with his background in photography and electronics engineering, works as a physics instructional resource manager. He develops, maintains and sets up a large number of demonstration experiments for physics lectures and several student labs. He presents the demonstrations during the lectures. He successfully introduced LabVIEW in the field of physics education more than a decade ago. His continuing efforts to complement traditional apparatus with modern data acquisition and data presentation technologies made the students to understand the experiments, and the concepts more easily. The extensive use of LabVIEW has helped the aim of blending solid scientific knowledge with a creative and esthetically pleasing mentoring of physics.

The author can be contacted by e-mail for more technical information about the LabVIEW programs, the hardware design of the signal conditioning and the experimental setups at:

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