Experiments with the Edaq530 measurement system

Péter Makra and Júlia Tandori

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Contents

Chapter 1

The Edaq530 measurement system

1.1 Introduction

These days one hardly needs to elaborate on how many new possibilities the use of computers in natural science education opens up by extending the limits of experiments to include phenomena that used to be difficult to demonstrate and by enlisting the computer as a motivating factor. In recent years, education forms which encourage student experiments have grown more significant: enquiry-based learning (or IBL, following the US spelling 'inquiry') has become increasingly preferable to traditional lecture-style, frontal teaching that tends to relegate students to passive recipients of information.

For this method to be successful, modern, handy, easy-to-use experimental tools are needed. Though manufacturers of teaching tools offer several excellent solutions, these are not necessarily tailored to the budget of Central European schools, and may not always provide the flexibility that a creative, agile teacher would need to put their own ideas into practice.

The Edaq530 measurement system was developed to address these issues in the spring of 2010. Originally it was distributed to the participants of a teacher training, and since then it has become very popular amongst physics teachers who have an affinity for experiments. It is used in several Hungarian schools: for instance, in the *Endre Ságvári* Secondary School of the University of Szeged, a laboratory based on this measurement system has been working for a number of years now.

1.2 Contents of the kit

The main element of the kit is the Edaq530 data acquisition unit. This is practically a three-channel voltage registration device with a measurement range of 0–3.3 V that can be connected to a computer. The device runs its own driver program, which interprets the measurement settings made in the program running on the computer (`Edaq530.exe`), collects measurement data and relays these to the measurement program. The technical details of the data acquisition unit can be found in Appendix A. Appendix B contains an installation guide.

Modern measurement devices can only measure voltage directly. In itself, this would support only a tiny fraction of possible experiments, but most physical quantities can be converted into voltage or an electrical quantity directly related to voltage (such as current, resistance or capacitance) by the appropriate sensor, and thus become available to this type of measurement. On the basis of the formula describing the quantity-to-voltage conversion, the measurement program running on the computer calculates the value of the quantity we wish to measure and shows it on the screen. This is the key to the versatility of digital devices: if we want to measure a different quantity, we only need to replace the sensor and change a few settings in the measurement program, whilst the measurement device stays the same.

Edaq530 is no different. The measurement kit contains several sensors, using which we can measure speed, swing period, magnetic field, illuminance, pressure and temperature. The contents of the kit are detailed by Table 1.1. We shall elaborate on the use of individual sensors and the associated settings in a subsequent section.

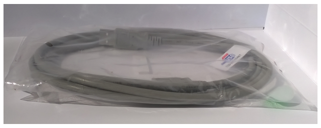
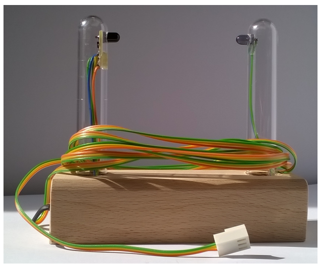
Picture	Accessory	Quantity
	Edaq530 three-channel with USB connectivity	1
	USB flex	1
	Photogate	2
	Thermistor	3
	Hall sensor	1
	Pressure sensor	1
	Photoresistor	1
	Extension flex for sensors	3

Table 1.1. Contents of the kit

1.3 Manual

1.3.1 Input connectors

The measurement device has three input connectors. Their pinning is shown in Fig. 1.1: of the three pins, one represents the ground, the other is the 3.3 V supply voltage and the third is the measurement input whose voltage is being measured. The input signal can be a voltage between 0 and 3.3 V. The sensors in the kit are wired according to this pinning, but if custom sensors are connected, please make sure the connexions are properly arranged. To ensure proper connexion, the connectors can only be attached in a given orientation, which is enforced by the plastic edge underneath the pins. Please be aware of this and do not force the connectors if they are not properly orientated.

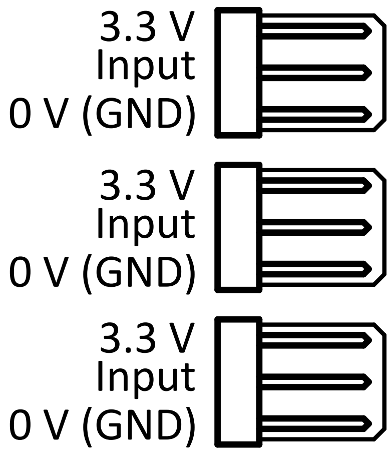


Figure 1.1. Input connectors

The three input channels are referred to as **A**, **B** and **C**. The alignment of these is shown in Fig. 1.2 – channel **A** is located on the same side as the power indicator LED.

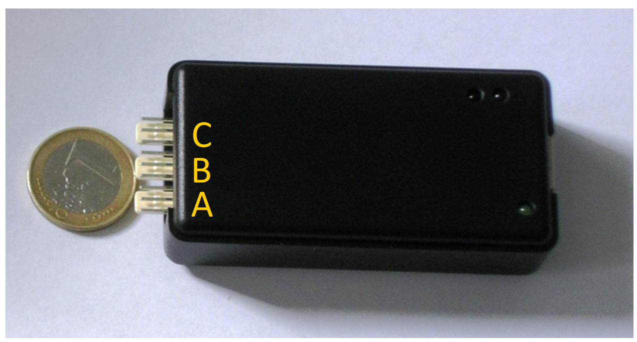


Figure 1.2. The alignment of the channels

With this input arrangement we can measure voltage signals directly. Several sensors (eg thermistors or photoresistors), however, do not provide voltage output, but it is rather their resistance that changes as a function of the quantity to be measured. In this case, we connect the sensor into a voltage divider with a known probe resistance R_p and measure the voltage U across the terminals of the sensor (see Fig. 1.3).

From this voltage U, knowing the values of the reference voltage U_{ref} (3.3 V in our case) and the probe resistance R_p, we can determine the resistance R of the sensor:

$$I = \frac{U_{ref}}{R + R_p} \tag{1.1}$$

$$U = R \cdot I = U_{ref} \cdot \frac{R}{R + R_p} \tag{1.2}$$

$$R = R_p \cdot \frac{U/U_{ref}}{1 - U/U_{ref}} \tag{1.3}$$

In previous versions of the measurement kit, the probe resistance R_p used to have to be connected externally into the measurement circuit, but in the current version it is incorporated into the data acquisition unit and can be connected into the circuit by choosing the sensor interfacing option Resistance output (see subsection 1.3.4).

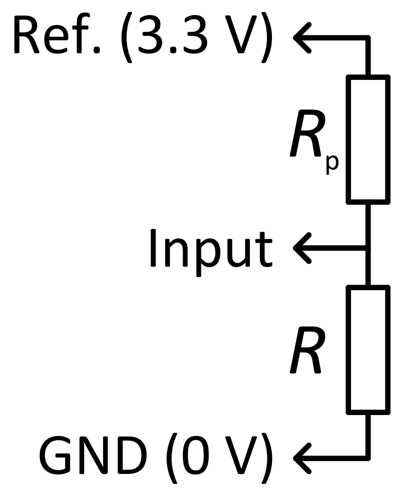


Figure 1.3. Measuring resistance using a voltage divider

1.3.2 Measurement program: startup and basic functions

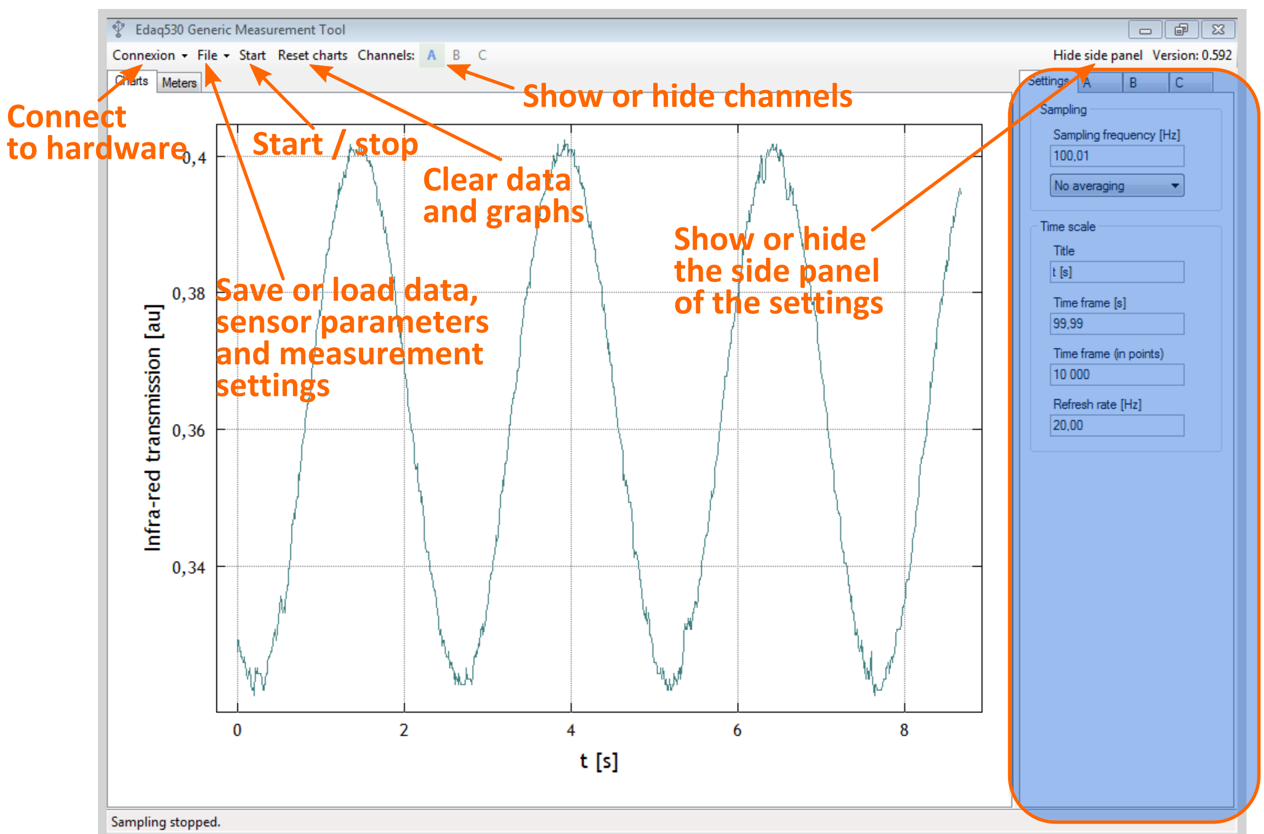


Figure 1.4. The main menu

Having installed the required components (see Appendix B), execute the file Edaq530.exe. Note: before starting the program for the first time, wait for Windows to complete the installation of the required drivers, or else you will receive an error message. Wait until the text containing the version of the data acquisition unit appears on the status bar (eg EDAQ530C (c) 30/06/2010 www.noise.physx.u-szeged.hu). If connexion to the device fails, unplug the USB flex from the device, plug it back again and choose the option Rescan devices from the menu Connexion (see the top of Fig. az 1.4) or press CTRL + R. If the version information appears on the status bar, connexion to the device has been established and it is ready to measure.

Using the options listed in the File menu (see Fig. 1.12) sensor scaling information can be exported (Save sensor...) and imported (Load sensor from file...). In the same menu, there is an option to save (Save measurement setup...) and load (Load measurement setup from file...) the whole measurement setup as an xml file. Measurement data (more precisely, the last 100 000 measurement points per channel) can also saved as a text file using the option Save measurement data.... The button Reset charts clears the charts and level crossing tables of all the channels without having to stop the measurement. The buttons next to the label Channels: can be pressed to select which channels are shown. A channel is active if its label is blue against a green background. The button Hide | Show side panel hides or shows the side panel that contains the settings.

The indicator taking the largest part of the screen can function in chart mode (Charts) or in meter mode (Meters). The desired mode can be selected by clicking on the appropriate tab. The channels displayed can be selected in the main menu as explained above, by clicking on the label of the channel in question.

1.3.3 Channel-independent settings

Whilst the sensor interfacing, scaling and appearance of the individual channels can be set independently, there are a number of settings, such as the sampling rate, the label and the properties of the x axis and the display refresh rate, that affect all channels simultaneously. These settings can be accessed in the Settings tab of the side panel on the right side (see Fig. 1.5).

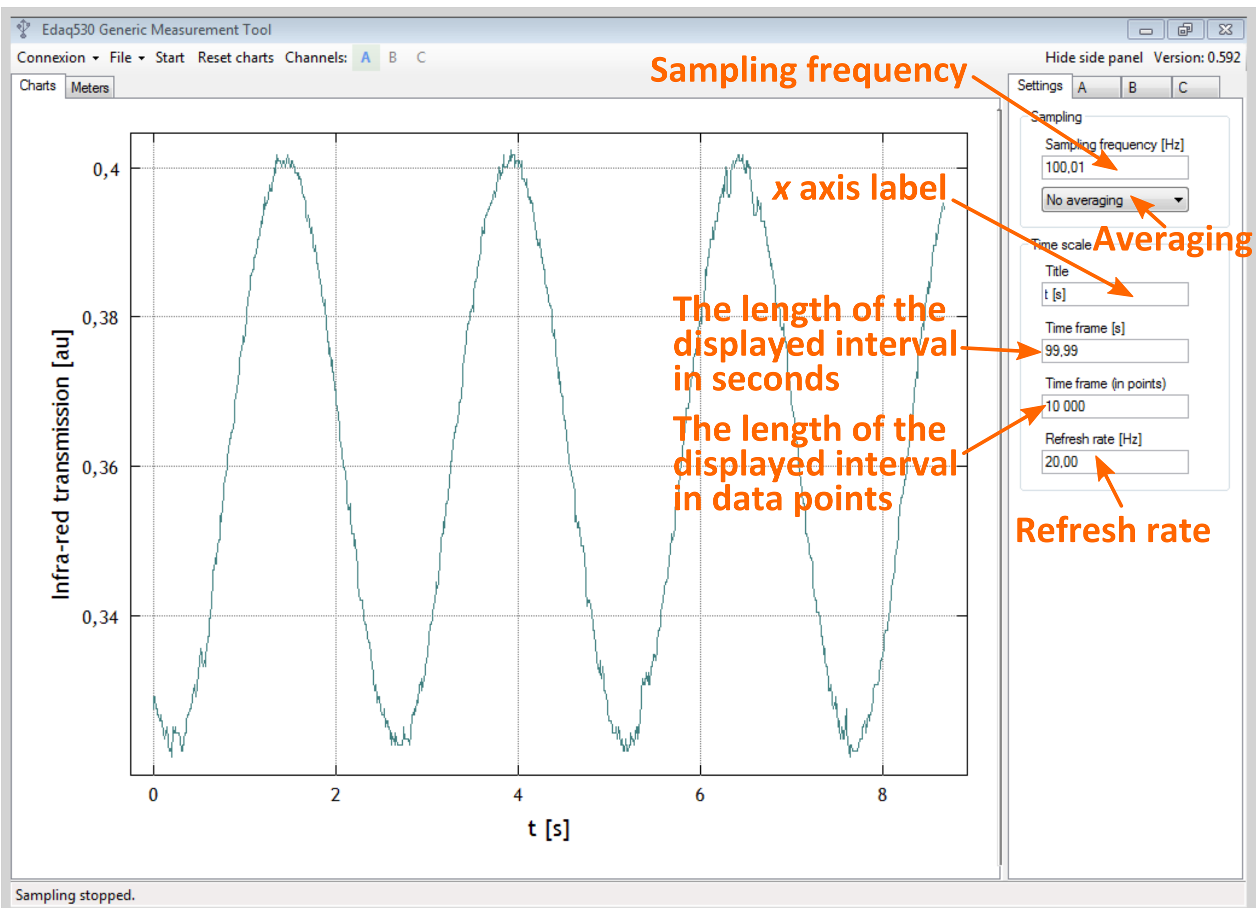


Figure 1.5. Channel-independent settings

In the Sampling frequency [Hz] field we can specify the sampling rate if the data acquisition unit is connected. This value tells us how many data points are collected per channel in a second. After applying this setting, the data acquisition unit sends feedback on the actual sampling rate value set, so the displayed value may differ slightly from the one we entered. Below that, there is a drop-down menu to select how many data points the data acquisition unit should average before sending the result to the computer. In the Title field the label of the x axis can be set. In the fields Time frame [s] and Time frame (in points) we can set the length of the data range visible in the charts. The two are linked; depending on the actual value sampling frequency, setting one field will determine the value in the other, according to the following:

$$\text{Time frame (in points)} = \left[\text{Time frame [s]} \cdot \text{Sampling frequency [Hz]}\right], \tag{1.4}$$

where [...] indicates rounding to the nearest integer. The value of the field Refresh rate [Hz] determines how many times in a second the display will be refreshed. Higher values yield more fluid, less intermittent display, but tax the computer more heavily, so if we have a less powerful computer, it might be prudent to set a lower value. The accepted values range from 0.1 Hz to 100 Hz.

The sampling rate and the averaging can only be set if no measurement is in progress (during measurement, these controls are greyed out), whilst the rest of the parameters listed here can also be altered during measurement.

1.3.4 Channel-dependent settings

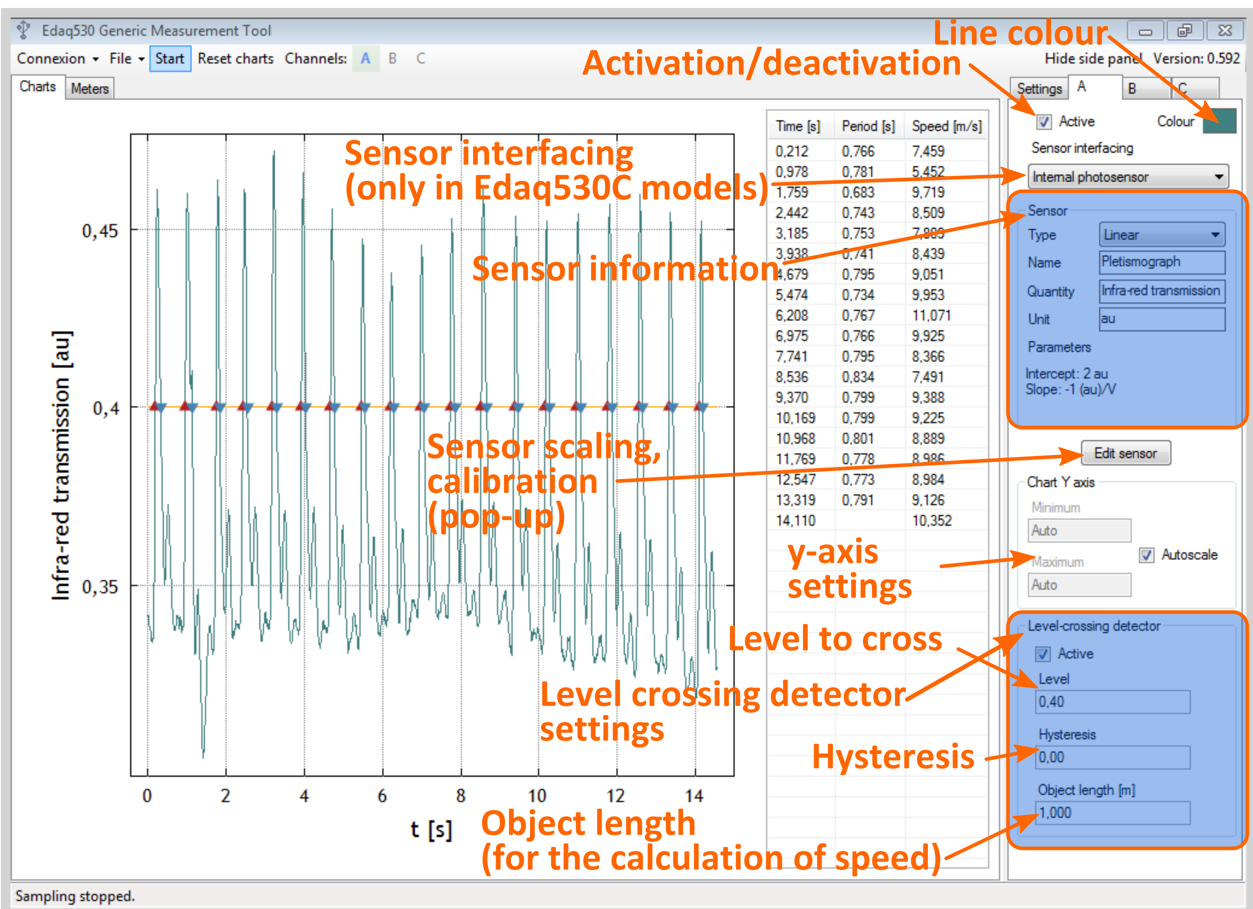


Figure 1.6. Channel-dependent settings

Individual channel settings can be accessed clicking on the tab bearing the channel label (**A**, **B** or **C**) in question. The settings of the three channels are largely identical, though certain settings are only available for given channels.

Using the Active tick box, the signal of the given channel can be shown or hidden in the charts or meters. The effect of this tick box is equivalent to that of the labels in the Channels: region of the main menu. The Colour button brings up a colour picker where we can set the colour in which the signal of the given channel appears in the chart and in the meters.

The Sensor interfacing drop-down sets the way the sensor is connected and evaluated. This drop-down is only available in models Edaq530C. The options are the following:

- Voltage output. Available for all channels. The simplest measurement method: the data acquisition unit samples the input voltage directly.
- Resistance output. Available for all channels. We use it for sensors whose resistance changes as a function of the quantity to be measured (such as thermistors). When selecting this option, the data acquisition unit connects the sensor into a voltage divider with probe resistor having a known resistance, thus by measuring the voltage across the terminals of the sensor we can determine the resistance of the sensor and through that, the value of the quantity to be measured. Its main advantage is that we voltage divider circuit does not have to be built separately but it is realised inside the data acquisition unit, so the sensor can be connected to the input of the device directly.
- Internal photosensor. Only available for channel **A**. When it is selected, channel **A** measures the signal of the built-in photosensor instead of an external signal.
- Voltage difference. Only available for channel **B**. When it is selected, the signal in channel **B** is the differential signal (that is, the voltage difference) between the inputs **B** and **C**. We use it for sensors which have differential output (eg, thermocouples). The measurement kit does not contain any sensors which would require such interfacing.
- Wheatstone bridge. Only available for channel **B**. When it is selected, a Wheatstone bridge is established between the inputs **B** and **C**, increasing the sensitivity of the measurement. It is used for certain sensors (such as a number of pressure sensors). The measurement kit does not contain any sensors which would require such interfacing (the pressure sensor included has voltage output and can be used with the Voltage output setting).

In the Sensor block we can set the scaling of the sensor. In the Type drop-down, we chan choose between three scaling types:

- Linear. For sensors having a linear relationship between the voltage directly measured and the quantity to be obtained. Naturally we can set two parameters in this case: the Slope and the Intercept of the line describing the relationship.
- Thermistor. For the most common type of thermistor, whose resistance can be approximated as an exponential function of the temperature. The two principal parameters are the Characteristic resistance measured at room temperature and the B coefficient characterising the temperature dependence.
- Photoresistor. For photoresitors whose resistance follows an exponential function of the temperature. The three principal parameters are the Characteristic intensity, the associated Characteristic resistance and the Exponent.

Using the Name field, we can name the sensor; in the Quantity field, we can specify the symbol of the quantity to be measured – this will appear as the label of the y axis of the chart and in the meter display. The Unit field allows the unit to be entered – this will be shown in the label of the y axis of the chart and in the meter display. The scaling parameters of the sensors can be specified numerically in the window that pops up upon pressing the Edit sensor button. If these are not known (eg from the data sheet of the sensor), we can perform calibration ourselves in the same pop-up window. Both the Sensor interfacing drop-down and the controls of the sensor block are only active when no measurement is in progress; during measurement, they are greyed out.

In the Chart Y axis block we can set up the y axis of the chart belonging to the given channel. If the Autoscale tick box is ticked, the Minimum and Maximum fields are inactive. Unticking the box activates these fields and we can specify the minimum and the maximum.

In the Level-crossing detector block, the properties of the level crossing detector can be defined. The Active tick box turns level crossing detection on. In its active state, a level-crossing table appears on the right side of the chart area (see Fig. 1.10). The Level field sets the level the crossing of which is to be detected, the Hysteresis field regulates the width of the hysteresis range, which is applied to avoid level crossings caused by noise, whilst the Object length [m] field specifies the length or width of the object that crosses the path of the light. We discuss the principle of level crossing detection and the meaning of these parameters in the next section.

1.3.5 Level crossing detection

In several cases we might need to be able to determine the time instant at which an event occurred and the time that elapsed until the next similar event (eg a period of an oscillation). The easiest way to accomplish this is to set a level and record the instant at which the signal exceeds or falls below this level. With regard to the latter, we can distinguish between upward and downward crossings, which also allows us to determine the speed of an object when applied to the signal of a photogate. The signal is at about 0 V when nothing blocks the path of light, and it rises near the supply voltage when an object crosses this path. Consequently, the instant at which an object enters the 'field of vision' of the photogate is signalled by an upward crossing, whilst the next downward crossing corresponds to the instant at which the opposite end of the object leaves the path of the light. If we divide the length L of the object by the difference between the time instant of an upward crossing (t_{up}) and the time instant of an adjacent downward crossing (t_{down}), we can obtain the average speed of the object for the interval of passing through the photogate:

$$\bar{v} = \frac{L}{t_{\mathrm{down}} - t_{\mathrm{up}}}. \tag{1.5}$$

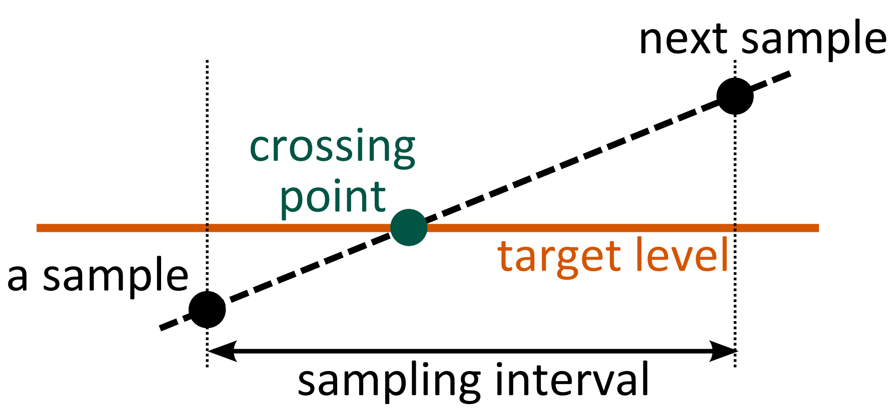


Figure 1.7. Simple level crossing scheme

In Fig 1.7 we can see the principle of the level crossing detection. Since we can only determine the time instants immediately before and after the level crossing, we need linear interpolation to estimate when it occurred.

Noise in the measured signal can result in spurious level crossings (see Fig. 1.8). To avoid this, we supplemented the simple scheme outlined above with hysteresis. In the level crossing scheme with hysteresis, we only consider an event to be a level crossing if the signal enters the hysteresis region from outside and crosses the hysteresis region without meandering out of it temporarily. The time of the level crossing is determined from the instants immediately before and after crossing using linear interpolation. The principle of this method is illustrated in Fig. 1.9.

If level crossing detection is enabled for a given channel, a level crossing table appears to the right of the corresponding chart (see Fig. 1.10). The first column of this table (Time [s]) contains the time instants of upward crossings, the middle column (Period [s]) indicates the time elapsed until the next upward crossing, whilst the third column (Speed [m/s]) lists the average speed calculated from the Object length [m] and the time between adjacent upward and downward crossings, according to Eq. (1.5). In the context menu, the Copy content to clipboard

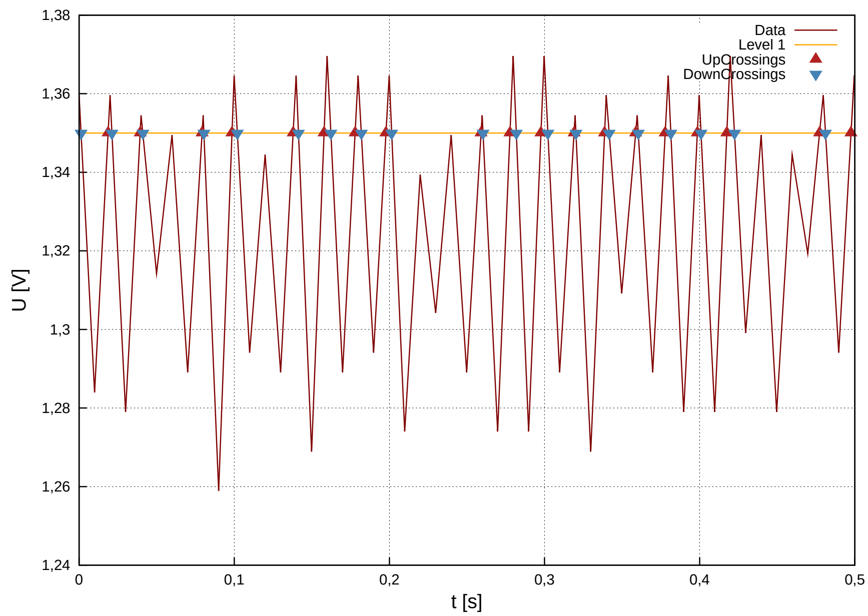


Figure 1.8. The effect of noise on level crossings

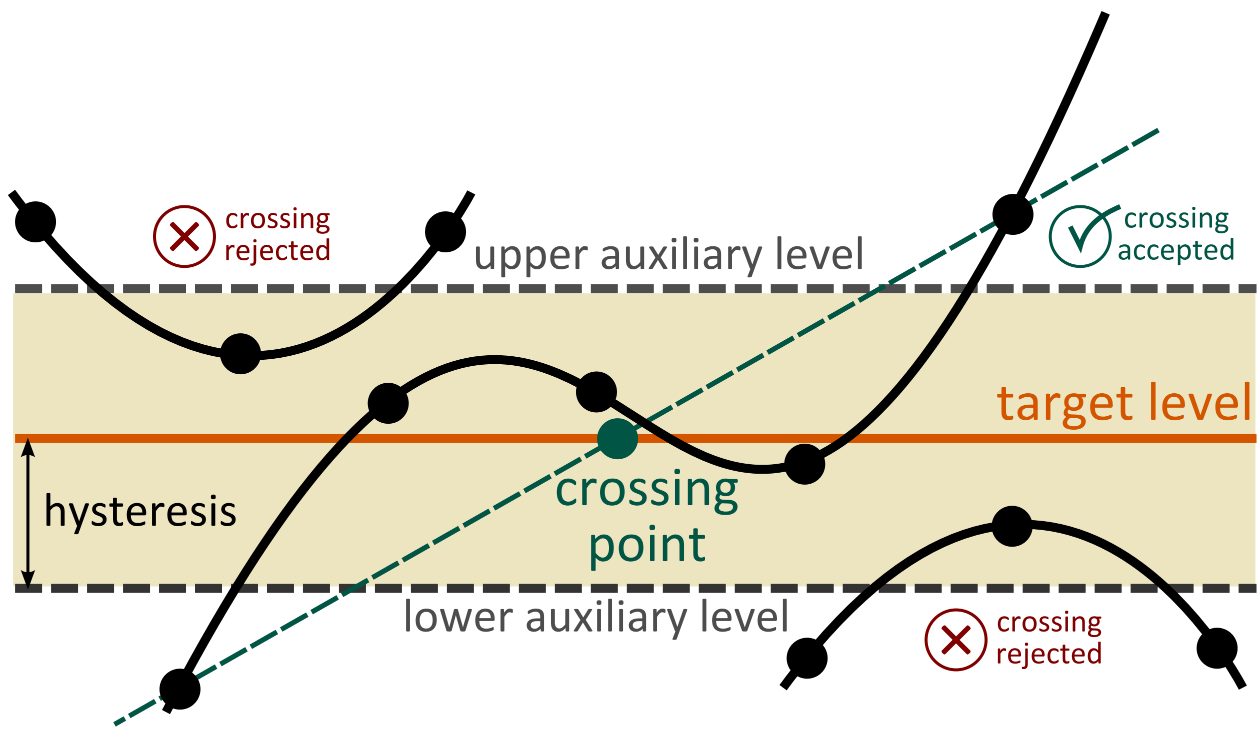


Figure 1.9. Level crossing scheme with hysteresis

command allows us to copy the content of the level crossing table to the clipboard (whence we can insert it into an Excel spreadsheet, for instance), whilst the command Clear empties the level crossing table without clearing the associated chart.

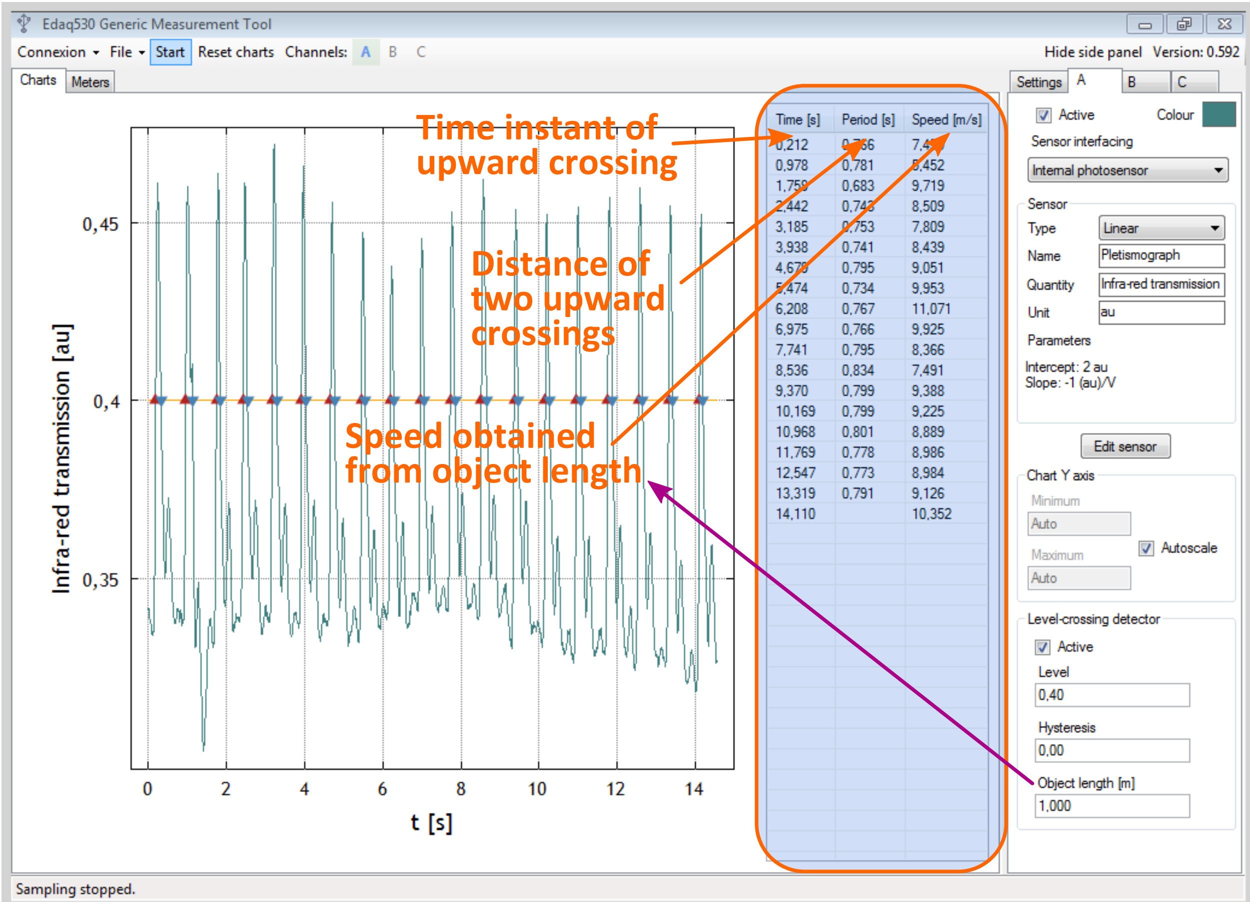


Figure 1.10. The level crossing table

1.3.6 Scaling and calibration

As we have previously mentioned, it is connecting the appropriate sensor that enables the data acquisition device, which can only register voltage in itself, to measure almost any physical quantity. In order to calculate the value of the quantity we are interested in from the actual voltage, we need to know the function that links the two quantities, along with the relevant parameters. As mentioned above, Edaq530 implements three types of scaling: Linear, Thermistor and Photoresistor. The appropriate scaling can be selected in the Type drop-down of the Sensor block. The parameters of the selected scaling can be set in the window that pops up when we press the button Edit sensor. In the same window, we can also perform calibration (see Fig. 1.11).

The calibration window has two modes: direct parameter setting mode (Edit mode) and Calibration mode. We can choose between these using the Mode drop-down at the top of the window. In both modes, the fields available in the main measurement window can be accessed, but we can also find a table which enables us to set the parameters of the sensors in greater detail. In Edit mode, we can enter the values of the parameters characteristic of the given sensor directly, if these are known (eg from the data sheet of the sensor), whilst in Calibration mode we can register the measured voltage–target quantity data pairs required for the calibration. The first column of the table is read-only, but in the second column we can enter the values.

During calibration, we should like to determine the scaling parameters by associating the voltage values the data acquisition unit shows at the moment with the target quantity values registered by an independent measurement device (eg in the case of a thermistor, a mercury thermometer). The former are automatically recorded in the first column, whilst the latter we have to enter into the second column. Such a data pair can be added to the calibration data array by pressing the Add point button. If this calibration array contains at least two such pairs of

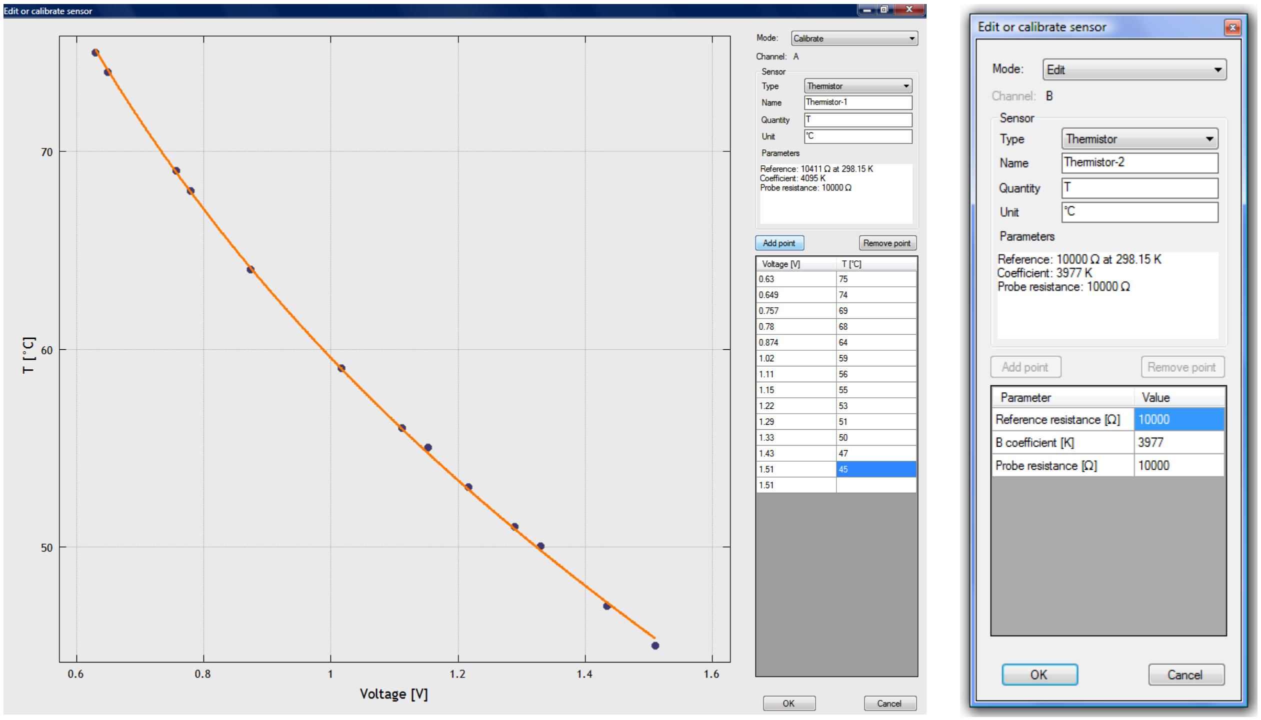


Figure 1.11. The calibration window

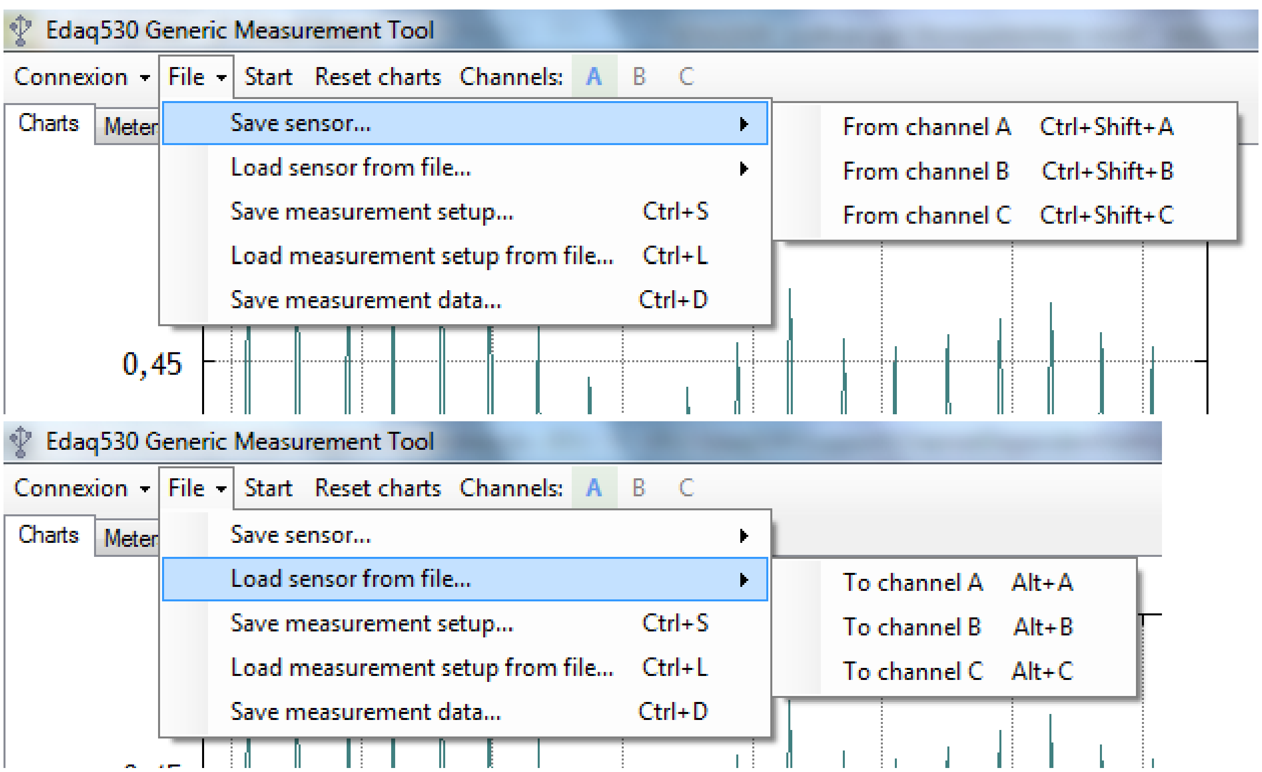
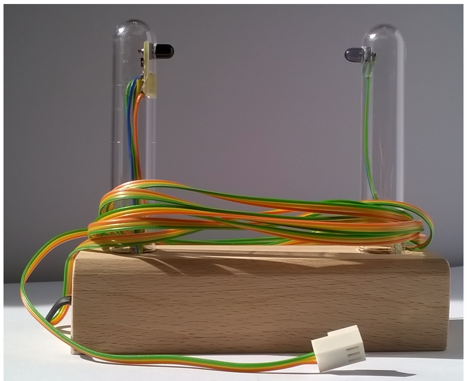


Figure 1.12. Exporting and importing sensor settings and measurement setup

data, a calibration curve will appear on the left plotting the measured values and a theoretical curve based on the



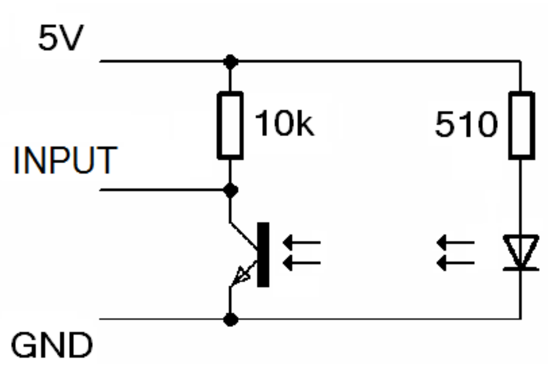


Figure 1.13. A photogate (left) and the corresponding circuit diagram (right)

parameters that yield the best fit. These curves are refreshed whenever we add a new calibration pair. If we find an outlier, we can select the row that contains it and remove it by pressing the button Remove point. If we press OK, the scaling parameters determined by the fit will be accepted as the new parameters of the sensor. The program uses least-squares regression to fit a line on the calibration data: this is straightforward for linear scaling, whereas for thermistors and photoresistors, the scaling is exponential, so it can be linearised with a logarithmic function and then the same regression method can be applied.

As we mentioned, the sensor settings can be exported from and imported into each channel using the appropriate option in the File menu (see Fig. 1.12). The whole measurement set-up can also be saved and loaded from the same menu. In this case, not only the sensor scaling but all other settings (such as width of the visible range, the channel selection, the sampling rate, the refresh rate, &c) are saved.

1.4 Sensors

1.4.1 Photogate

Photogates consist of a photodiode and a phototransistor in an exactly opposite position (Fig. 1.13). The emitter of the phototransistor is connected to the ground. When the path of the light from the photodiode is not blocked, the phototransistor opens and pulls the input down to ground. If something crosses the path of light, the phototransistor closes and the input voltage rises to the supply voltage. Thus the photogate can detect objects' passing through it. Applying level crossing detection on the photogate signal, we can perform kinematics experiments, measure speed and determine the period of a pendulum.

The appropriate settings in the measurement program:

- Channel: any
- Sensor interfacing: Voltage output
- Sensor » Type: Linear
- Scaling parameters: any (only the time axis matters)

1.4.2 Built-in photosensor

Edaq530 also contains a built-in photosensor (Fig. 1.14). Its primary function is to measure heart rate. If we lay a fingertip on the diode-transistor pair, the infrared light coming from the diode will be partially reflected from the fingertip and partially absorbed in it. The degree of absorption depends on haemoglobin concentration. Since the latter varies with the pulse, the signal in the chart will reflect the pressure variations within the pulse wave. Applying level crossing detection on the signal, we can determine the time that passes between pulse peaks and from that, obtain the pulse.

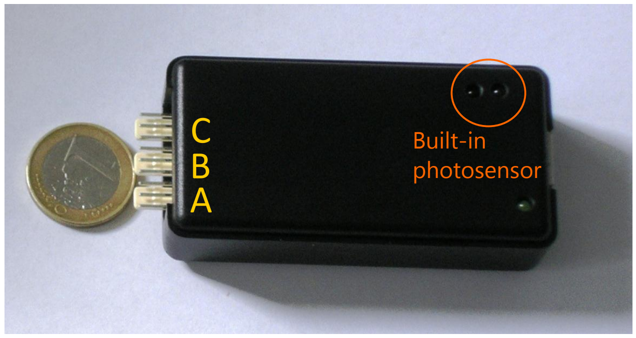


Figure 1.14. The built-in photosensor

The appropriate settings in the measurement program:

- Channel: only **A**
- Sensor interfacing: Internal photosensor
- Sensor »Type: Linear
- Scaling parameters: any (only the time axis is valid)

1.4.3 Thermistor

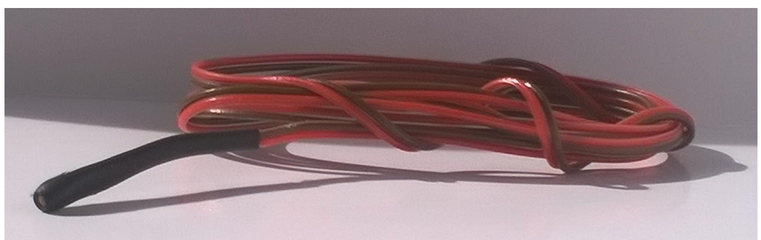


Figure 1.15. A thermistor

The thermistor (Fig. 1.15) is a sensor whose resistance is strongly temperature-dependent. We can measure the resistance using the method discussed in subsection 1.3.1. The temperature dependence of the resistance of the termistor can be approximated as follows:

$$R(T) = R_0 e^{B(1/T - 1/T_0)} \tag{1.6}$$

$$T(R) = \frac{1}{\frac{1}{T_0} + \frac{1}{B}\ln\left(\frac{R}{R_0}\right)} \tag{1.7}$$

For the thermistors included in the kit, the relevant parameters are $T_0 = 25°\mathrm{C} \Rightarrow R_0 = 10\,\mathrm{k}\Omega \pm 5\%$,, $B = 3977\,\mathrm{K}$.

The appropriate settings in the measurement program:

- Channel: any
- Sensor interfacing: Resistance output
- Sensor »Type: Thermistor
- Scaling parameters:
  - Characteristic resistance $= 10\,000\,\Omega$
  - B Coefficient $= 3977\,\mathrm{K}$

1.4.4 Hall sensor

Figure 1.16. A Hall sensor

Hall sensors are based on the Hall effect (Fig. 1.17): when we place a current-carrying conductor or semiconductor in a magnetic field that is perpendicular to its plane, a magnetic deflection force will act on the charge carriers, resulting in charge separation along the plane of the conductor or semiconductor. In equilibrium, the voltage generated by this charge separation will be proportional to the magnitude of the magnetic field vector and can thus be used to measure magnetic field strength.

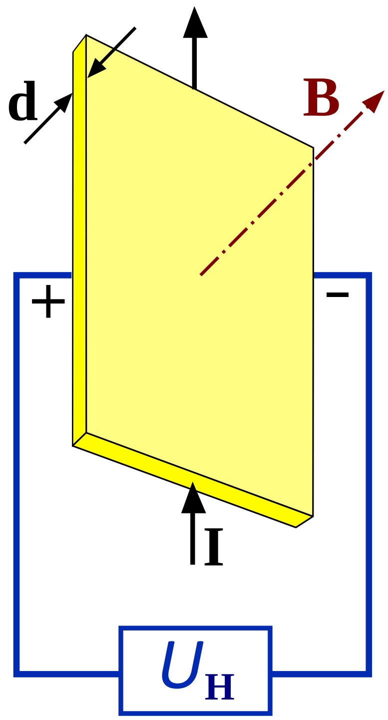


Figure 1.17. The Hall effect

The appropriate settings in the measurement program:

- Channel: any
- Sensor interfacing: Voltage output
- Sensor » Type: Linear
- Scaling parameters: to be determined using calibration

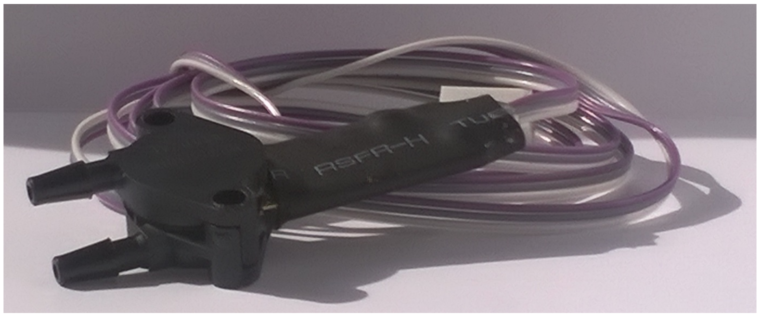


Figure 1.18. A pressure sensor

1.4.5 Pressure sensor

Pressure sensors can operate on several different principles: piesoresistive, capacitive, inductive, piezoelectric or optical types exist. The basic idea is that the degree of deformation of a membrane is proportional to the pressure difference between the two sides of the membrane. Pressure sensors can be differential or absolute – the one included in the kit is differential.

The appropriate settings in the measurement program:

- Channel: any
- Sensor interfacing: Voltage output
- Sensor »Type: Linear
- Scaling parameters: to be determined using calibration

1.4.6 Photoresistor

Figure 1.19. A photoresistor

A photoresistor is a sensor whose resistance varies with illumination. We can measure resistance using the method discussed in subsection 1.3.1. The resistance of a photoresistor, similarly to that of a thermistor, can be approximated with an exponential characteristics:

$$I = I_0 \left(\frac{R}{R_0} \right)^A , \tag{1.8}$$

where R denotes the resistance at the illuminance to be measured I, whilst R_0 stands for the resistance at the reference illuminance I_0.

The appropriate settings in the measurement program:

- Channel: any

- Sensor interfacing: Resistance output
- Sensor » Type: Photoresistor
- Scaling parameters:
  - Exponent = −0,65
  - Characteristic illuminance = 10,76 lux
  - Characteristic resistance = 17 kΩ

Chapter 2

Experiments

2.1 Measuring the acceleration due to gravity with a picket fence

2.1.1 Tasks

Objectives ♦ To measure the acceleration due to gravity with the tools available. To get acquainted with the displacement-time and velocity-time graphs of linear motion with constant acceleration.

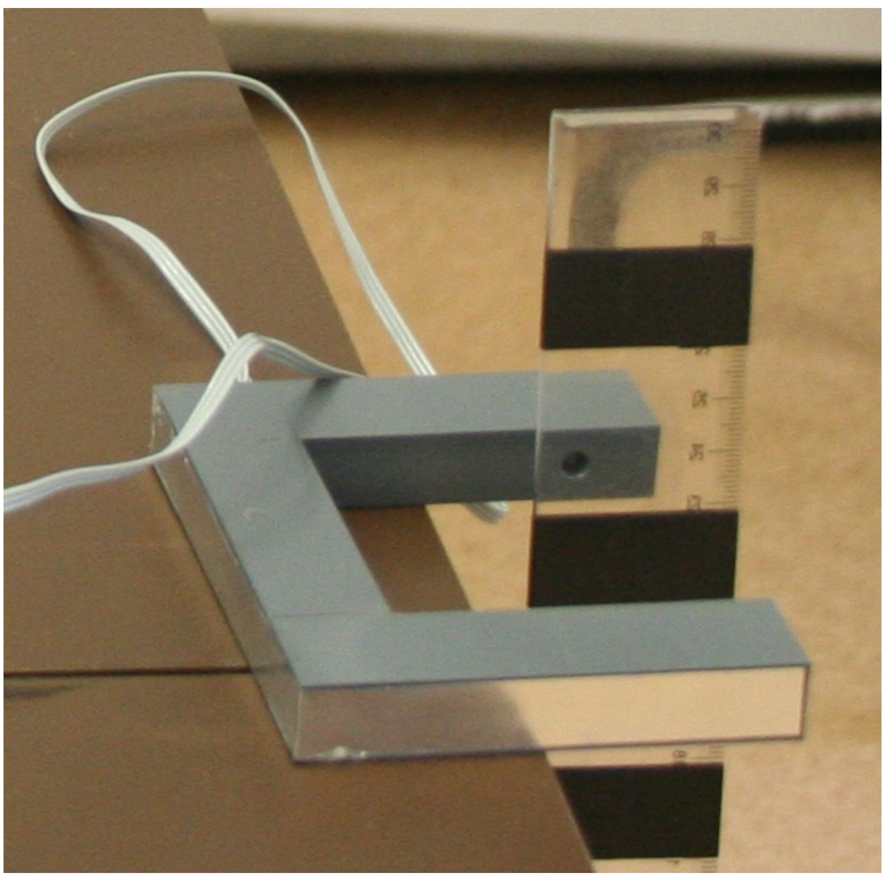


Figure 2.1. The picket fence and the photogate

Measurement steps

1. Connect the photogate to one of the channels and activate level crossing detection on that channel. Set the sampling rate to the maximum, 1000 Hz.

2. Make a picket fence. Take a clear plastic ruler and tape it over at regular intervals (eg 5 cm; see Fig. 2.1). Measure the width of the tape stripes and enter the value in metres into the field Object length [m] in the level crossing detection settings.

3. Place the ruler into the path of light and let go of it from a vertical position.

4. Copy the level crossing table to the clipboard and analyse it in a spreadsheet program.

5. Plot the velocity-time graph. Fit a line to the data points. What is the connexion between the slope of the line and the acceleration due to gravity g? What value does it yield for g? What is the relative error of the measurement with respect to the accepted value?

6. Plot the displacement-time graph. What kind of curve is it? How can we obtain the value of the acceleration due to gravity from this curve? What value does it yield for g? What is the relative error of the measurement with respect to the accepted value?

2.1.2 Background

Tape stripes will block the path of light whilst they pass through the photogate. The level crossing detector will record the time instants when the stripe entered the path of light (first level crossing) and when it left the path of light (second level crossing). The difference between these two time instants yields the time it takes for the given stripe to travel through the path of light. Using this and the width of the stripe, we can obtain the average speed of the picket fence for the period in which the given stripe crossed the path of light. If this period is short, the average speed can be considered a reasonable approximation of the instantaneous speed at any of the two instants. For the next stripe there will be another pair of level crossings, from which the speed after the time it takes for the picket fence to travel the distance between two consecutive stripes can be determined. Consequently, the level crossing table will contain the time instants and the speeds of each stripe's passing through the path of light. From this, the velocity v time graph can directly be plotted. If we insert a column with the position of the stripes (eg 5 cm, 10 cm, 15 cm, 20 cm...), we can also plot the displacement-time graph.

2.1.3 Teachers' guide

Fig. 2.2 shows an example of processing the results of the experiment in a spreadsheet program. Data typeset in blue are those exported from the program itself, whilst those in black we have to enter on the basis on the distance between tape stripes. Plotting column C as a function of column A will yield the velocity-time graph, whilst plotting column D also as a function of column A will result in a displacement-time graph. Fitting a line to the former and a parabola to the latter, we can get the value of the acceleration due to gravity. The slope of the linear fit will yield g, whilst the quadratic coefficient of the parabola will be equal to $g/2$, since the equations defining the position and the velocity in linear motion with constant acceleration are the following:

$$x(t) = v_0 t + \frac{g}{2} t^2,$$

and

$$v(t) = v_0 + g t.$$

A summary of our sample measurements can be found in Table 2.1. Discuss with students what factors might cause the measurement error.

	A	B	C	D
1	Channel A	U [V]		
2	Time [s]	Period [s]	Speed [m/s]	*x* [m]
3	6.36990343	0.06527	0.62847795	0
4	6.43517301	0.03919	1.19710646	0.05
5	6.47436573	0.03151	1.59471265	0.1
6	6.505871	0.02622	1.91221409	0.15
7	6.53208807	0.02381	2.15163081	0.2
8	6.55590238		2.43938797	0.25

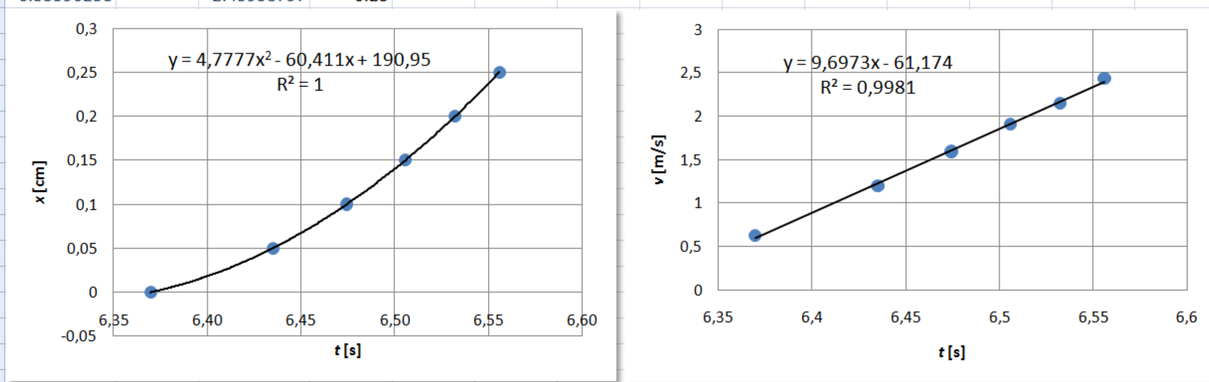


Figure 2.2. Analysing the picket fence experiment in a spreadsheet program

Method	g [m/s^2]	Relative error [%]
$x(t)$	9.56	2.6
$v(t)$	9.70	1.2

Table 2.1. Sample measurement results

2.2 Studying a simple gravity pendulum

2.2.1 Tasks

Objectives ♦ To arrive inductively at physical laws through measuring how the period of a simple gravity pendulum depends on the parameters of the pendulum (such as mass or height of release). To develop an empirical concept of energy exchange in pendulum motion, and through this, in simple harmonic motion.

Measurement steps

1. Connect the photogate to one of the channels and activate level crossing detection on that channel. Set the sampling rate to the maximum, 1000 Hz.
2. Assemble a simple physical pendulum using a laboratory stand, some thread and a bob from a set of weights with a known mass. Measure the diameter of the bob and enter the value in metres into the field Object length [m] in the level crossing detection settings. Thus you can measure the speed of the bob when it passes through the photogate. Place the photogate on the base of the stand so that the equilibrium position of the pendulum bob crosses the path of the light.
3. Measure the period of the pendulum and the speed of the bob in the equilibrium position (when passing through the photogate) for different values of the height of release and throughout several swings. Note that what you see in the level crossing table is half the period. Export the data into a spreadsheet program and indicate the height of release.
4. Decide whether the period depends on the height release. Plot the corresponding graph.
5. Measure the period for different values of the length of the thread. Plot the period as a function of this length.

6. Using the values of the height of release and the speed in equilibrium, investigate to what extent the pendulum obeys the law of conservation of mechanical energy. What fraction of the initial mechanical energy is lost in half a swing? Does it show any correlation with the speed in the previous half-period?

7. Measure the period for different values of mass of the bob. Does the period depend on the mass?

2.2.2 Background

The principle of the measurement is the same as that in section 2.1. The photogate measures the average speed of the pendulum bob for the interval in which it crosses the path of light. We know that the period T of the simple gravity pendulum is given by

$$T = 2\pi\sqrt{\frac{L}{g}}.$$

This means that the period depends only on the length of the thread and not on the mass of the bob.

We apply the law of conservation of mechanical energy to the simple pendulum. The initial kinetic energy is 0, whilst the initial potential energy is

$$E_{\mathrm{P}} = mgh,$$

where h is the height of release, that is, the height difference between the release position and the equilibrium position. In the equilibrium position, the potential energy is 0, whereas the kinetic energy is

$$E_{\mathrm{K}} = \frac{1}{2}mv^2,$$

where v isthe speed in the equilibrium position. If there is no energy loss from friction, the mechanical energy in the two positions is the same:

$$mgh = \frac{1}{2}mv^2.$$

2.2.3 Teachers' guide

Table 2.2 shows an example of the conclusions we can draw from such an experiment. As can be seen in the table, the law of conservation of mechanical energy is obeyed with a good approximation for the first few swings: the initial kinetic energy is nearly equal to the potential energy in the equilibrium.

Height of release [cm][1]	h [m]	v [m/s]	E_{P} [mJ]	E_{K} [mJ]
30	0.19	1.93	93.2	93.0
25	0.14	1.62	68.7	65.9
20	0.09	1.33	44.1	44.1
15	0.04	0.87	19.6	18.9

Table 2.2. Equilibrium speed and energy values as functions of the height of release

We can also use this measurement set-up to introduce potential energy and kinetic energy in an inductive manner. If we plot the the equilibrium speed as a function of the height of release, we can see that the graph is not linear but resembles that of the square root function. However, if we plot the square of the velocity as a function of the height difference, we can see that the dependence is linear (see Fig. 2.3). Fitting a line to the data series, weobtain a slope of $19.51\,\mathrm{m/s^2}$, which is approximately equal to $2g$, whilst the intercept is approximately zero, so

$$v^2 = 2gh,$$

[1] measured from the level of the desk

that is,

$$\frac{1}{2}v^2 = gh.$$

It takes just a step forward to show that for the actual energy, one also needs the mass.

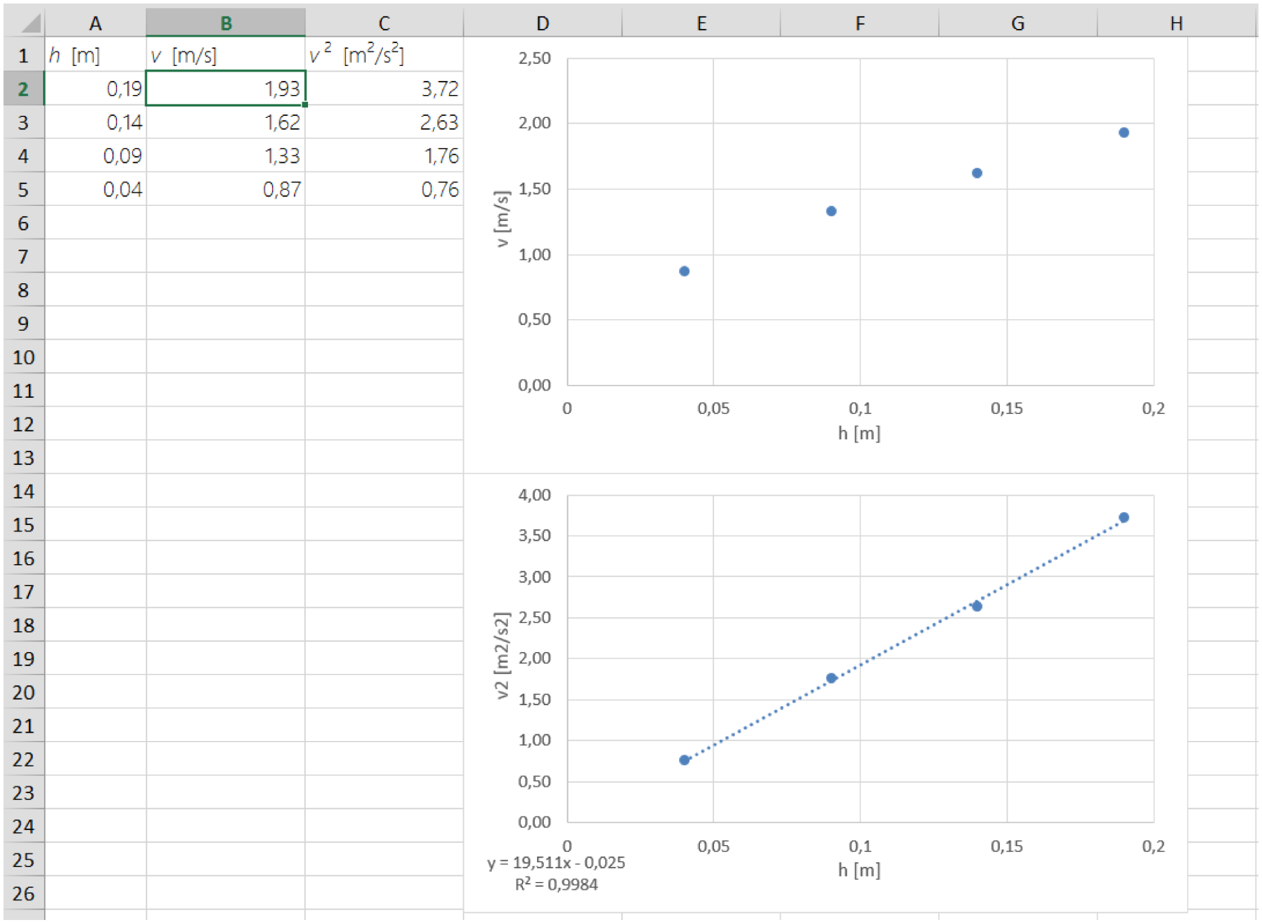


Figure 2.3. Analysing the relationship between equilibrium speed and height of release in a spreadsheet program

2.3 Magnetic measurements

2.3.1 Tasks

Objectives ♦ To study the magnetic field of a solenoid. To explore the practical applications of Hall sensors. To measure the period of circular motion.

Measurement steps

1. Connect the Hall sensor to one of the channels.

2. According to the data sheet of the Hall sensor, the voltage across the sensor at a magnetic field of 0 G is 1 V, and it shows a linear dependence on the magnetic field with a slope of 0.5 mV/G (the data sheet states that these values may vary in a wide range, so precise magnetic measurements require the calibration of the individual sensor). Determine the scaling parameters required to obtain the magnetic field in gauss, and set these in the program.

3. Fix the sensor in the longitudinal axis of a solenoid (eg using plasticine and an object of appropriate height), and connect the solenoid through an ammeter to a variable power supply.

4. Measure the magnitude of the magnetic field as a function of the current. Enter the data into a spreadsheet program and plot the function.

5. Connect a variable-speed PC fan to the power supply with a small magnet attached to one of its blades. Position the Hall sensor in a way that the magnet passes under it with each turn. Activate level crossing detection for the given channel and measure the period of rotation for different values of the output voltage of the power supply. To enhance the precision of the measurement, set the sampling rate to 1000 Hz.

2.4 Measurements with a pressure sensor

Figure 2.4. Measurements with a pressure sensor

2.4.1 Tasks

Objectives ♦ To study hydrostatic pressure. To get acquainted with the concept of calibration.

Measurement steps

1. Connect the pressure sensor to one of the channels. Attach a flexible tube (eg a fuel hose) to one of the inlets of the sensor. Tape over the end of the hose to prevent water from entering it, since the pressure of water vapour biases the measurement. Fasten the hose to a skewer or other stick and make a length scale on it. Fill a tall container with water.

2. Using the calibration window, calibrate the pressure sensor in units of centimetre of water or Pa: in calibration mode, enter the pressure values corresponding to the given depth into the second column of the calibration table.

3. Prepare a concentrated salt solution. Measure the pressure with the calibrated sensor in different depths.

4. Plot the pressure as a function of depth. Fit a line to the curve and determine the density of the salt solution from the slope thus obtained.

2.5 Studying how thermal equilibrium is reached

2.5.1 Tasks

Objectives ♦ To investigate the background of calorimetric problems experimentally.

Measurement steps

1. Connect two thermistors to two of the channels. Set thermistor scaling and use the default values. Set a low sampling rate (eg 1 Hz).

2. Pour water at room temperature to a larger beaker. Fill a smaller beaker that will fit into the larger one with hot water. Measure the mass of the water in each beaker, then sink the smaller beaker into the larger one. Stick a thermistor in each beaker.

3. Measure the two temperatures as functions of time until the common temperature is reached.

4. Does the common temperature tally with the value obtained from simple calorimetric calculations? If there is a difference, does the heat capacity of the beakers account for it?

5. What kind of function describes the time dependence of the temperatures? Try to prove your hypothesis.

2.6 Changing the melting point of ice with the addition of salt

Objectives ♦ To cast light on the physical background of salting. To perform a quantitative analysis of the change in the melting point.

Measurement steps

1. Connect a thermistor to any of the channels. Set thermistor scaling and use the default values. Set a low sampling rate (eg 1 Hz).

2. Make a water-ice-salt mixture with increasing salt concentration. Take 100 g of 0 °C ice, add salt in 3-g doses, and after each dose, stir the water-ice-salt mixture and measure the temperature.

3. Plot the temperature of the mixture as a function of the amount of salt and specify the lowest temperature you obtained. How much salt was needed to reach this temperature?

2.7 Measurement of heart rate

Objectives ♦ To apply the measurement principles learnt to measure physiological parameters.

Measurement steps

1. Make sure that nothing is connected to the input of channel **A**. Choose the Internal photosensor sensor interfacing option in channel **A**. Set the sampling frequency to about 100 Hz.

2. Lay your fingertip on the built-in photosensor (see Fig. 1.14). Find the position and pressure at which the pulse waves are clearly defined in the chart. If needed, mirror the signal on the x axis by setting a slope of -1. Activate level crossing detection and set the level so that only the peaks of the pulse wave can cross it.

3. Measure our heart rate in resting state. The Period [s] column of the level crossing table contains the time that passes between pulse peaks. We can get the heart rate from this if we relate it to a 60-s interval:

$$\text{Heart rate} = \frac{60\,\text{s/min}}{\text{Period [s]}}. \tag{2.1}$$

4. Perform a few physical exercises (eg ten press-ups). Measure your heart rate continuously after the exercise and plot the values as a function of time.

5. Observe how the Valsalva manoeuvre affects your pulse. The Valsalva manoeuvre means forced expiration against closed airways. This drives blood from the pulmonary circulation towards the left ventricle, triggering various circulatory responses.

Appendix A

Technical data

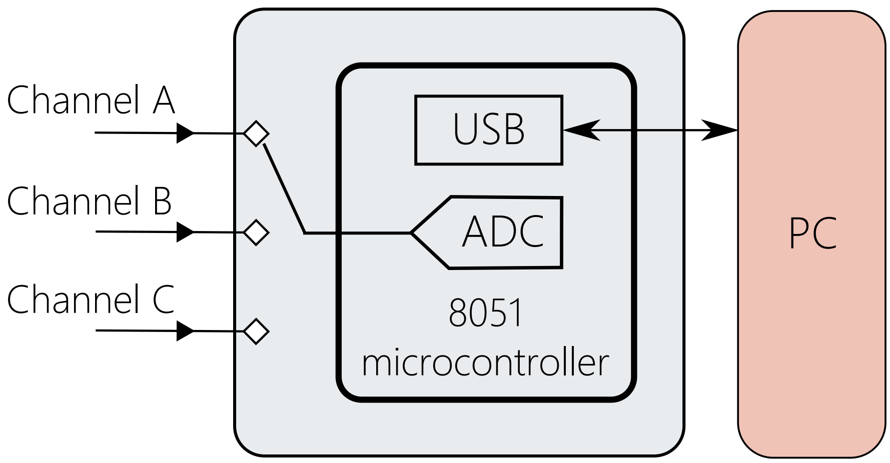


Figure A.1. Schematic diagram of Edaq530

Edaq530 is basically a voltmeter capable of registering the voltage of three channels quasi-simultaneously as functions of time, at a maximum sampling frequency of 1000 Hz. The device digitises the measured voltage and sends it to the measurement program running on the PC, which in turn displays the data in the appropriate format. The measurement range is between 0 and 3.3 V, digitisation resolution is 12-bit, so the voltage step is $\Delta U = 3.3\,\mathrm{V}/2^{12} \approx 0.81\,\mathrm{mV}$.

The 'heart' of Edaq530 is a Silicon Laboratories C8051F530A microcontroller (hence the number in the name), which runs a command interpreter and task scheduler program written in C. The microcontroller also contains a 12-bit analogue-to digital converter, which is responsible for the digitisation of the signals. The digitised data are forwarded to the PC by a USB communication chip manufactured by FTDI. On the PC, a measurement program communicates with the data acquisition device and displays the measurement data.

The microcontroller contains a single analogue-to-digital controller, so the input channels cannot be measured simultaneously. The device connects the signal of the individual channels to the converter alternately (Fig. A.2), introducing a time shift equal to one third of the sampling interval (the time that passes between two successive analogue-to-digital conversion events) between the channels (see Fig. A.3).

To reduce noise, Edaq530 can perform averaging. When set, averaging takes place in the device itself before the data are forwarded to the computer. 1, 4, 8 or 16 averages can be set. Averaging does not influence the sampling rate, since when averaging is set, the device applies a higher (4, 8 or 16 times faster) internal sampling rate, and what the measurement program displays as sampling rate is the rate at which the averaged data arrive in the computer.

The technical parameters of the device are summarised in Table A.1.

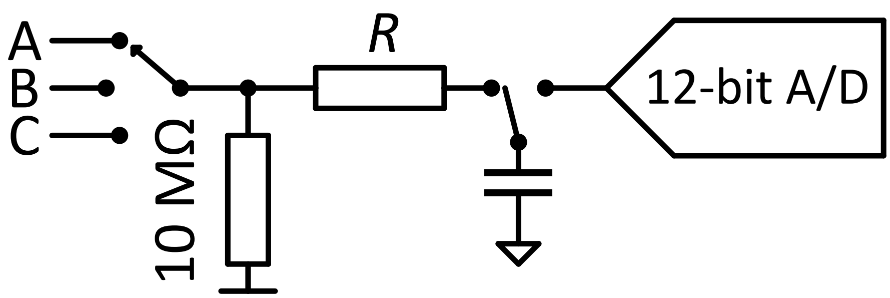


Figure A.2. Sharing the analogue-to-digital converter between the input channels

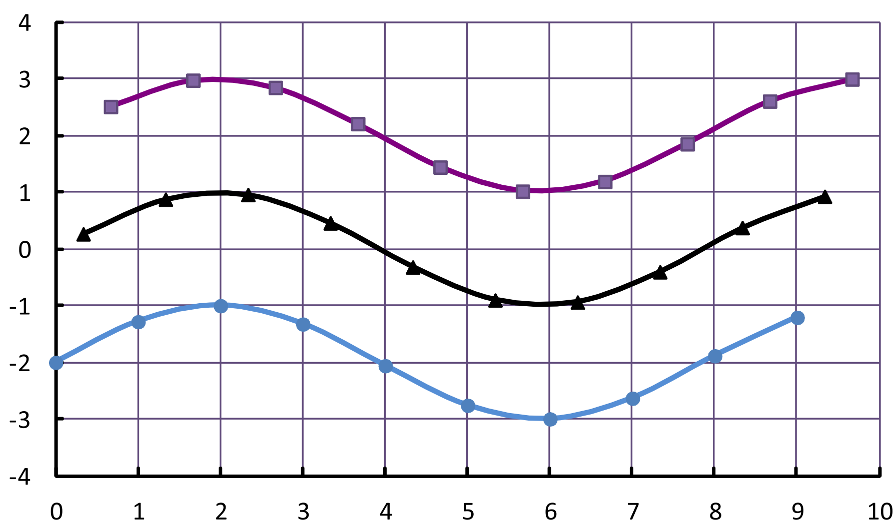


Figure A.3. Time shift between the channels

Measurement range	0–3.3 V
Maximum sampling rate (per channel)	1000 Hz
Resolution	12 bits
Voltage quantum	≈ 0.81 mV

Table A.1. Main technical parameters of Edaq530

Appendix B

Installation

Installation consists of three main steps. First, install the driver of the USB chip, then make sure that the .NET framework (version 2.0 or later) is installed on your computer and finally copy the files of the measurement program to a location of your choosing. We summarise the steps in what follows.

B.1 The USB chip

The manufacturer of the USB chip is FTDI (Future Technology Devices International Ltd). The current version of the driver is available at the following address:

http://www.ftdichip.com/Drivers/D2XX.htm.

We included in the package the latest version available when writing this document (CDM v2.12.00 WHQL Certified.exe).

First, run the installer **without connecting the Edaq530 unit.** Older versions of the driver do not require user intervention; the latest version displays an installation dialogue. In this case, follow the instructions given.

Having installed the driver, connect Edaq530 to the computer. Windows will then detect new hardware and will automatically configure the USB chip. Wait for the 'Hardware is ready to use' message. With this, the installation is finished.

B.2 The .NET framework

The measurement program requires the .NET framework version 2.0 or later to run. From Windows Vista, the .NET framework is a part of the operating system, so we have nothing to do in this case. For Windows XP or 2000, the framework needs to be installed separately. We can use Windows Update to install it, or download the installer directly from the following address:

http://www.microsoft.com/en-gb/download/details.aspx?id=21.

B.3 The measurement program

Unzip the archive Edaq530.v0.597.zip to a location of your choosing. The program is then ready to run: you can start it by executing Edaq530.exe.

Publications

[1] Zoltán Gingl and Katalin Kopasz. High resolution stopwatch for cents. *Physics Education*, 46:430–432, 2011. http://arxiv.org/abs/1102.2006.

[2] Kopasz K, Gingl Z, Makra P, and Papp K. A virtuális méréstechnika kísérleti lehetőségei a közoktatásban. *Fizikai Szemle*, LVII:267–270, 2008.

[3] Kopasz Katalin. *Számítógéppel segített mérőkísérletek a természettudományok tanításához.* PhD thesis, Szegedi Tudományegyetem, 2013.

[4] Kopasz Katalin, Makra Péter, and Gingl Zoltán. High resolution sound card stopwatch extends school experimentation. *Acta Didactica Napocensia*, 5(2), 2012. http://dppd.ubbcluj.ro/adn/article_5_2_7.pdf.

[5] K Kopasz, P Makra, and Z Gingl. Edaq530: A transparent, open-end and open-source measurement solution in natural science education. *European Journal of Physics*, 32(2):491–504, 2011. http://arxiv.org/abs/1009.0432.

[6] Gingl Zoltán, Mingesz Róbert Zoltán, Makra Péter, and Mellár János Zsolt. Review of sound card photogates. *European Journal of Physics*, 32(4), 2011. http://arxiv.org/abs/1103.1760.