POSITION SENSORS

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SEP
Science Enhancement Programme

The Science Enhancement Programme (SEP) is part of Gatsby Technical Education Projects. It undertakes a range of activities concerned with the development of curriculum resources and with teacher education. For further information, visit www.sep.org.uk

CONTENTS

POSITION (ANGLE) SENSORS

INTRODUCTION

Students will all have met this type of potentiometer before, probably acting as a variable resistor in a simple light-dimming circuit or as a volume control. Whilst they could again measure the resistance of the potentiometer at various angles of rotation of the model aileron, resistance is not the factor used to sense the position of a real aileron or robot arm: its position is sensed through a **potential divider** set-up which provides a voltage output to an A to D (analogue to digital) converter and then to a computer for analysis. Although both resistance and potential divider are dealt with here, understanding how the potential divider works is more relevant to understanding position sensors in the real world.

Although a linearly scaled potentiometer has been used, the voltage output does not vary linearly with the angle of rotation. This is due to the relatively low impedance of available voltmeters, and indeed of *DrDAQ*. At a later stage an operational amplifier set up as a voltage follower or buffer could be incorporated between the model aileron unit and the voltmeter or *DrDAQ*. Such a device provides an extremely high input impedance with a low output impedance, resulting in a very linear output from this same potentiometer. It is an enlightening task which brings home the importance of resistance/ impedance.

There are other devices in use which sense angular position, one of the most common being the **optical shaft encoder** described in 'About position sensors'. It is not very difficult to make such a device and the Salters Horners Advanced Physics Course Resources pack 2, published by Heinemann Educational, includes construction details for one attached to a model airliner front nose-wheel, to model the method by which the position of an Airbus nose-wheel is sensed.

For graph plotting, dealing with uncertainties and best-fit lines, software packages such as djb microtech's Simple Data Handling software may be found preferable to the use of a spreadsheet.

***Note**: The displayed resolution of the angle of rotation on the computer screen will not actually be correct. Although this can be dealt with in setting up PicoScope it is better to leave it as it is, and discuss the issue with students.*

Typical results

The results with a multimeter/voltmeter and with DrDAQ will not agree due to their differing impedances:

Angle of rotation /°	Voltage output / V using a voltmeter	Voltage output /mV Using DrDAQ
0	0.00	9
30	0.07	66
60	0.67	582
90	1.21	1054
120	1.71	1509
150	2.24	2034
180	2.82	2603
210	3.36	3119
240	3.95	3798
270	4.56	4683
300	4.69	4994

POSITION (ANGLE) SENSORS
TECHNICAL NOTES

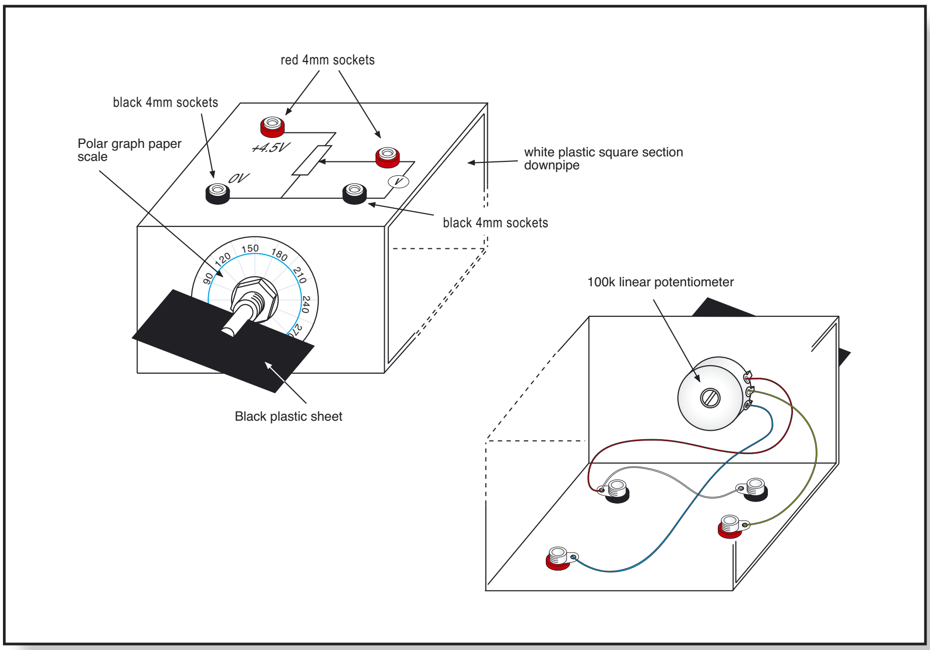
USING A ROTARY POTENTIOMETER TO SENSE THE POSITION OF A MODEL AILERON

(I) USING A MULTIMETER OR VOLTMETER

Note: *Many components and items of equipment are commonly available in science departments, or can be obtained from a wide range of suppliers. Where equipment and components are listed with a supplier and product code, these are less widely available and are the versions used when the activities were developed, so any sample results will be based on them. It may be possible to obtain the same or equivalent equipment or components from other suppliers.*

Equipment:
6V (4.5V) battery
multimeter or voltmeter
connecting leads
model aileron unit – see construction diagram
2 x red 4mm sockets
2 x black 4mm sockets
100kΩ linear potentiometer
equipment wire black
black plastic sheet 1.5mm thick
liquid polystyrene cement
white square-section plastic downpipe
polar graph scale

For polar graph paper (to make potentiometer scale) – go to freeware site at ***http://www.engj.ulst.ac.uk/sidk/graph/graph.htm*** for download of a programme to print polar and many other kinds of graph paper. Mark the scale every 30° from 0° round to about 300°.



Diagrams of construction of model aileron

(II) USING A ROTARY POTENTIOMETER WITH PICOSCOPE ON DrDAQ TO SENSE THE POSITION OF A MODEL AILERO

***Note**: The activity notes and technical notes are for DrDAQ and associated computer equipment, but other datalogging equipment could also be used, with modification of the student activities Word version.*

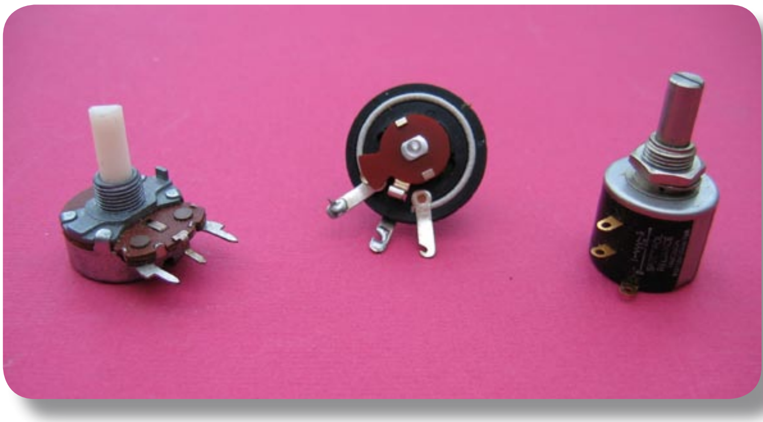
***Note**: If the computers are connected to a network you may need to provide some additional notes for the students on their use with DrDAQ and PicoScope.*

Additional equipment:
computer
*DrDAQ** and associated connecting cable, plus PicoScope software (Pico Technology)

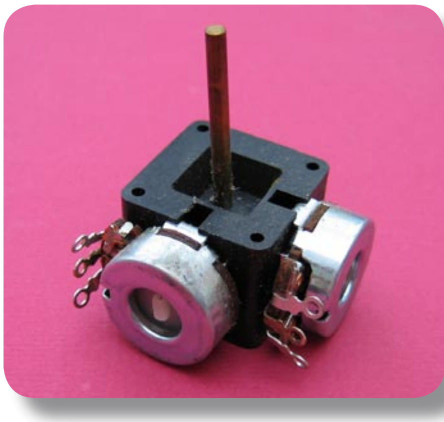
*It is useful to mount *DrDAQ* onto half square-section downpipe using Velcro. Then link *DrDAQ's* V terminal to a red 4mm socket, its R terminal to a 4mm blue socket, its DO terminal to a 4mm yellow socket and its GND terminal to a 4mm black socket.

About position (angle) sensors

It is fairly common for a **potentiometer** to be used as a position sensor, whether it is a rotary or a linear version. Indeed, many robot arms use them, as do some computer games joysticks like the one shown, with its outer casing removed.

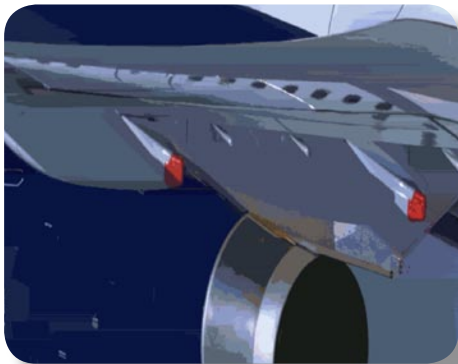


Rotary potentiometers



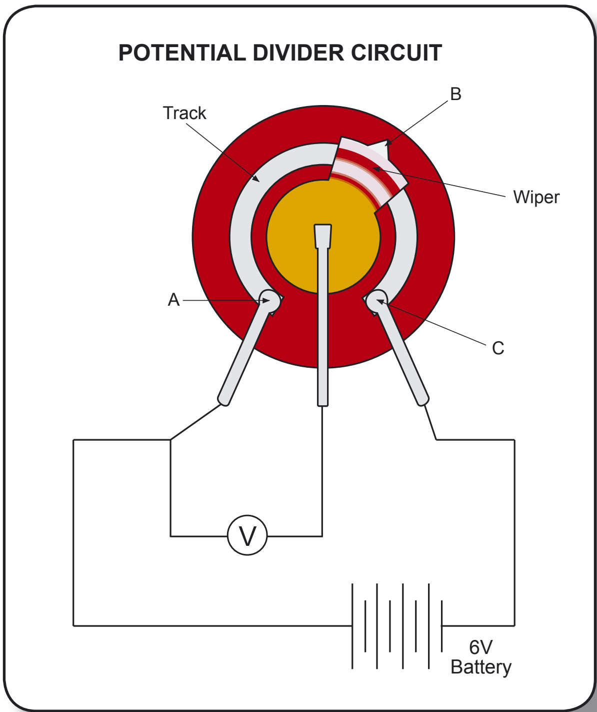
Joystick with outer casing removed, showing two rotary potentiometers

Although you will be most used to a rotary potentiometer as a variable resistor, often in a volume control or as part of a potential divider network, it can also play the part of a position sensor. For example, many aircraft, such as the A321 Airbus shown, use them to sense the positions of their ailerons and their flaps.



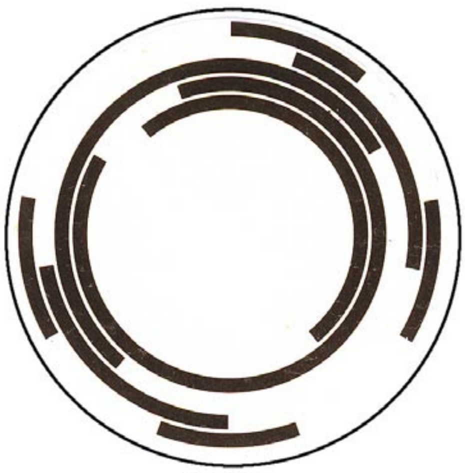
A320 Airbus and close-up of ailerons (courtesy Airbus)

About position (angle) sensors



Potential divider circuit

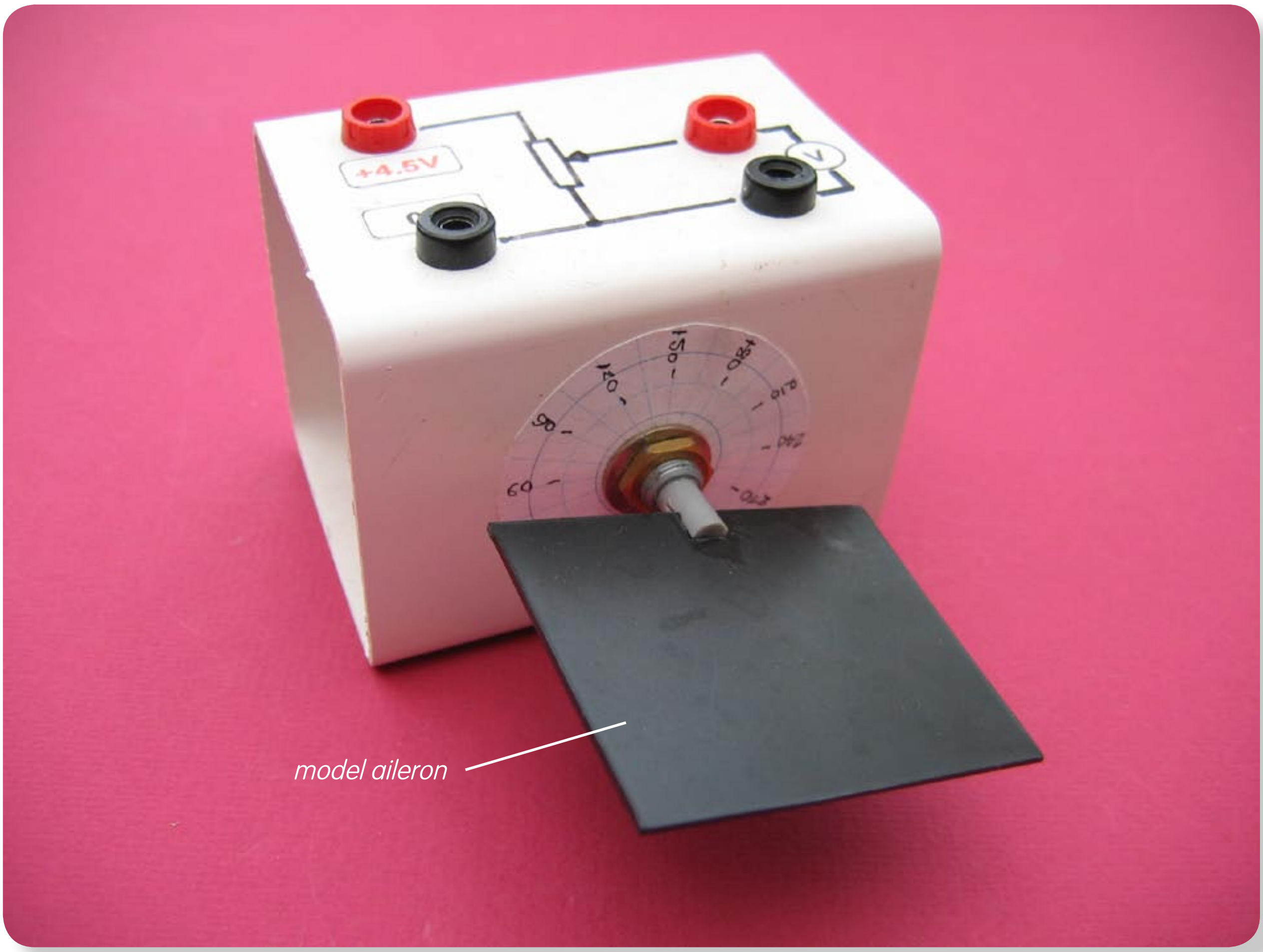
The arrangement used is that of a **potential divider,** with the spindle attached to the aileron or flap. As the aileron is rotated, so the spindle of the potentiometer rotates and moves the position of the wiper on the track. If the wiper is at position A then the voltage output will be 0V, at C near 6V (this depends on the internal resistance of the battery and the resistance of the voltage measuring device), and at B some value between 0V and 6V. This voltage information is fed to the aeroplane's computer, which then adjusts the pilot's display panel to show the aileron's position.
A problem can, however, occur with the use of potentiometers as position sensors. Whatever is being moved needs to be capable of overcoming any frictional resistance that occurs between the wiper and the resistive track. To avoid this problem the use of **incremental** and **absolute shaft encoders** is also common. The descriptions here are of **optical shaft encoders**, but there are also **magnetic** versions of shaft encoding systems. The **incremental shaft encoder** disc consists of holes or slits through which light from a light emitting diode (LED) can shine. Opposite the LED is a photodiode or phototransistor light sensor. The faster the disc rotates, the more flashes of light this light sensor will receive, so the number of flashes can be used to indicate the **amount of rotation** that has taken place, or to measure the **speed of rotation**.



Absolute shaft encoder disc

The **absolute shaft encoder** works on a similar principle involving shining light onto a rotating disc but, instead of sensing position by counting flashes of light, this system uses a disc with black and white sections on it as shown. Light shining on the disc from a series of LEDs will be absorbed by black sections but reflected by white sections: the exact position of the disc, and whatever is attached to it, controls which combination of which light sensors will be illuminated.

Using a rotary potentiometer to sense the position of a model aileron

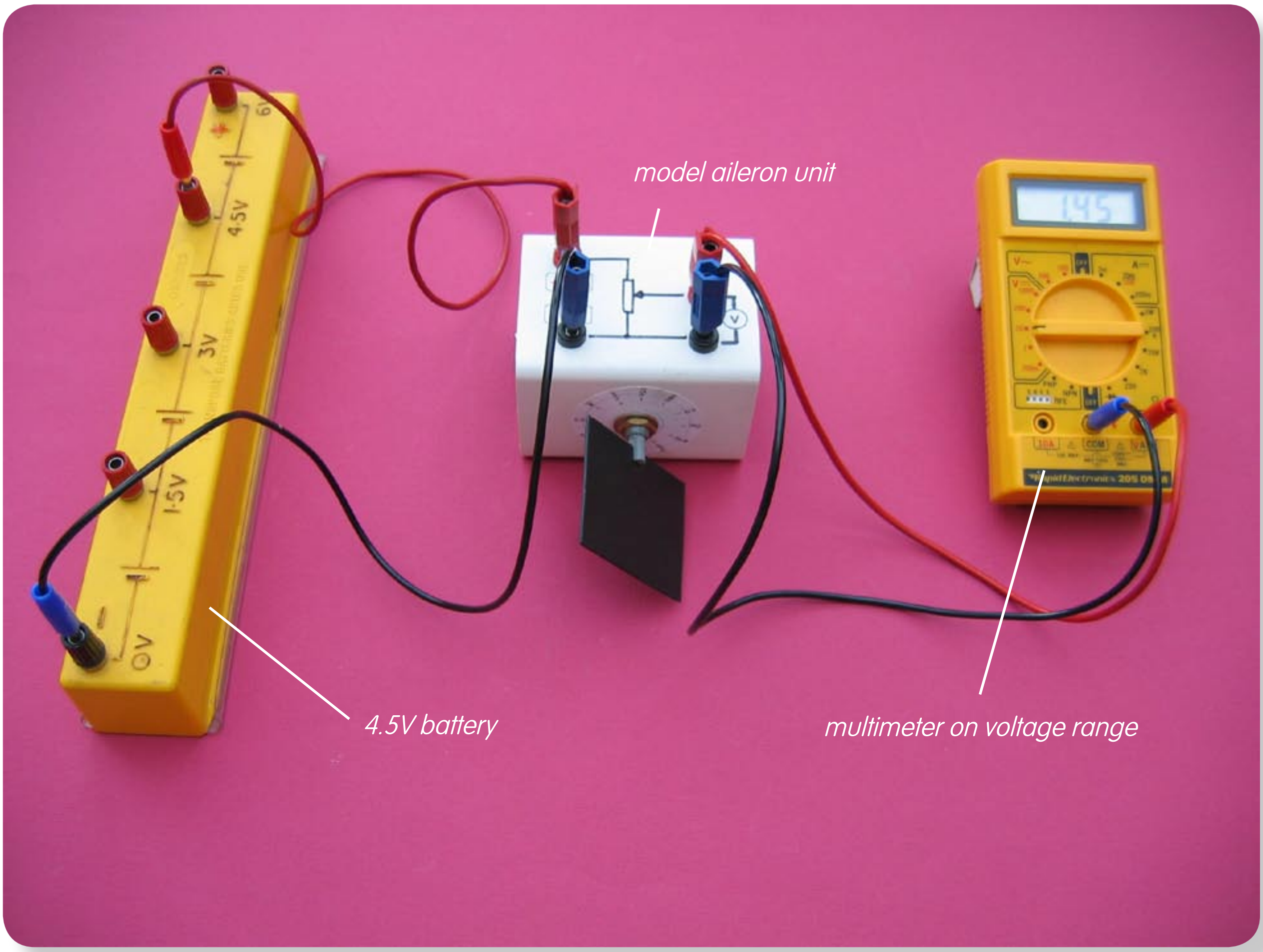


Model aileron attached to a rotary potentiometer

You might have thought that the simplest way to sense a model aileron's position when it is connected to a rotary potentiometer is to measure the change of resistance with angle of turn. Whilst this is a simple approach which would work, it is not the one used commercially: this relies on the measurement of a **voltage output** from a potential divider set up.

Activity (i): Using a multimeter (or voltmeter)

Procedure



Set up of model aileron with battery and multimeter

Calibration:

- Connect the red +4.5V socket on the model aileron unit to the +4.5V socket on the battery and the black 0V socket to the 0V socket of the battery.
- Connect the output voltage sockets to a multimeter set on its 20V range or to a 5V or 10V voltmeter.
- Check that rotation of the model aileron does change the voltage output.
- Record the voltage output from the sensor for each of the angles of rotation listed from 0° to around 300°. In reality an aileron would never rotate through such a large range.
- Now plot a graph of voltage output (Y-axis) against the angle of rotation (X-axis) and incorporate a best-fit line. You could do this manually or by entering your results into a graphing package or spreadsheet.

Using the calibrated rotation sensor:

You will now have **calibrated** the rotation sensor, producing a graph or calibration 'curve' which you will be able to use to help you find the value of an unknown position or angle.

- Rotate the model aileron but **do not** note its position at this stage. Record the voltage output.
- Using your calibration 'curve' note down what you think the model aileron's position must be.
- Now check what its position is.

Activity (i): Using a multimeter (or voltmeter)

Results

Angle of rotation /°	Voltage output /V
0	
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	

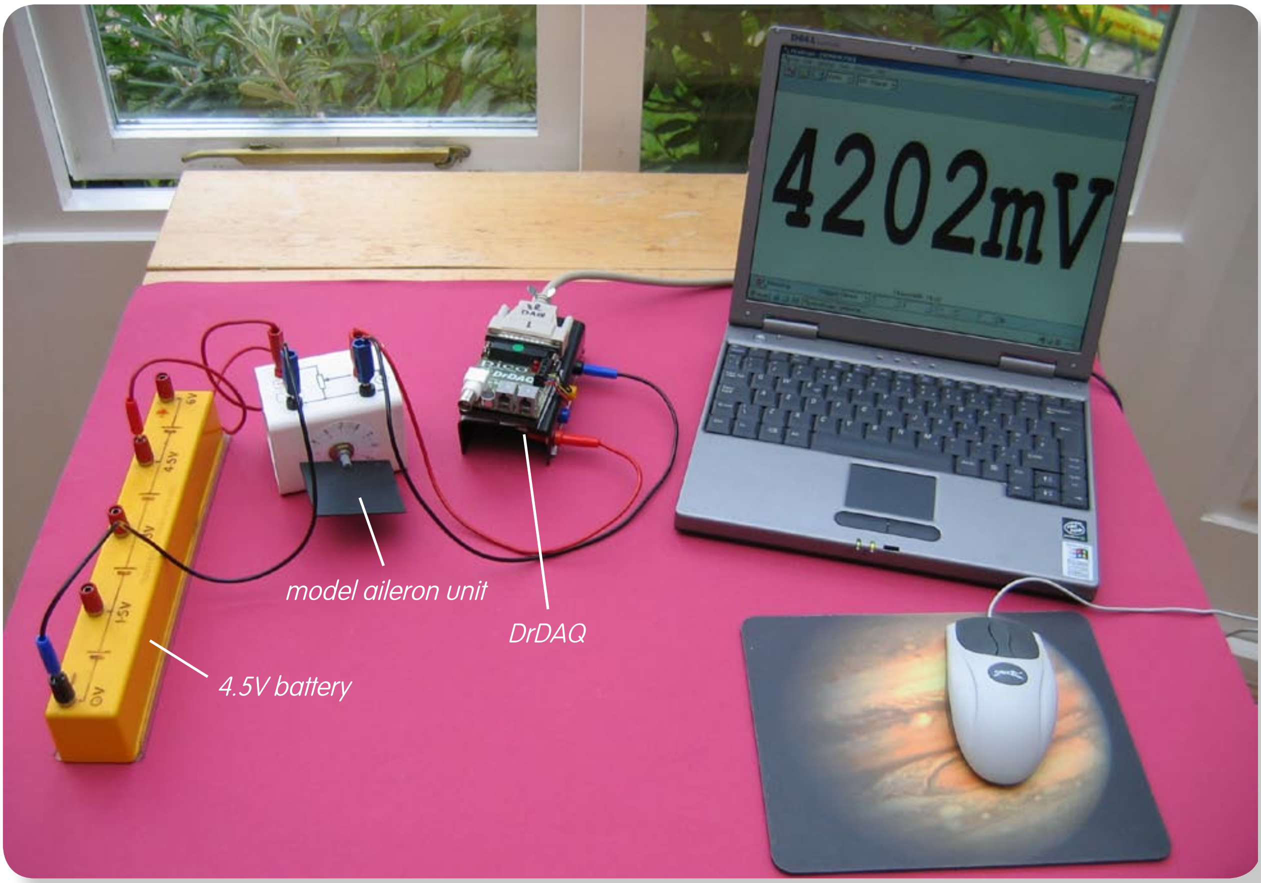
Questions

Does your graph show the voltage output to be
(a) **linearly related to** the angle of rotation of the model aileron
and
(b) **directly proportional to** the angle of rotation? Explain.

How close was your estimated position to its actual position?

Activity (ii): Using PicoScope on DrDAQ

Procedure



Model aileron with rotary potentiometer sensor set up to use with PicoScope on DrDAQ

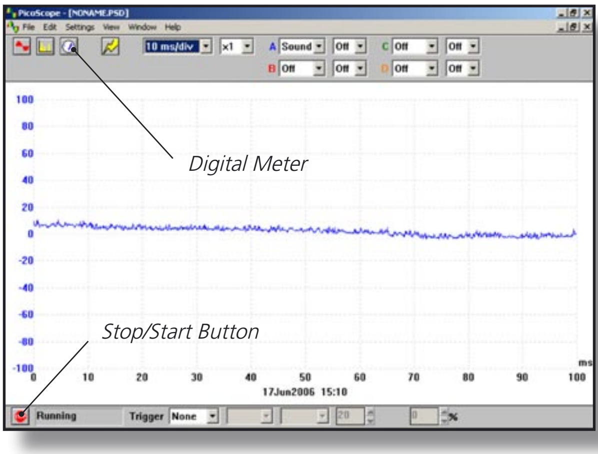
Calibration:

Note: If you are connected via a network you may need to obtain additional instructions.

Before the computer is switched on check that DrDAQ has been plugged into the computer.

- Connect the red +4.5V socket on the model aileron unit to the +4.5V socket on the battery and the black 0V socket to the 0V socket of the battery.
- Now connect the **red** output voltage socket of the model aileron unit to the **V** socket on *DrDAQ* and the **black** output voltage socket to the **GND** socket on *DrDAQ*.

Activity (ii): Using PicoScope on DrDAQ

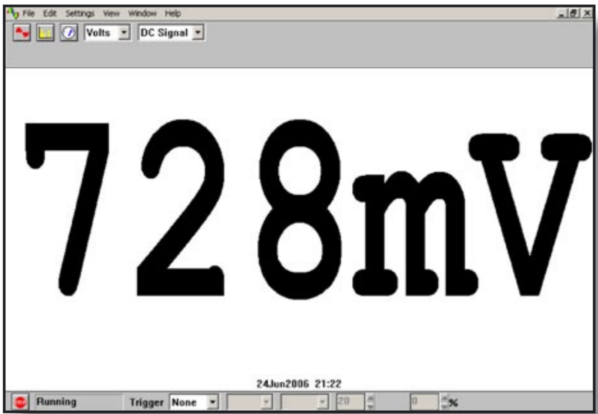


DrDAQ opening screen

- Switch on and load the *PicoScope* software. If necessary, enlarge by clicking the ☒ in the top right-hand corner of the screen to provide a full screen display as shown with the program already running.

Note: If the program appears to have frozen at any time then it can usually be unfrozen by pressing the F10 function key. If this does not succeed then close down the program by pressing the **Ctrl, Alt** and **Delete** keys simultaneously, and then restart the program.

- Click the **STOP** button in the bottom left-hand corner of the screen.
- Close down the Oscilloscope mode by clicking the lower of the two Xs in the top right-hand corner of the screen.



Digital Voltmeter display

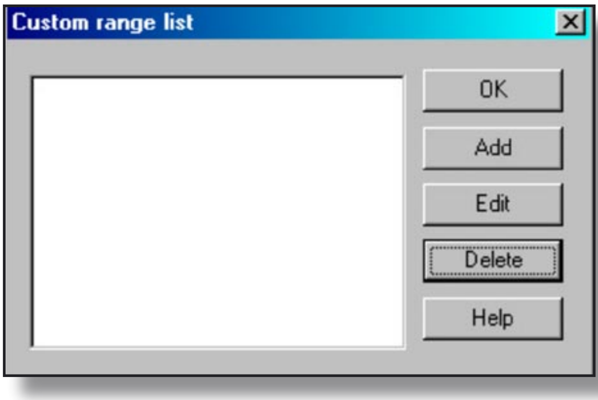
- Now click on the **Digital Meter icon** in the Toolbar, select **Volts** and **DC Signal** and then click the **GO** button to put PicoScope into Display Voltmeter mode. Rotate the model aileron to check that the potentiometer sensor is functioning and you should get a display like that shown, though not necessarily of that value.
- Record the **voltage output** from the sensor for each of the angles of rotation listed from 0° to around 300°. In reality an aileron would never rotate through such a large range.
- Now plot a graph of **voltage output** (Y-axis) against the **angle of rotation** (X-axis) and incorporate a **best-fit line**. You could do this manually or by entering your results into a graphing package or spreadsheet.

Activity (ii): Using PicoScope on DrDAQ

Using the calibrated angle of rotation sensor:
You will now have **calibrated** the sensor, producing a graph or calibration 'curve' which you will be able to use to help you find the value of an unknown position or angle.

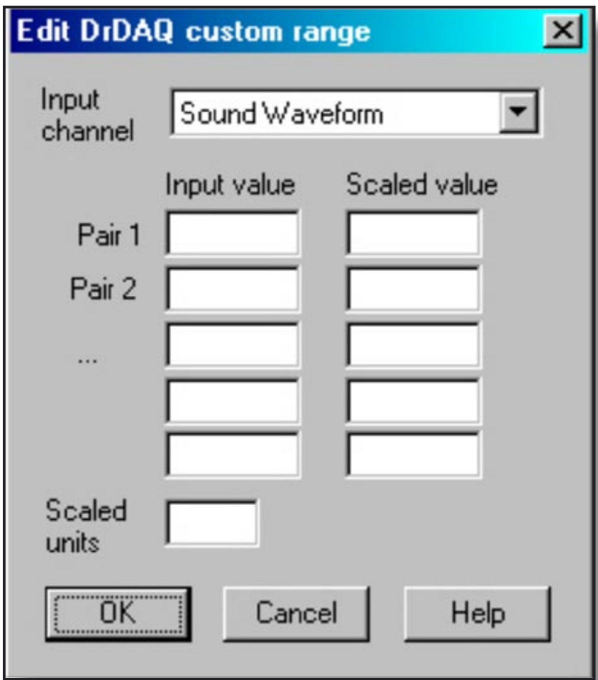
- Rotate the model aileron but **do not,** at this stage, note its position. Record the voltage output.
- Using your calibration 'curve' note down what you think the model aileron's position must be.
- Now look at what its position is.

It would be unusual to find an instrument which had not been calibrated for direct use. With a computer-based device it is often possible to calibrate it so that it automatically displays the quantity you wish to measure directly on the screen. In this case you would want to get the computer to 'convert' the voltage output from the sensor to give an angle display on the screen. With PicoScope this is easily done by setting up a **Custom Range.**



Custom range list

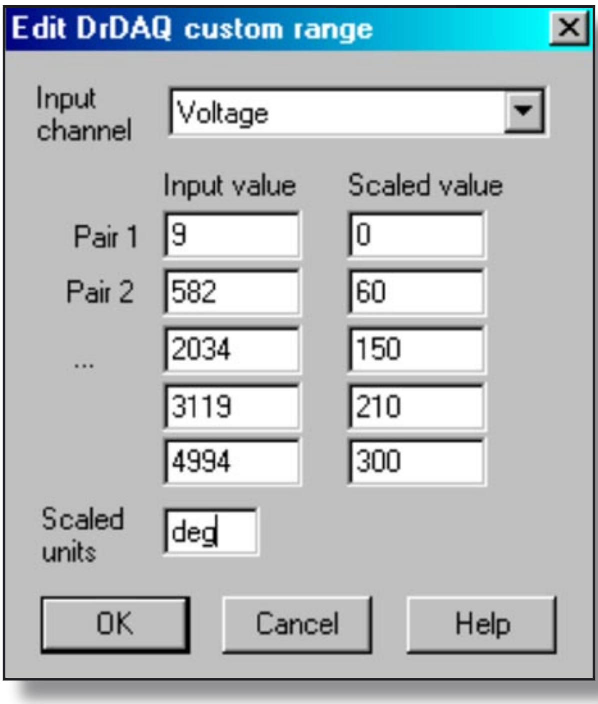
- Click the **STOP** button. Now click on **Setting**s in the Menu bar and then on **Custom ranges** in the drop-down menu to display the Custom range list as shown.



Edit DrDAQ Custom range box

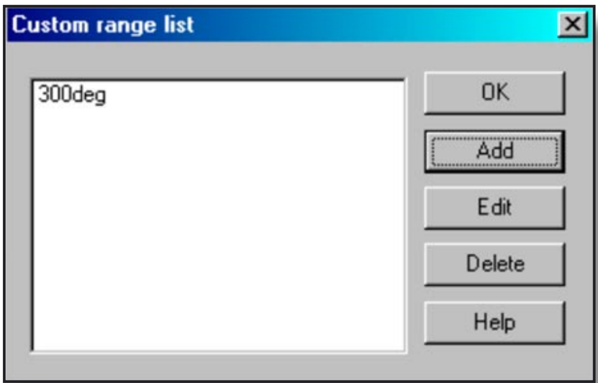
- Click on **Add** to display the Edit DrDAQ custom range box.

Activity (ii): Using PicoScope on DrDAQ



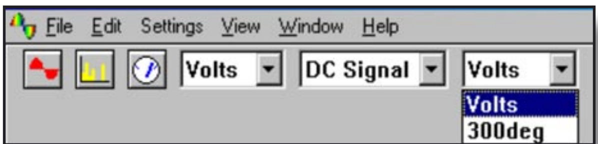
Adding values and scaled units

- Select the Input channel 'Voltage' by clicking on the down arrow alongside. Now type in your pairs of data into the two columns – **output voltages into the Input value column** and the **angles into the Scaled value column.** Ensure that you input the **smallest angle (0°)** and the output voltage that this produced as **Pair 1.** Make the **last pair** the **largest angle** (around 300°) and its corresponding output voltage.
- Type 'deg' (for degrees) into the **Scaled units** box.



Custom range list with new range added

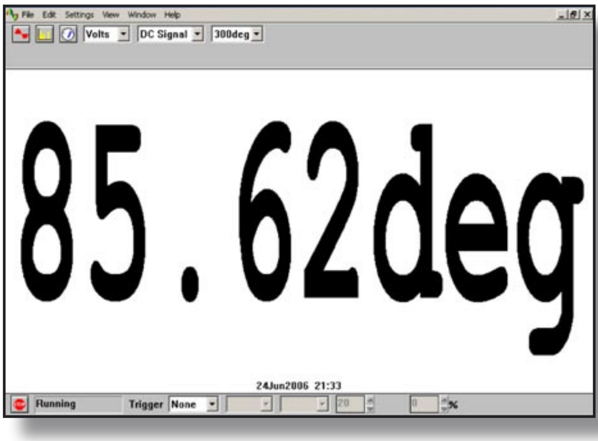
- Click the **OK** button. You should now see a '300deg' range appear in the Custom range list.
- Highlight this new range and click the **OK** button.



New range to select

- Click on the down-arrow next to the right-hand 'volts': you should see an extra box for this new range, as shown.

Activity (ii): Using PicoScope on DrDAQ



Unknown angle displayed in degrees

- Select this new range, rotate the model aileron to a new angle and then click the **GO** button. You should now see a digital meter reading displayed directly as a angle (although not necessarily the value shown)
- Click the **STOP** button.

- To return the program to its original state, first click on the down arrow alongside '330deg' and reset to 'Volts'. Now click on **Settings** in the Menu bar and then on **Custom ranges** in the drop-down menu to display the Custom range list. Highlight the newly added range and click the **Delete** button to remove it, then click the **OK** button.
- To finish with the program click **File** on the Menu bar and **Exit** in its drop-down menu to leave the program.

Note: When you keyed your data into the 'Input value' and 'Scaled value' columns you were giving the computer information from which it could estimate other values that occur in between – it **interpolates**. It is doing the same job that you do with a graph and best-fit line. If the relationship between the data is a linear one then only two pairs of data items are needed, but otherwise a spread of data pairs across the range is needed.

Activity (ii): Using PicoScope on DrDAQ

Results

Angle of rotation /°	Voltage output /mV
0	
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	

Questions

Does your graph show the voltage output to be
(a) **linearly related to** the angle of rotation of the model aileron
and
(b) **directly proportional to** the angle of rotation? Explain.

How close was your estimated position to its actual position?

How well does the displayed value for the 'unknown angle' value match with the actual value?