



Module 2, Lesson 5 – Programming a calibrated temperature sensor

Teacher

45 minutes

Purpose of this lesson

- Use values calculated in the previous lesson, to program the NXT so that it displays temperature readings on its screen in degrees Celsius.

Materials

Copy of the lesson

Computer with Mindstorms software

1 NXT with Thermistor

1 Beaker

Hot water

Ice

1 Thermometer

Graph paper (or Excel)

Procedure – Part 1

Linear approximation of sensor behavior

You currently have an NXT program which outputs the quantity (1024 – “raw sensor value”). In the previous lesson, you found the equation of a straight line relationship between temperature and the quantity (1024 – “raw sensor value”). In this lesson, we will use this straight line equation to program the NXT so that it outputs temperature values in degrees Celsius.

Your straight line equation has the form: $Y = m \times X + b$

Compare:

$$\text{Temperature } ^\circ\text{C} = m \times (1024 - \text{raw value}) + b \quad \text{equation 1}$$

Equation 1 tells us that to convert from (1024 – raw value) to degrees Celsius, we multiply by m , and then add on b .

Procedure – Part 2

- 1) Add two more steps to your NXT program, to perform multiplication by the value m, and then addition of the value b, so that the NXT displays temperature in degrees Celsius on its screen. (Use the values for m and b which you calculated in the previous lesson).

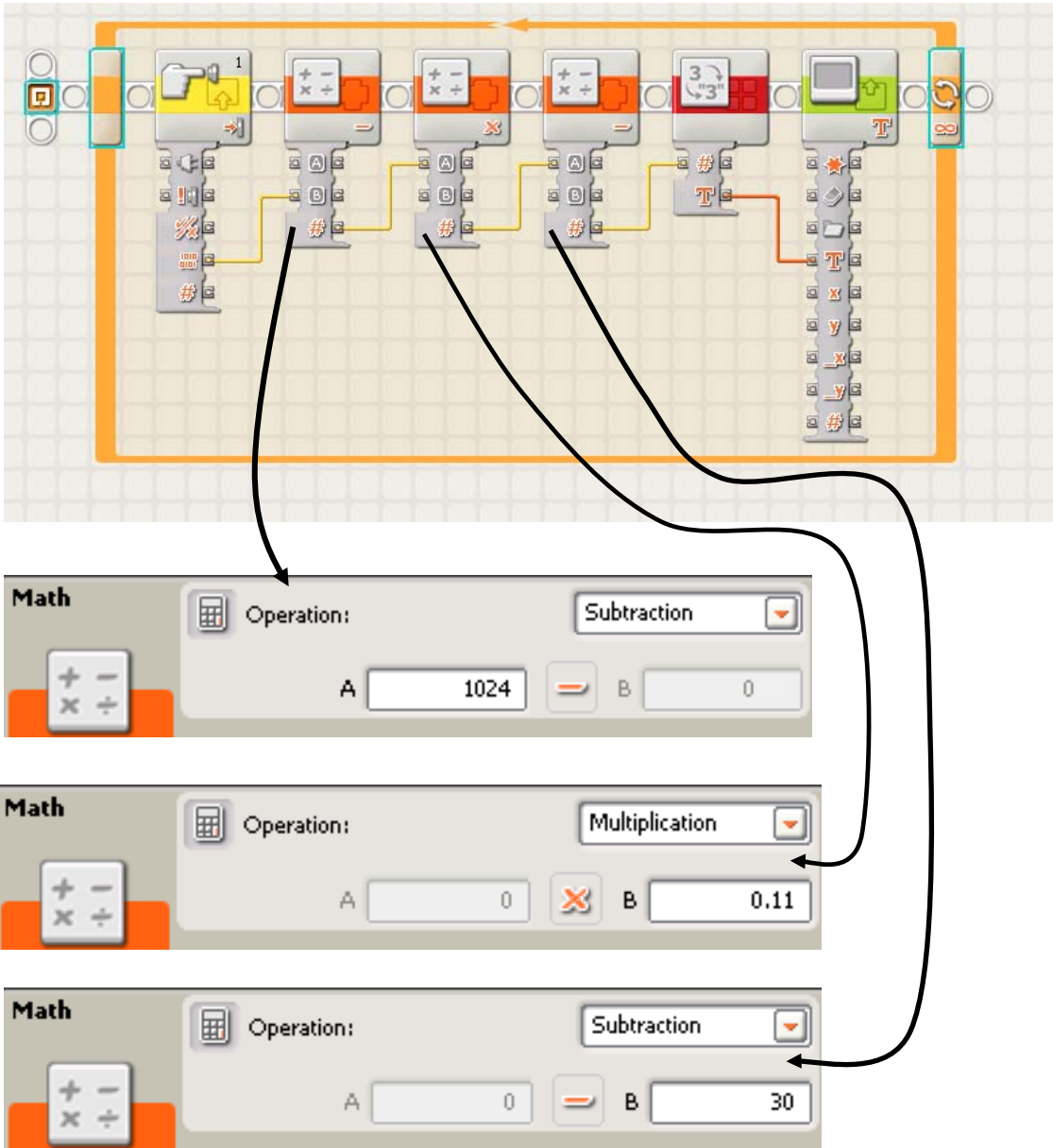


Fig. 1. Example program to display temperature in degrees Celsius.

Notes on programming

The following program (see fig. 1 above) means:

In an infinitely repeated loop:

Read the raw sensor value (0-1024 from the voltmeter in the sensor port)

Subtract the raw value from 1024

Multiply by m (using two math blocks, e.g. $\times 11 \div 100$)

Add b (here we use *minus* 30, because b is negative)

Convert the resulting number into text

Display this text on the NXT screen

Keep on repeating

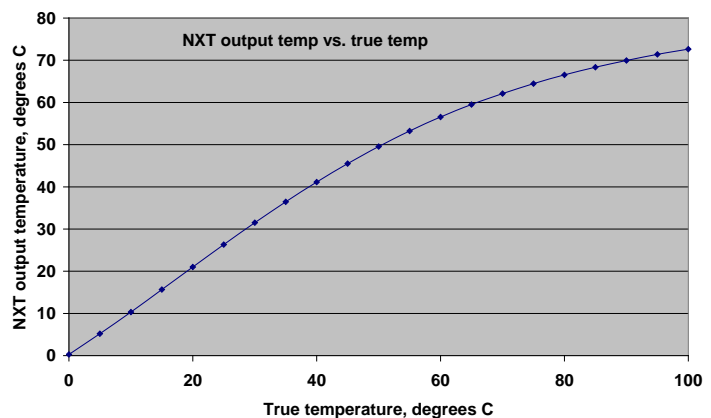
In this example the value of m is 0.11 and the value of b is -30. Note that “adding m” is equivalent to a subtraction because m is a negative number.

2) Now place the thermistor in cups of water at various temperatures. Try to cover from 0°C up to 100°C (or as hot as your teacher will allow you to go in the classroom). In each case, measure the true temperature with a thermometer, and then read off the temperature as measured by your NXT sensor system.

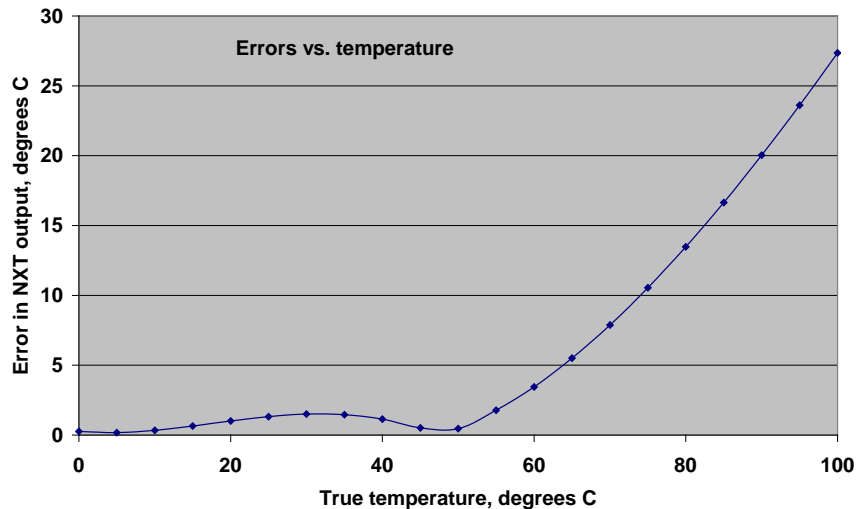
Thermometer (Temp °C)									
NXT (Temp °C)									

Assessment

1) Plot a graph of NXT output temperature versus true temperature. Use the horizontal axis (x-axis) for true temperature, and the vertical axis (y-axis) for the temperature displayed by your NXT. *Graph should look something like this:*



2) Plot another graph showing how the errors of your temperature measuring system vary with temperature. Use the horizontal axis (x-axis) for true temperature, and on the vertical axis (y-axis) plot the absolute difference between NXT output and true temperature. Note, sometimes the NXT will overestimate, and sometimes it will underestimate. Hence difference between NXT output and true temperature will sometimes be positive and sometimes be negative. By “absolute value”, we mean the magnitude of this error, ignoring its sign.



Can you come up with a formula for this absolute error?

A formula for calculating absolute error without sign, would be:

$$\text{Absolute error} = \sqrt{(\text{NXToutput} - \text{TrueTemp})^2}$$

Alternatively this will also give same answer:

$$\text{Absolute error} = \sqrt{(\text{TrueTemp} - \text{NXToutput})^2}$$

The squaring makes negatives into positives, then the rooting takes us back to the original value.

4) If you wanted to market your temperature sensing device, what would you advertise as its effective range of operation?

Accurate region is the approximately linear region in the 0-40°C range.

5) Estimate the accuracy of your system over this effective range.

Students can simply estimate a sensible plus/minus figure for their temperatures by eye.

Alternatively, they could take an average error over the 0-40°C range. Students could do this by sampling the graph of question 3, say every 5 degrees and averaging.

For more advanced students, you could note that the proper way to do this is to calculate an rms error (root mean square error), and discuss the meaning of rms.