SENSE IT

Module 2, Add on Lesson – Turbidity Sensor

Student

90 minutes

Purpose

- Construct a sensor to measure the turbidity of water
- Graph data and reason about curves and linear relationships
- Calibrate the turbidity sensor
- Write an NXT program to display and collect turbidity measurements

Materials

Copy of the lesson	Liquid electrical tape
1 Half of an NXT cable	electrical tape
1 NXT	1 Pencil
Solder and soldering iron	Paper clips
4 feet of Hook-up wire	Plastic cups or beakers
1 6 inch length of PVC tubing	Graph paper (or Excel)
1 LED	Balance/scale
1 100Ω resistor	clay
1 Photoresistor	Solutions of known turbidity for calibrating and assessing sensors

Background

Turbidity refers to how clear or how cloudy the water is; clear water has a low turbidity level and cloudy or murky water has a high turbidity level. High levels of turbidity can be caused by suspended particles in the water such as soil, sediments, sewage, and plankton. Excess soil can enter a waterbody by erosion or runoff from nearby lands. Sediments can be stirred up by activity in the water, caused by organisms living in the water, humans, machinery, and powerful weather events.

Turbidity is often measured to provide a quick estimate of the total suspended solids or sediments (TSS) concentration (in milligrams dry weight/L). If the turbidity level of the water is high, there will be many suspended particles in the water. These solid particles will block sunlight and can prevent aquatic plants from getting the sunlight they need for photosynthesis. The plants will produce less oxygen thereby decreasing the dissolved oxygen levels. The plants could die and decompose in the water, which will further reduce the dissolved oxygen levels.

Suspended particles in the water also absorb additional heat from sunlight which will result in warmer water. Warm water is not able to hold as much oxygen as cold water so dissolved oxygen levels will decrease.

Suspended particles are also destructive to many aquatic organisms. Excessive amounts can clog the gills of fish and interfere with their ability to find food. They can also bury bottom dwelling creatures and eggs. Suspended particles can transport pollutants through the water.

There are several methods to measure turbidity. One method is with a Secchi disk. This disk has a black and white pattern on it – a "Secchi pattern". The Secchi disk is slowly lowered into the water until it is no longer visible – then the depth at which it disappears from view can be used as a measure of turbidity. This "Secchi depth" is inversely proportional to turbidity – a large Secchi depth indicates a low turbidity and a small Secchi depth indicates a high turbidity. A Secchi disk is useful in deep water, but not very usefu in shallow water because you might not be able to lower it deep enough for it to disappear from view.

For shallow waters it can be useful to measure turbidity with a transparency/turbidity tube. A turbidity or transparency tube is a graduated glass or plastic measuring cylinder, with a small black and white Secchi pattern at the bottom. Sample water is collected and added to the tube until the Secchi pattern on the bottom is no longer visible – the depth of water in the tube can now be used as a measure of turbidity. The tube is calibrated so that the turbidity can be read off the side in appropriate units.

Units of turbidity

There are a variety of different units that can be used to measure turbidity. Secchi depth is often used in deep water. Turbidity tubes are sometimes calibrated in Jackson Turbidity Units (JTU)- originally defined as a measure of how much water is needed to obscure a candle flame viewed through a turbidity tube. Electronic turbidity meters are typically calibrated in Nephelometric Turbidity Units (NTUs) which are a measure of how much light is scattered or reflected off particles suspended in the water.

Often the purpose of measuring turbidity is to estimate the total suspended solids (TSS) in the water. In such cases the turbidity sensor can simply be calibrated in units of grams of suspended solid per liter of water. This is the approach we will take in this lesson. Note that this method will not give you an accurate measure of the suspended solids in the actual lake or river you are measuring, unless you use the same kinds of solids when you calibrate your sensor in the laboratory. For example, for the same number grams of suspended solid, different kinds of solids (substance, particle size, etc) will cause different turbidities.

A turbidity reading of 0-10 NTU is considered normal. A clear mountain stream might have a turbidity of around 1 NTU, whereas a large river like the Mississippi might have a dry-weather turbidity of around 10 NTUs. These values can jump into hundreds of NTUs during runoff events. Therefore, the turbidity meter to be used should be reliable over the range in which you will be working.

A Secchi depth less of less than 1 meter indicates a high concentration of suspended solids.

Electronic turbidity sensor
In this lesson you will build an electronic sensor to measure turbidity. The sensor consists of two main components: a light source (light emitting diode or LED lamp) and a light sensitive device (photoresistor). The LED and the photoresistor are fixed a short distance apart in such a way that water can flow between them. The more turbid the water, the less light from the LED lamp will reach the photo-resistor. The photo-resistor is a device which changes its resistance depending how much light falls on it. Therefore, by measuring the resistance of the photo-resistor, you can measure how much or how little light reached it from the LED lamp, and therefore turbidity.

<u>Procedure</u>
Part 1 – Constructing a turbidity probe and connecting it to the NXT

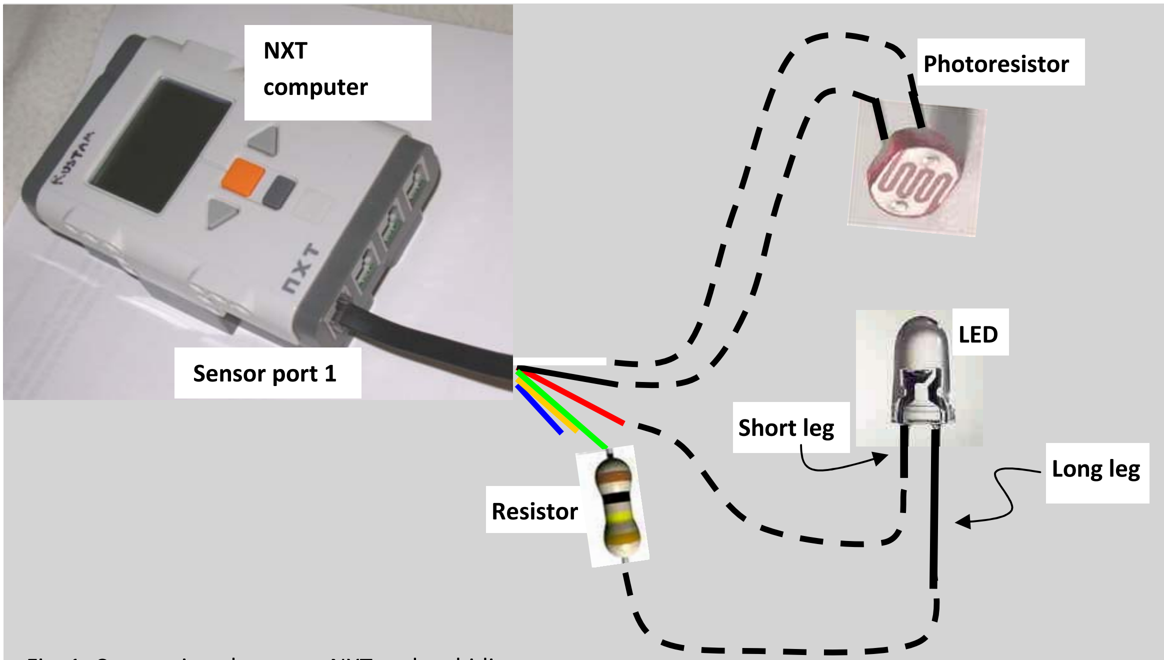


Fig. 1. Connections between NXT and turbidity sensor components

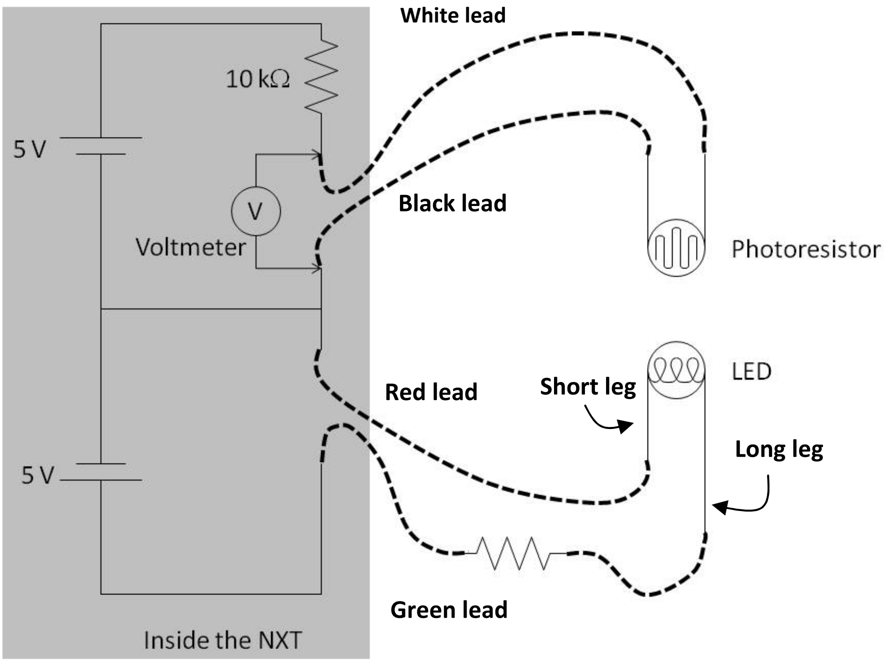


Fig. 2. Circuit diagram of NXT and turbidity sensor components.

How it works:

The green and red leads supply 5V across the resistor and LED, which makes the LED light up – this part of the circuit is just like connecting a battery across a light bulb. The resistor is included simply because it causes less current to flow through the circuit , preventing the LED from being damaged by too much current.

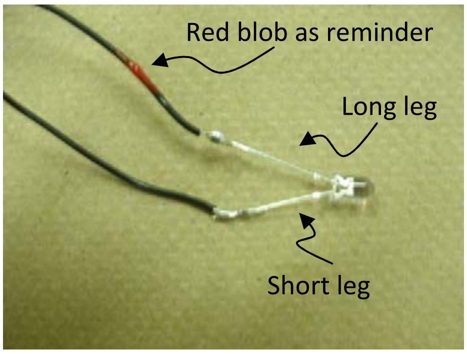
The black and white leads connect the photoresistor across the NXT's internal voltmeter – the same way as the thermistor across the NXT voltmeter.

As water turbidity increases, less light will reach the photoresistor, and resistance increases. Similar to the thermistor, the photoresistor forms a potential divider circuit with the NXT's internal 10kΩ resistor and the NXT's internal 5V battery. The bigger the resistance of the photoresistor, the bigger the portion of the NXT's 5V will be divided across it, and increased raw values measured by the NXT's internal voltmeter.

Construction:

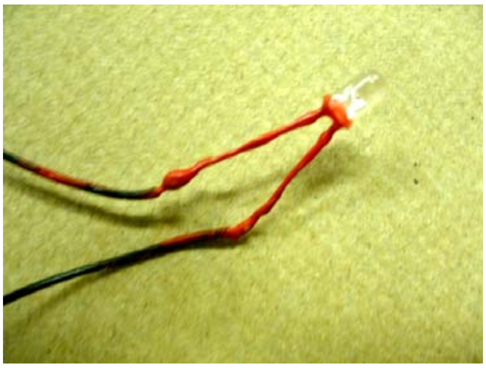
1) Apply liquid tape to the LEDs and photoresistors as shown (make sure to leave the ends bare to solder hook-up wire). Try to coat the wire legs fully so that the wire is fully covered all the way up to the base of the component itself. The sensor will only work if the connections are fully waterproof. Be careful not to block the LED lens or the photoresistor surface.

2) Solder each of the LED legs to a piece of hook-up wire. CHECK WHICH LED LEG IS LONGEST, AND LABEL THE HOOKUP WIRE CONNECTED TO IT (for example, you could use a blob of liquid tape, as shown). Later we will have to be careful to connect the LED across the NXT the right way round-it only works one way and not the other.



3) Solder the leads of the photoresistor to two more pieces of hook-up wire.

4) After soldering, coat the connections to both the LED and the photoresistor with liquid tape. Make sure no bare wire or solder is left unsealed. Your sensor may not work properly if any wire or connection is left exposed to the water.



5) Solder the resistor to the other end of the hook-up wire connected to the longer lead of the NXT (the one you marked with a red blob in step 1). (If you forgot to mark the wire and now you can't tell which lead is which, ask your teacher for help).

6) Take half of an NXT connector cable, strip off an inch of the black outer jacket, and strip the ends of black, white, red, and green leads which you find inside. The yellow and blue leads are not needed so they can be clipped off short or just folded out of the way.

7) See figure 1. Solder the free end of the resistor to the green lead.

8) See figure 1. Solder the red lead to the remaining end of hook up wire coming from the short leg of the LED.

9) See figure 1. Solder the two hook up wires from the photoresistor to the white and black leads – it doesn't matter which way round.

10) Coat any exposed wire or soldered connections with liquid electrical tape.

11) Wrap a pencil with black electrical tape, this will minimize light reflection.

12) Fold back a few inches of each of the four hookup wires and tape them to the black NXT connector cable. Place the LED and photoresistor 1 inch apart. The distance between the LED and photoresistor will alter results between sensors, so do not become overly concerned if your data does not exactly match with classmates data.

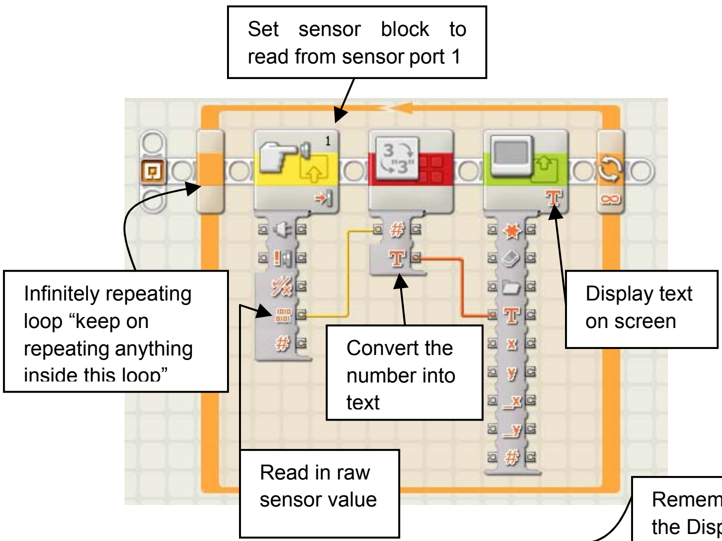
13) Place the LED and photoresistor toward one end of the pencil, not the center. To minimize the amount of water your sensor will require to collect data, the LED and photoresistor should be placed closer to the end of the tube you will submerge in the water, however not at the very end of the tube because that will allow too much light between the LED and photoresistor.

14) Secure all of the wires to the pencil wrapped with electrical tape - this will help prevent accidental strain on the solder connections.

15) Slide all of the wires and pencil into the PVC tube section and secure wires and pencil with paperclips to the end of the tube to prevent the sensor from moving too much within the tube.

Experiment 1 – variation of NXT raw values with turbidity

NXT programming: Write and download the following program into the NXT. It measures the voltage across the photoresistor (as an NXT raw value) and displays it on the screen.



This NXT code means:

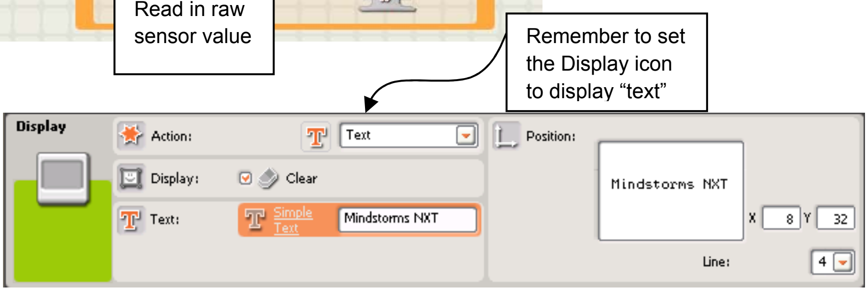
In an infinitely repeating loop:

Read the raw sensor value (0-1023)

Convert this number into text

Display the text on the NXT screen

Keep on repeating



Experimental procedure:
1) Submerge your turbidity sensor in the water and read the corresponding NXT raw value from your NXT screen. Record your values in table 1.

2) Repeat this procedure for several successive dilutions. Each time you put your sensor in a cup, you MUST do three things:

- Rinse your sensor in the rinse water.
- Stir the cup very well (and right down to the bottom) right before you put your sensor in.
- Try to take your measurement within 10 seconds or so after stirring.

Note to teachers: Time permitting, you may want students to measure each container two or three times (stirring before each trial), and average the results.

Table 1

Turbidity **TSS (mg/L)**	0					
NXT Raw Value						

6) Plot a graph of your results. Use the horizontal (x) axis for NXT raw value, and the vertical (y) axis for turbidity.

Experiment 2 – calibrating and testing your turbidity sensor
Modify your NXT program to output turbidity in correct units of TSS mg/L instead of "raw NXT values".

To do this, you must first find a mathematical equation which describes the relationship between NXT raw values and turbidity in mg/L, and then program this equation into the NXT so that it can convert from NXT raw values to TSS mg/L.

1) Using a ruler (or Excel), plot a best fit straight line through the points that you plotted on your graph in experiment 1.

2) Find the equation of this straight line in the form of **y = mx + b**
i.e. use your graph to find correct values for the constants **m** and **b**, where **m** is the gradient of the line, and **b** is the y-intercept.

You now have a relation of the form:

$$\text{turbidity} = \mathbf{m} \times \text{“NXT-raw-value”} + \mathbf{b} \qquad \textbf{equation 1}$$

compare: $$\mathbf{y} = \mathbf{m} \times \mathbf{x} + \mathbf{b}$$

This equation converts NXT-raw-values into turbidities.

3) Add more program blocks to your NXT program – use equation 1 to make your NXT output turbidity in units of mg/L TSS.

Your program needs to do the following:

In an infinitely repeating loop:

Read the raw sensor value (0-1023)

Multiply raw sensor value by gradient value **m**

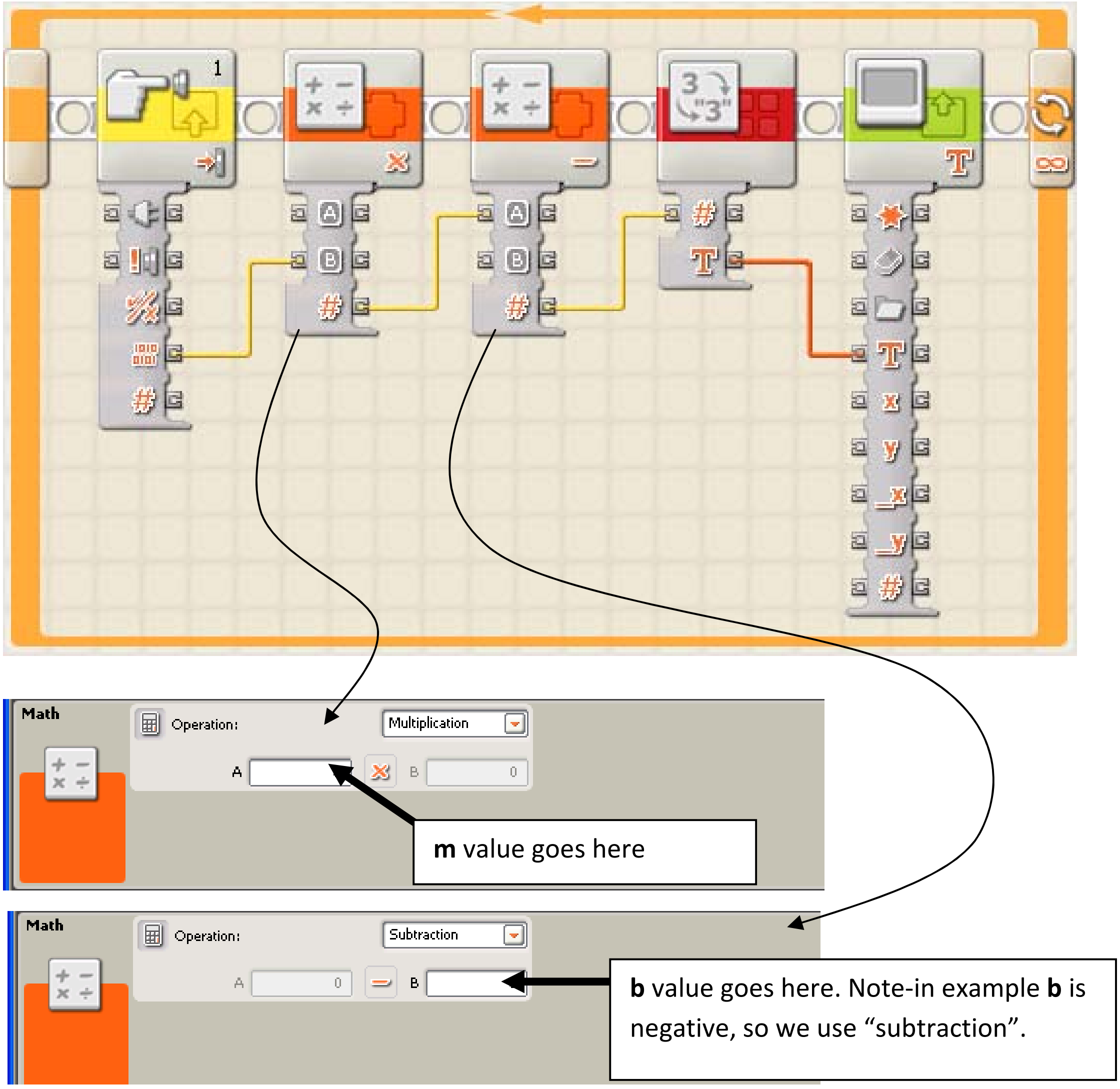
Add the y-intercept value **b**

Convert the resulting number into text

Display the text on the NXT screen

Keep repeating

Your program should look something like this (see next page):



Your NXT should now display turbidity in units of mg/L TSS.

4) Test your sensor by re-measuring the solutions of known turbidities. Does your NXT display the correct turbidity values in mg/L TSS?

5) Ask your teacher for samples of unknown turbidity and use you sensor to measure the turbidity. Record your results below.

Assessment

1) In steps 4 and 5 above, what was the error in each case, and what was the average error?

2) If you were going to market the turbidity sensor, what would you advertise as its accuracy?

3) What are the possible sources of error?

4) List two improvements you could make to create a more accurate turbidity sensor.