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UNIVERSITY OF NEVADA, RENO

USER MANUAL



Introduction to Lego Kit, NXC and ROS

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INTRODUCTION TO THE LEGO MINDSTROMS EDUCATION KIT

What's in the kit?

The kit contains two pamphlets which provide the details of the parts in the kit. The pamphlet with the number 4581599 (at the top of the pamphlet), provides a picture of each part, its part number and quantity of the part in the kit.

For example: Here the picture represents the part called ½ yellow Bush, 10x means there are total of 10, ½ yellow Bush in the kit and the number after x is the part number.  10x 4239601

The other side of this pamphlet and the other pamphlet represents the same details as the side that we just saw but without the part numbers. You will be given other sensors, detail of which is not included in these pamphlets because those are ordered separately. Details of those parts are given briefly in the next section and will be discussed throughout the paper. So now that you know what's in the kit, let's move on to how to use those parts.

Where to use what?

Most of the connectors, bricks and plates will be used to build the robot. If you need to build a specific type of robot the step by step instructions will be given in the lab handout. Otherwise, you can use those parts as you need to meet your assignment details.

The part with the number 4558295, is called the intelligent micro-computer LEGO **Brick** (also known as the NXT brick), acts as the brain of the robot. The brick has a USB port which lets the user download the programs from computer to the brick. Besides the USB port, the brick has four input ports (1 to 4) to connect sensors and multiplexer for sensors (multiplexer is used if the robot requires more than four sensors) and three ports (A to C) to power motors. The brick can be charged using the charger or the 4 batteries. So no matter what the assignment is, the NXT brick is the one thing that is necessary.

The other essential part of building robots is the use of **motors**. Without motors, the robot would not be able to move. Motors are also useful when you need to rotate certain part of your robot. For example, if the robot is supposed to collect and hold balls, use motors to open and close a gate.

Now, let's learn what each sensor in you kit is helpful for in general manner. Following sensors can be connected to any of the four ports on the bottom of the NXT brick; to connect a sensor to the brick use the standard NXT wire provided in the kit.

Details of Sensors and Multiplexer

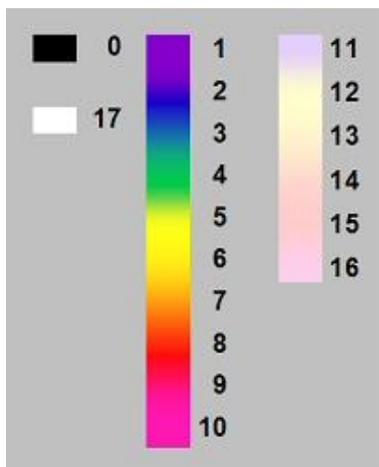
Touch Sensors:

Touch sensor helps robot avoid obstacles in its way. Furthermore, it helps detect which way the robot should go, whether the robot is stuck somewhere or not. The use of two touch sensors would make it easy for the robot to avoid obstacles, since it would help detect where the obstacles are and what the robot needs to do in order to avoid them. To connect touch sensor to the NXT brick use the cables provided in the kit.



Hi-Technic Color Sensors:

These sensors are used for the projects that are related to colors. Some of the possible usages are: search for a certain color item, follow a given colored line, avoid a certain colored object, or read the color value and based on that make a specific decision. There are many other ways one can use color sensor but for lab purposes the usage will be limited to the things mentioned above. The color sensor can detect a wide range of colors. Following is the chart of colors that a color sensor can detect and the values corresponding to those colors.



The color sensor operates by using a single white LED to illuminate the target and analyses the color components of the light reflected by the target's surface and calculates a color value which is returned to the program. Since it uses a single LED for best results, it should be positioned straight above the target surface and not at an angle to the target surface.

Sound Sensor:

This sensor is not very useful in noisy area since the sensor is able to measure noise level frequencies around 3-6 kHz where the human ear is most sensitive. The sound sensor can measure sound level in dB and dBA. To trigger the sensor user can clap hands, whistle or snap fingers to create the sound. Our lab environment is not the best environment for using the sound sensor but if noise level is kept to minimum it would work as designed.



Light Sensor:

This sensor is used to detect the light intensity. This sensor enables the robot to distinguish between light and dark, as well as determine the light intensity in a room or the light intensity of different colors. You will learn about ‘Photophilic’ (attracted to light) and ‘Photophobic’ (afraid of light) robots. So based on the lab requirements your robot will use light sensor to follow or move away from the light.



Ultrasonic Sensor:

Just like color and light sensor, Ultrasonic sensor is used as a robot’s eyes. The sensor can detect the objects and measure its closeness in inches or centimeters. The maximum distance this sensor can measure is 233 cm with a precision of 3 centimeters. How it works is that it sends out ultrasonic sound waves that bounce off an object ahead of it and then back at it. Then it senses the time it took for that to happen. Based on those two tasks the sensor returns the signal to the program.



Hi-Technic Compass Sensor:

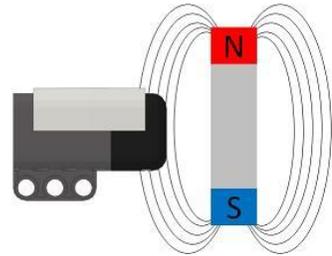
The Hi-Technic compass sensor is designed to calculate the angle it’s facing. The compass sensor has a digital magnetic compass that measures the earth’s magnetic field to calculate the angle. The calculated value of the angle is returned as a number from 0 to 359. Based on our testing, we found that the sensor is very sensitive and getting precise results requires the robot stay



horizontal, should be mounted at least 6 inches away from the motors and at least 4 inches away from the NXT brick. So when required to use this sensor the user must be very careful not to ignore the given details.

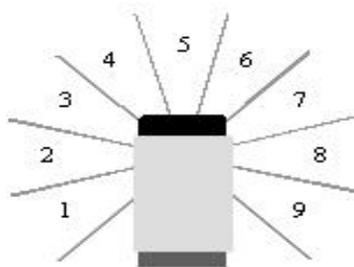
Hi-Technic Magnetic Sensor:

The magnetic sensor is used to detect the magnetic fields that are present around the front of the sensor in a vertical orientation. The picture on right side shows how the magnet should be placed for the sensor to detect the magnetic fields correctly. When the magnetic field has north uppermost, the reading will increase.



Hi-Technic IR Seeker Sensor:

IR seeker is a multi-element infrared detector and is used to detect infrared signals. One of the sources of infrared signal is the Hi-technic IR Electric Ball. The curved end cap of the sensor is designed to increase directional performance by minimizing distortion of light signals entering the sensor. The IR seeker can receive signals from 9 different angles. Following picture shows those 9 directions and its values.



For example if the value returned from the signal is 5, then the object is right ahead of the sensor. And if it's 1 or 9 then the object is behind and on left or right respectively.

When no signal is detected the sensor returns 0.

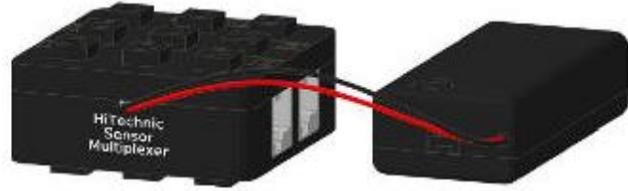
Hi-Technic Infrared Electronic Ball:

The electric ball is designed to work with IR seeker sensor. The ball has 20 infrared LEDs which helps IR seeker detect where the ball is. To turn the ball on, user needs 4 AAA batteries to power it. Since the ball has plastic shell which can be broken easily, users needs to be careful in using it. With the ball and the IR seeker a robot can be designed to play soccer. Also, if there is more than one robot designed for the same task, they can compete with each other and that would definitely be an exciting lab environment.



Hi-Technic Sensor Multiplexer:

This is very helpful equipment when a user has to use more than four sensors. With the sensor multiplexer, 4 sensors can be connected to one NXT sensor port. And if needed, more than one multiplexer can be used as well. Most of the



sensors mentioned above can be used with it but there are a few exceptions. Multiplexer requires standard 9 volt battery to power each of the attached sensors. It supports wide range of digital and analog sensors. Most of the sensors mentioned above can be used in any combination with the sensor multiplexer. Some of the exceptional sensors are: sound sensor and Hi-Technic magnetic sensor.

As mentioned above, these are the main parts which are not included in the kit and are ordered separately. Also, these are the parts that will be used on regular basis in lab. The limits and orientations of these parts should be kept in mind while building a robot and writing the program for it. These parts are sensitive so be careful to not get the sensors scratched otherwise the results might not be as precise.

Building a robot

Refer to the instruction manual in the CD provided in the kit to build your first robot. After that use the lab guidelines to build the robot that would meet all the requirements. For further help, use http://cache.lego.com/downloads/education/9797_LME_UserGuide_US_low.pdf.

Introduction to ROS

ROS is an open source operating system for robots. It provides the basic operating system services such as hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management. It runs on Unix based platform. It is implemented in C++, Python, and Lisp. More information about ROS can be found here: <http://www.ros.org/wiki/ROS>.

Using ROS with NXT:

ROS provides a NXT software stack that is essential to interface NXT robots with ROS. NXT-ROS supports NXT touch, RGB color, ultrasonic, accelerometer, gyro, and range sensors. There are some issues with using NXT-ROS which are explained in the following section.

Issues for using NXT with ROS:

Most of the sensors we are using are Hi-Technic, the reason is that they provide better results compared to regular sensors. For example, regular color sensor detects only red, green and blue while Hi-Technic color sensor has wider range and can detect colors all the colors between white and black. Hi-Technic color sensor can tell a difference between red and light pink, and from solid blue to light blue. So the main issue with ROS is that it is not compatible with all of the Hi-Technic parts. Following is the list of issues with ROS:

- ROS doesn't support Hi-technic color sensor. To use the color sensor with ROS, the user needs to be using RGB color sensor. And as we know Hi-technic color sensor provides larger spectrum for the color range compared to the RGB color sensor.
- ROS doesn't support IR Receiver and IR Seeker sensors which are used with Electronic IR ball.
- Compass sensor is another sensor that is not supported by ROS.
- Multiplexer is not supported by ROS which is a very important component in lab environment where more than 4 sensors could be used on regular basis.
- With ROS, if one has a question that he/she would like to get a response to then that person needs to rely on ROS community members' response. ROS's support website (<http://www.ros.org/wiki/Support>) says, "If you didn't get a response then likely nobody has had time to answer you. Alternatively, it could be that nobody knows the answer." So with this way

of support one might get response as soon as in a few seconds or never. ROS has a large community of users and a lot of questions are asked on regular basis so getting response is not a big problem but sometimes there are questions which no one has answer to and that is when one is left on its own to figure things out.

Those were the main problems with using ROS and that is why we chose to work with NXC (Not Exactly C). NXC works well with all the mentioned sensors and other NXT sensors and parts. NXC has a great web support; this website - <http://bricxcc.sourceforge.net/nbc/nxcdoc/nxcapi/main.html>, has the guide to NXC, function list, examples, library files and other related information to get user started with NXC and is great for reference use. Also with Google, some of the solutions to NXC related issues can be found. So, until the ROS becomes compatible with NXT sensors and parts, NXC is the best option. For more information about NXT-ROS, visit <http://www.ros.org/wiki/Robots/NXT>.

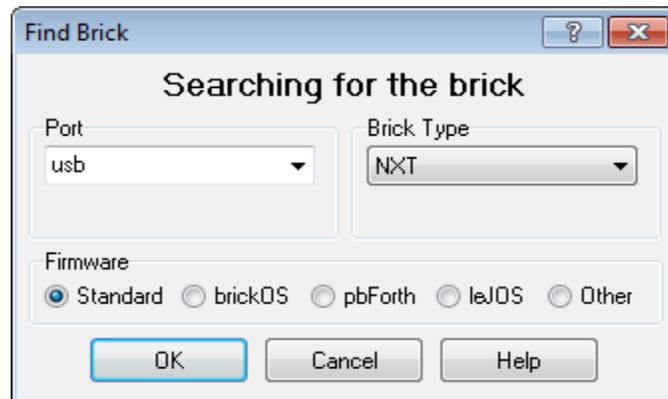
Introduction to BricxCC

Bricx Command Center also known as BricxCC is an Integrated Development Environment (IDE) used to program the Lego Mindstorms series. It runs on Windows PCs (XP, Vista and Windows 7). BricxCC allows one to write programs, download them to the robot, start and stop the programs, browse the NXT flash memory and much more. Several programming languages can be used to program the robots in the Lego kit such as Next Byte Codes (NBC), Not Quite C (NQC), and Not eXactly C (NXC). This tutorial will use BricxCC as the programming environment and NXC as the programming language to program the robots. BricxCC can be downloaded from here:

<http://bricxcc.sourceforge.net/>

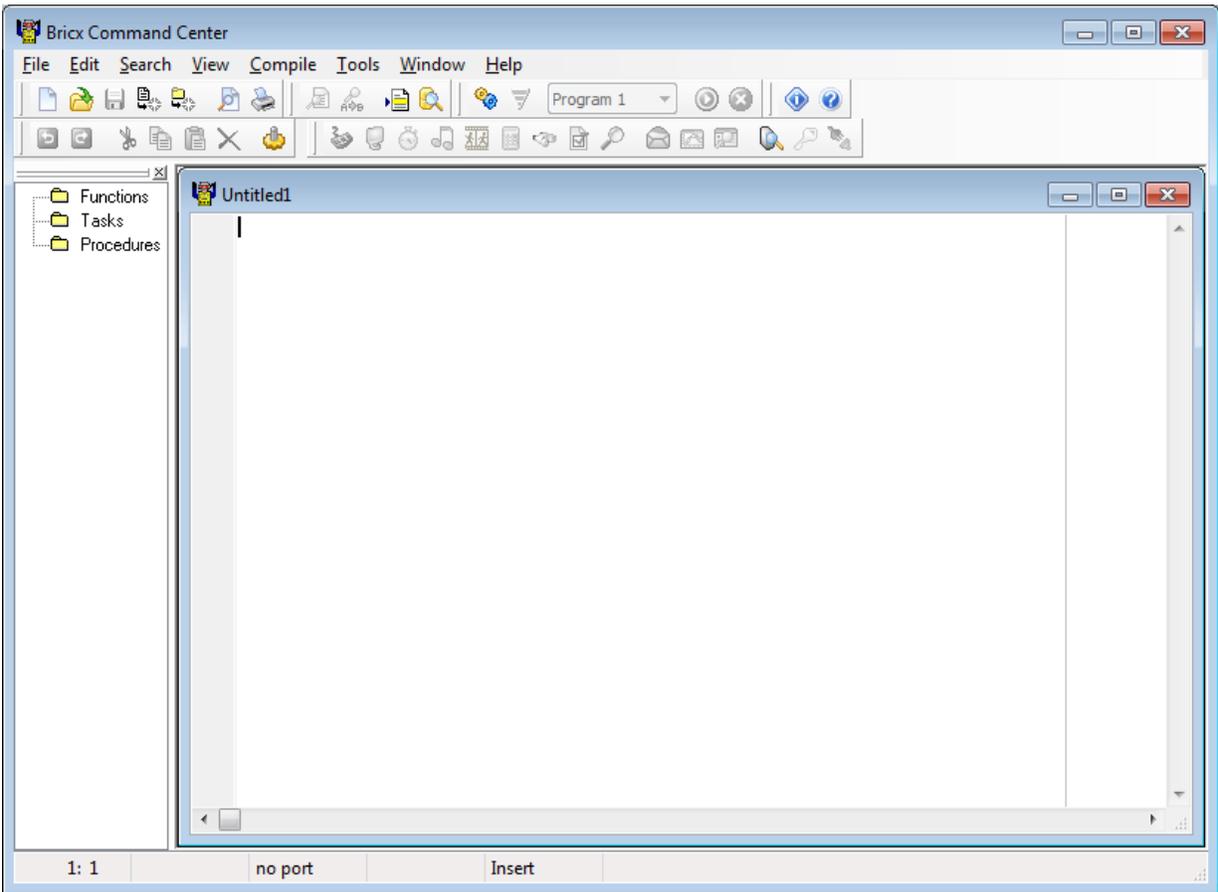
Starting with Bricx CC:

After starting the Bricx CC program, the following window appears. Select USB as a port and NXT as a brick type and click on OK.



- There is an alternate way to search for the NXT brick. After starting the Bricx CC, go to Tools from top bar menu and click on Find Brick.

The following is the screenshot of the user interface window:



The user interface window looks like and acts like a text editor. It allows one to create a new file, open a file, save, compile, download programs and etc. To create a new file, click on *File* and choose *New*. This will open a new window to start writing the program. Here is a program toolbar which will be constantly used to compile, download, run, and end programs.



Let's get familiar with what each of the buttons are used for. (From left to right), the first button is the compile button which allows the robot to execute the program, the second is the download button, it allows the user to download the program to the NXT brick via USB cable provided in the kit (the download button will not be activated if user has errors in the program, the user will be notified about the error at the bottom of the Brick CC screen), the third is the run button, it allows the

user to run the program, and the last button in red is the stop button which stops a running program. User must follow those buttons in given order. First compile the program, then download it to the NXT Brick, run the program and end the program when needed.

The downloaded programs can be found on the NXT brick. After turning on the brick, go to *My Files*, then go to *Software files* and the program files will be located under the *software files*. To run a specific program from the NXT brick itself, go to *Run*.

NOTE: In case, the user is unable to communicate with the brick, go to *Tools*, click on *Close Communication*, and then click on *Find Brick* in order to start the communication. Also if the brick hangs, take out the battery from the brick. This should be done only if other approaches fail.

Introduction to NXC

Not eXactly C (NXC) is a high level, open source programming language, invented by John Hansen. It is used to program the Lego Mindstorms NXT kit. The NXC Application Programming Interface describes the built-in functions, constants, and macros that can be used to program a robot. This document will describe the NXC implementation specifically with BricxCC.

Basic NXC Functions:

1. OnFwd(byte output, char pwr) :

This function sets **output** to forward and turns motors on with given **pwr**.

- **output:** Desired output ports. It can be a constant or a variable. Motors can only be connected in PORT A – C on the NXT brick.
- **pwr:** the motor output power. It ranges from 0 to 100. Negative numbers can be used to reverse the direction.

Example: OnFwd(OUT_A, 100)

The above function will turn on the motor connected to the *output port labeled A* on the NXT Brick with *100% power*.

2. **OnRev(byte output, char pwr) :**

This function sets output to reverse and turns the motors on.

- output: Desired output ports. It can be a constant or a variable.
- pwr: Output power, 0 to 100. Negative numbers can be used to reverse the direction.

Example: OnRev(OUT_AC, 75)

This will allow the robot to move backwards with power level 75.

3. **Wait(unsigned long ms):**

It makes a task sleep for specified amount of time.

- ms: the number of milliseconds to sleep.

Example: Wait(4000)

This statement tells the robot to sleep for 4 seconds.

Alternate function for wait: Wait(SEC_sec): This also makes a task sleep for specified amount of time.

Example: Wait (SEC_1): Allows the robot to sleep for 1 second.

4. **Off(byte outputs):**

It turns the specified motors off.

- Output: Desired output ports. It can be a constant or a variable.

Example: Off(OUT_B) : This will turn off the motor connected to port B.

5. **Random(unsigned int n) :**

Returns a signed or unsigned 16-bit random number. If the optional argument n is not provided, the function will return a signed value. Otherwise the returned value will range between 0 and n (exclusive).

- n : Returns a maximum unsigned value.

Example: Random(40): This statement will generate random numbers between 0 and 40.

6. **PlayTone(frequency, duration):**

This function plays a tone at a specified frequency and for allotted amount of time.

- Frequency: defined in Hertz
- Duration: defined in 1/1000 of a second.

Example: PlayTone(100, 300) – this plays a tone at the frequency of 300 for 0.3 seconds.

7. Unsigned long CurrentTick():

This function allows you to keep track of current system count. It returns milliseconds in a long integer.

Example: var = CurrentTick() – var will contain the current system count in milliseconds.

8. ClearScreen():

It clears the NXT brick screen.

9. NumOut(x, y, number):

- Lets the user specify the coordinates and the number.

Example: NumOut(0, LCD_LINE1, 20) : this function will print the number 20 on x coordinate and y coordinate 1. LCD_LINE1, is the first line of the LCD screen. There are total of 8 lines on the LCD screen.

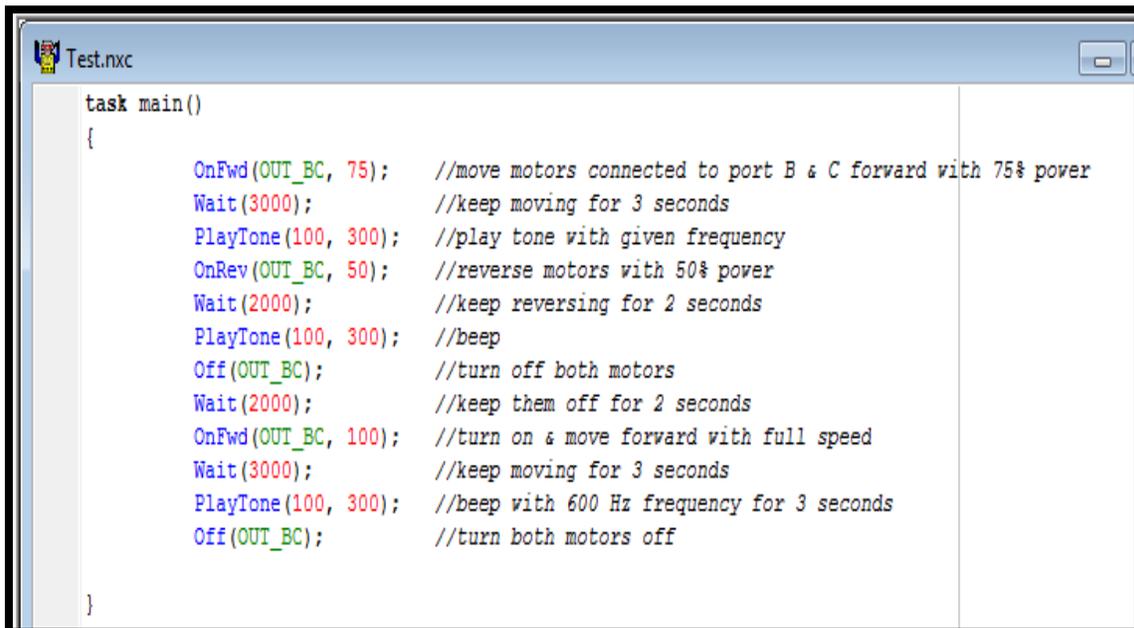
10. TextOut(x, y, string):

- Lets the user specify the coordinates and the string.

Example: TextOut(1, LCD_LINE6, “Hi”) : this will print the string “Hi” on specified coordinates.

Here is a sample program using the above functions:

Note: More functions can be found in the [NXC_tutorial.pdf](#)



```
task main()
{
    OnFwd(OUT_BC, 75); //move motors connected to port B & C forward with 75% power
    Wait(3000); //keep moving for 3 seconds
    PlayTone(100, 300); //play tone with given frequency
    OnRev(OUT_BC, 50); //reverse motors with 50% power
    Wait(2000); //keep reversing for 2 seconds
    PlayTone(100, 300); //beep
    Off(OUT_BC); //turn off both motors
    Wait(2000); //keep them off for 2 seconds
    OnFwd(OUT_BC, 100); //turn on & move forward with full speed
    Wait(3000); //keep moving for 3 seconds
    PlayTone(100, 300); //beep with 600 Hz frequency for 3 seconds
    Off(OUT_BC); //turn both motors off
}
```

Macros:

NXC allows defining macros. Macros are a list of commands or actions that you use frequently. For instance, if you want your robot to move forward for random seconds and beep with the frequency of 100 for 0.1 seconds, you can do the following:

```
#define move_forward \  
OnFwd(OUT_BC, 75);  
PlayTone(100, 100);  
  
#define random_time \  
int time;  
time = Random(5);  
Wait(time);  
  
/***** Main Program*****/  
int time;  
task main( )  
{  
    move_forward;  
    random_time;  
    move_forward;  
    random_time;  
}
```

Sensor Functions:

1. **Touch Sensor:** To configure the touch sensor, use the following function:

Void SetSensorTouch(const byte &port)

- port : The port to configure.

Example: SetSensorTouch(IN_1) : Indicate the type of the sensor and the number of the port to which the sensor is connected to.

2. **Light Sensor:** To configure the light sensor, use the following function:

Void SetSensorLight(const byte &port)

- port : The port to configure.

Example: SetSensorLight(IN_2) : Indicates the type of the sensor and the number of the port to which the sensor is connected to. To read ambient light intensity with led off, configure sensor as follows:

SetSensorType(IN_2,IN_TYPE_LIGHT_INACTIVE)

SetSensorMode(IN_2,IN_MODE_PCTFULLSCALE)

ResetSensor(IN_2)

3. **Sound Sensor:** To configure the sound sensor, use the following function:

Void SetSensorTouch(const byte &port)

- port : The port to configure.

Example: SetSensorSound(IN_3) : Indicate the type of the sensor and the number of the port to which the sensor is connected to .

4. **Ultrasonic Sensor:** To configure the ultrasonic sensor, use the following function:

byte SensorUS(const byte &port)

- port : The port to configure.

Example: SensorUS(IN_1) : Indicate the type of the sensor and the number of the port to which the sensor is connected to. It returns a value between 0 and 255. Since an ultrasonic sensor is an I2C digital sensor its value cannot be read using the standard Sensor(n) value. The port must be configured as a Lowspeed port before using this function. Use the following function to configure the port as lowspeed:

Void SetSensorLowspeed(const byt &port, bool bIsPowered = true)

- port: the port to configure

- bIsPowered: A boolean flag indicating whether to configure the port for powered or unpowered I2C devices. The default value for this optional parameter is true.

5. **Compass Sensor:** Read the compass heading value of the HiTechnic Compass sensor on the specified port. Use the following function:

int SensorHTCompass(const byte &port)

- port : The port to configure. The port must be configured as a Lowspeed port before using this function.

Example: SensorHTCompass(IN_2) : Indicates the type of the sensor and the number of the port to which the sensor is connected to.

6. **Color Sensor:** Read the compass heading value of the HiTechnic Color sensor on the specified port. Use the following function:

int SensorHTColorNum(const byte &port)

- port : The port to configure. The port must be configured as a Lowspeed port before using this function.

Example: SensorHTColorNum(IN_3) : Indicates the type of the sensor and the number of the port to which the sensor is connected to.

7. **Magnetic Sensor:** To configure the sensor on the specified port as a HiTechnic Magnet sensor, use the following function:

Void SetSensorHTMagnet(const byte & port)

- Port: The sensor port. Input port constants are used when calling NXC sensor control API functions.

Example: SetSensorHTMagnet(IN_1) : indicates the type of the sensor and the number of the port it is connected to.

8. **Infrared Seeker Sensor:** To read HiTechnic IRSeeker2 AC values, use the following function:

bool ReadSensorHTIRSeeker2AC(const byte port, byte &dir, byte &s1, byte &s3, byte &s5, byte &s7, byte &9)

- Port: The sensor port

- dir: the direction.

- S1: The signal strength from sensor 1.

- S3: The signal strength from sensor 3.

- S5: The signal strength from sensor 5.

- S7: The signal strength from sensor 7.

- S9: The signal strength from sensor 9.

Example: byte s1, s3, s5, s7, s9

Bool result = ReadSensorHTIRSeeker2AC(IN_1, dir, s1, s3, s5,s7, s9)

It read direction, and five signal strength values from the HiTechnic IRSeeker2 sensor in AC mode. Returns a boolean value indicating whether or not the operation completed successfully. The port must be configured as a Lowspeed port before using this function.

Multiplexer:

The HiTechnic Sensor Multiplexer, (SMUX) allows the user to connect four NXT sensors to a single NXT port. The NXT sensors can be connected to the SMUX using the NXT wire provided in the NXT kit. SMUX uses the digital I2C communications protocol and uses a 9v battery. Sensors supported by SMUX from our kit are:

1. HiTechnic Color Sensor
2. HiTechnic Compass Sensor
3. HiTechnic IRSeeker
4. Touch Sensor
5. Light Sensor
6. Ultrasonic Sensor

Note: The SMUX does not support the sound and the magnet sensor. To use SMUX with NXC, the user needs to download the NXC driver. The driver provides all the definitions, functions and variables that are required for the SMUX to work with different sensors. It can be found here:

<http://www.hitechnic.com/file.php?f=970-smux-driver-nxc-0.4.zip>.

Multitasking with NXC:

NXT and NXC both supports multi-threading, which is an ability of an operating system to execute different parts of a program simultaneously. A task can be defined using the keyword *task* in the following manner:

```
task name ( )  
{  
    //code for the task goes here  
}
```

To schedule the listed tasks to execute once the current task has completed executing, the following function would be useful:

```
Precedes (task task1, task task2, task task3, ..., task taskN)
```

All the tasks will execute simultaneously unless other dependencies prevent them from doing so. Any number of tasks may be listed in the Precedes statement.

Tasks can be stopped as follows:

```
stop functionName;
```

In order to stop all the running tasks concurrently, use the following statement:

```
StopAllTasks( );
```

Bricx CC and NXC are the best options because they have all the features that are essential to program a robot. Since, ROS doesn't support many of the sensors; NXC is an appropriate choice for the class due to its compatibility with all the equipment provided in the NXT kit. NXC is similar to C, so it makes it easy for the students to learn and use it for the class because they will already be familiar with C. NXC and the Bricx CC IDE will definitely help the students gain knowledge about how to program robots to do specific tasks.

Useful Links

1. NXC Tutorial 1: http://www.engineering.uiowa.edu/~cie/Labs/NXC_tutorial.pdf.
2. NXC Tutorial 2: <http://bricxcc.sourceforge.net/nbc/>
3. NXC Data Structures: <http://bricxcc.sourceforge.net/nbc/nxcdoc/nxcapi/annotated.html>
4. NXC Data Fields:
http://bricxcc.sourceforge.net/nbc/nxcdoc/nxcapi/globals_0x72.html#index_r
5. NXT Robot Examples: <http://www.legomylegobot.com/>
6. NXT Sensors: <http://www.hitechnic.com/products>
7. Multiplexer Driver: <http://www.hitechnic.com/file.php?f=970-smux-driver-nxc-0.4.zip>.
8. ROS: <http://www.ros.org/wiki/ROS>
9. NXT ROS: <http://www.ros.org/wiki/Robots/NXT>
10. More help needed Contact us: Navneet at saggunavi@gmail.com and Nirali at b.niralie@gmail.com.