

5 Basic robotics with Lego NXT

5.1 Introduction

We will use the LEGO mindstorm system in this course. Besides having common LEGO building blocks to construct different designs, this system consist of a micro-processor, called the **brick**, which is programmable and which controls the sensors and actuators. The actuators are stepping motors that can be told to run for a specific duration, a specific number of rotations, or with a specific speed. Our tool kit also includes several sensors, a light sensor that can be used to measure the wavelength of reflecting light and also small distances, an ultrasonic sensor to measure larger distances, a touch sensor, and a microphone. The motors can also be used to sense some externally applied movements.

We will use a basic tribot design as shown in Fig.5.1 for most of the explorations in this course. We will build the basic tribot in the following tutorial and will outline an example of a program to avoids walls and then work on a program so that the tribot can follow a line. After this we will use a robot arm configuration to discuss the important concept of a configuration space and demonstrate path-planing.



Fig. 5.1 Basic Lego Robot with microprocessor, two motors, and a light sensor.

5.2 Building a basic robot with Lego NXT

5.2.1 Building the tribot

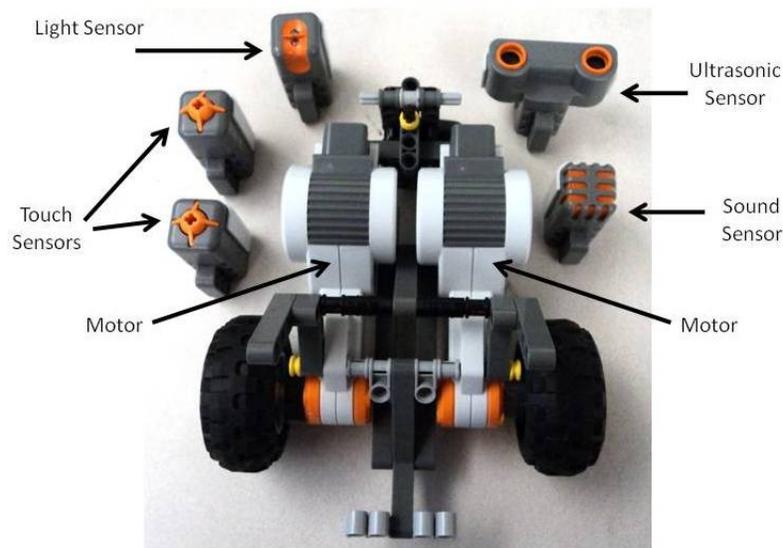
1. Charge the battery

Before constructing the robot, plug the battery pack into the NXT brick controller and plug it into an outlet to recharge the battery.

2. Construct the NXT

Follow the instruction booklet included with the Lego kit to construct the robot. There are mini programs illustrated in the manual that can be implemented directly on the NXT brick. Although this is not the method that will be used to control the NXT, you may implement them if you have time in order to get an idea of how the sensors and motors function. The instruction manual is organized as follows:

Section	Pages
NXT brick base construction	8-23
Sound sensor mounting	24-27
Ultrasonic sensor mounting	28-31
Light sensor mounting	32-39
Touch sensor mounting	40-45



Sensors & constructed NXT brick base

5.2.2 Mindstorms NXT toolbox installation

We will use some software to control the Lego actuator and gather information from their sensors within the Matlab programming environment. To enable this we need to install software developed at the German university called 'RWTH Aachen', which in turn uses some other drivers that we need to install. Most of the software should be installed in our Lab, but we will outline briefly some of the installation issues in case you want to install them under your own system or if some problems exists with the

current installation. The following software installation instructions are adapted from RWTH Aachen University's NXT Toolbox website:

<http://www.mindstorms.rwth-aachen.de/trac/wiki/Download4.04>

Currently, the toolbox is not available for USB connections are not available on Mac because of 64-bit compatibility issues; therefore, you will only be able to connect to the NXT via Bluetooth if you are using a Mac.

1. Check NXT Firmware version

Check what version of NXT Firmware is running on the NXT brick by going to "Settings" > "NXT Version". Firmware version ("FW") should be 1.28 or greater. If it does not, it needs to be updated (Note: The NXT toolbox website claims version 1.26 will work, however it will not)

To update the firmware:

The Lego Mindstorms Education NXT Programming software is required to update the firmware. In the NXT Programming software, look under "tools" > "Update NXT Firmware" > "browse", select the firmware's directory, click "download".

2. Setting up a USB Connection [Windows Users only]

The toolbox requires different installation instructions depending on whether you are running 32 or 64-bit Matlab. To check which version you are running, in Matlab go to "Help" > "About".

On 32-bit Matlab [Windows Users only]

- **Install USB (Fantom) Driver**

If the Lego Mindstorms Education NXT Programming software is already on your computer, this should already be installed. Otherwise, download it from: <http://mindstorms.lego.com/support/updates/>

- * If you run into problems with the Fantom Library on windows go to this site for help:
<http://bricxcc.sourceforge.net/NXTFantomDriverHelp.pdf>
- * If you have Windows 7 Starter edition the standard setup file will not run properly. To install the Fantom Driver go into Products and then LEGO_NXT_Driver_32 and run LegoMindstormsNXTdriver32.

- **Download the Mindstorms NXT Toolbox 4.04:**

Download: <http://www.mindstorms.rwth-aachen.de/trac/wiki/Download4.04>

- * Save and extract the files anywhere, but do not change the directory structure.
- * The folder will appear as "RWTHMindstormsNXT"

On 64-bit Matlab [Windows Users only]

- **Download libusb-win32**

Download: <http://sourceforge.net/projects/libusb-win32/files/>

- * Save and extract the files anywhere.
- * Open the extracted folder and go to "bin". Run the **inf-wizard** and follow the instructions. This will install a device driver for the NXT connection.

- **Download the Mindstorms NXT Toolbox 4.04:**

Download: [http://projects.cs.dal.ca/hallab/wiki/index.php/RWTH_Mindstorms_NXT_Toolbox_\(64-bit\)](http://projects.cs.dal.ca/hallab/wiki/index.php/RWTH_Mindstorms_NXT_Toolbox_(64-bit))

- * Save and extract the files anywhere, but do not change the directory structure.
- * The folder will appear as "RWTHMindstormsNXT64"

3. Install NXT Toolbox into Matlab

In Matlab: "File" > "SetPath" > "Add Folder", and browse and select "RWTH-MindstormsNXT" or "RWTHMindstormsNXT64"- the which is a **subfolder** of file you saved in the previous step.

- Also add the "tools" folder, which is a subdirectory of the RWTHMindstormsNXT folder.
- Click "save" when finished.

4. Download MotorControl to NXT brick

Use the USB cable for this step. Lego's Phantom Driver is also required for this step. This will already be installed if you have the Lego Mindstorms Education NXT Programming software or if you downloaded it when setting up a USB connection with 32-bit Matlab in Windows. Otherwise, download it from: <http://mindstorms.lego.com/en-us/support/files/default.aspx#Driver>

- **Windows:** Download the NBC compiler (<http://bricxcc.sourceforge.net/nbc/>). Unzip the folder and move the file "nbc.exe" to RWTHMindstormsNXT/tools/MotorControl. Under RWTHMindstormsNXT/tools/MotorControl, double click TransferMotorControlBinaryToNXT, and follow the onscreen instructions. If this fails, try using NeXTTool instead of nbc; download from <http://bricxcc.sourceforge.net/utilities.html> (be careful to download NeXTTool not NextTools!). Again, unzip the folder and move the file "NeXTTool.exe" to the MotorControl folder.
- **Mac:** Download the NeXT Tools for Mac OS X from <http://bricxcc.sourceforge.net/utilities.html>. Run the toolbar and open the NXT Explorer (the globe in the toolbar). With the arrow key at the top, transfer the file MotorControl22.rxe (found in RWTHMindstormsNXT/tools/MotorControl) to the brick.

5. Setting up a Bluetooth connection [optional if you're connecting via USB]

- To connect to the NXT via bluetooth you must first turn on the bluetooth in the NXT and make sure that the visibility is set to on. Then use the bluetooth device on your computer to search for your specific NXT. The name of your NXT can be found at the top center of your NXT's screen.
- Create a connection between the computer and the NXT. When you create the connection between the NXT and the bluetooth device the NXT will ask for a passkey (usually either 0000 or 1234 on the NXT screen and press the orange button. The computer will then ask for the same passkey. To test the connection, type the command `COM_OpenNXT('bluetooth.ini');` in the Matlab command window. The command should run without any red error messages.
- Make sure that the bluetooth.ini file is present. There are sample files for Windows and Linux (Mac) in the main RWTH toolbox folder. If it is not

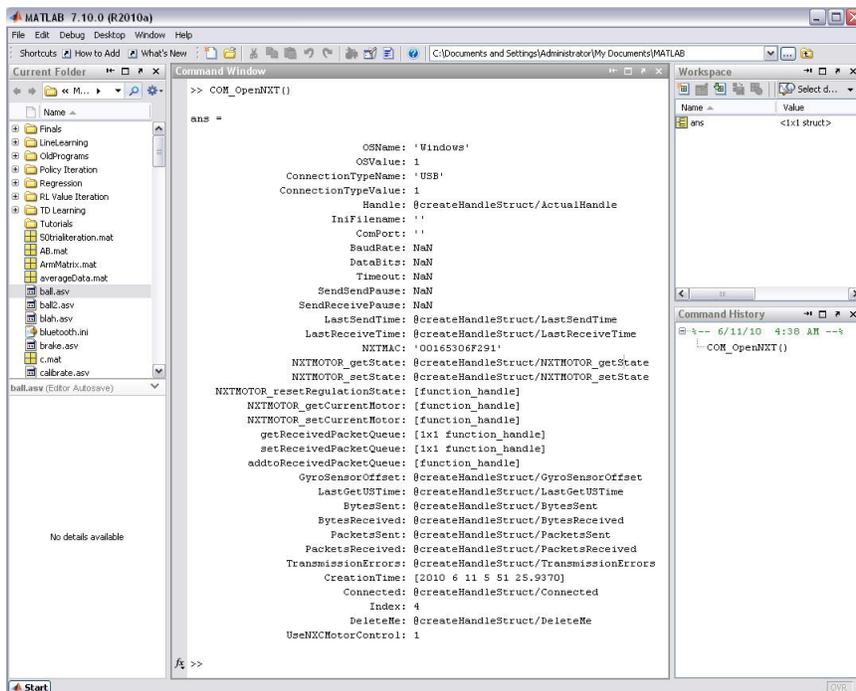
present, create one by running the command `COM_MakeBTConfigFile` in Matlab.

- Check if the **serial ports** are correct in the "bluetooth.ini" file are correct. In **Windows**, go to the Control Panel, click "Hardware and Sound">"Devices and Printers". Find the NXT device, right click it and go to "Properties". The COMPort will be listed under the "Services" tab (i.e. "COM3"). On **Mac**, The port name can be found by typing `ls -l /dev` in a terminal window, or by going to "System Preferences">"Bluetooth Devices". Select your NXT and click on the gear symbol (left hand bottom corner). The COMPort should be listed there.
- Turning the NXT off and back on again can help. After every failed `COM_OpenNXT('bluetooth.ini');` command type `COM_CloseNXT('all');` to close the failed connection for a clean new attempt.
- To switch on a debug mode enter the command `DebugMode on` before entering the command `COM_OpenNXT('bluetooth.ini');` .

6. Does it work?

In Matlab, enter the commands below into the command window. The command should execute without error and the NXT should play a sound.

```
h=COM_OpenNXT('bluetooth.ini'); % to test a USB connection, omit the
bluetooth.ini COM_SetDefaultNXT(h);
NXT_PlayTone(400,300);
```



Note that there are some examples included with the RWTH Mindstorm's NXT Toolbox, under `RWTHMindstormsNXT/demos`.

5.3 Basic NXT toolbox commands

The instructions in this section have been adapted from RWTH's website. Installation instructions from:

<http://www.mindstorms.rwth-aachen.de/trac/wiki/Download4.03>

Coding instructions from:

<http://www.mindstorms.rwth-aachen.de/trac/wiki/Documentation>

You can find more instruction on installation and usage of the RWTH Mindstorms NXT Toolbox from both of these sites.

5.3.1 Startup NXT

The first thing to do is make sure the workspace is clear. Enter:

```
COM_CloseNXT('all');
close all;
clear all;
```

To start, enter:

```
hNXT=COM_OpenNXT;      %hNXT is an arbitrary name
COM_SetDefaultNXT(hNXT); %sets opened NXT as the
                        %default handle
```

5.3.2 NXT Motors

Motors are treated as objects. To create one, enter:

```
motorA = NXTMotor('a'); %motorA is an arbitrary name, 'a' is
                        %the port the motor connected to
```

This will give:

```
NXTMotor object properties:
      Port(s): 0 (A)
      Power: 0
      SpeedRegulation: 1 (on)
      SmoothStart: 0 (off)
      TachoLimit: 0 (no limit)
      ActionAtTachoLimit: 'Brake' (brake, turn off when stopped)
```

5.3.3 Basic Motor Commands & Properties

Below is a list of these properties and how to change them:

Power

Determines speed of the motor

```
motorA.Power=50; % value must be between -100 and 100 (negative
                % will cause the motor to rotate in reverse)
```

SpeedRegulation

If the motor encounters some sort of load, the motor will (if possible) increase its power to keep a constant speed

```
motorA.SpeedRegulation=true; % either true or false, or
                             % alternatively, 1 for true, 0 for
                             % false
```

SmoothStart

Causes the motor to slowly accelerate and build up to full speed.

Works only if ActionAtTachoLimit is not set to 'coast' and if TachoLimit>0

```
motorA.ActionAtTachoLimit= true; % either true or false, or
                                % 1 for true, 0 for false
```

ActionAtTachoLimit

Determines how the motor will come to rest after the TachoLimit has been reached.

There are three options:

1. 'brake': the motor brakes
2. 'Holdbrake': the motor brakes, and then holds the brakes
3. 'coast' the motor stops moving, but there is no braking

```
motorA.ActionAtTachoLimit='coast';
```

TachoLimit

Determines how far the motor will turn

```
motorA.TachoLimit= 360; % input is in terms of degrees
```

Alternative Motor Initiation

Motors can also be created this way:

```
motorA=NXTMotor('a', 'Power', 50, 'TachoLimit', 360);
```

5.3.4 Other Motor Commands

SendToNXT

This is required to send the settings of the motor to the robot so the motors will actually run.

```
motorA.SendToNXT();
```

Stop

Stops the motor. There are two ways to do this:

1. 'off' will turn off the motor, letting it come to rest by coasting.
2. 'brake' will turn cause the motor to be stopped by braking, however the motors will need to be turned off after the braking.

```
motorA.Stop('off');
```

ReadFromNXT();

Returns a list of information pertaining to a motor

```
motorA.ReadFromNXT();
```

Entering `motorA.ReadFromNXT.Position()`; will return the position of the motor in degrees.

ResetPosition

Resets the position of the motor back to 0

```
motorA.ResetPosition();
```

WaitFor

Program will wait for motor to finish current command. For example:

```
motorA=('a', 'Power', 30, 'TachoLimit', 360);
motorA.SendToNXT();
motorA.SendToNXT();
```

This command will cause problems as the motor can only process one command at a time. Instead, the following should be entered:

```
motorA=('a', 'Power', 30, 'TachoLimit', 360)
motorA.SendToNXT();
motorA.WaitFor();
motorA.SendToNXT();
```

The exception to this is if TachoLimit of the motor is set to 0.

5.3.5 Using Two Motors At Once

Some operations, for example driving forward and backwards, require the simultaneous

```
use of two motors. Entering:
B=NXTMotor('b', 'Power', 50, 'TachoLimit', 360);
C=NXTMotor('c', 'Power', 50, 'TachoLimit', 360);
B.SendToNXT();
C.SendToNXT();
```

will start the bot moving, but the signals for both motors to start at will not be sent at exactly the same time, so the robot will curve a little and fail to drive in a straight line. Instead, you should enter:

```
BC=NXTMotor('bc', 'Power', 50, 'TachoLimit', 360);
```

OR

```
BC = NXTMotor('bc');
BC.Power=50;
BC.TachoLimit=360;
```

Turning left or right can be achieved by only running one motor at a time, or by moving both motors, but one slower than the other.

5.3.6 Sensors

The following commands are used to open a sensor, plugged into port 1:

```
OpenSwitch(SENSOR_1);           % initiates touch sensor
OpenSound(SENSOR_1, 'DB');      % initiates sound sensor, using
                                % either 'DB' or 'DBA'
OpenLight(SENSOR_1, 'ACTIVE'); % initiates light sensor as
                                % either 'ACTIVE' or 'INACTIVE', The following com-
                                % plugged into Port 1
OpenUltrasonic(SENSOR_1);      % initiates ultrasonic sensor
                                % plugged into Port 1
```

mands are used to get values from the sensor plugged into port 2:

```
GetSwitch(SENSOR_2);          % returns 1 if pressed, 0 if depressed
GetSound(SENSOR_2);          % returns a value ranging from 0-1023
GetLight(SENSOR_2);          % returns a value ranging from 0 to
                                % a few thousand
GetUltrasonic(SENSOR_2);     % returns a value in cm
```

To close a sensor, ex. Sensor 1:

```
CloseSensor(SENSOR_1); %properly closes the sensor
```

5.3.7 Direct NXT Commands

PlayTone

Plays a tone at a specified frequency for a specified amount of time

```
NXT.PlayTone(400,300); % Plays a tone at 400Hz for 300 ms
```

KeepAlive

Send this command every once in a while to prevent the robot from going into sleep mode:

```
NXT.SendKeepAlive('dontreply');
```

Send this command to see how long the robot will stay awake, in milliseconds:

```
[status SleepTimeLimit] = NXT.SendKeepAlive('reply');
```

GetBatteryLevel

Returns the voltage left in the battery in millivolts

```
NXT_GetBatteryLevel;
```

StartProgram/StopProgram

To run programs written on LEGO Mindstorms NXT software, enter:

```
NXT_StartProgram('MyDemo.rxe') % the file extension '.rxe' can be  
                                % omitted, it will then be automatically  
                                % added
```

Entering `NXT_StopProgram` stops the program mid-run.

5.4 First examples

The following exercises are intended to explore how to use RWTH's Mindstorms NXT Toolbox.

5.4.1 Example 1: Wall avoidance

The following is a simple example of how to drive a robot and use the ultrasonic sensor. The robot will drive forward until it is around 20 cm away from a barrier (i.e. a wall), stop, beep, turn right, and continue moving forward. The robot will repeat this 5 times. Attach the Ultrasonic sensor and connect it to port 1. The study and run the following program.

```

COM.CloseNXT('all');           %cleans up workspace
close all;
clear all;
hNXT=COM.OpenNXT('bluetooth.ini'); % initiates NXT, hNXT is an arbitrary name
COM.SetDefaultNXT(hNXT);      %sets default handle

OpenUltrasonic(SENSOR_1);

forward=NXTMotor('BC'); &% setting motors B           C to drive forward
forward.Power=50;
forward.TachoLimit=0;
turnRight=NXTMotor('B'); &% setting motor B to turn right
turnRight.Power=50;
turnRight.TachoLimit=360;
for i= 1:5
    while GetUltrasonic(SENSOR_1)>20
        forward.SendToNXT();           %sends command for robot to move forward
                                        %TachoLimit=0; no need for a WaitFor() statement

    end %while
    forward.Stop('brake');              %robot brakes from going forward
    NXT_PlayTone(400,300);              %plays a note
    turnRight.SendToNXT;                %sends the command to turn right
    turnRight.WaitFor;                  %TachoLimit is not 0; WaitFor() statement required
end %for
turnRight.Stop('off');                 %properly closes motors
forward.Stop('off');
CloseSensor(SENSOR_1);                 %properly closes the sensor
COM.CloseNXT(hNXT);                    % properly closes the NXT
close all;
clear all;

```

5.4.2 Example 2: Line following

The next exercise is writing your own program that uses readings from its light sensor to drive the NXT and follow a line.



Setup:

1. Mount light sensor, facing downwards on front of NXT and plugged into Port 3.
2. Mount a switch sensor on the NXT, plugged into Port 2.
3. Use a piece of dark tape (i.e. electrical tape) to mark a track on a flat, light coloured surface. Make sure the tape and the surface are coloured differently enough that the light sensor returns reasonably different values between the two surfaces.
4. Write a program so that the tribot follows the line.