2 Sensing, acting and control

This is a busy chapter where we review some fundamental techniques for robotics. We will learn how to acquire images from a webcam and to filter the image in order to look for specific items. We will then explain how to use a Lego NXT with Matlab, that is, how to send motor commands and how to receive sensor information that we can then use in our math lab program. We will practice this programming with some first robotics tasks. Furthermore, we will discuss some basic kinematics models for some example robots and finally review some basic control theory as it is essential in robotics applications and it also provides us with a framework to explore machine learning methods.

2.1 Basic computer Vision

Cameras and other sensors that can sense physical objects in the environment, such as infrared cameras to sense heat distributions or scanning sonars for underwater applications, are an important source of sensory information. The main challenge with such data is how to interpret them as we usually want to extract more meaningful information from them such as recognizing objects or distances to obstacles. Vision is a major sensory source for humans and our brain is specialized in interpreting signals from our eyes. Machine learning has contributed considerably to recent progress in computer vision including object tracking and object recognition. We will not enter into this discuss here but rather show how to use a webcam with Matlab and how to do basic operations on such acquired pictures of videos that typically form the first stage of more sophisticated vision systems. These techniques will also become handy in later experiment.

2.1.1 Acquiring data from webcams with Matlab

In order to process video streams, we will use Mathwork's Image Acquisition Toolbox in Matlab[3]. First we make sure the toolbox is installed in your Matlab version and configured and describe commands to retrieve information of your specific system. To do so, use the command

```
imaqhwinfo

ans =
```

[3] There are also some alternatives, For example see http://www.mathworks.com/matlabcentral/fileexchange/35554-simple-video-camera-frame-grabber-toolkit

```
    InstalledAdaptors: {'dcam'  'gige'  'macvideo'}
        MATLABVersion: '8.1 (R2013a)'
          ToolboxName: 'Image Acquisition Toolbox'
       ToolboxVersion: '4.5 (R2013a)'
```

More specific information can be obtained with

```
>> HD=imaqhwinfo('macvideo')

HD =

       AdaptorDllName: [1x85 char]
    AdaptorDllVersion: '4.5 (R2013a)'
          AdaptorName: 'macvideo'
            DeviceIDs: {[1]}
           DeviceInfo: [1x1 struct]
```

More specific information of the supported video format and size can be obtained by inspecting the previously ceated HD object,

```
HD.DeviceInfo(1)

ans =

              DefaultFormat: 'YCbCr422_1280x720'
       DeviceFileSupported: 0
                DeviceName: 'FaceTime HD Camera (Built-in)'
                  DeviceID: 1
     VideoInputConstructor: 'videoinput('macvideo', 1)'
    VideoDeviceConstructor: 'imaq.VideoDevice('macvideo', 1)'
          SupportedFormats: {'YCbCr422_1280x720'}
```

Now we are ready to show how to create a video stream and to display it in a Matlab figure window. On a windows system, likely the most common way to achieve this is

```
1 stream = videoinput('winvideo', 1);
2 preview(stream);
```

Under normal circumstances, a new window opens with a preview of the video stream. Mac and Unix user should replace the string `winvideo` with `macvideo` or `unixvideo` respectively. The number ofter this string represents the ID of the camera. The build-in camera has usually ID=1, but you might need to specify another number when you use an external camera. The string you should use is also specified in the VideoInputConstructor line from the DeviceInfo command.

In order to process a frame in this video image we need to retrieve a single frame from the video stream that we created previously. First, we specify the colorspace we want to obtain, such as RGB, then get a snapshot from the video steam, and finally display it with the `imgshow` command,

```
set(stream,'ReturnedColorSpace','rgb');
frame = getsnapshot(stream);
imshow(frame);
```

The picture is stored as object *frame* in the Matlab Workspace. Its size depends on the resolution of the webcam and the chosen colorspace. With a 720x1280 resolution and in RGB for example, the obtained *frame* will be a 720x1280x3 *uint8* object. As an example to process this image directly with Matlab, let us extract the red component and display this alone with the *imshow* command

```
frameGrey=frame(:,:,1);
imshow(framGrey)
\end{verbatim}
The reason that this image appears in grey is that the values  ...
    in the two dimensional matrix are now interpreted as grey  ...
    values.

Finally, in order to read continuously from a camera and  ...
    display the obtained frames in a loop one can use the  ...
    following program.  Press the \textit{q} key to terminate  ...
    the loop.

\begin{lstlisting}
close all; clear all;

stream=videoinput('winvideo',1);
triggerconfig(stream,'manual');

VideoLoop=figure;
while true
    frame=getsnapshot(stream);
    imshow(frame);
    %retrieves a keyboard interruption
    key=get(gcf,'currentkey');
    %if the pressed key is 'q', the loop is interrupted and  ...
        the figure closes
    if strcmp(key,'q')
        close(VideoLoop);
        break;
    end
end
```

2.1.2 Image filtering with convolutions

Let us now start manipulating a singe grey image further. As a first example let us created a new smoothened image I^{mean} by averaging the pixels over a certain region, say over a region of size 11 by 11 pixels. The value of a pixel at (x, y) of the new image is then defined by us to be the average pixel values of an 11×11 image patch, and we shift around the centre pixel at (x, y),

$$I^{\text{mean}}(x, y) = \frac{1}{121} \sum_{u=-5}^{5} \sum_{v=-5}^{5} I(x - u, y - v). \tag{2.1}$$

The new image is a bit smaller than the original as the pixels at the edges don't have pixels on one side. We could adjust for this in various ways such as buffering a surrounding are with with constants pixels or using periodic boundary conditions where we add pixels from the other side of the matrix. In order to accommodate filters with even sizes of pixels, we could also assigned the average within a patch of the image to the upper left corner of this patch, or too any other location within the patch. The important part is that we are moving a square systematically around the image and in this way generate a new processed version of this image.

In order to generalize this averaging procedure later to averages with different weights, we define a matrix $k(u, v)$ with indices u and v. to continue the example above, both indices could run between the values of -5 and 5. All the elements of this matrix are set to one, $k(u, v) = 1$, so that the above equation is equivalent to

$$I^{\text{mean}}(x, y) = \frac{1}{N^2} \sum_u \sum_v I(x - u, y - v)k(u, v), \tag{2.2}$$

where $N = 11$ is the number of pixels in the filter.

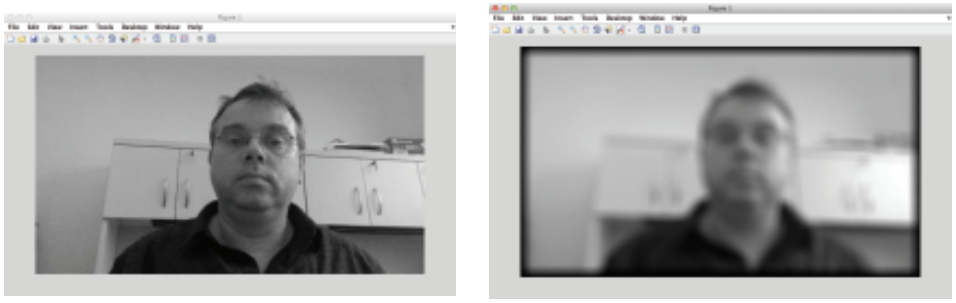


Fig. 2.1 Original picture on the left and the filtered version with a uniform filter of size 40×40.

An example of such a procedure is shown in Fig. 2.1. On the left side is the original image acquired with a webcam with 720×1280 pixels. On the right is a smoothened version of it using the procedure just defined. The image is a bit more blurry, but we will see that this will be useful for some of the applications below such as when downsampling images or to reduce noise in the image.

The matrix k is called a kernel, and the operation described in eq.2.2 is called a **convolution**. For a large number of pixels it is sometimes more convenient to describe the image as a continuum, so that a convolution can be written as

$$I^{\text{mean}}(x, y) = \int_u \int_v I(x - u, y - v)k(u, v)dudv. \tag{2.3}$$

Of course, we can define convolutions in different dimensions, not just in the two dimensional picture plane described here. By defining different kernel function we can achieve different effects. For example, it might seem more natural to average an image more smoothly, given nearby nodes more weight than distant nodes. This can be achieved with a **Gaussian kernel**

$$k(u,v) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-(u,v)^2}{\sigma^2}}. \tag{2.4}$$

Smoothing with Gaussian kernels is a common technique in computer vision, and the resulting picture for our test image is shown in Fig. 2.1b. The kernel function also defines a filter, and a convolution can be seen as a linear filtering operation.

Exercise

An example program that was used to produce the filtered image shown on the right in Fig. 2.1 is given below. This program uses the build in Matlab function *conv2()* to calculate the 2-dimensional convolution. Write a Matlab function that replaces this function and implements the convolution from scratch. Explain the black border in the filtered image.

```
1 original=frame(:,:,1);
2 imshow(original)
3
4 filter=ones(40);
5 filtered=conv2(filter,double(original));
6 filtered=filtered./max(max(filtered))*255;
7 imshow(uint8(filtered))
```

2.1.3 Linear filtering: Finding a color blob

An easy way to localize some environmental object is by tagging it with some unique colour and trying to detect this in the image. This will be used later for some exercises in localization and planing. For the following exercise take some coloured electrical tape of some other coloured material and attach it to the robot arm. We can first test it statically, but we will later use it to detect the location of the arm when the arm is moving.

To detect a certain colour in an image we need to process the colour channels. We can write a little application that takes an image and in which we could point to a location in the image to return the values. This program is shown in Table **??**. (explain program)

Once we have RGB value for the target colour we can use them to locate the colour in a video stream. For this it is useful to take some of the absolute differences between a video screen colour values and the target values. Small values indicate pixels close to the target colour. Since the target area corresponds to a cluster of such pixels, we could use an averaging method such as Gaussian smoothing followed by finding the minimum to locate the centre of the target area.

An alternative to the colour method for finding the position of the robot arm it motion segmentation. Segmentation of an image is an important step in building scene representations, and the following sections talks about some methods that commonly build the basis of segmentation for still images. The beauty of video streams is that there is more information in it that we can use for segmentation. In the example with the robot arm, we assume that only the robot arm is moving. We can therefore use differences of video captures in consecutive frames to determine the moving object.

Finally we want to translate the tracking of the robot arm to a number representing the degrees of rotation of the upper motor of the robot arm. For this we will use machine learning techniques. The first is to use linear regression on the motion segmented robot arm. The other is to use the support vector regression to map the (x, y) coordinates to rotation angles. Note that both cases correspond to supervised learning that require measurements that we will use as teacher signals.

Exercise

- Write a program to locate a colour blob in a video stream and indicate this target location with a circle. Similarly, use as an alternative motion segmentation and compare the location estimation in form of a pixel coordinate between the two methods.
- Write a program that translates a pixel coordinate to the estimation of the rotation angle of the motor and compare the location estimation of the two segmentation methods with the coordinates returned by the motors.

2.1.4 Gradient filters: Edge detection

While Gaussian smoothing is useful for noise reduction, it does not help us much with the identification of objects. To work towards such a goal we should recognize that objects are somewhat defined by their extensions, and the borders of objects are typically characterized by edges in a two-dimensional image. It is hence useful to think about how to build filters that highlight edges. For example, let us consider an image with a sharp vertical edge like the one give by the matrix

$$I^{\mathrm{v}} = \begin{pmatrix} 100 & 100 & 100 & 10 & 10 & 10 \\ 100 & 100 & 100 & 10 & 10 & 10 \\ 100 & 100 & 100 & 10 & 10 & 10 \\ 100 & 100 & 100 & 10 & 10 & 10 \end{pmatrix}$$

and lets convolve this with the filter $k = (1, -1)$ the resulting image is

$$I^{\mathrm{vedge}} = \begin{pmatrix} 0 & 0 & 90 & 0 & 0 \\ 0 & 0 & 90 & 0 & 0 \\ 0 & 0 & 90 & 0 & 0 \\ 0 & 0 & 90 & 0 & 0 \end{pmatrix}$$

Similar, let us consider an image with a horizontal edge

$$I^{\mathrm{h}} = \begin{pmatrix} 100 & 100 & 100 & 100 & 100 & 100 \\ 100 & 100 & 100 & 100 & 100 & 100 \\ 10 & 10 & 10 & 10 & 10 & 10 \\ 10 & 10 & 10 & 10 & 10 & 10 \end{pmatrix}$$

and the filter $k = \begin{pmatrix} 1 \\ -1 \end{pmatrix}$. The resulting image highlights a horizontal edge

$$I^{\text{vedge}} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 90 & 90 & 90 & 90 & 90 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Of course, edges in our webcam pictures are never this sharp, and it is hence useful to smoothen them. A continuous version of edge filters is for example described by Gabor functions such as the ones shown in Fig. 2.2a and b. A Gabor function is described by a sinosodally-moduated Gaussian,

$$k(u,v) = e^{-\frac{u^2+\gamma v^2}{2*\sigma^2}} \cos(\frac{2\pi}{\lambda}u + \alpha). \tag{2.5}$$

The example of a 64^2 pixel filter with parameters $\gamma = 0.5$, $\sigma = 10$, $\lambda = 32$, and $\alpha = \pi/2$ is shown in Fig. 2.2a. This filter can also be rotated with a rotation matrix

$$\begin{pmatrix} x \\ y \end{pmatrix} \leftarrow \begin{pmatrix} \cos(\alpha) & \sin(\alpha) \\ -\sin(\alpha) & \cos(\alpha) \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \tag{2.6}$$

as shown in Fig. 2.2b for $\alpha = \pi$. The figure also includes an example of applying these filters to an image from a webcam.

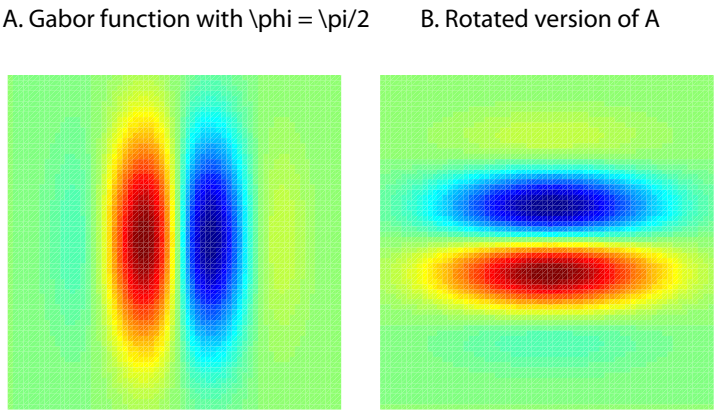


Fig. 2.2 Example of Gabor functions for (a) vertical and (b) horizontal edge detection. (c) Original image. (d) Filter Image using filters in (a) and (b).

Exercise

Take an image of your choosing and use Gabor filters to filter the image. Show the resulting image with two different angular parameter.

2.2 Building and driving a basic Lego NXT robot

2.2.1 Arm and Tribot

We will actively use the Lego Mindstorm robotics system in this course. This system is based on common Lego building blocks that we use for two principle designed

that we build below. The Lego NXT robotics system includes a microprocessor in a unit called the **brick** which can be programmed and used to control the sensors and actuators. The brick is programmable with a visual programming language provided by Lego, and there exists a multitude of systems to program the brick with other common programming languages. We will be using the brick mainly to communicate with the motors and sensors while implementing the machine learning controllers on an external computer connected by either USB cable or wireless bluetooth.

We will be using two basic robot designs for the examples in this course. One is a simple **robot arm** that is made out of two motors with legs to mount it to a surface and a pointer as shown in Fig.2.3 A. Our basic robot arm is constructed by attaching the base of one motor, that we call elbow, to the rotating part of a second motor, that we call the shoulder, as shown in Fig.2.3A. We also attach a long pointer extension to elbow that will become useful in some later exercises. Finally, we add some legs that we can be taped to a table surface in order to stabilize Motor2 to a fixed position. The precise design is not crucial for most of the exercises as long as it can rotate freely both motors.

We will also use a basic terrestrial robot called the **tribot** shown in Fig.2.3B. The tribot used here is a slight modification of the standard tribot as described in the Lego NXT robotics kit. A detailed instruction for building the basic tribot is included in the Lego kits, either in the instruction booklet or the included software package. It is not crucial that all the parts are the same. The principle idea behind this robot is to have a base with two motors to propel the tribot. and several sensors attached to it. There is commonly a third passive wheel that is only used to stabilize the robot, and we included a way to lock it to a straight position to facilitate cleaner movements along a straight line. Some versions of Lego kits have tracks that can be used in most of the exercises. The exact design is not critical and can be altered as seen fit.

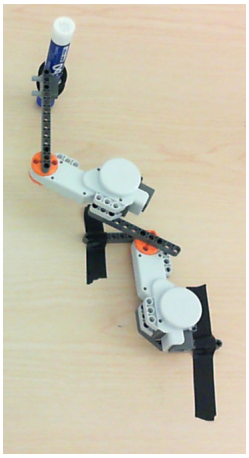
2.2.2 NXT Matlab Software Environment

The 'brain' of our robots will be implemented on PCs and we will use a Matlab environment to implement our high-level controllers. Most examples are minimalistic in order to concentrate on the algorithmic ideas behind machine learning methods explored in this book. While there are more advanced robotics environments with more elaborate frameworks such as ROS (Robot Operating System), we want to keep the overhead small by using only direct methods to communications with actuators and sensors. This section describes the Matlab environment and packages that we use in the following.

2.2.3 Mindstorm 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

A. Robotarm with attached dawing pen



B. Tribot with ultrasonic, touch and light sensor

Fig. 2.3 (A) A robot arm made out of two motors, shoulder and elbow, a pointer arm, and some support to tape it to a table surface. This version has also a pen attached to it. (B) Basic Lego Robot called tribot with the microprocessor, two motors, and three sensors, including a ultrasonic and touch sensor pointing forward and a light sensor pointing downwards.

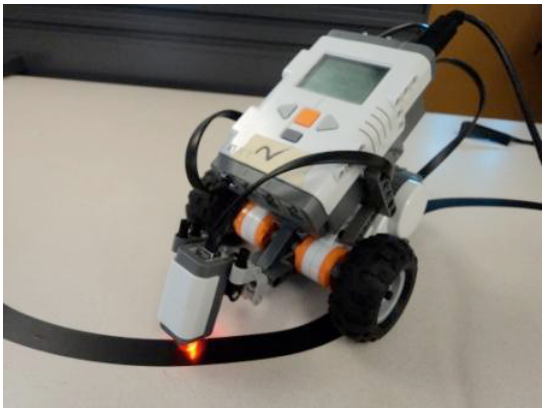


Fig. 2.4 Basic Lego Robot with microprocessor, two motors, and a light sensor.

RWTH Aachen University's NXT Toolbox website:
http://www.mindstorms.rwth-aachen.de/trac/wiki/Download4.03

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. 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. **Install USB (Fantom) Driver (Windows only)**
   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.
   The fantom USB driver seem not to work on the Mac, but we will anyhow use the bluetooth connections.
3. **Download the Mindstorms NXT Toolbox 4.03:**
   Download: http://www.mindstorms.rwth-aachen.de/trac/wiki/Download
   - Save and extract the files anywhere, but do not change the directory structure.
   - The folder will appear as "RWTHMindstormsNXT"
4. **Install NXT Toolbox into Matlab**
   In Matlab: "File" > "SetPath" > "Add Folder", and browse and select "RWTHMindstormsNXT" - the file you saved in the previous step.
   - Also add the "tools" folder, which is a subdirectory of the RWTHMindstormsNXT folder.
   - Click "save" when finished.
5. **Download MotorControl to NXT brick**
   Go to http://bricxcc.sourceforge.net/utilities.html for the download. Use the USB cable for this step

Windows: Download NeXTTool.exe to RWTHMindstormsNXT/tools/MotorControl. Under RWTHMindstormsNXT/tools/MotorControl, double click TransferMotorControlBinaryToNXT, click "Run", and follow the onscreen instructions. If this fails, try using the NBC compiler (download from http://bricxcc.sourceforge.net/nbc/) instead of the NeXTTool; again save it under the MotorControl folder.

Mac: Download the NeXTTools for Mac OS X. Run the toolbar and open the XNT Explorer (the globe in the toolbar). With the arrow key at the top, transfer the file MotorControl21.rxe to the brick.

6. **Setting up a Bluetooth connection**

   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. By default the name is NXT, but as a first step we will rename each brick.

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.

If there is an error check to see if the COMPort the Matlab code is looking for is the same as the one used in the connection made between the bluetooth device and the NXT. Also 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');` . Also, make sure that the bluetooth.ini file is present. There are sample files for Windows ad Linux (Mac) in the main RWTH toolbox folder. Also, check if the port name is correct by typing `ls -ltr /dev` in a terminal window.

7. **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');
COM_SetDefaultNXT(h);
NXT_PlayTone(400,300);
```

2.2.4 Basic Matlab NXT commands

The following is a summary of most Matlab commands from the NXT toolbox. The documentation from the RWTH web site contains always updated information.

2.2.4.1 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
```

2.2.4.2 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:

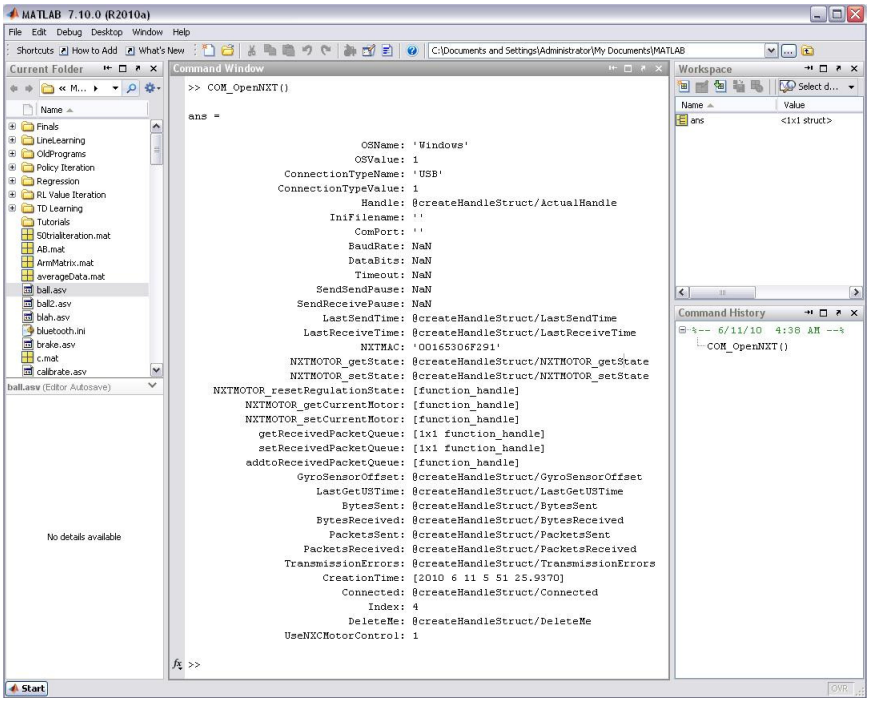


Fig. 2.5 Example of calling the `COM_OpenNXT()` command without arguments. The command returns some information of about the system.

```
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)
```

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 it 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);
```

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();
```

The immediate repetition of the motor 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.

2.2.4.3 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.

2.2.4.4 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',
                               % plugged into Port 1
OpenUltrasonic(SENSOR_1);      % initiates ultrasonic sensor
                               % plugged into Port 1
```

The following commands 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
```

2.2.4.5 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

2.2.5 First examples:

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;\mbox{}\\

hNXT=COM\_OpenNXT('bluetooth.ini'); &\% initiates NXT, hNXT is ...
    an arbitrary name\\
COM\_SetDefaultNXT(hNXT);&\%sets default handle\\\mbox{}\\

OpenUltrasonic(SENSOR\_1);\\\mbox{}\\

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;\mbox{}\\

for i= 1:5\\
\indent while GetUltrasonic(SENSOR\_1)>20\\
\indent\indent forward.SendToNXT(); &\%sends command for robot ...
    to move forward\\
\indent\indent &\%TachoLimit=0; no need for a WaitFor() statement\\
\indent end \%while\\
\indent forward.Stop('brake'); &\%robot brakes from going forward\\
\indent NXT\_PlayTone(400,300); &\%plays a note\\
\indent turnRight.SendToNXT; &\%sends the command to turn right\\
\indent turnRight.WaitFor; &\%TachoLimit is not 0; WaitFor() ...
    statement required\\
end \%for \mbox{}\\

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;
```

Exercises: Line following

Writing a controller that uses readings from its light sensor to drive the tribot along a line. You can use electrical tape for the line to follow.