Lego MINDSTORMS NXT
Problem Solving with Robots [PRSOCO601]

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This document has been produced primarily from the book *Maximum Lego NXT* [1]. There is no requirement for you to purchase this or any other books. These notes will be sufficient for any assignments for this module.
MINDSTORMS is both a toy and an engineering tool. Yes, there are many examples of professional engineers using it to rapidly prototype inventions. Most toys do one thing and soon lose their novelty. MINDSTORMS is always new. Owners can create a unique invention, play with it for as long as it holds their attention, then destroy it and reshape it into something new. It is a toy that never grows old.
LEGO released the MINDSTORMS Robotics Invention System (RIS) in 1998, causing a tidal wave of interest in the robotics community. Since then, owners have anxiously awaited the next step in the evolution of MINDSTORMS – the MINDSTORMS NXT.

1 A Brief History of MINDSTORMS

In 1987, the MIT Media Laboratory began developing a device they called the Programmable Brick, under sponsorship from the LEGO Group. Between 1987 and 1998 they turned out several different versions of the Programmable Brick. The final version is a big red brick with four output ports for motors and six input ports for sensors (see Figure 1).

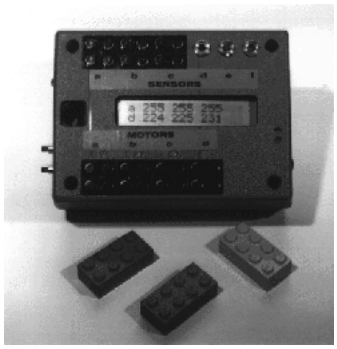

Figure 1: MIT Programmable Brick

The Robotics Invention System soon followed with the heart of the RIS Kit – the yellow RCX brick. (see Figure 2). It was modest compared to today's technology, using an 8-bit processor at 16 MHz and a scant 32 kilobytes of memory - less memory than the Commodore 64 had in 1982. Even with these limitations, MINDSTORMS users built incredible machines. More than a million people purchased an RIS kit. The MINDSTORMS community is now the largest robotics community on earth, easily able to share their robot designs and code with others.
Many schools embraced the technology as a learning tool. Now that the hardware has been further refined, it is even more suitable for education. There is no underestimating the effect this technology will have on kids. As more schools adopt MINDSTORMS, we may see a robotics boom in the coming years as these students enter the business world. University students have also embraced LEGO, using it for research and graduate projects.

Figure 2: RCX Brick

The big surprise for LEGO was the hacker community. Hackers soon unlocked the RCX brick and began using alternate programming languages such as Java. Many attribute the success of the RIS kit to the availability of these programming languages. LEGO has tried to expand the user base of MINDSTORMS. Roughly 70% of MINDSTORMS owners are adults, with an average age in their mid-thirties, so it seemed natural for LEGO to want to expand ownership to their traditional younger audience.
Between 1998 and 2006 there was a long wait for a sequel. Unknown to MINDSTORMS users, LEGO began work on a sequel in early 2004. On August 2, 2006 LEGO rolled out the NXT kit. Will the kit exceed the popularity of the previous generation? If the technology inside the NXT brick is any indication, it will be.

2 Discovering the MINDSTORMS NXT Kit

Let's examine the major parts inside the kit.

2.1 NXT Intelligent Brick

The new brick (Figure 3), which LEGO calls the NXT Intelligent Brick, looks inspired by the iPod in many ways, such as color and menu navigation. Think of it as an iPod for motors. The NXT brick is very durable.

Figure 3: NXT Brick

Although technology generally becomes smaller with each generation, the NXT is actually slightly larger than the RCX brick. The NXT is 7.2 cm by 11.2 cm. With six AA batteries, NXT weighs 286 grams (160 grams without batteries). Bigger is sometimes better, as is the case here. The NXT brick contains an Atmel 32-bit ARM processor running at 48 MHz. This processor has direct access to 64 KB of RAM, and 256 KB of flash memory. The flash RAM stores programs and data even when there is no power, which saves battery life.
There are a few things that make this memory limitation irrelevant. First, robots don't use heavy-duty graphics or sound, which consumes heaps of memory in modern computers. For a good example, look at the specification for the Mars rovers Spirit and Opportunity (Figure 4), launched in 2003. Each contained 256 KB of flash memory. If that's enough memory for NASA, you can trust it is enough memory for your own projects.

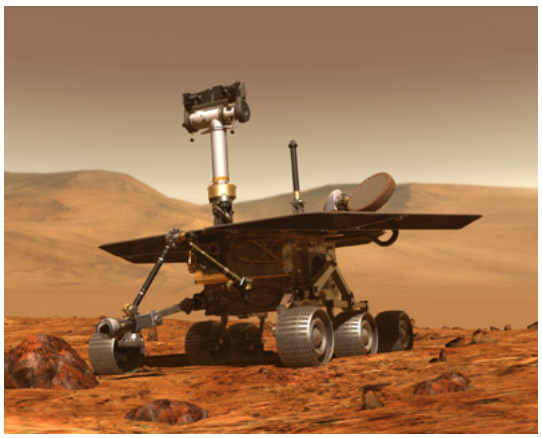

Figure 4: Mars Rover

2.2 Batteries

The NXT brick uses six AA batteries which provide 9 volts. However, there are rechargeable batteries. One is a rechargeable lithium ion battery from LEGO. This battery provides at least 7.4 volts (closer to 8.2 volts after recharging). It fits into the regular battery case, but it also increases the depth of the NXT brick slightly.
LEGO also sells an AC adapter for charging the lithium ion battery which, conveniently, can be done while it is still inside the NXT brick. People who want to create robots that operate 24 hours a day, seven days a week (such as an Internet controlled robot) will find the lithium battery a necessary accessory.

2.3 Speakers

The NXT contains a sound amplifier chip that can play sampled sound. You can even make your own recordings and upload them to the NXT brick. Don't expect this to sound like MP3 quality, however. Because of memory limitations, the NXT can only play low fidelity sound

with a low sample rate. LEGO has also included a library of sounds, including some robot sounds to enhance your creation.

2.4 Input and Output Ports

The NXT has four sensor ports and three motor ports. The sensor ports use a standard protocol called Inter-Integrated Circuit or I^2C (pronounced I-squared-C). I^2C is a bus that allows transmission of data to and from sensors. Philips invented the standard in the early 1980s and since then it has seen some use in cell phones and other small devices.

2.5 Cables

The NXT kit contains seven cables (one for each port) with three different lengths. The LEGO NXT uses a connector known as RJ12, which looks much like a phone connector.

2.5.1 USB

A USB cable can be used to upload code and data to the NXT, and it is the only method for uploading firmware (more on this later). The USB port can transmit data at 12 Mbits per second. This solution is familiar to most computer users and easy to use. LEGO supplies a standard USB cable which is identical to a printer cable.

2.6 LCD Display

The NXT display is robust, allowing bitmapped images. It has a resolution of 100 x 64 pixels and an area of 26.0 mm x 40.6 mm. The display is black and white only. The LCD requires 17 milliseconds to draw a new screen. It can refresh the display almost 60 times per second (60 Hz) and easily displays animations such as the introductory animation when the NXT it first powered on. Several games have already been created for the NXT, such as Tetris.
The menu system on the NXT is brilliant. You can access any number of functions using the four buttons: two light grey arrow keys, an orange enter key, and a dark grey back key. The functions contained in the menu system range from Bluetooth settings to playing sound files.

3 Motors

Proprioception is the ability to keep track of internal conditions of body parts. When you move your arm, you know its position even with your eyes closed. Robots can also have proprioception by sensing the position of the motor axle. The new NXT motor uses built-in tachometers to keep track of axle rotation. It can turn in any number of directions for thousands of rotations and come back to the exact starting position at any time. This new feature opens up incredible possibilities for robot creation, especially with navigation and robot arms.

LEGO generously includes three motors in the NXT kit. Each motor weighs 81 grams. The NXT servo motor contains gears that reduce the speed of the motor and increase power.

4 Sensors

4.1 Touch Sensor

The touch sensor (Figure 5) is the most basic sensor in the NXT kit. It has a simple switch activated by the orange button on the front. The button has an axle hole, allowing you to connect parts directly to the sensor switch.

Figure 5: Touch Sensor

4.2 Light Sensor

The light sensor measures the intensity of light entering a tiny lens on the front of the sensor. The sensor is also equipped with a red light-emitting diode (LED) which illuminates the scene in front of the sensor. The sensor can also detect light invisible to the human eye, such as infrared (IR) light emitted from a television remote control. The light sensor is used to perform a variety of functions. By pointing the light sensor down, the robot can follow a black line. Sometimes the sensor is used to prevent a robot from driving off the edge of a table, since the sensor values decrease significantly when an object (such as a floor) is farther away (far objects do not reflect as much light as near objects). The light sensor can also distinguish dark objects from light objects, since dark objects reflect less light.
Light sensors have two modes:-

Active mode — the light sensor LED is illuminated. This is often used for line following or object detection.

Passive mode — the light sensor LED is extinguished. This mode is used for ambient light detection, such as measuring the sun's brightness.

4.3 Sound Sensor

The sound sensor is a brand new addition to MINDSTORMS. Although it resembles a microphone, it really just measures the loudness of sound in decibels (0). You can't use the

sound sensor to record sound files to the NXT brick. Since sound is louder when the source is near, the sound sensor allows robots to home in on sound sources. It can also react to sounds, such as clapping.

4.4 Ultrasonic Sensor

Even though the ultrasonic sensor (Figure 6) looks like a pair of eyes, it actually has more in common with the sound sensor than a camera. The ultrasonic sensor sends out a sound signal that is inaudible to humans (like a bat), then measures how long it takes for the reflection to return. Since it knows the speed of sound, it can easily calculate the distance the signal traveled.

Figure 6: Ultra Sonic Sensor

The ultrasonic sensor is the only I^2C sensor included in the NXT kit. It measures distances to solid objects in centimeters or inches. The sensor is capable of measuring distances up to 255 centimeters, though returns are inconsistent at these distances, probably because the return ping becomes weaker. The sensor is accurate from 6 to 180 centimeters, with objects beyond 180 centimeters not reliably located. It has an accuracy of plus or minus three centimeters, though the accuracy is better for close objects.

5 Using the LEGO Software

LEGO calls their software development language NXT-G (Figure 7). It is very advanced and capable. The G stands for Graphical, which means you will be using a graphical interface to develop code.
LEGO is not known for software expertise but with the NXT, LEGO turned to Texas-based software developer National Instruments to develop their programming environment. The results are quite amazing. As with the original software, users create programs by dragging building blocks into an open area from a reservoir of predefined blocks. Each block is essentially a method, and the user selects different parameters for the method using radio buttons, sliders and drop down menus.
The programming environment is more full-featured than might be expected. You can create custom blocks (like methods) that contain lots of code for a specific task. This makes it easier to fit a lot of code into the limited graphical area. The software also allows import of new blocks as new devices become available for the NXT brick.

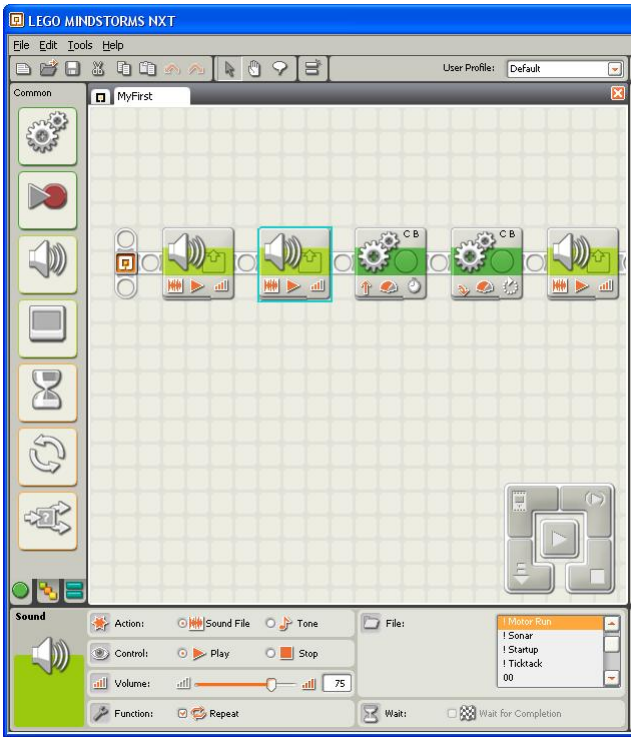

Figure 7: Lego Programming Environment

Although the graphical paradigm is easy to get into, especially for new programmers, it can be hard to manage code beyond a certain size and complexity. If you are used to Java or some other language, it isn't always obvious what a program is doing or how the blocks function.

References

[1] Brian Bagnall. *MAXIMUM Lego NXT*. Variant Press, 2007.