

CHAPTER 6

BUILDING A HOVERCRAFT CONTROL SYSTEM IN ROBOTC

1. INTRODUCTION: PROGRAMMING CONCEPTS

The computer is basically a calculator, just without the push buttons. There is little (in most cases, nothing) that a computer can do that a calculator cannot; the one thing that separates the two is the way that they are controlled. A push-button calculator is controlled when a person presses its buttons, which causes it to perform various functions—in particular, the functions that the person wanted, acting in the order that the person pushed the buttons, on whatever data the person entered into the calculator ... by pushing buttons.

The computer is fundamentally identical to this picture: a person gets a computer to perform specified functions in a specified order, on data that is either entered into the computer by the person or gathered by the computer from its environment at run time. The only significant difference is that there is no button-pushing; the person controlling the computer must decide ahead of time what functions to perform, and, because the data values might not be known until run time, the person must anticipate the possible values and provide contingency plans. For example, a person using a calculator to perform a complex calculation will stop halfway through if it is clear that the divisor of a term is zero or so near to zero as to produce an essentially infinite result. There is no such human oversight at the time of running a computer program, so the possibilities must be written explicitly into the sequence of steps, in this case by checking the value of a divisor against zero before using it in a division operation.

This, then, is the main point to remember when writing control systems for computers: that they are like very fast, very small (and trusting) children. They will do whatever you tell them to, even divide by zero, a billion times a second, so it is up to you to be quite certain that what you *tell* them to do is exactly what you *want* them to do, because 999,999 times out of a million, any perceived misbehavior on the part of a computer is due to a design error in the program—i.e., it is doing precisely what you told it to do.

What makes autonomous control interesting (and extremely challenging) is the interplay between the computer program and the real-world environment in which the computer finds itself. When you drive a car, you are well aware of your senses, and you respond to what you see and hear by changing the car's controls (steering wheel, accelerator, brakes, etc.). You also anticipate the

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behavior of the car; for instance, you probably prepare for a right-hand turn well before you reach the street at which you intend to take the turn. When you control an RC hovercraft, you do essentially the same thing: you watch what the hovercraft is doing, how much it drifts when you turn off the fans; you also anticipate where it will be and how much to correct for oversteer and tailspin in making turns.

What you will find the most challenging is how to operate in an environment where your senses are taken from you and replaced with far simpler and far more limiting ones. Compared to your senses, the hovercraft you build will have extremely rudimentary sensory inputs—such as binary tape detectors (light sensors detecting the presence or absence of a black tape underneath), distance sensors, and/or gyroscopes. Unless you explicitly create it in your program, your hovercraft will have no ability to remember past behavior (e.g., where it was a moment ago and what it was doing) or anticipate future stimuli and prepare for appropriate reactions.

What is Programming All About?

You have a set of resources at your disposal, for example:

- Computer/s (one or more microprocessors)
- Memory (temporary and/or permanent storage)
- Input devices (sensors)
- Output devices (actuators)

You also have a set of desired behaviors, for example:

- Follow a path
- Avoid hitting obstacles
- Turn on/off lamp when handclap detected
- Play brief salsa motif when simple task accomplished

A program is the connection between these two sets of things; it is your way to tell the system (e.g., hovercraft) how to behave. For instance, here is a program that will cause a walking robot to follow a path:

```
do the following forever:
  if on the path and the path is in front of you
    take a step forward
  otherwise
    turn slightly to the right
```

It should be relatively clear what this does, and how it does it. The robot is instructed to take a single step at a time and only when it is guaranteed that the step will keep the robot on the path (the “take a step forward” action is only allowed if the path is directly ahead). When the path is not directly ahead, the robot turns, a little bit at a time, until the path *is* directly ahead.

But what else does the robot do? What would be expected behavior of the robot, and what would be unexpected? Is walking the wrong way down the path an expected behavior? How about spinning in one place, forever? How about walking in circles or in a zig-zag manner? Should we expect the robot to exhibit any of these behaviors?

One should be able to look at code and imagine all its possible behaviors. For instance, at the end of the path, we should expect the robot not to stop, but to make a 180-degree turn, little by

little, and return the way it came, so walking backward down the path is expected. How about doing this before we reach the end of the path—is that possible? Consider cases in which the path turns to the left, or the robot is walking at an angle a little to the right of the path—the robot will reach the edge of the path, at which point there will be no path directly ahead, and the robot will turn to the right until it is facing the way it came, at which point it will walk the wrong way down the path.

Can the robot spin in one place forever? What happens if it starts off the path, or if it accidentally steps off the path? In those circumstances, you should expect the robot to spin forever, because the code will not allow it to take a step unless the robot is already standing on the path. In addition, if the “slight” amount the robot turns is about 90 degrees and the robot is pointing 45 degrees away from the direction of the path, no matter how many times the robot turns, it will never face down the length of the path, and so it will never take a step forward. How about walking in circles? Is that ever possible? Yes, in scenarios similar to the one above (if the degree of turning and width of the path are just right). How about a zig-zag motion? Since the code does not ever have the robot turn left, this would be an unexpected behavior.

These are the types of questions that it is well worth asking of your code, as even the simplest code can produce complex behaviors. Will the code work if the robot starts out off the path, for instance next to it but facing it? Or how about starting off next to it but facing away? Is the code robust enough to handle unexpected situations, such as walking in a line that is just slightly askew, so that after some number of steps the robot finds itself off the path? Or what if the steps that the robot takes are so large that it could step off the path when close to the edge?

Here is a more robust version of the code, one that handles many of these odd conditions:

```
do the following forever:
  if the path is in front of you
    take a step forward
  otherwise
    turn slightly to the right
```

Can this spin forever? Yes, but only if the path is out of sensory range. Can this walk in circles? Just like before, it depends on the degree of turning and the width of the path relative to the step size. Unlike the previous code, this handles situations where the robot is not on the path, for instance at start or if the robot accidentally steps off the path; it also handles cases where the robot is pointing slightly askew relative to the path. Zig-zag is unlikely to happen, but the robot can still accidentally turn around and walk the wrong way down the path if it hits the right edge of the path before reaching the end of the path. The following would be an obvious solution to that problem:

```
do the following forever:
  if the path is in front of you
    take a step forward
  otherwise
    turn slightly toward the path
```

This avoids making 180-degree turns before the end of the path, but this code presupposes the ability to know just where the path is. Previously, all code worked with simple binary detectors: i.e., the path is or is not in front of us. This last piece of code requires more information: the path is in front of us, or, if not, we can tell whether it is to the left or to the right of us. Depending on the types of sensors you have at your disposal, this information may be trivial to get, or it may be impossible to get, and so understanding the abilities of your sensor devices is crucial in the development of your system’s capabilities.

Just as important is understanding the abilities of your actuators: for instance, how is it that you cause the robot to turn? How do you know how far it turns each time? Do you need to know

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whether you are pointing straight or not, and, if so, how do you verify it? What actuator “takes a step forward” for you? How does it work? How far forward do you travel, and does the robot halt immediately after a step, or come to a “rolling stop,” or drift significantly (e.g. if the robot is actually on wheels or rollers or floating off the ground)?

What is the NXT?

We will describe the Lego NXT controller in more detail a few pages from now, but here it is worthwhile to look at it in purely functional terms, including the sensory inputs that it accepts and the actuators it can control.

The NXT is a small computer, and so it can be programmed like any other computer. Its advantages are firstly that it is lightweight and battery powered and thus makes a good hovercraft controller (as opposed to a desktop or even laptop computer, which would weigh too much for a small hovercraft), and secondly that it has a diverse modular array of sensors and actuators designed to work with it, for instance:

- light sensor — a sensor returning a value proportional to the amount of light it detects, which can be used to determine the lightness/darkness of the terrain that you are traveling over or to head toward a bright light in the darkness
- accelerometer — a sensor returning values proportional to the amount of acceleration it detects along 3 axes, which can be used to measure a system’s movement in 3 dimensions (acceleration is the 1st derivative of velocity and the 2nd derivative of position) ... note that the accelerometer measures both its movements and the effects of gravity, the sensor’s constant acceleration in the up/down direction
- gyroscope — a sensor returning values proportional to the angular rotation it detects, which can be used to measure a system’s movement in three dimensions, much like an accelerometer; its advantage is that, unlike the accelerometer, it does not also lump together the effects of movement and the effects of gravity
- compass — a sensor returning a heading (which way it is pointing relative to Magnetic North), which can be used to keep a system pointing in a known direction
- proximity sensor — an ultrasonic sensor returning a value proportional to the distance to the nearest object along the line of sight, which can be used to sense when approaching obstacles such as people, walls, traffic cones, etc.
- servo — an actuator that can be told to rotate any number of degrees, which can be used to implement wheels for propulsion, wheels for steering, doors that open and close, robotic arms, rudders and vanes, pulley systems, etc.
- motor — an actuator that can be told to spin at different speeds (i.e., run at different power levels), which can be used to implement wheels for propulsion, fans/propellers, etc.
- home-grown actuators such as relays and transistors, which can be connected to the NXT by customizing a Lego output cable (i.e., cutting and splicing) and that enable the NXT to control actuators requiring much more power than the NXT is capable of delivering, such as high-power lift fans and thrust fans—in particular, the kinds of fans you will need to power your hovercraft

These are extremely powerful sensors and actuators. At any time, the NXT can read the values of four different sensors connected to its inputs, and it can control the behavior of three different actuators connected to its outputs. Your job in the development of your hovercraft’s control system

is to determine which of these sensors and actuators make the most sense for you to work with, and then to develop a control program that periodically reads the input sensors values and controls the various actuators accordingly.

Examples of How To Get the NXT To Do Stuff

The following are some code samples of how to write RobotC code for the NXT. Do not worry if the syntax is confusing; we will discuss C-language specifics in detail in the “C Programming Basics” section of the chapter. This section is meant to serve as a preview.

The first example is a basic “hello, world” program, which just means that this is one of the simplest possible complete programs that you can imagine.

```
task main()
{
    nxtDisplayTextLine(3, "Hello");
    nxtDisplayTextLine(4, "World");
}
```

This prints a message on the NXT’s LCD screen, taking up two separate lines of the display. Several things to note:

- The `task main` statement indicates two things: first, that it is a “task,” a unit of code to execute together that is delimited by the curly braces, and second that it is the “main” task, which means that it will get executed first, before any other group of code that might be found in the program.
- As mentioned above, the curly braces delimit the code—like parentheses in mathematics, curly braces in C indicate what things should be grouped together.
- The print-out statements are function calls, wherein the stuff in the parentheses is the function’s *arguments*—the instructions to the print-out mechanism. The first argument tells the NXT which line on the LCD display to print on, and the second is a *string* (a bunch of characters beginning and ending with double quotes) that tells the NXT what to print.
- All statements end in semicolons; this is a C-language convention.

Note also that the display function `nxtDisplayTextLine` can take additional arguments, allowing it to print out variables (a tool that is quite useful for debugging). The following example demonstrates this ability:

```
// Port to which the sensor is connected
const tSensors LightSensor = (tSensors) S1;

task main()
{
    int light_reading;

    /*
    this is another way to specify comments -- everything between the slash-
    asterisk and the asterisk-slash is ignored, within a line or multi-line
    */
    while (true) {
        light_reading = SensorValue(LightSensor);
        nxtDisplayTextLine(2, "Light = %d", light_reading);
    }
}
```

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This example has a bit more to it:

- The very first line begins with two ‘/’ slash characters. This is a *comment*: the double-slash indicates that the rest of the line should be ignored by the NXT, as it only contains information useful to the programmer. This is where you make notes to yourself in the code.
- The second line is actually generated by the RobotC programming environment (we’ll get to that in class), and it declares that the object `LightSensor` is a sensor object that corresponds to a light sensor plugged into input 1 of the NXT.
- The first line of the main task is a variable declaration. It specifies that the object `light_reading` is to be used as an integer.
- The `while (true)` statement indicates that the subsequent code block (the set of statements delimited by the curly braces) should get executed repeatedly, as long as the value in parentheses evaluates to *true*. Since it is already declared to be true, that means the code block will loop forever. This is how you implement the `do the following forever`: statements in the pseudocode examples at the beginning of the chapter.
- The `nxtDisplayTextLine` function now has an additional parameter at the end: the variable that we wish to print to the screen. Also in the string is the odd-looking “%d” which indicates that a decimal-value integer will be printed out at that point.

So far we have shown how to print textual information to the NXT’s display and how to get read data values from the NXT’s sensor-input ports. The following example shows how to drive values to the NXT’s output ports:

```
// Port to which the sensor is connected
const tSensors LightSensor = (tSensors) S1;

task main()
{
    motor[motorA] = 50;
    motor[motorB] = 50;

    wait1Msec(1000);

    while (SensorValue(LightSensor) > 50) {
        // do nothing, i.e. keep going
    }

    motor[motorA] = 0;
    motor[motorB] = 0;
}
```

This starts up the NXT’s motors at a 50% power level (presumably driving wheels on the left- and right-hand sides), which moves the NXT forward at about half speed. After a 1-second delay, the NXT starts reading its input sensor value: it keeps reading the value over and over again while the value is greater than 50 (a percentage value, indicating the presence of light). Once the light reading is less than 50%, indicating the presence of a shadow or dark object, the `while` loop exits, and the motor power levels are set to 0, turning them off. Some things to note:

- `motor`, `motorA`, `motorB`, etc. are all reserved keywords. This means that the NXT expects them to be used in a certain way (as shown). So, for example, you can’t have a

variable called “motor” or “motorB” that you read and write the way the variable `light_reading` was used in the previous code example.

- The square brackets indicate an *array*, a C-language data structure that gathers together a set of similar objects. The name of this particular array is “motor”, and the number in the brackets is the index into the array—so in this example `motor` indicates an array of things (probably motors), `motorA` being one and `motorB` being another.
- The value used to set a motor value is a number between 0 and 100, indicating a power level corresponding to a percentage of maximum.
- The `wait1Msec` function does as one would expect: it stalls for the specified number of milliseconds and then goes on. This stalls the execution of code, not the NXT, so while the code is stalling, the motors are still running along at power level 50.

Returning to the earlier theme of fully understanding one’s code, how could this example produce odd behavior? For instance, note that it does *not* have the behavior of moving forward until detecting a dark spot and then stopping: it moves forward *for a minimum of 1 second* before it even looks for lightness/darkness, so if the dark spot is small and less than one second of travel away, the NXT could drive right over it without ever stopping—however, there are times when you might want exactly this behavior.

The following starts detecting the lightness/darkness immediately and also gives an example of time measurement:

```
// Port to which the sensor is connected
const tSensors LightSensor = (tSensors) S1;

task main()
{
    int timeTaken;

    ClearTimer(T1);
    motor[motorA] = 50;
    motor[motorB] = 50;

    while (SensorValue(LightSensor) > 50) {
        // do nothing, i.e. keep going
    }

    // found dark - stop & print results
    timeTaken = time1[T1]; // stop timing
    motor[motorA] = 0;     // shut down motors
    motor[motorB] = 0;

    nxtDisplayTextLine(2, "Time = %d", timeTaken);
}
```

This starts moving immediately and stops as soon as darkness is detected; in particular, if the NXT starts on a dark spot, it will halt before the motors have much time to get moving. Like the “motor” keywords, `time1` and `T1` are reserved keywords that must be used as shown: `time1` is an array of timers, `T1` being one of those timers. The call to `ClearTimer` sets timer `T1` to 0, so that the reading of the timer later on (in the statement `timeTaken = time1[T1];`) gets the time in milliseconds from the time of the clearing to the time of the reading. This gives the amount of time the NXT spent driving around, searching for darkness.

Pseudocode as a First Draft

In the beginning of the chapter, some code was offered as example control programs, but the code was written in English and probably would not run on any computer as-is. This is *pseudocode*, the most commonly used form of sketching out one's programming ideas.

In general, before writing a complex piece of software, one should formulate a reasonable picture of what it is the program should do: just as an artist draws sketches before starting to paint, so should an engineer sketch out the overall program before starting to write actual code. Pseudocode is a popular medium because it tends to be self-explanatory, and, despite its simplicity, it can still help discover design flaws, as we saw in the previous examples. For example, here is a rudimentary vehicle-control algorithm for following a dark line on a light floor, assuming that the vehicle has two downward-pointing light sensors (`lightL` and `lightR`) at the front, each one positioned on either side of the line, and two motors (`motorL` and `motorR`) that provide forward thrust:

```
do forever:
  read forward light sensors (lightL, lightR)
  respond to the 4 possible combinations of values:
    1. (light, light) -- sensors are straddling line
       set motor speeds as follows:
         motorL = 100%
         motorR = 100%
    2. (light, dark) -- lightR is on the tape, so turn right
       set motor speeds as follows:
         motorL = 100%
         motorR = 50%
    3. (dark, light) -- lightL is on the tape, so turn left
       set motor speeds as follows:
         motorL = 50%
         motorR = 100%
    4. (dark, dark) -- we are perpendicular to the tape, so spin slowly
       in a clockwise motion until we are not perpendicular to tape
       set motor speeds as follows:
         motorL = 20%
         motorR = -20%
```

This is not a particularly robust program, but it does specify reasonably well what is intended and how it will happen. Because the “code” is mostly human-readable English, it is self-documenting; any engineer reading it should be able to understand what it is intended to do as well as how it expects to go about it.

Note in particular the indentation; here, as in regular programming languages, the nesting of statements indicates their “scope” ... e.g., everything below and indented further right than the `do forever` statement is subservient to that statement (it comprises a loop that will execute until the computer is shut off); the numbered statements that are indented more than the `respond to the 4 possible combos` statement are the four possible sensor-value combinations, and one would expect that only one could be true, so for any given sensor reading only one will execute; the `motorX = ...` statements are indented further right than the `set motor speeds` statements above them, and so both `motorL` and `motorR` will be set if the previous `set motor speeds` statement is executed.

6.2 C PROGRAMMING BASICS

The RobotC environment does not implement the entire C programming language; it implements only a subset, but the subset it implements is more than powerful enough to create just about any control system you will need. This section offers a primer on the topic ... in general, when a complete valid statement is shown, it is terminated with a semicolon; code snippets without semicolons at the end represent code that would be part of a larger statement.

Data Types

The following RobotC data types are at your disposal, not all of which are classic C types:

- **Boolean values** — Booleans are useful for specifying variables that indicate “true” or “false” and nothing else in between. For instance, your code could use these to indicate light/darkness detected by various sensors. Ultimately, they are represented by integers having the value 0 (false) or 1 (true).

```
bool right_sensor_onTape;  
bool left_sensor_onTape;  
  
if (right_sensor_onTape) {  
    // do something  
}
```

- **Integers** — We have seen integer values in the previous code examples; integers are declared as “int” and hold positive or negative integers. In the NXT, they are 16-bit quantities, so they hold values between -32768 and 32767 . Any number outside of this range does not exist, as far as the NXT is concerned; for instance, if you have the value 32767 in a variable and you add the value 27 to it, the result will “wrap around” the number scale, and you will be left with a large negative number.
- **Floating point numbers** — Floating point numbers are used to represent fractions, which are otherwise not convenient to do with integers. For instance, if you did the following:

```
int a = 3;  
int b = 5;  
int c = a / b;  
  
nxtDisplayTextLine(2, "Value = %d", c);
```

you would get garbage results. The variable “a” would get the results of the division, rounded down to the nearest integer, because a is incapable of holding a non-integer value.

```
float a = 3.0;  
float b = 5.0;  
float c = a / b;  
  
nxtDisplayTextLine(2, "Value = %f", c);
```

This works as expected. Note the “%f” in the display function ... this indicates that the variable is a floating-point number and should be interpreted and printed out as such.

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- **Characters** — Characters are a subtype of integer; they are 8-bit quantities that range from 0 to 256 and are used to represent ASCII alphanumeric codes. They are declared as follows:

```
char a, b;
```

One thing to note about characters is that, while it is possible to use them like integers, it is more convenient to use them as printable ASCII codes, as follows:

```
char a = 37; // this is valid, but only used in small computers
a = a + 1;   // this is valid, but only used in small computers

char b = 'G'; // this is more often used
```

Note that when you use an ASCII value directly (like the letter G in the example above), you need to put single quotes around it.

- **Arrays** — An array is an aggregate data type, in particular a linear set of similar data objects. So, for example, you could have a bunch of integers packed together as follows:

```
int array[25];
```

This produces a grouping of 25 integers that are all packed together right next to one another. They are accessed as follows:

```
array[0]    // the first item in the array
array[1]    // the second item in the array
array[i]    // the "ith" item in the array (valid for 0 <= i <= 24)
array[24]   // the last item in the array
array[25]   // a bug in your code just waiting to wreak havoc
```

Note that the index into the array has to be an integer, and in particular it has to be a positive integer value that is less than the size of the array, otherwise you get weirdness. If you index into an array using an index value that is negative or equal to/larger than the size of the array, you will be reading data, but not data that is part of the array; you'll get garbage.

- **Strings** — A string is a character array, declared as follows:

```
string robotName = "walle";
```

Note the double quotes at the beginning and end. In particular, the double quotes at the end come *before* the terminating semicolon. This will drive you nuts if you are American and have spent the last two decades of your life being told by your teachers always to put the punctuation *inside* the quotes. The rest of the English-speaking world is a bit more logical in this regard.

- **Structures** — Like arrays, structs are another aggregate data type. While arrays are great for collecting sets of similar data items, sometimes you want to create a set of potentially heterogeneous objects. The C “struct” type allows just that. The following gives an example of how to declare a struct:

```
typedef struct {
    int grade;
    string firstname;
    string lastname;
    char letterGrade;
    float GPA;
    int examplearray[12];
} myStruct_t;
```

This example creates a new user-defined data type called a “myStruct_t” which can be used to create variables in the same way that you can create variables of type `bool`, `int`, `float`, and `char`. Note that not all the fields need to be of different type; for instance, one could have a struct that is entirely integers. Also note that a struct can contain aggregate data types like arrays (or even other structs).

The members of the struct are not indexed as in an array; they are referenced by name. The following code snippet shows how to create an object of this type, as well as how the various fields of the struct are referenced.

```
task main()
{
    myStruct_t example;

    example.grade = 10;
    example.firstname = "Brockton";
    example.lastname = "Veendorp";
    example.letterGrade = 'A';
    example.GPA = 3.5;

    if (/* student is graduating */) {
        example.grade = example.grade + 1;
    }
}
```

- **Arrays of Structs** — Often times, the main reason to use a struct is to create a whole array of data records. The following is an example, which could be used within a hovercraft to keep track of the previous 50 sensor readings.

```
struct {
    int lightL;
    int lightR;
    int fanL;
    int fanR;
} history[50];
```

For example, if sensor readings and corresponding actions were taken once every tenth of a second, this would keep track of the last five seconds’ worth of light-sensor readings and the power levels given to the two thrust fans. Individual components in this aggregate data type would be referenced as follows:

```
history[10].fanL
history[i].lightR
```

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One thing to note about the invocation above is that the syntax is slightly different than shown in the previous section; specifically, there is no “typedef” keyword. Thus, this statement creates an array of structs called *history*, but it does not create a type that can be instantiated. The more complex method would be as follows:

```
typedef struct {
    int lightL;
    int lightR;
    int fanL;
    int fanR;
} state_t;
state_t history[50];
```

For the relatively small control programs you will write in this class, the simpler facility (making a single struct, not a whole typeclass of them) is probably more than sufficient.

- **Void** — the non-type. For purposes of basic programming in RobotC, this is generally only useful for declaring a function that does not return a value, i.e.

```
void turn_off_motor(int id)
{
    motor[id] = 0;
    return;
}
```

as opposed to the following, which returns an integer value:

```
int add_two_ints(int a, int b)
{
    return a + b;
}
```

We’ll get into more detail on functions in the *Control Structures* section below.

Operations on Data

You can read data, you can write data, and you can perform various arithmetic and logical operations on data. Examples are given below.

- **Reading/writing data**

```
a = 3;           // assignment operation; puts the integer 3 into variable a
a = 3.5;        // puts the floating-point value 3.5 into the variable a
a = b;         // reads variable b and puts whatever is found into variable a
x = list[2]    // reads the 3rd item in array “list” & writes it to variable x
list[0] = y;   // reads y and writes it to the first item in the array “list”
list[i] = y;   // puts y into the ith slot of the array, e.g.:
                // if i=1, y is written into the second slot of the array;
                // if i=32, y is written into the 33rd slot of the array; etc.
a[x] = b[y];   // yes, this is possible, and can be very useful
a[f(x)] = 1;   // works if we know that function f returns an integer
                // of the proper size
```

- **Arithmetic and logic operations** — these operations work on integers and floating point numbers and produce a result of the same type as the input variables. So — add an integer to an integer, and you get an integer; add a float to a float, and you get a float. Be careful when

operating on variables of different types; while it can be very useful, it creates an unintended bug 99 times out of 100. The following are examples:

```
a + b      // addition
a - b      // subtraction
a * b      // multiplication
a / b      // division
a++;       // increments a by 1
a--;       // decrements a by 1
a = b++;   // reads b, puts it into a, and then increments b by 1

a & b      // bit-wise AND function (e.g. 0010 AND 0110 equals 0010)
a | b      // bit-wise OR function (e.g. 0010 OR 0110 equals 0110)
!a         // logical negation (turns a non-zero number into zero, and
           // turns a zero into a 1 - e.g. if a==0110, !a equals 0)
~a         // bit-wise negation (e.g., if a==0110, ~a equals 1001)

a += b;    // short-hand for a = a + b;
a -= b;    // short-hand for a = a - b;
a *= b;    // short-hand for a = a * b;
a /= b;    // short-hand for a = a / b;
a &= b;    // short-hand for a = a & b;
a |= b;    // short-hand for a = a | b;
```

- **Boolean operations** — note that Boolean values are either 0 or 1 (false or true)

```
a == b     // equivalence operation; produces a Boolean result
a != b     // true if a does not equal b
a < b      // true if a is less than b
a <= b     // true if a less than or equal to b
a > b      // greater than
a >= b     // greater than or equal to
a = !b;    // puts the Boolean negation of b into a
a = ~b;    // puts the bit-wise negation of b into a
a && b     // true if a is true (or non-zero) AND b is true (or nonzero)
a || b     // true if a is true (or non-zero) OR b is true (or nonzero)
```

Control Structures

RobotC offers the following control structures for your code:

- **Task** — Perhaps the most fundamental control structure is that of the *task*, a RobotC-specific mechanism that corresponds roughly to a running program. We have already seen the main task; your program can have up to ten (10) others as well. Every task in your program is almost like a separate program that can run alongside the original main task, just as you can have Microsoft Word running alongside your browser, your email client, and your session of Quake III Arena, all at the same time, all on the same computer. Usually splitting out a program into separate tasks is done for convenience of logic and/or readability of code. Here is an example that starts up a separate task to pulse the motors on and off, something that you would need to do if you were to use relays instead of transistors to control your motors.

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Building a Hovercraft Control System in ROBOTC

```
// global variables - necessary since we can't pass args directly to tasks
int motorA_power = 0;
int motorB_power = 0;

// reads motorA_power power value and "stutters" the output to motorA
// to approximate that power value -- loop 10 times per second
task stutter_motorA()
{
    int mSec_on = motorA_power;
    int mSec_off = 100 - mSec_on;

    // loops ten times a second
    while (true) {
        motor[motorA] = 100;
        wait1Msec(mSec_on);
        motor[motorA] = 0;
        wait1Msec(mSec_off);
    }
}

// reads motorB_power power value and "stutters" the output to motorB
// to approximate that power value -- loop 10 times per second
task stutter_motorB()
{
    int mSec_on = motorB_power;
    int mSec_off = 100 - mSec_on;

    // loops ten times a second
    while (true) {
        motor[motorB] = 100;
        wait1Msec(mSec_on);
        motor[motorB] = 0;
        wait1Msec(mSec_off);
    }
}

// assumes motorA is on left and motorB is on right
task main()
{
    // start them up just so we know it is safe to stop them later
    motorA_power = 0;
    motorB_power = 0;
    StartTask(stutter_motorA);
    StartTask(stutter_motorB);
}
```

```
while (true) {
    if (/* sensor readings tell us we should turn right*/) {
        StopTask(stutter_motorA);
        StopTask(stutter_motorB);
        motorA_power = 100;
        motorB_power = 50;
        StartTask(stutter_motorA);
        StartTask(stutter_motorB);
    } else if (/* sensor readings tell us we should turn left */) {
        StopTask(stutter_motorA);
        StopTask(stutter_motorB);
        motorA_power = 50;
        motorB_power = 100;
        StartTask(stutter_motorA);
        StartTask(stutter_motorB);
    } else if (/* sensor readings tell us we should stop */) {
        StopTask(stutter_motorA);
        StopTask(stutter_motorB);
        motorA_power = 0;
        motorB_power = 0;
        StartTask(stutter_motorA);
        StartTask(stutter_motorB);
    } else { // go forward
        StopTask(stutter_motorA);
        StopTask(stutter_motorB);
        motorA_power = 75;
        motorB_power = 75;
        StartTask(stutter_motorA);
        StartTask(stutter_motorB);
    }
}
}
```

The main task starts up the tasks whenever it wants the thrust fans to go; the global values are used to indicate the desired power levels for the fans.

The responsibility of the tasks is to buffer the main task from having to stutter the motors (this is one way to effectively achieve a lower power level, which would be useful if you are using relays and not transistors to control your fans). You can imagine how difficult it would be if you had to intertwine into the main code loop the `while(true)` loops in the stutter tasks that implement the timed on/off behavior. It would be nasty-looking code, prone to exhibiting weird bugs, etc. The task allows the behavior to be consolidated in one place, where it can be shut off at will and from outside the task. Unfortunately, RobotC does not allow one to pass arguments directly to a task, thus the necessity of the `motorX_power` global variables (which are a bit hack-ish).

We start the tasks with zero power levels at the beginning of the program (first actions of the main task); this is done in case trying to stop a non-existent task turns out to cause a run-time error (it may or may not; you might want to experiment to find out for yourself).

- **Function** — We have already seen functions in action. For instance, the `StartTask` and `StopTask` primitives are functions predefined by RobotC. You can also declare your own functions. When invoked, functions are unlike tasks in that they do not become independent entities. That is, when you call a function, it is as if you executed the function's code in place. The following erroneous code example illustrates:

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Building a Hovercraft Control System in ROBOTC

```
// takes as arguments the motor identifier and a power value and "stutters"
// the output to approximate that power value -- loop 10 times per second
void stutter_motor(int whichMotor, int powerLevel)
{
    int mSec_on = powerLevel;
    int mSec_off = 100 - mSec_on;

    // loops ten times a second
    while (true) {
        motor[whichMotor] = 100;
        wait1Msec(mSec_on);
        motor[whichMotor] = 0;
        wait1Msec(mSec_off);
    }
    return;
}

// assumes motorA is on left and motorB is on right
task main()
{
    while (true) {
        if (/* sensor readings tell us we should turn right */) {
            stutter_motor(motorA, 100);
            stutter_motor(motorB, 50);
        } else if (/* sensor readings tell us we should turn left */) {
            stutter_motor(motorA, 50);
            stutter_motor(motorB, 100);
        } else if (/* sensor readings tell us we should stop */) {
            motor[motorA] = 0;
            motor[motorB] = 0;
        } else { // go forward
            stutter_motor(motorA, 75);
            stutter_motor(motorB, 75);
        }
    }
}
```

This is an attempt to simplistically re-do the previous task-based example using functions; the stuttering behavior is implemented in functions which are called by the main task, instead of tasks that are started & stopped by the main task. This would be a more elegant way, for example, to pass arguments from the main task to the subroutines that actually perform the stuttering.

Though it might appear to be a more elegant way to write the previous code example, this code fails to work: as soon as the `stutter_motor` function is called, it will go into an endless loop and never return. This is not meant to disparage functions, merely an illustration of how they differ from tasks. Functions are extremely convenient, as they allow the passing of arguments (as shown) as well as return values. Because of this they allow a programmer to use a modular approach to program design, wherein the low-level details of how things are done are kept in very low-level functions, and the high-level functions (the main task and the handful of functions it calls) can be written in such a way as to hide all of those low-level implementation details.

Taking a modular approach tends to facilitate reading, understanding, and thus debugging one's code. For instance, the following code is a rewrite of the earlier example that uses a function to initialize the global variables and start/stop tasks.

```
// global variables - necessary since we can't pass args directly to tasks
int motorA_power = 0;
int motorB_power = 0;

task stutter_motorA()
{
    // as before
}

task stutter_motorB()
{
    // as before
}

// takes as input power levels for motorA and motorB
void run_motors(int mA, int mB)
{
    StopTask(stutter_motorA);
    StopTask(stutter_motorB);
    motorA_power = mA;
    motorB_power = mB;
    StartTask(stutter_motorA);
    StartTask(stutter_motorB);
    return;
}

// assumes motorA is on left and motorB is on right
task main()
{
    // start them up just so we know it is safe to stop them later
    motorA_power = 0;
    motorB_power = 0;
    StartTask(stutter_motorA);
    StartTask(stutter_motorB);

    while (true) {
        if (/* sensor readings tell us we should turn right*/) {
            run_motors(100, 50);
        } else if (/* sensor readings tell us we should turn left */) {
            run_motors(50, 100);
        } else if (/* sensor readings tell us we should stop */) {
            run_motors(0, 0);
        } else { // go forward
            run_motors(75, 75);
        }
    }
}
```

This code should be much easier to read than the original example upon which it is based. This is the power of functions; whenever you see the same block of code happening over and over again, with only minor variations, that is a sure bet that you should encapsulate the code in a function call.

As mentioned, another aspect of functions is that they can return values, as in the following code example.

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```
const tSensors light1 = (tSensors) S1;
const tSensors light2 = (tSensors) S2;
const tSensors light3 = (tSensors) S3;
const tSensors light4 = (tSensors) S4;

float get_sensor_avg()
{
    float avg;
    int sum = SensorValue(light1);

    sum += SensorValue(light2);
    sum += SensorValue(light3);
    sum += SensorValue(light4);

    avg = (float)sum;
    return avg / 4.0;
}

// prints out a new sensor reading every 0.1 second
task main()
{
    while (true) {
        nxtDisplayTextLine(2, "Avg = %f", get_sensor_avg());
        wait1Msec(100); // wait a tenth of a second
    }
}
```

Among other things, this code example illustrates the C-language notation for casting data types into other types, in particular how to create a floating-point number out of an integer. The `(float)` notation in front of the variable name `sum` near the end of the function tells the system to read the integer value of `sum` and then turn it into a floating-point number before putting its value into the variable `avg` (which is a floating-point number).

- **While loop** — We have already seen the while loop in action. Formally, it takes as an argument a Boolean statement (something that evaluates to either true or false) and conditionally executes whatever code block comes after it. The important thing to remember is this ordering: first the evaluation of the condition statement and then the execution of the following code block. This happens repeatedly until the condition statement evaluates to false, at which point the NXT moves on to execute the instructions that come after the while loop.

```
while (condition) {
    // code block to be executed (one or more instructions),
    // often called the "loop body"
}
// following instructions
```

This produces a loop format, because the code block will be executed repeatedly until the condition becomes false (the integer value 0). As soon as the condition evaluates to false, the NXT jumps to the “following instructions” after the loop body.

Note again that the condition test happens before the loop body; this means that it is possible for the loop body to be skipped, if for example on the first test of the condition it evaluates to false. Sometimes, this is not desired; sometimes a programmer might wish for the loop body to be executed at least once before evaluating the conditional value. This is what the do-while loop is for, described next.

- **Do-while loop** — As mentioned above, sometimes a programmer needs a loop structure in which the loop body is executed at least once before evaluating the conditional value. For this, the do-while loop is used, as shown below.

```
do {  
    // code block to be executed (one or more instructions),  
    // often called the "loop body"  
} while (condition);  
// following instructions
```

This structure is also a loop; the loop body will be executed repeatedly until the NXT evaluates the Boolean condition to false. The difference is that the loop body is guaranteed to be executed at least once, even if we know ahead of time that the condition is false, for instance in the following (contrived) case:

```
do {  
    // loop body  
} while (false);
```

This will execute the loop body once, then test the conditional which is hard-coded to be false; the condition will fail, and the loop will terminate, passing control to the following instructions.

One thing to note: the semicolon at the end of the `while ();` statement is required for a do-while loop.

- **For loop** — The for loop is generally used for iteration; it takes the following form:

```
for ( /*initialization*/ ; /*condition*/ ; /*update*/ ) {  
    // loop body  
}
```

The semicolons between the three components (initialization, condition, update) are required, even if a particular component is left blank. The components function as follows:

- **initialization** — This happens once, at the start of the loop, before the condition evaluation. It is a good way to set up the variables that will be in use.
- **condition** — This is identical to the while-loop condition; it is evaluated before the loop body, so if it evaluates to false on the first pass, the loop body is never executed.
- **update** — This is a statement that is executed after the loop body and before the next evaluation of the condition statement.

Here is a typical use of the for loop:

```
int i, array[1024];  
  
for (i=0; i<1024; i++) {  
    array[i] = 0;  
}
```

Note that the *initialization* and *update* components can have multiple statements, each separated by commas.

- **If/then/else** — This control-flow structure was shown in an earlier code example. It allows a programmer to specify one or more code blocks, at most one of which will be executed, based on one or more conditionals.

A simple if-then example that executes the code body only if the sensor value satisfies some conditional, so the code body may or may not be executed:

```
if (SensorValue(mySensor) < 50) {  
    // code body -- react to the sensor result  
}
```

The following if-then-else example provides two options, one of which is guaranteed to be executed:

```
if (SensorValue(mySensor) < 50) {  
    // turn left  
} else {  
    // turn right  
}
```

Having a simple else statement at the end of an “if” construct is the default case; it specifies code that will be executed if all other conditionals fail. The following is a more complex example:

```
int value = SensorValue(mySensor);  
if (value < 25) {  
    // turn left  
} else if (value < 50) {  
    // turn right  
} else if (value < 75) {  
    // go back  
} else {  
    // stop  
}
```

Note that later conditions in an if-else control block are tested only if all earlier ones fail, and later conditions are not tested if an earlier test succeeds, so only one code block will execute, in particular the first to satisfy its corresponding condition. So the following would be an error:

```
int value = SensorValue(mySensor);  
if (value < 25) {  
    // turn left  
} else if (value < 75) {  
    // go back  
} else if (value < 50) {  
    // turn right  
} else {  
    // stop  
}
```

The third condition will never succeed; any value greater than 25 and less than 50 will be caught by the second conditional. Note also that we read the sensor value only once and not multiple times, which would have been the case, at least potentially, if we had placed the `SensorValue(mySensor)` function call in each of the conditionals.

- **Switch** — If you have a control structure similar to the following, where your conditionals are, for the most part, testing for equality as opposed to greater than/less than, you might want to use a switch statement:

```
int value = SensorValue(mySensor);
if (value == 1) {
    // turn left
} else if (value == 2) {
    // go back
} else if (value == 3) {
    // turn right
} else if (value == 4) {
    // spin around
} else if (value == 5) {
    // stop
} else if (value == 6) {
    // spin clockwise
} else if (value == 7) {
    // spin counterclockwise
} else if (value == 0) {
    // shut down
} else {
    // blink lights
}
```

This type of construct can be difficult to read, and because it is difficult to read, it can harbor latent bugs easily. A better construct is the switch statement, which would implement the construct above as follows:

```
int value = SensorValue(mySensor);
switch (value) {
    case 1:
        // turn left
        break;
    case 2:
        // go back
        break;
    case 3:
        // turn right
        break;
    case 4:
        // spin around
        break;
    case 5:
        // stop
        break;
    case 6:
        // spin clockwise
        break;
    case 7:
        // spin counterclockwise
        break;
    case 0:
        // shut down
        break;
    default:
        // blink lights
}
```

At the `switch (value)` statement, the value will be read once, and the NXT will immediately jump to which ever code block has the corresponding value expressed with its `case` statement. The `default` case is not required but is an extremely good idea to use, even if it is left empty by putting no code after it (perhaps include a comment to the effect that the omission of corresponding code is intentional).

The various `break;` statements are required, except for the very last case in the list. If a particular `break;` statement is omitted, the program will compile successfully, but at run-time the control flow will “fall through” from one case to the next.

- **Continue and break in loops** — There are two statements that provide extremely powerful ways to augment the behavior of loops. The *continue* statement causes a loop to halt mid-loop and go directly to the top of the loop. For example, here is its use in a while loop:

```
while (true) {
    int value = SensorValue(mySensor);
    if (value == 1) {
        // turn left
    } else if (value == 2) {
        // go back
    } else {
        continue;
    }
    // blink lights
    // update state
    // etc.
}
```

In this example, the *continue* statement causes the execution of the code to skip over the stuff at the end of the loop (blink lights, update state, etc.) and go straight to the top of the loop, at which point the conditional is re-evaluated, and the sensor value is read.

A *break* statement similarly disrupts control flow, but it instead causes control to exit the loop entirely.

```
while (true) {
    int value = SensorValue(mySensor);
    if (value == 1) {
        // turn left
    } else if (value == 2) {
        // go back
    } else {
        break;
    }
    // blink lights
    // update state
    // etc.
}

nxtDisplayTextLine(3, "Error situation");
```

This example is just like the previous one, except that the *continue* statement is now a *break* statement. This is one way to exit a loop that would otherwise execute forever. It is usually used in loops to detect anomalous or erroneous situations; normal events should be reflected in the while loop’s conditional.

An additional note on loop and if/then conditionals: they are usually Boolean statements, statements that evaluate to either 0 (false) or 1 (true). Because a computer only understands numbers, these are represented with integers, which can have the value 2 or -37, or 1023, and so on. Thus, while it is best practice to use code similar to this:

```
char x, array[1024];
int i;

for (i=1023; i > 0; i--) {
    x = array[i];
}
```

it is just as valid to say the following (the only change to the code is that $i > 0$ has been replaced by simply i).

```
char x, array[1024];
int i;

for (i=1023; i; i--) {
    x = array[i];
}
```

Why does this work? Because the NXT checks to see if the conditional is zero or non-zero; it does not do a strict test of 0 vs. 1. So any number other than 1 is considered equivalent to 1 for the purposes of determining a Boolean result. As soon as the variable i reaches the value zero, both of these loops will terminate.

6.3 THE LEGO[®] NXT[®] CONTROLLER

The NXT incorporates a microprocessor capable of storing programs that provide instructions for controlling the fans and other actuators used in your team's hovercraft. In this application, the control of the fans was complicated by the need to steer the hovercraft and to control its speed particularly around curves in the track. Moreover, the requirement is for autonomous control, which implies that the NXT must be programmed so that it provides command signals to the lift and propulsion fans that enable the hovercraft to negotiate the track in the minimum possible time.

Decision based control requires sensors in the system that provide feedback signals, which give information essential in controlling the system. When the system is in operation, the sensors provide continuous signals that are monitored by the NXT. When the level of a feedback signal deviates sufficiently from a specified level, the power to one or more actuators (fans) is adjusted to maintain the sensor signal within a control band centered about the control level. For decision-based control to be effective, the microprocessor must be provided with instructions that establish the upper and lower levels of the control band. Sensor signals that are outside the control band cause the controller to energize actuators (fans), which adjust the parameters affecting the system so as to maintain control. Programming for decision-based control is more challenging as the program entails a more structure involving forks, jumps and loops and sometimes loops within loops.

The NXT, shown in Fig. 6.7, is a controller that contains an Atmel ARM processor (AT91SAM7S256), which incorporates a high performance 32 bit RISC architecture. This processor contains 256 Kbytes of flash memory (non-volatile) with single cycle access at 30MHz. It also contains an additional 64 Kbytes of SRAM (static random access memory). The ARM processor

includes three different clocks to provide timing signals with frequencies that range from 22 to 42 kHz for the slow clock and 80 to 220 MHz for the PLL clock.

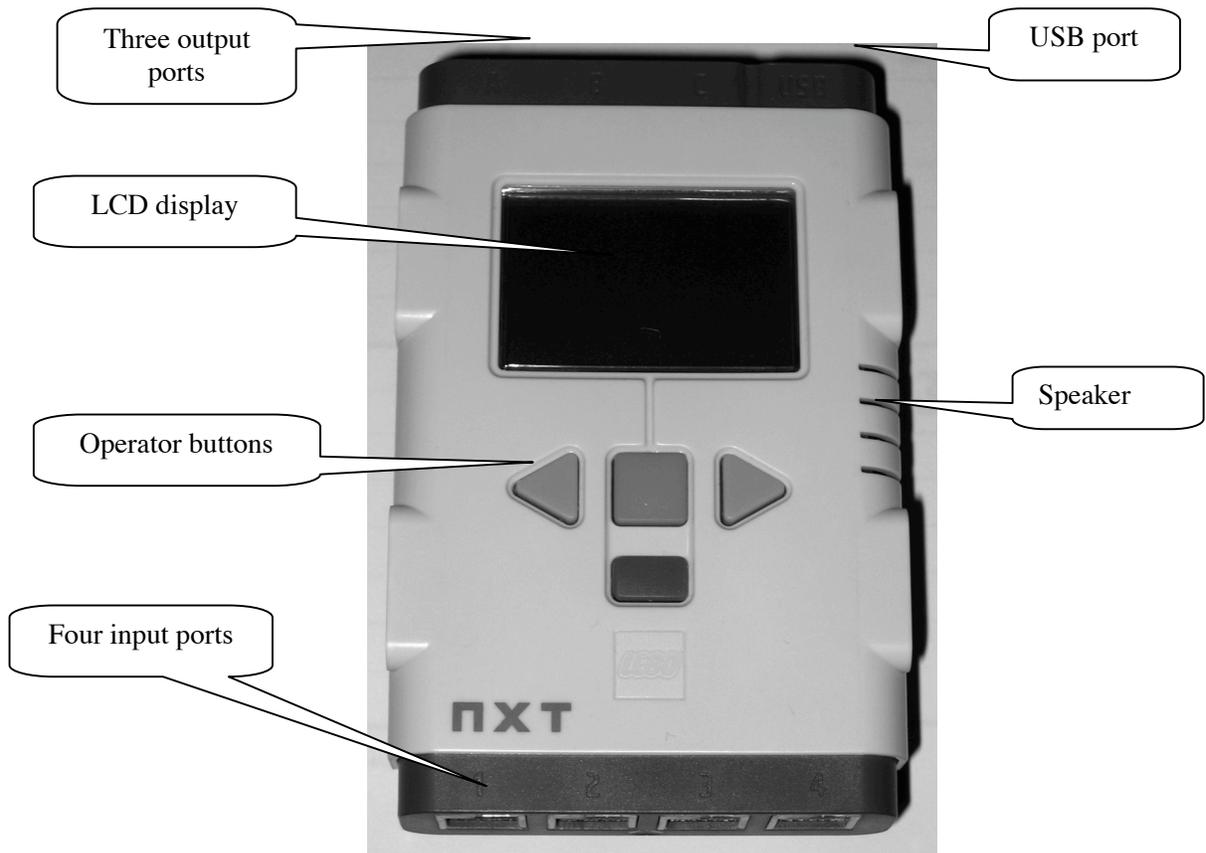


Fig 6.7 The NXT controls the actions of autonomous robots and vehicles.

The NXT also contains an 8-bit Atmel co-processor (ATmega48) that is used with the main processor for measuring voltage and controlling actuators. This processor contains 4 Kbytes of flash memory (non-volatile) with single cycle access at 30MHz. It also contains an additional 512 bytes of SRAM and 256 bytes of EEPROM memory. It has two 8-bit timer/counters, one 16-bit timer/counter and a real time counter. Voltage is measured with an eight channel 10 bit analog to digital converter (ADC). The 10-bit ADC in the NXT can acquire and store voltage measurements at frequencies up to 200 Hz. Six pulse width modulated (PWM) channels are available in the co-processor for supplying power to the motors and actuators, although the NXT only uses three of these channels.

Communication between the NXT and a computer is accomplished with either a USB cable or by Bluetooth wireless connection (radio). A CSR BlueCore™ 4 single chip radio and base band integrated circuit is employed to implement a Bluetooth 2.4GHz system, which provides enhanced data rates up to 3Mbps. The chip interfaces to 8Mbit of external flash memory and contains 47 Kbytes of RAM. When used with the CSR Bluetooth software stack, it provides a fully compliant Bluetooth system for data and voice communications. The BlueCore™ transmitter is powered by a 6-bit digital-to-analog-converter with a dynamic range greater than 30 dB. Its receiver incorporates channel filters and a digital demodulator for improved sensitivity and co-channel rejection. The USB 2.0 communication port is capable of 12 Mbits/s.

The number of programs you can store in the NXT is only limited by the memory available. The NXT microprocessor can perform both integer and floating point (decimal) mathematics. You can program the NXT to read and write files to its memory.

Input Ports and Sensors

There are eight ports on the NXT. The four input ports are located on the base of the unit below the display and control buttons, as shown in Fig. 6.7. These ports, numbered 1, 2, 3 and 4 are equipped with a six wire interface that can receive both analog and digital signals from sensors. Instructions in the LEGO User Guide for the NXT give the standard port locations for each of their sensors as:

- Port 1: Touch sensor
- Port 2: Sound sensor
- Port 3: Light Sensor
- Port 4: Ultrasound sensor

It is important to note that Port 4 is a high speed data connection that functions with an I²C communication protocol, which is used with the LEGO ultrasonic sensor. The sensors are wired to the input ports using the 6-wire industry standard RJ121 connector with right side adjustment.

Sensors are classified as either active or passive. The passive sensors do not require power from the NXT to operate. The LEGO touch sensor, a simple momentary switch shown in Fig. 6.8, and the LEGO sound sensor, a microphone shown in Fig. 6.9, are examples of passive sensors. On the other hand, active sensors require power from the NXT to function. The LEGO light sensor, which contains a IR light source and a photodiode as shown in Fig. 6.10, is an example of an active sensor. The LEGO ultrasonic sensor, shown in Fig. 6.11, requires a communication channel to accommodate the timing signals required when bursts of sound are transmitted and received.



Fig. 6.8 The LEGO touch sensor (a contact switch) is a passive device that does not require power to function.

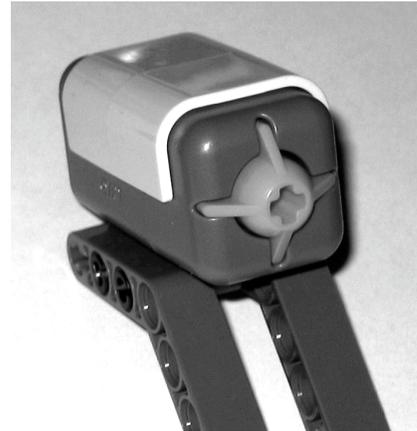


Fig. 6.9 The LEGO sound sensor (a microphone) is a passive device that does not require power to function. It measures sound in decibels (dB) or adjusted decibels (DbA).

Fig. 6.10 The LEGO light sensor is an active device that requires power to light its IR source. Its readings range from 1 (dark) to 100 (bright).

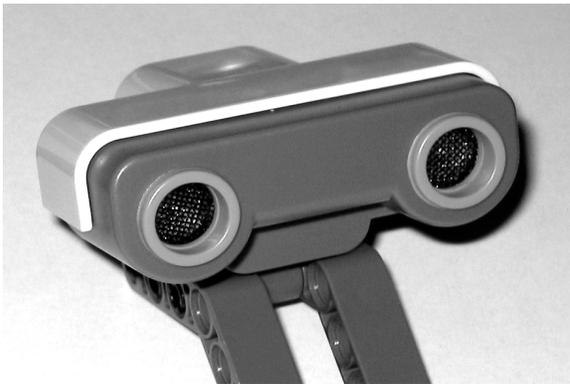


Fig. 6.11 The LEGO ultrasonic (sonar) sensor requires a communication channel to send and receive signals in order to measure time for sound propagation to and from a target.

Output Ports

The three output ports, located on the top edge of the NXT above the LCD, are labeled as A, B, and C. These ports are also equipped with a 6-wire interface to provide power (voltage pulses) to motors, lights or sound making devices and to receive input from encoders that are installed in the LEGO servo motors. Instructions in the LEGO User Guide for the NXT give the standard port settings for the motors as:

- Port A: Motor for additional function
- Port B: Motor for movement
- Port C: Motor for movement

Each port may be operated in one of three modes—**on**, **off** and **floating**. When a port is programmed in the **on** mode, a motor or actuator connected to that port receives pulse width modulated power. When a port is programmed in the **off** mode, the motor actuator attached to that port is braked so it stops abruptly. When a port is programmed in the **floating** mode, a motor connected to that port does not receive power, but it is permitted to freewheel until it stops due to frictional forces.

The LEGO servomotor, shown in Fig. 6.12, contains a small motor, gearing and an encoder. The gearing increases the torque of the motor but decreases its speed. The motor is equipped with an encoder that provides a signal which enables measurement of the angle of rotation of the motor shaft to within $\pm 1^\circ$. Two of the six wires in the standard RJ121 connector are used to connect the encoder signal to the NXT.

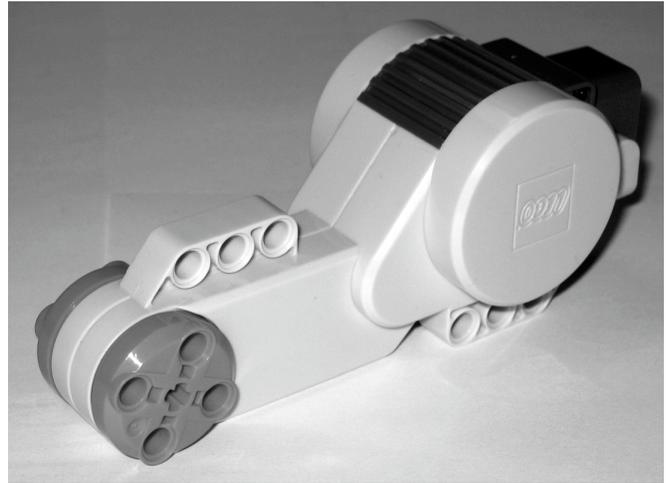


Fig. 6.12 The LEGO servomotor is connected to the output ports.



Fig. 6.13 Sensors and motors arranged around the NXT controller.

RCX motors and lights can be connected to the output ports of the NXT; however, an adapter cable is required to interface with its 6-wire RJ121 connector. In addition several companies¹ are producing special purpose sensors and output devices that are compatible with the NXT.

Communication with the NXT

Communication between the NXT and a computer is accomplished with either a USB cable or by Bluetooth wireless connection (radio). A CSR BlueCore™ 4 single chip radio and base band integrated circuit is employed to implement a Bluetooth 2.4GHz system. This chip provides a fully compliant Bluetooth system for data and voice communications at rates up to 3Mbps. The USB 2.0 communication port is faster with a transfer rate of 12 Mbps.

The Controller Buttons and Display

Near the center of the NXT, you will notice a liquid crystal display (LCD) and four buttons as shown in Fig. 6.7 and Fig. 6.13. The square orange button performs three functions—turns the NXT on, enters (selects) the icon that appears in the lower center of the LCD window and runs the program selected. The two light-gray triangular buttons are used for menu navigation as they to move the various icons across the LCD window. The small dark gray rectangular button is used to cancel the selection or to go back. It is pressed repeatedly until the “Turn-off” icon appears. Pressing the orange button when this icon is centered in the LCD shuts down the NXT.

When the NXT is turned on a short tune is heard and three icons appear near the bottom of the LCD, which include the “My Files”, “NXT Program” and “Try Me” icons. These and other icons are defined in Fig. 6.14 to Fig. 6.17. The gray triangular button enables you move progressively among the various options available. The icon of interest is centered in the display and it is selected by pressing the square orange button.

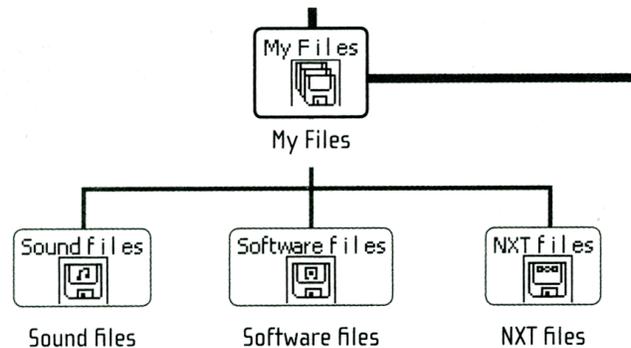


Fig. 6.14 The My Files icon and the three types of files that are options for storage in the NXT.

Storing Programs

The NXT stores three different types of programs as indicated in Fig. 6.14, which include sound files, software files and NXT files. Programs written on a computer are downloaded into “software files” and songs written on a computer are downloaded into “sound files”. Programs written directly on the NXT without using a computer are stored in the “NXT files”. The NXT Program icon that provides entry into a large number of commands available within the NXT is presented in Fig. 6.15. The programs written on a computer are downloaded to the NXT by a USB cable connected to a

¹ These companies include: www.mindsensors.com; www.techno-stuff.com; www.hitechnic.com; and www.lmsensors.com.

computer's serial port. The NXT can also send and receive signals with its Blue tooth technology. When a program is successfully downloaded, the NXT responds with a burst of sound confirming its transmission.

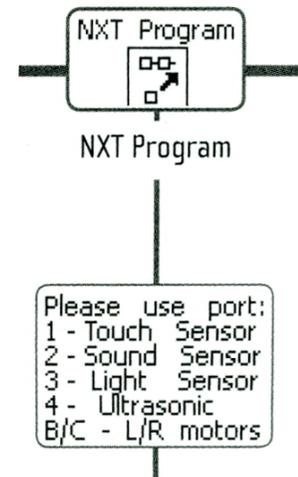


Fig. 6.15 The NXT program icon that enables programming to be performed directly on the controller.

The signals from the sensors are monitored by selecting the “View” icon that is accessed on the LCD by repeatedly pressing the triangular gray button. After the “View” icon is selected you have a choice of monitoring the signal from a large number of different LEGO sensors as indicated in Fig. 6.16. If a sensor is wired to a port, its output can be monitored on the LCD independent of a program running. In this sense, the NXT is functioning as a digital multimeter with its output converted to the units of measurement for the sensor involved.

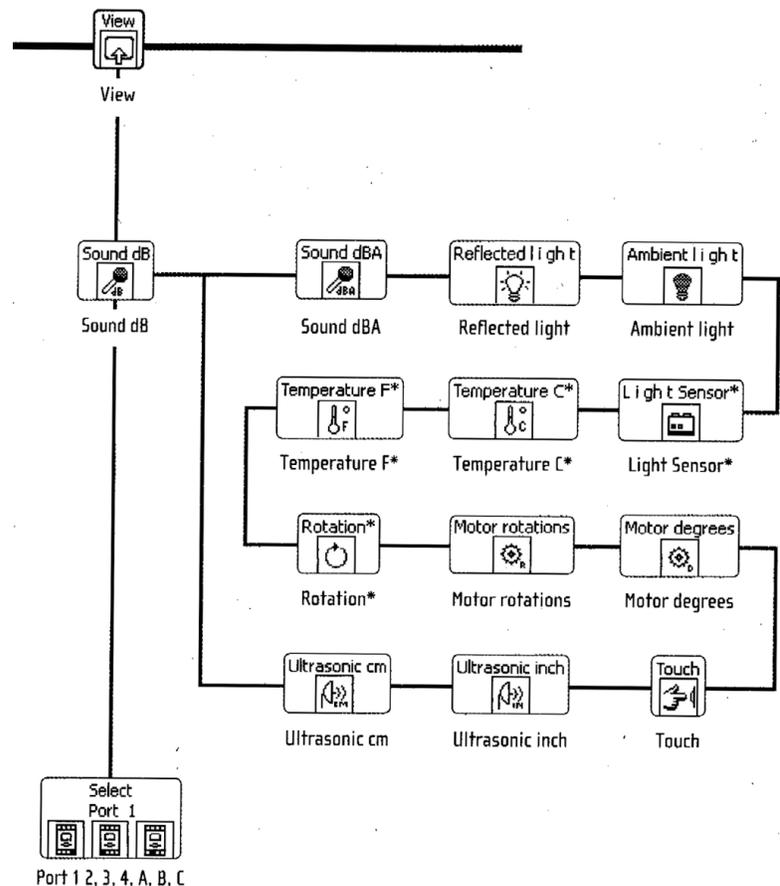


Fig. 6.16 The View icon enables measurements from the LEGO sensors to be monitored on the NXT display.

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When a program is running, the output from the sensors connected to the four ports is displayed in a listing that is shown continuously on the LCD. The NXT display also shows the output of its internal clock in hour, minute, second and tenth of a second running time for the program. Turning the NXT does not reset its internal clock and the time displayed is cumulative for a given program.

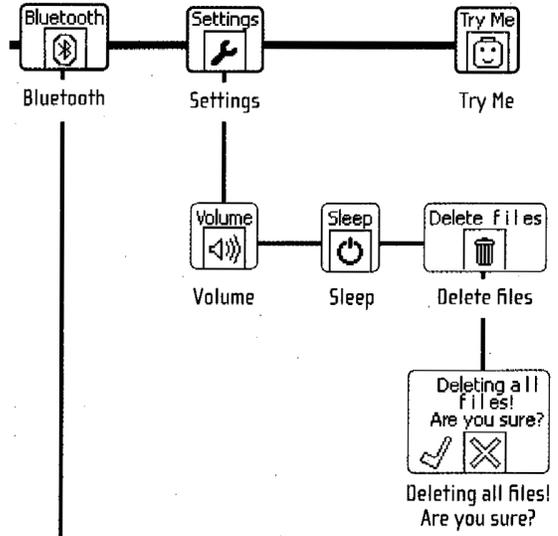


Fig. 6.17 The Bluetooth, Settings and Try Me icons that enable communication, NXT adjustments and a simple trial program.

The Bluetooth, Settings and Try Me icons are defined in Fig. 6.17. The Bluetooth icon provides access to several icons not presented in Fig. 6.17, which include Contacts, Connections, Search, On/Off and Visibility. The Settings icon enables access to Volume, Sleep and Deleting files. The Try Me icon issues a burst of sound when it is selected.