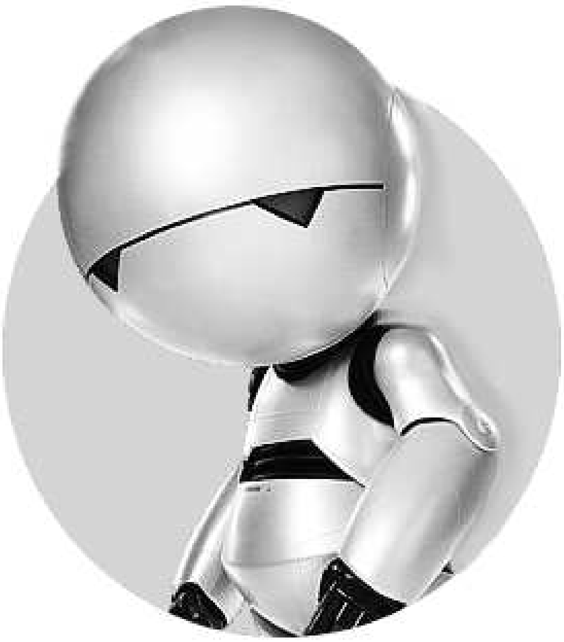
Intelligent Autonomous Robotics

User Manual

Version 1.1



September 21, 2005

Contents

1 Robotics Hardware

The computer/electronic hardware for the *Intelligent Autonomous Robotics* (IAR) consists of:

- The *Brain Brick*, a single board computer (SBC) with an ARM XScale compatible processor running at 400 MHz.
- The *Interface Board* which connects motors and sensors to the BrainBrick.
- The *Power Board*, to which the battery is connected, and which supplies the BrainBrick and all the other boards with power.
- Additional sensor boards (currently the *LDR board*, the *IR board*, and the *Compass board*) which can be daisy-chained over an I2C bus to the power board, to share data with the Interface board, and power from the battery.

You should start by identifying each board and its connections. Note that most connections are designed to fit one way only: this is the correct way! Never force a connection, and disconnect by pulling on the connector, not the wires.

WARNING: The battery must *always* be disconnected *before* you change any connections between the boards. Plugging things in and out while the system is powered could cause significant damage to the boards. The motor on/off switch *does not* disconnect power to the rest of the system. You must disconnect the battery.

1.1 Brain Brick

The core module is a single board computer (SBC) consisting of of a 400 MHz Intel XScale (ARM) processor module and a PC/104+ compatible base module. It has been enclosed in a black box that gives you access to the ethernet and serial ports, as shown shown in figure 1. It is powered and transfers data to the other boards via a direct connection to the Power Board.

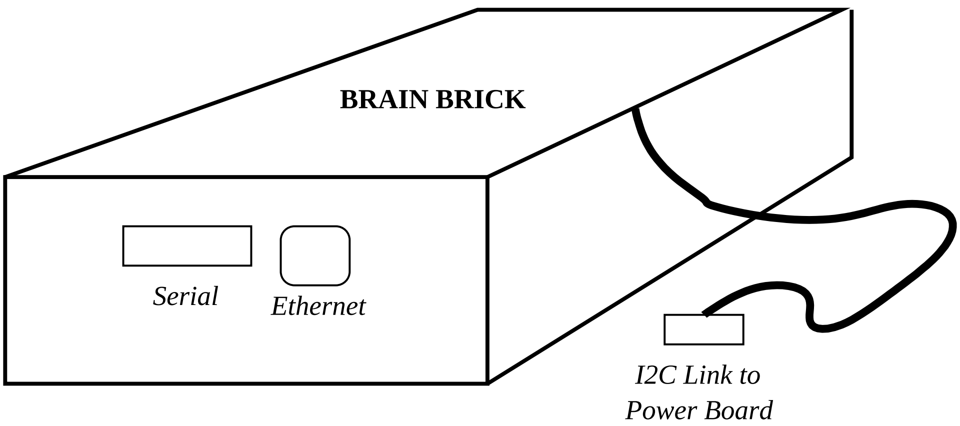


Figure 1: Brain Brick

1.2 Interface Board

The interface board (figure 2) is mounted on top of the black box. It provides connection points for 4 motors. The motors can be set to forward, stop, or reverse; motors 1 and 2 can also be set to slow forward or slow reverse. It also provides connection points for 6 microswitches (or whiskers or conduction sensors) and 1 Hall-effect sensor. It has 8 user-programmable LEDS. It is powered and transfers data to the other boards via a direct connection to the Power Board.

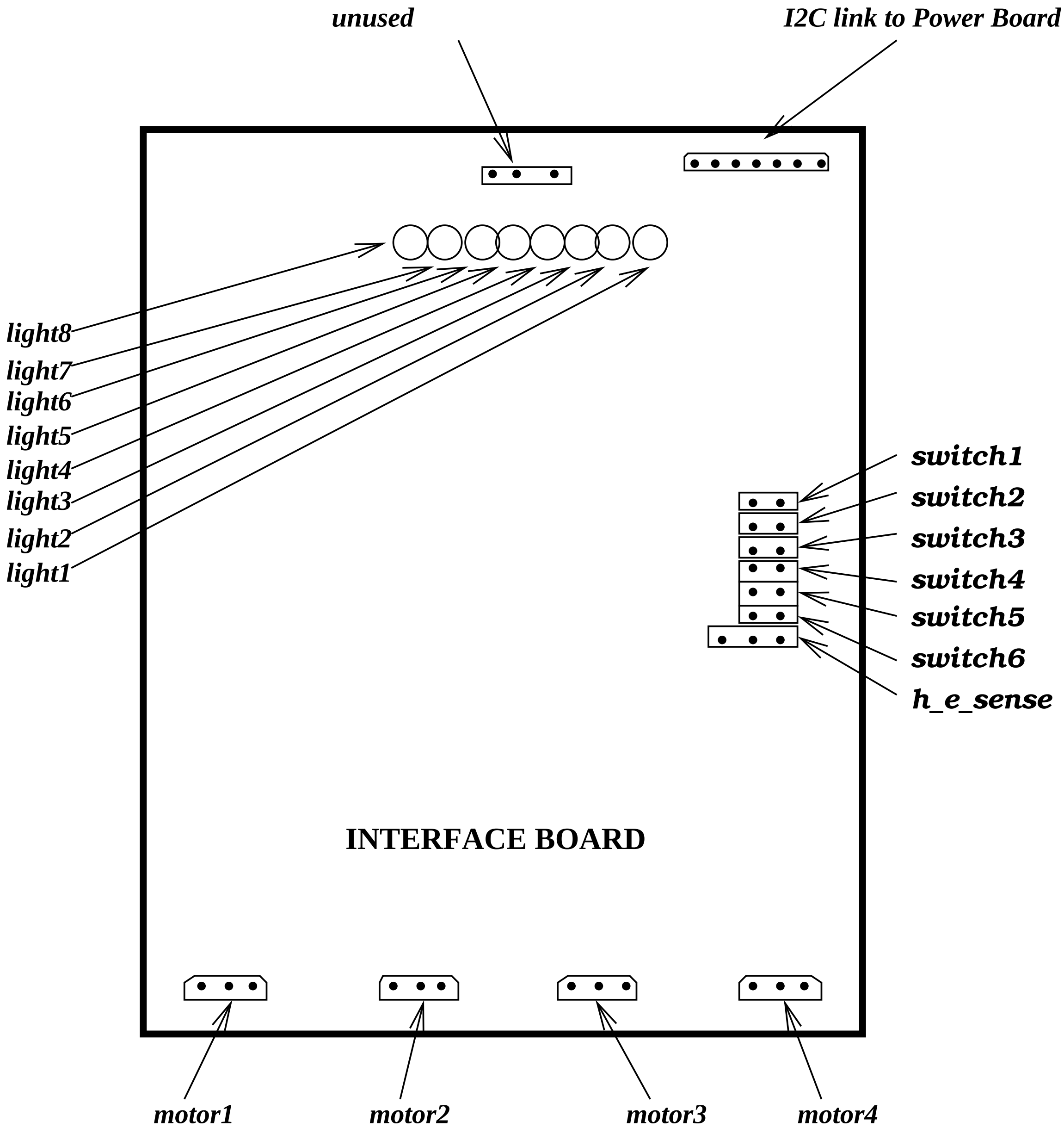


Figure 2: Interface Board

1.3 Power Board

The Power Board (figure 3) is where the Battery is connected. It supplies the other boards with power, and transfers data, via the I2C links. The motor on/off switch will turn off the motors *only* (e.g. if your robot is out of control and you want to stop it moving). It does not disconnect any other power. **To power off**, you must disconnect the battery. To power cycle (e.g. to reboot the BrainBrick) you must disconnect and reconnect the battery.

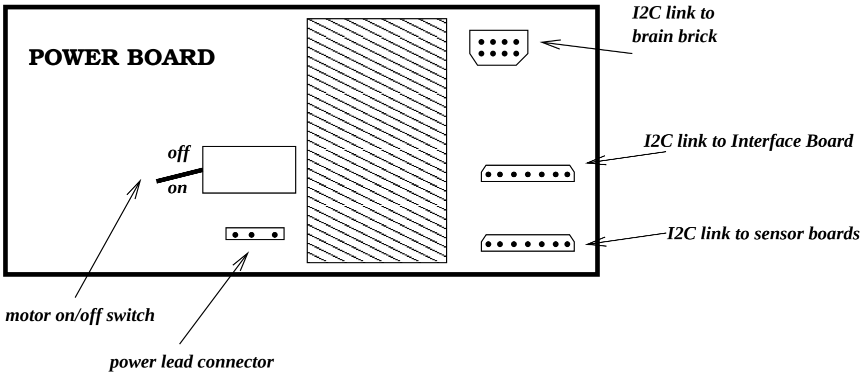


Figure 3: Power Board

1.4 LDR Board

The LDR Board (figure 4) connects up to 4 Light Dependent Resistors. It can be daisy-chained with other sensor boards to the Power Board via the I2C connectors.

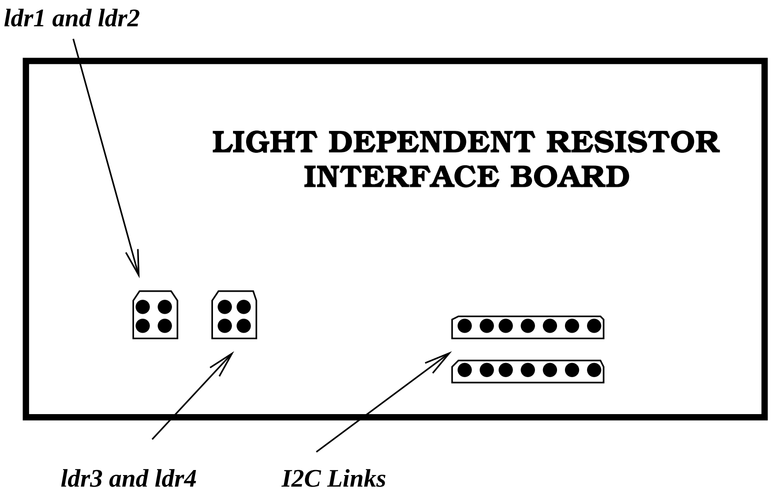


Figure 4: LDR Board

1.5 IR Board

The IR Board (figure 5) connects up to 2 Active Infra Red sensors. It can be daisy-chained with other sensor boards to the Power Board via the I2C connectors.

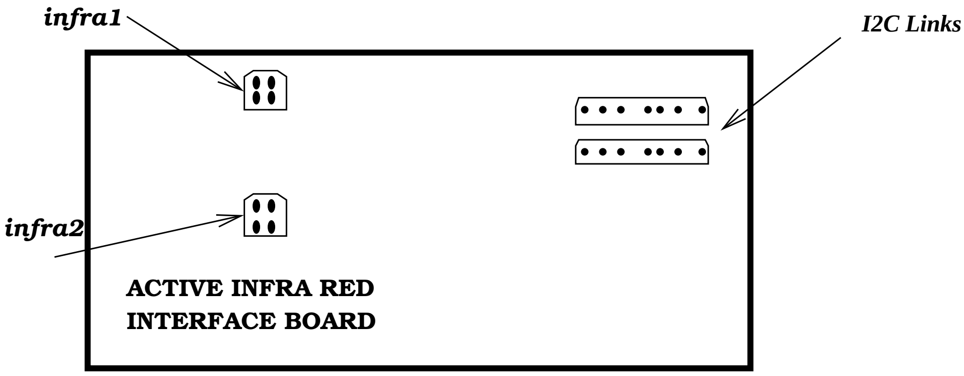


Figure 5: Infrared Board

1.6 Compass Board

The Compass Board (figure 6) measures up to 8 different directions (N,NE,E,SE,S,SW,W,NW). It can be daisy-chained with other sensor boards to the Power Board via the I2C connectors.

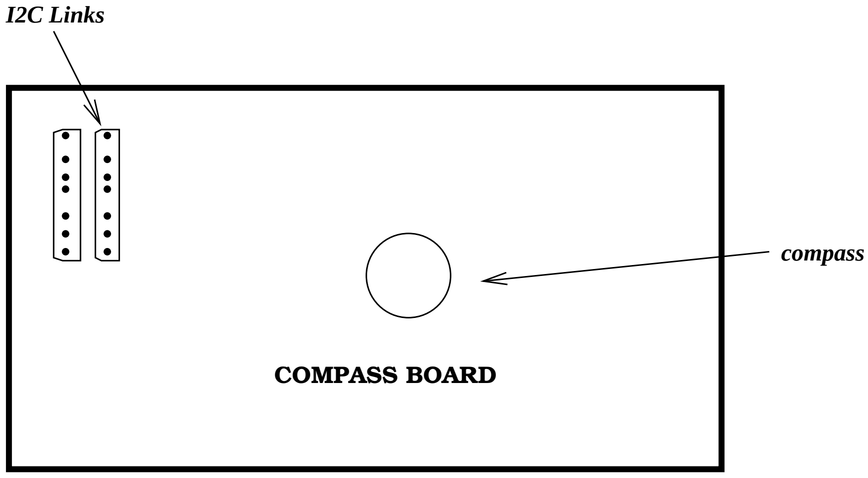


Figure 6: Compass Board

1.7 How it all connects

Please be careful and check you have the right configurations! Make all connections before plugging in the battery. Note that you do not need to have any of the sensor boards (LDR, IR or Compass) connected, or any motors or switches, for the system to run, i.e. the minimal testing configuration requires only the Brain Brick, Interface Board, and Power Board.

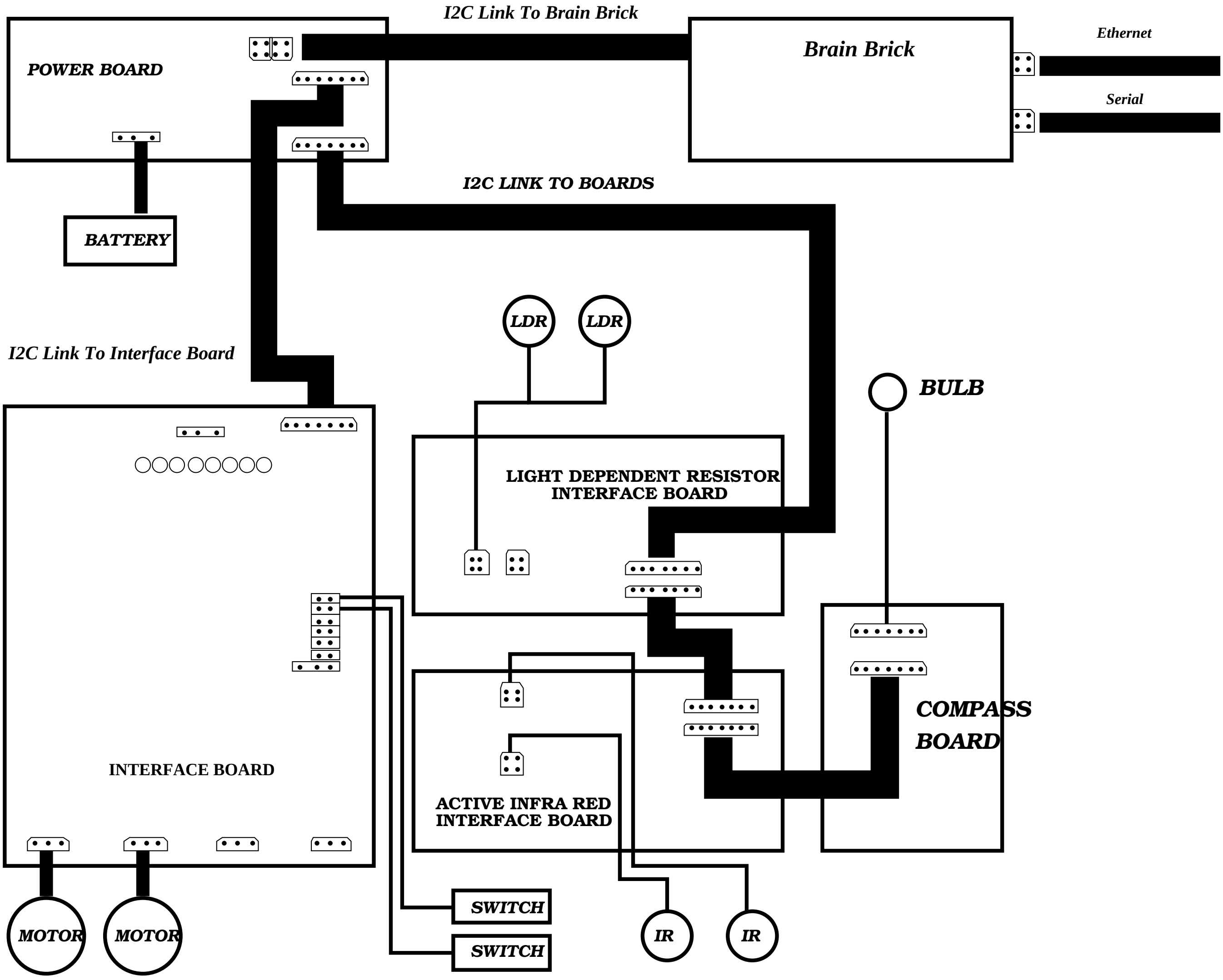


Figure 7: Connecting Hardware

REPEAT WARNING: The battery must *always* be disconnected *before* you change any connections between the boards. Plugging things in and out while the system is powered could cause significant damage to the boards. The motor on/off switch *does not* disconnect power to the rest of the system. You must disconnect the battery.

2 How to use the robot hardware

2.1 Physical configuration

The minimal configuration needed to test the basic functions, and download and run programs, is to connect the power board, brain brick and interface board. You can add or remove switches and motors from the interface board, or connect or disconnect other sensor boards and sensors as required. See section 1.7.

Once you have made (and checked) the connections, power up the system by connecting the battery. An empty battery will be indicated by a red light on the power board.

2.2 Software configuration

Your course demonstrator will provide you with a tar ball (e.g. *Name.tar.bz2*) containing all the files necessary for this course. Note that this is specific to the (named) Brain Brick you were issued. While in your home directory type e.g.:

```
tar xvfj Name.tar.bz2
```

which will create a folder **~/iar**. This folder includes a bin/ directory containing scripts for automatic login (**~/iar/bin/iarlogin**) to the Brain Brick and for uploading a new program (**~/iar/bin/iarupload**). To avoid having to reference the location of these tools every time, include (**PATH=$PATH:~/iar/bin**) in your **~/.brc** file.

The other directory the folder includes is the **~/iar/template** directory which includes example programs and corresponding Makefiles (see below)

2.3 Connecting to the Brain Brick by ethernet

The Brain Brick runs an embedded Linux system (*Linux-2.6.7*) based on BusyBox which is a collection of (tiny) standard Unix tools. It should behave more or less other Linux based systems, but has only a very limited number of system tools installed.

Most interaction with the Brain Brick is done over an Ethernet connection. Use any of the free cables available in the teaching lab to connect to the network, via the port on the black box. To login into your Brain Brick, use:

```
iarlogin
```

It will automatically log you in as *user* without the need to provide a password. Once logged in, you can use the terminal (shell) to navigate through any files on system.

Login can also be done using the provided **~/iar/.ssh** rsa keys using **ssh**

```
ssh -i ~/iar/.ssh/rsa_user
```

And you can copy files to or from the BrainBrick using **scp** e.g.

```
scp -i $RSAKEY user@$Name:$PathToYourData $Destination
```

This is most likely to be used if you have saved data on the module while running a program and want to retrieve it for analysis.

2.4 Connecting to the BrainBrick by the serial cable

You can also connect to the BrainBrick via a serial cable, and will need to do so for several functions (see below). With the system off, plug the serial cable from the Dice machine you are using into the port on the black box. Start a terminal emulation program, e.g. **minicom**.

A simple test function for the BrainBrick hardware has been provided: **iartest**. To use it, connect the serial cable and start the terminal emulation program. Then switch on the system and login via the ethernet, and run the command:

```
iartest
```

You can then check various functions, including the lights, switches, and motors as well as the LDR and AIR boards, through the terminal emulator interface.

2.5 Compiling a program for the BrainBrick

In order to generate a binary that can be run on the BrainBrick, a cross-compiler is needed (assuming a Host with Intel x86 architecture). The cross-compiler toolchain is based on the GNU compiler collection (*gcc-3.4.3*)and should therefore be very similar to usual compiler setups. It includes a few additional features, in particular it includes header files for the IAR library for robot control program development.

The **~/iar/template** directory includes four files :

- *Makefile*
- *functions.c*
- *functions.h*
- *controller.c*

The Makefile includes all necessary compiler and linker commands to generate a single binary from the C source files. The file *functions.c* includes all lower level function implementations used in *controller.c*. The control program *controller.c* represents the actual robot control program; it makes use of the functions defined in *functions.h*.

To compile, simply type `make`. This will generate an executable called *controller* that you can upload to the BrainBrick (see below).

To compile your own program, make a copy of the **~/iar/template** directory. Make any changes you wish to the program. If you change the filenames or create more files, you may need to make appropriate changes to the Makefile, e.g. to change the specified name for the output binary. To compile your program simply type `make` in this directory. This will create a binary with the name you specified in the Makefile (e.g. `controller01`).

Example:
`cp -r ~/iar/template/ ~/iar/controller01`
`cd ~/iar/controller01`
Make any desired changes to the controller.c file and the Makefile.
`make`
new executable : controller01

2.6 Loading and running a program on the BrainBrick

To upload you program onto the BrainBrick, make sure the BrainBrick is connected to the network (e.g. try `ping $Name`). Type
`iarupload $PathToYourExecutable`
E.g. if you are in the template directory, use
`iarupload controller`
This will upload the program onto your BrainBrick as **/iar/upload/autostart**. To start the program you need to type:
`/iar/upload/autostart`
You can then disconnect from the ethernet and watch it go.
Note it is a good idea in general for your program to not do anything (in particular, not to start the motors) until it detects that you have hit a 'start' microswitch. This gives you time to put the robot on the floor, and avoid it leaping off the desk.

To stop a running program you can either power-cycle/reboot the system or login over ethernet and use the Linux **kill** command. Or more tidily, you could include a stop switch that ends the program. If you want to run the same program again, you do not need to download it again but simply to type `/iar/upload/autostart` as before.

3 C Programming

The BrainBrick is programmed in C. C is a very simple and powerful programming language but it is very easy to make mistakes. Explaining the basics of C does not take long but would exceed the scope of this manual. In this section we aim to give you pointers for getting started, and some example programs that you can modify. Note that it is not a principal aim of this course to teach you C; in general, you only need to know enough to be able to write and debug programs for this specific task, i.e. robot control; so we will be trying to support you with direct examples for any of the kinds of things you will need to do.

There are many good reference books for C. The most frequently recommended is "The C Programming Language" by Brian W. Kernighan and Dennis M. Ritchie.

There are also many websites providing an introduction to C programming, e.g.:
http://www.le.ac.uk/cc/tutorials/c/
http://www.eskimo.com/ scs/cclass/notes/top.html
http://www.eskimo.com/ scs/C-faq/top.htm

You might find it particularly useful to look at some of these "Introduction to C for Java programmers" sites: http://www.comp.lancs.ac.uk/computing/users/ss/java2c/
http://www.cs.vu.nl/ jason/college/dictaat.pdf

Basic things you need to know:

- Arithmetic, relational and logical operators are the same as Java
- The loop and conditional syntax is the same as Java
- The basic data types are `int` (can be `long` or `short`, `signed` or `unsigned`), `char`, `float`, `double` and `void`.
- There is no boolean type: test conditions are integer expressions that if evaluating to 0 are false, non-zero are true. Logical operators will evaluate to 0 or 1.
- You can also define a `struct`; similar to a Java class but it can only have data elements.
- Variables can be global (declared outside a function) or local (declared inside a function - all declarations must occur at the start of the function).
- Statements beginning `#` are preprocessed before compilation, and used either to `#include` other files (including standard library files) or to `#define` constants or macros. These appear at the start of the file.
- The remainder of the file consists of functions, including one main function. Functions need to be defined (or declared) before they are invoked.
- There is no function overloading (no two functions can have the same name).
- C has no exceptions so it is important to do explicit error checking.

More complex issues you may need to read up on are arrays and pointers, passing arguments to and returning values from functions, I/O, characters and strings, dynamic memory handling, and threading. But we will try to provide examples to help you with these.

3.1 Example program

This program demonstrates, how to use two IR sensors to make a robot avoid obstacles. The variables *lefteye and righteye* get periodically updated with the latest IR sensor readings. The program compares these values against a defined threshold and reacts by making the robot move away from the side of the sensor with the highest reading.

```
/* Include IAR sensor library*/
#include <iar_ctrl.h>

/* definition of threshold for IR sensors */
#define THRESHOLD 150

/* a short wrapper functions for driving the motors */
void drive(short left, short right){
     set_motor_1(left);
     set_motor_2(right);
}

/* main control program */
int main(void){

     /* variables to hold the IR values */
     int lefteye, righteye;

     /* initialise motors !  */
     reset_motors();

     /* wait until switch_1 is pressed */
     while(!get_switch_1());

     /* main program loop */
     while(true){

          /* read the IR sensors */
          lefteye = get_ir_1();
          righteye = get_ir_2();

          /* react to sensor readings */
          if(lefteye > THRESHOLD)
            drive(FFWD,SFWD); /* make a slight right turn */

          if(righteye > THRESHOLD)
            drive(SFWD,FFWD); /* make a slight left turn */

          if(lefteye < righteye){
            drive(FFWD,SFWD);
          }
          else if(lefteye > righteye){
            drive(SFWD,FFWD);
          }
          /* if(lefteye == righteye) */
          else{
            drive(SFWD,SFWD); /* slow down */
          }
     }

     return 0;
}
```

3.2 Example of MultiThreading

This program demonstrates how to use threads to implement robotic functions (behaviours) that run in parallel.

```
/* POSIX thread library */
#include <pthread.h>
/* IAR sensor library*/
#include <iar_ctrl.h>

/* thread to flash led 1 */
void *flash_led_1(void *arg){

     /* flash LED1 in 1 sec intervals */
     while (true){
           set_light_1(TOGGLE);
           sleep(1);
     }
}

/* thread to flash led 8 */
void *flash_led_8(void *arg){

     /* flash LED8 in 1 sec intervals */
     while (true){
           set_light_8(TOGGLE);
           sleep(1);
     }
}

/* main loop :  start two threads to flash led1 and led8 */
int main(int argc, char **argv){

     /* thread declarations */
     pthread_t thread_led1;
     pthread_t thread_led8;

     /* start thread to flash led1 */
     if(pthread_create(&thread_led1, NULL, flash_led_1, NULL) != 0)
           exit(1);

     /* flash led1 for 3 seconds*/
     sleep(3);
     /* start thread to flash led8 */
     if(pthread_create(&thread_led8, NULL, flash_led_8, NULL) != 0)
           exit(1);
     /* let both leds flash for another 7 seconds */
     sleep(7);
     /* stop threads */
     pthread_cancel(thread_led1);
     pthread_cancel(thread_led8);

     return 0;
}
```

3.3 IAR Sensor Library

The IAR sensor library (**libiar**) enables control programs to interface with the IAR interface board and the variety of add-on sensor boards. For your convenient reference, here is the library header file with all the relevant function definitions.

```
/* led commands */
#define OFF 0
#define ON 1
#define TOGGLE 2
#define NONE 3
#define ALL 4

/* motor commands */
#define FFWD 0 /* fast forward */
#define SFWD 1 /* slow forward - only for motor 1, 2 */
#define STOP 2
#define FREV 3 /* fast reverse */
#define SREV 4 /* slow reverse - only for motor 1, 2 */

/* has to be called once before any motors are used !  */
int reset_motors();

#define set_motor_1(command) set_motors(MOTOR1,command)
#define set_motor_2(command) set_motors(MOTOR2,command)
#define set_motor_3(command) set_motors(MOTOR3,command)
#define set_motor_4(command) set_motors(MOTOR4,command)

#define set_light_1(sw) set_leds(sw,LED1)
#define set_light_2(sw) set_leds(sw,LED2)
#define set_light_3(sw) set_leds(sw,LED3)
#define set_light_4(sw) set_leds(sw,LED4)
#define set_light_5(sw) set_leds(sw,LED5)
#define set_light_6(sw) set_leds(sw,LED6)
#define set_light_7(sw) set_leds(sw,LED7)
#define set_light_8(sw) set_leds(sw,LED8)
#define set_lights_off() set_leds(NONE,0)
#define set_lights_on() set_leds(ALL,0)

#define get_switch_1() get_switches(SWITCH1)
#define get_switch_2() get_switches(SWITCH2)
#define get_switch_3() get_switches(SWITCH3)
#define get_switch_4() get_switches(SWITCH4)
#define get_switch_5() get_switches(SWITCH5)
#define get_switch_6() get_switches(SWITCH6)
#define get_hall_effect() get_switches(HALLEFFECT)

#define get_ir_1() get_irs(AIR1)
#define get_ir_2() get_irs(AIR2)
#define get_ldr_1() get_ldrs(LDR1)
#define get_ldr_2() get_ldrs(LDR2)
#define get_ldr_3() get_ldrs(LDR3)
#define get_ldr_4() get_ldrs(LDR4)

int get_compass();
```