RoboCom

User manual and documentation

IRALab
University of Milano – Bicocca
D.I.S.CO.

Table of contents

Table of contents ... *2*

Chapter 1 – Introduction ... *4*
- Robot packages ... 4

Chapter 2 – Specifications ... *5*
- Main components ... 5
- Physical characteristics ... 5
  - Measures ... 5
  - Materials ... 6
    - Special profiles ... 6
    - Other materials ... 6
    - Planes ... 6
- Batteries ... 7
  - Charging ... 7
- Electrical schema ... 8
- Electronics ... 9
  - DC-DC 24V to 18V board ... 9
  - DC-DC 24V to 5V board ... 10
  - IRABoard v1.1 ... 10
    - Evolution ... 10
    - Specifications ... 11
- Motors ... 13
  - Maxon codes ... 13
  - Combination technical data ... 13
  - Planetary Gearhead ... 13
  - Motor ... 13
  - Tacho ... 14
- Transmission ... 14
- Wheels ... 16
- MacMini ... 17
  - Hardware ... 17
  - Software ... 17
- Vision system (optional) ... 18
  - Camera ... 18
  - Mirror ... 18
  - Tuning plane ... 18

Chapter 3 – Start using RoboCom ... *19*
- Mounting the battery pack ... 19
- Inserting battery pack, electronic case and MacMini ... 19
- Connect all the plugs and switch on the robot ... 20
  - The electronic case connectors ... 20
  - The MacMini connectors ... 20
  - The main power connector ... 20
- Verify serial connection, encoders and motors ... 20
- Start testing your command software ... 21

Chapter 4 – IRABoard documentation ... *22*
- Design Choices ... 22
  - Microprocessor Clock and Oscillator Frequency ... 22
  - Pulse Width Modulation ... 22
  - Encoders ... 23
  - Serial Line Interface ... 24
- Control ... 24
  - PID Control ... 24
- Timing issues ... 26
- Concurrency issues ... 26
- Eeprom ... 27

Source Code Description ... 27
The language ... 27
The environment ... 27
The compiler ... 27
The code ... 27
definitions.h ... 28
ROBOT MAIN.c ... 28
rs232.c ... 29
controller.c ... 30
eeprom.c ... 30

Chapter 5 - How to use IRABoard ... 31
Test program in C/C++ Language ... 31
Commands ... 33
Enable Motors ... 33
Disable Motors ... 34
Change Set point Value ... 34
Configuring parameters ... 35
Using internal EEPROM ... 36
Return distance or speed ... 37
Debug information ... 38
Auto tuning parameters ... 39

Chapter 1 – Introduction

The RoboCom is a multi purpose robot, designed for carrying modest weights (max 50 kg) in indoor and outdoor spaces. The presence on the robot of a powerful PC allows both easy communications with other computers (e.g. wireless, Bluetooth, etc.) and easy interface to sensor devices.
The high wheels allows the robot to drive without problems also on grass and rough grounds. The motors are kept high with respect to the wheels in order to protect them against accidental hits with objects. The skeleton is completely in aluminum to reduce the robot's weight and designed for high resistance to solicitations.
The batteries are easily chargeable, no need to extract them from the robot or to charge separately, thanks to the unique plug of the battery pack. The electronic case is designed for quick plug-in and plug-out, without any risk of mistakes with plugs.
The MacMini's I/O ports are fully accessible and the computer's case itself is easily extricable from the robot.
A set of security power switches and LEDs grants an easy emergency stop and diagnosis of the robot's status.

Robot packages

The main units of RoboCom are:

- The robot's skeleton
- The battery pack
- The electronic case
- The Mac Mini
- The radio remote emergency stop

Optional components are:

- Omni directional camera with support
- Additional battery packages
- Battery charger

FOTO

Chapter 2 – Specifications

Main components

DISEGNO AUTOCAD CON SPIEGAZIONE

Physical characteristics

Measures

Global

Width:	mm 600
Depth:	mm 540
Height:	mm 790

Case

Width:	mm 510
Depth:	mm 350
Height:	mm 270

Main plane

Width:	mm 510
Depth:	mm 350
Height:	mm 370 from ground

Battery pack

Width:	mm 300
Depth:	mm 120
Height	mm:90

Electronic case

Width:	mm 320
Depth:	mm 100
Height:	mm 120

Mac Mini

Width:	mm 165
Depth:	mm 165
Height:	mm 50

Vision system

Width:	mm 120
Depth:	mm 120
Height:	mm 420

Materials

Special profiles

Item profiles (www.item.info):

Product code	Length (mm)	Quantity	Description
370.03	510,00	2	Profile 5 20x20, natural
370.03	514,00	2	Profile 5 20x20, natural
370.03	156,00	2	Profile 5 20x20, natural
370.03	199,00	2	Profile 5 20x20, natural
370.03	284,00	1	Profile 5 20x20, natural
370.86	268,00	1	Profile 5 80x20, natural
370.86	284,00	1	Profile 5 80x20, natural
419.01	260,00	1	Profile 6 30x30, natural

Other materials

Rectangular aluminum profile (wheel legs):

Width:	80mm
Depth:	40mm
Height:	
Thickness:	4mm

Planes

Steel sheets:
Thickness: 0.5mm

Width	Height	Description

Batteries

The battery pack includes four FGH 20902 High rate 12V 9Ah batteries.

Battery pack DC output: 24V 18Ah

Charging

Recharge the battery pack is very easy as shown by the following steps:

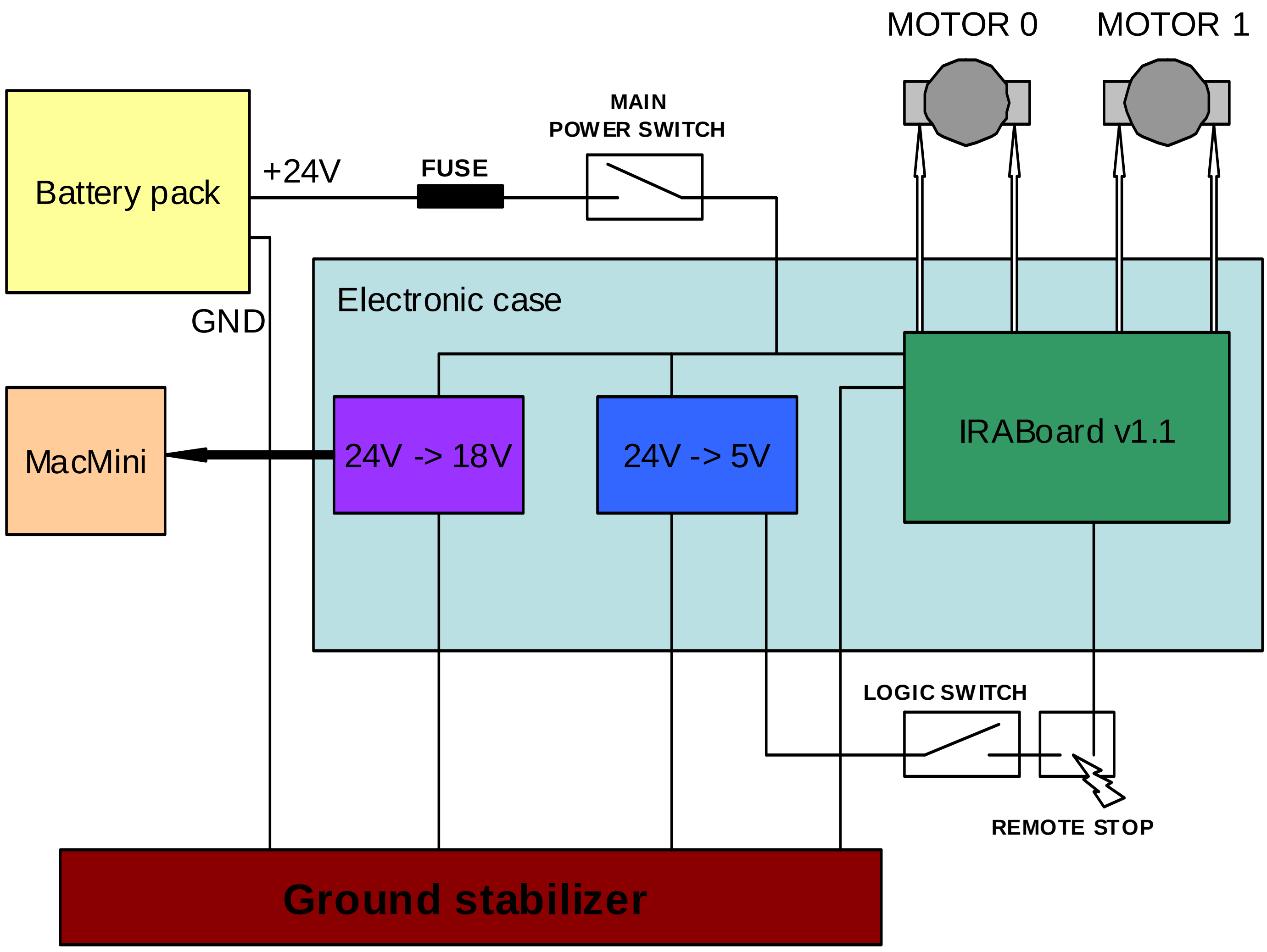
1. Ensure that the robot and the MacMini are turned off
2. Unplug the robot power plug from the battery pack power plug
3. Plug the charger's plug in the battery pack power plug
4. Plug the charger to the power grid
5. The charger's LEDs indicates the charging status
6. When the green LED lights the battery pack is fully charged
7. Unplug the charger from the power grid
8. Unplug the charger's plug from the battery pack power plug
9. Ensure that the robot's power switches are turned off
10. Plug the robot power plug in the battery pack power plug

Electrical schema

The following electrical schema shows the power supply wires in the robot. We can see that the ground wire coming from the batteries goes to the ground stabilizer. This stabilizer is a piece of copper from which departs the ground wires for all electrical components.
On the +24V line we find a fuse and the main power switch, which is highly recommended to be turned off if the robot is not in use.
Inside the electronic case there are 3 electronic components:

- The 24V to 18V switching step down power converter board, which powers the MacMini
- The 24V to 5V switching step down power converter board, which powers the IRABoard
- The IRABoard v1.1

(for details see the electronic section).



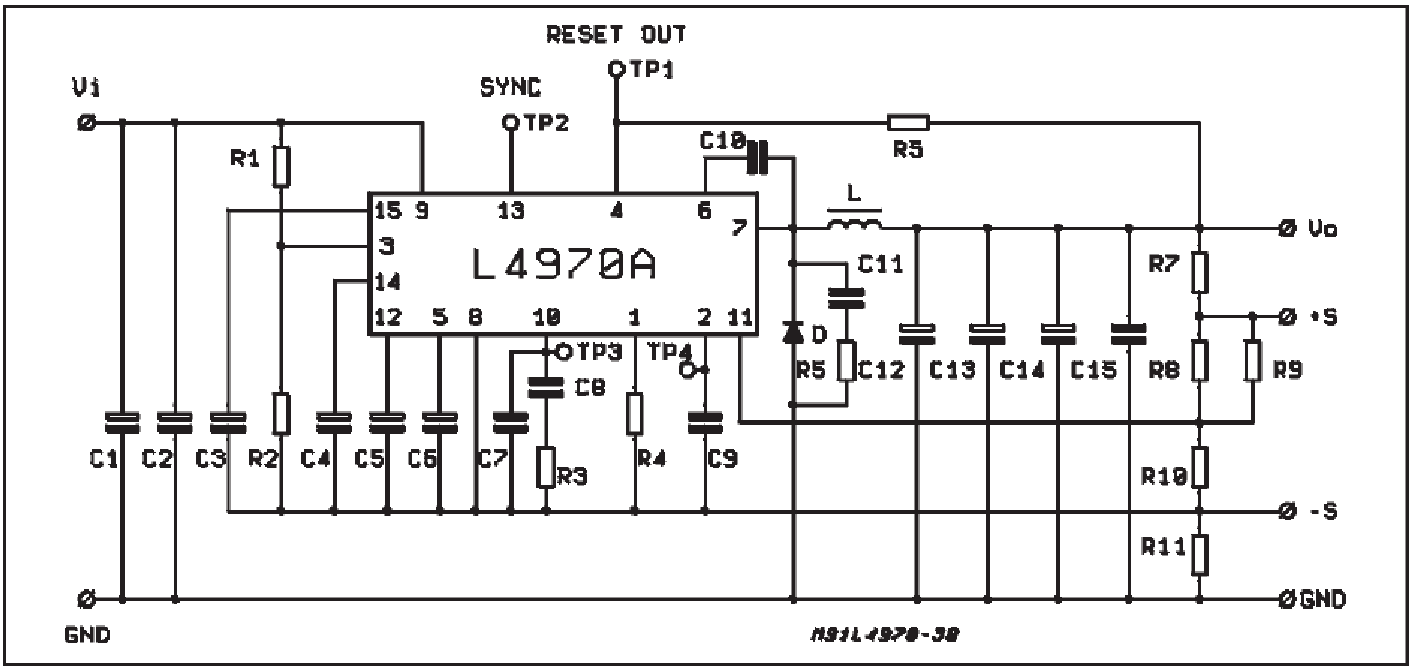
Electronics

The electronic case contains the all the electrical and electronic components of the RoboCom. There are 3 components.

DC-DC 24V to 18V board

We implemented the evaluation board of the ST L4970A 10A step-down switching regulator. This board carries two big capacitors (3300 uF) which grants clean output even in case of perturbations on the power line.
The ST L4970A component is a step-down switching regulator; with an appropriate RC oscillator in the circuit this component outputs 18V DC with a maximum of 10 amperes. It is provided in a 15-lead multiwatt plastic power package, which requires an adequate cooling system.
We use this board to power the MacMini. A little trick is needed when powering the MacMini without his own power adaptor, because there is a 3rd wire, called iSense, which allows the boot. Without this wire the MacMini will not boot.

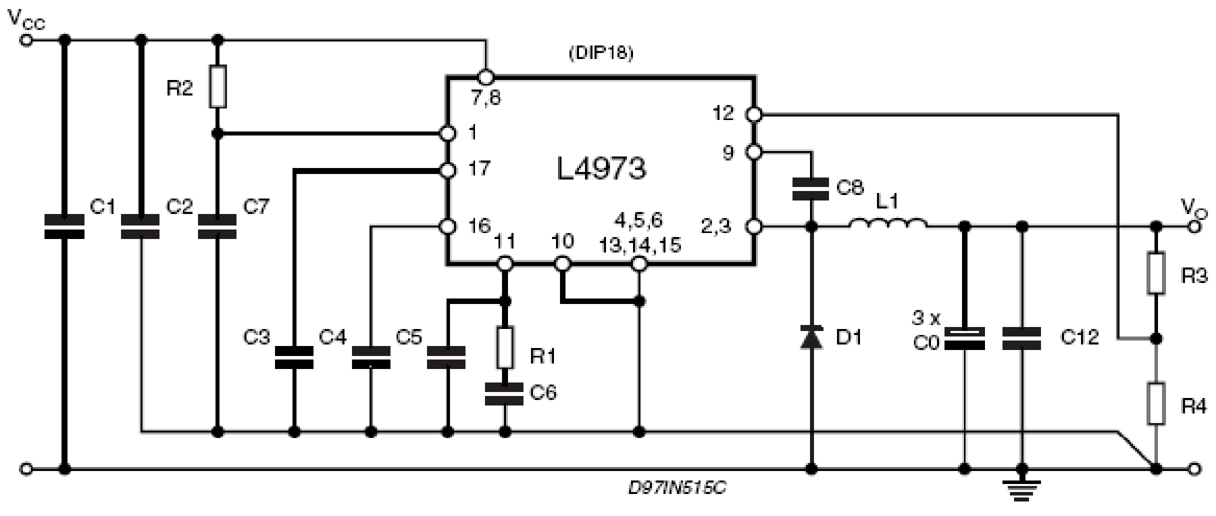
The following is the schematic of the board as provided by ST.



DC-DC 24V to 5V board

We implemented the evaluation board of the ST L4973 3.5A step-down switching regulator.
This board is significantly smaller than the previous one, the component is provided in a 18-pin PowerDIP package and needs only a few components.
The ST L4973 component is a step-down switching regulator; with an appropriate RC oscillator in the circuit this component outputs 5V DC with a maximum of 3.5 amperes.
We use this board to power the IRABoard v1.1 for the logic sub circuit. See also the ‘Future work’ section.

The following is the schematic of the board as provided by ST.



IRABoard v1.1

Evolution

The IRABoard v1.1 is the empowered version of the IRABoard v1.0, while the IRABoard v2.0 is currently under development. This family of powerful boards have grown from the experiences achieved by the IRALab in the last years. This experiences drove us to very important improvements, which will be discussed in the following.
During the development of the v1.0 we encountered heavy problems due to the electrical noise driven by the H bridges. In order to solve that critical situation (the noise disturbs reset the microcontroller) we decided to physically divide the two sub circuits (i.e. the logic and the power one) over the same board.
The resulting v1.0 worked well under some conditions, but it revealed to be unreliable in normal robot activity conditions. The biggest problems was the RS-232 communication between the board and the PC (invalid characters or sequences), which commonly causes the PIC’s firmware crash.
For the v1.1 we redesigned a big part of the circuit, optimizing the space and shorting the communication wires. The result is a robust board which we tested for more than 5 hours of continuative work.

Specifications

The main components of the logic part of the board are:

The **PIC18F452** Microchip's microcontroller. This component is the operating core of the entire board. It communicates via RS-232 with the MacMini, interfaces with the HCTL in order to retrieve the encoder count and generates the PWM signal for both the H-bridges. For more information about the firmware see the dedicated section.

Follows a list of the main features of this microcontroller:

- Linear program memory addressing to 32 Kbytes
- Linear data memory addressing to 1.5 Kbytes
- Up to 10 MIPs operation:
- DC - 40 MHz osc./clock input
- 4 MHz - 10 MHz osc./clock input with PLL active
- 16-bit wide instructions, 8-bit wide data path
- Priority levels for interrupts
- 8 x 8 Single Cycle Hardware Multiplier
- Two Capture/Compare/PWM (CCP) modules. PWM output: PWM resolution is 1- to 10-bit
- Addressable USART module: Supports RS-485 and RS-232
- Single supply 5V In-Circuit Serial Programming™ (ICSP™) via two pins
- In-Circuit Debug (ICD) via two pins

The **HCTL-2032** Agilent's Quadrature Decoder/Counter Interface. This component receives the signals from the two encoders, decode them and count the ticks of the motor's rotation. The counter are two 32bit signed registers (one for each motor) which are accessible to the PIC via an 8-bit tristate interface. The microcontroller periodically reads this value and resets the counter.

Follows a list of the main features of this microcontroller:

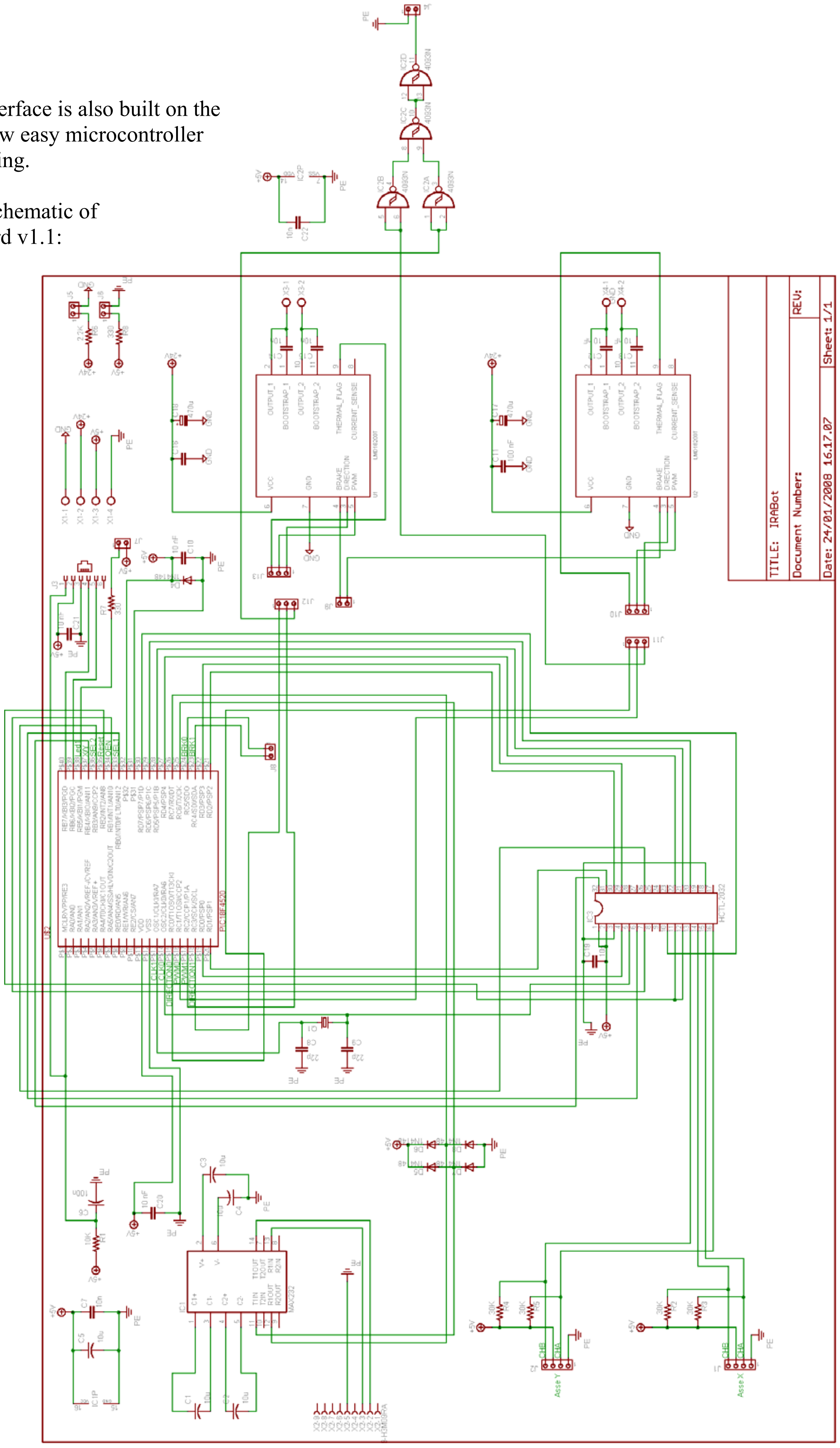
- Up to 33MHz clock operation
- Programmable count modes (1x, 2x, 4x)
- High noise immunity
- Schmitt trigger inputs and digital noise filter
- 32-bit binary up/down counter
- 8-bit tristate interface
- 8, 16, 24 or 32-bit operating mode
- TTL/CMOS compatible I/O
- 32 pin PDIP

The **MAX232** component for the voltage conversion of the RS-232 signal.

The **LMD18200** H-bridges by National Semiconductors. The LMD18200 is a 3A H-Bridge designed for motion control applications. The device is built using a multi-technology process which combines bipolar and CMOS control circuitry with DMOS power devices on the same monolithic structure. Ideal for driving DC and stepper motors; the LMD18200 accommodates peak output currents up to 6A.
This components are the power supplier for the motors, according to the PWM, direction and break signals coming from the microcontroller.

An ICD2 interface is also built on the board to allow easy microcontroller reprogramming.

This is the schematic of the IRABoard v1.1:



Motors

The motors are a Maxon product. The specifications are the following:

Maxon codes

Gear	203123
Motor	148867
Encoder	110513

Combination technical data

No load speed at gear output	min-1	103
Max. cont. torque at gear output	Nm	9.1
Interm. perm. torque at gear output	Nm	23
Length	mm	161.9

Planetary Gearhead

Gear order no. 203123

Description	Planetary Gearhead GP 42 C Ø42 mm 15 Nm, ball bearing, ceramic

Reduction		74:1
Number of stages		3
Max. cont. torque	Nm	15
int. permissible Torque	Nm	23
Max. efficiency	%	72
Average backlash, unloaded	deg	1.0
Mass inertia	gcm2	15
Gearhead length	mm	69.9
Weight	g	460
Max. motor shaft diameter	mm	10.0

Motor

Motor order no. 148867

Description	RE 40 Ø 40 mm, Graphite brushes, 150 Watt

Power rating	W	150
Nominal voltage	Volt	24.0

No load speed	min-1	7580
Stall torque	Nm	2.28
Speed/torque gradient	min-1 mNm-1	3.33
No load current	mA	137
Starting current	A	76
Terminal resistance	Ohm	0.317
Max. permissible speed	min-1	12000
Max. continuous current	mA	5770
Max. continuous torque	mNm	170
Max. power output at nominal voltage	W	438
Max. efficiency	%	91
Torque constant	mNm A-1	30.2
Speed constant	min-1 V-1	317
Mechanical time constant	ms	5
Rotor inertia	gcm2	138
Terminal inductance	mH	0.082
Thermal resistance housing-ambient	KW-1	4.7
Thermal resistance rotor-housing	KW-1	1.9
Thermal time constant winding	s	41.6
Length	mm	71.0
Weight	g	480

Tacho

Tacho / resolver order no. 110513

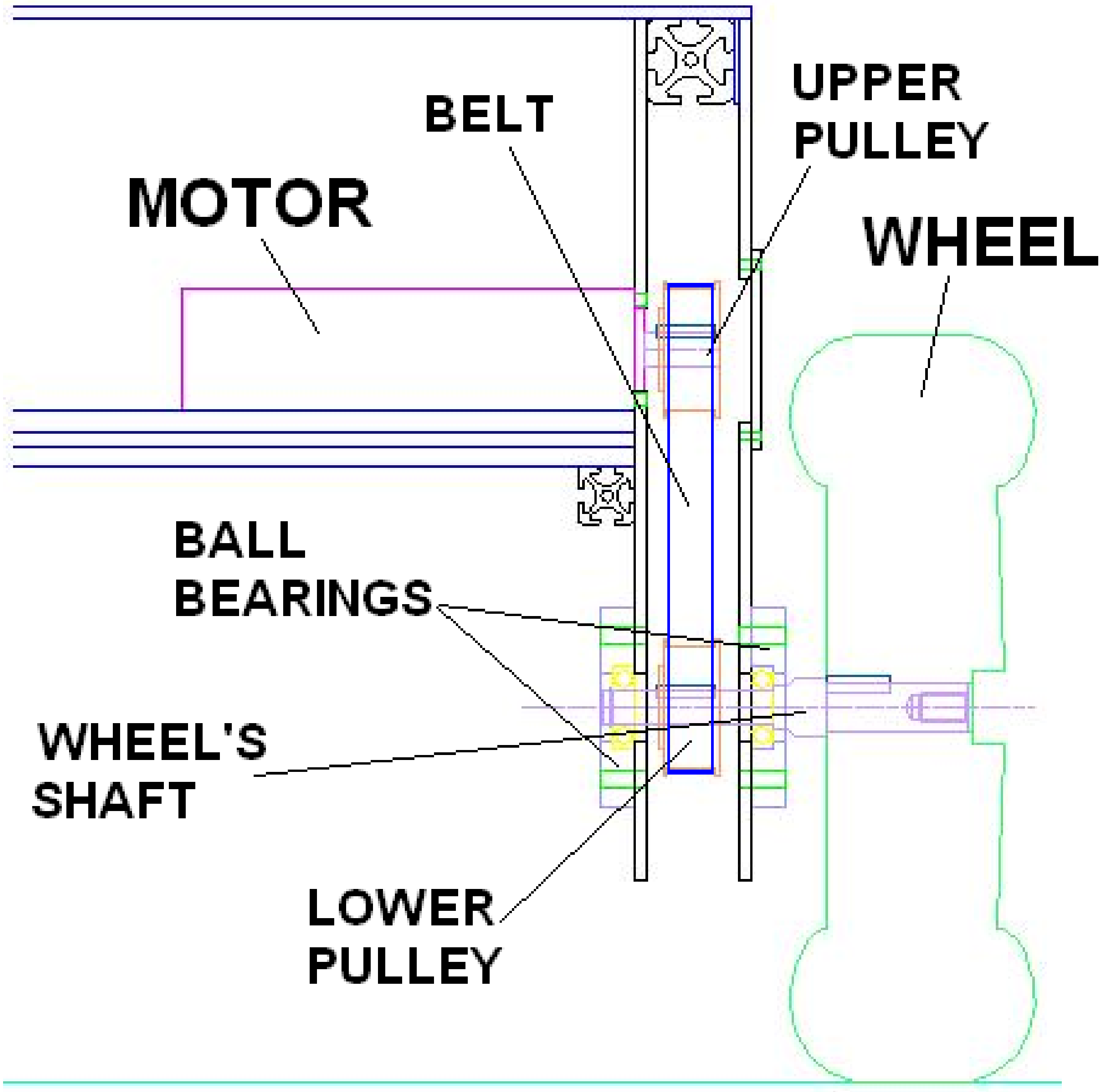
Description Digital-Encoder HEDS 5540 Ø 10 mm 500 counts per turn, 3 channels

Axle diameter	mm	4
Counts per turn		500
Number of channels		3
Max. operating freq.	kHz	100
Diameter	mm	10
Length	mm	21.0

Transmission

The transmission for each motor/wheel consists of two pulleys and a belt. We chose the belt based transmission with the aim of minimize the maintenance operations. Indeed, the belts don't need any maintenance at all, while the chains need lubrication and cleaning.
The two motors are not placed at the same height in order to reduce robot's width. With this trick we gain in width 6 cm.
The upper pulley is fixed on the motor's shaft, the torque transmission granted by a XXXXXXXX(linguetta). The toothed belt transmits the motion to the lower pulley which is fixed on the wheel's shaft. This shaft is steel-made so as to resist to any possible solicitation and is hold by two ball bearings.

The following scheme shows the transmission system.



Wheels

The robot has two drive pneumatic spoked wheels in front (moved by the motors), and a pivoting wheel on the rear. The front wheels are fixed on the steel shaft which receives motion by the belt.

Technical data:

Front

Producer	3Emme Italy (www.3emme.com)	
Product number	260DALPN17 (black tire)	
Wheel diameter	mm	260
Hub diameter	mm	17
Wheel thickness	mm	80
Wheel weight	Kg	1.48

Rear

Producer	GS Euromarket (http://shop.gseuromarket.com)	
Product number	SCP200F	
Wheel diameter	mm	200
Pivoting plane height	mm	239

FOTO

MacMini

Hardware

1.83GHz Intel Core Duo processor
Apple Remote with Front Row
2GB RAM
Intel GMA 950 graphics processor
DVI connector, VGA adapter
Slot-loading optical drive
80GB hard drive
Built-in gigabit Ethernet
Analog and digital audio
Expansion via USB and FireWire

Software

By default a Ubuntu Linux distribution is installed, but end user may choose alternative operating systems.
For robot control we provide the complete documentation of the command set, which can be used via COM ports communication.

Vision system (optional)

The MRT 06 is a omnidirectional vision system, composed by a firewire camera, a bi-conical omnidirectional mirror and a tuning plane for camera centering.

Camera

The camera is fixed on the tuning plane on the floor of the video system and is directed upwards.

Interface	IEEE-1394a (FireWire) 400 Mbps, 2 ports (6 pins)
Camera Type	IIDC-1394 Digital Camera, V1.04 Specification compliant
Sensor Type	Sony™ Wfine* ¼" color CDD with progressive scan (ICX-098BQ)
Resolution	VGA 640 x 480
Optics	Bright (F 2.0) lens, with with 4.3 mm focal length.
Lens filters/coating	Antireflective coating and infrared cut filter
Video Modes	YUV (4:1:1, 4:2:2, 4:4:4), RGB-24bit, Monochrome-8bit
Frame Rates	30, 15, 7.5 and 3.75 frames per second
Gain	Automatic or Manual Control 0-30 dB
Shutter	Automatic or Manual Control 1/3400s-1/31s
Gamma	ON / OFF (visual use / image processing use)
White Balance	Automatic or Manual Control
Color Saturation	Adjustable
Backlight Compensation	6 modes + OFF
Sharpness	Adjustable
Special Features	Software sleep mode, Color bar generator
Power Supply	8 to 30 VDC, by 1394 bus or external jack input Consumption 1W max, 0.9 W typical, 0.4 W sleep mode
Dimensions (WxHxD)	62 x 62 x 35 mm
Housing & Weight	Silver gray plastic polymer, 60 gr

Mirror

The mirror is a bi-conical omnidirectional mirror and is fixed in front of the camera (i.e. on the top of the vision system). The image retrieved by the camera of this mirror is the conical projection of the surrounding world. This image should be straighten via software.

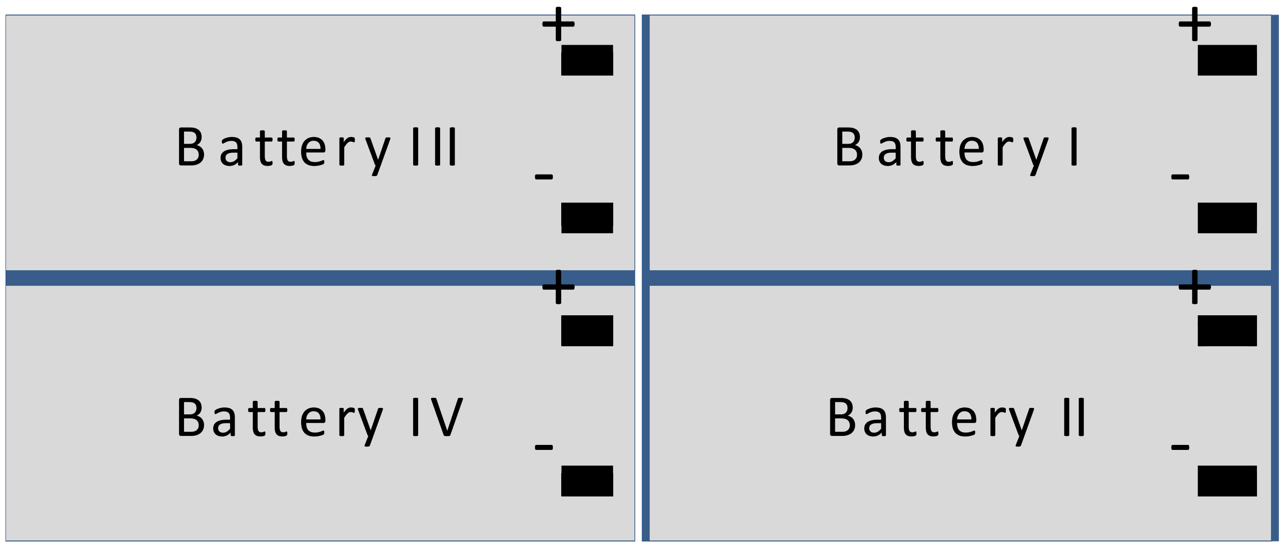
Tuning plane

The camera lies on a tunable plane with 2 degrees of freedom. The tuning should be performed with a screwdriver from the outside of the vision system. This operation is fundamental for centering the camera's optical axis with the mirror's one.

Chapter 3 – Start using RoboCom

Mounting the battery pack

The battery pack consists of four batteries and their container.
Place the batteries in the container in numerical order like shown in the figure and fix them with the belt. Plug the power wires in the battery plates like indicated by the labels on the wires.



Inserting battery pack, electronic case and MacMini

Now that the battery pack is assembled put them in the robot the way indicated by the arrows on the battery container; now push them in the direction of the motors until the pack reaches the motor plane border. The battery pack is in position.

The electronic case must be placed beside the battery pack. Put the case in the remaining space beside the battery pack and push them to the end.

Finally remains the MacMini. Put them in the appropriate space on the rear of RoboCom, the I/O ports on the right side of the robot. Fix them with the belts.

Connect all the plugs and switch on the robot

There are some plugs you may need to connect disconnect while working with RoboCom.

The electronic case connectors

There is the main connector, a big plug you'll see in the area of the case. It includes the power wires coming from the batteries/switches and going to the MacMini and the remote emergency stop.

The motors wires come from the motors and terminate in two green easy-on plugs. Plug this male connectors to the correspondent female on the IRABoard, as indicated by the labels.

The encoder wires come from the encoders and terminate in two black little plugs. Plug this male connectors to the correspondent female on the IRABoard, as indicated by the labels.

The RS232 serial connector coming from the MacMini is the last connector you must plug. On the IRABoard it must be plugged on the bottom of the front side of the board.

The MacMini connectors

On the MacMini you need to connect at least the power connector coming from the electronic case and the USB plug of the USB/USART converter, also coming from the electronic case.
Other devices may be plugged like the omnidirectional camera, sonar or laser devices and similar.

The main power connector

LAST, remember, LAST, you need to connect the main power connector to the battery pack's one you settled up before. Be very careful to plug this connector the correct way, otherwise you may **irremediably damage the robot**.

At this point you may switch the power switches on and begin the test phase.

Verify serial connection, encoders and motors

If you completed all the previous steps then now you can switch on the MacMini. When logged run minicom in a command window and try to send some commands to the robot.

On each command you send two events must happen:

- The communication led on the board (the yellow one) will change his status (blink)
- A response to your command should appear on minicom.

Try to execute the command ‘C2’; on minicom it should appear the string ‘OK’.

Let’s test the encoders. Type the command ‘D3’; minicom will start to write the motion controller status. Two values are important for us, ‘E0’ and ‘E1’: the encoder reads.
Rotate the robot’s wheels clockwise and counterclockwise: the ‘E0’ and ‘E1’ values should change.
Verify that the ‘E0’ value changes when you rotate the wheel corresponding to the Motor 0 (each motor is labeled with his number); furthermore verify that the value is positive when you rotate the wheel clockwise and negative when you rotate the wheel counterclockwise.
Do the same for the Motor 1.

If something goes wrong verify you plugged the connectors the right way.

Let’s now verify the motors.
LIFT THE ROBOT, SO THE WHEELS DON’T THOUCH THE GROUND AND ARE FREE FOR ROTATING.
Type the command ‘T2’.
WARNING: be very careful while using this command, because it sets both the motors rotation speed at maximum (clockwise) for several seconds.
When the wheels stop, look at the minicom window, you should read the following:

```
        TICK_MOTOR_0 = 1349
        TICK_MOTOR_1 = 1352
```

(the values may change in a little range)

If one of the two values is 0, there is a mistake with the motor wires. Verify that you plugged the right motor in the right female connector on the IRABoard.

If all behaves like you expect the robot is well settled.

Start testing your command software

Now all is ready for start using the robot. See the next chapter for the documentation of the IRABoard firmware and communication, then write your code and enjoy the RoboCom.

Chapter 4 – IRABoard documentation

The whole content of this chapter is taken from the **AIRBoard user manual**, with only some modifications to match the hardware differences.

Design Choices

In this section we will explain in detail the design choices in the design of the IRABoard control unit software and hardware along with their rationale.

Microprocessor Clock and Oscillator Frequency

Since the oscillator frequency is correlated with the clock frequency according to the following formula:

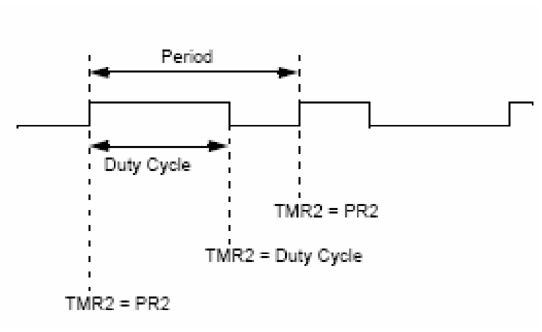
Fclock = ¼ Fosc

we have chosen the maximum oscillator frequency allowed, which is 40 MHz on the PIC18F452. Notice that, in order to obtain this frequency, a particular oscillator configuration must be used:
10 MHz crystal and HS/PLL oscillator mode2

Pulse Width Modulation

Pulse Width Modulation (PWM) is a common and simple way for interfacing digital and analog devices. Since in IRABoard the control logic is programmed with a digital microcontroller and the DC motor is driven by an analog power circuit, we use PWM to connect them.

A PWM signal is a periodic signal made up of pulses with a variable width. Period and duty cycle –that is the width of the pulses in time units– are the characteristic parameters of such a signal (see figure beside).



Period is fixed during the operation of the system and the main considerations that must be addressed regarding its choice are:

- Audible frequency band: the PWM frequency must be outside the audible frequency band, otherwise a disturbing noise would be heard.
- Compatibility with analog circuits: the PWM frequency must be chosen so that analog circuits (that will receive that signal as input) would be able to process it.

The PWM period can be specified writing an integer value into the PIC PR2 register that can be calculated using the following formula:

$$\text{PWM period} = [PR2 + 1] \cdot 4 \cdot Tosc \cdot (TMR2Prescalevalue)$$

where Tosc is ¼ 10^{-7} at 40Mhz. In our case, the PWM frequency chosen is 20KHz. To obtain this value, we put:

$$PR2 = 7C_{16} = 124_{10}$$

and a TMR2 prescale value of ¼.

The duty cycle is the information that a PWM signal carries and it generally varies over time. It is the output of the control logic for the power circuit that will drive the motor to the desired rotation speed.

The PIC18F452 has a maximum PWM duty cycle resolution of 10 bits and its value can be calculated using the following formula5:

$$PWMdutycycle = (CCPR1L : CCP1CON < 5 : 4 >) \cdot Tosc \cdot (TMR2prescalevalue)$$

where CCPR1L:CCP1CON<5:4> are the registers containing the desired PWM duty cycle value (CCPR1L stores the eight MS bits, the fourth and fifth bits of CCP1CON stores the two LS bits). It is important to notice that the PWM duty cycle has to be in the following range:

$$PWMdutycycle \in [0, PWMperiod]$$

as is quite obvious from the definition of PWM duty cycle. If the PWM duty cycle equals the PWM period or exceeds it, we obtain a constant signal that is always in the “high” state (electrically speaking, a constant signal of +5V).

Having chosen a PWM period of 500 · Tosc · TMR2prescalevalue we have a 9-bit PWM duty cycle resolution since values that we can write to CCPR1L:CCP1CON<5:4> registers must be in the range [0, 500].

As stated above, the PWM duty cycle express the desired motor rotation speed computed by the control logic. Since, for a generic DC motor, we can have two direction of rotation, we have two information (direction and rotation speed) that need to be communicated to the analog circuit. This is performed by a signal that carries only this information, the direction bit.
In addition our H-bridges accept the *brake* information (implemented inverted: low = brake), which signals to the bridge to stop the motors. The H-bridges, when the brake bit is low short-circuit the two motor wires together; this action forces the current induced by the inertial motor rotation to re-enter in the motor, strongly braking the rotation.

Encoders

The encoder measures the motor rotation speed, providing a feedback to the control logic. We used optoelectronic encoders, produced by HP. As can be read from Maxon catalogue, they work according to the following principle: a LED light is sent through a finely screened code wheel that is rigidly mounted onto the motor shaft. The receiver (photo transistor) changes light / dark signals into corresponding electrical impulses that are amplified and processed in the electronics.

These encoders provide three signals: two of them (Channel A and B) are 90° phase shifted square signals that can be counted for exact motor shaft positioning or rotation speed determination; furthermore, rotation direction can be derived by comparing each other. The third signal provides zero crossing and could be used as a reference point for precise angle determination. In our setup, Channel A and B are processed by the HCTL2032, which we already discussed.

Serial Line Interface

The IRABoard can be interfaced to any device through a common RS232 serial line connection. This interfacing method has been chosen for several reasons:

- The PIC18F452 has a built-in USART circuit that allows easy serial communication from the software point of view
- RS232 interface is commonly available in almost every personal computer
- Only few electronic components are needed to build the circuit responsible for TTL-RS232 signal level conversion

Among the drawbacks of serial lines the most important one is the limited data transfer rate that they can achieve. This is not an issue in our case due to the limited computational resources available that prevent us from setting too high baud rates. Regarding serial line settings, in our setup we have chosen to operate in a full-duplex asynchronous fashion: data can flow in each direction as soon as it is produced, without clock synchronization issues. Each character sent over the line is represented by 8 bits, with one start bit and one stop bit. Baud rate used is 115200 bps.

In IRABoard, serial line data management is interrupt-driven: when a character is received into the RCREG register an interrupt will be raised and the corresponding interrupt service routine (ISR) will be executed. Notice that this is an high-priority ISR, meaning that it cannot be interrupted by any other ISR. Received characters are copied into a buffer to store the whole command string. When the terminator character '\r' is received, the buffer content is transferred into a second buffer, where the complete command string can be parsed.

Control

PID Control

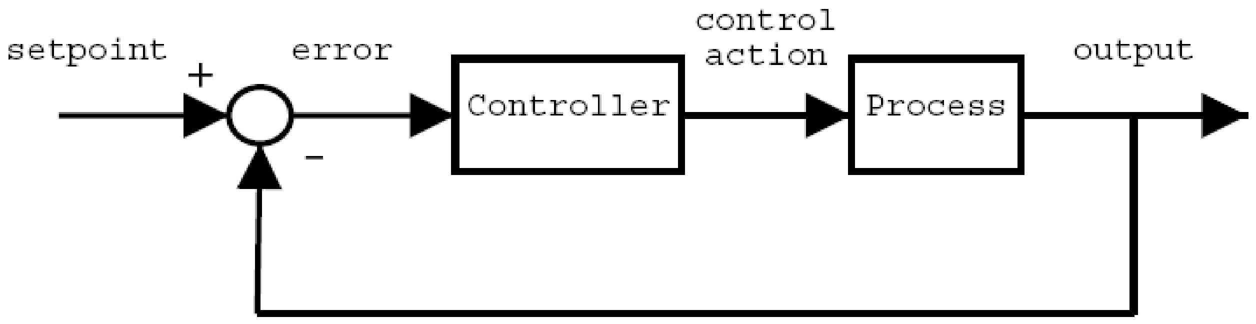
The process that IRABoard will control is a DC brush motor. From control point of view, this system can be modeled as a second order system, where input variable is the voltage applied to the motor armature and output variable is the rotation speed. From the physical model of the motor we can derive the following transfer function applying Laplace Transform:

$$\frac{\dot{\theta}}{V} = \frac{K}{(Js+b)(Ls+R)+K^2}$$

where:

- K is the electromotive force constant
- J is the moment of intertia of the motor
- L is the electric inductance
- R is the electric resistance
- b is the damping ratio

We have chosen a closed-loop control system.



This control architecture ensure both high disturbance rejection in noisy environments and low residual error with respect to open-loop control systems. This can be done thanks to the feedback provided by the encoders. The control algorithm implemented is a digital PID.
This kind of controller is common in industry, and suits well in control systems where process can be modeled as a second order transfer function. It is written in an incremental form, so that the control law is:

$$u(k) = u(k-1) + K_p \cdot [e(k) - e(k-1)] + K_i \cdot e(k) + K_d \cdot [y(k) - y(k-1) - y(k-1) + y(k-2)]$$

where u(k) is the control output at instant k, e(k) is the error at instant k, y(k) is the process output at instant k.

Notice that this formulation differs from the standard continuous-time PID controller: here the derivative action is applied on the process output, not on the set point. This approach guarantees smoother control action behavior in case of a set point step variation.

From the software point of view, the control algorithm is contained into a subroutine that is called with a fixed sampling time period and its main tasks are:

- Reading encoders data stored into timers
- Computing control output
- Applying the control output

Regarding the first sub-task, it is needed in order to compute current motor rotation speed, which compared to the set point value yields the control error.

Although this would seem a natural and simple way to design the control routine, it is not efficient: two ratios between two big integers should be computed at each control cycle, and this is a time-consuming operation for a microcontroller with limited resources.
We adopted the following strategy: instead of comparing the computed speed with the set point, the set point is transformed in a way that can be directly compared with ticks. This transformations require two ratios too, but they are computed every time the set point is changed, not at each control cycle.

The second sub-task, computation of control action, is done according to the above depicted control law. In order to do this, we need to maintain state variables to store past errors, control action and process output. It is worth to notice that attention must be paid in order to avoid the "integral windup" problem that affects PID controllers. This problem may cause very large response times of the controlled system, due to the presence of an integrator which, in case of control output saturation, may diverge. A solution for this problem is the following: the discrete integrator (part of the PID algorithm) is "stopped" when the control output saturate, preventing the integrator from reaching too large values. In other words, the sum that realize the discrete integrator is not performed when control action saturate.

Third sub-task involves the control action application. A saturation must be introduced here, since PWM duty cycle values must stay in a given set.

Timing issues

In IRABoard, in order to perform control action every sampling time, a timer generated interrupt is used. Our PIC is equipped with three hardware timers registers, of which only the third (Timer2) is used. It performs the counter within the PWM circuit as a time-base generator, and must be set to operate at the PWM frequency.
Fortunately, it is also possible to use this timer as an interrupt generator with a programmable postscaler. This means that an ISR will be called every fixed amount of time that must be a multiple of the PWM period.
In our case, the chosen sampling time was Ts = 100Hz. To have the control routine called 100 times per second, we set TMR2 postscaler equal to 10 and a software trick has been introduced so that the control routine is called every 20 TMR2 interrupts.

Concurrency issues

In order to make the whole system correct with respect to concurrent behavior, the ISR with the control routine runs at low priority. This means that the control routine can be interrupted (only) by the RS232 ISR, which has high priority. This may cause delays, but they are of little amount since RS232 ISR has short-time execution. This gives us two advantages:

- No serial received character will be overwritten, since RS232 ISR will be executed as soon as the character arrives on the receiving buffer.
- The RS232 ISR is executed as an atomic operation, which is needed to preserve correct program state, since multiple memory location are accessed/modified by it.

Furthermore, since the control routine is executed into an ISR, it can interrupt program body execution (command string parsing for example) guaranteeing to be executed at a given frequency.

Eeprom

As you can see in Datasheet errata about pic18Fxx2 family, when reading the stored data, the contents of the EEDATA register may be corrupted if the RD bit (EECON1<0>) is set immediately following a write to the address byte (EEADR). A NOP instruction between the registers writing should solve the problem.

Source Code Description

The language

The code has been written in C language. It is not an ANSI C, but it is a Microchip1 version, very similar to the ANSI C, including some libraries (such as string.h) rewritten for working on small devices, with a little amount of memory and low computer power. The most important thing while programming this device is clock cycles saving: it is better to have longer code than compact code, but slower to execute. However we must remember that PIC has a little amount of memory and the code cannot be too long. This is the trade off we have considered programming the PIC.

The environment

The entire code has been written with MPLAB IDE environment v6.30 by Microchip. The code can be modified with any text editor, but we advise to use this suite because the PIC18 specific compiler can be easily integrated with this environment. MPLAB IDE allows also to compile the source code to obtain the hexadecimal file that must be written on the PIC. MPLAB IDE can write the hexadecimal file on the PIC, but also different program can do it.

The compiler

The code has been compiled with MPLAB C18 compiler v.2.20 by Microchip. This compiler has been designed to be integrated with MPLAB IDE suite. This is the specific compiler for PIC18 family. If we change PIC family (i.e. PIC17 family) we must change the compiler because the libraries of each compiler has been written for one specific PIC family.

The code

The program has been divided in various modules, each of them performing a particular function. Every module has been organized with the ANSI C typical structure: an header file (.h extension) that contains the functions and local variable declarations and a code file (.c extension) that contains the functions source code. There is also an header file that contains all global variable declarations and all definition strings (the classic "#DEFINE" preprocessor directives).

definitions.h

This header file is the most important, because it contains all constant strings and global variable definitions. The constant strings (#define preprocessor directive) are very important because we can indicate each PIC pin with a mnemonic string. In this way, if we change pin layout, we have to change only the #define string, without changing the mnemonic string in the code. The #define directive is also useful for other characteristics: we can define mnemonic strings with a particular value or define boolean variables and all Eeprom mnemonic strings.
Global variables are useful because they keep their value even when the subroutine has finished, and these values are available to each module. We have chosen to use many global variables to keep the variable value for different elaboration steps and in each module. We can find in definitions.h all global communication buffer, encoders and controller variables.

ROBOT MAIN.c

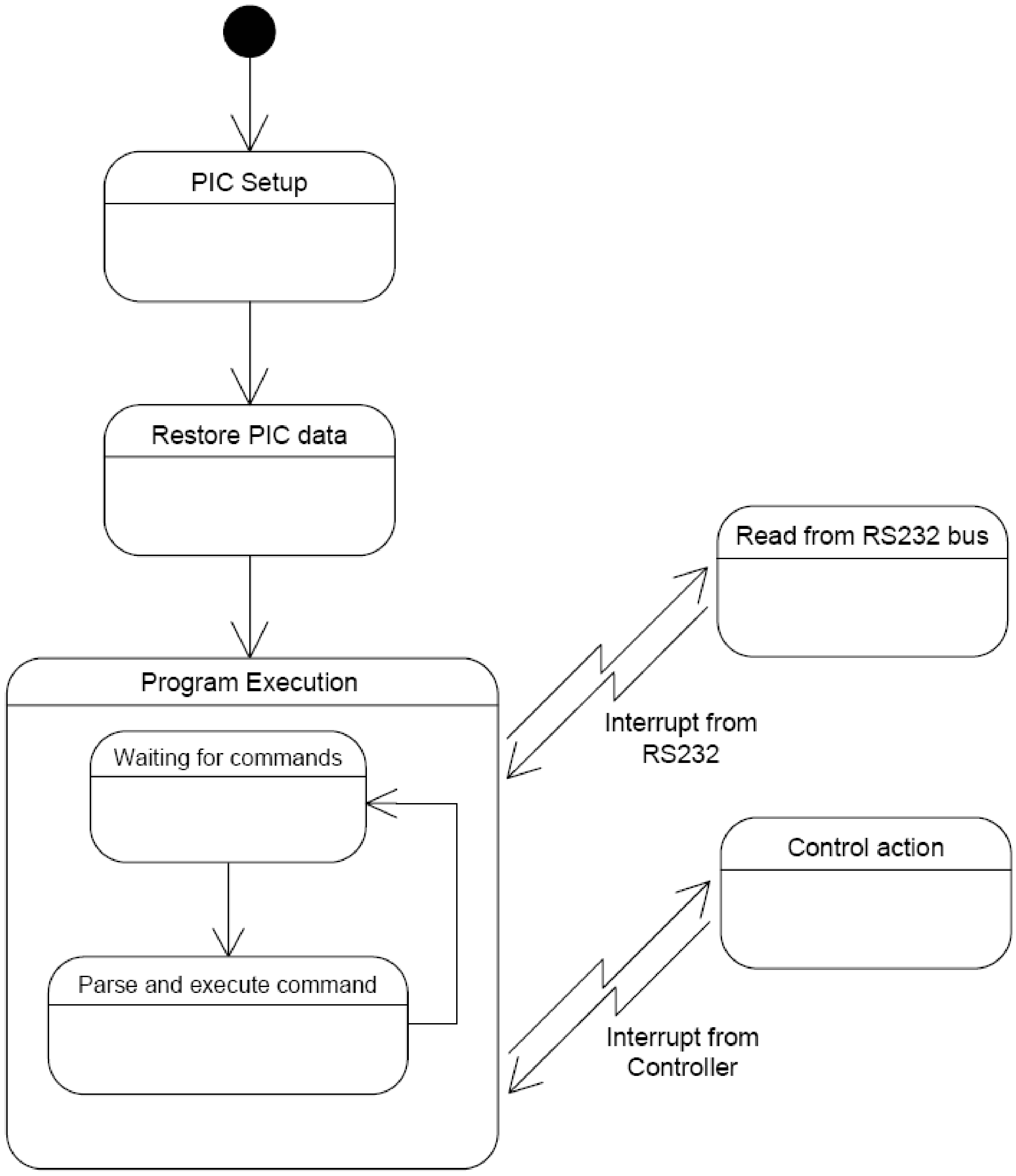
This is the main file. It contains all global variables declarations, the interrupt service routines and the command interpreter. When we turn on the IRABoard, the sequence of operation is:

1. Initialize all pic feature (rs232, timer and PWM)
2. Load from internal EEPROM all controller constants
3. Start an infinite loop: this is a polling loop which can be interrupted by serial bus and control interrupt service routines. When IRABoard receives a terminal character (carriage return) from communication buffer, it calls the interpreter routine to parse the command and then execute it (if valid).

We can see this sequence in the diagram on the next page.

The subroutines contained in this module are:

- control_isr: this is the control interrupt service routine. It is called each sampling period.
- rs232_isr: this is the serial bus interrupt service routine. It is called at each character arrival from the serial bus.
- executeCommand: this is the subroutine that execute the command received from the upper layer. It is called when the serial bus isr receive the end string character (carriage return).
- Setup: this is the initial PIC setup routine. It sets all pic features we need.
- restoreData: this is the subroutine that load all pic parameters from pic internal EEPROM. It is called after Setup subroutines.
- main: the main subroutine.



<u>rs232.c</u>

This file contains all rs232 serial bus subroutines. This module is not the original Microchip's, because the original had some bugs (specially in the putsUSART and putrsUSART subroutines), so we rewrote it. The new version is so smaller than the original and contains only the subroutines necessary for our application. The subroutines contained in this module are:

- putsUSART: this is the subroutine that writes a string on the serial bus. The string has to be placed in the PIC RAM memory: this means that the string must not be within the double quote (i.e. constant string). Example of use is putsUSART(variable); where variable is a string variable.

- putrsUSART: this is the subroutine that writes a string on the serial bus. This string has to be placed in the PIC ROM memory: this means that the string is a constant string, write within the double quote. Example of use is putrsUSART("Welcome in IRABoard");.
- ReadUSART: this is the subroutine that read a single character from the serial bus. Example of use is character = ReadUsart();.
- WriteUSART: this is the subroutine that write a single character into the serial bus. Example of use is WriteUSART('\r');.
- read_rs232: this is the subroutine called by serial bus interrupt service routine. When a character arrives, this subroutine retrieve it from rs232 input register and copy it in the command buffer. When a terminal character (carriage return) is received, the command buffer is passed to the proper subroutine for command parsing and execution.

controller.c

This file contains the controller subroutine. It contains only one subroutine, but it is the most important in IRABoard, since it is the engine controller algorithm. Actually the engine control is a digital P.I.D, but it is possible to write in IRABoard any type of control (e.g. fuzzy controller). If we want to change control algorithm, we have to modify this file. The only subroutine contained in this module is:

- engine control: this is the subroutine that contains the engine control algorithm.

eeprom.c

This file contains all EEPROM subroutines. This module is not the original Microchip, because it does not exist. We have written this module with datasheet information. The address necessary for store or load data is 8 bits data: the only reason for this choice is that EEPROM maximum size is 256 bytes and with 8 bits we can cover all memory space.
The subroutines contained in this module are:

- readByteFromIE: it reads a single byte data (8 bits) from the EEPROM memory. Example of use is data = readByteFromIE(address); where address is the memory location of the data we want.
- writeByteToIE: it writes a single byte data (8 bits) it the EEPROM memory. Example of use is writeByteToIE(address, data); where address is the memory location we want store the value and data is the value to save.
- loadEEPromValue: it reads a floating point value from the EEPROM memory. The floating value is stored in scientific notation (mantissa and exponent), so we can store a big range of number with few memory locations. Example of use is value = loadEEPromValue(address); where address is the memory location of the value we want.
- storeEEPromValue: it writes a floating point value in the EEPROM memory. Example of use is storeEEPromValue(address, value); where address is the memory location we want store the value and value is the value we want to save.

Chapter 5 - How to use IRABoard

The use of IRABoard is very simple. First of all, we have to configure the serial bus with the proper values, otherwise the communication will not be possible. For testing the communication we can use a terminal emulation program (HyperTerminal on Windows or Minicom on Linux) or a test program written in C/C++ language.

The values to use are:

- bus speed: 115.200 bps
- hardware flow control: disabled
- bit parity: no parity
- eventual modem initializations: disabled

Test program in C/C++ Language

We can use IRABoard with a test program written in C (or C++) language. To use a test program we have to include the header file "sstream.h", and then we must create a function to initialize the serial communication.
We can do that in the constructor method if we are programming with C++. An example of initialization code (constructor method) could be the follow:

```
SerialCommunicationAIRBoard::SerialCommunicationAIRBoard()
{
        mBaudRate = B115200;
        mModemDevice = strdup("/dev/ttyS0");
        mHardwareFlowControl = false;
        InitCommunication();
        StartMotors();
}
```

The functions InitCommunication and StartMotors start respectively the serial communication and the motors. The InitCommunication function initializes the serial port with the correct configuration bits. An example of initialization communication could be the follow:

```
void SerialCommunication::InitCommunication(void)
{
        // Open modem device for reading and writing and not as
        // controlling tty because we don't want to get killed
        // if linenoise sends CTRL-C.
        if ((fd = open(mModemDevice, O_RDWR | O_NOCTTY )) <0)
        {
                perror(mModemDevice);
                exit(-1);
        }
        // save current serial port settings
        tcgetattr(fd,&oldtio);
```

```
// clear struct for new port settings
bzero(&newtio, sizeof(newtio));
// BAUDRATE: Set bps rate. You could also use cfsetispeed
// and cfsetospeed.
// CRTSCTS : output hardware flow control (only used if the
// cable has all necessary lines. See sect. 7 of
// Serial-HOWTO)
// CS8 : 8n1 (8bit,no parity,1 stopbit)
// CLOCAL : local connection, no modem contol
// CREAD : enable receiving characters
if (mHardwareFlowControl)
{
        newtio.c_cflag = mBaudRate|CRTSCTS|CS8|CLOCAL|CREAD;
}
else
{
        newtio.c_cflag = mBaudRate|CS8|CLOCAL|CREAD;
}
// IGNPAR : ignore bytes with parity errors
// ICRNL : map CR to NL (otherwise a CR input on the other
// computer will not terminate input)
// otherwise make device raw (no other input processing)
newtio.c_iflag = IGNPAR | ICRNL;
// Raw output.
newtio.c_oflag = 0;
// ICANON : enable canonical input
// disable all echo functionality, and don't send signals to
// calling program
newtio.c_lflag = ICANON;
// initialize all control characters
// default values can be found in /usr/include/termios.h,
// and are given in the comments, but we don't need them here
newtio.c_cc[VINTR] = 0; // Ctrl-c
newtio.c_cc[VQUIT] = 0; // Ctrl-\
newtio.c_cc[VERASE] = 0; //del
newtio.c_cc[VKILL] = 0; // @
newtio.c_cc[VEOF] = 4; // Ctrl-d
newtio.c_cc[VTIME] = 0; // inter-character timer unused
newtio.c_cc[VMIN] = 0; //blocking read until 1 character arrives
newtio.c_cc[VSWTC] = 0; // '\0'
newtio.c_cc[VSTART] = 0; // Ctrl-q
newtio.c_cc[VSTOP] = 0; // Ctrl-s
newtio.c_cc[VSUSP] = 0; //Ctrl-z
newtio.c_cc[VEOL] = 0; // '\0'
newtio.c_cc[VREPRINT] = 0; // Ctrl-r
newtio.c_cc[VDISCARD] = 0; // Ctrl-u
newtio.c_cc[VWERASE] = 0; // Ctrl-w
newtio.c_cc[VLNEXT] = 0; // Ctrl-v
newtio.c_cc[VEOL2] = 0; // '\0'
// now clean the modem line and activate the settings for
// the port
```

```
        tcflush(fd, TCIFLUSH);
        tcsetattr(fd,TCSANOW,&newtio);
        // terminal settings done, now handle input
}
```

Variables newtio and oldtio are defined as private struct termios. The structure Termios describes a general terminal interface for controlling asynchronous communications port. In order to use this structure, we must include "termios.h" header file. To see the other functions descriptions, use Linux man pages.

Commands

In this section, we describe the commands available to use the IRABoard. The basic syntax of a command is

```
<COMMAND><DEVICE>[<VALUE1>][<VALUE2>]
```

Where

- <COMMAND>: is the specific command we want to execute;
- <DEVICE>: is the device we want to command. Possible values are:
  - 0 for the motor0
  - 1 for the motor1
  - 2 for both motor0 and motor1.
- <VALUEx>: is the command parameter (if exists). This value can be a motor set point, or a value we want to store into PIC EEPROM. The <VALUEx> is optional because it is not used by all commands; it will be specified in the appropriate section.

The command is finished when we send the terminator character, that is a carriage return. If we are using a terminal emulation program (such as minicom or HyperTerminal), we must press the enter key. If we are using a program test, we must insert the character '\r' at the end of the command string. In this manual we indicate the variables between "<" and ">" and optional variables between "[" and "]".

Enable Motors

This command enable the motor specified in the <DEVICE> value; its syntax is:

```
a<DEVICE>
```

<DEVICE> is the device we want to enable.

When a motor is enabled, it will start the control action to react with the current set point (it could have been previously set). Before enabling a motor, it is better to set the correct set point (the default set point values are zero, so that the robot will not move even if we enable motors without giving set point values).

Possible examples:

```
a2	//start both motors
a0	//start only motor 0
```

Disable Motors

This command disable the motor specified in the <DEVICE> value: its syntax is:

```
b<DEVICE>
```

<DEVICE> is the motor we want to disable.

When a motor has been disabled, every change in set point value will not produce any result, until next habilitation. The motors will be automatically disabled after a number of cycles with no-command set in the Eeprom.
Possible examples:

```
b2	//disable both motors
b1	//disable only motor 1
```

Change Set point Value

This command allow to change set point values for the motors; its syntax is:

```
m<DEVICE>+<VALUE0>[+<VALUE1>]
```

<DEVICE> is the motor for which we want to change set point.

According to the devices, we can have different values. When <DEVICE> is equal to 0 or 1, the new set point value is <VALUE0> and <VALUE1> is not used; when <DEVICE> is equal to 2, we must use both <VALUE0> and <VALUE1>: Some examples are (for simplicity, we will consider the motors always active):

```
m1+010+010	//set motor1
ERROR 7		//error: bad command
m1+010		//set motor1
OK		//operation ok
m2-020		//set both motors
ERROR 7		//error: bad command
```

The command sequence above shows a typical use of this command. As we can see, the first command produces an error, because we have chosen to change set point value only to motor1 but we have specified two values. The second command is correct since we have specified only one value to motor1. The third command produces an error since we have chosen to change both set point values, but we have passed only one value.

```
m2+000+000	//set both motors
OK		//operation ok
```

```
m0+050          //set only motor0
OK              //operation ok
m1+050          //set only motor1
OK              //operation ok
m2+099+099      //set both motors
OK              //operation ok
```

This command sequence shows the use of all cases, without errors.
The first command stops both the motors (they are still enabled).
The second command change set point value only to motor0.
The third command change set point value only to motor1: now both engines have the same set point value.
The fourth command change set point value to both the motors.

When the motor is controlled in speed, the new set point value is expressed in MAX speed percentage and it can be both positive and negative. The MAX speed value is, in absolute value, 100 and the MIN value is 0 (value greater than +100 or less than -100 takes the controller to saturation zone). If we want to move the robot to its MAX speed, we must set the set point value to +100 (or -100 if we want to change the direction). If we want to stop the robot (without disabling motors), we have to set the set points value to 0.

> The sign represents the direction of motor rotation. Usually with positive set point values, the motor rotation is clockwise and with negative set point values the motor rotation is counter-clockwise. Warning! If the wheels are opposed (such as with bidirectional robots) and we want to move the robot on a straight direction, we must set one set point positive and the other negative. This is necessary because if we set both set points with the same sign, the wheels will rotate both clockwise, and robot will turn around itself.

We have chosen to represent the speed as max-value percentage (when the motor is controlled in speed), and not with absolute values (such as in cm/sec), because we are always sure that +100 represent the MAX speed even if we change motors or wheels while absolute speed value may change.

Configuring parameters

This command configure the control parameters of motor specified in the <DEVICE> value and other parameters; its syntax is:

```
c<DEVICE>
```

<DEVICE> is the device we want to configure.

This command is useful if we want a quick configuration of all parameters. The parameters configured are the constant of the PID controller (kp=0.5, ki=0.1, kd=0.3) and maxtick value (maxtick=240) according with device choice, and others parameters needed for correct working of PIC (with suggested values, see below in ”Using internal EEPROM” section).

Possible examples:

```
c2    //configure both motors
c0    //configure only motor 0
```

Using internal EEPROM

This command allow to use PIC internal EEPROM to save robot and control parameters. The syntax is slightly different from other commands since we have to specify the operation we want to perform and not the device. The syntax is:

```
e<OPERATION><VARIABLE>[=<VALUE>]
```

There are only two possible values for <OPERATION>:

r	read a value from EEPROM
w	write a value to EEPROM

We have to specify also the variable we want to save or restore. Each variable is contained in <VARIABLE> and it is represented by a mnemonic string. Strings representing variables are:

- **kd0**: motor 0 control derivative constant. It is a positive floating point value.
- **ki0**: motor 0 control integrative constant. It is a positive floating point value.
- **kp0**: motor 0 control proportional constant. It is a positive floating point value.
- **kd1**: motor 1 control derivative constant. It is a positive floating point value.
- **ki1**: motor 1 control integrative constant. It is a positive floating point value.
- **kp1**: motor 1 control proportional constant. It is a positive floating point value.
- **ct**: controller sampling period multiplier. It is a positive integer value. It is expressed in milliseconds. The advice value is 10.
- **nc**: It is the number of no-command cycles after that the program disable the engine. The advice value is 5000.
- **maxtc0**: MAX tick for motor 0. It is a positive integer value (between 1 and 250, it depend on battery condition, advice value is 240). This value can be computed using the auto-tuning command
- **maxtc1**: MAX tick for motor 1. It is a positive integer value (between 1 and 250, it depend on battery condition, advice value is 240). This value can be computed using the auto-tuning command
- **ticsp0**: ticks to space for motor 0. It represents the covered space (in millimeters) by one tick. To calculate this value, we have to follow two steps. First of all, we have to reset encoder counters using command r2e and then move the robot by hand (with motors disabled), by one meter straight. Then we have to use the command r2e again to read the ticks number. We have to move the robot very slowly to have an exact measure. We have to repeat this step many times to have a reliable ticks number. The second step is calculate the "ticks to space value". We have to use the formula:

$$TICKS\_TO\_SPACE\_0 = \frac{1000}{TICKS\_PER\_METER}$$

where TICKS PER METER is the ticks number we have just retrieved. It is a positive floating point value.

- **ticsp1**: ticks to space for motor 1. It represents the covered space (in millimeters) by one tick. To calculate this value, we have to follow the steps shown above. It is a positive floating point value.

If we want to write a variable into the EEPROM, we must also specify the value to store adding "=<VALUE>" in the command syntax. The value representation is the same of normal computers: if the value is a floating point, we must use a "dot" to separate integer and decimal part, while if the value is an integer, we must write an integer number.

Now we will show some example of use.

```
erkd0=1
ERROR 7     //error: bad command
ewki1
ERROR 7     //error: bad command
erki2
ERROR 7     //error: bad command
er
ERROR 7     //error: bad command
```

The command sequence above shows some example of typical error. The first command is wrong because we want to perform a read, but we also specify a value. The second command is wrong because we want to perform a write, but we do not specify any value. The third command is wrong because we specify a not existent mnemonic string. The fourth command is wrong because we do not specify any parameter.

```
ewkd0=1.5   //write in the internal Eeprom the value for kd0
OK          //operation ok
erkd0       //read from the internal Eeprom the value for kd0
  kd0=1.5   //the value for kd0 is printed
OK          //operation ok
```

This command sequence shows two correct commands. The first command write the value 1.5 in the EEPROM space associated to the mnemonic string "kd0". The second command retrieve from EEPROM memory the value of variable "kd0" and write it on the serial bus.

Return distance or speed

This command allows to read the current speed value and the covered distance since last read command; its syntax is:

```
r<DEVICE>[<TYPE>]
```

<DEVICE> is the device we want to query for distance or speed
<TYPE> is the data type we want to check. The possible values are:

- s   we want to read the speed. It is expressed in ticks/second
- e   we want to read the space. It is expressed in ticks.

<TYPE> is optional since we may want both current speed and covered space for both devices. In this case, we must write only the command “r2”, without any other parameters, and the AIRboard will return speed and space for both devices. If we do not want both, <TYPE> is required. Now we will show some example of this command.

```
r2          //print both distance and speed for both the motors
  453  345  //the covered space for motor0 and motor1
  23   67   //the current speed for motor0 and motor1
OK          //operation ok
```

This example shows the use of command r2 : it returns both speed and covered distance for both the motors. Here we have not specified the <TYPE>, so IRABoard has returned all data.

```
r2e         //print covered space for both the motors
  453 345   //the covered space for motor0 and motor1
OK          //operation ok
r2s         //print current speed for both the motors
  23 67     //the current speed for motor0 and motor1
OK          //operation ok
```

This command sequence has the same effect of the previous, but here we have used two commands instead of one. As we can see the results are the same.

```
r0e         //print covered space only for motor 0
  453       //the covered space for motor 0
OK          //operation
r0s         //print speed only for motor 0
  23        //the current speed for motor 0
OK          //operation ok
```

In this example, the commands print the covered space and the current speed only for motor 0.

Debug information

This command allows to change debug level and the information returned by IRABoard. This feature is useful to get values and messages during IRABoard tests. Its syntax is:

```
d<DEBUG VALUE>
```

<DEBUG VALUE> is the value of the debug level. The values are:

- 0 it does not return any message. It is the default value.
- 1 it returns only the command results (OK if the command execution has successfully terminated, ERROR code if the command execution has failed).
- 2 it returns advanced debug messages such as intermediate elaboration results. It shows EEPROM operation result and enable/disable operation on kicker and motors.
- 3 it returns ALL messages, even the controller results (set point, PWM and tick) step by step.

> **Warning!** This causes slowing down in the execution because of writing on the serial bus. We recommend to use this feature with a monitor and terminal emulation program (such as HyperTerminal under Windows or minicom under Linux).

We have said above that when a command execution fails, an error message is printed with a special code. They are:

- ERROR 1: bad device. This error is shown when we indicate in the command a device not valid.
- ERROR 2: bad data. This error is shown when we indicate in the command a not valid data (i.e. numbers in wrong format).
- ERROR 7: bad command. This error is shown when we indicate a wrong command (i.e. EEPROM write request without associated value)
- ERROR 99: unknown command. This error is shown when we indicate a command that does not exist

Auto tuning parameters

This command allows to get/set automatically some important robot parameters, such as MAX encoder ticks; its syntax is:

```
t<DEVICE>
```

<DEVICE> is the device we want to set parameters automatically.

This feature is very important because if we change the motors or encoders, we can retrieve these parameters automatically. The most important parameter retrieved is MAX encoder ticks (i.e. actually NUM encoder ticks at the MAX speed) for both the motors. When these parameters have been calculated, they are automatically written in the EEPROM (the mnemonic strings are maxtc0 or maxtc1).

> **Warning!** This command set the motor to its MAX speed. Before start auto tuning, if you are testing traction motor, you should raise the robot, so it can’t start without control at its MAX speed. If you are testing rotation motor, pay attention no one finds near the robot. The test lasts about 5 second.