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RWTH Aachen (Germany)
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Mobile robot electronic system with a network and micro-controller based interface

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<<February, 2008>>

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Table of contents

1. Introduction and Goals

Nowadays mobile robots are expected to be a desire at several services to afford man facilities and increase safety in any kind of duties.

Mobility is a key issue in robotics and a challenging subject for any research and development. It combines cognitive capabilities focused on sensorial input and human interaction with intelligent control of the drive systems and requires real mechatronics engineering solutions to enable robust and reliable operation.

In the European Centre for Mechatronics [W1] mobile robots have been research subjects for years. A mobile platform with semi-autonomous functionality has been developed years ago. It has been used as a demonstration and test platform to study mobility and cognitive control.

In the University of Minho [W3] and RWTH University [W2] that kind of research is also important and the industry support gives a solid development sign to the institutions.

As the control system capacity on board of the vehicle has reached limits, a new system architecture with more powerful controller elements was planned to replace the old one.

In this context the key objective of the project was to design and develop a new embedded system capable of controlling the mobile platform drives using *ATMega* microcontroller technology.

To meet this goal a number of tasks were to consider:

- Introduction to vehicle system architecture and drives functionality
- Introduction to microcontroller technology
- Development of a microcontroller hardware platform
- Development of a concept to control the drives and to enable driving modes
- Development of controller software
- Development of a user interface for remote control
- Integration and functionality test
- Documentation

The work was performed in the labs of the APS - European Centre for Mechatronics.
The duration of the project was 5 months.
Technical assistance was provided by the APS project engineer Christoph Dreyer.
Supervisor in Germany is Prof. Günther Starke, Head of Research at the APS.
Technical assistance and Supervisor in Portugal was provided by Prof. Dr. Fernando Ribeiro.

1.1. Thesis structure

This report is organized in the following order:

- The State of the Art will be presented
- The Robot will be presented as well as respective block diagram of the system implemented
- An introduction of theory to D.C. Motors as well PWM signals, Gearheads, Motors Drivers and Encoders, Power regulators and Microcontroller programmers as well the I2C protocol will be done.
- Details of the Microcontroller unit will be presented next.
- The desktop programming (Server/Client) and (Server/Microcontroller) is presented.

- The schematics, Proto-board, Strip-board, PCB and hardware connections are shown as well.
- A chapter about software and hardware considerations is presented.
- Finally the conclusions are presented.

2. State of the Art

Robots are more and more available for research and commercial applications. This robot is under research phase of development, as well as the control structure of the system.

The market shows some solutions of robots that are either autonomous or remote-controlled but robots with some autonomous capabilities are more common.
Remote-controlled robots can be found widely in military robots but service but tactical or service robots are usually autonomous.
Some chassis with only motors and without any control can also be find but comparing them to this one can lay to misunderstood since this robot has also software to the client and server and hardware like the microcontroller system and sensors.

Since this robot was developed under 5 month and is still under a development stage, it is not fair to make a direct comparison with other already finish robots. Even through the state of the art compares this work with most relevant similar projects.

Usually, preceding the autonomous development, a solid mechanic structure and control system is designed as well as low level programming to drive the motors and to make use of sensors. In this robot system those things were tested and the *I2C* communication support was included as well of serial and *TCP/IP.* The robot is remote control and has feedback regards to temperature, current, speed and position. The robot next development stage is to apply autonomous algorithms but that is overtaking within this thesis.

The proposed robot system has not, in the concern of this thesis, a specific application, even so, due to its powerful motor power, size and mechanicals part it can be compared with military device and also because this robot is, as many military robots, remote controlled but not yet autonomous.

This thesis was done in a 5month research, testing and production. The products below were done in a lot of years and probably with bigger team works, reason why probably these products are often provided with more sensors and automatisms controls as well as they are already in the market.

The existing robots are usually expensive and with lack of automations, reason why several approaches of a robotic platform are being devolved in several companies regarding the specific needs as size, cost, automatisms, simplicity.

Old robots platforms were design to a specific robot, and a change in the hardware implies a hard work wither in programming as in physical attachments. The system proposed is applied to this specific but can easily, at least some components, be connected to other mobile systems.

The proposed robot used *I2C* to avoid complexity at hardware and software level, the robot can easily grow with new hardware with only 2 wires, for communications with the controller, which decrease the complexity of adding new components. At the same time, the platform independent server computer can easily be equipped with USB components with "*plug and play*" capabilities.

2.1. iRobot Create™ Programmable Robot

Figure 1 shows the iRobot,

Figure 1 – iRobot [W24]

According to [W24], *iRobot* is, since at least 15 years, a global leader in robotics, it has platforms for technological development and it is software is meat to developers to perform network based robotic behaviour.

As the robot system proposed in this thesis the low-level software infrastructure is done and future used need to project high level behaviours, loggers and debugging tools are also provided in both but the *iRobot* itself, as shown in figure 1, it is a small robot with upgrade capabilities as shown in figure 2 but to get this type of applications, is obvious that lot of software as well as mechanical and electrical hardware were developed in out of the *iRobot* package concern.

Like this proposed method, the *iRobot* Command Module also used the same family of the micro-controller, it used the ATMega168.

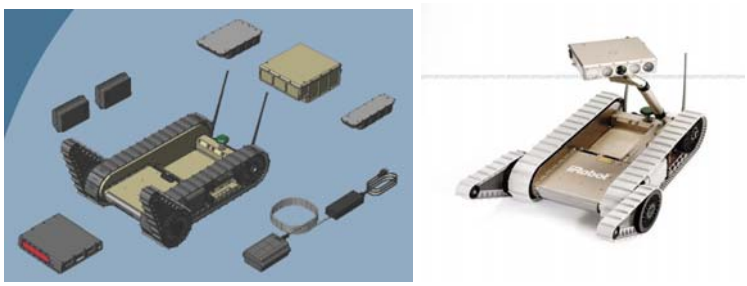


Figure 2 – iRobot pack [W24]

Figure 3 – the *iRobot Packbot* in Iraq [W25]

One of the examples of applications is the *iRobot Packbot* in Iraq as shown in figure 3.

“April 24, 2007 - The remarkable success of robots in Iraq and Afghanistan is now well documented. UAVs have proven invaluable at every level and robotic ground systems, primarily *iRobot’s Packbot*, have performed tens of thousands of missions and saved countless lives from the dreaded Improvised Explosive Device (IED).” [W25]

2.2. MobileRobots's P-series

Pioneers, PeopleBots, PowerBots and PatrolBots are physically different robots, from the *MobileRobots's P-series*, but with the same standard core architecture. [W26]

“Since 1995, Mobile Robots platforms have contained all of the basic components for sensing and navigation in a real-world environment, including battery power, drive motors and wheels, position / speed encoders, and integrated sensors and accessories. They are all managed via an onboard microcontroller and mobile-robot server software.” [W26]

Differently than the proposed platform independent system, these robots are called “Embedding Linux in a Mobile Robot”.

Figure 4 shows the Pioneer 2-DX picture and bloc diagram, which has similarities in the bloc diagram even so in a primitive way.

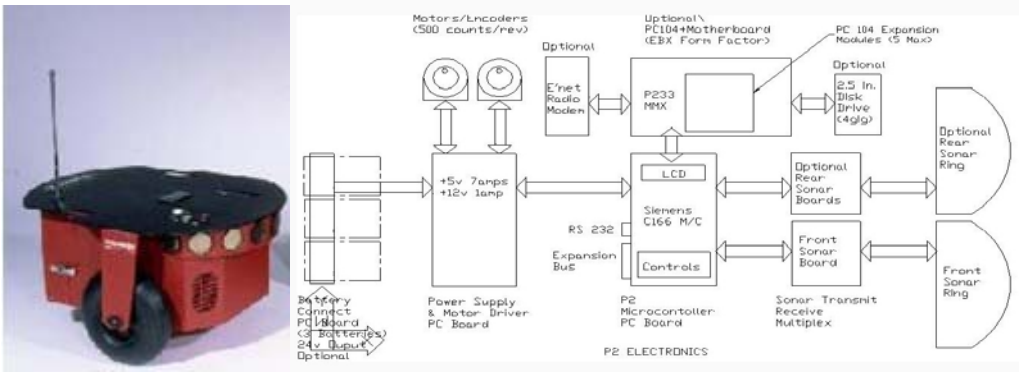


Figure 4 – *ActivMedia* Mobile Robot Pioneer 2-DX [W26]

Figure 5 shows the Pioneer 3-AT that is an evolution of the Pioneer 2-DX and it is rated at a 6,995$ cost.

Figure 5 – *ActivMedia* Mobile Robot - PIONEER 3-AT [W26]

“Pioneer 3AT is a mobile robotic skid-steer base with 4 drive wheels, microcontroller, motors, encoders, 1 battery, std. Pioneer software & no sonar, OS, ARIA, ARNetworking, MobileEyes, MobileSim, Mapper Basic & manuals; charger & ethernet or laptop connector not included.” [W26]

The bare P3-AT base with included ARIA software has the ability to:
Drive controlled by keys or joystick, plan paths with gradient navigation, display a map of its sonar and/or laser readings, localize using sonar (with optional laser upgrade), communicate sensor & control information relating sonar, motor encoder, motor controls, user I/O, and battery charge data, test activities quickly with ARIA API from C++ programs, simulate behaviors offline with the simulator that accompanies each development environment. [W26]

As the proposed robot, this one can communicate with a client computer through a “robot-to-laptop connector” but the microcontroller used is an ARCOS instead of the wise known AVR *Atmega*.

Technical specifications:
“The rugged P3-AT 50cm x 49cm x 26cm aluminum body with 21.5cm dia, drive wheels loves to run outdoors. The four motors use 38.3:1 gear ratios and contain 100-tick encoders. This skid-steer platform is holonomic and can rotate

in place moving both wheels, or it can move wheels on one side only to form a circle of 40cm radius.” [W26]

“A small proprietary ARCOS transfers sonar readings, motor encoder information and other I/O via packets to the PC client and returns control commands. Users can run the robot from the client or design their own programs under RedHat Linux with Motif or under WIN32 using their favorite C/C++ compiler. Our robotics development environments supply library functions to handle navigation, path planning and many other robotic tasks.” [W26]

2.3. SWORDS

Figure 6 shows the Swords, one of the tested, applications to remote control robots

Figure 6 – Principle of operation [W22]
http://www.gizmag.com/go/5098/

Swords, aka Special Weapons Observation Remote Direct-Action System, is a military robot system developed to a combat scene, it was finish in January 2006.

“The diminutive remote-controlled US$230,000 SWORDS machine shares the same base as the Explosive Ordnance Disposal (EOD) Talon robots which have been deployed in Bosnia, Afghanistan and Iraq. Unlike many of it is flying robotic (UAV) brethren, the weaponised Talon is not autonomous, being under the direct control of a soldier watching from up to a mile away through an array of cameras which can include both night and thermal vision.” [W22]

It makes use of AC power or lithium batteries and the control is deal over two joysticks, one for the robot platform and the other to the weapon.
To provide security over the communications a 40 bit encryption is implemented.
Up to five firing systems can be deal with this system. [W22]

2.4. Talon robot soldiers shipped to Iraq

Figure 7 shows the *Talon Robot*

Figure 7 – Principle of operation [W22]
http://www.gizmag.com/go/3550/

US Army launch to Iraq and Afghanistan one hundred of TALON robots at the end of 2004. Those robots are equipped with off-the-shelf chemical, gas, temperature, and radiation sensors.
TALON robots can be used in missions as clearing live grenades to neutralizing mines in shallow water, and can be adapted for small mobile weapons systems for military purposes. [W22]

"The TALON is a general-purpose modular robot with a versatile 64-inch pincer arm. It is controlled through RF or a fibre optic link from an attaché-sized operator control unit (OCU) or wearable OCU. On the ground the TALON can reach a vehicle speed of 6.6 km/h and last a four-hour run time. Mounted on the TALON robot are:

- Smiths APD 2000 advanced portable chemical agent detector.
- Draeger Multiwarn II gas detector.
- Raytek Raynger MX4+ temperature sensor.
- Thermo FH40GL radiation detector." [W22]

2.5. Termibot

Termibot, as shown in figure 8, is a remote-controlled robot that makes use of thermal imaging to detect and eradicate termites.

Figure 8 – *Termibot* [W28]

Termibot was release in May,2007 to reach places where human pest controllers can't go. [W28]

“When a telltale heat or moisture signature is detected, Termicam breaks termite nests open to confirm the infestation, then pumps pest control chemicals directly into the source. It is an ingenious non-invasive pest control device - but its appeal won't be limited to exterminators.

"It is basically a remote controlled robot that can fit into confined spaces," says Rice, "it carries a video camera and lights so the operator can see where it is going and steer it around obstacles. It can go over on a fairly good angle and right itself if necessary." When the thermal or moisture signature of a termite hotspot is detected on one of the device's two LCD screens, the Termibot uses a probe to break open the termite nest, exposing and video recording the insects as they scuttle to repair the breach. The operator is then able to inject pest control poisons directly into the termite colony, an effective eradication

leaving minimal toxic chemicals around the area in comparison to spraying.” [W28]

"It is currently controlled via a long cable," Rice tells us, "but we'll have it fully remote once we've finished further testing. We're currently field testing it under houses, it is available to all our franchises but because we're busy expanding and franchising around the world, it won't be ready to go to market until later in the year." [W28]

“Rice says he's already had several enquiries from outside the pest control industry; the remote control thermal camera will be of interest to anyone who needs to use thermal imaging in confined spaces. Once client in Brunei is looking at having it lightly modified to act as an air conditioning duct cleaner, and Rice sees applications for the *Termibot* in sewage and water tunnel investigations, electrical equipment testing, military and bomb disposal applications, and even search and rescue to detect the heat signatures of people trapped under snow or rubble.” [W28]

2.6. 914 PC-Bot

Figure 9 – 914 PC-Bot [W27]

Figure 9 shows the 914PC-Bot, it is a $5,000 robot.

“The 914 can serve as a "networked, mobile sensor platform for RFID readers, hazmat detectors, and access management devices." The company suggests, "Now you can move the sensor, vs. the asset."

The 914 stands 21-inches tall, and weighs about 55 pounds (25kg). It has a two-wheel drive train with two "caster ball" wheels, each powered by a DC stepper motor. Other sensors include a camera in the head unit, and a sensor array comprising eight IR sensors, presumably used for obstacle avoidance.
The 914 is powered by twin 12-volt lead-acid batteries, and comes with a charger.

“Since the 914 is really just a standard PC trapped in a robot's body, it can run any standard PC operating system. *WhiteBox* Robotics supports Linux on the device, as well as Microsoft's Robotics Studio. When used with Linux, the company also appears to support the open source Player/Stage robot and sensor programming library.” “[W27]

3. Presentation and Implementation architecture

This chapter will present the robot and its block diagram to provide an understanding of the general structure of the robot system architecture and the robot components.

3.1. The robot

The figure 10 shows the robot: it is a solid multi terrain tank style robot and it can be seen the two chosen motor drivers, a DC converter, the microcontroller display and the batteries that provide power to the microcontroller system as well as to the motors. The motors and the encoders can also be seen.

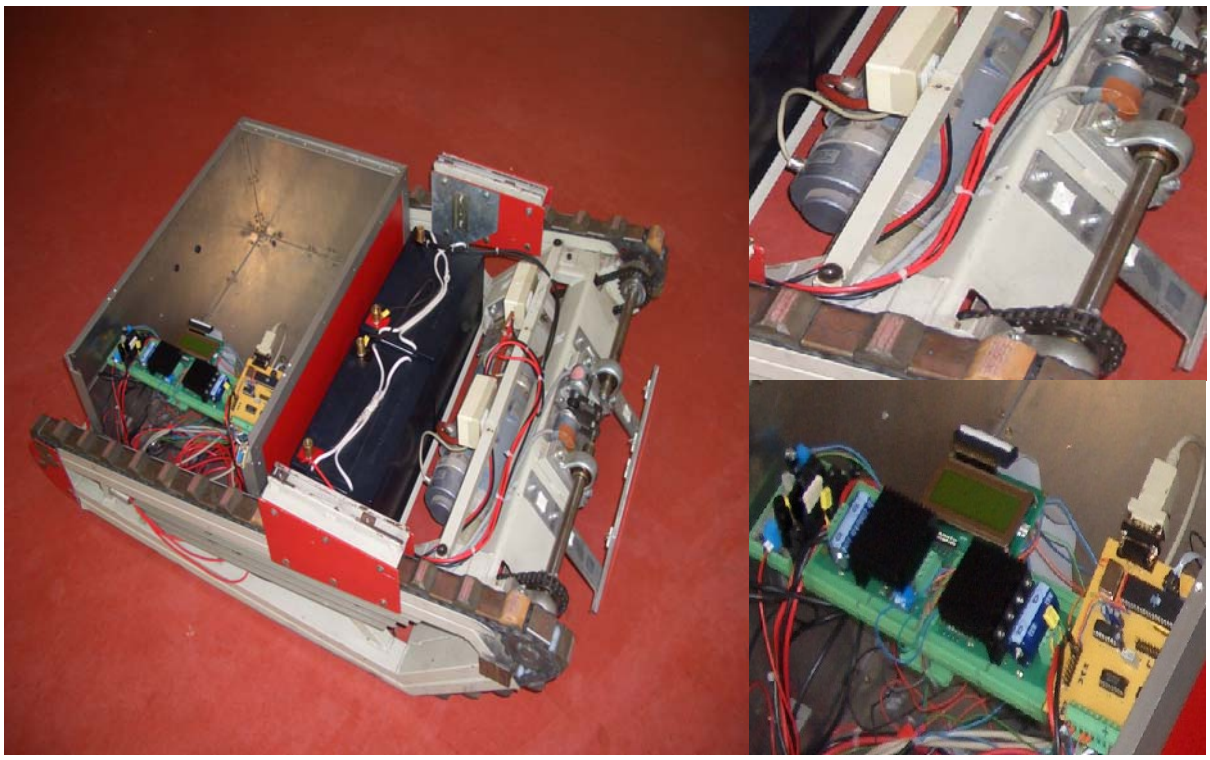


Figure 10 – The Robot

The tank is a Remote Operated Vehicle (ROV) and it is in the process of being converted into an autonomous robot.

3.2. Block Diagram

The block diagram is shown in figure 11 displays the way the several components are connected.

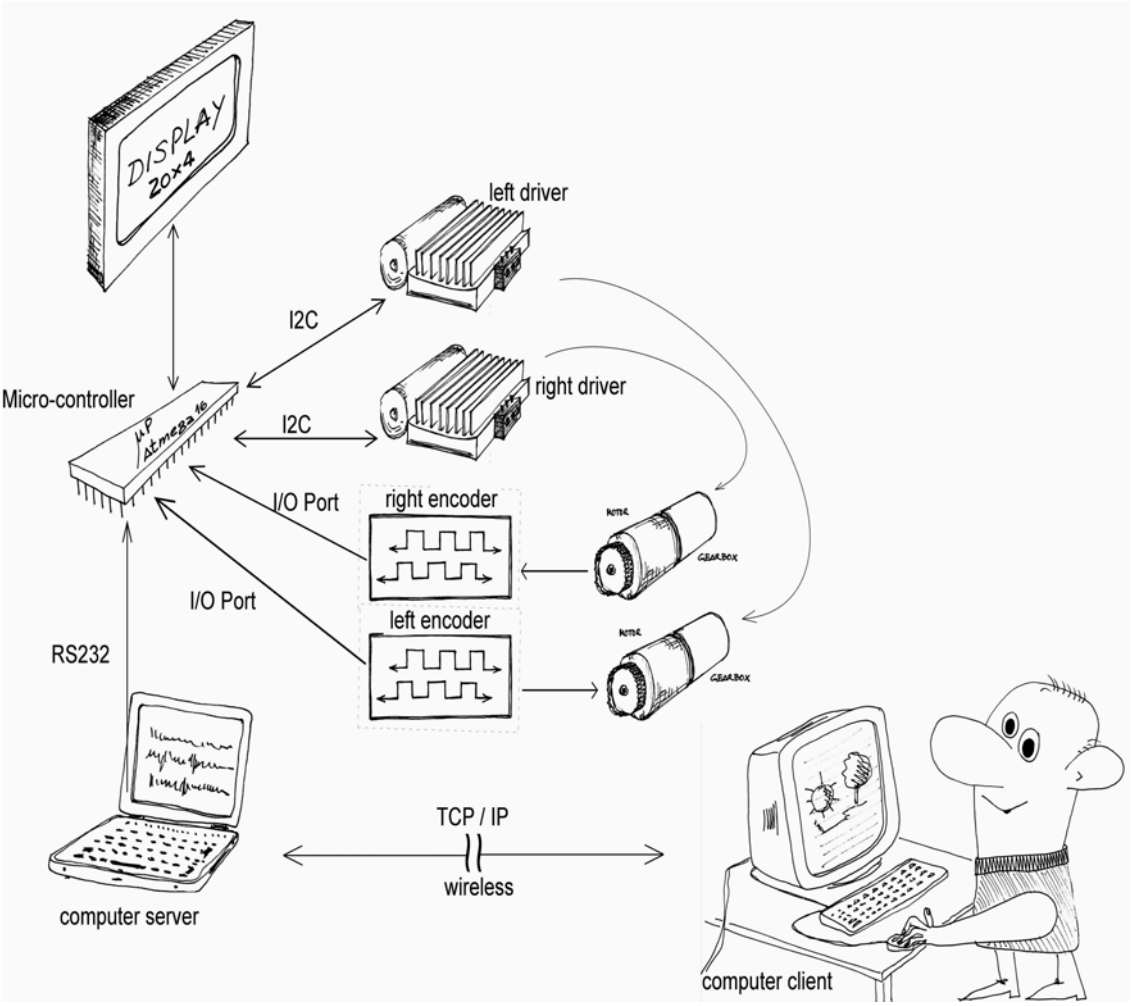


Figure 11 – Block Diagram

As shown, the system is based in multiprocessor, it is composed by two computers, one is the *Client* and the other one is the *Server*, a microcontroller as well as the drivers, encoders and a display.

Client and *Server* based architecture of this robot inherits that its interconnection is provide through a wireless network to make the robot control without any wires.

Tasks that are likely to be critical to performance and safety are implemented in a micro-controller. The system robustness is this way increased comparing to robot systems based only in computers [B2].

The a*tmega16* microcontroller is the center of the hardware of the robot: the display connected to it gives feedback of the microcontroller states and has an important duty about diagnose, repair and maintenance of the robot. For example, if a miss to connection of the motor drivers to the *I2C* bus occurs, it will show a message saying “Motor Left: Error, Motor Right: Error”.
Status monitoring of the system parameters during an operation cycle can be also archived with the display.
The *Server* connects to the *Atmega16* microcontroller over *RS232* protocol.

Atmega16 microcontroller code was written in C language but C++ language is used to Server and Client computer code.

The connection between the *DC regulator* and the *Atmega16* microcontroller and the encoders and the power side of the motor drivers is not represented in the pictures to avoid confusing mesh of wires in the schematic.

The physical picture of the robot and the interconnections of the several components of the robot system were briefly presented in the block diagram as well as the communications protocols between them.

4. Detailed working method

This chapter will present the electronic and mechanical components of the robot system as well of theory used to deal with them.

4.1. D.C. Motor

D.C. motors are used rather than other designs because they are smaller and have high efficiency. Furthermore, the D.C. motor has a very high start-up torque and they absorb sudden rises in load easily [W22].

DC motors are also simple to control; even so they are heavier and less efficient than induction motors.

The use of this type of motors is also efficient in this case because the robot is powered by batteries which provide the same type of current that these motors need, so power converters are avoided and the consequent loss of efficiency is spare.

4.1.1 Composition of a D.C. motor

The figure 12 shows the composition of the D.C. motor.

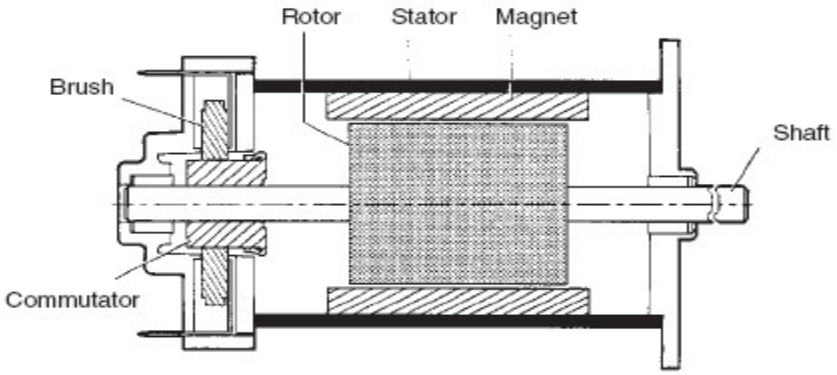


Figure 12 – Composition of a D.C. motor [W22].

The motor used by this robot has this composition [W22] and has an additional gearbox at the shaft.

The stator has the cover of the motor as well as the magnets that create the stator magnetic filed [W22].

The rotor is mainly formed by a metal carcass carrying coils and the commutator that selects the coil through the electric current will flow. The commutator has the duty of transforming the induced altering tension into a continuous tension [W22].

4.1.2 Principle of operation

The principle of operation of a D.C. motor is based on rules of electromagnetic attraction [W22].

The rotor is energised to act as an electromagnet with the polarity given by the current flow direction [W22].

The figure 13 shows that D.C. motors have two magnets fields, one of them is fixed(stator) and the other one is physically movable [W22].

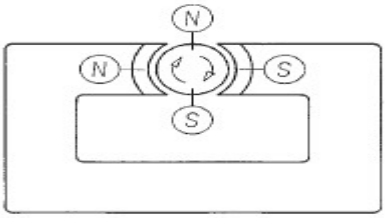


Figure 13 – Principle of operation [W22]

A torque is created to make the poles of the rotor align to the poles of the stator. This attraction and repulsion between the magnetic fields makes the rotor, which is the movable part, spin, and then the brushes are constantly breaking and making contact with the commutator [W22].

The maximum torque is achieved when the axis between the poles of the stator is perpendicular of the poles of the rotor [W22].

“The rotor coils are then energised and de-energised in such a way that as the rotor turns, the axis of a new pole of the rotor is always perpendicular to that of the stator. Because of the way the commutator is arranged, the rotor is in constant motion, no matter what its position. Fluctuation of the resultant torque is reduced by increasing the number of commutator segments, thereby giving smoother rotation.”

[W22]

To change the spinning direction of the motor one of the magnetic fields must exchange, since the stator has permanent magnets, the way is to invert the rotor magnetic field. This can easily be done by changing the polarity of the tension applied to the rotor coils, the direction of the current will this way be reversed as well as the rotation direction [W22].

4.1.3 Robot motors characteristics

The robot has two motors provided from the manufacture ENGEL, the series is GNM5480E and the motors are typed “Permanent Magnets, Direct Current”

they are coupled with gear-heads and the main characteristics can be seen at table 1.

Full table of characteristics can be find in the attachment “Motor Specifications” as well as the dimensions.

Nominal voltage	UN	24	Volt
Nominal output power	P_2	250	W
Efficiency	η max	85	%
No-load speed	no	3,267	rpm
No-load current	Io	1,435	mA
Speed constant	k_n	137	rpm/V
Nominal speed		3,000	rpm
Motor operating temperature range		–20 to 100	°C

Table 1 – Robot motor characteristics

4.2. PWM

A powerful and common method to control D.C. Motors over a microcontroller is by using of Pulse Width Modulation (PWM) signal [B1].

The PWM signal consists in a square wave and varying its duty cycle will provide a varying mean power applied to the D.C. motor [B1].

The figure 14 shows respectively a 10%, 50% and 90% of duty cycle.

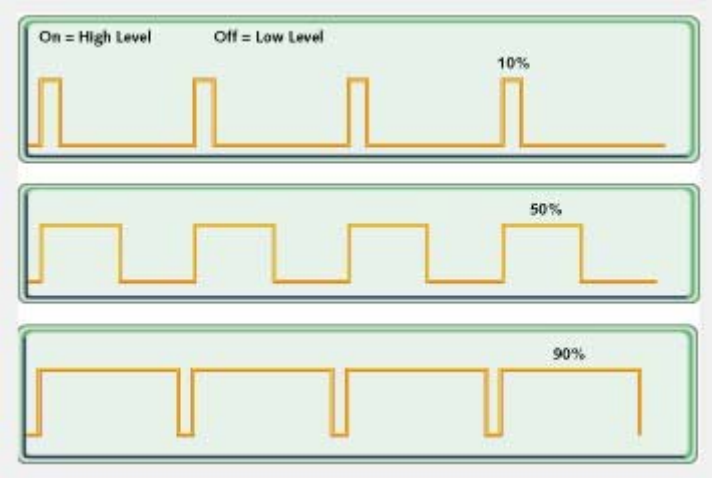


Figure 14 – PWM signals of varying duty cycles [B1].

4.3. Gearheads

In applications, when high speed is not as important as the involved torques, it is usual connected a gearhead to the motor [W21].

With a gearbox the motor binary can increase and the startup effort is soften.

To avoid degradation and damage of the gear/pinion several gears are used instead of only one, this way the forces are distributed and the material of which they are done can be “soften”. The lubrification degradation is also archived this way. [W21]

To make a description of what and by what is composed a gearhead is necessary to say that it has satellite gears and an annular gear. This one usually forms the gearhead case on the outside and has gear teeth cut in the inside diameter. The satellite gears are carrier plates with pins that fit the inside diameters of the satellite gears. Figure 15 illustrates a single-stage planetary gearhead having three satellite gears. [W21]

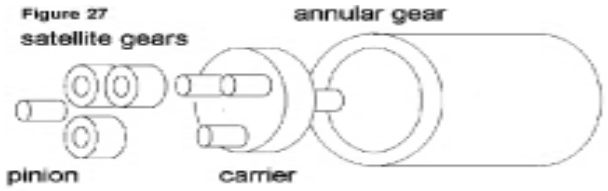


Figure 15 – Gearheads [W21]

The gear shaft is attached directly to the motor shaft and then a bearing couples the driven load.

The gearbox is selected depending on the maximum required torque and the duty cycle [W21].

The direction of rotation of this gearhead output shaft is the same as the input one. One of the disadvantages of this gearhead is the high noise but, besides that, they are relatively smaller than other types found in the market to the same operation conditions. [W21]

It increases also loss of efficiency and weight to the system, which could be a problem in a platform feed by batteries.

The lengthening of the annular gear/case and multiple stages stacking can allow high gear ratios. [W21]

The gearheads series are “G6.1” and they are of planetary type; it is rated at a 16.8:1 ratio and 70% of efficiency at either clockwise or counterclockwise direction, the torque is 11Nm.

4.4. Drivers

The medium/high current motors of the robot must be able to run in both directions and in variable speed, to archive that, either an H-bridge should be projected or, to reduce the *time to market*, a solid driver should be chosen.

Because the actual markets provides a reasonable range of driver solution to different applications and are price competitive, the conclusion is that the best s solution is to acquire one. It spares time because that kind of project, involving high currents, from the practical point of view would increase the number of difficulties which wouldn’t provide enough time to take the project this far.

There are three drivers pondered:

One of them is shown in figure 16, the RN-VNH2:

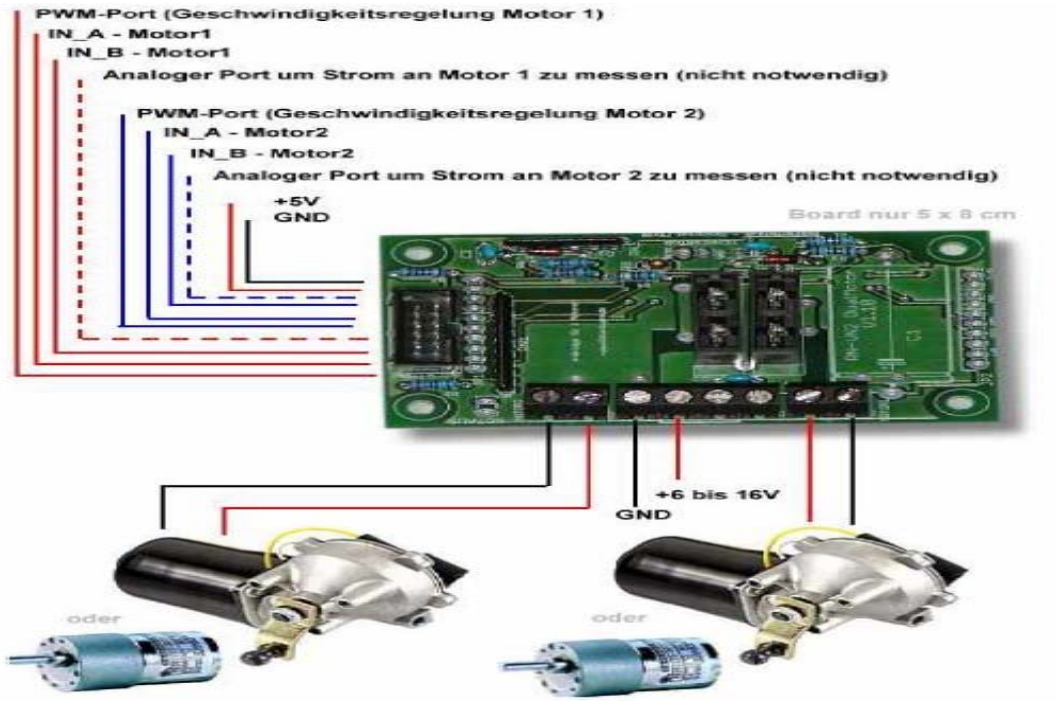


Figure 16 – RN-VNH2 Driver [*picture provided by the manufacturer datasheet]*

This driver [16] does not provide the necessary 250W, the motors need. But it was used for testing and experimenting, using a smaller motor.

The *atmega16* was programmed to provide the *PWM* signal [Chappter 4.2.] to the driver. The direction, speed and acceleration ramps were made and tests about controlling those values with computer were made as well, those tests involve the use of the *USART (Universal Synchronous Asynchronous Receiver Transmitter)* to perform communication between *atmega16* and one *computer*.

The work before described was ponder later because, within the project, when doing research about drivers and robot controls technologies a protocol called *I2C* came up.
The protocol will be explained later on another chapter [chapter 4.9.], but the choices about the driver were now about two divergent drivers: one from *Sabertooth [*17*]* or the *MD03.*

The "*Sabertooth 2x10*" is a driver capable of driving the robot motors with the software that was done and tested with RN-VNH2 Driver.

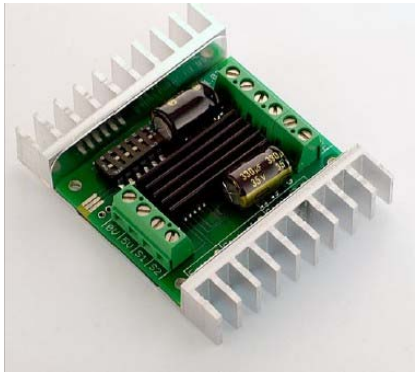


Figure 17 – *Sabertooth Driver [W12]*

The *MD03* is the driver shown at figure 18 and it is a driver capable of “talking” *I2C* and up to eight *MD03* modules can be connected (switch selectable addresses) to a system *[W23].*

The MD03 was chosen because the I2C capabilities matched the project intention of a modular system design and has the power capabilities that the system requires.

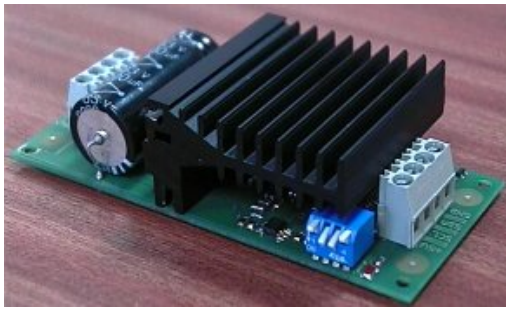


Figure 18 – *MD03 Driver [W23]*

In this robot the addresses were chosen with no specific criteria and they can be seen at table 2.

	Motor Right	Motor Left
Adresses	0xB0	0xB2

Table 2 – MD03 addresses of left and right motor

"I2C communication protocol with the *MD03* module is the same as popular *eeprom's* such as the *24C04*." *[W23]*

The MD03 has 8 registers numbered 0 to 7.
The reading operation of the registers is done in the following order:

1. sending a start bit
2. sending the module address with the read/write bit low
3. sending the register number to be read
4. sending then a repeated start
5. sending the module address again with the read/write bit high

[W23]

4.5. Encoder

Nowadays to make possible the use of modern motion control techniques, values representing the locations of the robot are needed. To do that, the spin of each motor of this robot must be log.

Devices, that provide the knowledge of where the robot motors are, make possible to synchronize the movements of the robot and at same time gives feedback to the control system, to act if some kind of behavior is not reached.

This robot has two incremental encoders that are used to precise how much is each motor running and they provide the speed of each motor after some computation.

The system of an incremental encoder is usually based on transmitting/reception method:

One disk with holes is in the middle of the transmitter and the receiver.
The transmitter has a stationary light source and the receiver has two stationary light detectors,

The disk is mounted at the shaft. As the disk rotates, the holes in it make the receivers to get the light each time the hole is aligned with the light transmitter. Figure 19 can illustrate this process:

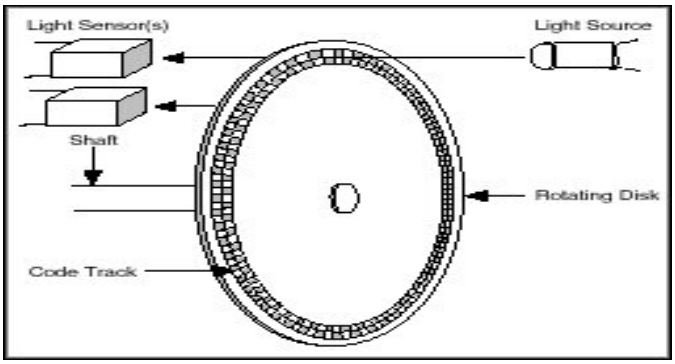


Figure 19 – Encoders signals [W20]

The outputs of this system are two square wave signals representing the number of holes that are reached between the transmitter/receptor, typically one output is called channel A and the other one is channel B and an extra channel usually called channel Z is often included to detect the “once per revolution index mark”.

A visual perspective of the signals above described can be seen in figure 20.

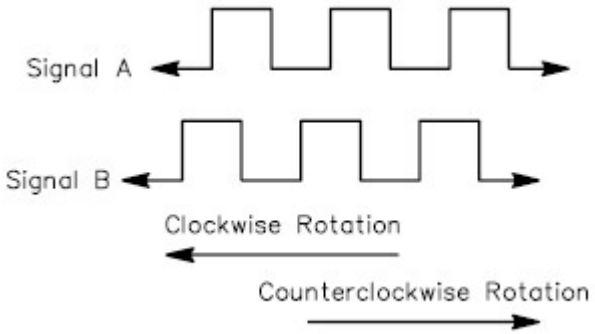


Figure 20 – Encoders signals [W19]

“The position of the two detectors is important. As one senses a change from dark to light, the other will not sense a change or transition. Because of this physical arrangement, two detectors give four transitions per division on the disk and each transition occurs at a unique angular position on the shaft. By

counting the transitions, it effectively multiplies the line count by four, hence the name quadrature (X4) multiplication. “ [W18]

To sense the direction of rotation the encoders have two channels 90 electrical degrees out of phase. A rising edge of the square wave indicates one direction, and the falling edge of the square senses the other direction.

To get the direction, each encoder, as shown in figure 21, was also coupled to a D type flip-flop. With channel A as flip-flop clock input (*clk*) signal and channel B as the input *data* (*D*) signal is possible, using the combination of these two signals, to obtain the output of the flip-flop (Q) representing the direction of rotation. This output (Q) is connected to an input pin of atmega16 so the microcontroller can know if pulses are to be increased (Output of the flip-flop is 0) or decreased (Output of the flip-flop is 1).

Combination:

Q → signal B low at signal A is rising edge

/Q → signal B high at signal A is rising edge

To make use of these sensors, a connection between channels A of each encoder was connected to an external interrupt of *atmega16* which is programmed to catch rising edges and make the digital count of the pulses.

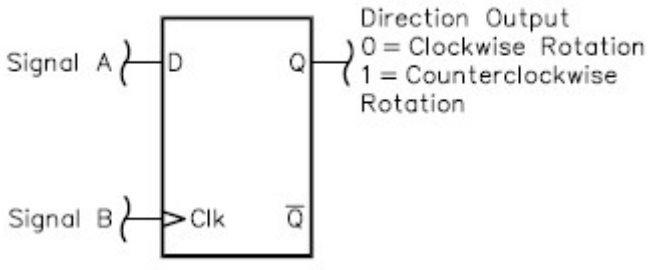


Figure 21 – Encoders Flip-Flops [W19]

The both encoders of the robot can be seen on figure 22.

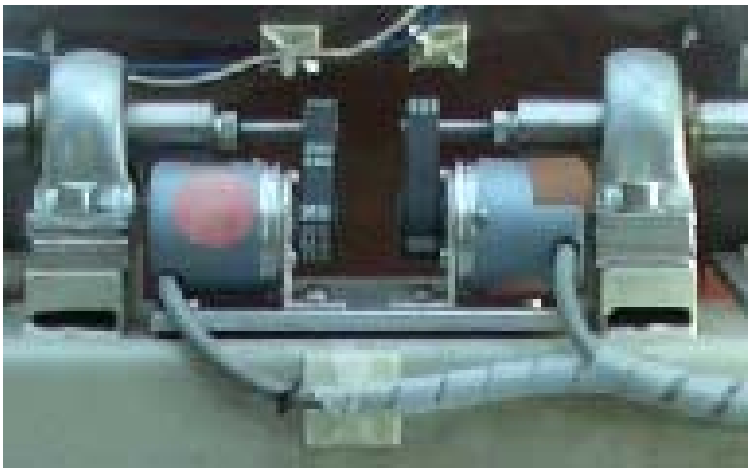


Figure 22 – Robot encoders

4.6. Batteries

The batteries used in this robot are Lead Acid batteries, they are popular because they are easy available, rechargeable and inexpensive.

The problem is they are very heavy and large but, in this case, that is not a huge problem because the tank is powerful and big enough to carry them, even so that is a problem to equation if the robot goes on the market or in further improvements.

Another problem is the loose of charge even if they aren't in use and high discharge rates will be translated in a short time battery life.

There are three existing main types of lead acid batteries: Wet Cell, Gel Cell, and Absorbed Glass Mat (AGM). They are mainly distinguished by the price, degrade, and deep cycle needs.

The Gel Cell batteries were chosen and they are best used in very deep cycle applications even so the AGM batteries provide a greater life cycle. They don't need maintenance and don't flow out acid.

“80% of all battery failure is related to sulfating build-up. This build-up occurs when the sulfur molecules in the electrolyte (battery acid) become so deeply discharged that they begin to coat the battery's lead plates. The buildup will become so bad that the battery will die.” [W13]

It is important to know and have in mind some things about lead acid batteries this way preventing battery failure:

- The first point to remember is not to make a partial recharge of the batteries, all charges should be integral done to its full potential. [W13]
- A second point, and also a very important one, is to recharge them often because without being used for a long time these batteries will slowly discharge internally. [W13]

These robot batteries are serial connected to make a 24V power supply, that connection can be seen on Figure 23.

The type is *Exide* and they are rated as gel cells which are a maintenance-free motive power batteries technology as well as they are robust, safe and reliable Low self discharge is also archived by those.

Figure 23 – Serial Connection between two *Exide* batteries

4.7. Step-Down Switching Regulator

A regulator was needed to convert the 24V from the batteries to a regulated 5V to feed the microcontroller, encoders and the other components.

The regulator component is a LT1076 that is rated at 2A, is a monolithic bipolar switching regulator and requires only a few external parts for normal operation. It has built-in power switch, oscillator, control circuitry, and all current limit components.

The classic positive “buck” configuration was adopted and the switch output is specified to swing 40V below ground which is perfect to the 24V of the robot because it is in the middle of the rated range.

The schematic of the regulator can be seen in the figure 24 and the board in figure 25.

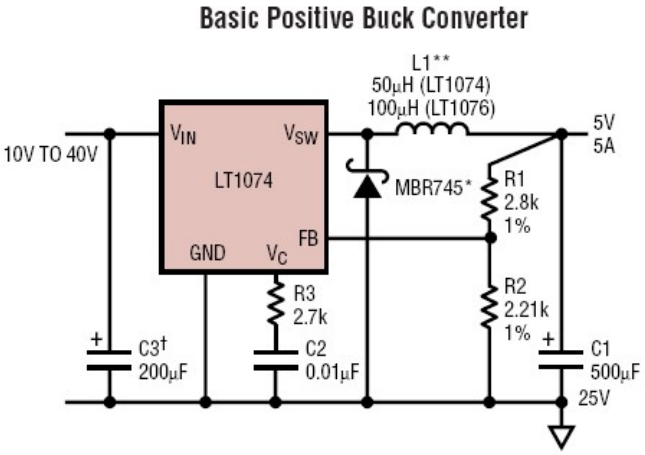


Figure 24 – Regulator Schematic [LT1074 datasheet]

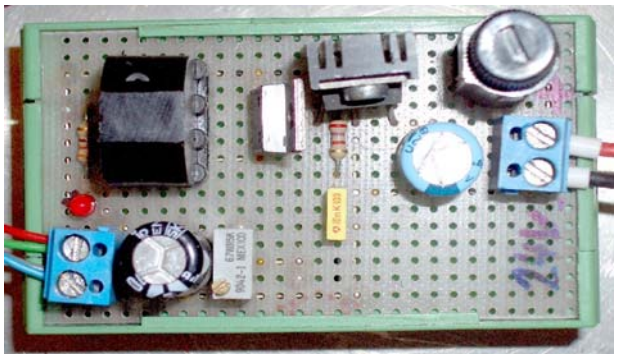


Figure 25 – Regulator Board

4.8. AVR Programmer

To flash the microcontroller with applications, a programmer is needed.
The microcontroller chosen for the project is part of AVR family.

At chapter 5. the microcontroller will be explained but, in this one, only the programmer will be discussed.

The circuit presented on figure 26 and *PonyProg* flash program [W6] was chosen because it is very cheap and can be easily hand-made done.
The problem of this circuit is that it needs to be use together *PonyProg* [W6] to enable flashing the microcontroller and *PonyProg* can use *RS232* but "*USB to RS232"* adapters often don't work or are very slow (more than 10 minutes to program) to avoid *USB* adapter the solution to a laptop could be a *PCMCIA* or a *PCI* adapter that native emulate a *COM* port but a *PCMCIA* card was tested and even so it was very slow.

So, to flash the microcontroller with this programmer, a desktop computer, with native *COM* port, was used. This approach will not allow a remotely programming of the microcontroller of the robot and beside that JTAG and AVR Studio integrations are not possible.

In the future, to provide a fast remote programming of the microcontrollers the "*Atmel AVRISP MK2"* or "AVR Dragon" programmer would provide better

results as well as other advantages as the AVR Studio Integration, USB Serial In-System Programming and the JTAG Support (“Hardware debug” with “AVR Studio” in real time, which means that the instructions done with AVR Studio debugger can automatically be seen on the hardware)

The board can be seen on figure 27:

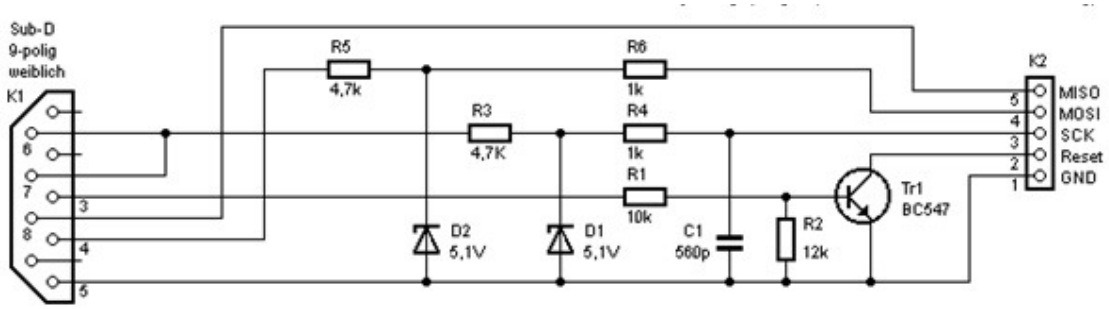


Figure 26 – “*SI-Prog”* Programmer Schematic

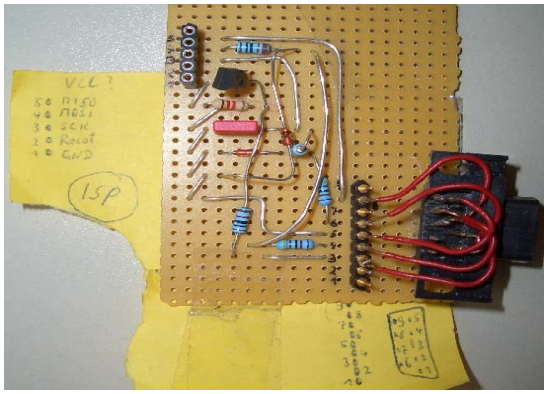


Figure 27 – Programmer Board

4.9. *I2C - TWI*

One of problems of the robots is that to provide more intelligence to them more and more sensors are added and that implies more and more wires.

To minimize that, *I2C (Inter Integrated Circuit)* also known as *TWI (Two Wire Interface) [W15]* is the communication protocol chosen because it can easily link multiple devices together with only two wires each. [W17]

The devices have a built-in addressing scheme to be distinguished and avoid the need for chip select or arbitration logic which can provide simplicity to the system as well as less money spent in extra hardware such as multiplexers and logic chips.

Standard *I2C* devices operate up to 100Kbps but fast-mode devices operate at up to 400Kbps and 3.4Mbps can be reached with the version 2.0 high speed mode.
Almost all available *I2C* devices can operate at speeds up to 400Kbps.

I2C provides good support for communication with various devices. On-board peripheral devices can be accessed intermittently; it is a simple, low-bandwidth, short-distance protocol.

Philips originally developed *I2C* for communication and due patent concerns *Atmel* use the name *TWI* (Two Wire Interface) instead of I2C.

Several *I2C*-compatible devices are manufactured by several companies and can be found in embedded systems. Some example are *eeproms*, thermal sensors, and real-time clocks, video decoders and encoders, audio processors, displays, motor driver, etc.

The figure 28 shows the typically *I2C* interconnection system:

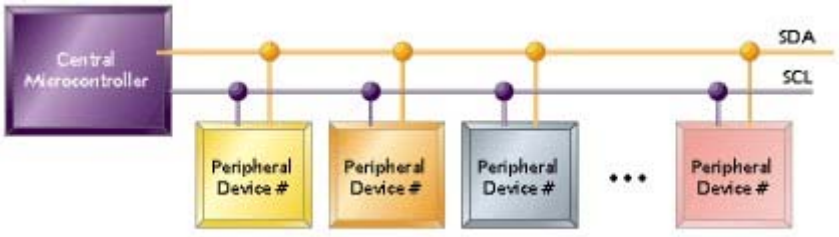


Figure 28 – I2C typically interconnection system [W14]

Below, the figure 29 shows the specific interconnections with the I2C bus: the microcontroller is the master of the I2C Bus and both drivers are I2C slave devices.

The two resistors are called “pull-up resistors”, they need to be present on the clock line (SCL) and on the data line (SDA). They are used to do the interface between different types of logic devices and they ensure that the circuit assumes the default value when no other component forces the line input state.

Since the chips are design often open-collector, the chip can only pull the lines low and they float to VDD otherwise; this way, the master can sense if a simultaneously transmitting is happening, letting the pin float and sensing the line, if the line is still at VDD, probably, no transmission is being done from other device. [W17]

The programming of *atmega16* master software is described at chapter 5.4.8

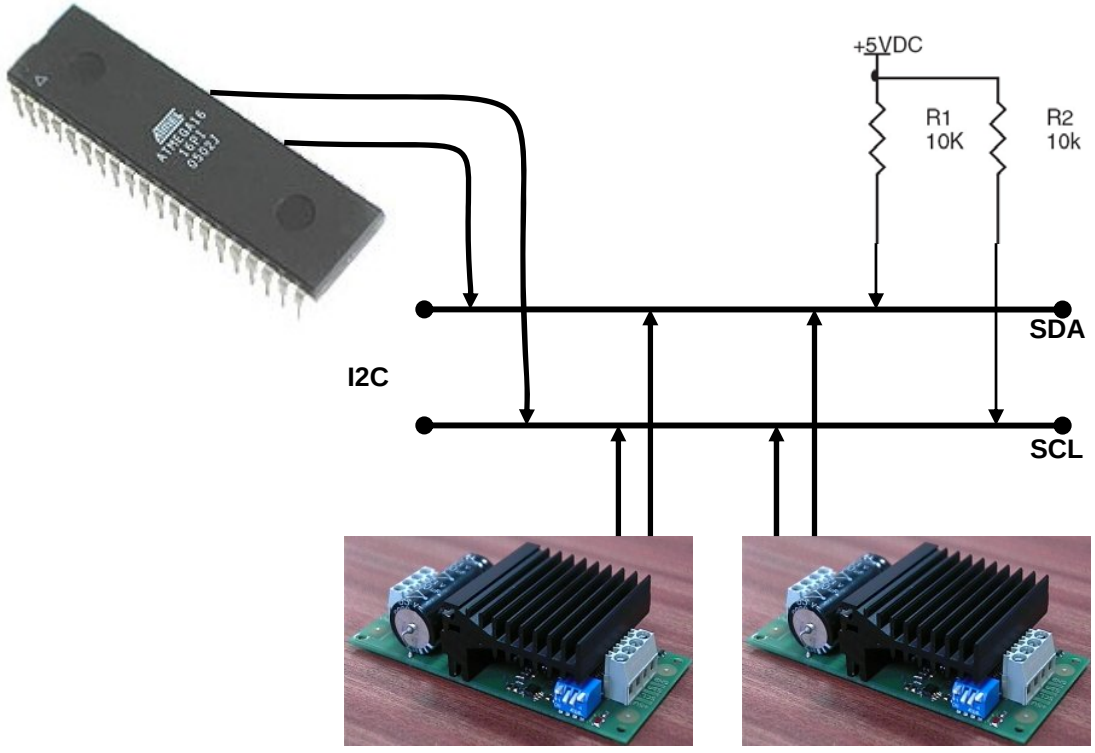


Figure 29 – Robot I2C interconnection system

The two *I2C* signals are *Serial Data* (*SDA*) and *Serial Clock* (*SCL*).

I2C matches the *Master/Slave* topology.

The *I2C Master* is the device that can start and stop communications and has usually the duty of controlling the clock.
An *I2C Slave* is a device that is addressed by the master. When the master asks a slave for data, the slave has the possibility to hold off the master in the middle of a transaction using “clock stretching” [W17] (the slave keeps SCL pulled low until it is ready to continue). This makes synchronism of slow slave devices possible but most I2C slave devices don't use this feature.
It is duty of every *I2C Slave* to monitoring the bus and responding only to its own address.

The I2C protocol supports multiple masters and multiple slaves.

The transmitting protocol inherits the data sending of each byte, start with the MSB (most significative byte).

Figure 30 shows a typically communication between a master issuing the start condition (S) followed by a 7-bit slave device address to start a communication with a Slave.

The eighth bit after the start (*read/not-write*) is used to signal the slave if the master will send more instructions (Slave will receive more data) or if the master is ready to receive data (Slave can transmit data).

After each byte sent by the Master, the Slave must reply with an ACK bit to signal the reception of the previous byte.

This 9-bit pattern is repeated if more bytes need to be transmitted.

Figure 30 – I2C Packages [W14]

The issue of the stop condition (P) is done instead of the ACK at the end of a master reading transaction (slave transmitting).

If a master write transaction (slave receiving) is being performed, the master issue the stop condition (P) when it receives the last ACK of the data sent.

This chapter presented the electronics, some mechanical components were also presented as well of characteristics of the drivers and I2C.

5. Microcontroller Unit

In this chapter the microcontroller software is about to be presented in order to provide understanding about the microcontroller unit and its duties.
The protocol of communications used from the server to the microcontroller and from the microcontroller to the server will also be presented.

5.1. Introduction

There is a large variety of microcontrollers on the market. The *Atmega16* belongs to AVR family and was the microcontroller chosen to make a new embeddable system capable to control the I2C motor drive system, to read the encoders and to give local feedback through a display and to perform communications with the server.

Other microcontroller family could be chosen to the robot system but the cost of the device programming must not get high as well of the compilers that must be freely available. 8051, Microchip PIC®, and Atmel AVR® were possibilities that matches the criterion.

The traditional 8051 has a simple architecture and it is familiar to most embedded engineers. The amount and quality of tools and sample source code available is ample but it is common that each manufacturer provides proprietary features and migration from one variant to another usually implies new programmers. The typical architecture of some models are standard for several manufacturers but those don't have engrossing stuff like A/D and D/A converters, I2C, In-circuit programming, etc. [B2] That lack of standardization

makes and the problems with upgrading do not meet to the project objectives so it was placed apart.

A PIC microcontroller were considered an expensive solution that the Atmel AVR (The PIC official programmer(PICstart Plus) cost 3 times more than the AVR one(STK500) [B2]).

AVR microcontroller is manufactured from Atmel [W4] and its family is largely used worldwide so it is easy to get access to libraries or fragmented source codes all over the internet [W10] and its versatility makes possible to make use of several different features and to perform simple future migration of the source code within microcontrollers of the same family and it is possible to use different compilers and different programming languages.

Atmega16 has a number of features which make it very good to this project. It has 3 Timers, 4 PWM channels, I2C also known as TWI(Two wire interface), 8 ADC's, USART, SPI and 32 I/O ports [W9]. The pinout can be seen of figure 31.

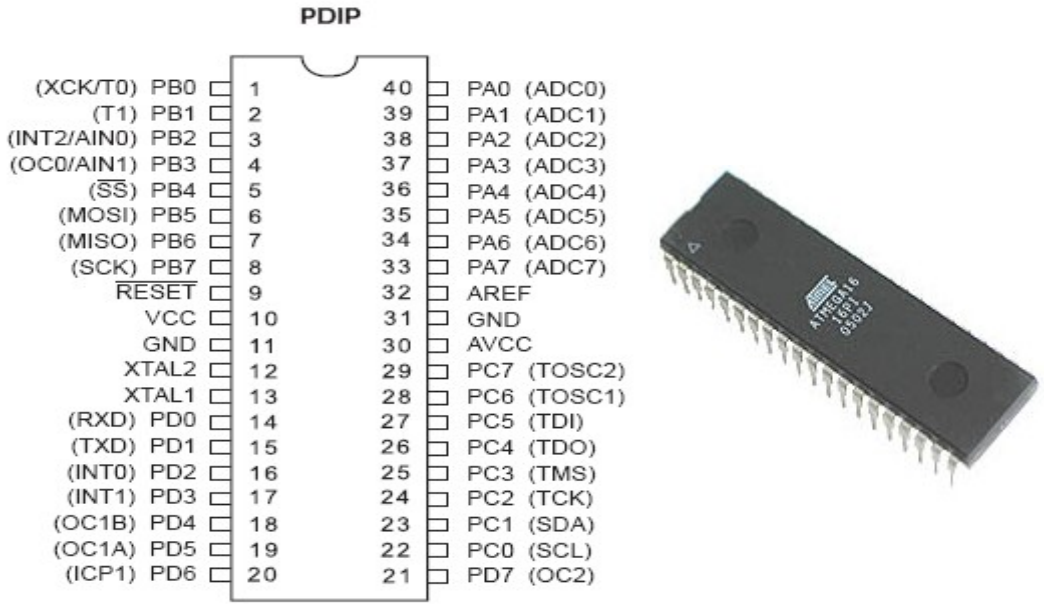


Figure 31 – *Atmega16* pinout [W9]

The editor and debugger used was "AVR Studio" that is freeware and has a very good and powerful debug mode and simulator [W11] .

The language used is C, the medium level rate of this language makes a good power/control ratio which makes the robot programming flexible.

The way the program was made intended to have modularity and an easy to use structure for future programmer who will improve the robot.

The modularity was made by using of many files, each one giving its own main functions, even so they can depend on the others, for example: the *USART (Universal Synchronous Asynchronous Receiver Transmitter)* functions uses the *MOTOR* functions after decoding a command sent by the computer *Server* program.

Each file can be compiled separately and then linked together. This provides a saving of time since it is not necessary to recompile the complete application when making a single change but only the file that contains it.

A systematic way of writing the program was chosen to provide an easy reading of it.

All *include files* that some file needs is specified at the header file (.h)

The main variables and the external ones are also included at the header file (.h)

Only the local variables are at respective “.Cpp” file

This chapter will present each one of the several “.Cpp” files and flowcharts of some functions.

5.2. Header Files Structure

The organization makes possible a fast access of functions, variables, etc.

So each header file has the same template layout which consist in define, at first include files, follow by constant definitions and variables used, at last, the functions prototypes are declared.

5.3. PIN List

The list of all currently used PIN's as well as a description is presented at table 3, even so, some might be described during this chapter.

PIN Variable Name	Description	PIN	DDR	PORT
error_led1_PIN	LED signal of error nr. 1,	7	DDRA	PORTA
error_led2_PIN	LED signal of error nr. 2	7	DDRD	PORTD
encoder0_direction_PIN	Encoder right Direction Signal, Set this pin high means running forward and set this pin low means running backward.	4	DDRD	PORTD
encoder1_direction_PIN	Encoder left Direction Signal, Set this pin high means running forward and set this pin low means running backward.	5	DDRD	PORTD
INT0	Encoder right Channel Signal, Used to count pulses from the encoder	2	DDRD	PORTD
INT1	Encoder left Channel Signal,	3	DDRD	PORTD

	Used to count pulses from the encoder			
LCD_DATA0_PIN	Pin for 4bit data bit 0 (Least Significant Data Bit)	0	DDRA	PORTA
LCD_DATA1_PIN	Pin for 4bit data bit 1	1	DDRA	PORTA
LCD_DATA2_PIN	Pin for 4bit data bit 2	2	DDRA	PORTA
LCD_DATA3_PIN	Pin for 4bit data bit 3 (Most Significant Data Bit)	3	DDRA	PORTA
LCD_RS_PIN	Pin for RS(Register Select) line This pin determines whether the data you're about to write is a command or a data byte	4	DDRA	PORTA
LCD_RW_PIN	Pin for RW(Read/Write) line Set this pin high to read from the display. Set this pin low to write to it.	5	DDRA	PORTA
LCD_E_PIN	Pin for Enable line, This line works to clock in data and commands.	6	DDRA	PORTA
SDA	I2C/TWI Data line	1	DDRC	PORTC
SCL	I2C/TWI Clock line, It is used to synchronize all data transfers over the I2C bus	0	DDRC	PORTC

Table 3 – All Pin List

5.4. Files

The files that compose the *atmega16* applications will be presented below:

5.4.1 atmega16.c

Atmega.c is the main file of whole microcontroller application.

The initializations of the modules (error support, *usart*, lcd, encoder, i2c, timers, interrupts and motor drivers) are done at the main file (*atmega16.c*), reason why *atmega16* header file connects all needed modules, as shown in figure 32.

After all initializations, the program will run in an infinite loop waiting for any command sent over the serial port and waiting for the timer to perform some computation (Virtual Heart Beat, Sending Sensors Data).

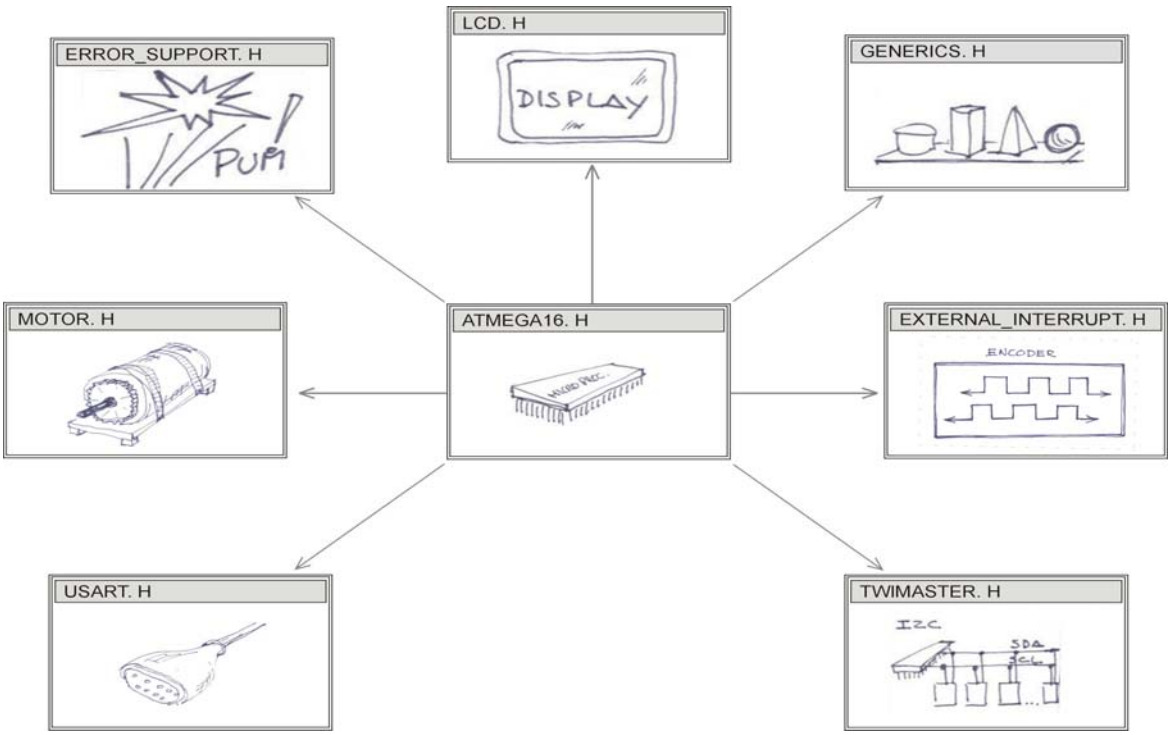


Figure 32 – *atmega16.h* interconnections

5.4.2 error_support.c

This module is used to help the programmer at the debug stage.
The features provided are the basic turn on and turn off of *leds*.
At the moment two LED's are defined:

LED Number 1: PORTA.7

LED Number 2: PORTD.7

It is very easy to include this file in any other and give them this debug capability and to increase the number of *leds* or change its port connections!

The functions provide are:

void error_support_init(void);

Initialization of the ports (output).

void error_on(int led_number);

Turn a LED On.

void error_off(int led_number);

Turn a LED Off.

5.4.3 external_interrupt.c

This module is used for the encoders.

The robot has two quadruped encoders, each one is connected to an *External Interrupt* and each time a transition is made by any encoder the microcontroller will count it.

Derived from the asynchronous and unpredicted pulse occurrence, an external interrupt was configured, this way this “time-critical” operation is separate from the main program execution [B1].

Generically, two main types of external interrupts could be implemented:

The Figure 33 plots those types of signals.

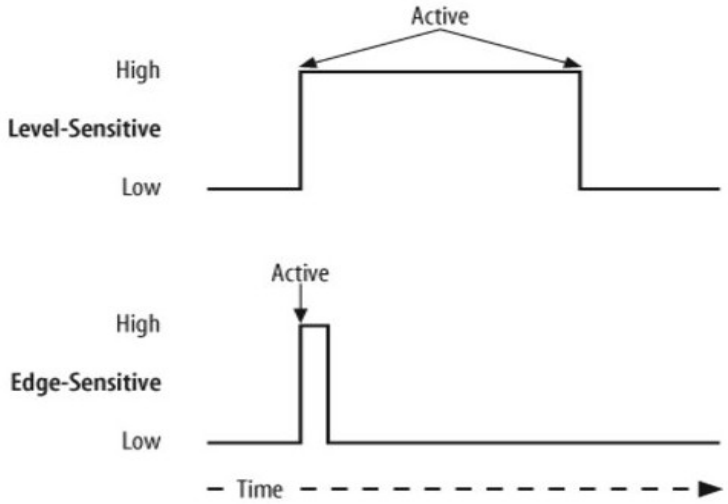


Figure 33 – Level- and edge-sensitive interrupt signals [B1]

Level-sensitive interrupts are attended at either a low-level or high-level [B1]. Edge-sensitive interrupts are attended at a transition that can be defined to be rising edge or falling edge sensitive interrupt [B1].

A edge-sensitive approach was chosen because even if, in theory, a pulse is skipped when a subsequent interrupt occurs [B1] (practically the test with both robot wheels running at same speed shown that the processor catch all pulses); an approach with level-sensitive would certainty provide worth results because the Level sensitive interrupt suspends other processing during all level time [B1] and pulses would be missed if both wheels were running at same speed.

Another PIN is defined, for each encoder, at the *header file* and the purpose is to know whenever the encoder is running forward or backwards and so the microcontroller knows if it has pulses to be increased or decreased respectively. The way those PINs gets its state was detailed described at chapter 4.5.

5.4.4 generics.c

This module provides two functions:

void delay_ms(unsigned short ms);
Used for make a variable delay

void wait_until_key_pressed(void);

Used to read a switch, actually is define to read PIND.2.

5.4.5 lcd.c

This module implements a free to use *HD44780U LCD library*; the author is *Peter Fleury [W16]*, after changes of the *PINs* options and adjustments to use 4 *PIN* data transfer and after prepare it to a 20x4 LCD, it looks just perfect to communicate with the LCD.

The main functions are:

void lcd_init(uint8_t dispAttr);

Initialize the display and select the type of cursor.

void lcd_clrscr(void);

Clear the display and set cursor to home position.

void lcd_gotoxy(uint8_t x, uint8_t y);

Set cursor to specified position.

lcd_puts(const char *s);

Display string without auto linefeed.

A function to display number was also added:

void lcd_puti(int int_value);

Display *int* value.

As an example of application, the following commands:

lcd_gotoxy(0,2);

lcd_puts("MD03 Right = OK!!");

Are used, (after the lcd inicialization) at the start of the main program, inside of a function to test the communication to the motor drivers

(*motor_drivers_init_test();*) and the result is the display writes "MD03 Right = OK!!" at the 1st column and 2nd line, providing that feedback to the user of the robot.

5.4.6 motor.c

This module functions respect to the motor drivers, the main functions are below described and interconnections can be seen at figure 34:

void motor_drivers_init_test(void)

It is used to make initial test to the motor drivers. Basically it tests the *I2C* communication, and updates the variable *motor_driver_error* with the result of the test. That variable is also useful to avoid sending commands to the driver when it is not connected, that way the microcontroller doesn't halt trying to send commands to a disconnected motor driver and so tests with others sensors and the computer can be made without these drivers. A feedback is also archived through the *lcd*.

void break_motor(void)

It is used to provide a simple a fast way to break the motors.

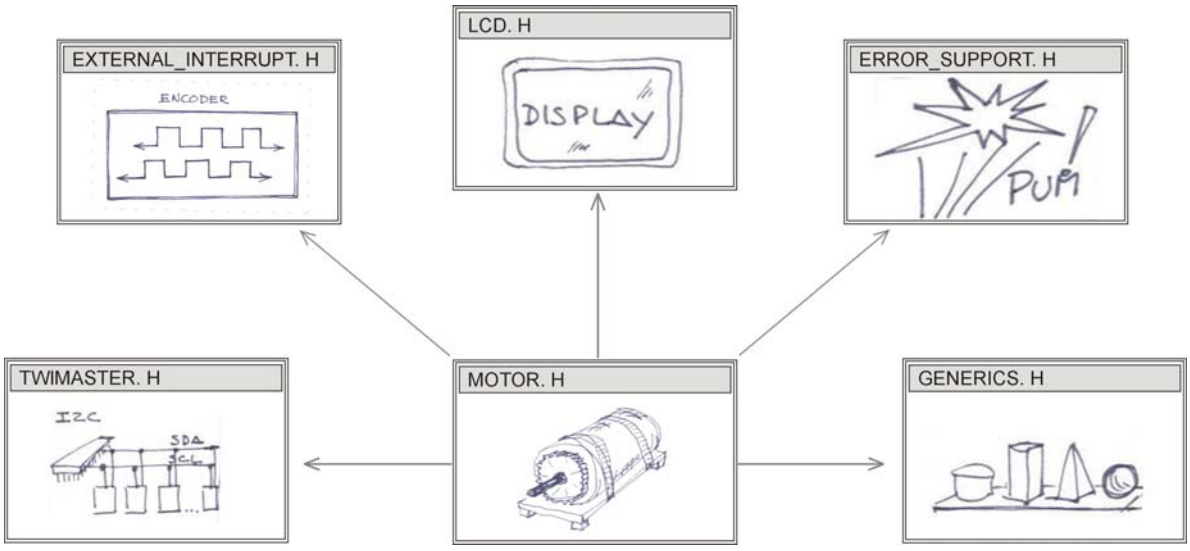


Figure 34 – *motor.h* interconnections

5.4.7 timer.c

The functions related to the timers are implemented in *timer.c* / *timer.h* files.

As usual at embedded systems [B1], when the timer is activated, the program will change its flow to the function ***SIGNAL(SIG_OVERFLOW1)*** and when it is completed it returns to the place where it was before.
(SIG_OVERFLOW1 is the address of the interruption vector respect to the timer/counter 1 overflow)

At figure 35 the interconnections with this module can be seen, the purpose of the timer is to:

- Calculate the speed of each motor of the robot.
- Deal with the “Virtual Heart Beat” a.k.a. “emergency ping”.
- Automatically send the sensor data to the *Server.*

void starttimer1(void);
Is used to start timer1.

void stoptimer1(void);
Is used to stop the timer1.

A “Virtual Heart Beat”, is identified at the code as an “emergency ping”, was created between *Server*/*Client* and *Server*/*Microcontroller* to avoid loss of control to the robot. In the microcontroller concern, it can be described as a command that is sent to *Server* every 2 seconds.
The *Server* when receives it has the duty to resends that command.
If, after four seconds, no acknowledge of the previous *ping* was received then a command to stop the motors is sent by the microcontroller to avoid damages caused by an uncontrolled robot.

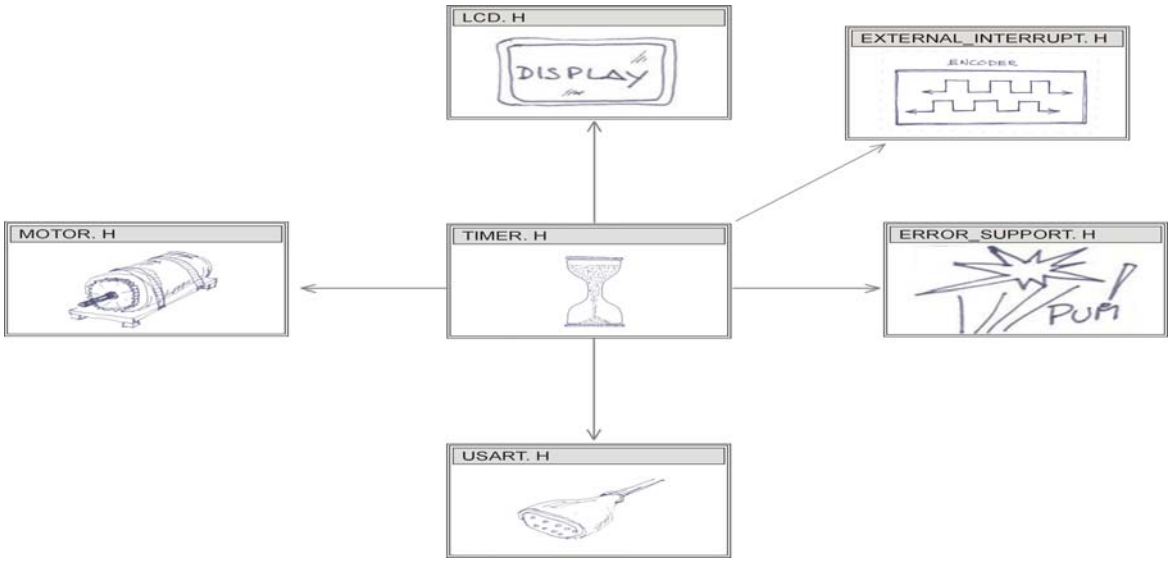


Figure 35 – *timer.h* interconnections

5.4.8 twimaster.c

This module implements a free to use *I2C library* and the author is *Peter Fleury [W16]*.
It is used to provide functions to communicate with the I2C devices.

The main functions provided in this library are:

void i2c_init(void);
Initialize the I2C master interface. Need to be called only once for each device.

void i2c_stop(void);
Terminates the data transfer and releases the I2C bus.

unsigned char i2c_start(unsigned char addr);
brief Issues a start condition and sends the address and transfer direction; returns 0 if the device is accessible or 1 if failed to access device.

unsigned char i2c_rep_start(unsigned char addr);

Issues a repeated start condition and sends the address and transfer direction; returns 0 if the device is accessible or 1 if failed to access device.

void i2c_start_wait(unsigned char addr);
Issues a start condition and sends address and transfer direction.

unsigned char i2c_write(unsigned char data);
Sends one byte to I2C device; returns 0 if the writing was successful or 1 if the writing process fails.

unsigned char i2c_readAck(void);
reads one byte from the I2C device, requests more data from device and returns that byte read from I2C device.

unsigned char i2c_readNak(void);
reads one byte from the I2C device; the reading is followed by a stop condition and returns the byte reading from I2C device.

As an example of application, the following commands:

```
i2c_start_wait (MD03_I+I2C_WRITE);   // set device addr. & write mode
i2c_write(addr_direction);           // write address
i2c_write(0);                        // ret=0 -> Ok, ret=1 -> no ACK
i2c_stop();
```

Write to the left motor driver a clockwise direction (0).

5.4.9 usart.c

This module is used to interact with the *USART (Universal Synchronous and Asynchronous serial Receiver and Transmitter).*

To connect the RS-232 to the *atmega16* USART a line drive is need [Max232 Datasheet] is show in figure 36.

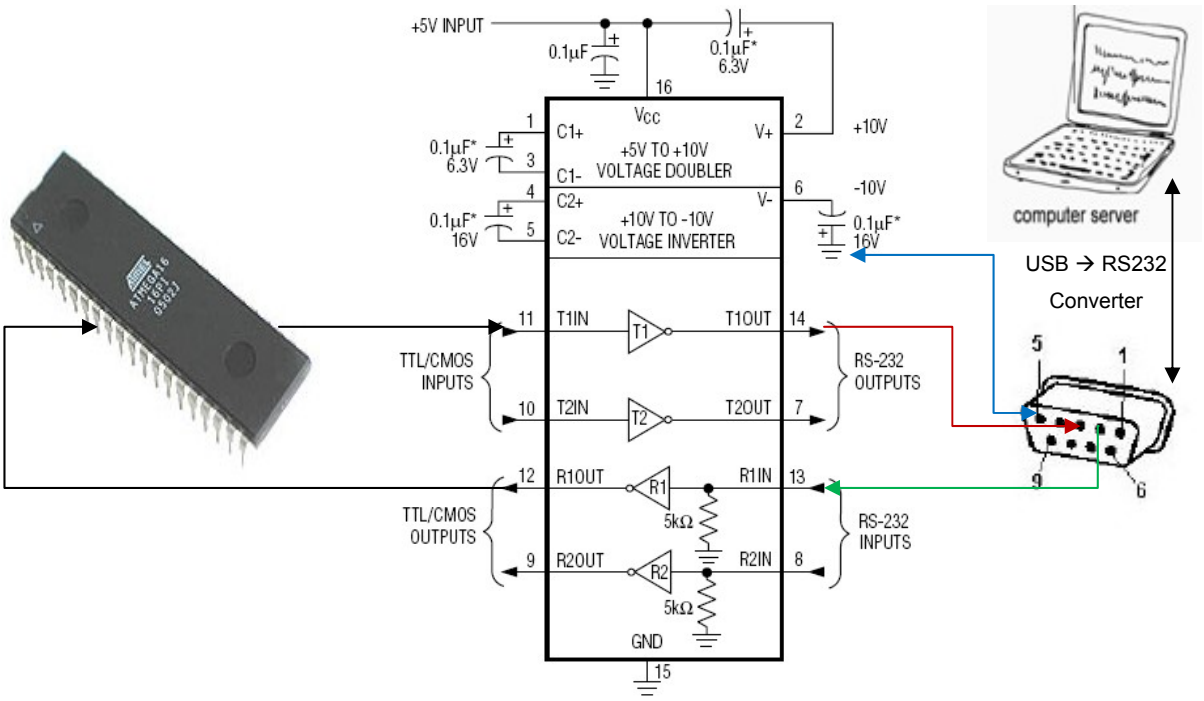


Figure 36 – *Atmega16* and RS-232 connection

Table 4 specifies the connections made:

Atmega16	**Max232**
Pin 14 (PD0/RX)	Pin 12 (R1Out)
Pin 15 (PD1/TX)	Pin 11 (T1IN)
Pin 31 (GND)	Pin 15 (GND)

Max232	**USB-RS232 converter**
Pin 13 (R1IN)	Pin 3 (TX)
Pin 14 (T1OUT)	Pin 2 (RX)
Pin 15 (GND)	Pin 5 (GND)

Table 4 – Pin connections between server and atmega16

This module provides the communication system between *atmega16* and the *server* program located on a laptop.

It also does the interpretation, followed by correspondent action, of any commands provided from the *server* and is able to send commands provided from other modules of the atmega16 (timers [chapter 5.4.7]) to the server.

The constant *Baud Rate* is calculated at the header file, it is just need to put the oscillator frequency (*F_OSC*) and the desired baud rate (*UART_BAUD_RATE*), so, it is easy to change the crystal oscillator because no extra maths need to be

done, only constant F_OSC has to be change in that case. Similarly, changes of baud rates only need an update of the respective constant.

The actual baud-rate, data bits, parity, number of stop bits and flux control type can be seen at table 5 and are specified at the *server* and at the *atmega16*.

Baudrate	38400 bps
Databits	8 bits
Parity	None
Stopbits	1bit
Fluxcontrol	none

Table 5 – Connection between server and atmega16 through RS-232

The communication between the Serial Ports is dealt with the following functions:

void usart_putc(unsigned char c);
Send a character via *USART.*

void usart_puts (char *s);
Send a string via *USART.*

void USART_init(void);
Make the initializations of *atmega16 USART.*

Figure 37 show interconnections within the timer module.
A protocol of communication was developed to get an understanding between *atmega16* and *Server* program; two versions were experimented because problems occur with the first one.

The initializations of the protocol are done with the following function:
void USART_init_variables(void);

After a command interpreting, the following function is called to provide it execution:

void UsartExeCmd(void);

Others functions were implemented:

void Send_Sensor_data_with_Usart(void);

Sends the sensors data to the *USART* (relatively to each motor, sends position, velocity, current and temperature)

void Send_Emergency_Ping_with_Usart(void);

Sends the “Virtual Heart Beat“, also known as, “emergency ping” to the *Server.*

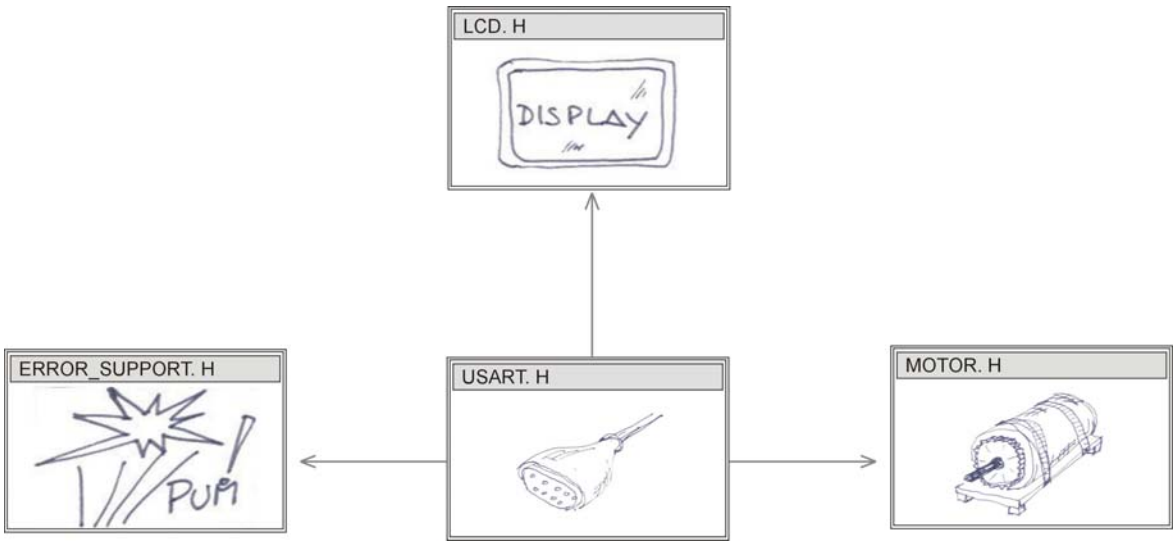


Figure 37 – *usart.h* interconnections

- **“Old Version Protocol” to the communication from the *Server* Computer to *Atmega16* and Problems about it**

Each command received by the *atmega16 usart* must have three bytes to define a command, following by three bytes defining a value and all of them in *ascii* format.

At the table 6 is shown the word composition layout.

Word Composition nr. *1*		…….	**Word Composition nr. *n***	
Function	Value	…….	Function	Value
3bytes	3bytes	……	3bytes	3bytes

Table 6 – Word Composition (Old Version)

This approach worked well for some time but, from time to time, a loss of control with the robot occurs because the command sent to the microcontroller stops to be interpreted because synchronisations were lost every time an error occurred and an overcome couldn't be reached without a microcontroller reset.

A simple lesson was learned: The commands with a fixed number a bytes as well as the respective values weren't a good choice due to the resynchronizations problems.

- **Protocol of communication from the *Server* Computer to *Atmega16***

Each command receive by the *atmega16 usart*, to be well interpreted, must have at least one alphanumeric byte followed by at least one numerical value and a 'Z' character to flag the end of each command/value frame.
All characters must be in *ascii* format.

At the table 7 is shown the word composition layout.

Word Composition nr. *1*			…….	**Word Composition nr. *n***		
Function	Value	'Z'	…….	Function	Value	'Z'
x bytes	y bytes	1 byte	……	u bytes	v bytes	1 byte

Table 7 – Word Composition

With this work the stability of the communication is improved because if a lack of communication occurs, the command is misunderstood but at least synchronism loss is avoided.

The flexibility was also improved by this method because commands and values can have different sizes.

An example of a shared command from the *Server* to the *Atmega16* can be seen at table 8, at line one, the frame is sent over RS232 to set the acceleration of the left motor to a value of 215; at line two the acceleration is set to 8.

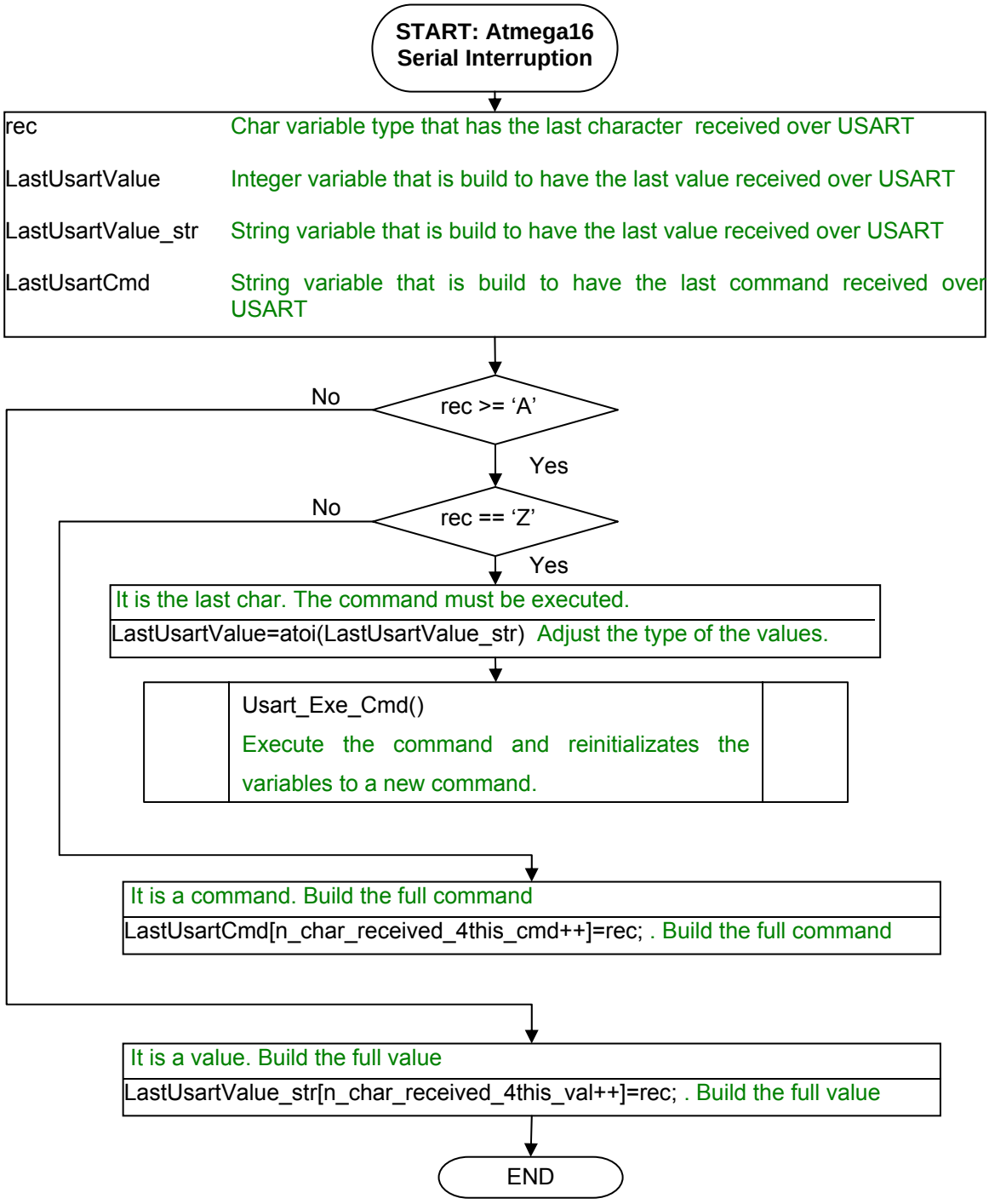
M	L	A	2	1	5	Z
M	L	A	8	Z		

Table 8 – Examples of shared commands from *Server* to *Atmega16*

A function:

QString conv_double_QString(double value_input)

Is used to brief convert a double integer value to a QString because the values are sent in the *ascii* format.



Flowchart 1 – Atmega16 Serial Interruption

- **Protocol of communication from the Atmega16 to the *Server* Computer**

The protocol of sending data from *atmeg16* to *server* computer is different from the opposite direction.

The server wants either all sensors data either a considerable amount of data and not only a specific value, so, instead of sending an extra character (as the 'Z' character in the communication from server to the atmega16) to signal the end of a specific frame, the process is implemented to validate a frame each time a new alphanumeric character appears. This way, to process the last received frame, the server must received an extra frame: that last frame its "END0" and does nothing except handling the possibility to the server know that previous value received has been completed.

The "END0" frame is, in reality, an undefined command/value by the server and so it can be replaced by any other appearance as "E0" or any other undefined command/value.

After a command/value is identified another function is called to execute.

Resuming, atmega16 can send several sets of commands and values with different size and when *server* receives the command/value "END0" it guarantees the process of the last command/value.

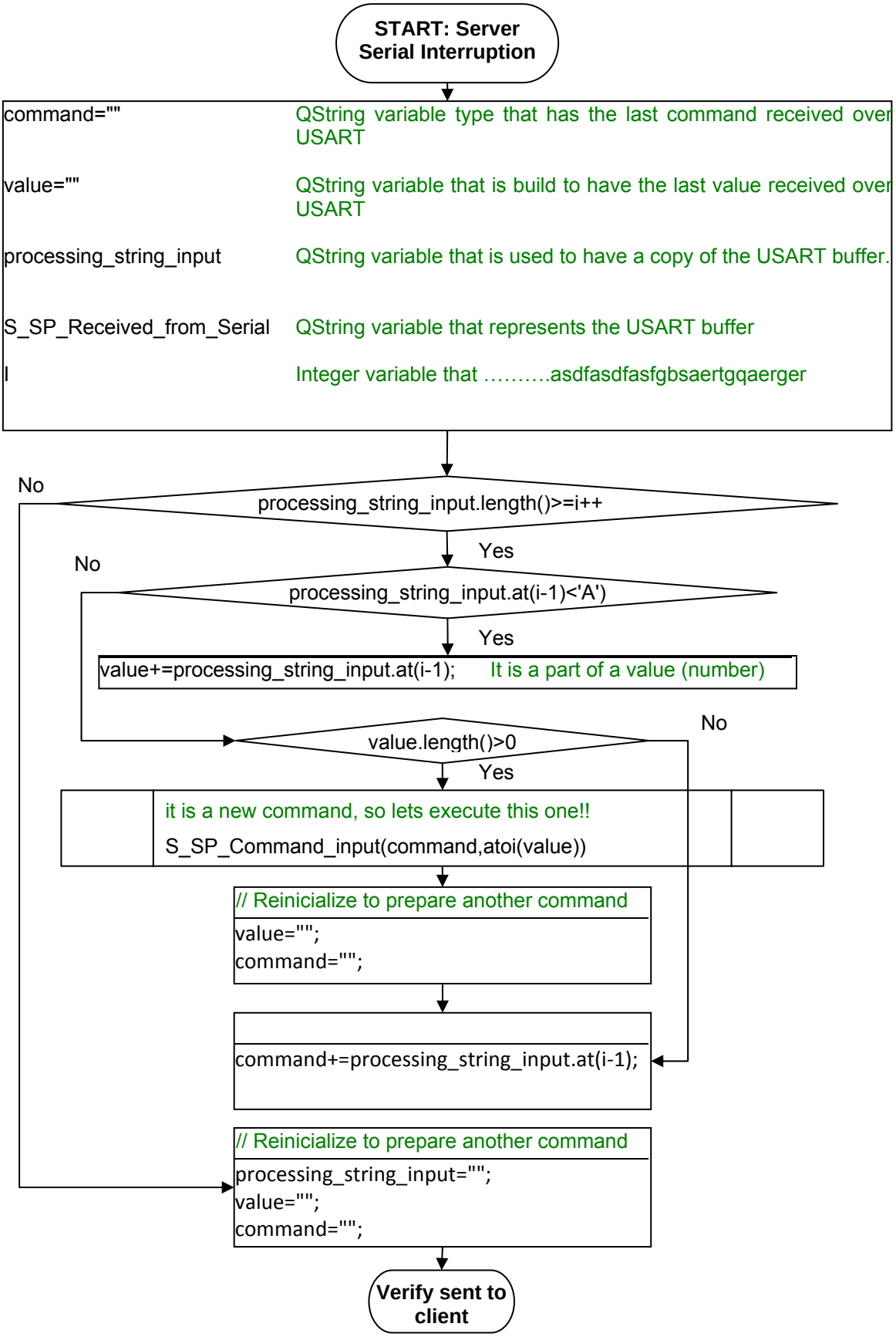
To ensure a correct explanation of the whole process of this communication, its need to keep in mind that inherent the serial port process, the operating system gets a variable amount of data from the serial port buffer and the server applications gets that frame which can contain several sets of commands/value. To deal with all amount and unpredictable data, every time the server gets data, a copy to a new variable is done and it is executed a reset of the old buffer to a null value and starts the process of indentifying commands/values. This way the buffer does not get to long and the process of indentifying commands/values

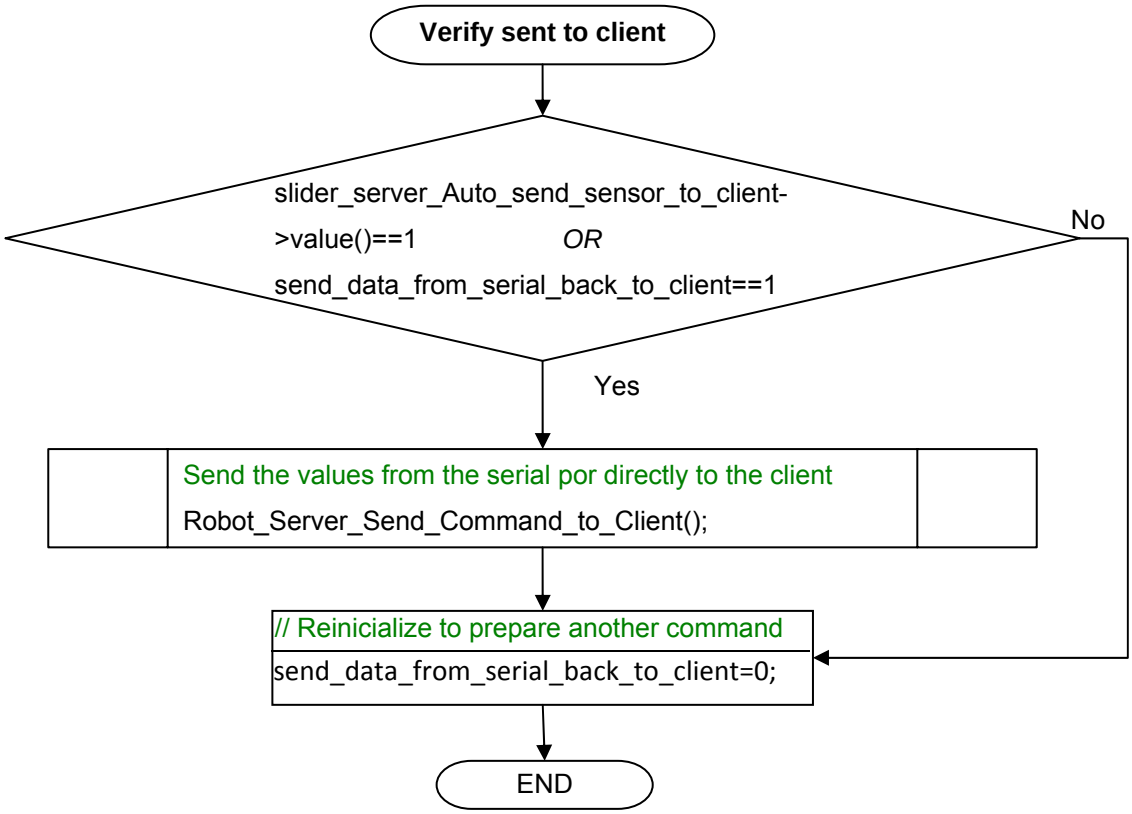
has a static data within the process (the buffer update is in other thread, reason why it has a dynamic growth)

An example of a shared command from the *Atmega16* to the *Server* can be seen at table 9, at line one, the frame is sent over RS232 to set the position of the right encoder to a value of 6459; at line, it can be seen a frame to set the encoder right position to 210 and the velocity to 5; at line three it can be seen an usually shared command that is the “Virtual Heart Beat” aka “Emergency Ping”.

E	R	P	6	4	5	9	E	N	D	0
E	R	P	2	1	0	E	R	V	5	E	N	D	0
E	M	P	0	E	N	D	0

Table 9 – Examples of shared commands from *Atmega16 to the Server*


START: Server Serial Interruption
command="" QString variable type that has the last command received over USART
value="" QString variable that is build to have the last value received over USART
processing_string_input QString variable that is used to have a copy of the USART buffer.
S_SP_Received_from_Serial QString variable that represents the USART buffer
I Integer variable that …….asdfasdfasfgbsaertgqaerger
No
processing_string_input.length()>=i++
Yes
No
processing_string_input.at(i-1)<'A')
Yes
value+=processing_string_input.at(i-1); It is a part of a value (number)
No
value.length()>0
Yes
it is a new command, so lets execute this one!!
S_SP_Command_input(command,atoi(value))
// Reinicialize to prepare another command
value="";
command="";
command+=processing_string_input.at(i-1);
// Reinicialize to prepare another command
processing_string_input="";
value="";
command="";
Verify sent to client



Flowchart 2 – Server Serial Interruption

The microcontroller unit was presented as well as the developed software, and the protocol of communications used between the server and the microcontroller.

6. Desktop Processing – C++

This chapter will fall upon the server and the client programming, the interface to the robot user and system configurations.

6.1. Introduction

The system proposed used two computers based at a server-client architecture, The client computer is not critical but the server used is, at the moment, a common laptop but later it will be replaced with an industrial and low-power consumption one.

Since the QT libraries are used, this system is platform independent, which means that the software platform can be use in a Windows, Windows CE, MAC, LINUX or an embedded Linux environment.

The use of a computer in the system was made because the computer can archive plug and play updates through USB ports, can make some parallel computation and the space of a laptop in the robot is no critical because the robot is big and a lot of space is still free for other components.

The language used for the desktop processing is C++ and QT libraries and tools were widely used.

“Qt sets the standard for high-performance, cross-platform application development. It includes a C++ class library and tools for cross-platform development and internationalization”

[W5]

The figure 38 shows the block diagram of QT framework.

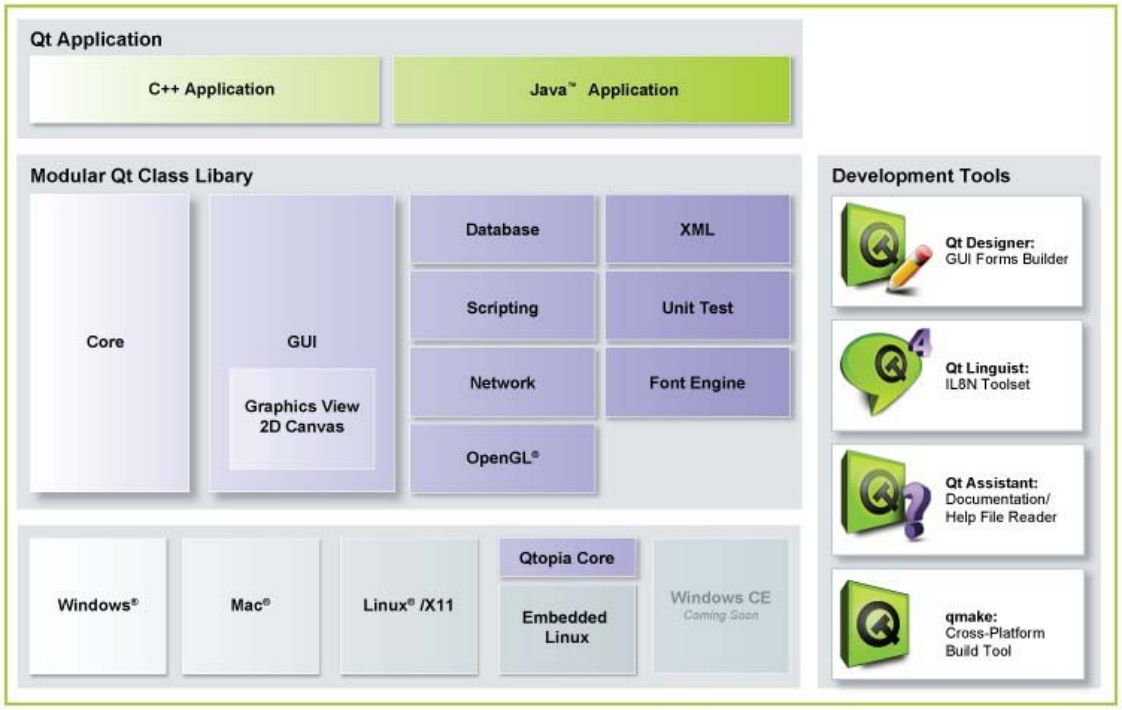


Figure 38 – Qt Block Diagram [W5]

The *Qt* uses a work philosophy of based in objects and uses directives of *Signal*/*Slots* which can be connected with each others.

The idea of a desktop program is to provide high level processing and to provide users to work remotely with the robot.

Two programs were made:
The "*Server"* and the "*Client*" which connect each other by the use of TCP/IP protocol.

A "Virtual Heart Beat", is identified at the code as an "emergency ping", was created between *Server*/*Client* and *Server*/*Microcontroller* to avoid loss of control to the robot. In the Client/Server concern, it can be described as a command that is sent from the *Server* to the *Client* every 2 seconds.
The *Client* when receives it has the duty to resends that command.

If, after four seconds, no acknowledge of the previous *ping* was received then a command to stop the motors is sent from the server to the microcontroller to avoid damages caused by an uncontrolled robot.

6.2. The Client

The *client* is used to transfer the values of the user interface directly to the server and is able to interpret incoming commands proceeding from the server to provide users to know the values of *Temperature* and *Current* of each motor drives and also the *Position* and *Velocity* of each motor.
It needs also to interpret the "Virtual Heart Beat" ("emergency ping") between the server and the client to avoid a loss of control of the robot derived from a lack of energy that could turn off the wireless router or even the *client* computer.

6.3. Class Client

The class "*Client*" makes possible to create a client based on an *IP* address and a *port*:

The constructor is shown below:
Client(const QString &host, Q_UINT16 port);

The function **SendStrToServer(QString texto);** makes possible to send a *QString* to the server and activates a *Signal* called ***logSentText*** to provide a way to log the data communications done by the *client*.

The *client* has a socket to receive data: the *Signal* **readyRead()** is connected to the *Slot* **socketReadyRead(),** this *Slot* also provides a way to log the data communications activating the *Signal* **logRecText()**

An example of interconnection of those *signals/slots* is shown below, the syntax is flexible but the first argument is always a *QObject*, and then the signal/slots are specified.
If the signals/slots are proceeding from the same *QObject*, it can be specified just once.

connect(client, SIGNAL(logSentText(const QString&)),cliente_log_sent, SLOT(append(const QString&)));

connect(socket, SIGNAL(readyRead()), SLOT(socketReadyRead()));

Others private *Slots* of each *Client* can be used:

- **closeConnection();**
- **sendToServer();**
- **socketReadyRead();**
- **socketConnected();**
- **socketConnectionClosed();**
- **socketClosed();**
- **socketError(int e);**

6.4. Interface and applications

Figure 39 shows the interface of the *Client* program and some description can also be seen under chapter 6.10. .

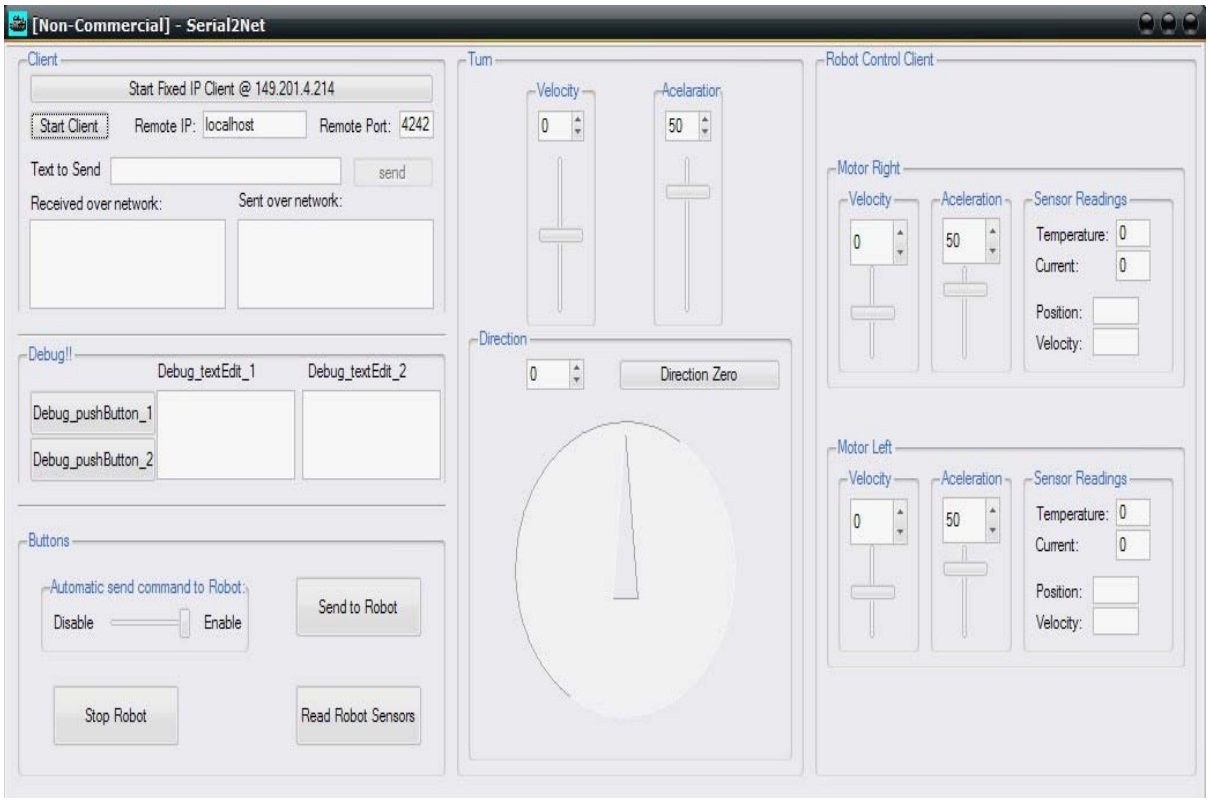


Figure 39 – *Client* Interface

The *Client* needs to interact with the *Server* in order to send commands that the user wants the robot to have.

The Client needs to listen to data from the Server, that data can be provided from the robot sensors but it is the server that transmits it (if the *Server* options are defined to).

The interface includes a *QgroupBox* named “Client” which has *Qbuttons* to connect to an IP address that can be chosen through a *QlineEdit*.

The data is sent as *ascii* format and the protocol adopted for command exchanged between the *server* and the *client* is the same as from *atmega16* to the *server*:

Several sets of commands and values with different size are being concatenated every time a character is received and when the word “END” appears the processing starts.
The client will interpret all commands / data it received and send it, one by one, to a function that will execute those commands; that function is **Client_Interpret_Command_Receive_from_Server(QString command, int value)**.

The commands that are currently being used are shown in the table 10:

TD	Turn Spinbox (Turn Direction)
TV	Turn Velocity
TA	Turn Acelaration
MRA	Motor Right Aceleration
MRV	Motor Right Velocity
MLA	Motor Left Aceleration
MLV	Motor Left Velocity
RAD0	Read All Data

Table 10 – Commands that are currently being used

Examples of shared command between *Server* and *Client* can be seen at table 11: at line one it is a command example of setting velocity of the right motor to a value of 50 and at line two it is a command example to a sensors reading and to set the velocity of both motors to a value of 68.

M	L	V	0	5	0	E	N	D	0

T	V	0	6	8	R	A	D	0	R	A	D	0

Table 11 – Examples of shared commands between *Server* and *Client*

The *Client* has a *QButton, as shown in f*igure 40, to signal to the *Server* that the *Client* commands should automatically be sent to the robot:

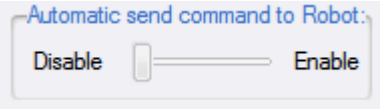


Figure 40 – Automatic send command to robot

To do that, every time any slider is released, it will check if “automatic send option” is active, and if so, it will call the function associated with the “*Send Button* “
(**pushButton_Robot_Client_Send_Command_to_Server_clicked()**)

Independent of the “Automatic send command to Robot” option, *Qbuttons* can be used to send to the server, data from velocity, acceleration and direction through “Send to Robot”, to read temperature, current, velocity, acceleration through “Read Robot Sensors” and to put zero velocity to both motors through “Stop Robot”.

6.5. The Server

The *Server* is used to interpret data from the client, to communicate with the microcontroller and is able to operate the robot in a standalone mode (without the *Client*)

It has a copy of the *Client* interface and once it receives a command of the *Client*, it interprets it and adjusts the values of the sliders at the *Server* side.

It can send commands to provide the client with values of Temperature and Current of the each motor driver and also the Position and Velocity of each motor.

6.6. Class Server

The class "*Server*" makes possible to create a server based on a TCP/IP port:

The data transmission from the Server to the Client is identically as the Client from the Server, the only difference is the behavior to the interpreted commands.

The function **data_recived_over_network(const QString& str_input)** is called each time the *server* receives data from a *client*.
When the "END" word appears all the commands will be interpreted, one by one, by the function **S_Command_received_from_client (QString command, int value)**.

The function **Robot_Server_Send_Command_to_Client()** is used to send the robot sensors data to the *client*.

6.7. Serial Port

With the *SerialPort* Class is possible to have control of the *Server* computer Serial Port.

Several *Slots* can be used:

- **openPort();**
- **closePort();**
- **saveBaudrate(QString);**
- **sendToPort(QByteArray);**
- **end();**

The slot **saveBaudrate(QString)** is useful to make that setup options need to be made only once per computer.

The following *Signals* are useful to get/send data from/to the serial port as well of to signal the results of the connections.

- **sConnected(QString);**
- **sDisconnected();**
- **sSerialError(int);**
- **sDataWritten(QByteArray);**
- **sDataRead(QByteArray);**

The function **S_SP_Analise_Data_input()** is used to interpret the data from the serial port and when a command/value is interpreted it calls **S_SP_Command_input (QString command, int value)** to deal with the data of the sensors of the robot and can follow that values to the client and update servers interface.

The protocol of communications between atmega16 and server can be seen of chapter 5.4.9

6.8. Setup Window and Log Window

The *Server* has a menu where the *Setup Window* (Figure 41) can be reached.
The *Setup* is used to allow the choosing of settings either of the Com Port as the Network.

Last settings are remembered between sessions.

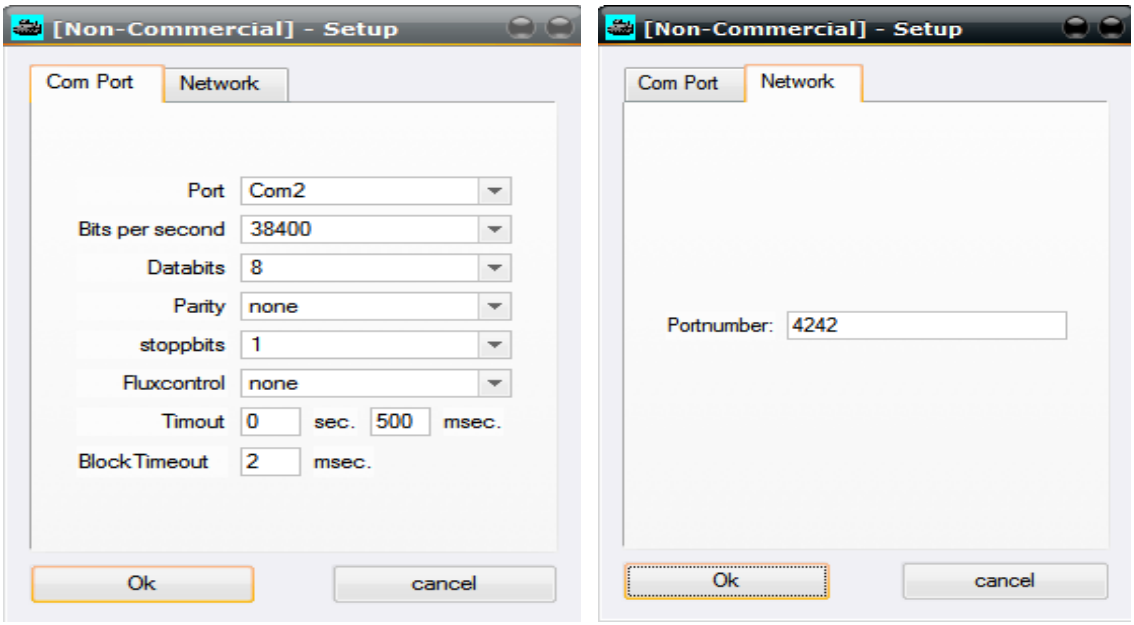


Figure 41 – Setup: Serial Com Port and Network settings

A *Log window* can be reached from this menu too (Figure 42)

This is a very useful window that shows every data that is shared through the Serial Port and is useful for debug proposes.

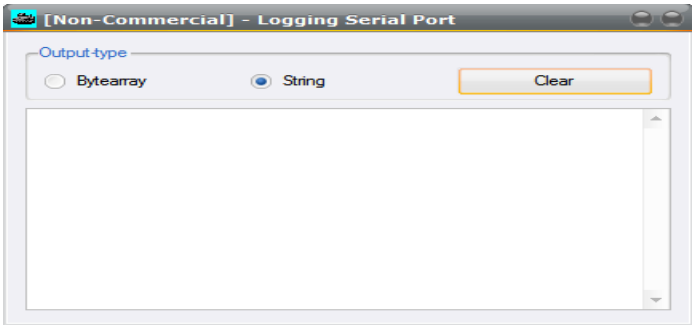


Figure 42 – Logging Serial Port

6.9. Interface and applications

The *server* main interface in shown at figure 43 and some description can also be seen under chapter 6.10. .

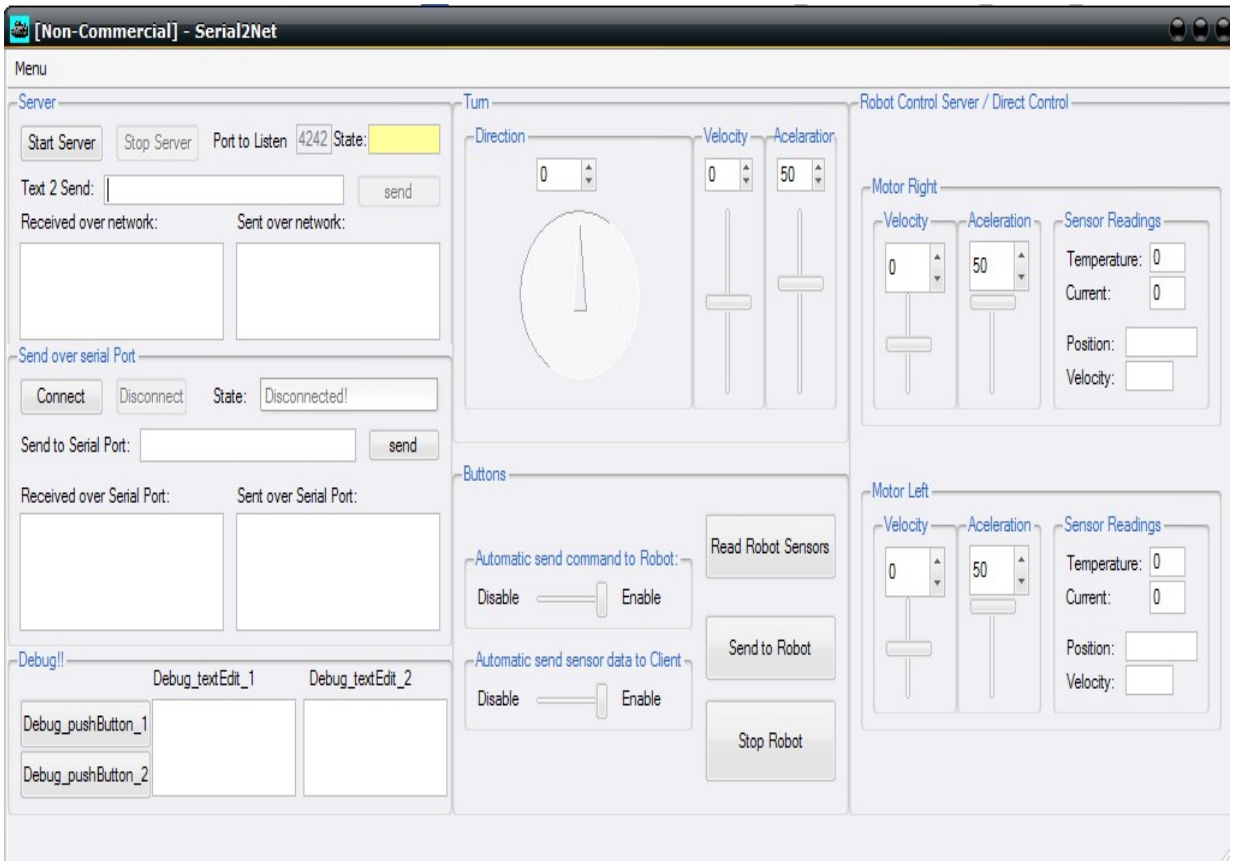


Figure 43 – Server Main Interface

The Server has a *Button (Figure* 44*)* to provide that the commands are automatically sent to the robot.

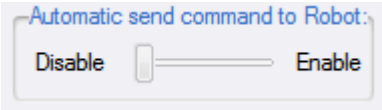


Figure 44 – Automatic send command to Robot

The behavior is the same as described in a similar button on the Client side (Figure 40):
Each time any slider is released, it will check if automatic send option is active, and if so, it will call the function associated with the “send Button“ (**pushButton_Robot_Server_Send_Command_To_Serial_clicked()**).

Independent of the “Automatic send command to Robot” option, *Qbuttons* can be used to send to the robot, through RS232, data from velocity, acceleration and direction through “Send to Robot”, to read temperature, current, velocity,

acceleration through “Read Robot Sensors” and to put zero velocity to both motors through “Stop Robot”.

The *server* has also a *Qbutton*, as shown in figure 45, to provide the data from the robot sensors to be automatic sent to the *client*.

Figure 45 – Automatic send sensor data to Client

To do that, every time the *server* interprets the sensors data from the *Serial Port*, it will forward those values to the *client* if this option is enabled.

Data transfers between Server and the Serial Port can be seen through two *QtextEdit*, as shown in figure46, regards to “Received over Serial Port” and “Sent over Serial Port”. *Qbuttons* to reserve/release the *COM Port* to the server are also provided and the state of the port can be seen through a *QlineEdit*.
It is also possible to sent command directly though a *QlineEdit* “Send to Serial Port” and the *Qbutton* “send”.

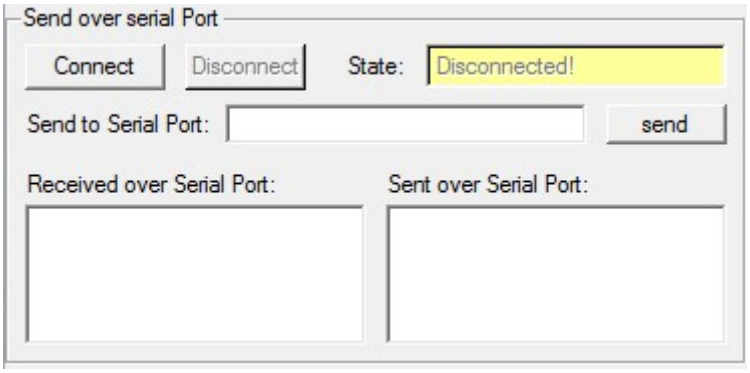


Figure 46 – “Send over serial Port” - *QbuttonGroup*

6.10. Identical interface components between *Server* and *Client*

The interface shown at figure 47 is identical between the server and the client even through the internal behavior is different because at the server side, the commands are interpret and sent over rs232 to the robot but at the client side the command are directly sent to the server over TCP/IP.

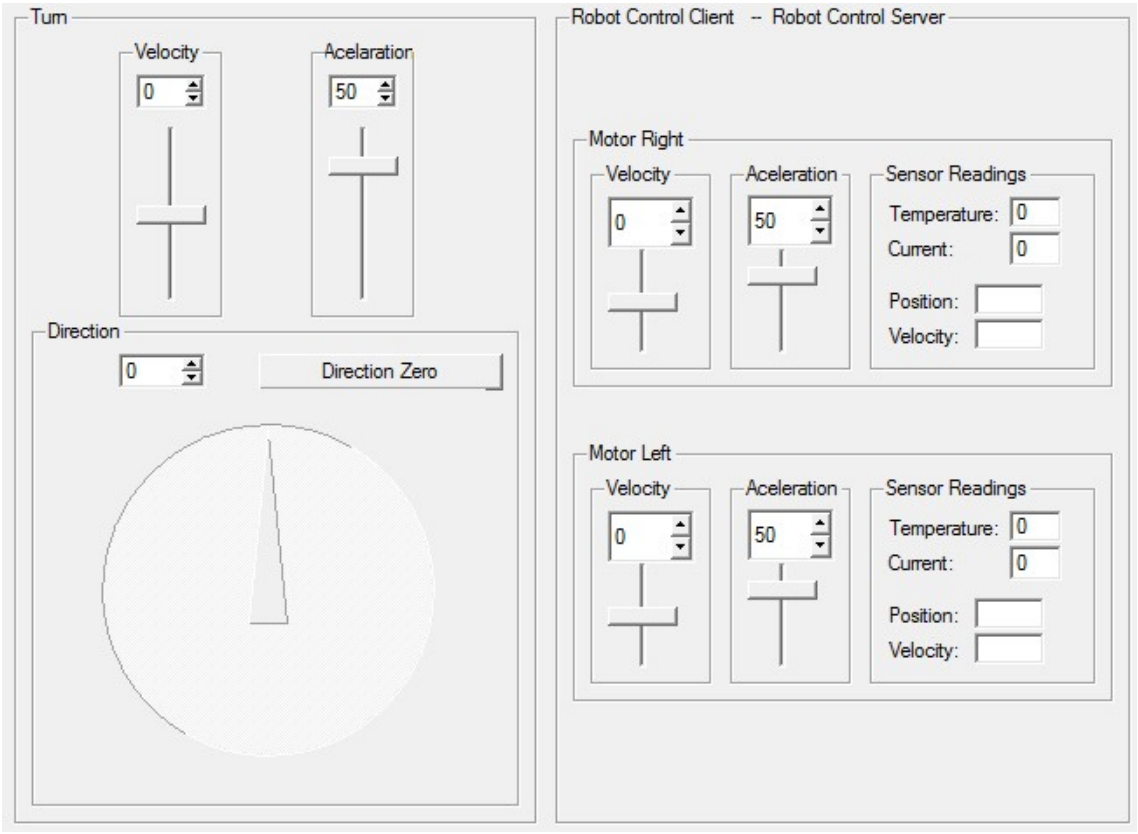


Figure 47 – Identical interface components between *Server* and *Client*

QbuttonGroups “Motor Left” and “Motor Right” are used to control the motors individually and the “Turn” *QbuttonGroup* is used to do the control both motors at once. Each one has *Qsliders* with connected *CspinBox* to provide interface of the desire velocity and acceleration of the motors.

Near each individual motor controls, “Sensor Readings” *QbuttonGroup* are used to give feedback of temperature, current, position and velocity respectively by use of *QlineEdit* widget.

In an operation that the control are done setting the velocity and acceleration of the robot (instead of individually control of each motor), a *Qdial* widget is used to set the turn direction of the robot, as well as a *Qbutton* to easily put the robot running in front.

Debug facilities are archived through two Qbuttons and two QtextEdit, as shown in figure 48, with simple functions it is possible to get feedback of some behaviour that can be useful to identify possible problems that might occur during the programming stage.

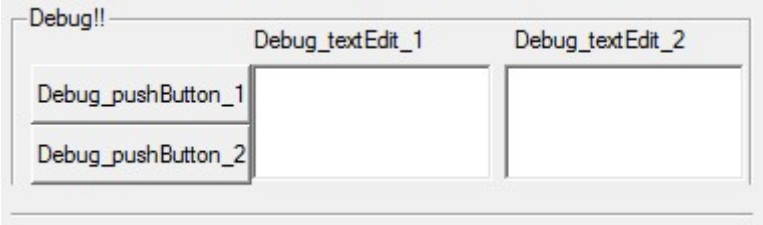


Figure 48 – Debug facilities widgets

Data transfers between Server and Client can be seen through two *QtextEdit*, as shown in figure 49, regards to “Received over the network” and “Sent over the Network”.

Figure 49 – Data transfers between Server and Client - *QtextEdit*

Some programming done and examples, the interface and the user options were discussed at this chapter.

7. Schematic, Proto-board, Strip-board, PCB and hardware connections

This chapter will show the physical connections and interfaces to the microcontroller as well of the schematics and the developed PCB's of the control unit.

7.1. Control hardware schematic

The control unit schematic, as shown in figure 50, was designed in Eagle [W7]. *Eagle*, that is a *pcb* and *schematic* design software, which has a freeware version which makes it desirable to learn and to use it.

Even through *Eagle* could be more "user friendly", it has an easy startup learning stage.

It is very popular software which means that is relatively easy to get new parts.

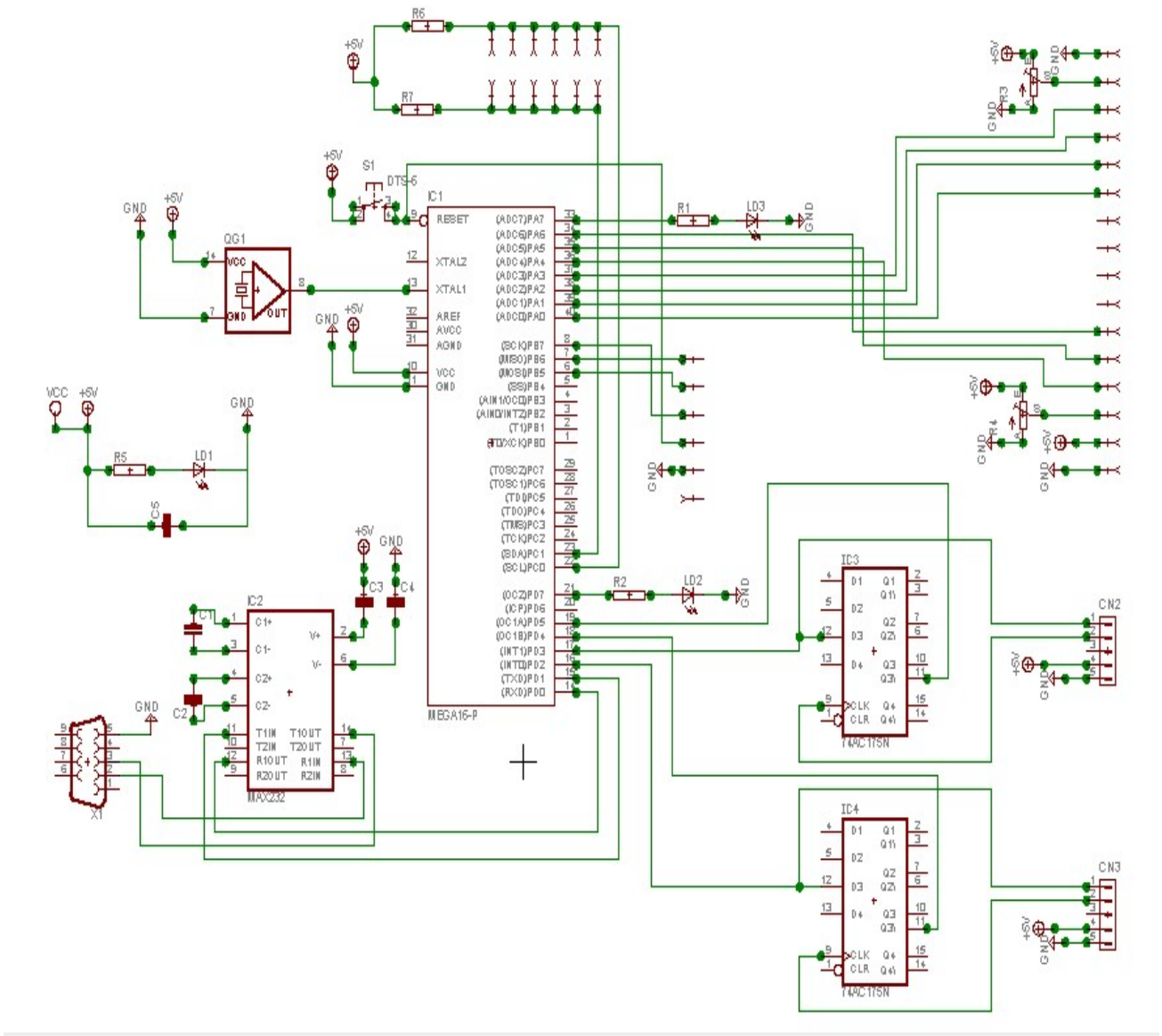


Figure 50 – Controller unit schematic

7.2. Proto-board and Strip-Board

On a first stage all of this hardware was on a *proto-board (*figure 51), and even so a strip-board (figure 52) was made.

The proto-board is still usable and it is probably preferable in future improvements of the system since it is easy to connect more hardware to it and change the place of components. Even so it is not as solid as the strip-board

and even the organization of the Proto-board was a concern at its developing stage, a strip-board can be even more organized and compact.

The figure 51 shows the board and below it is a legend to help future workers of the project to use it.

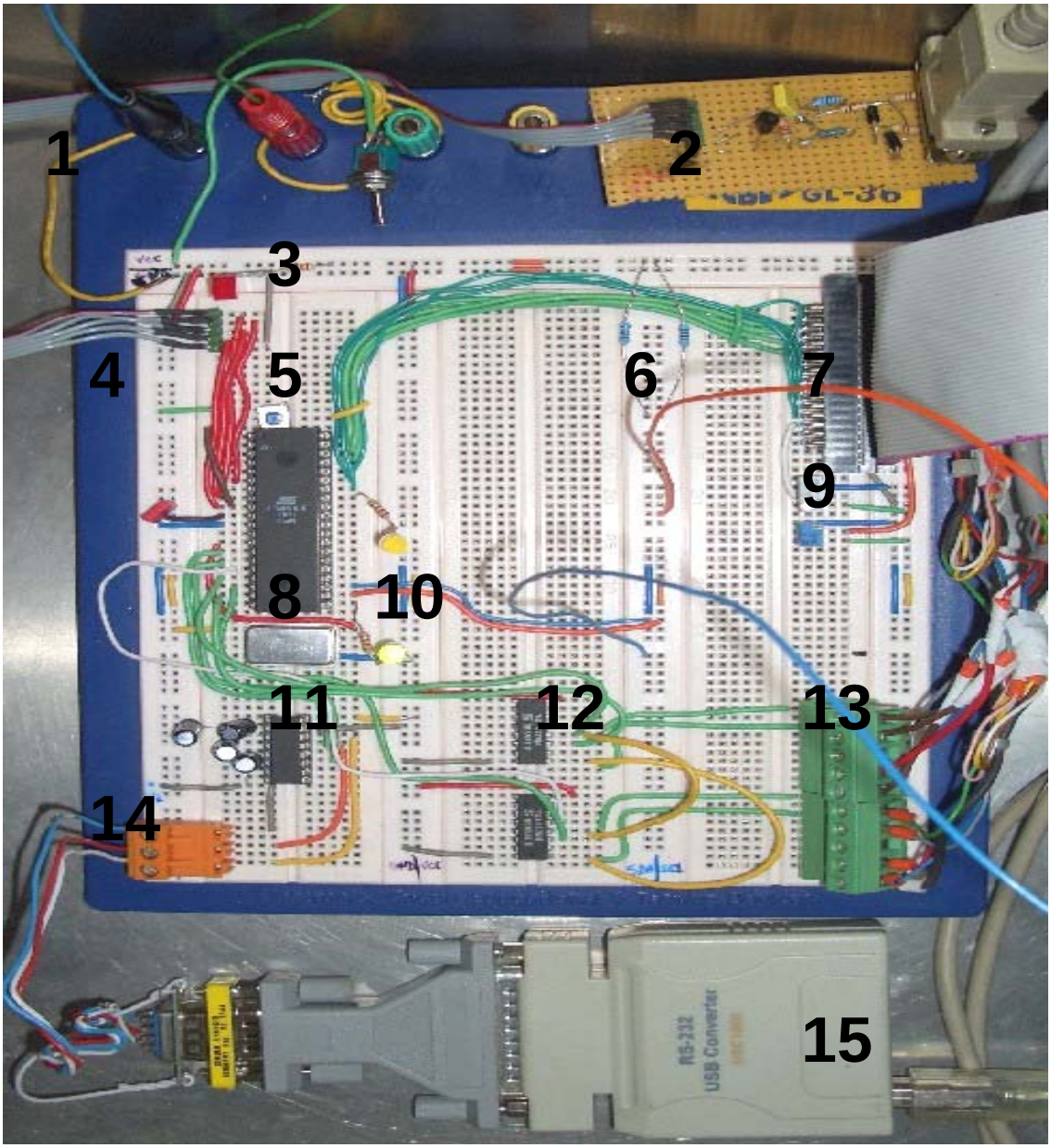


Figure 51 – Proto-Board

The figure 52 shows the strip-board that is more robust and much smaller than the proto-board but is not so flexible, even so more I2C devices are easily

connected to it; below it is also a legend to help future workers of the project to use it.

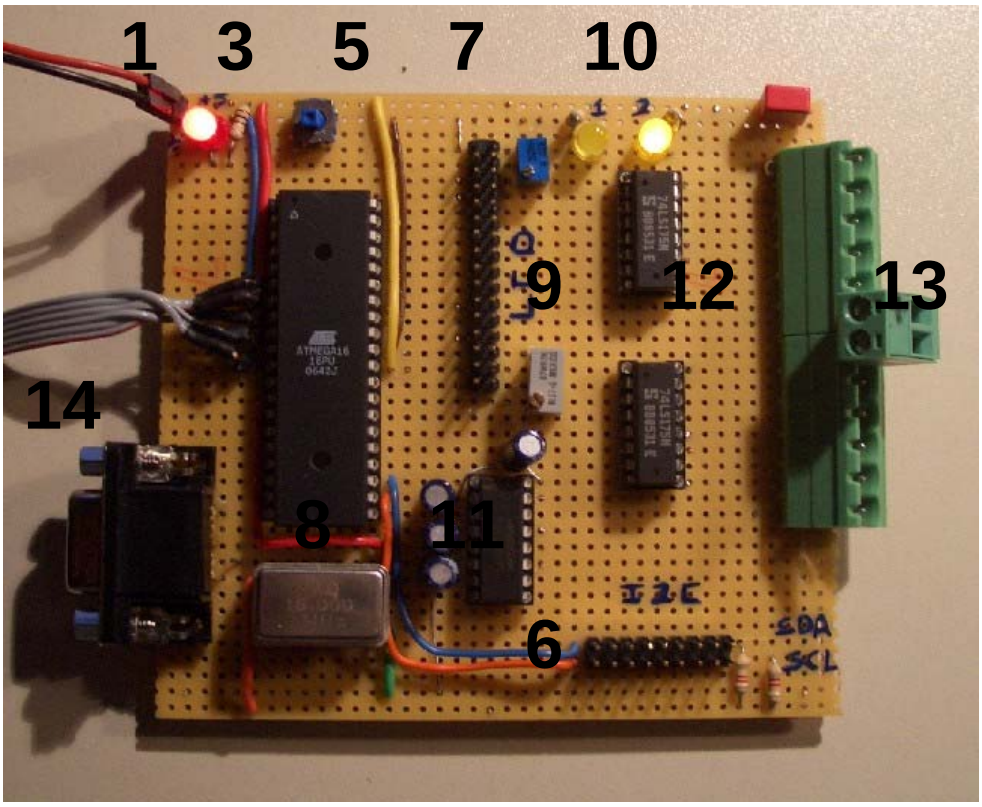


Figure 52 – Strip-Board

Figure 51 and figure 52 legends:

1) Power connectors (The red color of the cable correspond to the +5V and the Black one to the ground).

2) Programmer (In the figure, the red color of the flat cable needs to be respected).

3) Power on LED used to signal if the board is powered.

4) Proto-board connection of the Programmer (In the figure, the red color of the flat cable needs to be respected).

5) Reset tactile button used to reset the micro-controller.

6) I2C Bus, all I2C components are connected to this bus.
The first column/line is the SDA and has blue wires.
The second column/line is SCL and has orange wires.
(The wires of SDA and SCL from the motor driver have correspondent colors).

7) LCD Connector

8) Atmega16 Microcontroller and 16 MHz Crystal

9) Resistors to control the backlight intensity and the contrast of the display

10) Error LEDs to debug. (Matching error(1) and error(2) at debug software)

The upper one is being used when the motor driver initialization wasn't ok.

The bottom one is used when the microcontroller looses the connections with the server. This Led is turned ON and commands to stop motor are sent to the drivers.

11) RS232-TTL converter.

12) Flip-Flop D to help the microcontroller to know the direction of the encoders.

13) Encoders connectors.

14) RS232 connector.

15) USB/RS232 converter to interconnect the server and the microcontroller.

7.3. PCB Schematic

The PCB schematic was also done at *Eagle*, Figure 53 shows it.

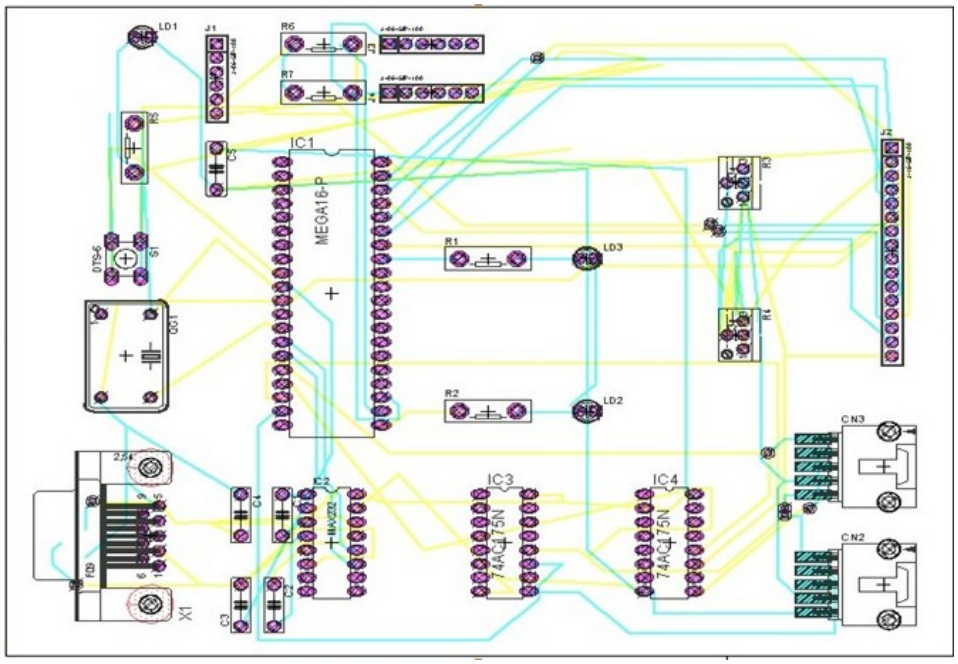


Figure 53 – PCB

7.4. 3D PCB

The 3D PCB, as shown in figure 54, was made with help of a freeware add-on to the Eagle [W8] as well as POV-Ray that is a freeware tool to design 3D.

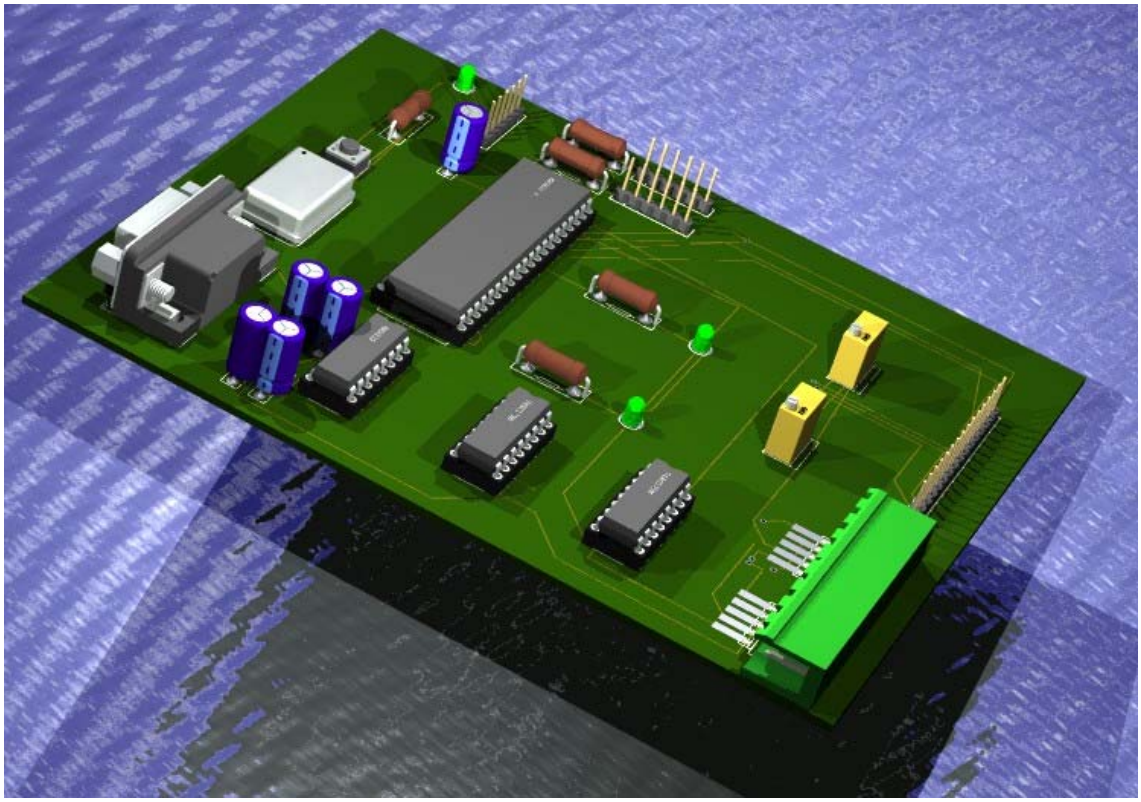


Figure 54 – 3D PCB

7.5. Hardware Connections

The figure 55 shows the D.C. regulator as well as the motor drivers their fuses and capacitors as well as the display used in the robot and below it is a legend to help future workers of the project to use it.

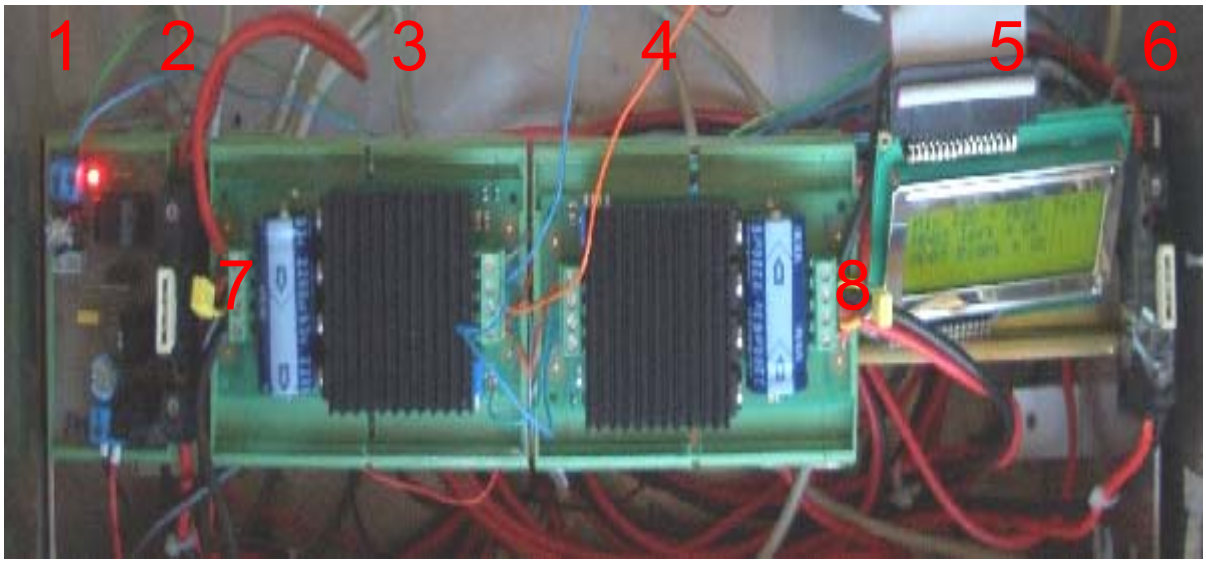


Figure 55 – Components – D.C. Regulator, Motor Drivers, Fuses and Display

Figure 55 legend:

1) DC 5V regulator (They have write with a pen, the polarity and tension of each side).

2) Fuse to left driver.

3) Driver left.

4) Driver right.

5) Display.

6) Fuse to right driver.

7,8) 10n Capacitors to avoid electrical noise.

The schematics and the developed PCB's of the control unit were presented.

8. Software and Hardware considerations

This chapter will present the interconnections process between components as well as the debug troubleshoots and adopted solutions to them.

One of the points with difficult expression on a report is the hardware and software debug phase.

This process consists in connecting all the hardware and software components being successfully tested individually,

What concern hardware, tests were carried out with a small motor and with small power supply. After that, the robot motors were tested with a 24V battery and the microcontroller was fed by the fixed power supply, now all the power is provided through the batteries.

Software debug can be spitted into the *Desktop* and the *Microcontroller* parts.
First the *USART* was implemented and then the *PWM* signals followed by debug *LEDs*.
Communication between the server and serial port was tested followed by the communication between server/client.
Everything was connected together as well the I2C communications with the drivers.

One of the motor characteristic is the electromagnetic brake; it needs to feed with 24V to release the motor. The breaks are constantly open in what this project concern, but, to archive low power consumption, a *relay* will be added further to possibility the control of it through the microcontroller.

Sometimes the motor control driver would crash and leave the motors running. This problem was sorted out by adding a 10n to each motor to avoid noise as well as a rewriting the applications with a better programming philosophy.

A “Virtual Heart Beat” was created between *Server*/*Client* and *Server*/*Microcontroller* to avoid loss of control to the robot. It consist of a ping every 2 seconds

This chapter presented some of the problems that occurs as well as the adopted solutions.

9. Moot Points

Issues that can cause some discussion will be presented at this chapter.

1. **Why does not any velocity control have been implemented on the robot?**

   It was planned to use *PID control* when the robot shows needs for it.

   The robot shows it can go through a straight line at any speed within all practical experiments. All terrain tests were not performed, but then it will need that control to increase accuracy in that environment.

2. **Why does the robot make use of a *Server* computer instead of only a microcontroller or a small board package like the "FOX Board" that can run a real Linux operating system with the size of only 66 x 72 mm?**

   The purpose of the system was the flexibility. To invest in specific hardware was avoided because the robot has not a practical finality at the moment. That way a laptop was used because it was cheap and flexible.

   Multi-platform capabilities were developed, so, whenever it makes sense to invest in low-power or smaller *Server,* the software is prepared to that.

3. **The robot makes use of *I2C* and *UART* communications. Which other choices were pondered?**

   I2C and *SMBus* are popular 2-wire protocols where data transfer makes use of only two wires. These protocols reduce circuit complexity to a system where multiple devices are intended to be added and controlled.

   The most significative differences between *I2C* and *SMBus* are relative to timeout, minimum clock speed, voltage levels and current levels.

I2C can be more than 30 times faster and slave devices have no timeout, which means that slaves can be slower in performance. [W29]

1-WIRE bus makes use of only one wire for addressing and data transfer but archives lower data rates and distance range, reason why it is typically used to communicate with small inexpensive devices. [W31]

These buses and even more with the *1-WIRE* bus, increase the overhead at addressing and acknowledge stages, that overhead can be reduced by using more wires to address the devices.

CAN (Controller Area Network) is an advanced communication protocol, it makes use of 2 or 4 wires to data transfer and archives a 40 meters bus instead of only 4 meter of the *I2C* but *CAN* operates only at 1Mbps instead of the 3.4Mbps of the *I2C*.

SPI (Serial Peripheral Interface) is based in an 8-bit serial shift register and a programmable shift clock. It has the advantage of a better noise immunity comparing to *I2C*. Addressing *SPI* devices is made by adding an extra wire to each device, reason why this protocol increases circuit complexity as the number of devices rise in a system. At top speed *SPI* is 3 times slower than *I2C*. [W30]

I2C is used at industry at small systems (smaller than 4 meters) and meet the complexity and speed that this robot system is intended.

4. **Why *PCB* was projected but not implemented?**
   The *PCB* was supposed to do instead the Proto-Board, but due to time-limitations at the ending of this thesis it was put aside.
   Priorities/Facilities ratio had importance at this point.

5. **How was the 10n capacitor of each motor chosen?**
   That was a value chosen by the motor driver manufacture and it is specified at the *MD03* datasheet.

6. **In a remote or hard access environment reconnecting the server could be an issue. What if some communication problem happens, how is the reconnection made?**

   "*Virtual Heart Beat*" handles this situation; it stops the robot when no *ping* is received at the specified time but whenever it receives a *ping* from the micro-controller or the *Client*, the process relaunch again.

7. **If several I2C master are connected to the system, what happens when two of them communicate at the same time?**

   At the moment only one I2C master is implemented but if, for some reason, another master makes sense they can interact each other by making use of arbitration logic and the "Bus busy detection" theory. [W32]

8. **Besides the critical duty of stopping the robot when the "virtual heart beat" processes indicate, which other critical duties has the microcontroller?**

   It has the duty of calculate the speed and position of the robot by sensing of each motor with accuracy and has the duty to be the *I2C Master* (generating the clock signal and addressing the slave when it needs to)

9. **Does the robot have some proximity sensor or any device to sense external environment?**

   Not at the moment. It will have within next improvements and the continuation of this project.

10. **Does the robot have any reference point when inserted in one environment?**

    The reference is done when the robot is turned on.

    At the start all variables are set to zero and values relative of how much each motor run are relative to that start moment.

    By adding other sensor to the system, the philosophies of setting the reference can the different than the actual.

11. **Why has the *server* a graphic interface? Could the graphic programming language be implemented only at the *Client* side?**
    That was made that way to make possible "*Access Restrictions*".

    The *Server* can have the full control of the robot, but the *Client* is able only to ask data to the *Server*, and it is the *Server* who decides what the *Client* can do.

    At developing stage, the *Server* can be programmed to do anything and a "*Remote Desktop Environment*" can be used to control the robot without any restrictions.

10. Conclusion / Further work

A final and informal presentation was done at the APS.
As main conclusions it can be said that the robot showed high stability with either fast or smooth control. The commands sent by the client are correctly interpreted and technical problems (as loss of internet connection) were successfully passed.

The system was built from the scratch except of the mechanical structure and all the problems that occurred during the developing phase were sorted out which gave the solid and confident characteristic to the robot.

The mobile robot was developed, with communications parts between all components.
The use of I2C gives a proof of efficiency, fast and expansible concept.
The software made at desktop level by use of qt libraries makes the system portable and flexible and the low level developed software at the microcontroller unit makes de system fast at duties as calculation the position, speed and acceleration of the robot and I2C communication leaving the desktop free for other duties.

Working abroad was a grateful experience, which allowed me to know people, other institutions, to meet different cultures and to get more technical acknowledgement and working skills.

Bibliography and WWW References

• Bibliography

[B1] Michael Barr, Anthony Massa, ” Programming Embedded Systems”, O'Reilly, ISBN: 0-596-00983-6, cp8, cp9, cp13
Here you can have an approach of embedded systems processing.
Different types of Interruption handling on a microcontroller as showed
A PWM tutorial with and some simple examples are showed.
A brief I2C explanation is presented.

[B2] *Lewin A.R.W. Edwards*, ” Open-Source Robotics and Process Control Cookbook - *Designing and Building Robust,Dependable Real-Time Systems*”, Newnes, ISBN: 0-7506-7778-3

• References WWW

[W1] http://www.aps-mechatronik.de/
Main page of APS - European Centre for Mechatronics
Here it is possible to find information referring members of the center, investigation developing projects, etc.
(Accessed on March, 2008).

[W2] http://www.fb6.rwth-aachen.de/en/1.php
Main page of Faculty of Electrical Engineering and Information Technology of RWTH University.

Here it is possible to find information referring members of the department, teaching activities and investigation developing projects, etc.
(Accessed on March, 2008).

[W3] www.dei.uminho.pt
Main page of Industrial Electronics and Computers department of University of Minho. Here it is possible to find information referring members of the department, teaching activities and investigation developing projects, etc.
(Accessed on March, 2008).

[W4] http://www.atmel.com
Page of Atmel.
Here you can find information about microcontrollers and the datasheet about atmega16, debuggers (AVRStudio) and other Atmel product.
(Accessed on March, 2008).

[W5] http://trolltech.com/products/qt
http://trolltech.com/products/qt/features
Page of QT.
Here you can find information about QT, help documentation with libraries specifications and features.
(Accessed on March, 2008).

[W6] http://www.lancos.com/prog.html
Page of PonyProg flash programmer.
Here it is possible to find the newest version of the software as well as different solutions to the programmer hardware.
(Accessed on March, 2008).

[W7] http://www.cadsoft.de/
Page of Eagle

Here you can download the freeware version of Eagle as well as many libraries of components
(Accessed on March, 2008).

[W8] http://www.matwei.de/doku.php?id=en:eagle3d:eagle3d
Page of Eagle 3D
Here you can download the freeware and open source version of Eagle 3D add-on as well of documentations about to use it.
(Accessed on March, 2008).

[W9] http://www.atmel.com/dyn/resources/prod_documents/doc2466.pdf
Datasheet of the microcontroller atmega16 provided by the manufacturer Atmel.
Here you can find information about the microcontroller atmega16 and some example code.
(Accessed on March, 2008).

[W10] http://www.AVRfreaks.net
Here you can find a large collection of projects suitable to learn you more about the AVR.
(Accessed on March, 2008).

[W11] http://www.atmel.com/dyn/resources/prod_documents/doc2466.pdf
AVR Studio
(Accessed on March, 2008).

[W12] http://www.dimensionengineering.com/Sabertooth2X10.htm
Here it is possible to find *Sabertooth* specifications
(Accessed on March, 2008).

[W13] http://societyofrobots.com/batteries.shtml
Page of Society of Robots.
Here you can find information about robots and how they are made and a nice tutorial about the different types of batteries

(Accessed on March, 2008).

[W14] http://www.embedded.com/story/OEG20010718S0073
Page of Embedded Systems Design,
Here you can find a nice tutorial about I2C functions.
(Accessed on March, 2008).

[W15] http://www.nxp.com/acrobat_download/applicationnotes/AN102161.pdf
Phillips manual about *I2C*.
(Accessed on March, 2008).

[W16] http://jump.to/fleury
Page of Peter Fleury
Here you can find libraries to use I2C and LCD with the atmega16 microcontroller
(Accessed on March, 2008).

[W17] http://en.wikipedia.org/wiki/I2C
Page of Wikipedia.
Here you can find nice tutorial about I2C functions.
(Accessed on March, 2008).

[W18] http://www.ormec.com/mktdocs/encres.htm
Page of ORMEC's - Motion control solutions
Here you can find nice tutorial about encoders.
(Accessed on March, 2008).

[W19] http://lab.artematrix.org/papers/Homebrew_Shaft_Encoder.pdf
Encoder
(Accessed on March, 2008).

[W20] ftp://ftp.ni.com/pub/devzone/pdf/tut_4623.pdf
Page of the *national instruments* with some principles of encoders
(Accessed on March, 2008).

[W21] http://www.faulhaber-group.com/n390840/n.html
Page of the manufacturer of this robot gearheads.
This you can find a nice tutorial about choosing the gearheads and how are they composed.
(Accessed on March, 2008).

[W22] www.crouzet.com/catalogue_web/pdf/ENG/ndb12_eng.pdf
Brief Description about D.C. motors
(Accessed on March, 2008).

[W23] www.robotstorehk.com/md03tech.pdf
Motor driver MD03 Datasheet
(Accessed on March, 2008).

[W24] www.irobot.com
iRobot Homepage
(Accessed on March, 2008).

[W25] http://www.gizmag.com/go/7151/
iRobot in Iraq
(Accessed on March, 2008).

[W26] http://www.linuxdevices.com/articles/AT3782871866.html
http://www.activrobots.com/ROBOTS/p2at.html
2008, MobileRobots Inc. (Accessed on March, 2008).
ActivMedia Mobile Robot (Pioneer and other types of robots)

[W27] http://linuxdevices.com/news/NS8152651349.html
914 PC-Bot
(Accessed on March, 2008).

[W28] http://www.gizmag.com/go/7208/
Remote-controlled robot uses thermal imaging to detect and eradicate termites.
(Accessed on March, 2008).

[W29] http://www.maxim-ic.com/appnotes.cfm/an_pk/476
I2C and SMBus comparing.
(Accessed on March, 2008).

[W30] http://www.ucpros.com/work%20samples/Microcontroller%20Communication%20Interfaces%201.htm
I2C and SPI comparing
(Accessed on March, 2008).

[W31] http://en.wikipedia.org/wiki/1-Wire
1-Wire Interface specifications
(Accessed on March, 2008).

[W32] http://www.i2c-bus.org/multimaster/
I2C Multi-Master Environment.
(Accessed on March, 2008).

Table of figures

Table of tables

Table of flowcharts

Table of abbreviations

I/O	Input / Output
TCP/IP	Transmission Control Protocol / Internet Protocol
I2C	Inter-Integrated Circuit
TWI	Two Wire Interface
DC	Direct Current
PWM	Pulse-width modulation
USART	Universal Synchronous Asynchronous Receiver Transmitter
APS	European Centre for Mechatronics
DDR	Data Direction Register
ASCII	American Standard Code for Information Interchange
A.K.A.	Also Known As
AGM	Absorbed Glass Mat

Attachments – Motor Specifications

The robot has two motors provided from the manufacture ENGEL, the series is GNM5480E and the motors are typed “Permanent Magnets, Direct Current” they are coupled with gear-heads and the characteristics can be seen at table 1 and the dimensions at figure **Error! Reference source not found.**.

Nominal voltage	UN	24	Volt
Armature resistance	R	0.106	Ω
Nominal output power	P_2	250	W
Efficiency	η max	85	%
No-load speed	no	3,267	rpm
No-load current	Io	1,435	mA
Stall torque	M_H	1,005	oz-in
Friction torque	M_R	14.16	oz-in
Speed constant	k_n	137	rpm/V
Back-EMF constant	k_E	7.30	mV/rpm
Torque constant	k_M	9.87	oz-in/A
Maximum peak current	k_I	115	Amps
Rotor inductance	L	0.33	mH
Nominal speed		3,000	rpm
Nominal torque		112.71	oz-in
Mechanical time constant	Tm	11.6	ms
Rotor inertia	J	52.4	x10-3oz-in-sec2
Thermal resistance	Rth1/ Rth 2	1.8	°C/W
Thermal time constant	τ w	40	minutes

Motor weight			lbs.
Maximum ambient temperature		40 (104)	°C (°F)
Motor operating temperature range		–20 to 100 (–4 to 212)	°C (°F)

Table 12 – Robot motor characteristics

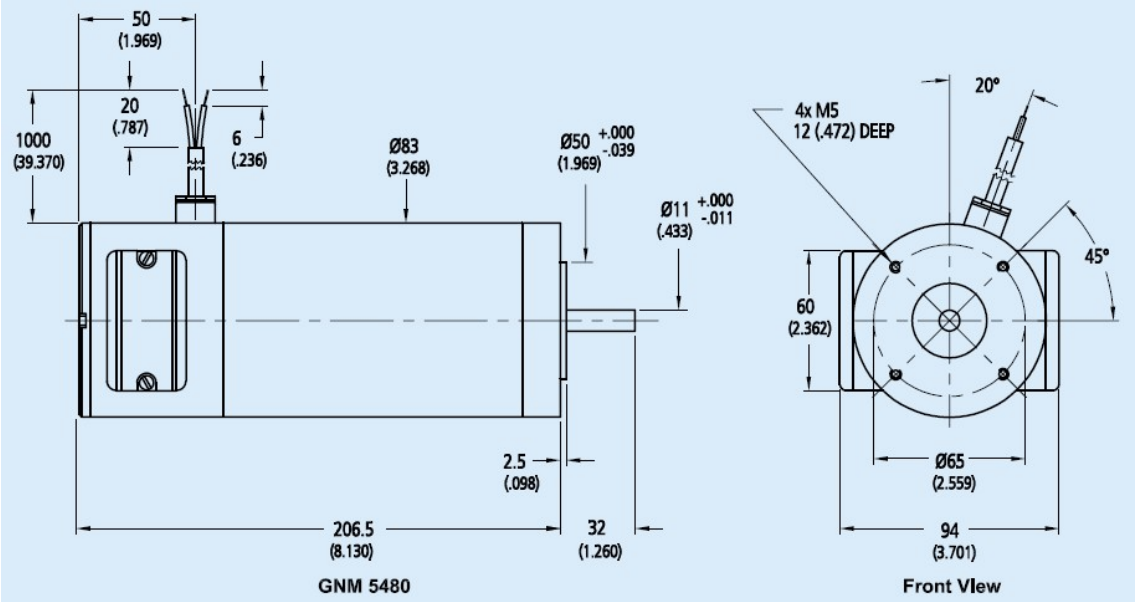


Figure 56 – Motor Dimensions

Attachments – CD Contents

The source code of the *atmega16*, the *server* and the *client* are provided in a CD and below the contents and description of the directory layout of the CD will be presented:

Root,

Document source of this thesis in .*doc* and .pdf formats.

Datasheets,

Contains the component data sheets used for design of this project and application and design notes used.

Schematics,

Contains the schematics of both control circuits in Eagle and also contains the PCB's.

Miscellaneous,

The miscellaneous specifications and application documents used designing the circuits.

Code Embedded,

The embedded C code used to create the drivers for the motor driver design.

Code desktop,

The desktop C/Qt code used to the *client* and the *server* design.