Universidad Carlos III de Madrid

DEPARTMENT OF SYSTEMS ENGINEERING AND AUTOMATION

FINAL YEAR PROJECT

INDUSTRIAL ENGINEERING

ANDROID CONTROLLED MOBILE ROBOT

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Madrid, 2 of July, 2013

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Acknowledgement

To start with, I would like to focus my appreciation to the main impulse and motivating force of this project: Juan González Víctores. I am aware of his effort to help and keep the robotics association alive, sacrificing his time for the benefit of the students who come and go always having learnt something new and exciting.

His constant and selfless help translates in the success of others, meaning that his contribution to the association and guidance make students achieve their goals while interacting with other students often to learn from one another and share resources, ideas, solutions, etc.

Regarding this project's framework (Robot Devastation) and its future versions and improvements I only wish Juan and his next students the best to carry on with this venture and I also hope the project reaches a good endpoint with a positive outcome for everyone involved.

As I have been working on this project, I have also received a positive lift from my friends and especially my family, always making sure I keep excited about moving forward. Without their kind support I would not manage to focus as much as I need in my career. In addition, it has been a great experience to have spent all my student life with my childhood friend Álvaro Martínez, who has been a great support from the first course to our attendance to the robotic association.

Abstract

As a part of an early stage project, it has been the goal of this project to serve as a prototype for such venture having set the paths to a wide range of new opportunities in the field of remote controlled robots interaction.

The initial and ongoing idea is to build a virtual environment for managing real robots states and field data and on the other side getting users to build their own robots with the capability of teleoperation. This way, robots may interact in the same location as users control them from any place in the world using internet and wireless networks for this purpose.

An important side of the project is to build an actual robot that is subject to wireless operation from a PC or a smartphone. In this context, a requirement of simplicity was set in order to focus on operability and functionality, as this project is meant to serve as a starting point for the soon-to-come fully operational robots. Along with simplicity comes the benefit of being able to reduce costs to a minimum, task that has been successfully accomplished.

In the end, on one side, an inexpensive and almost fully printable robot has been designed and built, and on the other side both the robot's software and the smartphone's software have been developed, resulting in an android controlled robot.

Resumen

Como parte de otro proyecto más grande y ambicioso, este proyecto se ha desarrollado para servir como prototipo tanto en la parte de comunicaciones como en la de aplicación para smartphone, abriendo camino a muchas posibilidades de mejora y ampliación.

La idea principal y objetivo a largo plazo es desarrollar una plataforma online mediante la cual se pueda operar remotamente robots que interactúen unos con otros (por medio de internet). Cualquier persona, desde cualquier parte del mundo, sería capaz de controlar su robot, que podría estar a su vez en cualquier otra parte del mundo, todo desde su teléfono móvil.

Una parte importante de este proyecto sería comenzar construyendo un robot apto para ser controlado por medio de una red inalámbrica (mediante estándar Wi-Fi por ejemplo) a través de un smartphone o PC. En este contexto, se ha querido primar la funcionalidad y la operatividad antes que desarrollar en exceso cada ámbito relacionado con el robot o su manejo (diseño, estabilidad, potencia, manejo, etc.). Una ventaja de este enfoque es que se consigue mantener el coste del proyecto al mínimo

En definitiva, se ha llevado a cabo el diseño y construcción de un robot imprimible casi al 100% (siendo así fácilmente duplicable), y por otro lado se ha desarrollado un software de control del robot tanto para el microcontrolador de éste como para la aplicación de móvil encargada de controlarlo, dando como resultado un robot controlado por Android.

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Chapter 1

Introduction

Nowadays, a new way of interacting with robots is starting to develop among both professionals and non-professional electronics users. Due to the recent development of **open source software** and more recently **open source hardware**, as well as the decreasing prices in the world of electronic tools, engineers find themselves in a situation where they can think of and carry out a vast range of projects. These projects may start out of the industrial environment per se, however, most of the experience, technical abilities and new ideas are subject to be applied later on in the industry of robotics.

There is, consequently, an approach between consumer electronics and traditional electronic components for developers, motivated by the philosophy of open tools, affordable for all users, which let engineers incorporate a wide range of functionalities to their projects.

Considering these open tools as framework, a big project is being developed at this time combining innovative ideas, wireless technologies and an open philosophy for users to become an active part of the big system. This idea is called 'Robot Devastation', a new-generation shooter with augmented reality and real robots. Users will be able to play online with others with a smartphone or PC, moving robots in championships and campaigns. Everything 24/7.

Robot Devastation (Fig. 1) is the big final project that serves as framework for ASROB, the UC3M Student Robotics Society, to develop a variety of projects related to it. If we talk about the future of Robot Devastation, this project has opened the way to the upcoming developments in each field related to it, as it is only in an embryonic stage and there is always much to create and improve.

Figure 1: Robot Devastation logo

The idea: Users' robots will be located in the same place and they will be equipped with a locomotive system and a camera as the minimum gear. These robots would be printable and open-source, although this could not be a requirement, and be adjusted to a series of parameters to be considered "legal" to enter this system.

Users could be located at any place in the world as long as they have access to the network, and would be able to control their robots either with a PC or their smartphone (preferred option to gain portability).

Last but not least, there will be a server in charge of managing all field data, that is to say, anything relevant that happened at the location where these robots would interact. In order to talk in greater detail about the server's behavior we should first define what kind of interaction there is supposed to be among the robots.

The purpose of this idea is to create a competitive environment modeled as a shooter game (classic first person shooting games) where users will compete and battle against others at anytime from anywhere.

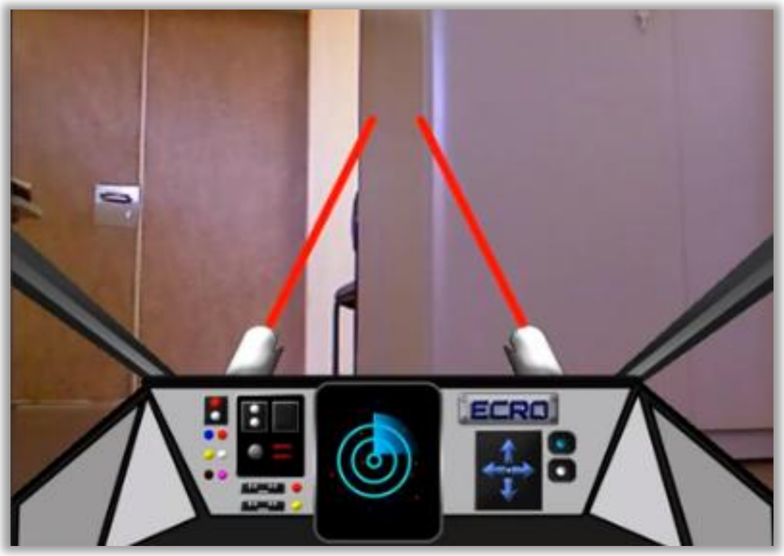


Figure 2: Robot Devastation PC interface [1]

In figure 2, we can see a prototype interface (for PC) with virtual shooting lasers to give users the right perspective of the target (other robot).

The server will keep record of all events happening in real time, receiving information about which robot is shooting which one, where this is happening, when, and also information about points, rankings, etc.

This facet of the Robot-Devastation project has not been covered at all in this project as it is in the field of computers science programming, more suitable for computer science students, hence being an ambitious project with modules in different areas of expertise. However, in this project in particular, a mobile robot has been built thought to be suitable with Robot Devastation as a first approach to the initial idea.

In addition, according to the philosophy of the robotics association, almost all material used in this project is open-source, both hardware and software, and the developments achieved in every area are constantly being published so that others can use what they consider is useful for their own projects. This assures that with a low-budget, we can develop applications that meet most of the requirements.

1.1. Motivation and aim of the project

Among all the technological and conceptual challenges faced in this project, there is one above all, which is meant to serve as a breaking point in the world of common user robotics, amateurs, and engineers, and this is enabling a certain mobile robot to be controlled from a smartphone using no more than an internet connection.

Given that the great majority of users have access to smartphones, an option to give wireless connectivity for any purpose comes handy so that developers will not concern themselves about implementing new hardware and software options to their existing projects. Instead, they can adapt their projects to be compatible with current connectivity protocols such as Wi-Fi or Bluetooth, and use a phone to interact with them. This means that any of them would be capable of controlling their hardware from their phones contrary to having to develop any significant extra parts.

Given this, we could make use of smartphones to our benefit with the purpose and idea of Robot Devastation. As it is in an Alfa state, there was no tangible 'product' related to Robot Devastation around which we could start to develop the applications and dynamic systems derived from it. Hence, the need to create a **small mobile robot** capable of being controlled from Android platforms making use of the most suitable wireless technologies available, which are for now, Wi-Fi internet protocols.

If we want users to be able to create their own robot designs as well as building them using layouts available on the internet we should make use of open hardware manufacturing tools such as the recent 3D printers, which are increasing their presence in many environments.

According to this open philosophy and as a need to materialize the user-client part of Robot Devastation, a concept of a robot is born for this project. It should be ready to connect to a wireless network almost instantly upon power on and subject to being controlled from a user interface with no delay in the communications. In addition, it should be printable as mentioned before. All this requirements have been met in the robot built for this project; figure 3.

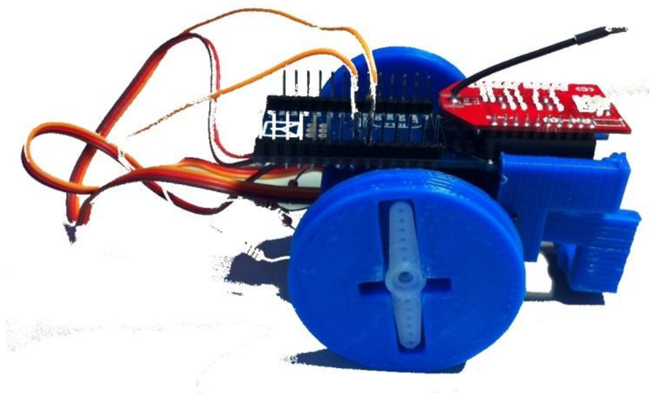


Figure 3: This project's Android controlled robot

Apart from achieving the communications part (wireless internet data transfer, low latency and reaching long distances between the operator and the robot), another important objective is to develop the robot and its associated communications system under a **low-cost** and open source philosophy (always if possible, depending on the part). This way we can bring potential future users closer to the project since the whole robot costs less than $100 (see Appendices).

The third objective/ challenge would be to provide the robot with a high **autonomy** in the sense of hours of use without the need for recharging. At the moment, the robot uses a LiPo battery which is a long battery life, but it could be enhanced by using solar cells (future versions, see Chapter 7, conclusions and future work).

1.2. Parts of the project

The first part is the design, manufacture and assembly of the robot's structure. For the purpose of 3D designing, a parametrical modeling software was used which will be discussed later along with other discarded options. Regarding the manufacture, the code from the 3D software is then translated into a machine code that can be read by a 3D printer which builds each piece layer by layer. Once the pieces are complete, they are assembled including the electronic components and the robot reaches its final shape, and we then proceed to modify the servos to achieve continuous rotation by hacking the electronics as well as its mechanical structure.

This is all covered in Chapter 3 (3D) and Chapter 4 (servos).

The second part concerns the programming and configuring the electronic components for this project. First the microcontroller board called Arduino based on the ATmega328P running at 8 MHz serving as the main "intelligence" for the robot. This board is in charge of reading the wireless transferred data and moving the robot's DC motors. Second, there is a smaller Wi-Fi module thought to be plugged on the Arduino enabling wireless connectivity with any device with internet connection, such as laptops, smartphones or other Wi-Fi boards. The main board is an open source electronics platform, which users can build from common single electronic components or buy preassembled. The programming software can be downloaded for free. The Wi-Fi board, is not open source hardware, but can be configured following its user's manual.

This is all covered in Chapter 5.

The third and last major part covers all the Java programming first for a Laptop and then for a smartphone, including socket processing, user graphics interface and data calculations, all destined to the creation of an intuitive application for moving the robot that is both simple and robust.

This is all covered in **Chapter 6.**

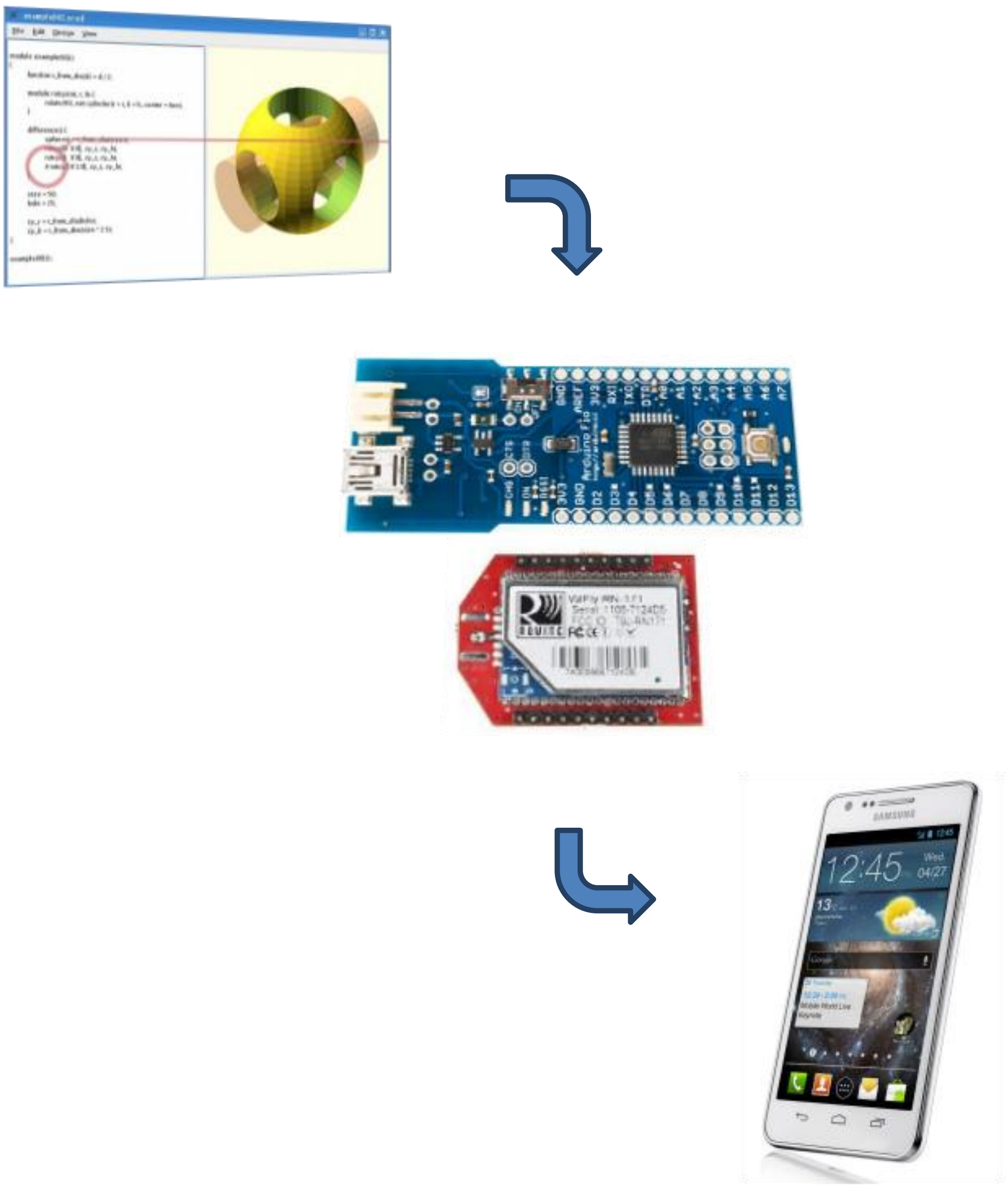


Figure 4: Project's workflow: Design, hardware and smartphone programming.

1.3. Document structure

Having passed the introductory part of this document (section 1), in the next chapters of the text we are going to discuss more extensively the different **parts** of the development of this project.

In the **second section**, we review the background technologies and environment surrounding every major part of this project.

In the **third section**, the design, manufactory and assembly of the pieces involved in the robot are going to be exposed in detail, as well as the procedures and tools involved.

In the next and **fourth chapter** we proceed to describe the election, electronic modification and implementation of the servos used as DC motors that make the robot's movement possible.

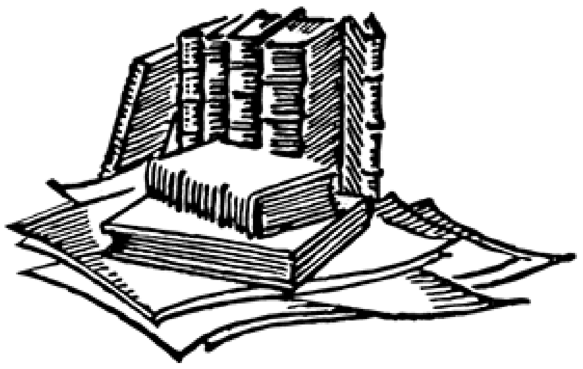
In the **fifth chapter**, we will take a look at the electronic configuration and hardware choice as well as all the programming.

Next, in the **sixth** section, we will discuss all topics related to the smartphone remote controlling and programming involved.

In the last section, we can find the conclusions to this project.

Chapter 2

Background



In the context of robotics there is much to be discussed about the technological challenges and possible different implementations for each single project or solution as a result of the increasing development and progress in every area involved. New ideas lead to new projects and every one of these projects lead to new ideas for improved projects, often as an exchange of resources between different parties. This interaction between developers among the world translates into an accelerated progress, in which anyone, from companies to single engineers can take part.

This technological background and its influences are discussed in this part of the report, dividing it the same way as the main document is structured. First, we talk about the background of 3D modeling and designing, followed by the background of electronics hardware and programming. Third, we will take a look at the implementation and incorporation of electric actuators and DC motors usually found both in industrial environments and in other electronics projects. Fourth and last, we discuss the foundations and background of smartphone oriented programming.

In all parts we start from a generalist point of view, talking about possible different implementations, and then converge around the particular cases involving this project.

2.1. Mechanical Structure

In order to build a machine's structure there are many professional and non-professional solutions in the market. For the most demanding robots the industry provides manufacturing methods and solutions that suit high precision requirements, high torques and forces, and machine parts that withstand high stresses and have a stable response during time. This is the case, for example, of robots used in assembly lines or paint shops. As the execution and field performance of these industrial robots must be robust and precise they are manufactured with the best suitable composite materials, such as carbon steel, titanium compounds or carbon fiber. Cast iron, steel and aluminum are most used for arms and bases.

These robot parts are manufactured with CNC (Computer numeric controlled) equipment, usually by other industrial robots (fig. 5). From the design to the manufacturing, every step is computerized according to the automation demands in the industry. Starting with the design we will discuss the options that we can find in the market.

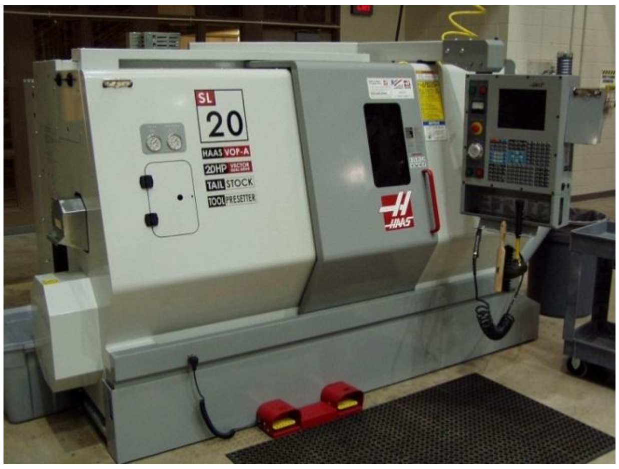


Figure 5: CNC machine

If we focus entirely on the engineering side of designing leaving on a secondary level the artistic approach we come across several software options where we can find what best suits our projects' needs, although it is never really possible to separate these two sides of designing. The two main concerns that arise when having to choose a certain program are budget and the complexity required. We will take a look at this more deeply further in this part.

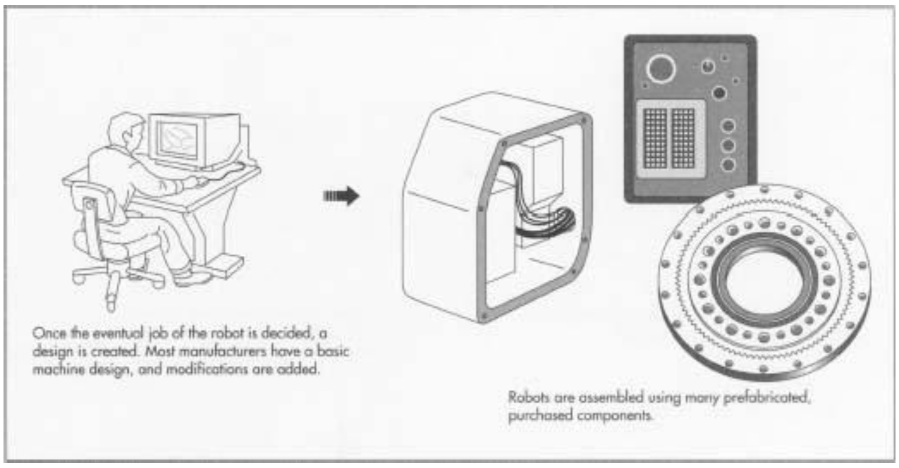

Once the eventual job of the robot is decided, a design is created. Most manufacturers have a basic machine design, and modifications are added.
Robots are assembled using many prefabricated, purchased components.

Figure 6: CAD/ CAM systems

In practice, it is most common to use CAD/ CAM solutions (computer aided design and manufacturing, fig. 6) which are programs specialized in working with CNC machines. In the same plant engineers design and manufacture using integrated systems sometimes specially built for their needs. Other times, general software can be used for most of the designing needs in the industry.

First, for example, it is well known for its professional use the software called CATIA [2] (computer aided three dimensional interactive application, see fig. 7). This software is fairly widespread among all areas of engineering that require 3D designing and it is a very powerful tool, but has the disadvantage of being an expensive commercial software as well as having a level of complexity above the average for this task. Apart from this software, there are many other commercial CAD tools, but they all share basically the same advantages and disadvantages mentioned (AutoCAD [3], AC3D [4], LightWave 3D [5], etc.)

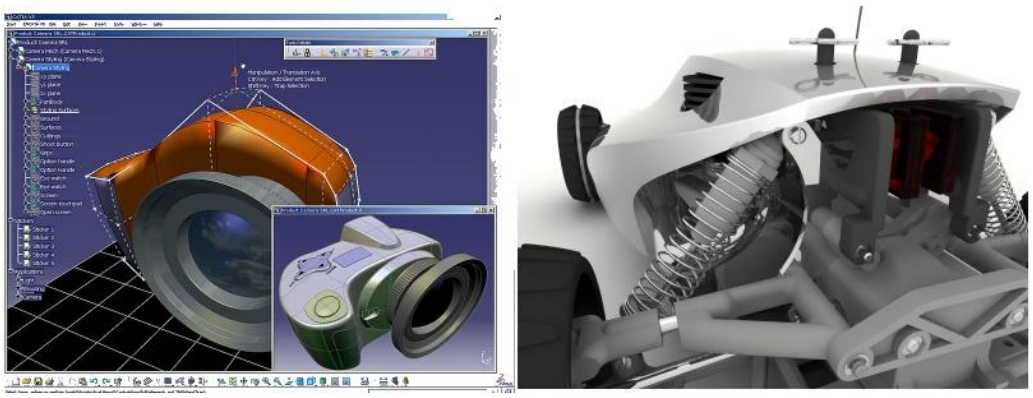


Figure 7: CATIA design and rendering

These are rather expensive options suitable for industrial purposes such as large scale manufacturing, aeronautics, etc. There are, on the other side, inexpensive or free tools (open source software) destined for less demanding projects that are, however, sufficient for most of the small projects or prototyping applications.

On the side of open source software tools we have less choice, but still there are some options with different peculiarities. We have, on one hand, interactive modelers such as Blender [6] or MeshLab [7] which allow for advanced 3D modeling, and on the other hand, a 3D parametric compiler called OpenSCAD [8].

For the manufacturing part, the CNC industrial equipment carry out operations such as machining, milling, laser cutting, threading, turning, etc. These machines execute code extracted from the designing software and execute movements according to a generated a set of instructions for each operation. For smaller projects, the designer can send the CAD file to a specialized shop and have their piece manufactured accordingly, which results in a higher unit cost.

Recently it is common to find both in professional and non-professional environments what is called a 3D printer which works adding layers of a certain material using a machine code as reference. 3D printers can be categorized from high precision state-of-the-art machines to affordable amateur printers. The first, are used together with professional CAD systems and the latter are usually used with open source software tools, both working with a digital model as reference (fig. 8).

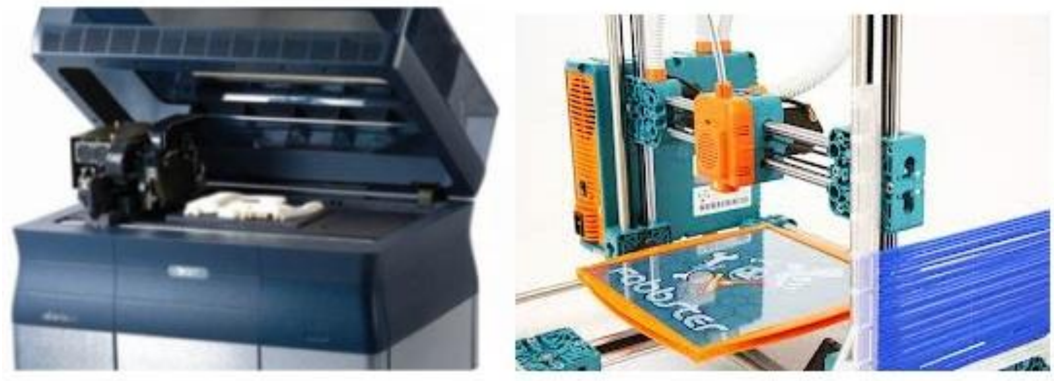


Figure 8: Professional and domestic use 3D printer

The pieces modeled with CAD software have to be “sliced” in order for the printer to be able to build each layer. With the CAD software, in this case OpenSCAD, we export the components into a STL format [9] which is an intermediate data interface between the rendering software and the machines code. This STL format approximates the object using triangular facets which, the smaller they are, produce a higher quality of surface.

3D printers have a working process called additive manufacturing since it works by adding successive layers of a special polymer until it “prints” the whole piece. Additive manufacturing is opposed to the traditional subtractive manufacturing which is a retronym for standard machining operations that use a raw object (filling, turning, milling, etc.) One advantage worth mentioning is that this technique allows for almost any shape, excluding thin based pieces that cannot support their own top parts.

A typical layer thickness resolution for 3d printers is 0.1 mm, although there are models such as the 3d systems’ ProJet series [10] that allow for lower resolutions, up to 16 micrometers. In the industry it is common to print a slightly oversized version of the object and then use a higher resolution subtracting process to remove the remaining material.

One last and important advantage of 3d printers is that most of them are approximately desktop sized, and certainly smaller than the common subtractive machines. This is the reason why it is advantageous to first print the piece and then perform machining processes on it.

Various polymers are used in 3D printers such as acrylonitrile butadiene styrene (ABS), PLA (ecological), polycarbonate (PC), polyphenylsulfone (PPSU) and high density polyethylene (HDPE). These polymers come as a filament wrapped around a cylinder forming a coil. This filament goes into the extruder and when it reaches the adequate temperature the plastic melts and the printer can start building the layers.

The previously mentioned non-professional printers are progressively entering the world of DIY (do-it-yourself) projects both in private and in academics environments (Universities, toy-shops). It is worth mentioning the longest running project in the desktop category called RepRap [11] which is a totally open source 3D printer whose full specifications are released under the GNU General Public License and capable of printing many of its own parts to create more machines. Another good example of a 3D printer is the Airwolf 3D (Prusa) which is also widespread among the open source community. In 2011 and 2012, prices of these printers have decreased drastically as they used to cost around 20000 US $ [12] compared to the less than $1000 that cost now.

2.2. Electronic hardware and programming

Previous to the release of the first single-chip microprocessor by Intel in 1971, there were, during the 1960s, computer processors built with hundreds of transistors and logic gates soldered, connecting several electronic boards which resulted in a poor performing and substantial heat loss, compared to the later integrated solutions. These were the boards used, for example, in the Apollo space mission [13] during the late 60s and early 70s. After this, the integration of a CPU in a single chip reduced the cost of processing power and its large scale production system led to lower unit costs (fig. 9). This automated manufacturing also led to doubling the number of components that could fit in a chip every two years [14]. These single chips had fewer electrical connections and thus an increased reliability. The world of electronics was soon to be revolutionized.

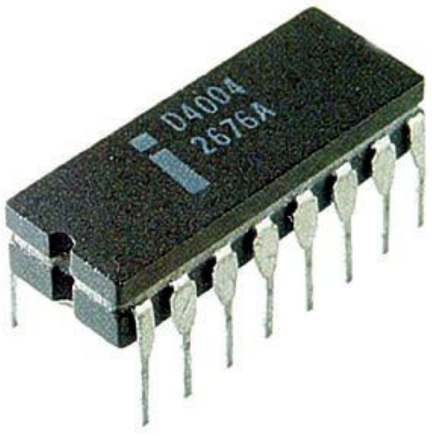


Figure 9: Intel 4004, the first commercial microprocessor

The previous medium-scaled integrated circuits architecture was used in the first microprocessors. The first, were used in calculators and other embedded systems such as terminals or automation devices. After this, in the mid-70s, they appeared in the first microcomputers. From this moment on, microprocessor architecture design starts to develop and expand.

In 1945, John Von Neumann published his organization of logical elements which IBM used to develop the IBM 701, the company's first commercial stored-program computer in 1952. Opposed to the Von Neumann architecture in which there are shared signals and memory for code and data, and the CPU can be either reading an instruction or writing/ reading data to/ from the memory, we have the Harvard architecture with physically separate storage and pathways for instructions and data. Also, in the Harvard architecture the CPU can both read an instruction and perform data memory access at the same time.

Computer architecture is the combination of microarchitecture and instruction set design. Microarchitecture is the way the instruction set architecture (ISA) is implemented in a microprocessor, so that a given ISA can be implemented with different microarchitectures. The instruction set architecture defines the codes that a central processor reads. A minimal hypothetical structure would include an Arithmetic Logic Unit (ALU) and a Control Logic section. The ALU performs logical operations while the logic section retrieves instruction operation codes from memory (fig. 10).

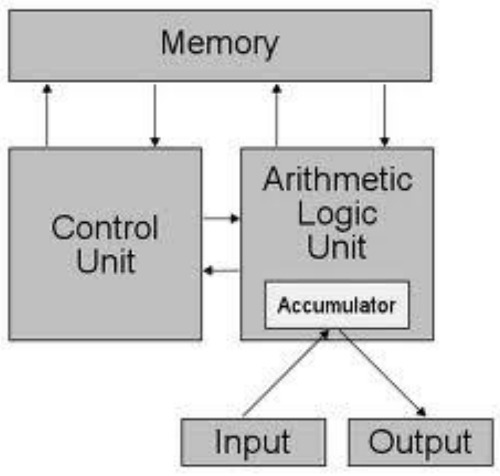


Figure 10: Basic Von Neumann processor architecture

In the next table we can see the differences between many of the processors found in the market.

Table 1: Basic information about CPU architectures [15]

Architecture	Bits	Introduced	Type	Design	Registers	Open
Alpha	64	1992	Register-Register	RISC	32	No
ARM	32	1983	Register-Register	RISC	16	Unknown
ARM	64	2011[2]	Register-Register	RISC	30	Unknown
AVR32	32	2006		RISC	15	Unknown
Blackfin	32	2000		RISC[4]	8	Unknown
DLX	32	1990		RISC	32	Unknown
eSi-RISC	16/32	2009	Register-Register	RISC	ago-72	No
Itanium (IA-64)	64	2001	Register-Register	EPIC	128	Yes
M32R	32	1997		RISC	16	Unknown
m68k	16/32	1979		CISC	16	Unknown
Mico32	32	2006	Register-Register	RISC	32[6]	Yes[7]
MIPS	64(32→64)	1981	Register-Register	RISC	32	Unknown
MMIX	64	1999	Register-Register	RISC	256	Yes
PA-RISC (HP/PA)	64(32→64)	1986		RISC	32	No
PowerPC	32/64(32→64)	1991	Register-Register	RISC	32	Yes[9]
S+core	16/32	2005		RISC		Unknown
Series 32000	32	1982	Memory-Memory	CISC	8	Unknown
SPARC	64(32→64)	1985	Register-Register	RISC	31 (of at least 55)	Yes
SuperH (SH)	32	1990s	Register-Register/ Register-Memory	RISC	16	Unknown
System/360 / System/370 /z /Architecture	64(32→64)	1964	Register-Memory/Memory-Memory	CISC	16	Unknown
VAX	32	1977	Memory-Memory	CISC	16	Unknown
x86	32(16→32)	1978	Register-Memory	CISC	8	No
x86-64	64	2003	Register-Memory	CISC	16	No

Today, most CPU architectures implement one of the next two instruction set design strategies: RISC, reduced instruction set computing, that uses a small, highly-optimized set of instructions that provide a high performance and a fast execution as opposed to CISC, complex instruction set computing with a specialized and more complex set of instructions.

	CISC	**RISC**
1	Emphasis on hardware	Emphasis on software
2	Multi-clock complex instructions	Single-clock, reduced instructions
3	Small code sizes	Larger code sizes
4	Many addressing modes	Few addressing modes
5	Easy compiler design	Complex compiler design
6	Pipelining does not function correctly because of complexity of instructions	Pipelining not a major problem, this option speeds up the processors

Table 2: CISC vs RISC CPU architectures

In table 1, we can observe the famous Intel's x86, which is a family of instruction set architectures, based on the 8086 (1978). Another worth mentioning microprocessors are the AVR [16] and ARM [17] families.

Intel has been one of the most important players in the recent history of microprocessor and embedded systems. As seen in the first picture of this chapter, the 4004 was the first commercial microprocessor by Intel in 1971. This 4-bit microprocessor was soon followed by an 8-bit 8008 processor, the first of its kind, which in turn was followed by the very successful 8080 (1974) with a much improved performance, being the first widely used microprocessor. Motorola had, at the same time, its competitor 6800. Later on, in 1978, a 16-bit processor called the 8086 was released and it was the first of the x86 family which powers most modern PC type computers. In the early 80s we started to see the first 32-bit processors being one of the most important the Motorola MC68000 [18]. Along with this processor another 32-bit worth mentioning units are the AT&T BELLMAC 32-A (the first with 32-bit data paths, buses and addresses), Intel's iAPX 432 and the first ARM (1985).

The next step were the 64-bit processors, which we could find in the 90s in several machines such as the Nintendo 64 gaming console, however, it was not until the early 2000s that this microprocessors targeted the PC market. Today the PC market is majorly divided between AMD and Intel, with an important share for both 32-bit and 64-bit architectures.

Microcontrollers

Sometimes abbreviated µC or MCU, microcontrollers are integrated circuits that can act as small computers used for embedded automatic controlled products or devices. Microcontrollers contain a similar structure as found in regular computers, integrating in a single circuit a processor core, memory and programmable input and output peripherals. The core is a microprocessor as described before, but there are several features that make microcontrollers the preferred solution for most systems that require an automatic response and behavior.

The following parts are usually found in a microcontroller:

- Central processing unit (CPU), ranging from 4 up to 64 bits.
- Volatile memory (RAM) for volatile data storage.
- Non-volatile program memory. This can be PROM, EPROM, EEPROM or flash.
- Serial input and output such as serial ports, and other serial communications interfaces (SPI, I2C, etc.)
- Peripherals such as timers or PWM generators.

- Clock
- Analog-to-digital converter or/and Digital-to-analog converter, with analog and digital inputs or outputs.
- In-circuit programming.

These features are what make a microcontroller different from a single microprocessor.

At the same time that Intel started producing the 4004 (1971), the first microcontroller was about to see the light thanks to the engineers Gary Boone and Michael Cochran [19]. The result of their work was the TMS 1000, the first lone-chipped CPU which went commercial in 1974. Soon after, and partly in response to this, Intel developed the 8048 (1977), a chip optimized for control applications becoming one of the most successful microcontrollers in the company's history. They sold over one billion 8048 chips mostly for keyboards and other numerous applications.

At this time, microcontrollers had two memory variants. One was only programmable once (PROM) and the other, called EPROM (erasable PROM) could be rewritten thanks to a quartz window allowing for ultraviolet light exposure and thus making it erasable. These two memories were actually the same, but the EPROM required a ceramic package instead of an opaque plastic package as found in the PROM version. Only the ceramic package with the quartz window made the EPROM a much more expensive option.

Later, in 1993, an electrically erasable programmable read-only memory (EEPROM) was introduced which allowed users to quickly erase the memory without the need of an expensive package. This kind of technology also allowed for in-system programming (write data in a completely installed system). In the same year, a new kind of EEPROM was introduced by Atmel called Flash memory and quickly other companies started manufacturing with this kind of technology. In the future, a possible new technology still under development could be used as a replacement for flash memories: The MRAM (magnetoresistive random-access memory), with a better performance, power consumption, and faster access times [20].

Nowadays, the unit cost of microcontrollers has decreased to a minimum, resulting sometimes, in $1 or fractions of a dollar per unit. It is estimated that around 55% of all CPUs are 8-bit microcontrollers of microprocessors. These inexpensive 8-bit processors suit perfectly for endless purposes such as automobiles, office and home systems, medical equipment, robots, toys, remote controls and many other embedded systems. 8-bit processors have the advantages of being robust and easy to program and they are rather inexpensive low consumption solutions with a size that fits almost in any system.

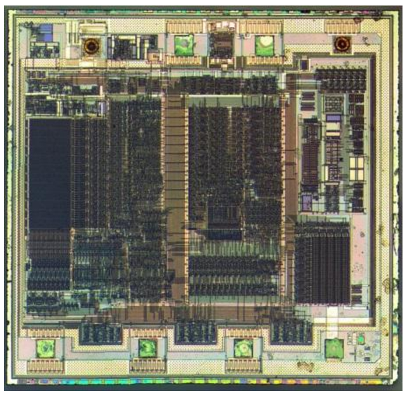


Figure 11: Die of an 8-bit PIC EEPROM microcontroller by Microchip [21]

Depending on the system requirements we can find processors from 4-bits, for devices that can operate with small data sizes, up to 64-bits microprocessors for the most demanding systems. The first, together with 8-bit processors can be found in digital calculators (HP-48) and remote controls, although nowadays it is becoming difficult to find 4-bits processors. 8-bit processors enable engineers to support a wide range of applications and functions including automotive, motor control, LCD drivers, USB connectivity, lighting applications and more. A typical mid-range automobile is estimated to have around 30 microcontrollers, typically for window lift, low end airbags, pumps, steering angle sensors, cooling fans and valve/ throttle control. This is the case, for example, of the 8-bit microcontroller family XC800 by Infineon [22]. However, in both industrial and automotive applications, it is becoming more common to find 32-bit microcontrollers as its unit cost is similar to the previously mentioned processors, but these can operate with bigger data sizes (fig 12.).

Figure 12: Some common microcontroller applications

It is worth mentioning a family of modified Harvard architecture microcontrollers from Microchip Technology called PIC [23], (Peripheral Interface Controller, see figure 11) popular among both industrial developers and hobbyists due to low cost and wide availability (users could usually get free samples). Also used for educational purposes, these microcontrollers have been used in the last years and have become tremendously famous.

In the last few years, supported by the internet community, there has been a substantial growth in the use of a new kind of open source microcontrollers and programmable hardware by a new generation of enthusiasts all around the world that use them as powerful tools to carry out projects either in the field of education or just as a hobby. For engineering students or graduates these new microcontrollers serve as great tools for developing their ideas or projects. Where PIC microcontrollers used to be the rule for small projects, prototypes and hobbyists devices a new family of microcontrollers called ARDUINO [24] has displaced it, becoming, in short time, a very famous tool for developing almost any engineering project that requires a microcontroller.

In 2006, the Arduino Uno was announced (Fig. 13), and from then on, the Arduino community started. This project is based on an Arduino microcontroller, and therefore, we will explore in detail the characteristics of this product.

It is quite essential, nowadays, that for a kind of technology such as this to succeed there is a huge community behind it to support it as well as a vast source of information where developers can easily find the solution to their problems and at the same time contribute to that community to help others.

Figure 13: Arduino UNO: The most used Arduino microcontroller

As we can see in the picture, in the Arduino microcontrollers we have a typical layout where we can easily spot the microprocessor, input/ output pins, serial peripherals, USB connector, a button, etc.

What makes this technology preferable over other options is the fact that every part of the Arduino family devices is open source, what makes it more accessible and maintainable. From users to companies everyone can contribute either writing new software such as libraries, firmware or program codes or developing new electronic boards based on the Arduino configuration.

The original Arduino boards are manufactured by the Italian company Smart Projects, and other typical Arduino-branded boards have been designed by the American company SparkFun Electronics.

Some of the official boards:

- Arduino Extreme with USB interface and ATmega8.
- Arduino Mini, a miniature version using ATmega168.
- Arduino Nano, even smaller with ATmega328.
- Arduino Bluetooth, with a Bluetooth interface.
- Arduino Mega with additional I/O and memory.

Many other Arduino boards can be found in the market manufactured by other companies or engineers.

Before starting in detail with the Arduino project, it is worth mentioning that other new devices are just starting to see the light and seem to be plausible competitors for the most demanding needs. Projects that may need a higher computing power and more versatility are becoming more frequent since they incorporate all components of a computer in a single embedded electronic board. As an example, we have single-board-computers (SBC) such as Raspberry Pi (fig. 14, BeagleBoard-XM or iMX233 suitable for running desktop software (Windows, Linux) and with a much larger RAM and flash memory than the typical microcontrollers. Processors on SBCs are also more powerful and capable of dealing with more computing workload.

This integration of computing power is an answer to the demands of complex systems of processes. Optimized chips for specific processes or particular tasks are rather expensive and rigid options, so these embedded systems are usually the answer for integrating all processing and automation power in one single board, resulting in a more affordable option.

Figure 14: Raspberry Pi

Arduino Hardware

The first Arduino microcontrollers were based on 8-bit Atmel AVR microcontrollers, typically the megaAVR series of chips, with complementary components to facilitate its integration with other circuits. More recently, a new version has been designed around a 32-bit

Atmel ARM. The pin connectors are exposed allowing the board to be connected to other external interchangeable modules called shields in order to get extra features (connectivity, battery, etc.). Most include a 5 Volt line regulator, although there can be found some that operate at 3V. They usually include a 16 MHz or 8 MHz crystal oscillator or ceramic resonator.

They come pre-programmed with a boot loader to help uploading programs to the flash memory so that they do not need an external programmer. All boards can be programmed with an RS-232 serial connection although the way this is implemented varies for some hardware versions. They use an FTDI cable (USB to serial) that can be detachable or incorporated to the board. There is also a way of programming it wirelessly either by Bluetooth or Wi-Fi.

The fact that the hardware design is open source means that users can be perfectly aware of every component of the board and, what is more, they can build their own version with single electronic components that are found in any electronics store. This way, developers can also program the microprocessor with an AVR programmer for the firmware (Fig. 15).

Figure 15: Tiny AVR ISP programmer [25].

Some companies such as DIGI, Roving-Networks or Adafruit Industries manufacture shields that suit Arduino projects. Roving-Networks and

DIGI have a variety of Radio modules that can operate with Bluetooth or Wi-Fi protocols and Adafruit makes, for example, a special shield for motor control.

Arduino boards can be powered with normal 9V or 5V batteries, LiPo batteries and also have a solar panel support (Fig. 16).

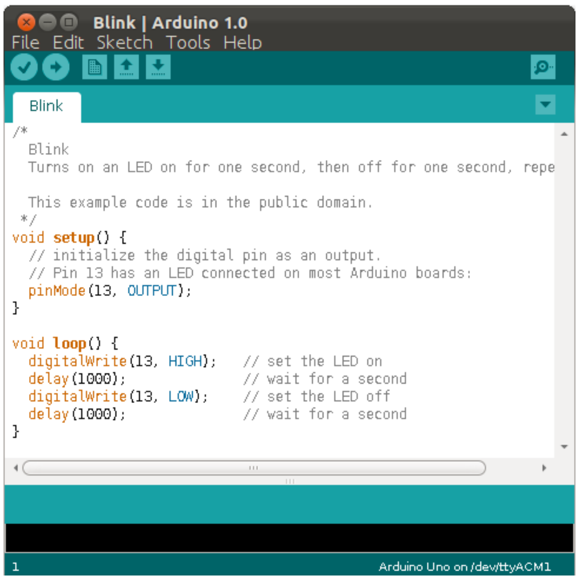
Figure 16: LiPo battery and small-sized solar cells [26]

Arduino Software

In order to program the Arduino microcontrollers, the founders of the project designed and created a tool intended to be easy and intuitive for new users. This is called the Arduino IDE (integrated development environment), a Java written program that allows developers to write, debug and compile programs as well as uploading them to the electronic board. It is derived from the Processing [27] programming language IDE which is an open source programming language built with the purpose of teaching the fundamentals of computer programming in a visual context.

The programs written for the Arduino are called Sketches and are written in C or C++. The IDE comes integrated with some libraries such as the Wiring library which makes it easy to operate with inputs and outputs, and other standard libraries for working with extra hardware (servos, internet shields, steppers or LCDs). Nevertheless, Developers can include extra libraries either creating them for particular needs (extra hardware, specific math functions, etc.) or using other developers' libraries. In line with the philosophy of open source coding, developers usually publish their new libraries and maintain the code for others to incorporate them in their own projects. These projects, if published, at the same time serve as guidance and support for others. This cyclic contact is what nourishes the developer's community, and in the end contributes to the Arduino project. In fact, as soon as a new piece of hardware that is subject to be incorporated to Arduino boards goes commercial, documentation in the form of libraries, code examples and troubleshooting instantly appears on specialized Arduino and DIY forums.

In order for users to make runnable cyclic executive programs in Arduino, they only need to write two functions called setup() and loop(). The First, is executed only once for initializing settings and variables. The loop() function runs cyclically until the board powers off (fig. 17).



```
/*
  Blink
  Turns on an LED on for one second, then off for one second, repe

  This example code is in the public domain.
 */
void setup() {
  // initialize the digital pin as an output.
  // Pin 13 has an LED connected on most Arduino boards:
  pinMode(13, OUTPUT);
}

void loop() {
  digitalWrite(13, HIGH);   // set the LED on
  delay(1000);              // wait for a second
  digitalWrite(13, LOW);    // set the LED off
  delay(1000);              // wait for a second
}
```

Figure 17: VIew of the Arduino development environment [24]

All Arduino software tools are available for Windows, Linux and Mac platforms.

Communications hardware

As mentioned before, Arduino boards allow for external modules or shields to be attached to them in order to provide extra features to an existing design. In particular, for external communications we have devices either for wired or wireless connections. For the first, there is for example, an Ethernet shield capable of providing internet (RJ-45) connections, and for the latter we can choose among various technologies depending on the protocols they use.

There are plenty RF modules available in the market belonging to the WPAN standards (wireless personal area networks) that operate in the 802.15 frequencies working group. The IEEE 802.15 is a group of standards for local area communications used in many devices and products. For example, we have the DIGI's ZigBee RF modules [28] that use the 802.15.4 standard or other DIGI's modules with 802.15.1 (first Bluetooth assigned standard). Apart from Bluetooth, and radio frequency, makers such as Roving-Networks or DIGI among others sell 802.11 b/g/n modules for Wi-Fi connections, capable of acting as server or clients depending on the desired topology or our system.

From all available devices for wireless communications, we have to choose one that is suitable for Arduino, not very expensive and pluggable into an XBee socket. At this point we have two options, first a DIGI's XBee Bluetooth module, which in short acts as a node for an Ad-Hoc connection allowing for two XBees modules to interact in short distances with low power consumption. Second, we have the option to use a Wi-Fi module (Roving Networks RN-171 [29]) which is a little bit more expensive.

The first module is easy to configure on windows, with a program called X-CTU but users need an extra device for it, an USB adapter. Also, these modules are thought to be used normally in pairs, communicating with one another so it is a bit of an issue to get one working with a more complex device, for example a smartphone. Another disadvantage of the Bluetooth module is that it only works well in short distances allowing only for Ad-Hoc connections. On the other hand it has three worth mentioning advantages which are lower consumption than the Wi-Fi module, lower market price and is easier to use.

The second option is the RN-171 Wi-Fi module which allows for more complex types of wireless networks. Users can interact with this module in Ad-hoc mode and more importantly, with an access point. Both ways this module can act as a server or as a client depending on what role it is playing in a specific topology. A drawback for using Wi-Fi Ad-hoc connections with Android is that only the last version (4, Jelly Bean) allows for it.

2.3. DC Motors

In the world of robotics, most of the times engineers incorporate DC motors to every kind of robot due to the electronic controlling advantages, motor sizes and the fact that robots are usually powered by DC currents and voltages. In the industry, robot actuators can also be pneumatic or hydraulic differing only in their capability to pressure the fluid. Pneumatic actuators, compared to hydraulic, are low cost ecological solutions for less demanding forces whereas hydraulic actuators stand high power loads. Both have the advantage of having non-electrical components, making them the best option for critical environments or processes.

The third and previously mentioned option, the electric actuators, is by far, the most implemented in industrial or domestic robots. There are basically three kinds of electric motors: AC, DC and stepper motors. In high-power single or multiphase industrial applications AC motors are used where a constant rotational torque and speed is required to control large loads. On the other hand, for light duty applications and since many autonomous robots are powered by DC batteries, the actuators that they incorporate must be DC motors or steppers. These are used along with microcontrollers, positional electronics and small robots.

Before entering into the types of DC motors we will discuss some important variables that should be considered when designing robot motion functionalities.

The two most important values when powering a DC motor are voltage and current, where voltage is related to speed and current to the torque that we make the motor develop.

Further considerations

It is important to bear in mind that a constant current produces a constant torque regardless of speed and given a constant load (constant torque) the speed of a motor only depends on the voltage applied to it. The maximum power (product of torque and speed) is produced at the operating point of half the no-load speed together with half the stall torque, although due to thermal considerations, a DC motor will not normally operate at maximum power. When supplying a constant voltage the speed and torque are inversely related so that the higher the torque that the motor is forced to develop, the lower the speed will be. Last, for lower noise generation and better life characteristics the motor should be chosen with higher voltage ratings than the voltage supply, and when using with gearing it should be selected for the minimum speed [30].

Types of DC motors

Brushed DC motor

These are a classical example of DC motors. The stator generates a permanent magnetic field that surrounds the rotor either with permanent magnets or electromagnetic windings whereas the rotor is made up with one or more windings. The rotor receives current through a commutator and carbon brush assembly, hence the term “brushed” (fig. 18).

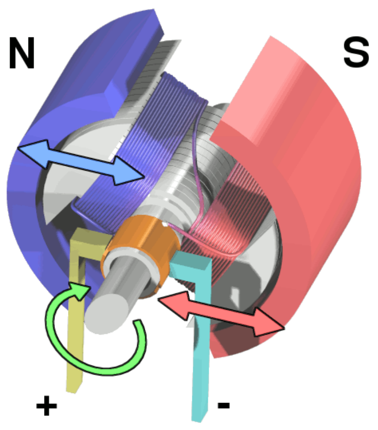


Figure 18: Two-pole brushed DC motor

With brushed DC motors, on one hand it is simple to modify the speed of the motor by applying different voltages, so in order to make it rotate faster one only has to increase the voltage. On the other hand, however, if the user wants to rotate it in both directions it is necessary to build a controller, an expensive option unless it is possible to build an H-bridge. It is possible to use pulse width modulation (PWM) to increase/ decrease the speed without compromising the power, which is a better option than changing the voltage. A square signal acts, in essence, as a variable average voltage. These motors are cheap, small and easily controllable but they produce a relatively low torque [31].

Brushless DC motors

In this type of motor the rotor is a permanent magnet whereas the stator is an electromagnet. Instead of using brushes, commutation is achieved electronically so in order to detect changes in orientation brushless motors generally use Hall-effect sensors to detect the rotor's magnetic field. These motors are more expensive than the previous kind because of their design complexity and they need a controller to control the speed and rotation.

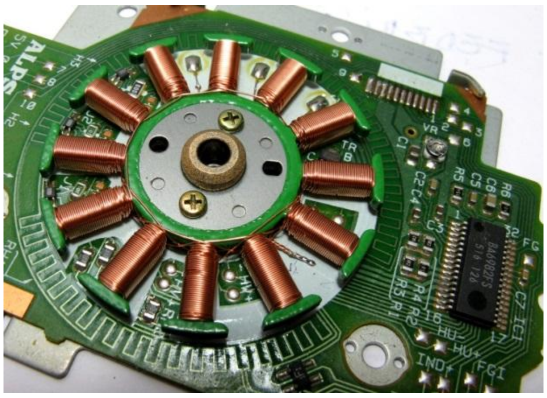


Figure 19: Floppy-Disk brushless DC motors

They are more efficient and have a longer life thus being more capable for robotic applications providing more torque and speed than brushed motors. They are usually found in floppy-disks (fig. 19) and other low-noise devices [31].

Stepper motors

Basically a sub-type of brushless motors, stepper motors only have more magnetic poles on the stator. They convert a pulsed digital input signal into a discrete mechanical movement and require a special controller for the current to be applied in the desired sequence. The rotor is made up of sometimes hundreds of magnetic teeth and it does not move in a continuous fashion but in discrete steps, thus the name stepper motor. They are used in many industrial control applications that require accurate positioning with low-time response [31].

Servomotors

These are brushed motors integrated with a control system that enables precise positioning as they are built coupled with a feedback control circuitry. The way to control them is by PWM and the typical positional and speed feedback devices are encoders, resolvers and potentiometers. They also incorporate a gear system to increase the torque and decrease the speed [31].

Servomotors, unmodified, do not exhibit continuous rotation and are used for various purposes from robotics, CNC machinery, automated manufacturing and RC devices. They are used for higher performance needs compared to stepper motors.

Their input is a signal that can be either analog or digital and it represents the position commanded for the output shaft. The difference between servos and the previous DC motors is that these are closed-loop mechanisms that incorporate circuitry and gearing.

Figure 20: Industrial servomotor

As mentioned before, servomotors are widely used in the industry due to their high performance in relation to accurate positioning, speed, and torque. Plus, they usually incorporate error control circuits (figure 20).

For **non-industrial** inexpensive solutions, there are also mass-produced servos suitable for any engineer or electronics amateur available from $2 to a range of $100-$200, offering a relatively good performance in most cases. They were commonly used in radio control devices (RC), but have had a huge increase in the world of small robotics.

These servos have a potentiometer for measuring the position of the output, and from the comparison between that position and the commanded position an error signal is generated to drive the motor. The servo will stop moving when it reaches the zero-error position (a PWM commanded position) (fig. 21).

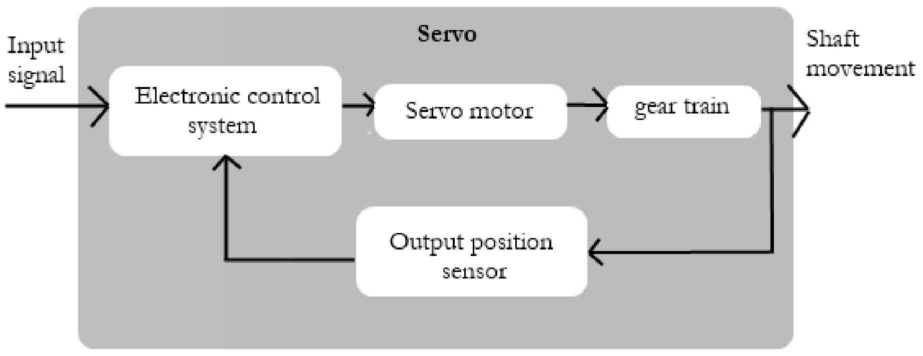


Figure 21: Servo block diagram

Servo hacking

As for these small versatile servos, it is common practice to use them for continuous rotation projects such as robot wheels, or robot arms that need to rotate more than the servo's limited angle range since most standard servos allow the shaft to be positioned only between 0 to 180 degrees. In order to do this, users have to modify some **mechanical** and **electrical** components of the servo. Each servo has its differences, so the way to achieve this varies from servo to servo.

First, one should eliminate any mechanical stops that the shaft, gears or potentiometer may have in order to let the shaft rotate beyond a full revolution.

Second, it is necessary to cancel the feedback that the circuit sends to the DC motor through the potentiometer, eliminating the electrical connection between this and the circuit that controls the DC motor. The potentiometer, however, should be kept as it normally is part of the shaft or the shaft itself.

These are the common steps to modifying servos, but the way it is achieved may vary from model to model. Next, some common parts found in a servo.

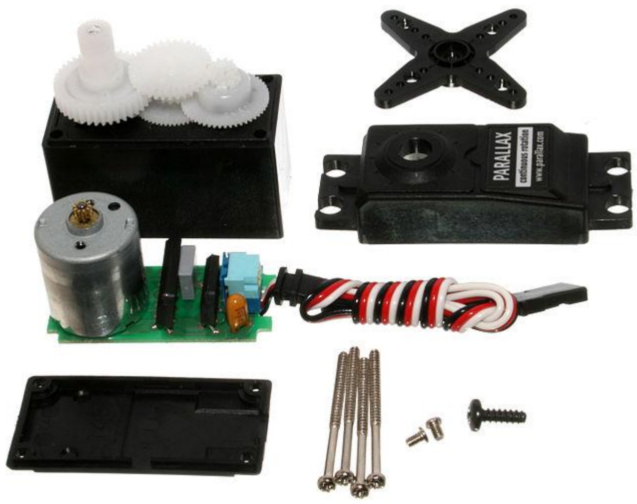


Figure 22: Common servo parts

Table 3: Widely used servos and their features [32]

Make - Model	Modulation	Weight	Torque	Speed	Motor Type	Gear Material	Street Price
TowerPro MG995	Analog	1.94 oz (55.0 g)	**4.8V:** (10.0 kg-cm)	**4.8V:** 0.20 sec/60°	Coreless	Metal	$11.95
TowerPro SG-5010	Analog	1.34 oz (38.0 g)	**4.8V:** (8.0 kg-cm) **6.0V:** (11.0 kg-cm)	**4.8V:** 0.17 sec/60° **6.0V:** 0.14 sec/60°	3-pole	Plastic	$8.90
Align DS610	Digital	1.85 oz (52.5 g)	**4.8V:** (9.6 kg-cm) **6.0V:** (12.0 kg-cm)	**4.8V:** 0.10 sec/60° **6.0V:** 0.08 sec/60°	Coreless	Titanium	$67.99
Align DS520	Digital	0.91 oz (25.9 g)	**4.8V:** (1.9 kg-cm) **6.0V:** (2.5 kg-cm)	**4.8V:** 0.09 sec/60° **6.0V:** 0.07 sec/60°	Coreless	Plastic	$49.99
Hextronik HXT900	Analog	0.32 oz (9.1 g)	**4.8V:** (1.6 kg-cm)	**4.8V:** 0.12 sec/60°	Coreless	Plastic	$3.65
Hitec HS-645MG	Analog	1.95 oz (55.2 g)	**4.8V:** (7.7 kg-cm) **6.0V:** (9.6 kg-cm)	**4.8V:** 0.24 sec/60° **6.0V:** 0.20 sec/60°	3-pole	Metal	$39.95
Hitec HS-311	Analog	1.52 oz (43.0 g)	**4.8V:** (3.0 kg-cm) **6.0V:** (3.5 kg-cm)	**4.8V:** 0.19 sec/60° **6.0V:** 0.15 sec/60°	3-pole	Plastic	$12.95
Futaba S3001	Analog	1.59 oz (45.0 g)	**4.8V:** (2.4 kg-cm) **6.0V:** (3.0 kg-cm)	**4.8V:** 0.28 sec/60° **6.0V:** 0.22 sec/60°	3-pole	Plastic	$24.99
Hitec HS-5955TG	Digital	2.17 oz (61.5 g)	**4.8V:** (18.0 kg-cm) **6.0V:** (24.0 kg-cm)	**4.8V:** 0.19 sec/60° **6.0V:** 0.15 sec/60°	Coreless	Titanium	$98.98
Futaba S3010	Analog	1.45 oz (41.0 g)	**4.8V:** (5.2 kg-cm) **6.0V:** (6.5 kg-cm)	**4.8V:** 0.20 sec/60° **6.0V:** 0.16 sec/60°	3-pole	Plastic	$24.99

Recently, it is also possible to purchase continuous rotation servos so that we can avoid tampering with them, but these are more expensive and not as common as the limited range servos.

Locomotion issues

When designing a robot, we should first consider the way we want it to move through its environment and how it should accomplish it, depending on what advantages and disadvantages each locomotion type has and how they suit our robot's requirements. [33]

Legged locomotion. Often inspired by biological systems, these kinds of mechanisms are very successful in moving through a wide area of harsh environments but often have problems with stability, complexity and power consumption. A legged robot is well suited for rough terrain, since it is able to cross gaps, climb steps and cross obstacles so it usually is the right choice when there are ground irregularities.

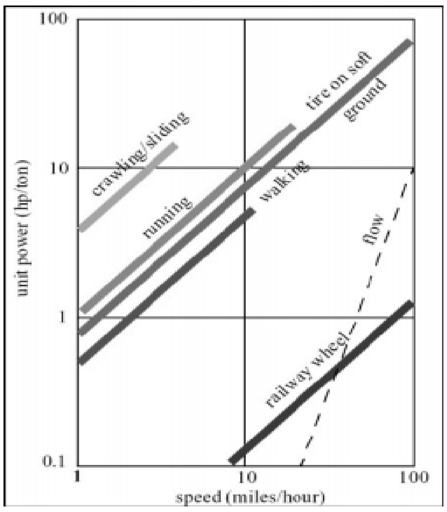


Figure 23: Power consumption of different locomotion mechanisms [33]

As we can see in figure 23 compared to wheeled robots, these are two orders of magnitude more inefficient on a hard, flat surface since legged motors need more motors and thus more degrees of freedom than the first. However, the legged locomotion is more power efficient than wheeled when the ground is softer.

Stability is also an important issue. From 1 leg to n legs, including 2, 4 and 6 (normally based on animal or insect movements) static and dynamic stability is a complex engineering challenge, certainly more difficult than the wheeled robots case.

Wheeled locomotion. This is the most popular method for providing robot mobility. It is normally more power efficient, and requires a simpler mechanical approach, less motors and it is stable most of the time. There are robots with two wheels, with a third stable point, but it is more common to find 4-wheeled robots for better traction (sometimes more 6 or more wheels). Stability here is not a major problem, but there are other issues worth mentioning. The focus on research in wheeled robotics is on traction, stability on rough terrain, maneuverability and control.

- **Stability**: It is only necessary that the center of gravity is on the stability polygon.
- **Maneuverability**. If the movement is differential, (turning is achieved by powering the wheels at different speeds) the robot will be omnidirectional. If the robot has an Ackermann steering configuration, used by cars, the vehicle will have a turning radius larger than itself, which results in less maneuverability.
- **Controllability**. The disadvantage of the differential configuration is that controlling the robot becomes harder than with the Ackermann configuration. For example, it is difficult to keep the robot in a straight line compared to standard vehicles since these use the same power for both wheels.

Here there are some examples for wheeled robots:

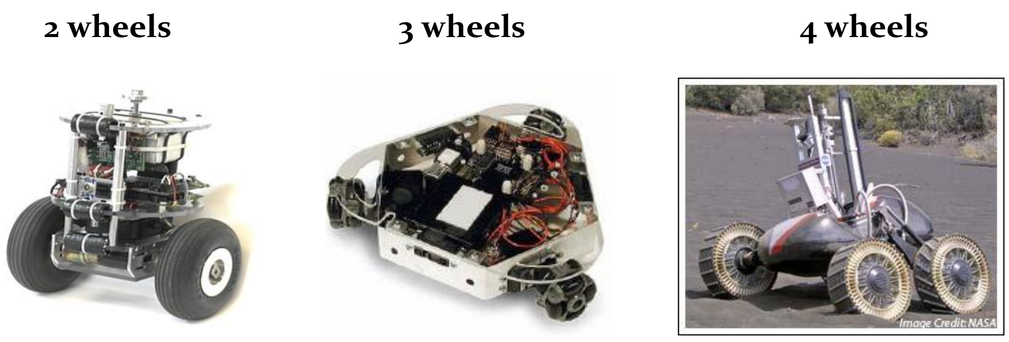


Figure 24: (a) Wheeled robot; (b) Kovan robot & (c) NASA's wheeled robot.

The first (fig. 24a) is the simplest configuration. For a correct balancing, it is necessary that the center of mass is below the axle. Difficult to control but good maneuverability. Cheap and small.

The second configuration (shown in figure 24b) consists in three steering wheels arranged in a triangle. Usually for indoors. Great maneuverability. All wheels driven by a single belt.

The last Image (fig 24c) shows NASA's rover. A 4-wheeled robot with the two front wheels acting as steering and the rear two as drivers. This is the preferable configuration for non-flat surfaces.

2.4. Smartphone Applications

Over the past few years, the market of touchscreen mobile devices has experienced an enormous growth to the extent that, according to the last surveys [34], around half of the **US** mobile consumers own smartphones. The **European** mobile market as measured by active subscribers of the top 50 networks is 860 million and the rate of smartphone adoption is accelerating, and is soon expected to reach a third of the sales [35].

A smartphone is a mobile phone built on an operating system, with more advanced computing capability than a feature phone (media players, camera, GPS, internet browsing, etc.).

Although the term was coined years before, the real push that opened this market was the original iPhone by Apple Inc. in 2007, one of the first mobile phones to use a multi-touch interface. After, in July 2008, Apple announced its second generation phone with **3G** support. By then, the App Store reached over 1000 million downloads in the first year having started with only 500. Two more versions of the iPhone have been released so far, being Apple the leading company in all aspects from design to functionality [36].

Following the success of the Apple's App Store other smartphone manufacturers soon launched their own software application stores, such as Google's Android Market or Blackberry's App World between others.

The Applications market is highly attractive for small companies and third-parties. In 2012, the Apple's Store recorded $5782 million of revenues, relatively high compared to other competitor's stores. This could be attributed to having the largest number of applications or apps available as well as the highest download volume in 2010. Also, only 28% of the apps in the Apple Store were free compared to the 57% in the Android Market [37].

In the next image we can see how deep the smartphone share is in each market:

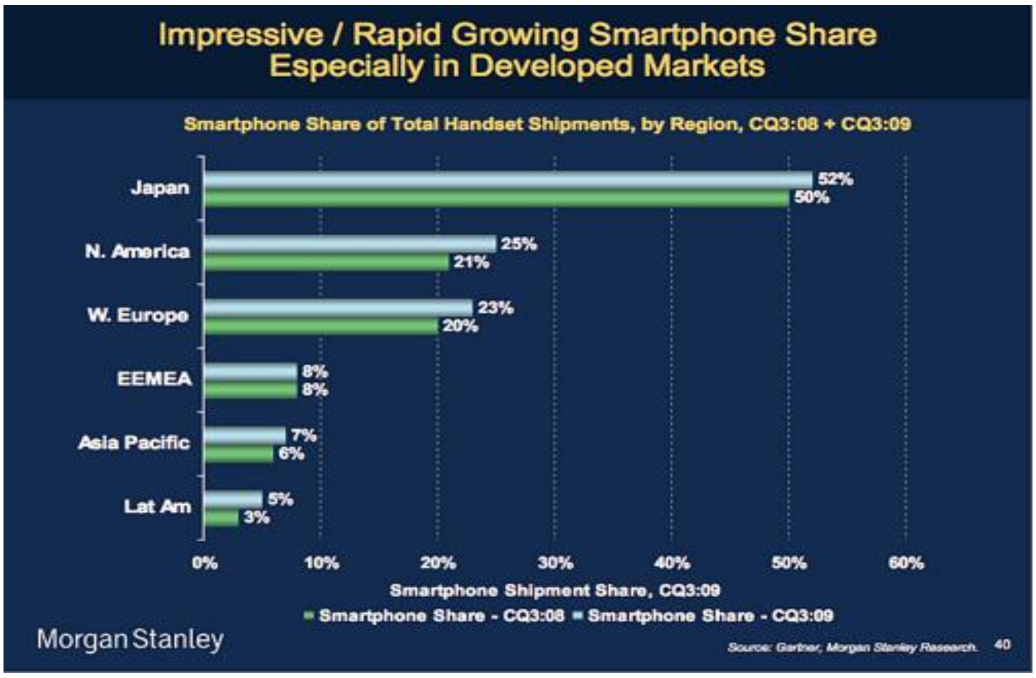


Figure 25: Smartphone share per region

As we can see, the leading market for smartphone sales is the Japanese market, followed by the American market. The special case of Japan can be explained by their early and massive use of mobile devices, with more rotation than in other markets and always 3 or 4 years ahead. In Japan, almost all technological advances are in more widespread than in other countries and the smartphone market has never been an exception for this. Forecasts are optimistic about a complete penetration of smartphones for all mobile device users as we can see next (by the end of 2014 an 80% of population is supposed to be carrying a smartphone):

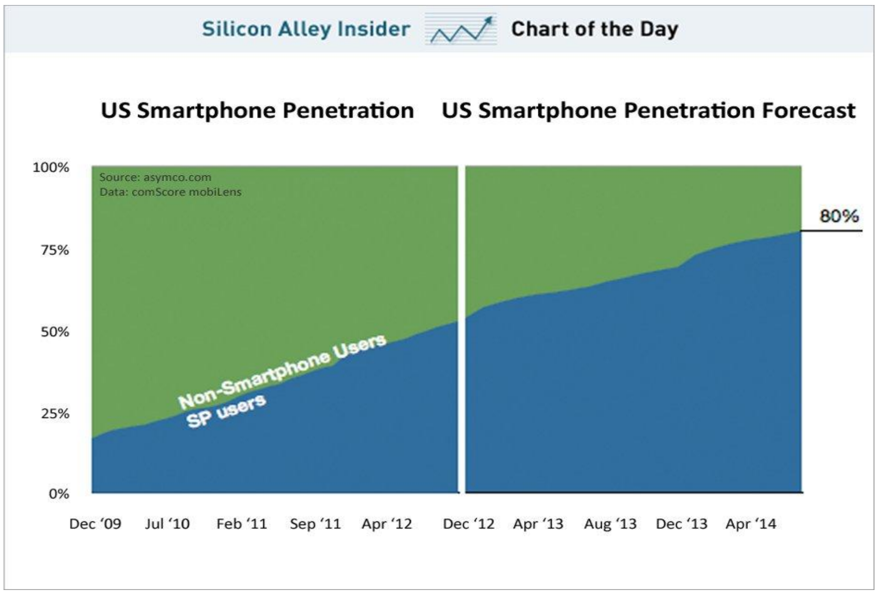


Figure 26: US smartphone penetration

In the rising years of smartphone technology the software and hardware market had the next distribution:

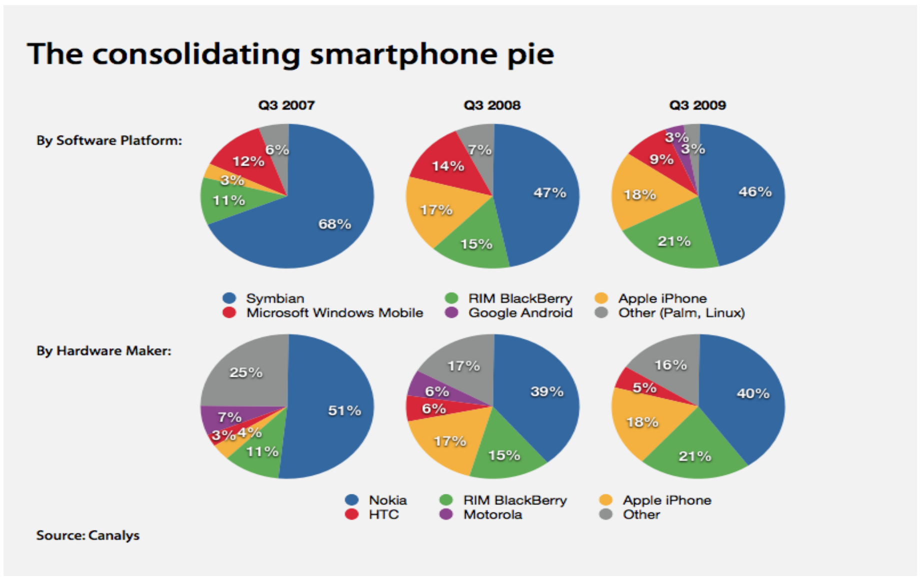


Figure 27: Software and hardware platform pie

We can see that both in software and hardware markets, Apple has experienced a notable growth while Nokia has decreased its share accordingly. It is important to remember that before the smartphone era, Nokia was the undisputable leader and Apple was not even a player in this market.

Nowadays, however, Apple's iOS and Google's Android are the two biggest competitors in both number of applications and market share, which translates into smartphone sales as users perceive the availability and utility of the applications software as a key factor for a mobile device election. Also, in the last 2 years tablets have joined this hardware market competing in the same application stores. Tablets are intended for different reasons (with less portability, bigger screens, less connectivity) but share almost all apps with smartphones.

The next chart shows the number of applications in each store for every of the last years.

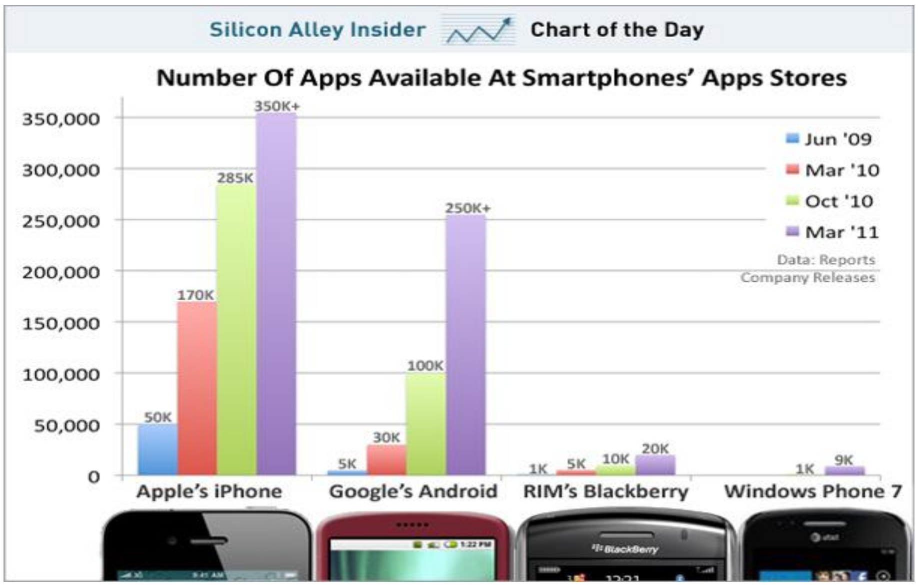


Figure 28: Apps available per platform

This actually does not translate into sales (hardware and software) in the same relation as shown for number of applications offered per store. In the next chart we can see how Apple's App Store is losing ground against Android, which is its major competitor right now. Before smartphones were ruling the technological panorama the most installed systems were from Nokia (Symbian), Microsoft, Palm and Blackberry (Rim).

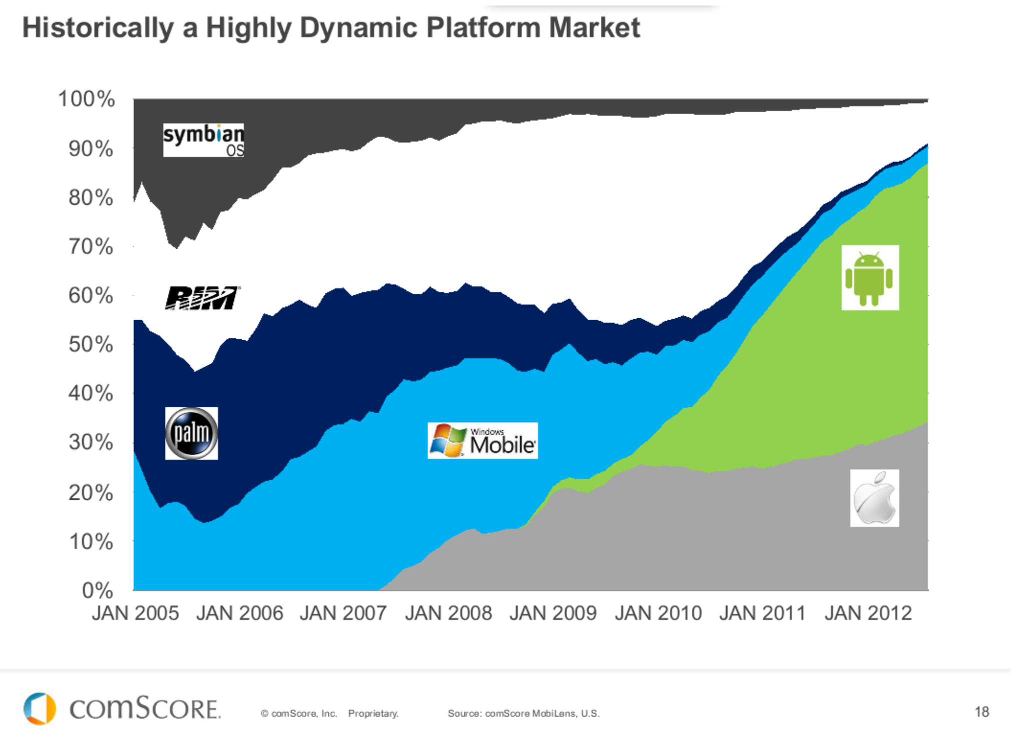


Figure 29: Platform market development

As mentioned before, Apple's iPhone meant a breaking point in both the perception users have from a mobile OS and the performance and usability that companies give to their systems (fig 31.). New mobile devices allow for user-friendly applications in all aspects possible, from internet browsing, web services, camera applications, etc. These requirements were only met first by Apple and also now by Android.

In conclusion, with this information we can foresee an attractive future for investors and developers in the applications software environment. Smartphones are becoming more than just a communicating tool to become all-in-one devices with which we can control and monitor any other electronic devices subject to wireless communications.

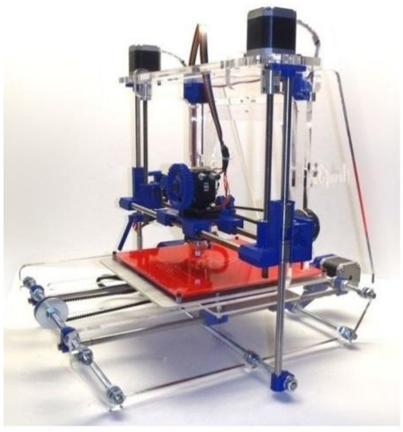
At this point, when developing applications most companies choose building multi-platform applications for both Android and iPhone. Both operating systems are widely used and cannot be set aside. However there are big differences in both worlds while developing and programming that should be noticed.

On one hand, **Android** is completely open source, has a large community of developers and is a light-weight operating system. It is completely free to start developing for it, and has a vast database of resources available on the internet, but applications should be runnable by many different devices, with different hardware configurations and computing power.

On the other hand, the **iOS** for iPhone is only intended to work in iPhones thus making it easier for developers to develop focusing less on hardware requirements and more on code. It is a proprietary system available only for Apple's devices and it costs $99 to become an iOS developer and purchase the complete developing toolset (version for developers outside Apple).

Chapter 3

Design and manufacture



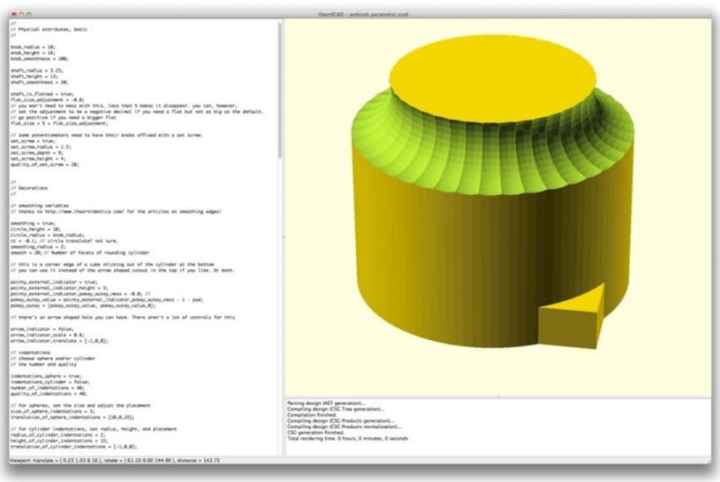
Although one of the main concerns of this project is providing robots with the capability of teleoperation, there has been no better way of carrying this out than building the robot itself, allowing for great versatility and full understanding between both the commanding part and the robot. This is also a substantial and important part, since we determine how the robot is going to physically behave according to how we implement the control and programming.

By being able to design the robot from scratch we try to simplify its mechanic behavior allowing for a more robust prototype in the sense that we can focus on the main issues rather than having to deal with unwanted working areas, such as behavior against obstacles, energy efficiency, high torques or accelerations, degrees of freedom or even less the appearance of the machine. Nevertheless, by designing the robot with the simplest way of movement, which is two wheels, we do not lose the flexibility that a more complex topology might provide. Instead, it can change speed and direction almost instantly when commanded and at the same time assuring reliability.

3.1. 3D modeling and design

For the purpose of designing and modeling the structure of the different parts of the robot there are different tools available, each having their advantages and disadvantages, as mentioned in the background chapter.

For this project it has been decided that OpenSCAD is the best choice since it focuses on the computer aided design aspects instead of the artistic aspects. This software is entirely open source, and a very powerful **parametrical** tool that works by rendering scripts (fig 32). This way, programmers build their models with parametrical code and the software compiles the scripts and renders the object. The great advantage of this program is that by being parametrical users can modify their objects' attributes by changing certain values of their code. However, this is also a disadvantage since it makes it more complicated to create objects compared to other alternatives.



```
//
// Physical attributes, basic
//

knob_radius = 18;
knob_height = 16;
knob_smoothness = 100;

shaft_radius = 3.25;
shaft_height = 13;
shaft_smoothness = 20;

shaft_is_flatted = true;
flat_size_adjustment = -0.0;
// you won't need to mess with this. less than 5 makes it disappear. you can, however,
// set the adjustment to be a negative decimal if you need a flat but not as big as the default.
// go positive if you need a bigger flat
flat_size = 5 + flat_size_adjustment;

// some potentiometers need to have their knobs affixed with a set screw.
set_screw = true;
set_screw_radius = 1.5;
set_screw_depth = 9;
set_screw_height = 4;
quality_of_set_screw = 20;


//
// Decorations
//

// smoothing variables
// thanks to http://www.theorirobotics.com/ for the articles on smoothing edges!

smoothing = true;
circle_height = 10;
circle_radius = knob_radius;
ct = -0.1; // circle translate? not sure.
smoothing_radius = 2;
smooth = 20; // Number of facets of rounding cylinder

// this is a corner edge of a cube sticking out of the cylinder at the bottom
// you can use it instead of the arrow shaped cutout in the top if you like. Or both.

pointy_external_indicator = true;
pointy_external_indicator_height = 3;
pointy_external_indicator_pokey_outey_ness = -0.0; //
pokey_outey_value = pointy_external_indicator_pokey_outey_ness - 1 - pad;
pokey_outey = [pokey_outey_value, pokey_outey_value,0];

// there's an arrow shaped hole you can have. There aren't a lot of controls for this

arrow_indicator = false;
arrow_indicator_scale = 0.8;
arrow_indicator_translate = [-1,0,0];

// indentations
// choose sphere and/or cylinder
// the number and quality

indentations_sphere = true;
indentations_cylinder = false;
number_of_indentations = 40;
quality_of_indentations = 40;

// for spheres, set the size and adjust the placement
size_of_sphere_indentations = 3;
translation_of_sphere_indentations = [10,0,15];

// for cylinder indentations, set radius, height, and placement
radius_of_cylinder_indentations = 2;
height_of_cylinder_indentations = 15;
translation_of_cylinder_indentations = [-1,0,0];
```

```
Parsing design (AST generation)...
Compiling design (CSG Tree generation)...
Compilation finished.
Compiling design (CSG Products generation)...
Compiling design (CSG Products normalization)...
CSG generation finished.
Total rendering time: 0 hours, 0 minutes, 0 seconds
```

```
Viewport: translate = [ 0.23 1.03 6.16 ], rotate = [ 61.10 0.00 144.90 ], distance = 143.72
```

Figure 30: A look into the OpenSCAD software [8]

As we can see, on the left side we type the code of the piece, while in the right side, we can see the rendered result. The objects are created using mathematical basic functions, from which, we can achieve more complex shapes.

Among the locomotion systems previously discussed, for this project, the 2-wheeled option has been selected in order to focus on other aspects of the robot, such as communications and interfaces, so that we can have the smallest robot to test (approximately 5 cm long) as well as the cheapest configuration.

There are 7 pieces modeled for this project's design. Some are created as new structure pieces and others are only 3D models of real objects like servos or the electronic board. Next, we describe each in detail.

Real objects 3D models:

- LiPo battery. Model of a lithium polymer battery for placing it under the robot. This will be discussed in a later section.

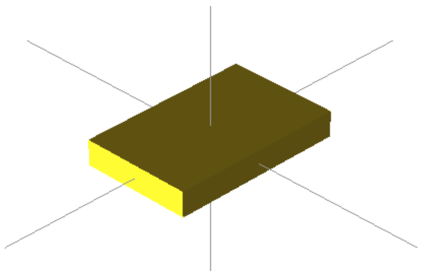


Figure 31: View of the LiPo battery

- Servos. After measuring all the distances of the servos, we build a 3D object that represents them accurately, in order to serve as a guide to design and develop the structure objects of the robot.

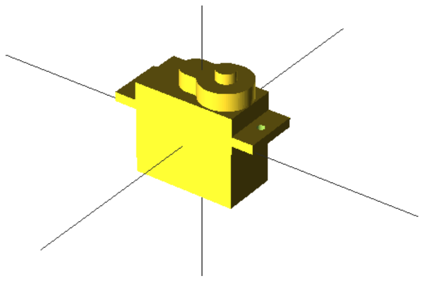


Figure 32: 3D representation of a TowerPro sg90

- Electronic Board. There is also an accurate 3D representation of the board also needed for the construction of the structure pieces.

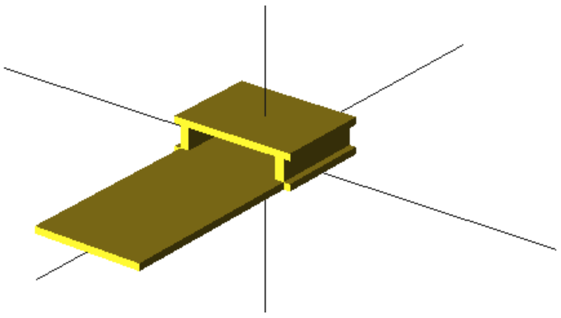


Figure 33: 3D view of the Arduino Fio board with the RN-XV on it

Structure objects:

As the servos are built opposite to one another, with nothing between them, they will constitute the main core of the structure so that the pieces that are going to be designed should basically hold the servos together firmly. The designed structural pieces should also be able to hold the electronic board, the Wi-Fi board and the battery always minimizing the complexity and number of pieces involved.

- Front part. This is a simple piece and it is destined to hold the front ends of the servos together by having two holes prepared for ISO metric M2 screws. There is no need for threads because the screw fits firmly in the holes.

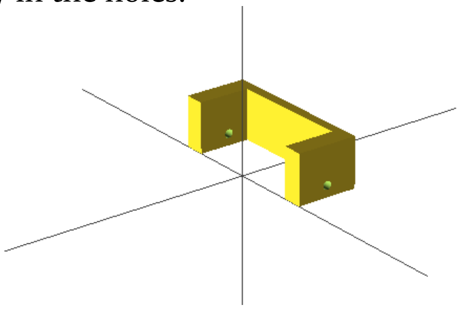


Figure 34: View of the front part

- Rear part plug. In the back of the robot we have two complex pieces. The rear part plug serves as a grip for the back part of the servos, with holes for M2 screws, and at the same time it works as a plug for the electronic board which fits tightly into the piece. This is actually the only way of assembling the electronic board since it does not come prepared for bolts or any other way of fastening.

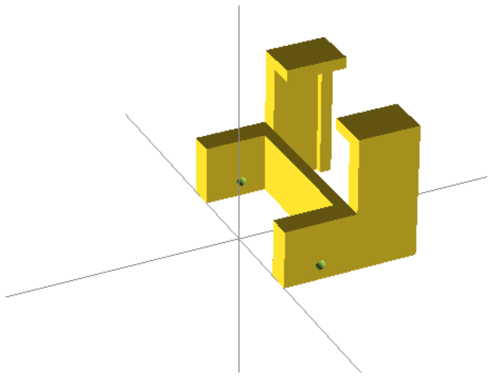


Figure 35: 3D model of the rear part plug

- Rear part support. This part is destined to serve as a third support for the rear weight of the robot, aside from the wheels. It also fits within the rear part plug using the same screws.

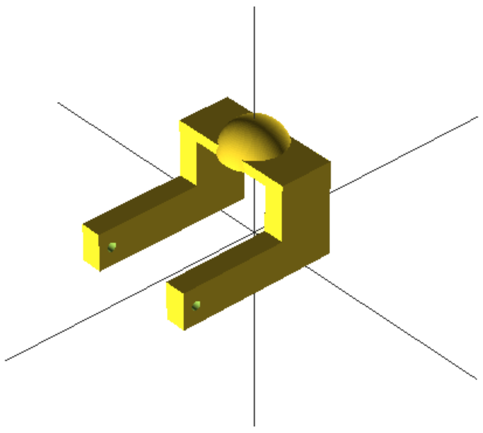


Figure 36: Rear part support

There is a modification of this part which has a marble destined to roll in any direction the wheels go. However, a more simple way is preferred, in which this rear support simply slides. The force of friction is insignificant since the robot weighs very little.

- The wheels. The wheels are designed so that the servos' plugs fit into the wheels very tightly, having for this purpose a hole similar to the plugs. These wheels also have a decrease in the radius of their center so that we can place a rubber O-ring to enhance the grip.

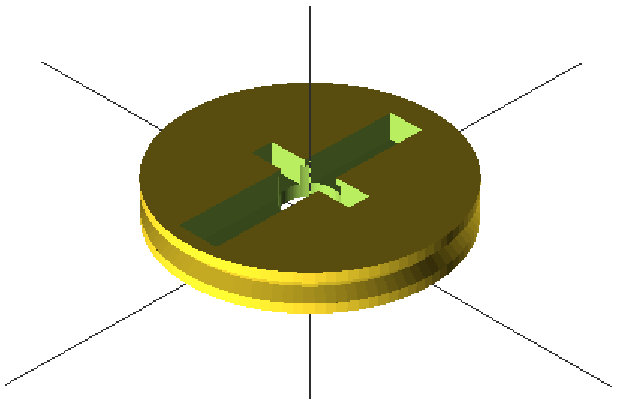


Figure 37: Top view of a wheel

In this design it has always been a priority to give the robot an easy **maintenance** and **functionality** so that it is not necessary to disassemble it for operations like changing or charging the battery, reprogramming the board, attaching or detaching the wheels and making any cable connection. All of these procedures can be done keeping the robot **assembled** and **intact**.

In the next picture we have an unassembled view of the robot, in which there is a better understanding of each piece separately.

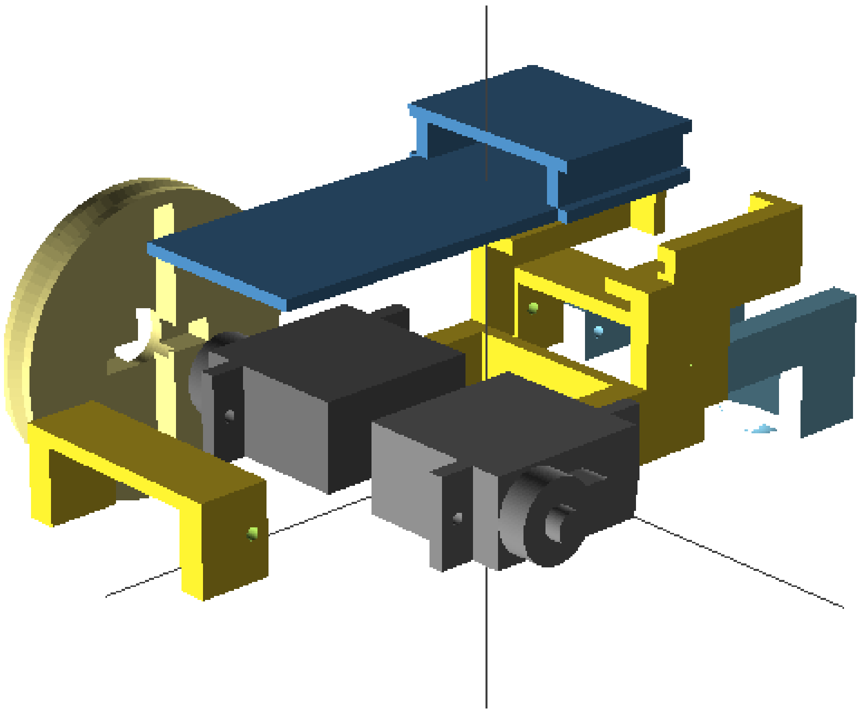


Figure 38: Unassembled complete robot

It is also worth saying that some pieces have been redesigned several times until they have met the requisites of the 3D printer. Not all shapes and angles can be printed because of the working process of the 3D printer which is adding layers from bottom to top in order to create the object.

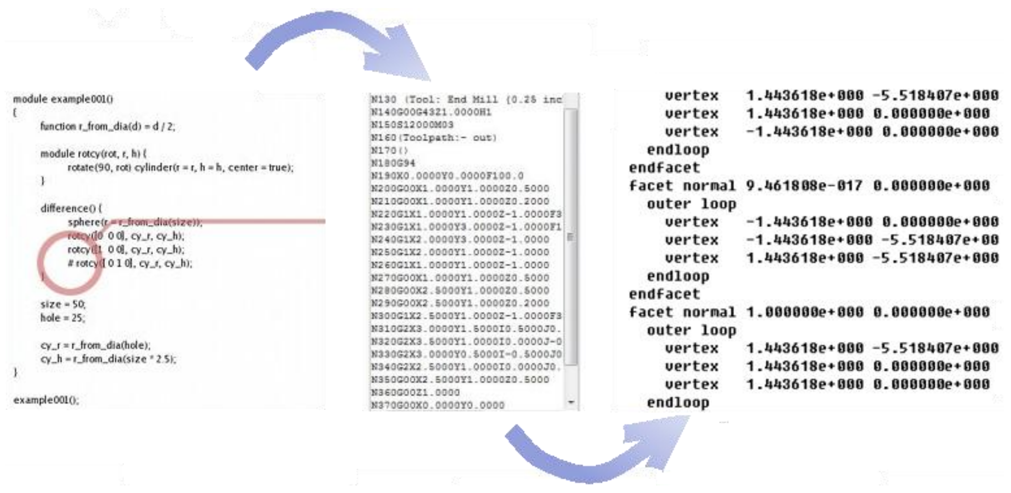
Finally, no matter how precisely we design the pieces to fit together we will always need some retouching in the sense that sometimes the precision of the printer is lower than the precision needed for all pieces to fit. Therefore, some smoothing is needed on some pieces' edges and holes.

3.2. Additive manufacturing or 3D printing

Once the pieces are designed, the next step is manufacturing the designed pieces. This is accomplished by a machine called a 3D printer.

The STL files are then opened by a program called ReplicatorG [38] (fig. 42) which serves as the main interface for operating the 3D printer. With this software we place the object in the adequate "printable" way (always with the largest part at the bottom) and then translate the STL code into GCode [39] which is the machines operative code. This code carries the information of how the printer will move and the order of the steps. [40] See figure 41.

After the GCode is generated we have to indicate some of the printer's options. Although it allows us to choose among many variables the two most important of them are the platform's temperature and the extruder temperature.



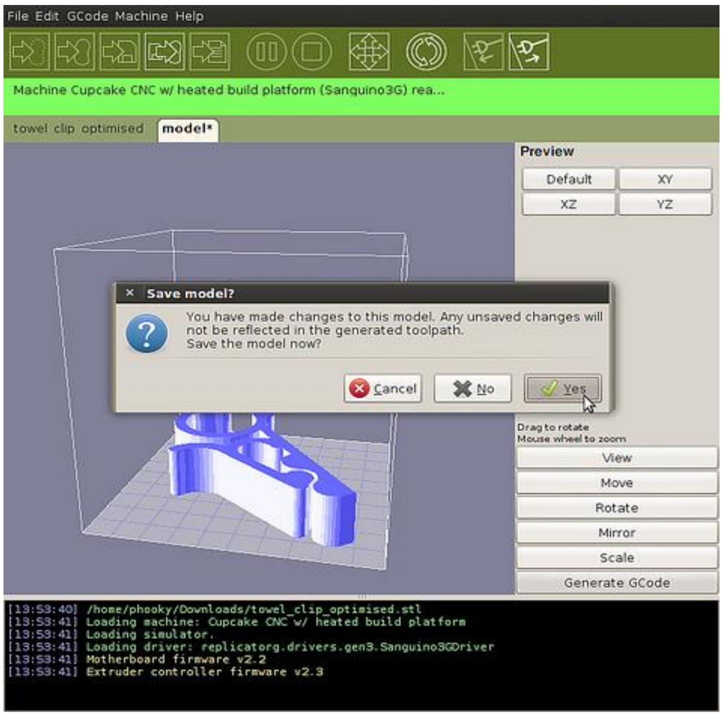
```
module example001()
{
	function r_from_dia(d) = d / 2;

	module rotcy(rot, r, h) {
		rotate(90, rot) cylinder(r = r, h = h, center = true);
	}

	difference() {
		sphere(r = r_from_dia(size));
		rotcy([0 0 0], cy_r, cy_h);
		rotcy([1 0 0], cy_r, cy_h);
		# rotcy([0 1 0], cy_r, cy_h);
	}

	size = 50;
	hole = 25;

	cy_r = r_from_dia(hole);
	cy_h = r_from_dia(size * 2.5);
}

example001();
```

```
N130 (Tool: End Mill (0.25 inc
N140G00G43Z1.0000H1
N150S12000M03
N160(Toolpath:- out)
N170()
N180G94
N190X0.0000Y0.0000F100.0
N200G00X1.0000Y1.0000Z0.5000
N210G00X1.0000Y1.0000Z0.2000
N220G1X1.0000Y1.0000Z-1.0000F3
N230G1X1.0000Y3.0000Z-1.0000F1
N240G1X2.0000Y3.0000Z-1.0000
N250G1X2.0000Y1.0000Z-1.0000
N260G1X1.0000Y1.0000Z-1.0000
N270G00X1.0000Y1.0000Z0.5000
N280G00X2.5000Y1.0000Z0.5000
N290G00X2.5000Y1.0000Z0.2000
N300G1X2.5000Y1.0000Z-1.0000F3
N310G2X3.0000Y1.5000I0.5000J0.
N320G2X3.5000Y1.0000I0.0000J-0
N330G2X3.0000Y0.5000I-0.5000J0
N340G2X2.5000Y1.0000I0.0000J0.
N350G00X2.5000Y1.0000Z0.5000
N360G00Z1.0000
N370G00X0.0000Y0.0000
```

```
      vertex   1.443618e+000 -5.518407e+000
      vertex   1.443618e+000 0.000000e+000
      vertex   -1.443618e+000 0.000000e+000
    endloop
  endfacet
  facet normal 9.461808e-017 0.000000e+000
    outer loop
      vertex   -1.443618e+000 0.000000e+000
      vertex   -1.443618e+000 -5.518407e+00
      vertex   1.443618e+000 -5.518407e+000
    endloop
  endfacet
  facet normal 1.000000e+000 0.000000e+000
    outer loop
      vertex   1.443618e+000 -5.518407e+000
      vertex   1.443618e+000 0.000000e+000
      vertex   1.443618e+000 0.000000e+000
    endloop
```

Figure 39: OpenSCAD to STL format and STL to G-Code [40]

The platform is the base on which the object will be laying and should be about 120 ºC. The extruder melts the plastic at 220 ºC and makes the plastic go through it as a fine strip.



You have made changes to this model. Any unsaved changes will not be reflected in the generated toolpath.
Save the model now?

```
[13:53:40] /home/phooky/Downloads/towel_clip_optimised.stl
[13:53:41] Loading machine: Cupcake CNC w/ heated build platform
[13:53:41] Loading simulator.
[13:53:41] Loading driver: replicatorg.drivers.gen3.Sanguino3GDriver
[13:53:41] Motherboard firmware v2.2
[13:53:41] Extruder controller firmware v2.3
```

Figure 40: A view of the software Replicator G [40]

After setting up the printing parameters with this program we command the printer to start working. Each piece takes, on average, about 20 to 30 minutes to be printed, which makes, for the entire robot, 1 hour and 40 minutes.

The material from which they are made in this case is called ABS (acrylonitrile butadiene styrene) and comes in a coil prepared to feed the printer. It is an inexpensive material, if we consider the €/g, compared to other manufacturing materials.

In the next picture we can take a look at the printer while building one of the wheels. As we can see, it works by adding layers from bottom to top using the extruder as starting point of the melted polymer.

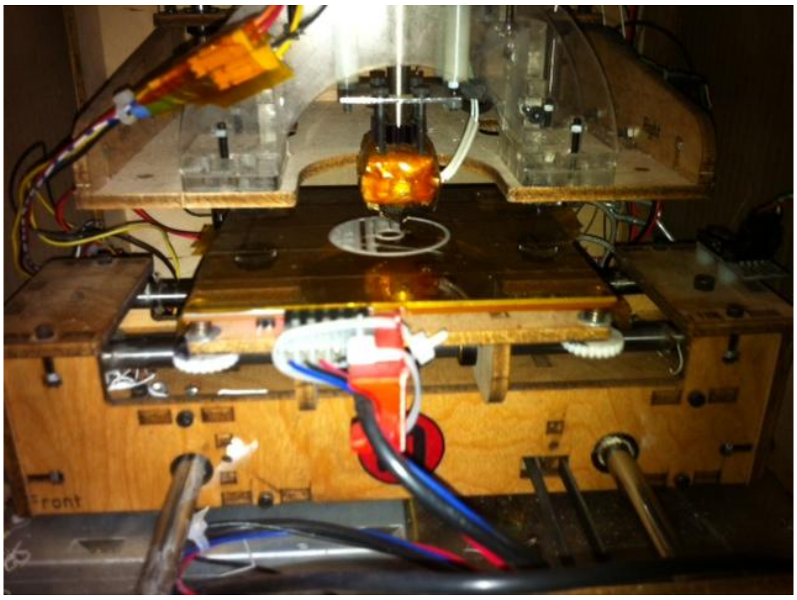


Figure 41: 3D printer building a wheel. [40]

3.3. Assembly

The next and last step of the manufacturing process is the assembly of the pieces once they all have been printed. However, first and as mentioned before, some pieces need their surfaces and edges to be smoothed in order to fit with the others.

When they are ready, we put together the two servos with their ends in opposite sides and attach to them the front and rear pieces using two screws for each one of them. After this we can plug the electronic board into the rear piece.

For the battery we use a sheet of Velcro placed under the servos. This way we can attach and detach the battery easily and as many times needed. In the next picture we can see the results so far:

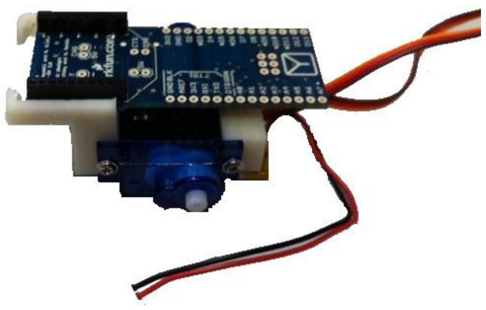


Figure 42: Preassembled robot

Prior to assembling the electronic board we have to solder the male headers in order to start working with the pins. Next, we assemble the rear part support, the wheels, and the Wi-Fi board.

The complete model

After all the pieces are assembled together, we can take a look at the final layout of the robot's design, a 3D model of the complete robot in which one of the wheels has been removed for a better view.

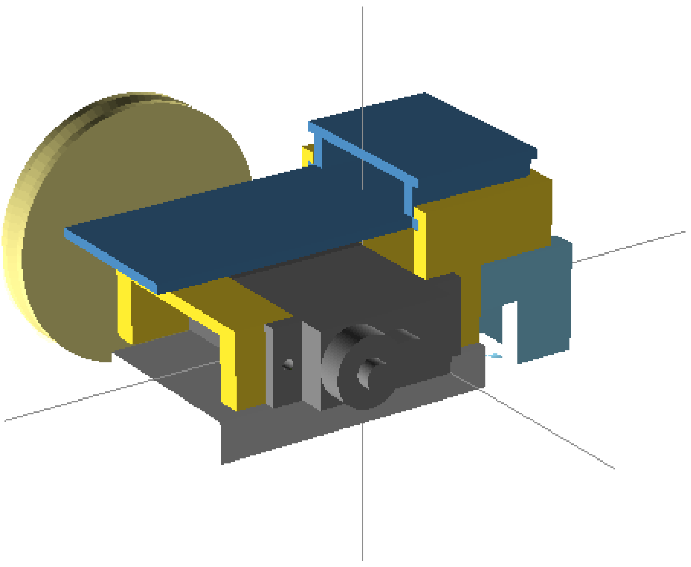


Figure 43: Assembled complete robot

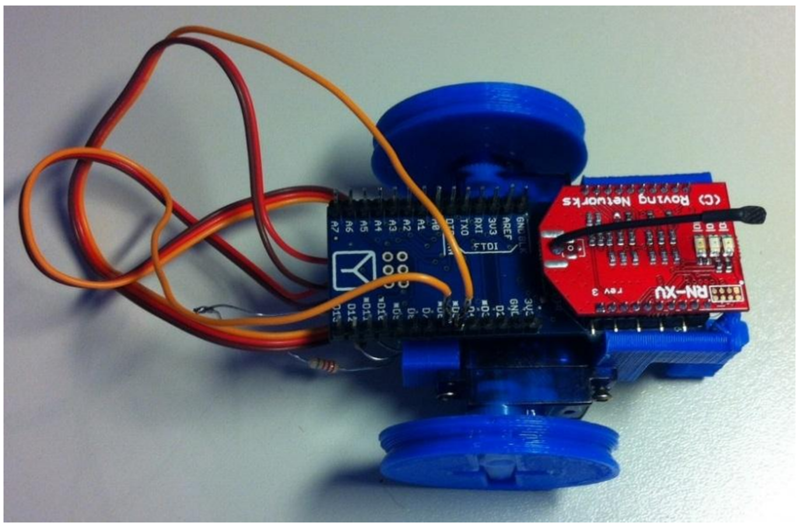


Figure 44: Top view of the assembled robot

Chapter 4

Servomotors and servo hacking

For the robot's wheels, we have to choose a pair of servos that suit our needs. They should be small enough, so that the we have the lowest power consumption and make the smallest robot possible with the tools at hand. All of this in line with the previously designed small parts of the robot.

Apart from the obvious specifications that we must seek in any servo such as torque, speed, voltage, ect. Another element to bear in mind while choosing a servo is budget. There is actually a huge variety of different servos offering similar features, and almost all of them could suit our robot's demands, so these are not really important at the time of choosing one servo or another. However, depending on the fiability that they provide, prices vary within a considerable range.

As mentioned in the first parragraph, the most important feature that we look for in a servo is size. The world of electronics is constantly developing devices with enhanced features but smaller sizes and the new generation of servos is not an exception. Although with less fiability, users can find in the market much smaller servos than before and even build their own controlling circuits for small DC motors using cheap affordable components.

Apart from the hardware (servos and electronics), it is important to remember that a limiting factor for reducing the robot's size is the accuracy with which the printer builds each piece. If we try to build pieces that are two small, the printer will not build them with the right accuracy.

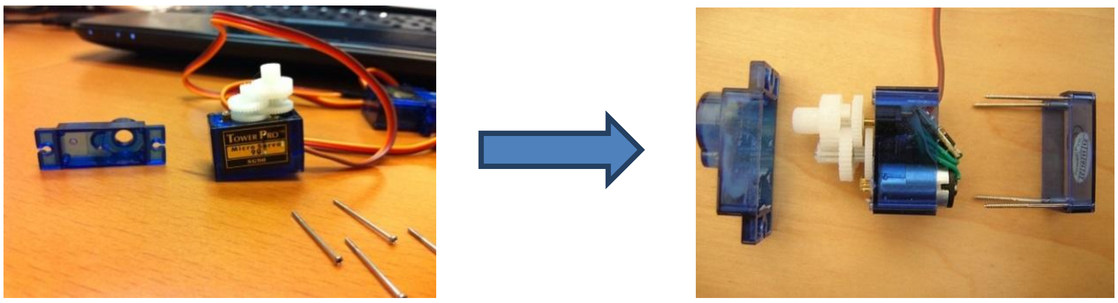
As this project focuses on communications and building the controlling interface, we could allow ourselves to choose a small cheap servo, only with the necessary features to move the robot. This is the TowerPro's SG90, a lightweight servo, which for the price, is very high-quality and fast.

It comes with accessories for attaching, and has two holes for screws. In the picture below, we can se these holes on the sides of the servo. It is to these fins that we attach the front and rear parts of the robot, using screws to hold them together.

This ~**$5** servo, which we can see in the introductory picture has one big disadvantage, shared with other similar medium-quality servos, which is that it requires time, effort and skills to modify it in order to make it rotate 360º. It is possible that upgrading to more expensive but continuous rotation servos is more worthwhile, in order to avoid all the trouble related to modifying the structure of these servos. However, it serves as a learning tool both in mechanics and analog electronics.

4.1. Continuous rotation modification

First, we have to get the four bottom screws out which will let us disassemble the top and bottom plastic parts:


Figures 45, 46 *[41]*, 47, 48 & 49: Unscrewed and modified servo

After this we have to remove three mechanical stops. First, two metal fingers in the potentiometer must be cut using a small screwdriver to lift the metal plate and then cut its ends with a diagonal cutter.

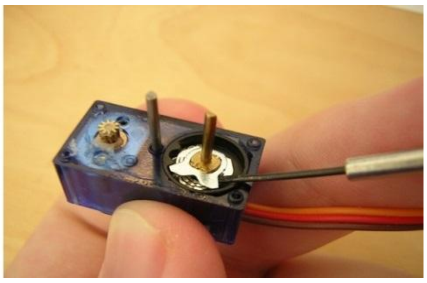


Figure 47: Mechanical Stops [41]

Next we remove the other mechanical stop which is a small nub on the bottom of the output gear, using a cutter this time but being careful not to break it. This way, the gear will be able to rotate freely.

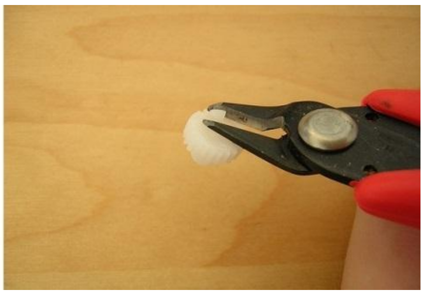


Figure 58: Output gear [41]

After removing the mechanical stops we have to reassemble the potentiometer and every gear in the right order engaging the motor's gear.

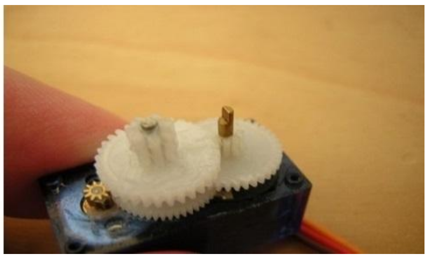


Figure 5: Gear train [41]

Now comes the most difficult part. In order to cancel the feedback that the potentiometer puts into the circuit we have to modify its electronic behavior:

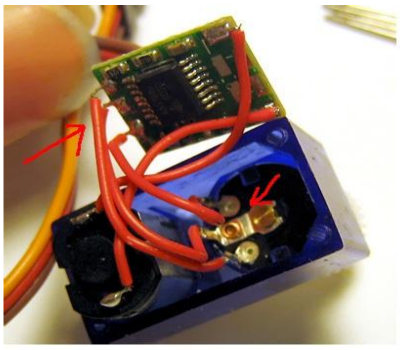


Figure 50: Potentiometer's wires [42]

First we cut the three wires that go from the potentiometer to the circuit (red arrow). We have to be really careful not to desolder any other wires since the tin unions are quite delicate and break easily.

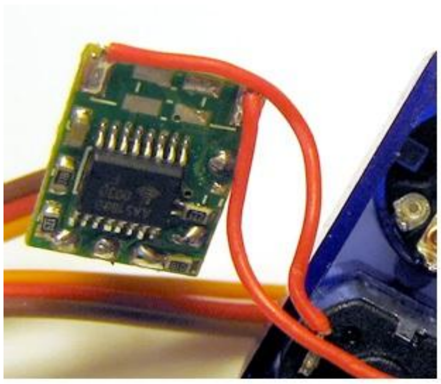


Figure 51: Tin ends [42]

Below the chip (H-bridge) we leave 3 tin ends that must be reconnected to fixed resistor values in order for the circuit to be closed and dismiss any changes in the position of the shaft. These were previously connected to the potentiometer.

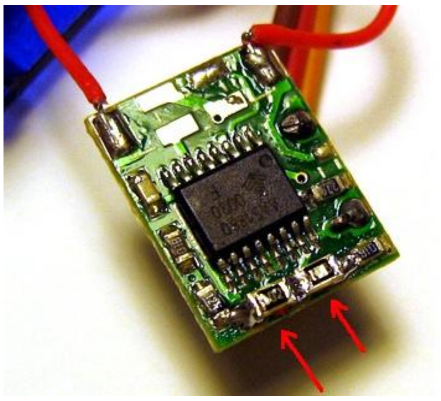


Figure 52: Soldered resistors [42]

In this picture two SMD 2.2 KΩ resistors have been soldered to the circuit. This is actually a quite difficult task if we lack specific soldering tools for SMD resistors, since any common solder will break or damage the board.

To solve this problem two common 1/4 W resistors have been used being really careful not to damage any part while soldering the resistors legs. However, this method has one big disadvantage; the new circuit with these resistors will not fit into the servo's box so the only way possible is to make a hole in the box and let the resistors out through it.

In conclusion, it is possible that this part of the project could be reconsidered because of its complexity and difficulty, in the sense that we could avoid the technical trouble involved in this in favor for a better performance servo. The only disadvantage would be an over cost for each servo.

Chapter 5

Electronic hardware and programming

In this part, we will cover everything related to the election and use of all electronic devices involved in the robot. In order to make the robot work and move we need a microcontroller destined to serve as the main "intelligence"; it deals with the possible inputs or outputs that the robot may implement, for example, activities such as running the servos, communicating with other devices or algorithm execution.

For this specific project, we also need a communicating module that will deal with the data transfer between the microcontroller board and the controlling device. This module might or might not come incorporated to the main board, meaning that we have the possibility of either an integrated solution or two separate but compatible devices for the microcontroller and communicating module.

The first choice must be the microcontroller. As mentioned in the background part, the best choice for a low-budget starting project with no professional requirements would be a microcontroller from the Arduino family.

5.1. Microcontroller

Now, depending on our project we should choose the adequate model that fit exactly with the robot's power, size and I/O requirements.

First we should know the minimum amount of **I/O** pins that the robot needs, so that there are enough digital and analog outputs for the servos and other controlled devices. In order to provide connectivity, the board should also allow for an external Wi-Fi, Bluetooth or RF module and they should be compatible.

Another factor to consider is the necessary computing power needed for receiving instructions, computing the algorithm and commanding the servos at the same time with the minimum lag. Any 32-bit microprocessor should be enough for this task.

For now, we still have several boards that suit our needs, most of them being more than enough for our needs, but if we want the microcontroller to be as small as possible our choices narrow a lot.

For these reasons the FIO [43] model has been chosen, which is an Arduino board intended for wireless applications (fig. 55).

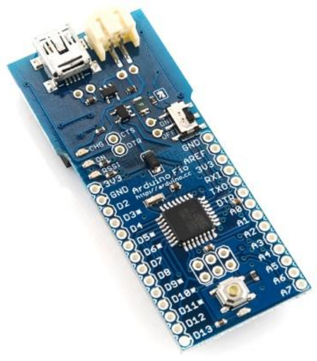


Figure 53: Arduino FIO

In the previous picture we can see a top view of the board, with the microprocessor in the middle and the I/O pins on the sides.

The Arduino Fio is a microcontroller based on the **ATmega328P** running at **8 MHz** and at **3.3V** (fig. 56). It has **14** Digital inputs and outputs and 8 analog inputs, an on-board resonator, a reset button and a socket for XBee modules. XBee is a standard pin-arrangement from DIGI for its RF and Bluetooth modules but it has been adopted by other companies so that we can find other maker's modules with different features all having the same pin arrangement.

Figure 54: ATmega328P [16]

It has connections and a USB internal charging circuit for a lithium polymer battery.

Summary

Table 4: Arduino FIO features

Microcontroller	ATmega328P
Operating Voltage	3.3V
Input Voltage	3.35 -12 V
Input Voltage for Charge	3.7 - 7 V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	8
DC Current per I/O Pin	40 mA
Flash Memory	32 KB (2 KB used by bootloader)
SRAM	2 KB
EEPROM	1 KB
Clock Speed	8 MHz

Memory

This microprocessor has 32 KB of flash memory for storing code (of which 2 KB are for the bootloader. It has 2 KB of SRAM and 1 KB of EEPROM.

Input and output

All 14 pins can act as digital output or inputs with an internal pull-up resistor of 20-30 kΩ (disconnected by default). They operate at 3.3V and provide or receive a maximum of 40 mA. Some pins have the next special functions:

- **Serial: RXI (D0) and TXO (D1).** Used to receive (RX) and transmit (TX) TTL serial data.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication.
- **LED: 13.** There is a built-in LED connected to digital pin 13.
- **8** analog inputs with 10 bits of resolution.

Communications

The ATmega328P provides UART TTL serial communication, available on pins 0 (RX) and 1 (TX). This serial connection can be monitored by the Arduino software through the serial monitor in which we can see the serial data sent to the Arduino from the computer and vice-versa. This should be done with a 3.3V FTDI cable. The mini-USB that comes with the board is only for charging the battery and not for uploading programs. For further use of the Serial communications interface we can use the SoftwareSerial library.

The ATmega328P also supports I2C and SPI communication. For I2C we should include the Wire library in the Arduino software. For the SPI communication we need to check the datasheet.

The board was designed by Shigeru Kobayashi and manufactured by SparkFun Electronics.

5.2. Microcontroller programming

In order to start using the board we must solder either the male or female headers on the board. In this case we soldered a row of male headers per row of I/O pins.

When it comes to programming the board we have two options: With an FTDI cable or wirelessly which only works with a pair of DIGI's RF modules. As this project uses another board it is a must to program it with the cable.

After this, we start developing the sketch or Arduino program. As mentioned before, there are two functions that we must implement in any program. However, before the first function we include the necessary libraries for our program, and then we write the setup() and loop() functions. First, in the **setup()** function we will initialize the variables, attach one digital output for each servo, and configure the software serial connection for carrying out the serial monitoring. (This will be explained along with the softwareSerial library).

In the setup() function we also set the data rate for serial data transmission with **serial.begin(9600)**. A working value for the Arduino FIO is 9600 bps (bits per second).

In the **loop()** section we will write the main algorithm in charge of receiving the instructions from the smartphone and commanding the servos. We read char values from the corresponding Arduino FIO buffer, which come from the default serial connection with the Wi-Fi module.

As the values received from the Wi-Fi module and sent to the Arduino are treated as characters, we need to implement a char to int transformation prior to executing any code that uses the received data.

The values sent from the Wi-Fi module to the Arduino are numbers from 0 to 180 coming from the commanding device (In this case an Android phone) that represent the desired servo speed. The algorithm then, groups any incoming char data in separate strings (to differentiate separate values) and converts the strings into integer values with the **atoi**() function.

Only after we have the data converted to an integer we can start developing the main algorithm which is in fact very simple, excluding a few issues. As we will receive information to move two separate servos, but there is only one data channel (Wi-Fi board) and only one buffer for the serial connection, we have to transform the data so that the Arduino program knows which servo it is intended to. To achieve this, we send values from different ranges being each range associated to one servo.

From the smartphone's application software values are sent from two different special sliding buttons, one for each servo. Both values travel through different listeners but are already sent with different ranges as there is only one channel.

The next image shows the flow chart of the steps explained above. It is a simplified flow of events that sum up the algorithm behind the robot.

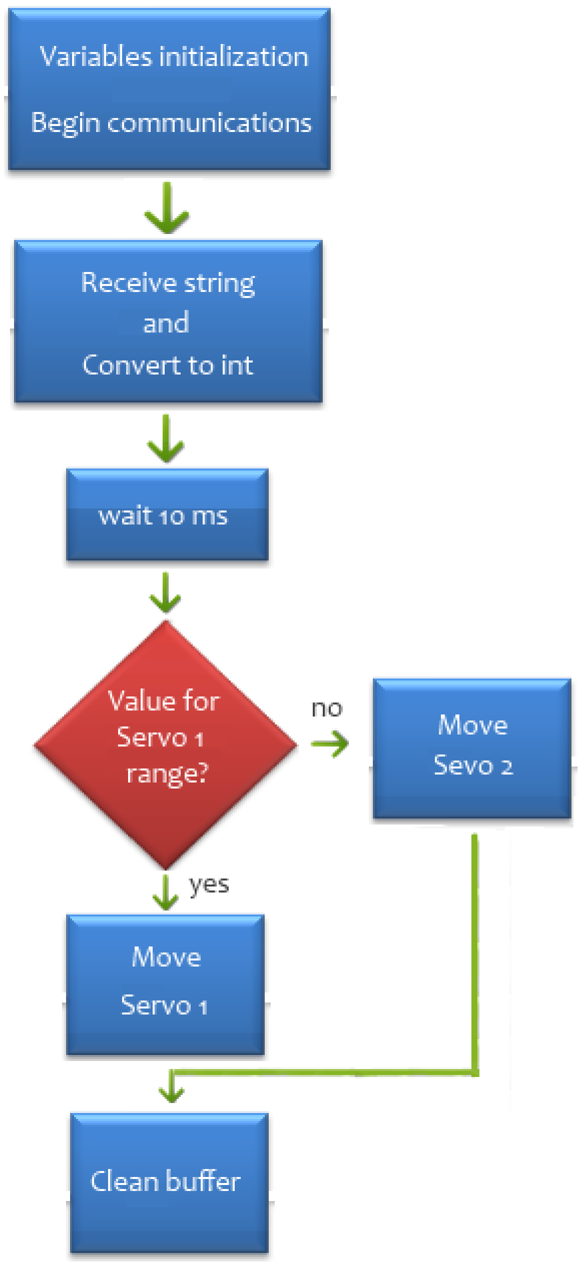


Figure 55: Main Arduino block diagram

Inside the "receive string and convert to integer" box there is also a sub-routine in charge of doing that task. The next image shows the flow chart for this task.

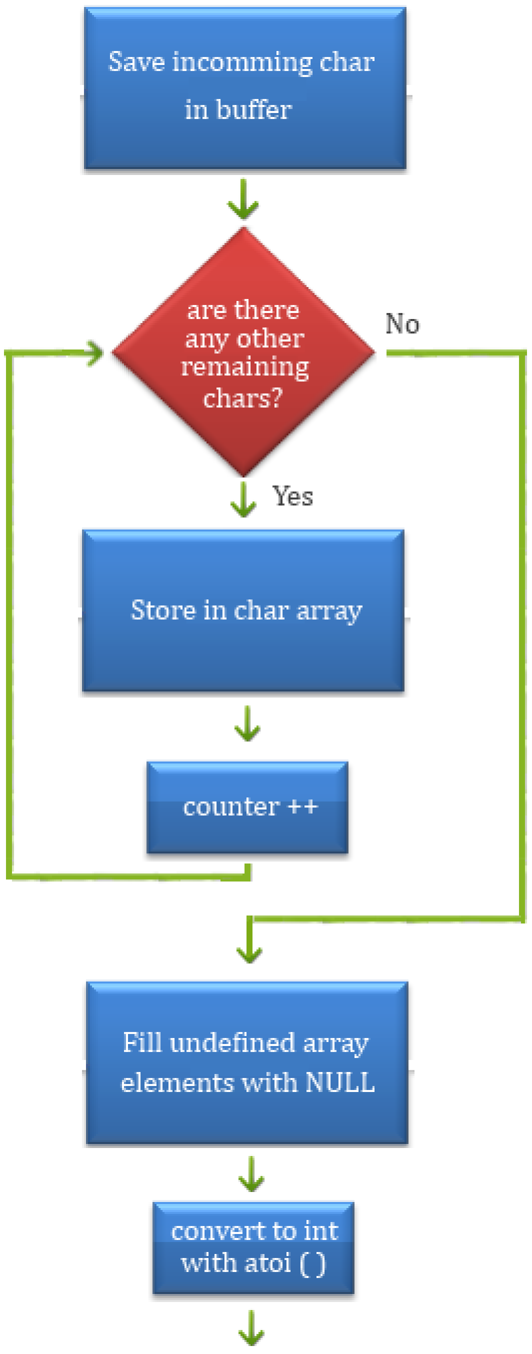

Save incomming char in buffer
are there any other remaining chars?
No
Yes
Store in char array
counter ++
Fill undefined array elements with NULL
convert to int with atoi ( )

Figure 56: Block diagram for storing string and converting to integer

When sent to the Arduino from the Wi-Fi module, a number can have from 1 to 3 digits. Each digit is sent separately and treated as a character. As the Arduino buffer allows for only one variable to be stored in it, we have to build a loop that first reads that incoming value, and then stores it in the first position of an array. If there is more incoming data, that is to say, another number's digit, we place it in the next position of the array.

As we do not know how many digits the number will have we still have an array with a variable number of elements which are undetermined, with no assigned value. In order to use the function atoi() which only works with a NULL ended string, we have to fill the remaining positions with NULL values or "\0". We then convert the string to an integer and it is ready to be read as a valid number for a servo.

After the data is written to the servo we clean the buffer for the next loop with serial.flush(). It is important that we add a delay of 10 ms between the data is being written in the serial buffer and when reading the data. This way we allow the buffer to have completed before we read any values.

Regarding the servos, from two of the digital pins capable of providing PWM signals we connect each servo's control wire whereas the other two go to the power supply, in this case, the battery. Servos have 3 wires: GND, VCC and signal (PWM control). Next we discuss more in deep how to write values to the servos in the loop() function.

In order for our program to deal with servos, we have two options: We could either write PWM signals by software as explained in the servo controlling section of the background chapter or use an available standard servo library (**Servo.h**). To simplify the program, in this project, the library option has been chosen. This library allows for attaching or detaching a servo to and from any digital pin, as well as writing a value to the servo controlling the shaft accordingly. For this we could either use the function write() or writeMicroseconds(), being the latter more precise.

On standard servos a value from 0 to 180 will command a position for the shaft, and on continuous rotation servos this will set up a speed, being 90 the value of no movement.

It is worth mentioning that near-end values (0 to 20 and 160 to 180) could not be well differentiated as many servos achieve full speed with lower values.

Technical issues

It is necessary to notice that this specific hardware configuration (FIO + RN-171 Wi-Fi module) is especially difficult to work with since they use for communicating the same serial (TX and RX) pins as used for uploading sketches. Here comes the biggest disadvantage of these two modules when used together. Despite all the advantages that come when choosing the FIO board (size, connectivity, ect.) it has been thought for being used with a DIGI's XBee Bluetooth or RF module, which even allowed for wireless programming, so if we want to connect it to the Wi-Fi module we will have to put up with some difficulties when making it work. As mentioned early, we have to detach the Wi-Fi module every time we want to upload a sketch, but this is not the biggest trouble. In order to start working with the module and check for incoming data we should use the serial monitor that comes with the Arduino IDE. However, the default serial pins are being used for data transfer to/ from the Wi-Fi module so that we cannot monitor this flow of information.

In order to solve this issue and achieve data transfer and proper monitoring we should use the **softwareSerial.h** library which allows for any other digital pin to serve as serial transfer (RX and TX). We then connect the RX and TX from the FTDI cable to these new pins and the rest (VCC, GND, ARef and DTR) to the corresponding FIO pins. For this we have to disassemble the FTDI cable. In conclusion, we have two running serial communications at the same time, one for monitoring the buffered read values, and other for communicating with the Wi-Fi module.

Layout

The next picture shows the electronic configuration of the robot. It is quite simple, only taking care in powering the servos with the battery and not with the Arduino, which can only supply 40 mA.

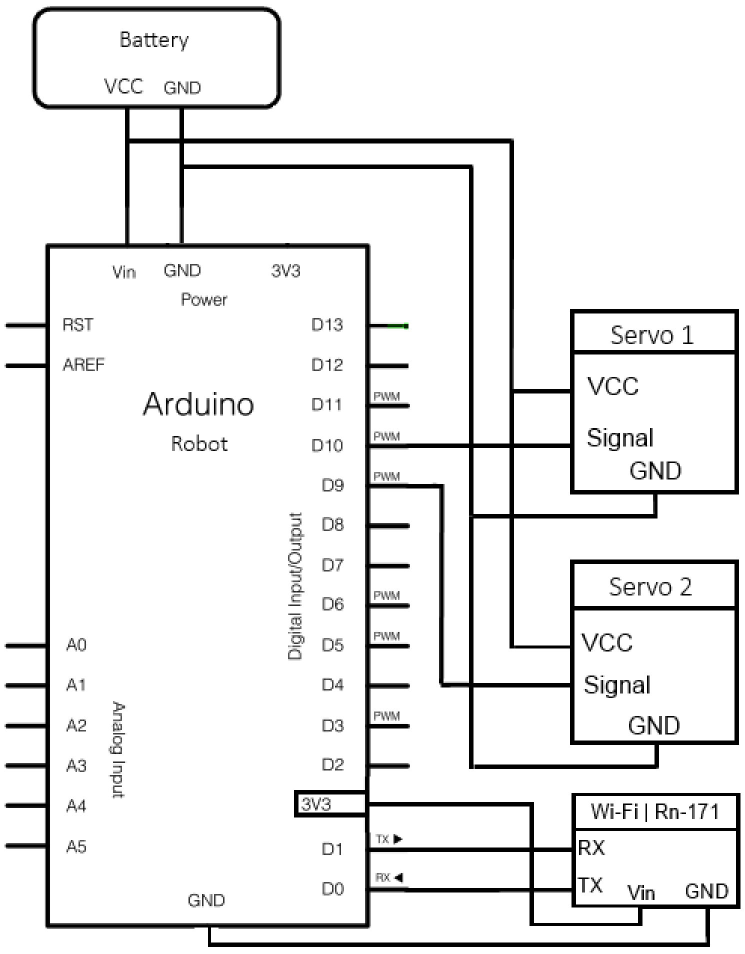


Figure 57: Robot, servos and battery layout

5.3. Wi-Fi module

After considering the pros and cons of the two main options for providing connectivity (Bluetooth or Wi-Fi), it has been decided that the best choice would be the Wi-Fi module. The advantages are data with ultra-low cost transport, the biggest connectivity range (if using local area networks with access point we can connect to everywhere in the world), and a greater versatility providing many different configurations. This way we have the possibility to interact with any device that is connected somehow to the network. A significant factor is that between 2009 and 2010 there was a 158% growth in Wi-Fi enabled consumer electronics and it was present in 90% cell phones [44].

The best choice is the Roving-Networks RN171XV (fig. 60), which is a standalone, complete TCP/ IP wireless networking module. Due to its small size and low power consumption it is perfect for mobile wireless applications such as sensing and portable devices. It is the best option for projects migrating from existing 802.15.4 architecture to a standard 802.11 TCP/ IP based platform without any changes in their existing hardware.

Figure 58: Roving-Networks RN-XV 171 Wi-Fi module [29]

The module incorporates a 32-bit processor, TCP/ IP stack, real-time clock, crypto accelerator a power management unit and analog sensor interface. It also offers additional functionality through its 8 programmable GPIOs (general purpose input/ output) and 3 ADCs. The ADCs provide 14-bit resolution while the GPIOs can be configured to allow standard functionality or status signaling to a host microcontroller minimizing the need for serial polling between the module and the microcontroller.

Among all the features (See manual, or main web site), we can outline some important ones:

- Based common 802.15.4 footprint.
- Access to every node. Ad-hoc and AP configurations.
- Low power
- 3.3V supply
- Secure Wi-Fi authentication
- Configuration over UART or wireless interface (telnet) using ASCII codes.

For this project the module has been connected to the Arduino hardware with the simplest configuration, only using PWR, TX, RX and GND for communicating with the microcontroller: A common serial communication. This is showed in the circuit layout in the 3.2 section.

The module has an endless set of applications and lets the user set multiple configurations according to their needs. To begin with there we will offer a general overview of the configuring commands, default features and working modes. Later we will see some typical applications in which to incorporate the module and some hints on how to implement them.

First of all, the module can be in two modes or states: Data mode or command mode:

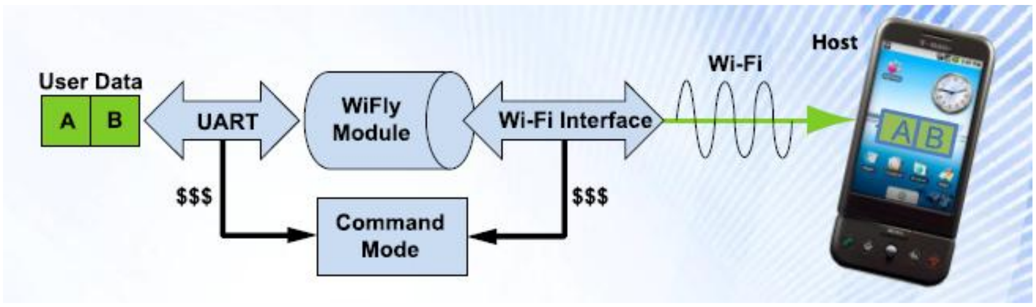


Figure 59: Wi-Fi module operating modes [44]

- **Data mode (default state).**
  - WiFly module like data pipe.
  - TCP/ UDP header stripped or added, transparent to UART.
  - Data written to UART is sent out to Wi-Fi.
  - Data received from Wi-Fi is read from UART.
- **Command mode.**
  - Used to assign data, SSID, pass phrase, etc.

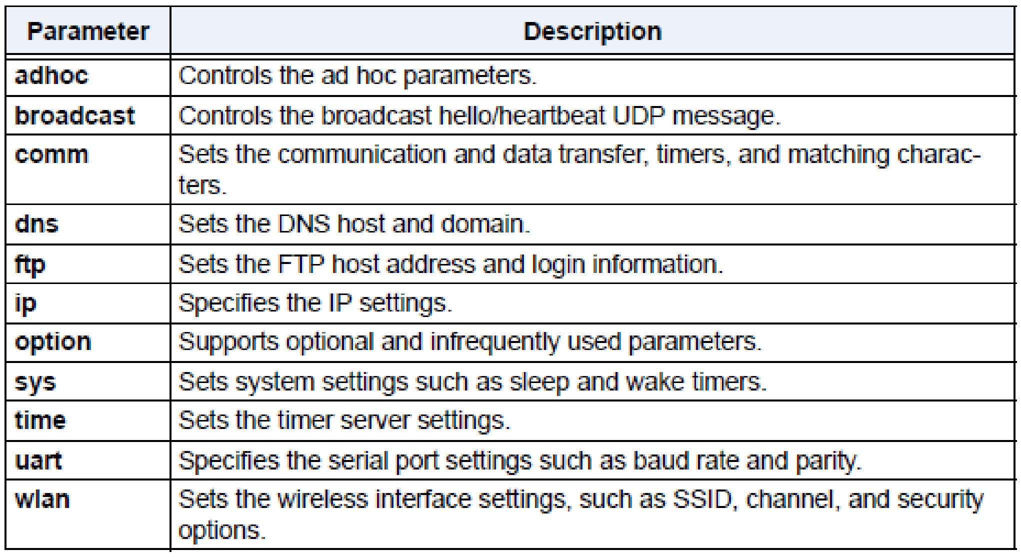
To configure parameters and/ or view the current configuration, we must put the module into command mode. There are various ways to connect to the Wi-Fi module and enter in command mode for the first time. In all of them, the user has to establish connection with the module and send the escape sequence **$$$**. If the module answers CMD it means we are in command mode.

Note: In the configuring part, next section, we will take a look at how to connect and configure the module.

Upon entering the command mode, the module can accept five types of commands:

- Set commands: These take effect immediately and are stored in memory. They include the categories shown in table 5.

Table 5: Set commands parameters



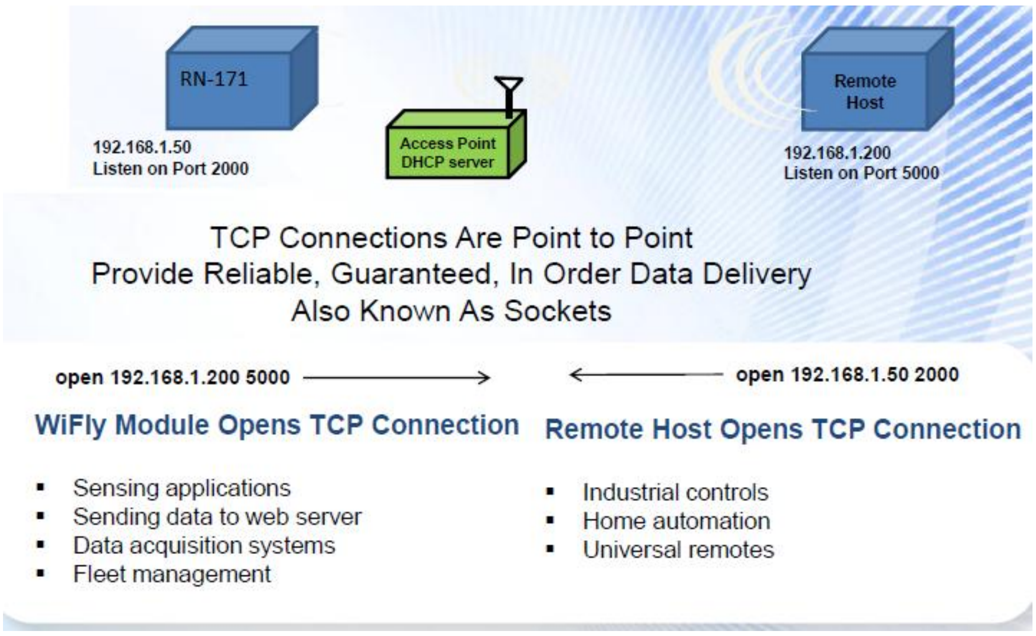
Parameter	Description
adhoc	Controls the ad hoc parameters.
broadcast	Controls the broadcast hello/heartbeat UDP message.
comm	Sets the communication and data transfer, timers, and matching charac-ters.
dns	Sets the DNS host and domain.
ftp	Sets the FTP host address and login information.
ip	Specifies the IP settings.
option	Supports optional and infrequently used parameters.
sys	Sets system settings such as sleep and wake timers.
time	Sets the timer server settings.
uart	Specifies the serial port settings such as baud rate and parity.
wlan	Sets the wireless interface settings, such as SSID, channel, and security options.

- Get commands: These commands retrieve the stored configuration and display it. They are basically the same commands as the "set commands" but take no parameters. Instead, they show the current configuration.
- Status commands: These commands display the interface status, the IP status, etc.
- Action commands: for scanning, connecting, disconnecting, etc.
- File I/O commands: to upgrade, load and save configuration, delete files, etc.

Some possible Wi-Fi applications

TCP connections and embedded applications

We can connect from/to module to/from host using TCP. In the next image we can see the typical applications for this module (fig. 62).



TCP Connections Are Point to Point
Provide Reliable, Guaranteed, In Order Data Delivery
Also Known As Sockets

WiFly Module Opens TCP Connection

- Sensing applications
- Sending data to web server
- Data acquisition systems
- Fleet management

Remote Host Opens TCP Connection

- Industrial controls
- Home automation
- Universal remotes

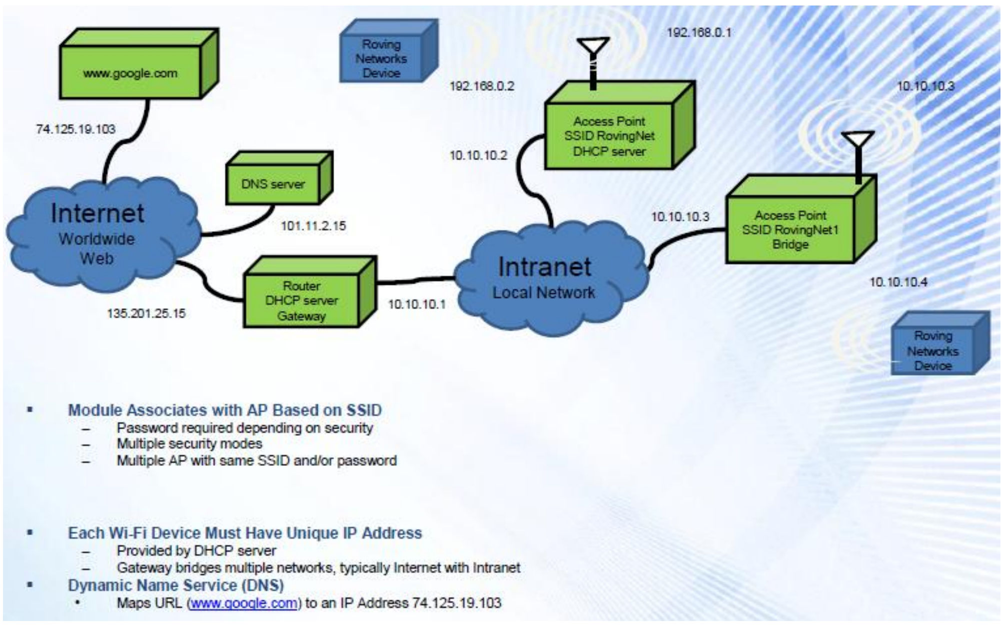
Figure 60: Typical TCP applications [44]

Roaming and FTP

Used for asset tracking, fleet management and remote sensor applications. The configuration is more complicated than the previous one and combines broadcast UDP, wake timers and auto join.

The module can act as an FTP client streaming files to/from FTP server (useful in data logger applications), and as an FTP server accepting multiple clients concurrently.

The next image shows this configuration:



- Module Associates with AP Based on SSID
  - Password required depending on security
  - Multiple security modes
  - Multiple AP with same SSID and/or password
- Each Wi-Fi Device Must Have Unique IP Address
  - Provided by DHCP server
  - Gateway bridges multiple networks, typically Internet with Intranet
- Dynamic Name Service (DNS)
  - Maps URL (www.google.com) to an IP Address 74.125.19.103

Figure 61: FTP client/ server configuration [44]

HTML client and sensors

In the next image we can see the architecture for this application:

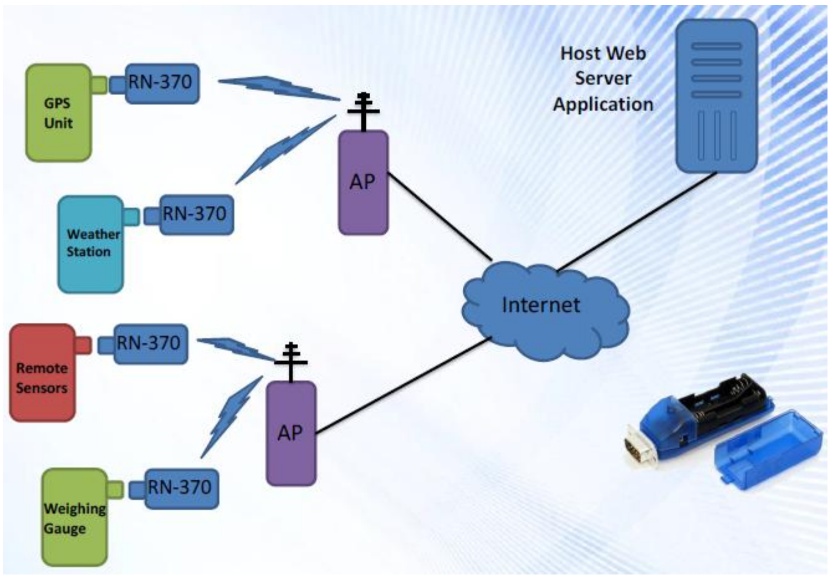


Figure 62: HTML client configuration [44]

With this configuration we can post data to a web server associating the module to an access point. (The image shows RN-370 modules but this also works with the 170 series). In HTTP client mode the module sends the next request message, including comm remote string and sensor readings:

GET /server.php?value=0F3000001111222233334444555566667777\n\n

When serial UART data arrives the module auto-connects to web server and sends.

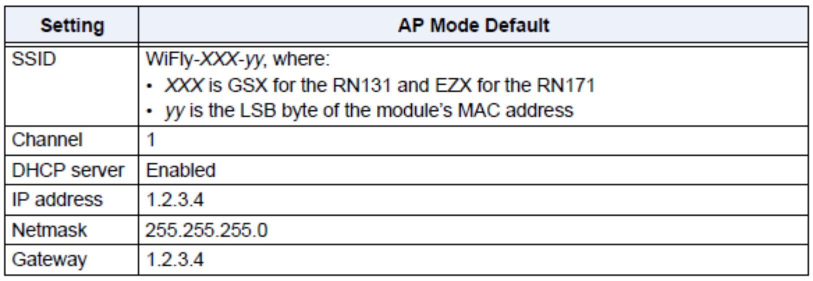
Access point mode (AP mode)

In addition to infrastructure and Ad-hoc mode, the module can act as an access point, providing several advantages over Ad-hoc mode:

- The module creates an AP network to which Android devices can join.
- The module runs a DHCP server and issues IP addresses to seven clients, which is much faster than automatic IP and Ad-hoc mode.
- The module supports routing between clients.

There are two methods for enabling AP mode, hardware and software. To enable it in **hardware**, we must hold the GPIO9 to 3,3V and then reset the module. It starts with the next default AP mode settings:

Table 6: Default access point mode settings



Setting	AP Mode Default
SSID	WiFly-*XXX-yy*, where: • *XXX* is GSX for the RN131 and EZX for the RN171 • *yy* is the LSB byte of the module's MAC address
Channel	1
DHCP server	Enabled
IP address	1.2.3.4
Netmask	255.255.255.0
Gateway	1.2.3.4

To enable it via software we use the next commands. After the first we do not need to enter them in the same order.

```
set wlan join 7                  // Enable AP mode
set wlan channel <value>         // Specify the channel
set wlan ssid <string>           // Set up network broadcast SSID
set ip dhcp 4                    // Enable DHCP server
set ip address <address>         // Specify the IP address
set ip net <address>             // Specify the subnet mask
set ip gateway <address>         // Specify the gateway
save                             // Store settings
reboot                           // Reboot the module in AP mode
```

Once the module boots up in AP mode, any client device can associate with the network the module is broadcasting. Once associated, the module DHCP server assigns an IP address to the client device.

Ad-hoc mode

An Ad-hoc network is a point-to-point network in that each Wi-Fi device is linked directly to all other devices on that network with no access point. All devices participate in keeping the network alive and each keeps track of the other active devices on the network by sending and receiving beacon and probe packets. In most cases, IP addresses are assigned through automatic IP, although one of the Wi-Fi devices can be configured as a DHCP server. There are also two ways to enable Ad-hoc mode.

The first, via **hardware**, we set GPIO9 high at power up. Upon powering up with that pin high, the module creates an Ad-hoc network with the next settings:

SSID	*WiFly-GSX-XX, (XX is Mac address)*
Channel	*1*
DHCP	*OFF*
IP address	*169.254.1.1*
Netmask	*255.255.0.0*

Via **software**, we introduce the next commands:

```
set wlan join 4
set wlan ssid "name"
set wlan chan 1
set ip address 169.254.1.1
set ip netmask 255.255.0.0
set ip dhcp 0
save & reboot
```

Once a computer is associated with the Ad-hoc network, we can use the module's IP address to open a connection or connect using telnet.

5.4. Wi-Fi module programming

The following part of the document explains how to configure and program the WiFly module (RN-171) to connect it to a WLAN and act as a server for any Android device to talk to it via TCP.

This chapter is a summary of an extended tutorial by the same author of this document on how to use and configure the module with Arduino. It can be found at http://asrob.uc3m.es/index.php/Tutorial_Wifly, a Spanish step-by-step tutorial for programming the module for the first time.

Among the many ways possible for the module to work (acting as access point, Ad-hoc or infrastructure) it has been decided that it would be appropriate to configure it to connect to a local network providing it with a static IP so that it would be reachable at all times and would have a wide coverage in a certain spot. Besides this is a much simpler configuration than making it broadcast its own wireless network. However, this last option (acting as an access point) would mean that we could use the robot in any place without the need for an external wireless network. The disadvantage of configuring it as an AP is a lower coverage area (less than 10 m).

The module will be configured so that it rapidly connects to a router at power up. Apart from the Wi-Fi module, we will use the next tools:

- Ubuntu
- Arduino FIO
- WiFly Manual and datasheet
- FTDI 3,3V cable and a small thin wire.

We will show three different ways to configure and achieve the same results. The first will be via hardware (and then telnet) and the last two, software. Configuration parameters will be stored in the module's memory so that every time it reboots it can auto-connect to the router.

Hardware and telnet

First of all, we enable the WiFly's Ad-hoc mode by connecting GPIO_9 (8th pin of the XBEE's pinout to VCC (3,3v, 1st pin). See images below:

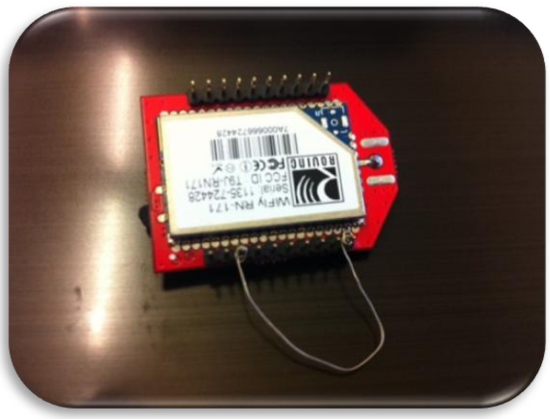
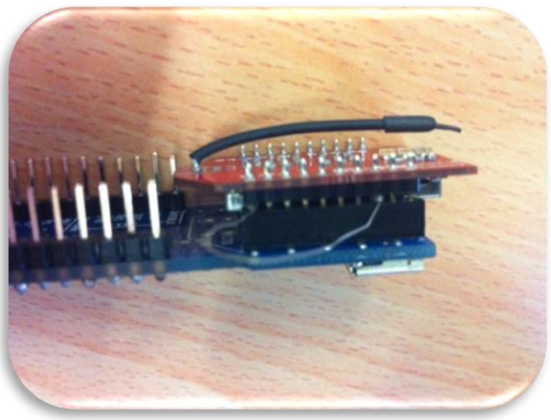



Figure 63: GPIO_9 to VCC & Figure 64: Module powered by FIO

Figure 65: Wire for short-circuiting GPIO_9 to VCCC.

By forcing it enter in Ad-hoc mode we can connect to it via telnet for the first time and then configure it. There is also a software way to configure it in Ad-hoc but we must first establish contact with it by forcing a hardware Ad-hoc.

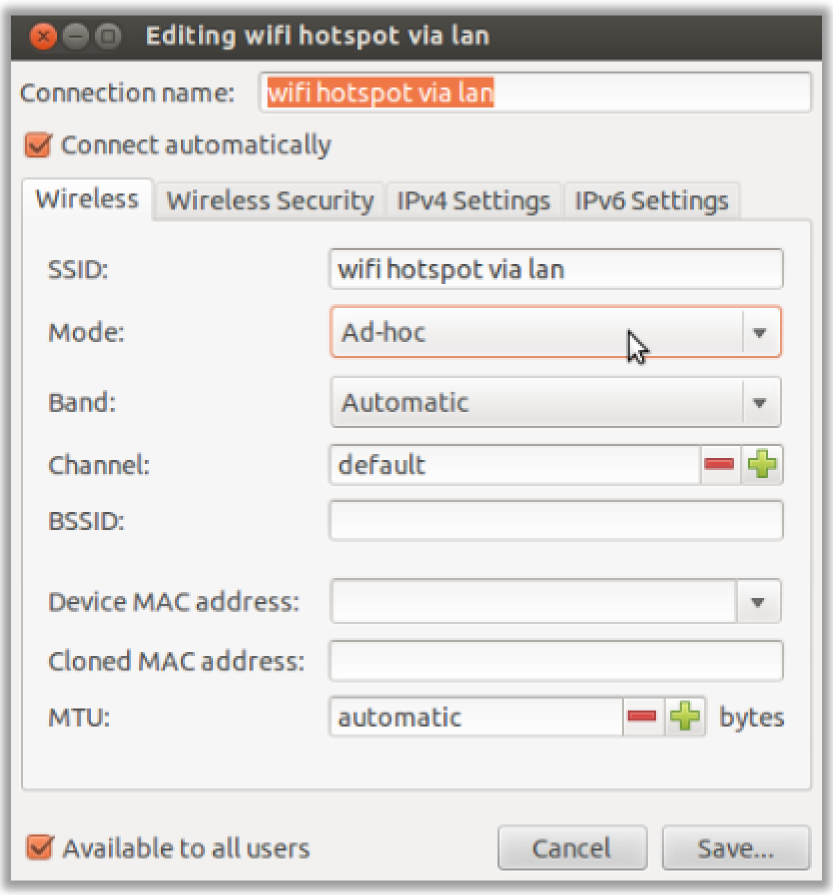
When powered up with the FTDI cable from a computer through the Arduino FIO (it could be from the battery) we should see the three LEDs on (amber, red and green). This means the connections are correct.

Second of all, we should try to reach its network. According to the manufacturer, the default values are:

- IP: **169.254.1.1**
- Netmask: **255.255.0.0**

This Netmask means that if we want to reach its net we should have a 169.254.XXX.XXX type of IP, being XXX any number from 0 to 254 (except for 1.1 which is the address of the module itself).

Once powered up we should wait (perhaps some minutes) until we can see WiFly-GSX-XX on the *available wireless networks* list on Linux (top-right corner, connection configuration). The last two XX are the last two bytes of the modules MAC address. Once it shows up (Fig. 68) we go to *edit connections* and select the WiFly-GSX-XX inside *wireless* and edit it. Inside the *wireless* tab we select Ad-hoc and leave everything else intact. In the *wireless security* tab we select none (for simplicity reasons) and in the IPv4 tab we select *manual method* and click on *add* in *address.*



Editing wifi hotspot via lan

Connection name: wifi hotspot via lan

☑ Connect automatically

Wireless | Wireless Security | IPv4 Settings | IPv6 Settings

SSID:	wifi hotspot via lan
Mode:	Ad-hoc
Band:	Automatic
Channel:	default
BSSID:	
Device MAC address:	
Cloned MAC address:	
MTU:	automatic bytes

☑ Available to all users

Cancel | Save...

Figure 66: Wireless connection configuration

At this point we have to set an IP for our computer that is inside the subnet ranged by 255.255.0.0. For example we can set an IP of 169.254.1.1 and a Netmask of 255.255.0.0. We then save the changes and connect to WiFly-GSX-XX.

Once connected, we open a prompt (Linux terminal) and ping to 169.254.1.1. This way we check if we can send and receive TCP packets to that address. If everything goes well we should receive data. To exit we press *ctrl + c*.

Now it is time to configure the module. From the terminal we type: *telnet 169.254.1.1 2000* which starts a communication with the module using the telnet protocol. (By default the module listens for telnet connections on port 2000). Once we open the connection the module answers “*HELLO*”.

After the connection is opened we type **$$$** without carriage return (to enter in configuration mode) and should receive “*CMD*”. We are now ready to configure it by typing the next commands followed by “enter”.

set wlan auth 0	Open network, no authentication.
set ip dhcp 0	DHCP off: It will not ask for an IP or gateway.
set ip adress X.X.X.Y.	We set the WiFly’s IP.
set ip host X.X.X.Z.	The router’s IP. (Same subnet).
set ip netmask 255.255.255.0.	
set wlan ssid "name".	
set wlan channel 0.	It will look in every channel.
set wlan join 1.	Automatically join the stored ssid.

After this we save and rebot.

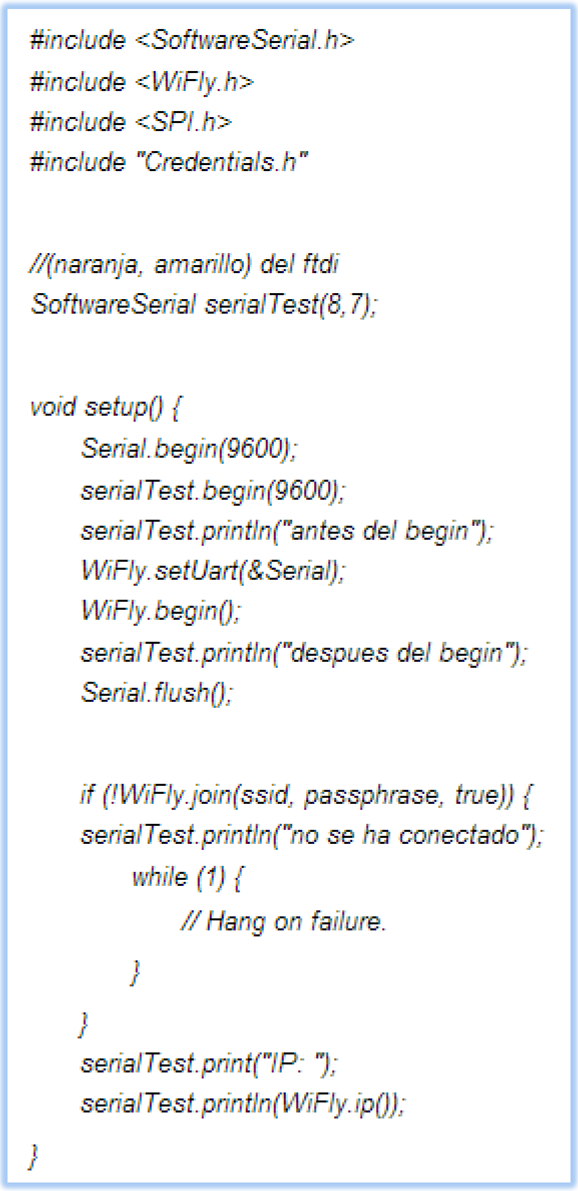
save.
reboot.

The next time we power the Arduino with the WiFly module plugged in, it will reach for the router’s network and connect to it using the assigned static IP.

Arduino IDE and library

On the internet we can find some libraries (written in C) destined to work with the WiFly module (WiFlyHQ [45], WiFlySerial [46], WiFly, etc.) and they all work in a similar way. The most complete and robust is the WiFly-Shield library [47]. To install it we have to download it and decompress it creating a libraries folder in the sketchbook, inside the Arduino folder. (“~/*sketchbook/libraries/*”*)*. This library comes with some example codes for Arduino (Client, Server, FTP, HTTP, etc.). To use it in a sketch we have to write *#include<WiFly.h>*.

In order to start working with it we write the next *setup()* function:



```
#include <SoftwareSerial.h>
#include <WiFly.h>
#include <SPI.h>
#include "Credentials.h"


//(naranja, amarillo) del ftdi
SoftwareSerial serialTest(8,7);


void setup() {
    Serial.begin(9600);
    serialTest.begin(9600);
    serialTest.println("antes del begin");
    WiFly.setUart(&Serial);
    WiFly.begin();
    serialTest.println("despues del begin");
    Serial.flush();


    if (!WiFly.join(ssid, passphrase, true)) {
    serialTest.println("no se ha conectado");
        while (1) {
            // Hang on failure.
        }
    }
    serialTest.print("IP: ");
    serialTest.println(WiFly.ip());
}
```

Within this initialization setup function, we will use the *WiFly.begin()* function to enter in command mode and connect to an external server to get the time and date. We should comment this part of the code in the *WiFlyDevice.cpp* file.

With the different *Serial.begin()* functions we initialize the serial ports. With the *SoftwareSerial.h* library we enable different TX and RX pins for serial comm. We also enable the UART to be able to communicate with the Wi-Fi module serially.

With the *join()* function we establish communication with the *ssid* and *passphrase* specified in the credentials file.

In order to make this work we need two FTDI cables. The first powers the Arduino FIO and loads the program to the board using the standard TX and RX serial pins, which also communicate with the Wi-Fi module through *Serial.print()*. The second cable only needs its yellow and orange wires to act as software RX and TX and will connect (through another USB port) to the defined pins by the *SoftwareSerial* object. See figure 69.

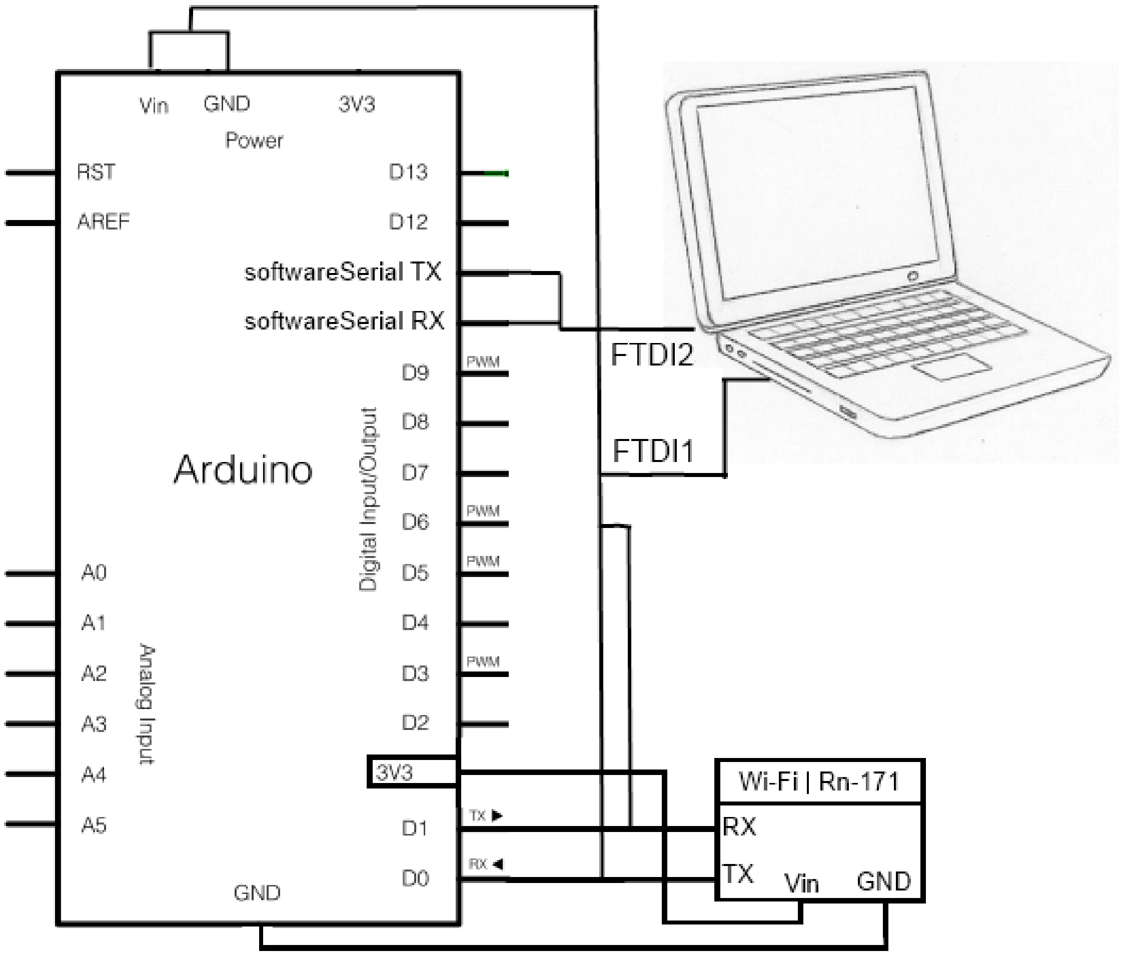


Figure 67: Layout for serial communication

Data flowing through this second cable will be showed in the serial monitor of the Arduino IDE. For this purpose we could have a *loop()* function as follows:

```
void loop() {
    while (Serial.available()) {
        int incomming = Serial.read();
    serialTest.println(incomming);
    }
}
```

With this function, any data coming through the Wi-Fi module will be read by the FIO's UART and written to the serial monitor through the second TX and RX (Software serial pins).

When the *setup()* sketch is run, the serial monitor shows the module's assigned IP with *serialTest.println(Wifly.IP())*. If we telnet to that IP and to port 2000 any data written with the line of commands from Linux will be quickly showed in the serial monitor (fig. 70).

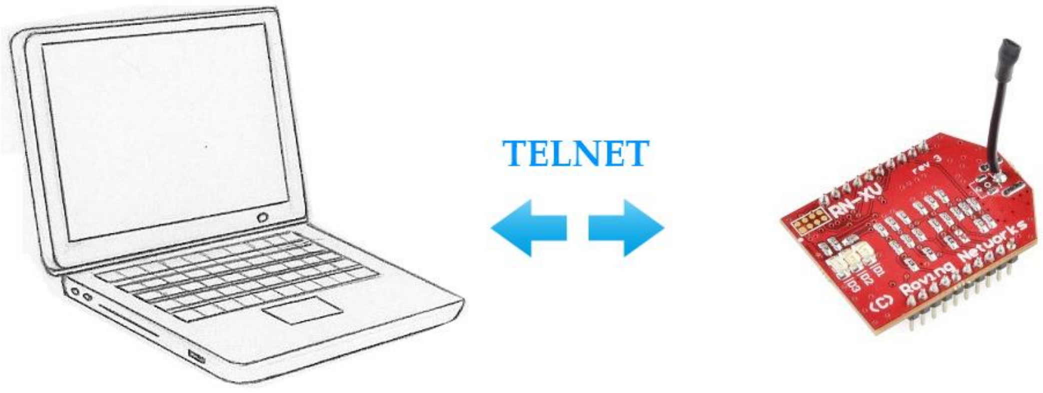


Figure 68: Telnet communication between Laptop and Wi-Fi module

This way we have established, through Arduino, a configuration, connection and data streaming.

Next, the last way to configure the Wi-Fi module.

Directly with Arduino Sketch and IDE

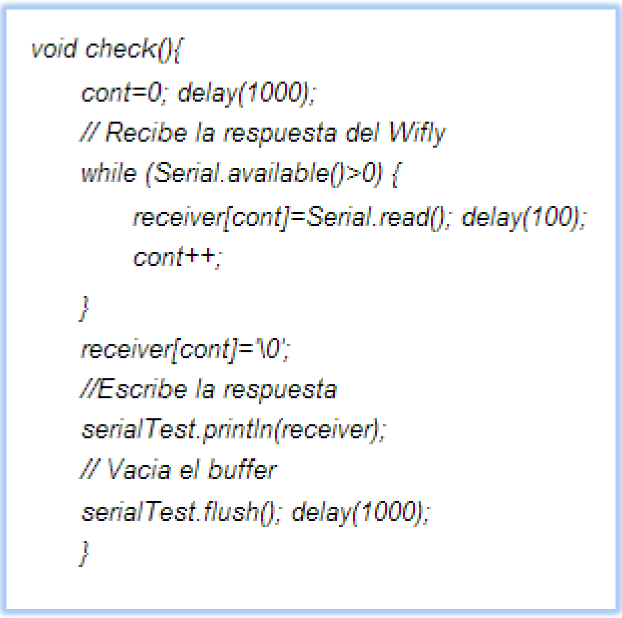
This last method for configuring the module is the simplest in terms of external help as we do not use libraries or extra material apart from the Arduino board and the Wi-Fi module. However we are required to dig into the user's manual and add a little bit of complexity to our code.

We will write a code in which the serial functions write() and read() will communicate with the Wi-Fi module using the UART. (Let us recall that this serial pins are the standard pins for serial communications, usually used for monitoring data and uploading sketches). This way, we use the same pins that the Arduino uses for talking to the module for uploading our program to the Arduino memory.

This program automatically sends to the Wi-Fi's module a set of instructions similar to the ones used in the first method. The same instructions that we use to configure it by telnet can be written to the UART and then serially read by the WiFly. The only precaution that we must take is that we should leave a few milliseconds between each instruction so that it can take effect.

```
#include <SoftwareSerial.h>

#include <SPI.h>
char receiver[512];
int cont;
SoftwareSerial serialTest(8,7);
void setup() {
      Serial.begin(9600);
      serialTest.begin(9600);


      Serial.flush();
      delay(1000);
            Serial.print("$$$"); check();
            Serial.print("set wlan auth 0\r"); check();
            Serial.print("set ip dhcp 0\r"); check();
            Serial.print("set ip adress XXX.XXX.XXX.XXX\r"); check();
            Serial.print("set ip host xxx.xxx.xxx.xxx\r"); check();
            Serial.print("set ip netmask 255.255.255.0\r"); check();
            Serial.print("set wlan ssid "SSID"\r"); check();
            Serial.print("set wlan chanel 0\r"); check();
            Serial.print("set wlan join 1\r"); check();
            //Serial.print("save\r");
            //Serial.print("reboot\r");
      serialTest.print("IP: ");
      serialTest.println(WiFly.ip());
}
```

Next, goes the *check()* function, which waits for the module to respond to each instruction and stores it in an array. Then, it prints this answer to the serial monitor.



```
void check(){
      cont=0; delay(1000);
      // Recibe la respuesta del Wifly
      while (Serial.available()>0) {
            receiver[cont]=Serial.read(); delay(100);
            cont++;
      }
      receiver[cont]='\0';
      //Escribe la respuesta
      serialTest.println(receiver);
      // Vacia el buffer
      serialTest.flush(); delay(1000);
      }
```

As *loop()* function we can use the same as found in the second method. Last, it is important to notice that we send the character '**\r**' as line feed for the instructions to take effect (unless we send the **$$$** command to start configuring the module, which does not go with \r).

Chapter 6

Android application software

This project focuses mainly in building a software application for controlling a robotic machine. In particular, the application controls a wheeled robot but it is possible to generalize the contents and functionality of this software to extend it to other types of robotic control (robot arms, humanoids, industrial machinery, etc.).

It has been developed for Android with the possibility of being run by smartphones and tablets with wireless internet connections.

Java was the preferred language for this project, although as mentioned in the background section it is possible to write parts of the code in both C and C++. The code has been written using Linux (Ubuntu distribution) and Windows both with Eclipse as IDE (integrated developing environment). Almost all features of the final application have been previously tested in an Android virtual device (AVD) where developers can check the behavior of their applications before installing them in a real device. There have been parts, however, that could not be run in an

AVD such as connectivity with other devices (TCP sockets) and some multi-thread code.

Before developing for Android directly, it has been the intention of this project to fully understand the possibilities given by the Java language when interacting with external electronic devices (Arduino) using sockets, and at the same time, understand the way data is transferred through a TCP connection and how it is treated by the Arduino board. This is covered in the next subsection.

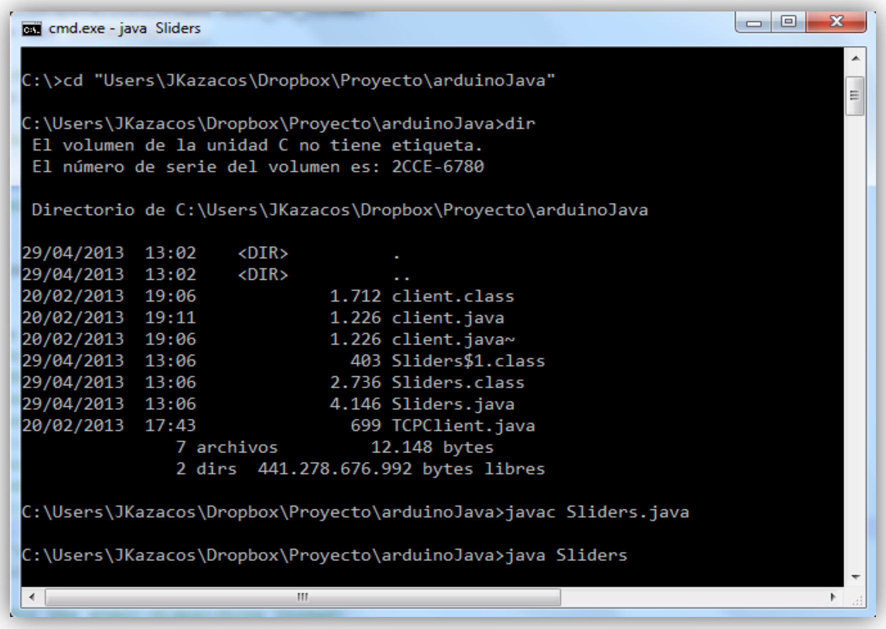
As explained before, all data transferred to the Wi-Fi module, either using Bluetooth protocols or TCP/IP protocols is treated always as characters.

For this reason, although we send integers with one or more digits, it is from the Arduino software side that we must implement a routine, if we need it, to convert these characters or strings into integers.

6.1. Java GUI

In order to test and demonstrate the communications with the Wi-Fi module and Arduino, a Java program has been built using simple TCP connections and a Java graphic user interface to interact with the servos.

The two most important console commands both in Windows and Linux to work with Java are ***Javac*** for compiling ***.java*** code and ***Java*** for running the resulting ***.class*** compiled file (fig. 71):



```
C:\>cd "Users\JKazacos\Dropbox\Proyecto\arduinoJava"

C:\Users\JKazacos\Dropbox\Proyecto\arduinoJava>dir
 El volumen de la unidad C no tiene etiqueta.
 El número de serie del volumen es: 2CCE-6780

 Directorio de C:\Users\JKazacos\Dropbox\Proyecto\arduinoJava

29/04/2013  13:02    <DIR>          .
29/04/2013  13:02    <DIR>          ..
20/02/2013  19:06             1.712 client.class
20/02/2013  19:11             1.226 client.java
20/02/2013  19:06             1.226 client.java~
29/04/2013  13:06               403 Sliders$1.class
29/04/2013  13:06             2.736 Sliders.class
29/04/2013  13:06             4.146 Sliders.java
20/02/2013  17:43               699 TCPClient.java
               7 archivos         12.148 bytes
               2 dirs  441.278.676.992 bytes libres

C:\Users\JKazacos\Dropbox\Proyecto\arduinoJava>javac Sliders.java

C:\Users\JKazacos\Dropbox\Proyecto\arduinoJava>java Sliders
```

Figure 69: Console commands for running Java

Note: it is important that we have previously installed the Java platform (Java SE), which includes the Java Development Kit (JDK) and the Java Runtime Environment (JRE) to run applications (More on this in the next section) [48].

With the first command we compile the code. After compiling, and if there has been no error, with the second command we launch the program. In the next image we can see the resulting Java GUI, which is a simple window with two controllers (sliders) that send information to the Arduino (fig. 72).

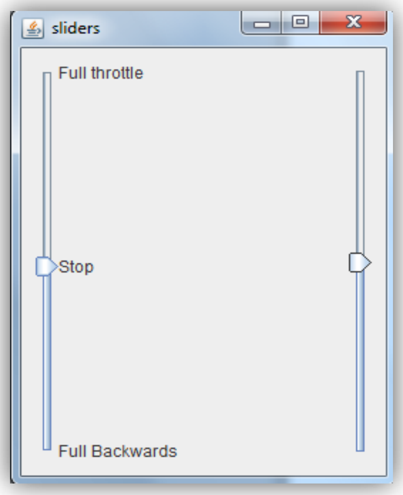


Figure 70: Java User interface program for robot control

This Java Application creates a socket and acts as a **client** in order to send the data to the Arduino (**server**, listening for incoming data).

What is a socket? *A* socket *is one endpoint of a two-way communication link between two programs running on the network. A socket is bound to a port number so that the TCP layer can identify the application that data is destined to be sent. An endpoint is a combination of an IP address and a port number* [49].

The Client-side knows the hostname of the machine on which the server is running and the port number on which the server is listening (fig. 73).

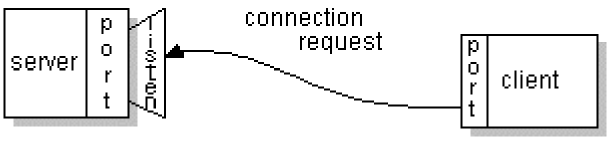


Figure 71: Client-server connection: client request [49]

The server-side: If there is no error in the connection, the server accepts the connection and gets a new socket bound to the same local port. It keeps the socket open so that it can continue to listen for client requests (fig. 74).

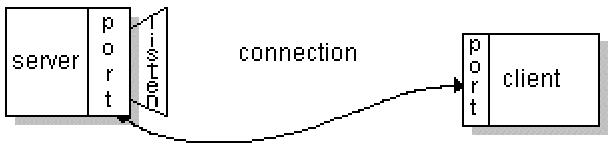


Figure 72: Client-server connection: server accepts connection [49]

Next, some captures of the Java code necessary for this application. In the first capture we create and show the window containing the program.

```
private static void createAndShowGUI() {
      //Create and set up the window.
      JFrame frame = new JFrame("sliders");
           frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      Sliders animator = new Sliders();

      //Add content to the window.
      frame.add(animator, BorderLayout.CENTER);

      //Display the window.
      frame.pack();
      frame.setVisible(true);
      //animator.startAnimation();
}
```

In the next capture we create and configure the Sliders. The class constructor of JSlider allows for initial, minimum and maximum values that will be sent through the socket.

```
    //Create the sliders
    JSlider rightSlider = new JSlider(JSlider.VERTICAL,
                                  MIN_RIGHT, MAX_RIGHT, INIT_RIGHT);
    JSlider leftSlider = new JSlider(JSlider.VERTICAL,
                                  MIN_LEFT, MAX_LEFT, INIT_LEFT);

    rightSlider.addChangeListener(this);
    leftSlider.addChangeListener(this);

    //leftSlider.setMajorTickSpacing(10);
    //framesPerSecond.setPaintTicks(true);
```

6.2. Android developing platform

In order to start developing for Android it is recommended to download the ADT Bundle (Android Developer Tools) [50]. It includes the Android SDK components (Software developing kit, a comprehensive set of development tools, a debugger, libraries, sample codes, etc.) and a version of the eclipse IDE with built-in ADT. This project has been developed completely under Eclipse, since it is the officially supported IDE. Some parts have been done in Linux and others in Windows.

Under Linux we must follow the next steps to have all packages configured and ready: After downloading the SDK we untar the .tgz into an appropriate location which we will refer to later when setting up the ADT plugin. The next step is downloading the ADT plugin and once Eclipse starts we must specify the location of our ADT directory. This plugin extends the capabilities of Eclipse to let us quickly set up Android projects, build an app UI, debug it and export app packages for distribution.

Now if we are running a 64-bit system we must install the ia-32 libs package using apt-get (Ubuntu):

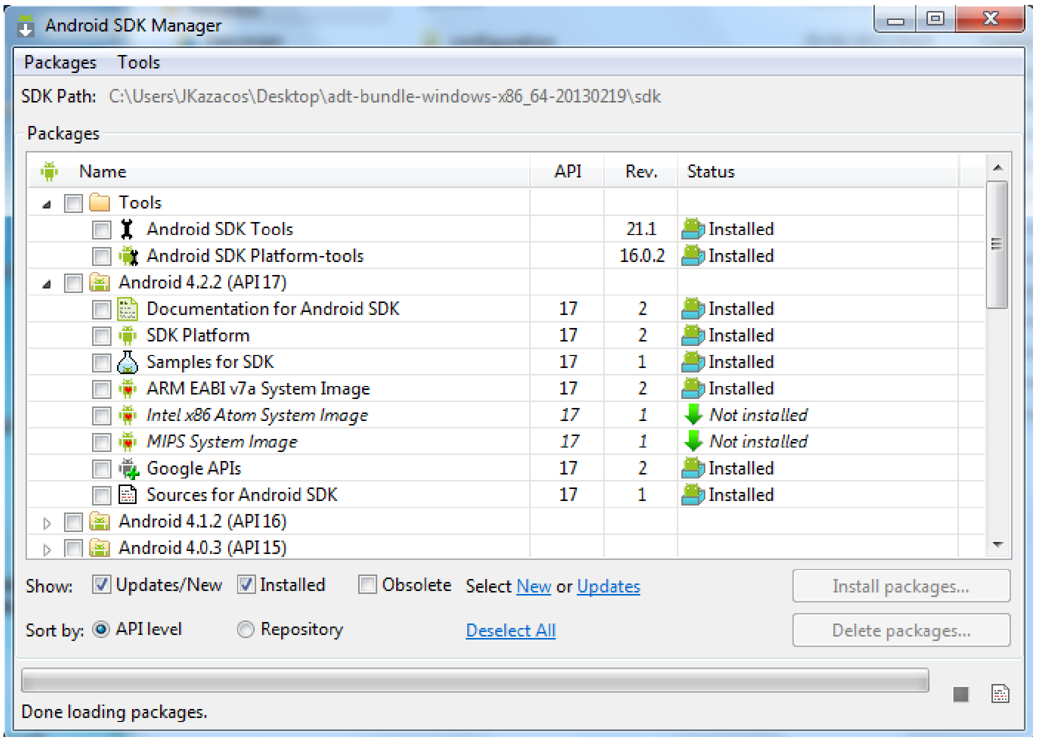
```
ubuntu : ~$ apt-get install ia32-libs
```

After, we install Java:

ubuntu : ~$ *apt-get install oracle-java7-installer*

Now, we have to launch the SDK manager and install the last Android platform and the latest SDK platform-tools. This is because the original SDK package includes only the SDK tools.

In the next picture we can see the SDK manager, which we can launch from Linux just by typing sdk in the command line.



SDK Path: C:\Users\JKazacos\Desktop\adt-bundle-windows-x86_64-20130219\sdk

Packages

Name	API	Rev.	Status
Tools			
Android SDK Tools		21.1	Installed
Android SDK Platform-tools		16.0.2	Installed
Android 4.2.2 (API 17)			
Documentation for Android SDK	17	2	Installed
SDK Platform	17	2	Installed
Samples for SDK	17	1	Installed
ARM EABI v7a System Image	17	2	Installed
Intel x86 Atom System Image	*17*	*1*	*Not installed*
MIPS System Image	*17*	*1*	*Not installed*
Google APIs	17	2	Installed
Sources for Android SDK	17	1	Installed
Android 4.1.2 (API 16)			
Android 4.0.3 (API 15)			

Show: [✓ Updates/New] [✓ Installed] Obsolete Select New or Updates

Sort by: [✓ API level] Repository Deselect All

Done loading packages.

Figure 73: Android SDK manager [50]

When the Android tools are updated or a new version is released, we can use the SDK Manager to quickly download them to our environment.

6.3. Basics of apps development

Once we downloaded and installed the set of tools included in the *SDK*, we can access them form the Eclipse IDE. The basic steps for developing applications are shown in figure 76.

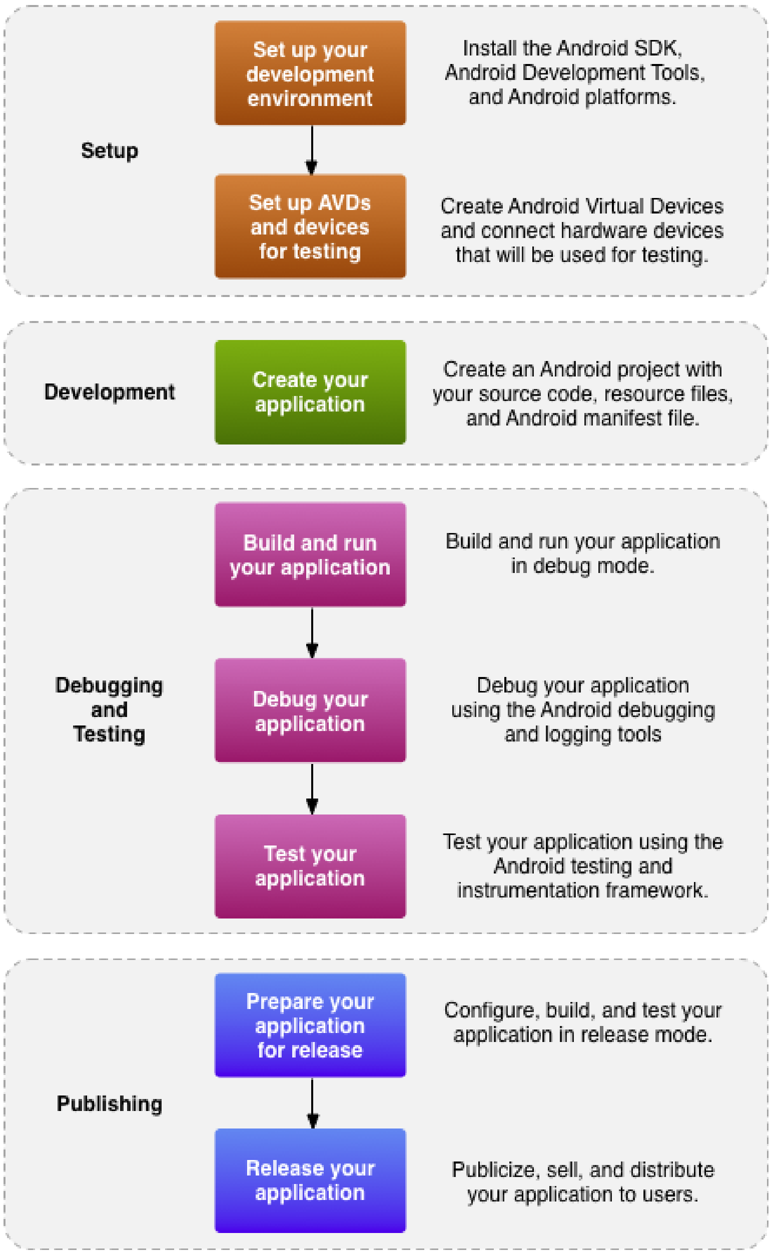

Setup
Set up your development environment
Install the Android SDK, Android Development Tools, and Android platforms.
Set up AVDs and devices for testing
Create Android Virtual Devices and connect hardware devices that will be used for testing.
Development
Create your application
Create an Android project with your source code, resource files, and Android manifest file.
Debugging and Testing
Build and run your application
Build and run your application in debug mode.
Debug your application
Debug your application using the Android debugging and logging tools
Test your application
Test your application using the Android testing and instrumentation framework.
Publishing
Prepare your application for release
Configure, build, and test your application in release mode.
Release your application
Publicize, sell, and distribute your application to users.

Figure 74: Basic steps for apps development [50]

Setup

During this phase we install the development environment (2º part of this chapter) and create our Android virtual device (AVD)

Development

We develop our source code and include all media files needed for the application (video, photo, music, etc.).

Debugging and testing

In this phase we build our project into a debuggable *.apk* that we can install or run on the emulator. We can also test the application using various SDK Android testing tools.

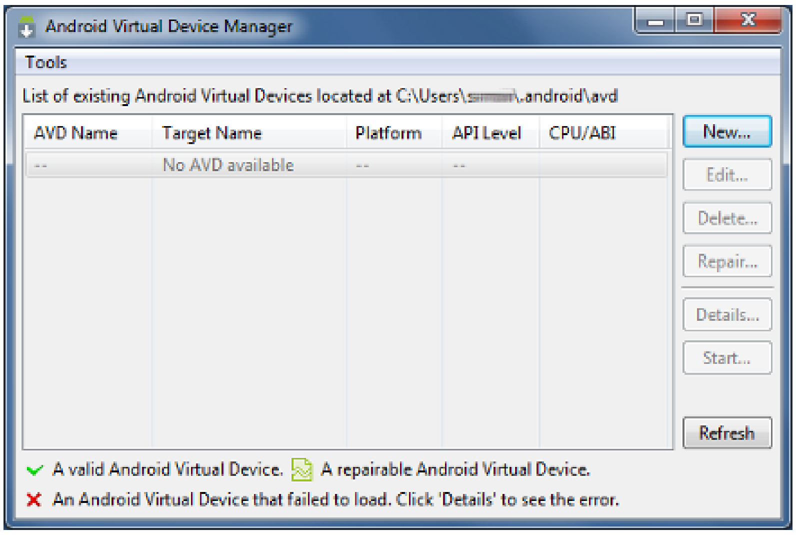
Publishing

The last step is building the application for release and distributing it.

In this project we will focus in the first two parts. First, we will see how to set up an Android virtual device followed by how to install the application on a real Android hardware, and last, we will cover the building and running.

Managing virtual devices

First, from Eclipse we launch the AVD manager (fig. 77) which is an emulator configurator that lets us model an actual device by defining hardware and software options to be emulated by the Android emulator. We can select a hardware profile for hardware features, for example, if it has a camera, a physical QWERTY keyboard, memory options and so on.



List of existing Android Virtual Devices located at C:\Users\s[redacted]\.android\avd

AVD Name	Target Name	Platform	API Level	CPU/ABI
--	No AVD available	--	--	

✓ A valid Android Virtual Device. A repairable Android Virtual Device.

✗ An Android Virtual Device that failed to load. Click 'Details' to see the error.

Figure 75: AVD Manager [50]

Through this window we create and configure as many virtual devices as we need. It is important that we test our application on different devices with different screens and features to enhance the application's performance.

Using hardware devices

First we have to declare our application as debuggable in our Android manifest. (This step is automatic with Eclipse). After this, we have to enable *USB debugging* under Settings > Applications > Development. Last, we have to set up our system to detect our device.

Under Ubuntu Linux we have to add a *udev*-rules file that contains a USB configuration for each type of device. Each device manufacturer is identified as a unique vendor ID.

- First, we log in as root and create this file:
  /etc/udev/rules.d/51-android.rules

We should use the next format to add each vendor to the file:

SUBSYSTEM=="usb", ATTR{idVendor}=="0bb4", MODE="0666", GROUP="plugdev"

- Then execute:

  chmod a+r /etc/udev/rules.d/51-android.rules

Building and running

When building an application Android projects are compiled and packaged into an *.apk* file containing the compiled *.dex* files, a binary version of the manifest and compiled and uncompiled resources.

The following diagram shows the components involved in building and running an application:

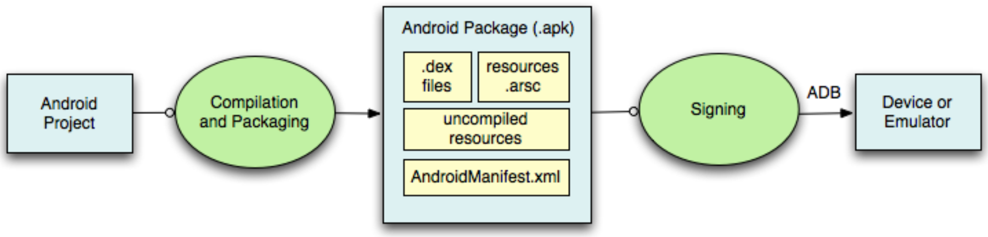


Figure 76: Project phases [50]

Before we run our project we should be aware of a few important directories and files in the Android project.

AndroidManifest.xml

This file describes the fundamental characteristics of the app and defines each of its components. We define how the resources are going to be displayed and how each feature will behave. Also, we specify the activities and services that will run in the application and the target Android version.

Src/

This is the directory for our app's main source files.

Res/

This folder contains several sub-directories for app-resources, for example:

Drawable/

Directory of the drawable objects (bitmaps) included.

Layout/

Files that define our app's user interface.

Inside this folder we will put all images (drawable objects, *.jpg, .png*, etc.) and the *.xml* files containing the layout information for each activity.

In Android, every app is built with activities or services. An activity is an application component that provides a screen with which users can interact to perform different actions. Every activity is given a window with a user interface. Every time that we open a new "window" from the classic computers point of view that window is an activity. When we transition from one screen to another, with different components and functions, we change from one activity to another.

Another application component of the same hierarchy is a service. A service can perform long-running operations in the background (but in the same thread) but does not provide a user interface.

Managing the activity lifecycle

The Android system, unlike other programming paradigms which implement a main() method, initiates code in an activity instance by invoking specific methods that correspond to different stages of its lifecycle. There is a sequence of methods for starting the application and other sequence to tear it down (fig. 79). This two make a sequence similar to a step pyramid being the top of the pyramid (**resumed**) the point at which the activity is running and the user can interact with it.

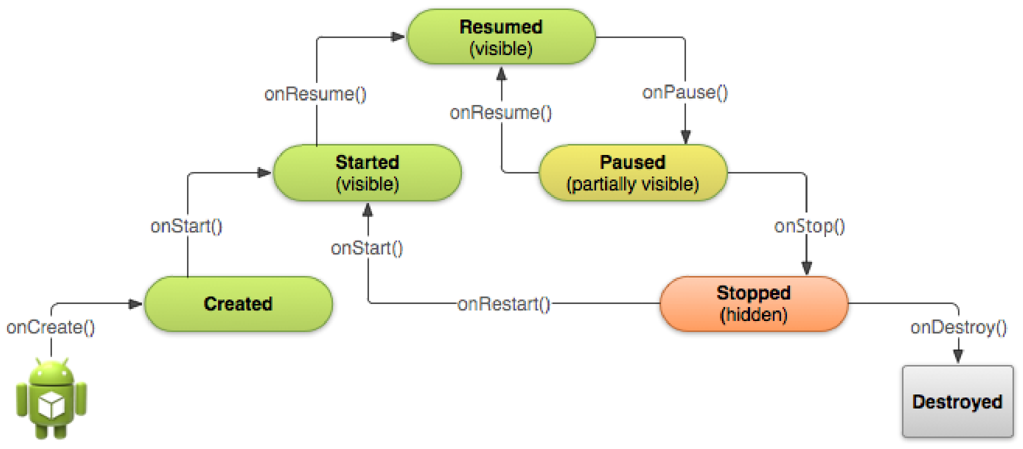


Figure 77: Activity lifecycle [50]

Depending on the complexity of our activity we probably do not need to implement every method of the lifecycle as the system normally manages them if they are not specifically defined. In the **paused** state, the system is partially obscured by other activity and cannot receive any input or execute any code.

In the stopped state the activity is completely hidden and not visible to the user (background). The instances and activity information is retained but cannot execute any code.

The created and started states are transient and the system quickly moves from them to the next state. After the system calls onCreate(), it quickly calls onStart() followed by onResume().

The onCreate() method is invoked when the user selects the app icon from the Android system and it is equal to a main method (launcher method). The onCreate() method should define the user interface as well as basic application startup logic.

Transitions between the other states are done by invoking the functions between them (Figure 79) but are normally not specifically defined as the system does that automatically (for example, if we do not implement the onDestroy() method, the system will destroy all local class references from memory when no longer needed).

This project's main application only defines the onCreate() method for building the user's interface, buttons, and other objects. The rest of the methods are managed by the system while users run the activity. However, for the second activity (controlling activity), we manually define the onStart() method for creating a second thread (apart from the main) in charge of sending cycling chain values for controlling the robot.

In the next section of this chapter we will take a look at the two activities (Main activity and Control activity) involved in the application, their function, some significant pieces of their code and the block diagram for each of them.

6.4. Application for robot control

This project's application consists of two Activities and two different threads for the second activity.

First, upon launching the application we have an initial screen (for the first activity) in which we can introduce an IP and port for later connecting to a robot using that address. If we do not introduce anything, the application will use default values. This first activity acts as an introductory screen, and the only thing left to do there is pressing a button to change to the controlling activity (fig. 80).

Basically, the user decides when to start controlling the robot, so the connections are not going to begin until the second activity is launched. It is a "waiting room" for the Android–robot interaction to begin running.

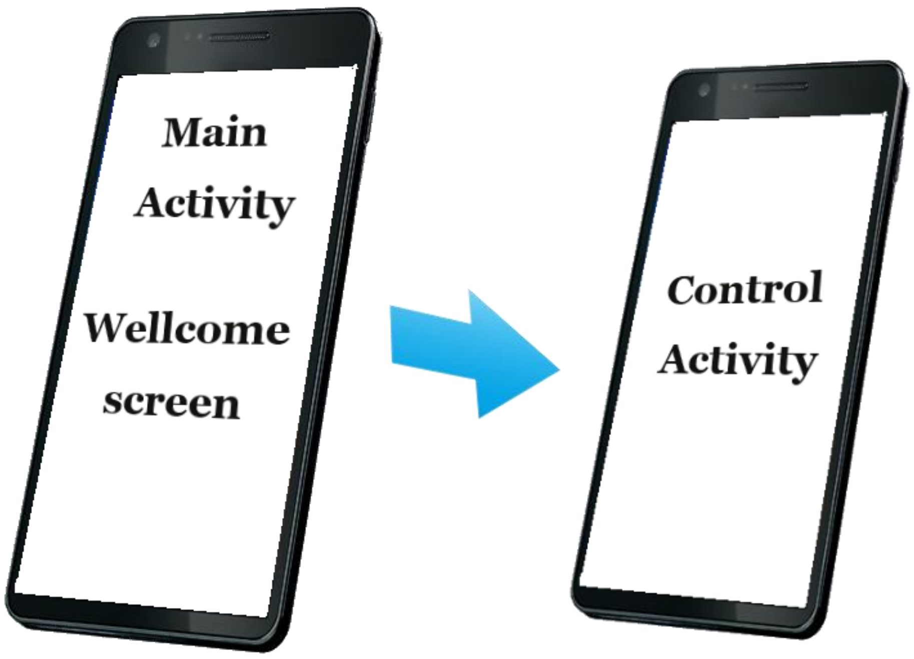


Figure 78: Main activity and Control activity

As we can see in the previous image, these two activities form the Android application.

6.4.1. Main activity

When launched (fig. 81), the application starts with this activity, defining so in the Manifest as the main activity (this way Android keeps record of the activities' hierarchy in the AndroidManifest.xml). It only serves as an introductory screen from which users can introduce an IP and a port, (different from default) that will be transferred to the second activity for connecting to the robot.

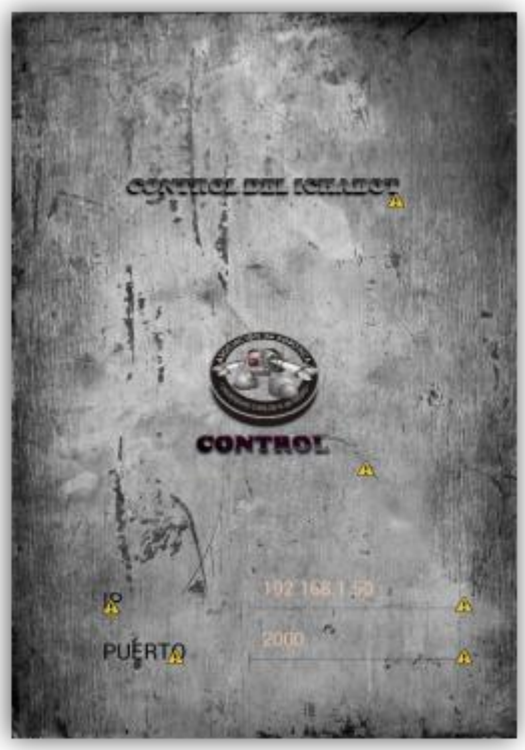


Figure 79: Main activity's graphical layout

The code for this activity is very simple, only having the onCreate() method and an event object that relates a button to the second activity. The controlling button (middle of the screen) starts the second activity and leaves this one behind. Within the onCreate() constructor, we set the rules for the layout (path to *xml* file) and the objects to build in the screen.

Next, the block diagram for this activity:

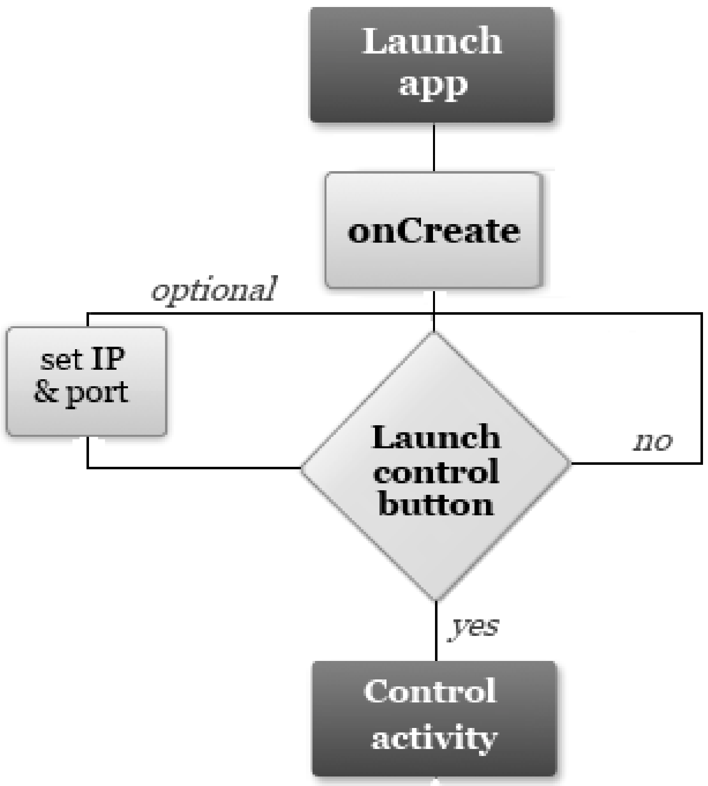


Figure 80: Block diagram for the Main activity

When the control button is pressed, the control activity is launched. In the next section we will explore in detail this second activity.

6.4.2. Control activity

In this activity users perform two important actions. First, with the connect button we can start the communications. The program opens a socket with either the previously specified address or the default IP and port. In the middle of the screen there is a text box that serves as a log for monitoring the sequence of actions that the program runs.

As we can see in Figure 83, the layout for this activity is in landscape mode by default so that it is easier to control using the thumbs. With the upper button we connect and with the bottom button we disconnect.

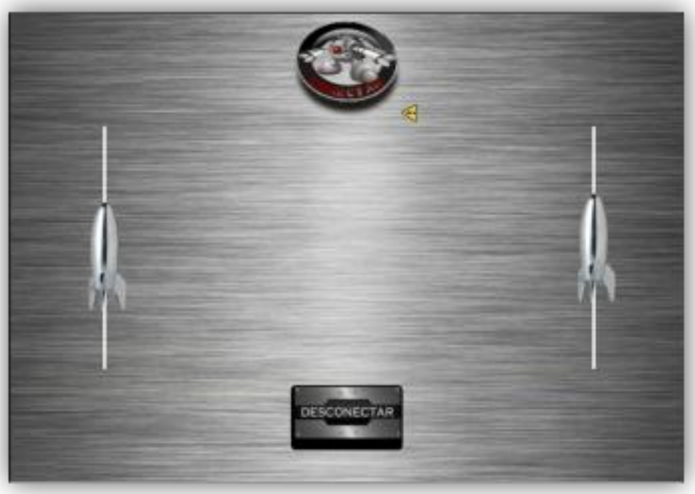
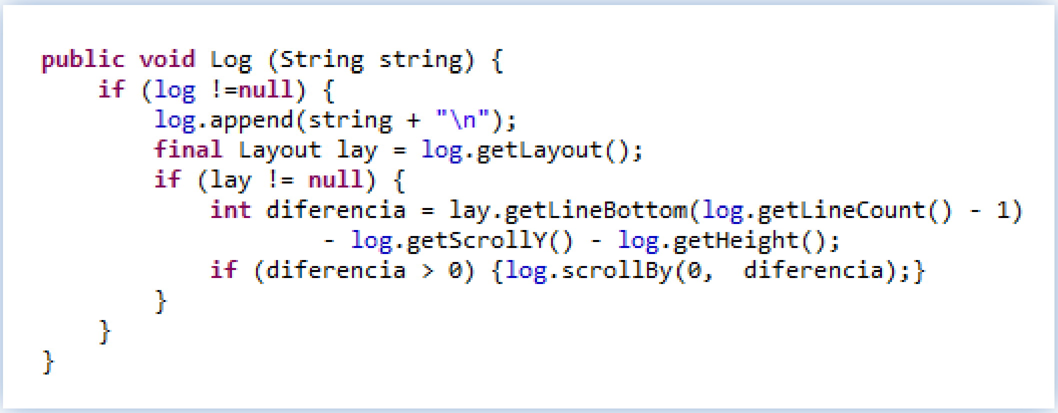


Figure 81: Graphical layout for the Control activity

If connected successfully, a "connection accepted" message will appear in the log showing the socket's IP and port. If there is an error, the log will try to catch the exception produced and will show the corresponding error. We then, can associate the message to a specific cause and try to solve it. This log text-box is able to auto-scroll when new messages are written and do not fit anymore. This way there is always room for more messages and users are able to scroll upwards to read previous messages.

In the next image we can see the code in charge of that function:



```
public void Log (String string) {
    if (log !=null) {
        log.append(string + "\n");
        final Layout lay = log.getLayout();
        if (lay != null) {
            int diferencia = lay.getLineBottom(log.getLineCount() - 1)
                    - log.getScrollY() - log.getHeight();
            if (diferencia > 0) {log.scrollBy(0,  diferencia);}
        }
    }
}
```

There is also a disconnect button to close the socket. This is always recommended and considered a good practice before closing the application, so that we do not leave a sleeping process in memory or a useless open connection.

Next, the code for opening the socket and connecting the seekbars' values (integers subject to be sent to the Arduino) to the socket's associated output object (socket.getOutputStream()). Apart from opening a TCP channel (as client) with the Arduino (server) we relate the constantly changing values from the seekbars to the output buffer of the socket (object that sends information to the server). If we needed to implement a two-way connection, we would use also an InputStream object (associated to the socket as well) to receive information from the server. This would be interesting if, for example, we were required to read field data from sensors or third applications (web services) and use that incoming data in our main application.

As this is a prototype, we should first focus on the main issues and build a robust application by debugging errors involved in this process. Later on, we could expand the functionality of the application as well as the robot.

```
public void InicioConexion (View view) {

    if (!conectado) {
        Log("Intentando iniciar conexión...");
        Log("IP: " + IP);
        Log("Puerto " + puerto);
        try {
                socket = new Socket(IP, puerto);
                Log("Conectado con Arduino");
                try {
                        salida = new PrintWriter(socket.getOutputStream(), true);
                } catch (Exception e) {
                        // TODO Auto-generated catch block
                        Log("error print-socket");
                        try {
                                Thread.sleep(4000);
                        } catch (InterruptedException e1) {
                                // TODO Auto-generated catch block
                                e1.printStackTrace();
                        }
                                e.printStackTrace();
                        }
                        conectado = true;
                } catch (UnknownHostException fallo) {
                        Log("No ha sido posible conectar - UnknownHostException");
                        Log(fallo.getMessage());
                        conectado = false;
                } catch (IOException fallo) {
                        Log("No ha sido posible conectar - IOException");
                        Log(fallo.getMessage());
                        conectado = false;
                }
    } else {
        Log("ya estas conectado");
    }
}
```

The codes showed in this document are a minor part of the complete code, but are also fundamental for the application and worth analyzing.

Next, the block diagram for this second activity together with the second thread for communications.

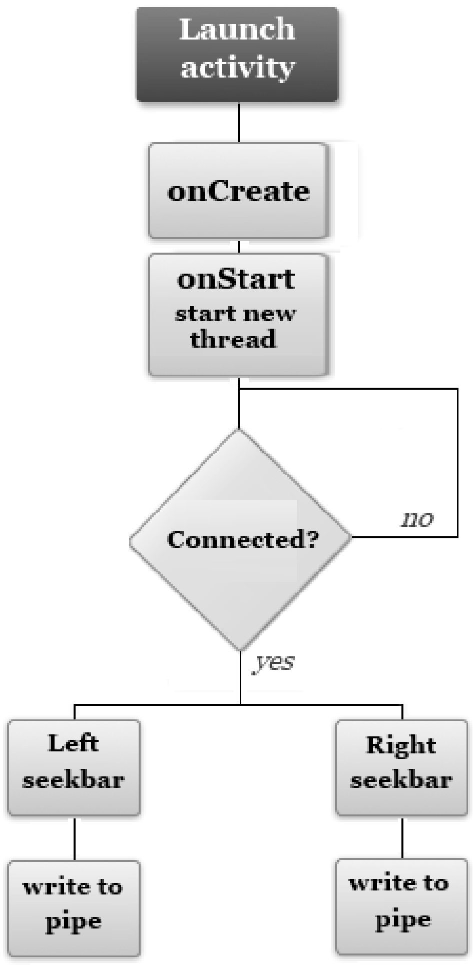


Figure 82: Control Activity block diagram

This program runs in the user's interface main thread and any changes in the seekbars are written in a variable that is accessible from the second thread through a pipe that connects both threads. It is not possible for a second thread to access (read or write) any variable or instance created in the main thread so a special binding is required between both threads.

The second thread (fig. 85) is constantly sending the values received from the first thread, regardless of whether any seekbar changes its value or not.

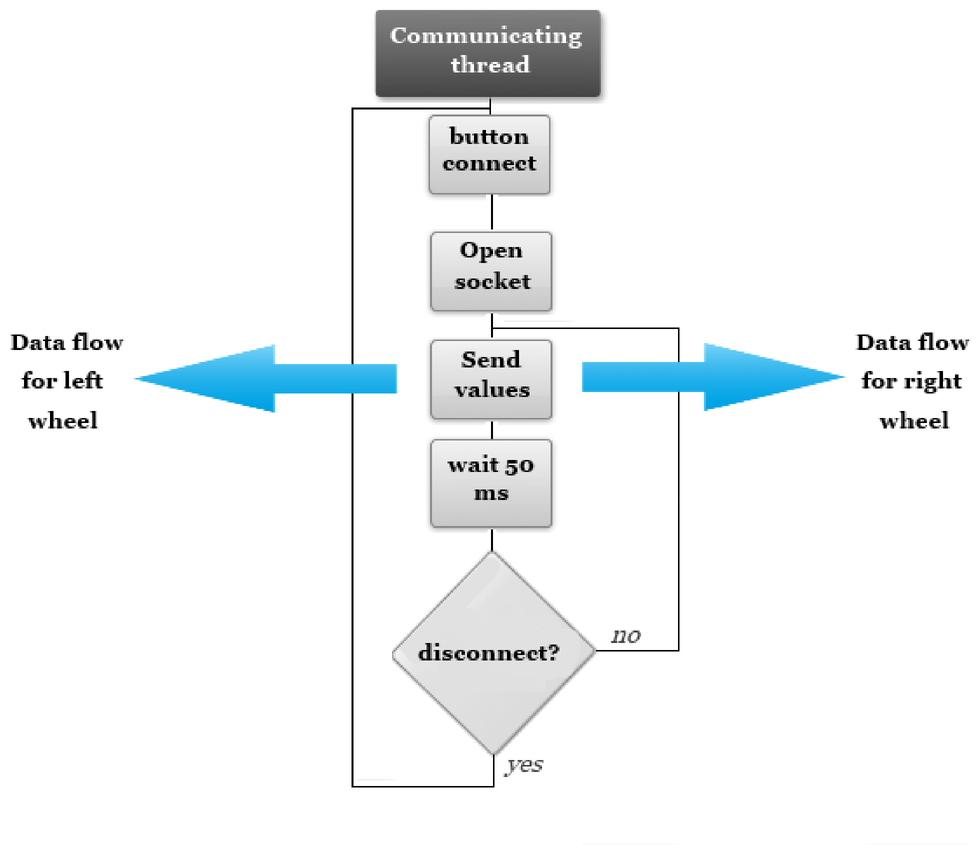
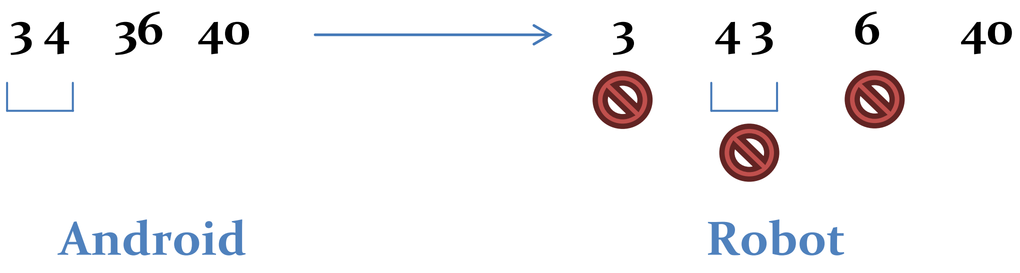


Figure 83: Second thread's block diagram

In order to control the robot, sending values to the Wi-Fi module, this implementation is not the only one possible. Indeed, there are other ways with different advantages and disadvantages to approach the issue of commanding a robot with numeric values. For example, the first way to develop the program was using a single thread for the second activity.

This way, we opened the connections in the main thread and any changes in a seekbar were treated as events which resulted in instantly writing the seekbars values in the output buffer, and then being sent to the robot. This was a simple solution from the Android side but an ineffective one for the robot since values were sent with no separation from one another making it incapable of distinguish different numbers.



This resulted in an erratic movement.

There was also another problem; we could not solve this from the Arduino side (robot) making it sample two-cypher numbers because the range covered numbers from one to three cyphers.

This implementation was the fastest but resulted inefficient. A solution for this problem came with the second implementation: Instead of sending a value for every event launched by the seekbars class listeners, we could only send a value when a seekbar stopped moving, that is, when users released their thumb from the screen (assuming they use that finger). This assured that values where sent isolated from one another making it impossible to create an overlapping in the data transfer.

However, there was a problem with this. Users did not get a fluid feeling when controlling the robot since they had to release and touch back again the screen with every change in direction, making it both rough and uncomfortable.

The third improvement was simple; we could make the change listeners wait a short delay before sending a value to the output buffer, so that there is no overlapping because the Arduino has time to process a single value before receiving another. This actually resulted to be really fluid since users do not perceive this delay (10 ms) which is perfect to create the right synchronization between both sides of the communication.

The last solution is probably the most professional but also the most complex of all. As previously mentioned we create a second thread in charge of a cyclic communication. This way the constantly changing seekbars and their associated event listeners are isolated from the code in charge of sending the values through the socket (fig. 86).

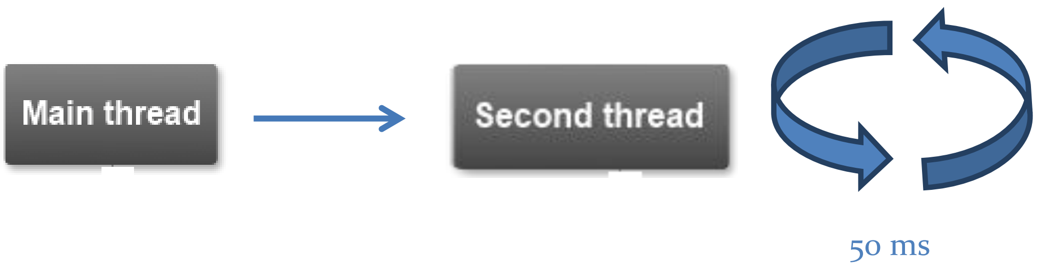
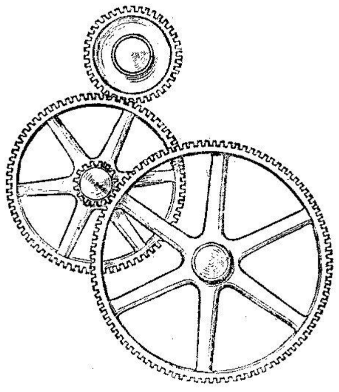


Figure 84: Multi-threading behavior

The complexity of this last implementation is far greater than the previous solutions since we are working with multi-threading and its implications. Although the user does not perceive it, values are actually sent always every 50 ms, which is a rigid rate, separating the user commands from the data transfer. This means, we have an indirect control which could be prejudicial for critical real-time applications. Actually, this last method has not proved to be 100% solid, since the application sometimes crashes in some Android devices. This could be, probably, because of the fact that Android versions behave differently and treat (or manage) threads and processes differently. Another issue is that the Android virtual machine does not always behave correctly when working with multi-threading applications.

Chapter 7

Conclusions and future work



Within the boundaries of this project and regarding its purposes in relation to manipulating low level wireless electronic modules as well as open source hardware and software (both Arduino and Android), we can assume that many of the initial goals have been accomplished resulting in an almost fully printable robot subject to teleoperation from any place in the world with an accessible Wi-Fi network. Nevertheless, almost none of the fields developed in this project can be considered in a dead-end state, as this is only an initial approach to the yet theoretical system that is currently under construction: Robot Devastation.

We are now expecting developers (electronics or computers engineers) to start digging into this project and pick an area that is yet to be built, as the UC3M robotics society is always available with the support and tools necessary for it. Although it may seem an arduous work at first, we encourage them to join this project, as it is worth the effort to work as part of a bigger project to have an understanding of the different areas and how they connect between them.

Among all that is left to be developed, we can start by mentioning a few inner projects that are already theoretically pre-defined (each one up to a certain point).

First, for example, we would need a group of computer engineers to build the server system: it should be a robust system in charge of managing all data at all times (24/7) and it should be accurate in terms of response time. If we consider Robot Devastation as a game, latency times should always be reduced to a minimum (which is a difficult task). A typical situation that we could think of would be an encounter between two robots (active at the same moment). These two start with life points and have the ability to aim and shoot the opponent decreasing its life points. All of this information would be managed from a server to which robots would constantly upgrade with their status. This status at the same time would be instantly reported to the user/ operator.

Second, from the electronics side, apart from improving the current robot (all its features are subject to redesigning for future versions), someone could provide a future version with sensors to achieve field information transmissions. Each robot would need a sensor to receive the shots from others and a shooting device as well. Besides, we could improve its performance by providing it with solar cells up to a point where the robot would need to recharge much less often.

As a conclusion to this, there will be a lot of work to do for a long time in all areas which will favor research and experience to those involved.

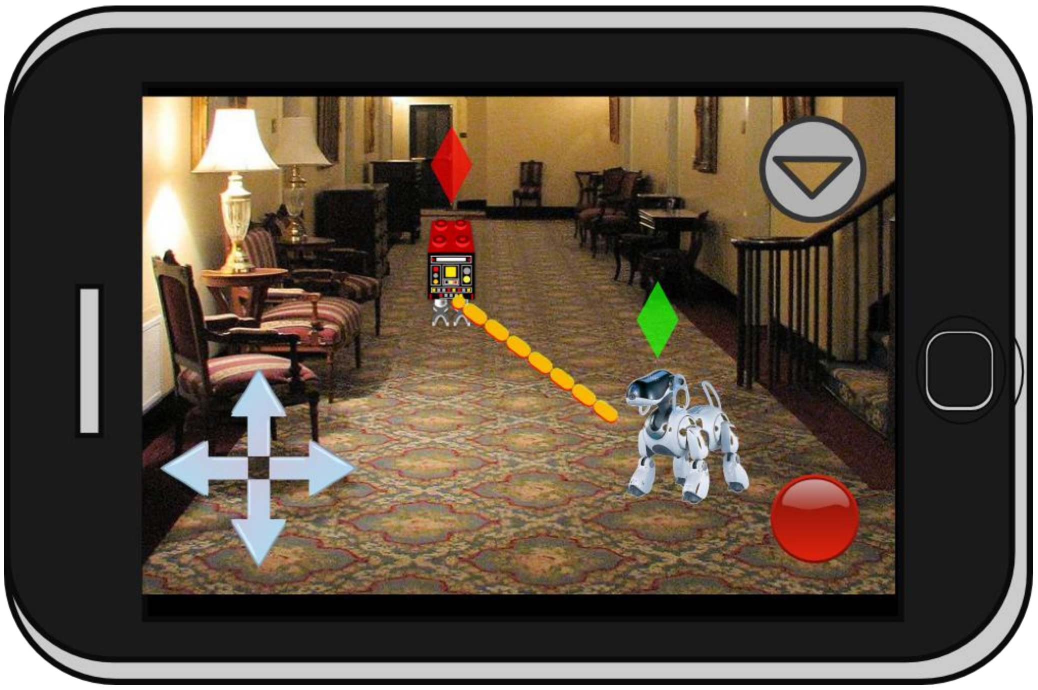


Figure 85: Concept of Robot Devastation by Santiago Morante

In the picture we can see a possible future version of the smartphone application in which we can actually see the environment at the time of playing as well as some augmented-reality objects.

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Appendices

PROJECT BUDGET

UNIVERSIDAD CARLOS III DE MADRID

Escuela Politécnica Superior

1. Author: Jorge Kazacos Winter
2. Department: Electronic Systems and Automation
3. Project Description: Android Controlled Mobile robot

   Duration: 10 months

   Indirect costs rate: 20%
4. Budget breakdown

LABOUR COST

Name	Category	Dedicated time (hours)	Cost per Hour (€)	Cost (€)
Jorge Kazacos Winter	Engineer	110	50	5500
Juan González Víctores	Senior Engineer	40	100	4000
Alberto Jardón Huete	Senior Engineer	4	100	400

Total **€9900**

EQUIPMENT COST

Description	Cost (€)	% of use	Duration (months)	Depreciation period (months)	Attributable cost (€)
3D printer	600	10	2	60	2
Arduino FIO	20	100	10	60	3.3
RNXV-171	35	100	10	60	5.83
LiPo battery	8.9	100	10	60	1.48
2 SG servos	3.5	100	10	60	0.58
Set of tools	20	100	10	60	0.33
Laptop	800	100	10	60	133.33
Android tablet	300	100	10	60	50

Total **€199.90**

Amortization formula: $\frac{A}{B} \times C \times D$ (for final cost).

Where A = Number of months of use of the equipment.

B = Depreciation period

C = Cost of the equipment

D = Percentage of use of the equipment.

And Indirect cost = 0.2 x (Labour + Amortization)

COST SUMMARY

Description of total cost	Total cost (€)
Labour cost	9900
Amortization cost	199.90
Indirect cost	2019.98
Grand total	**12119.88**