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Entitled

Design and production of a mini explorer robot

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Hicham Telli, Oussama Si Abdallah

Dedications

To those, who are, what we have most precious in life, our families, parents, brothers and sisters, who gave us everything we need, guided us, showed us the way to persevere and continue towards a better future.

To all our colleagues, friends and all those who have helped and supported us from near or far.

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Abstract

In this project, we are going to build a robot called Hexapod. This Hexapod designed to be an explorer robot. This project based on Arduino Mega, servo motors, RF Module.

The project divided to two part. First we are going to controller the Hexapod with a wireless controller. Secondly we will take off the Wireless controller and make it self-controlled or what called autonomous robot.

Résumé

Dans ce projet, nous sommes intéressés à construire un robot appelé Hexapod. Cet hexapode conçu pour être un robot explorateur. Ce projet basé sur Arduino Mega, servomoteurs, module RF.

Le projet s'est divisé en deux parties. Nous allons d'abord contrôler l'Hexapode avec une manette sans fil. Deuxièmement, nous allons retirer le contrôleur sans fil et le rendre auto-contrôlé ou ce qu'on appelle un robot autonome.

ملخص

في هذا المشروع، نحن سنقوم ببناء روبوت يسمى هيكسابود. تم تصميم هيكسابود ليكون روبوت مستكشف. سنستخدم أردوينو ميجا و محركات مؤازرة أو ما تسمى بمحركات سارفو ووحدة تعمل على موجات الراديو أر أف.

المشروع مقسم إلى جزئين، القسم الأول سنقوم فيه بالتحكم في هذا الروبوت عن طريق أداة تحكم لا سلكية، أما في الجزء الثاني فسنقوم بنزع أداة التحكم ونجعله الروبوت يقوم باتخاذ القرارات بنفسه أو ما يسمى بأوتونومي

General introduction

As a result of the great advances of the last few years many industrial processes have become largely automated, with the human operator playing an ever-decreasing role. The fully automated and unmanned factory is probably now only a few decades away. Although the idea of total automation is not new, it was not believed to be practicable until less than ten years ago. The study of automatic control and the use of automation systems dates back to the Second World War. But it was some years later that there was a huge leap forward in the design of automation systems. This comparatively sudden development marks the time at which the first industrial robot appeared. It was then that the term robotics started to be used to describe a new academic and industrial discipline. The evolution of automation systems into robotic systems has taken place in two stages, at least as far as industrial applications are concerned.

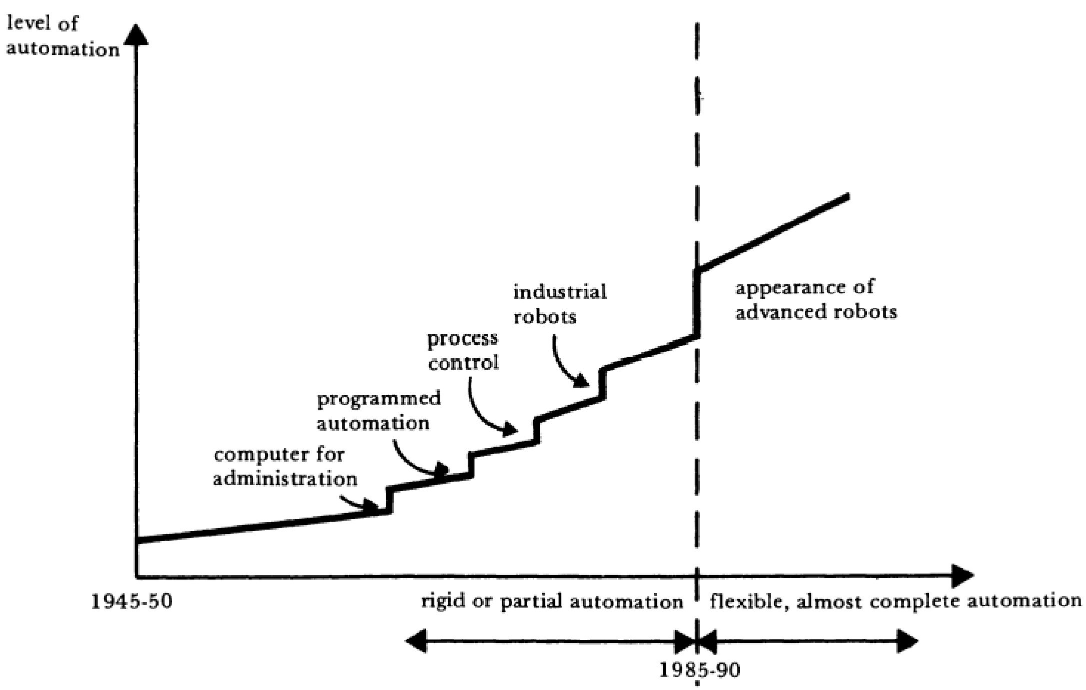

Figure 1: schema shows the development of robots in the last years

The fact that the word 'robot' exists in many languages is evidence of its recent coinage, despite the fact that it represents the fulfilment of an age-long aspiration: to create a device that can replace man in everything he cannot or does not wish to do himself, but still needs or wants to do, without presenting any threat to his authority. The term first came into use during the 1920s and 1930s, following the appearance of a play by the Czech author Karel Capek, called R. U.R. (Rossum's Universal Robots). In the play small, artificial and anthropomorphic creatures strictly obeyed their master's orders. These creatures were called 'robots', a word derived from the Czech “robota”, meaning “forced labour”.

In 1495, Leonardo da Vinci drew plans for a mechanical man. Real robots were only possible in the 1950s and 1960s with the introduction of transistors and integrated circuits. The first commercial, digital and programmable robot was built by George Devol in 1954 and was named the Unimate. It was sold to General Motors in 1961 where it was used to lift pieces of hot metal from die casting machines at the Inland Fisher Guide Plant in the West Trenton section of Ewing Township, New Jersey. Today, commercial and industrial robots are in widespread use performing jobs more cheaply or with greater accuracy and reliability than human

Chapter I: Explorer robots

1. Introduction:

A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks. It can be defined as a goal-oriented machine that can sense, plan and act.

2. Robots' components:

There a lot of different types of robots [1] and forms that exist in this world beside the different of their applications so that make the thing hard to determinate the whole components that build those robots so we will talk about the general components that used a lot to build it:

2.1. Structure:

The structure of a robot is usually mostly mechanical [1] and can be called a kinematic chain. The chain is formed of links (its bones), actuators (its muscles), and joints which can allow one or more degrees of freedom. Most contemporary robots use open serial chains in which each link connects the one before to the one after it. These robots are called serial robots and often resemble the human arm. Some robots, such as the Stewart platform, use a closed parallel kinematical chain. Other structures, such as those that mimic the mechanical structure of humans [2], various animals, and insects, are comparatively rare. However, the development and use of such structures in robots is an active area of research (e.g., biomechanics). Robots used as manipulators have an end effector mounted on the last link. This end effector can be anything from a welding device to a mechanical hand used to manipulate the environment.

2.2. Power source:

The types of power that are used for robots to work depends on a lot of things [3] for example the type of robot (fixed in place or mobile) and the environments [4] that exists in because some robots are far away from any source (solar energy) but in general the powers that more common is (lead-acid) and lithium batteries but that doesn't prevent exist another power sources:

- Fuel
- mechanical energy
- Thermoelectric
- Super capacitors

2.3. Actuation:

Actuators are the muscles of a robot, the parts which convert stored energy [5] into movement. By far the most popular actuators are electric motors, but there are many others, powered by electricity, chemicals, and compressed air:

- **Motors:** The vast majority of robots use electric motors, including brushed and brushless DC motors.
- **Stepper motors:** As the name suggests, stepper motors do not spin freely like DC motors; they rotate in discrete steps, under the command of a controller. This makes them easier to control, as the controller knows exactly how far they have rotated, without having to use a sensor. Therefore, they are used on many robots.
- **Servo motors:** Servo motors are not actually a specific class of motor but are a combination of specific parts, which happen to include a DC or AC motor, and are suitable for use in a closed-loop control system. They are used in robotics, automated manufacturing and computer numerical control (CNC) machining applications.
- **Air muscles:** The air muscle is a simple yet powerful device for providing a pulling force. The key to its behavior is the braiding visible around the outside, which forces the muscle to be either long and thin, or short and fat. Since it behaves in a very similar way to a biological muscle, it can be used to construct robots with a similar muscle/skeleton system to an animal.

2.4. Sensors:

To do a right control of any type of robots and move it or some pieces of it to the right place and the right position we need to use some components called sensors [6]. These sensors give information. This information can be obtained either internally to the robot (for example, joint positions and motor torque) or externally using a wide range of sensors. There are many and many types of sensors that use to control the movements the reactions of the robot we mention some of them:

- proximity (ultrasonic …)
- light
- sound
- contact
- Temperature
- Distance (laser range, infrared distance …)
- Navigation (GPS …)
- Pressure

2.5. Controllers:

The basic thing that you need to use to generate all the information that comes from sensors or actuators and send them again and build a complete robot that responsive and effective and to do its job that made for is to use an integrated circuit.

An integrated circuit (IC), sometimes called a chip or microchip, is a semiconductor wafer on which a thousand or millions of tiny resistors, capacitors, and transistors are fabricated. An IC can be a function as an amplifier, oscillator, timer, counter, computer memory, or microprocessor.

In general, the IC includes:

- Memory to store the control program and the state of the robot system obtained from the sensors
- A computational unit (CPU) that computes the control commands
- The appropriate hardware to interface with the external world (sensors and actuators)
- The hardware for a user interface.

3. Classification of Robots:

The classification of robots can be done on various criteria such as their power source, work environment, size of the robot [7], type of drive system used etc. But in this chapter only we will focus on some of them:

3.1. Classification of robots based on the power source:

On the basis of the power source, the robots can be classified into 5 major divisions namely electrical, hydraulic, pneumatic, nuclear, and green:

3.1.1. Electrical power source:

- Robots operating with the electrical power source can further be subdivided as AC or DC systems.
- Direct current systems usually provide greater torque but they often require more maintenance for the motors. The use of motors generates dust and spark that can create hazards to the process.
- DC systems are common for the hobby robotics world as those systems are usually mobile, battery-powered robots.
- AC powered robots are common in industries and these often use Servo motors. Stepper motors are also used for these systems.

3.1.2. Hydraulic Power Source:

- Hydraulic power generates a large amount of force and it is used for heavy loads in robotics. The system uses some other form of energy for generating hydraulic [8] pressure. The robot uses this hydraulic force for performing its tasks.
- However, due to the improvements in servo motors, the hydraulic powered robots are losing ground.
- Hydraulic robots have some drawbacks such as-as a hydraulic leak, fire hazard, increased noise, increased maintenance and the cost of oil.

3.1.3. Pneumatic Power Source:

- Pneumatic robots are powered by compressed air or compressed inert gases [9]. These are used for high speed and high load carrying capabilities.
- These systems are very fast and the industries use them as a ready supply of cheap pneumatic pressure.
- However, the biggest problem with these robots is the difficulty in maintaining their position. This is due to the fact that gas is compressible, and stopping it mid stroke leads to drifting.
- The only way to hold its position is to use hard stop and constant pressure.
- Pneumatic robots also suffer from the issue of noise and leaks.

3.1.4. Nuclear Power Source:

- Nuclear-powered robots used their own nuclear reactor that is smaller than the nuclear reactors of nuclear power plants or submarines.
- Nuclear powered robots are used by space agencies such as NASA for deep space exploration.
- Nuclear powered robots run for years and decades without the need for human interaction which makes them perfect fit for the space missions.
- However, if these robots are used on earth, there will be the need for proper disposal of nuclear material after the fuel is completely spent.

3.1.5. Green Power Source:

- Green Power source refers to a wide variety of power sources that have the commonality of easy replacement without any negative ecological impact.
- The potential green power sources for powering the robots include solar power, wind power, organic sources, natural heat sources etc.

3.2. Classification of robots based on movement:

3.2.1. Fixed robots:

Fixed robots are more prominent in the industries where the robots work in well defined environment. Robots are generally mounted on the stable bases. These can compute their positions on the basis of their internal configuration.

3.2.2. Mobile robots:

These robots [10] are not fixed to the surface and are capable of free movement over the surface. Mobile robots can be of various types such as legged robots, wheeled robots, swimming robots, and flying robot etc…

3.2.3. Wheeled robot:

- Wheeled robots have wheels for movement and are guided by the kinematics models that rely on motion. Wheeled robots can be either be single wheeled, two wheeled, three wheeled, four wheeled, or multi wheeled etc.
- Single wheeled robots use a single wheel for balancing itself and for travelling and navigating to other places. The example of single wheeled robot is the Murato girl (Seiko).
- Two wheeled robot consists of parallel wheels that have its centre of gravity below the wheel axle. Such robots used a tilt sensor for detecting the tilt of the robot for maintaining the balance of wheels. The example of two wheeled robot is the NBOT.
- Three wheeled robot consists of three wheels arranged in the triangular shape which makes it balanced. Generally, the front wheel of the robot acts as the steering wheel while the two rear wheels provide the motion.
- In the four wheeled robots, the first two wheels provide the steering and the rear wheels provide the movement. The example of four wheeled robot is the Scarab, the rover used by NASA.
- Multi wheeled robots have more than four wheels for motion. All the wheels must have the same speed for movement which makes it difficult to design. The example of multi wheel robot is the Mars rover with 6 wheels.

3.2.4. Legged robots:

- These are walking robots that use limbs for motion. These robots are difficult to design and are mainly used for movement in a highly unstructured environment.
- Legged robots [12] are capable of moving in any kind of path and terrain. Legged robots can either be bipedal, tripodal, quadrupedal or hexapod.
- The example of a bipedal robots are Honda's ASIMO, and Sony's QRIO. The example of the tripodal robot is the STRIDER robot from RoMeLa. The example of the hexapod robot is the OSU Adaptive Suspension Vehicle of the Ohio State University.

3.2.5. Swimming robots:

- Swimming robots are used for working under water and for assisting navigation in swimming. Example of swimming robots are the PacX Wave Glider and the Swumanoid robot.

3.2.6. Flying robots:

- Flying robots can either be a micro sized robots that mimic the morphology of an insect, or the larger unmanned aerial vehicles (UAVs). For example, the "Rustom" UAV of DRDO

4. Applications of robots:

The main thing that robots made for is to help human to do his job and make easier. Because of this principle pushed the human to invent many and many types of robot and hire them in many sides of his life. In this time we can almost see robots in every place and we can mention some of them:

- Automotive industry
- Assembly
- Medical laboratories
- Medicine
- Nuclear energy
- Agriculture

- Customer service
- Arts and entertainment

All of these applications above is a little normal because the humans can do it without any help of robots. But what about a robots can reach places and environments the humans can't reach because of its nature or maybe in the outer space so in this situation the humans made these robots called exploration robots. There is a lot of types of exploration robots and we can categorize it to two types:

4.1. Exploration robots on the earth:

4.1.1. Volcanos:

Exploring volcanos is very dangerous, risky and very difficult for humans to discover and do his researches and this is due to the difficulty of its nature (high temperature and gases) so the scientist made robots and one of them called "VolcanoBot 1" [13] to discover fissures. This robot was tested at Kilauea volcano in Hawaii.

Also the scientist use Drones with cameras and advanced equipment to reach high temperature places. Drones were used to observe the lava dome, a viscous plug of lava. The researchers were able to show that the lava dome shows movements on two different time scales: slow expansion and growth of the dome and fast extrusion of viscous lava.

Figure 2: explorer robot for volcanos

4.1.2. Caves:

NASA's been working on robotic cave exploration for a long, long time, and Team CoSTAR (a robots development team specialized on wheeled and legged robots) fit right in with that. This common goal made a collaboration between NASA and CoSTAR [14] team to reach that difficult challenge.

Discovering caves is too difficult because the risks. The nature of caves is not safe from rockslides, falling from high place, difficulty breathing due to dust and lack of oxygen In addition to the narrow places so those scientist need robots can avoid these problem, flexible, Dust and water repellent and can be controlled from outside.

4.1.3. Oceans:

- Remotely operated vehicles (ROVs) are robots tethered to the ship. Scientists on the ship manipulate an ROV through a long cable that connects the robot to the ship. ROVs can reach great depths and stay there for extended periods.
- Autonomous underwater vehicles (AUVs) are robots pre-programmed to collect data from particular parts of the deep ocean. While they're off collecting data, scientists conduct other research on board the ship.
- Hybrid vehicles combine the best features of ROVs and AUVs. On May 31, 2009, one hybrid vehicle "the *Nereus*" reached the deepest part of the ocean, the Mariana Trench. It dived 10,902 meters (6.8 miles) below the surface—quite a bit deeper than *Alvin's* 1964 dive. We can only imagine what new underwater technologies will accomplish 50 years from now.

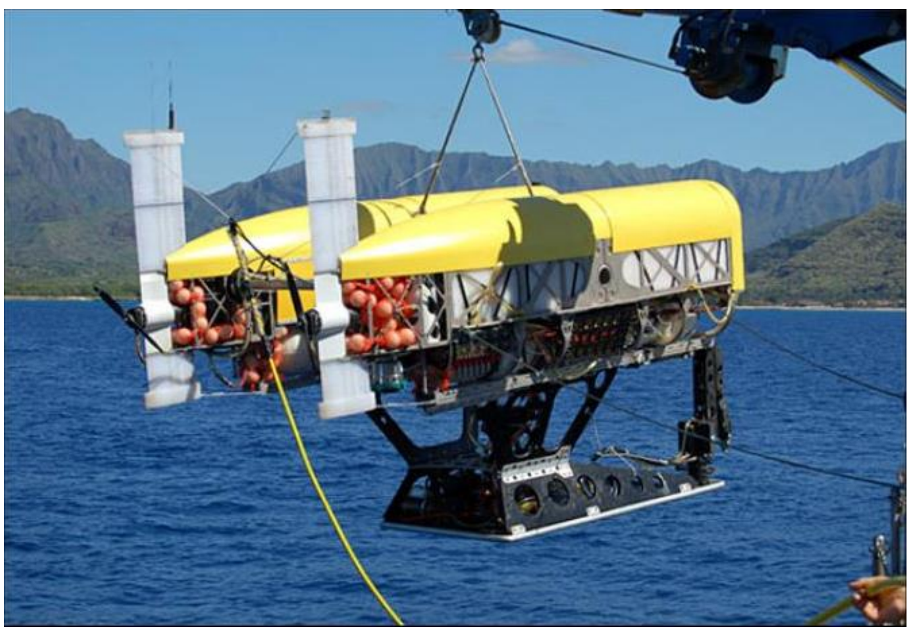

Figure 3: explorer robot for oceans

4.2. Exploration robots outside the earth:

The nature of the planets or the moon is too similar to the mountains and caves nature. So the space exploring robots have to be similar to caves and mountains robots but there are some things different for example we don’t know what really is in the planets and what we will face there and also the human can’t reach there so this companies was too prepared and created robots very equipped with everything they can imagine and here some space exploring robots:

- DLR ROTEX (1993) – 6 DOF autonomous manipulation experiment on ISS
- JAXA ETS-VII (1997-1999) – first satellite to be equipped with a robotic arm.
- CSA Canadarm 2 (2001) – service crane for the ISS assembly and maintenance.
- DLR ROKVISS (2005-2010) – a 2 DOF manipulation hardware test bed outside ISS
- MIT SPHERES (2006-present) – internal microsatellite testbeds aboard ISS.
- JAXA JEM-RMS (2009) – service arm on ISS.
- DARPA Orbital Express (2007) – autonomous satellite grappling.
- CSA Dextre (2008-present) – dual-armed external support system on ISS
- NASA JSC Robonaut 2 (2010-present) – dual-armed experimental system internal to ISS
- NASA GSFC Robotic Refueling Mission (2013) – ISS manipulation experiments.
- NASA Raven (2016) – ISS autonomous navigation and guidance system technology demonstrator.
- NASA Restore-L (2020) –satellite refueling mission.
- DARPA Phoenix Mission (2020) – multiple satellite repairs.

And we can’t forget the important orbital robot that NASA made ever it called rover “Curiosity”. Curiosity, is the most ambitious Mars mission yet flown by NASA. The rover landed on Mars in 2012 with a primary mission to find out if Mars is, or was, suitable for life. Another objective is to learn more about the Red Planet's environment.

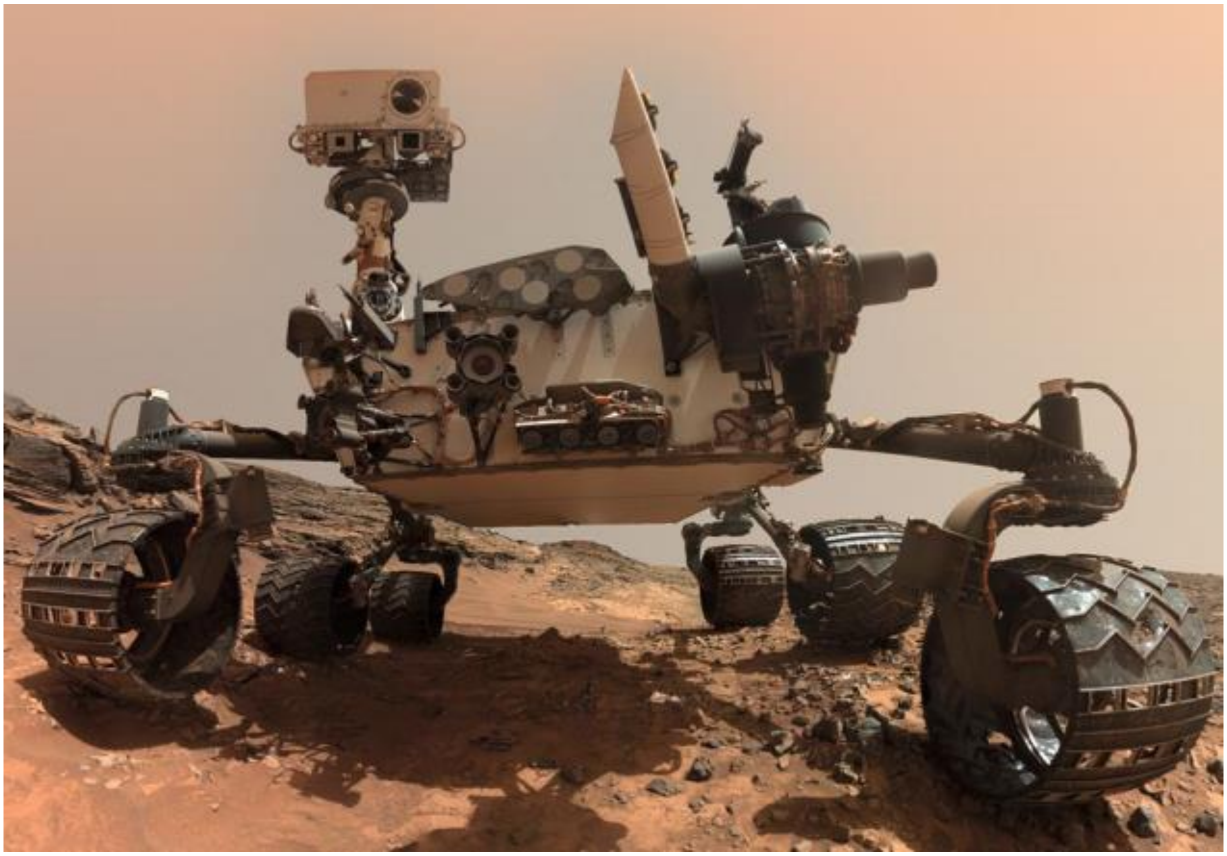

Figure 4: ROVER explorer robot on Mars

5. Autonomous Robots

Autonomy is a self-control [16] or the ability to make your own decisions. In humans, autonomy allows us to do the most meaningful tasks. This includes things like walking, talking, waving, opening doors, pushing buttons, etc.

In robots, autonomy is really no different. Autonomous robots, just like humans, also have the ability to make their own decisions and then perform an action accordingly. A truly autonomous robot is one that can perceive its environment, make decisions based on what it perceives. For examples with this autonomy and take the mobile robots as an example they can avoid obstacles, choose the right way that has to walk through and make decisions and another cool things make him unmanned and get close to behave exactly like a human.

With the current technological development, the scientists have been able to make autonomous robots and basically that means robots can control itself and make its own decisions without any human intervention.

5.1. Types of autonomous robots:

There are four types of robots:

5.1.1. Autonomous robots non-programmable:

These robots are very simple and do particular jobs, you can't reprogram it but still autonomous robots for example: The machine that throw balls.

5.1.2. Autonomous robots programmable:

These robots here can be programmed like the robots with arms in industries and you can reprogram it according to the application you need.

5.1.3. Adaptive autonomous robots:

These robots are more sophisticated than programmable robots. These robots can be equipped with extensions and sensors that makes it more effective and return feedbacks and reacting depending on those feedbacks.

5.1.4. Intelligent autonomous robots:

These robots' performance is highly efficient due to their situation-based analyzing and task performing abilities. And generally, these robots usually work with the artificial intelligent that make it collect data from the environment and also that makes it can react like an organism.

5.2. Applications of autonomous robots:

Dangerous applications:

- Space exploration
- Chemical spill cleanup
- disarming bombs
- Disaster cleanup

Boring and/or repetitive applications:

- Welding car frames
- Part pick and place
- Manufacturing parts.

High precision or high speed applications:

- Electronics testing
- Surgery
- Precision machining.

5.3. Components makes the robot autonomous:

Here in this part we will talk only about the equipment that belongs to the exploring Hexapod. There are many degrees of robots autonomy as we said before and that depends on the equipment that added to Hexapod and now we will mention the most popular equipment that used in robots to make it top level of autonomy.

5.3.1. Sensors:

The most common are:

- Infrared proximity sensor (IR)
- Ultrasound sensors (HC-SR04)
- Laser range finders (LRFs)
- GPS for localization

5.3.2. Cameras:

Cameras are used as the eyes of a robot. In many cases, two cameras are used, in order to provide the robot with binocular vision, allowing it to estimate the range to detected objects. There are many cameras available for robots, for example the CMUCam series which has been developed especially for use in mobile robots.

Figure 5: CMUCam camera series

5.4. Levels of autonomy:

With the current revolution in technology the thing of autonomy [16] become a lot common in robotic field. But there are many levels or degrees in autonomy, and these levels change depends on electronic equipment that added to the robot and also designed to describe how autonomous a robot is in executing a task and if the human stay with them and guide them or no. There are six levels of autonomy the lowest one is 0 and the highest is 5.

Level	Description	Time between interventions
0	Full manual teleoperation	n/a
1	Robot within line of sight (hands off)	5 minutes
2	Operator on site or nearby (eyes off)	1 hour
3	One operator oversees many robots (mind off)	8 hours
4	Supervisor not on site (monitoring off)	3 days
5	Robots adapt and improve execution (development off)	Extended operation

To explain these levels, we will use this picture here to understand how actually these levels designed:

Figure 6: farm operated with robots

Level 0:

Full manual teleoperation

Level 1:

Here, a human needs to be always within line of sight of the robot. For example in the picture above, a human have to watch the robot when it do its task and keep him in the road and prevent it from getting outside its path.

Level 2:

Now, the human operators switch to being (remote) supervisors: They don’t have to follow the robot, the robot may be out of line of sight, but the human still must remain on the field and keep monitoring the robot in case it needs rescuing. This capability is an enabling-point for high-value applications in many industries. For example, an agricultural robot might be able to navigate a way-point prescribed path avoiding most obstacles, and only get stumped once in a while. The target time between interventions increases to about an hour.

Level 3:

A Level 3 robotic team is sufficiently capable of dealing with edge cases for several days so that a single human can monitor a number of robots. This is where most multi-robot based farming systems begin to scale up. The human still might need to be on the field though to swap batteries, perform repairs, or rescue a stranded robot every so often.

Level 4:

In this level here, autonomous robots can really be deployed at large scale, without being constrained by labor costs. Also they are capable of dealing with many of the edge cases themselves, becoming sufficiently autonomous so that the human doesn't feel the need to be on the field. The robots are capable of finding their base stations, get a new battery, perform minor repairs, and get out of difficult cases (perhaps with help from a remote human). This level of autonomy needs not only the on robot software so developed and the infrastructure has to be typically a reliable connection with remote users.

Level 5:

At level 5, the robots begin to learn from their experience to improve operation beyond what the human designer has programmed in (using AI). They learn from each other, on site and from robot teams from other sites. They learn to predict how events affect their capabilities and plan proactively. Also they will be do teamwork and communicate with each other to be more effective, reduce time and produce more.

6. Conclusion:

Today we find most robots working for people in industries, factories, warehouses, and laboratories etc. Robots are useful in many ways. For instance, it boosts economy because businesses need to be efficient to keep up with the industry competition. Therefore, having robots helps business owners to be competitive, because robots can do jobs better and faster than humans can.

Adding intelligence to robots is questioned but future is the answer to this question and maybe there will be new ways to use robots which will bring new hopes and new potentials.

Chapter II: Robot design & components

1. Introduction:

In this chapter we will only concentrate about the mobile robots and do a deep explanation about the legged one that our project is for. Also, we will talk about the design of the robot and the specifications that make the hexapod looks like a spider. In addition, choosing the necessary components that make the robot walk like a real animal. Finally, we will discuss how to make a robot autonomous and how it will be full self-controlled.

2. Mobile legged robots:

Mobile robots have the ability to move in an environment unlike stationary industrial robots. And they can be classified by their travel environment: Water, air, ground, ice or space. Or by the device they use to move: Legs, wheels or tracks.

The scientist invented many types of legged robots and all are inspired from the nature (animals, human, insects …). They made robots with different number of legs (from one leg called "Hopper robots" to about two hundred in a millipede).

2.1. Definition of a Hexapod:

Hexapod [11] is by definition a robot that walks on six legs. As it can already attain a stable position with only three legs, six legs offer great flexibility. Even if one leg should get hurt and become unusable, a hexapod still can, in contrast to other mechanical machines with two or four legs, move without problems. Another advantage of six legs is the ability to operate an object with two legs while still standing or even walking on the other four

2.2. The advantages of six legs:

The wheel was one of the most important developments in human history. Due to this invention, the transportation of heavy loads was finally possible and travelling became easier and faster. Suddenly, one did not have to sustain all of the weight, but could transfer the majority of the power to the ground. On a paved street, fast movement was possible with small effort. But as soon as the earth was poured with water, the ground softened and the wheels were buried into the mud.

Furthermore, a robot [16] with six legs is more stable and can carry a bigger payload. Another important difference for industrial purposes is the system's ability to keep its payload constantly levelled when travelling over uneven terrain, something that is impossible with wheels. A further significant advantage is the possibility to unburden a leg. If one leg is malfunctioning, hurt or even broken, a quadruped cannot walk anymore. For a hexapod, even two defect legs do not necessarily mean that it cannot operate anymore, as there are still four legs left to maintain stability and advance.

So why do we not see hexapods everywhere? The answer is simple: They cost too much. Mostly, we do not need the options two additional legs deliver. Furthermore, it is mechanically a lot more complex to build a robot with this number of legs. But where money and the desire for two additional legs are present, for example the situation we have in space programs, hexapods are a designated tool. Due to their reliability, the NASA and the DARPA (Defense Advanced Research Projects Agency, USA) as well as other military institutes such as the US Air Force have heavily invested in this sector and funded many researches.

But then why not eight or even ten legs, one may ask. With them, a robot would even have a higher degree of flexibility and would be able to carry even more. The reason for mostly staying with six or less feet lie in energy-consumption: Even though eight legs provide more agility in rough terrain, more energy is needed in order to move them. Contrariwise, this demand affects size and mobility.

2.3. Walking mechanism in Hexapod:

At first sight, it does not seem to be much of a challenge to walk. The whole process is executed fairly autonomic without the need for cognition. Normally, we don't need to think consciously about how and in which way we move. It is rather the opposite: As soon as we start to think about how we shift our joints when walking, the movement gets clumsy and rather stiff.

In order to make the body move, our sub consciousness requires having extensive "motor intelligence".

First of all, as the system features more degrees of freedom than it needs, it has to deal with redundancy. In order to walk, the system cannot simply say "forward", it needs to select instantaneously among different alternatives of how to move which joints in order to use the optimal and appropriate one for a specific situation.

For each animal, multiple gaits are existing. Even though the number of mathematically possible combinations of six legs is enormous, only a few effective gaits are really used in practice. When running with wide steps, one is using other gaits with different intervals than while walking up a hill, where the steps are rather short. Of course, you can also run up a mountain, but you consume a much larger amount of energy with the wrong gait: With small steps, the exertion is distributed over more steps and is therefore easier to cope with.

2.4. The types of walking:

As we said before the researches inspired the Hexapod robots from nature and they follow the same ways for walking and in general they defined three ways to walk [17] or like they call them gaits, we have "wave gait", "tripod gait" and finally "ripple gait".

In order to understand the work of other researchers, gaits are noted in a specific way, whereby the different legs are given a specific number to identify them easily and fast. This numeration is done the following way: L1, L2 and L3 are representing the left legs, whereas R is referring to the right half. Counting begins at the front and is continued alongside the body and here we will take a cockroach as an example.

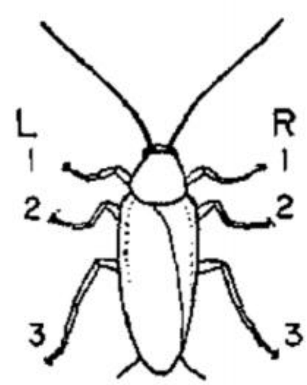

Figure 7: schema for a cockroach

2.4.1. The wave gait:

This artificial gait is also referred to as tetrapod gait, as four or more legs are on the ground at any time. This of course results in a leg pattern with significantly more stance phases, marking the main advantage of the wave gait: maximal stability. The disadvantage on the other hand is its slow-moving rate. Therefore, while used for slow and medium velocities as a walking gait, it is the ripple or the tripod gait that are chosen when fast motion is required.

For the wave gait, all legs are moved forward in succession, beginning from the rear-most one on the left side and after completion copied on the other side, thereby performing a wave movement. This process cannot be speeded up very much, as otherwise, one side of the robot would collapse due to lack of stability when two adjacent legs are simultaneously in swing phase. Because of clear stability reasons, the wave gait is preferred for walking on steep surfaces such as stairs.

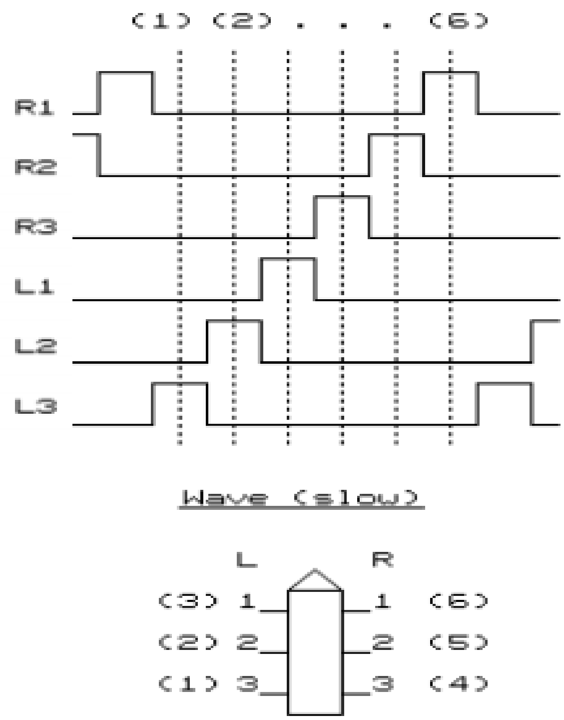

Figure 8: a chronogram for wave gait

2.4.2. The tripod gait:

The tripod gait is far and away the best-known and most commonly used gait when speaking of hexapod walking patterns. Most projects use this solution, as it is fast and still rather stable. The concept of this gait is, as its name indicates, based on the tripod, it consists of the front and back legs of one side and the middle leg of the other one. This triangle creates the most primitive form for a stable stand. The three legs form a phase which moves in unison and with a 180 degrees phase shift compared to the second tripod. During walking, the weight is constantly shifted from one tripod to the other.

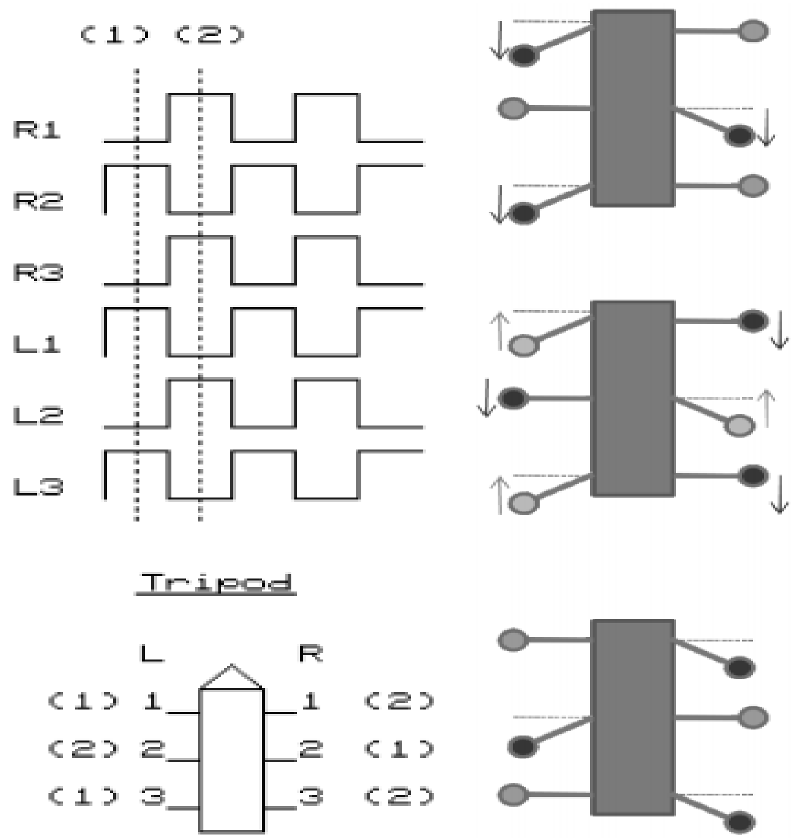

Figure 9: chronogram and schema for tripod gait

2.4.3. The ripped gait:

Even though not mentioned often, the ripple gait is a useful medium between the two previous gaits and unites stability and velocity. Compared to the tripod gait which only needs 2 “beats” (offsets) for one cycle, this gait, completing it in 3 beats (6 mini-beats), takes slightly more time to move one step forward. Still, it is remarkable two times faster than the wave gait with 6 beats required.

As before, this gait starts with L3. Then, a non-overlapping forward wave is performed on this side. After just half a beat, the other side starts with R1, performing the same movement backwards on the right side. After L1 has ground contact, R3 needs another half a beat to finish the cycle.

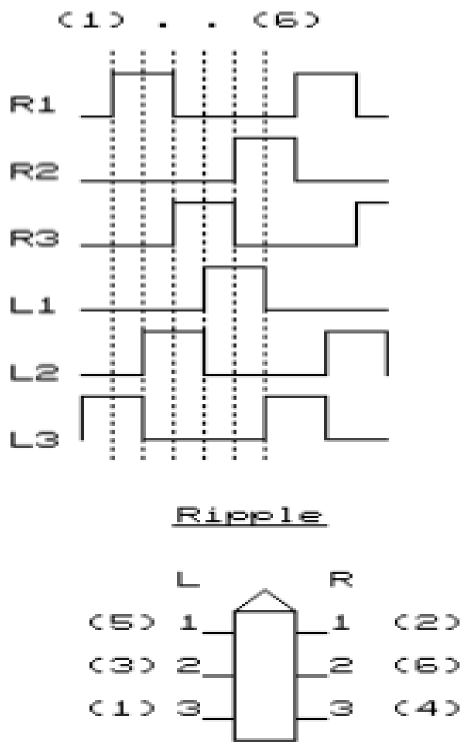

Figure 10: chronogram for ripple gait

3. Components:

- Servo motors
- Arduino Mega board
- RF radio module
- Ultrasonic sensor HC-SR04
- Joystick
- Battery
- The body of the robot

3.1. Servo motor:

MG90S is a micro servo motor with metal gear. This small and lightweight servo comes with high output power, thus ideal for RC Airplane, Quadcopter or Robotic Arms. The wiring of this servo is like all the servos it has three wires (brown for the ground, red for the power and it is typically +5V and the orange one is for PWM signal).

And here some additional features:

- Operating Voltage: 4.8V to 6V (Typically 5V)
- Stall Torque: 1.8 kg/cm (4.8V)
- Max Stall Torque: 2.2 kg/cm (6V)
- Operating speed is 0.1s/60° (4.8V)
- Gear Type: Metal
- Rotation : 0°-180°
- Weight of motor : 13.4gm

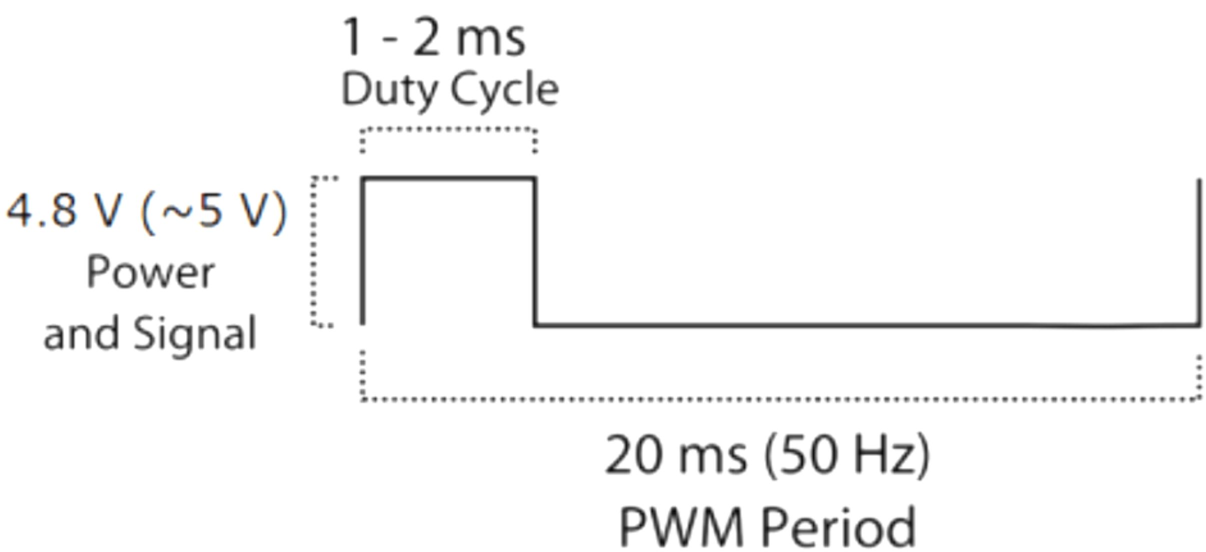

Figure 11: schema shows PWM signal for servo motors

From the picture we can understand that the PWM signal produced should have a frequency of 50Hz that is the PWM period should be 20ms. Out of which the On-Time can vary from 1ms to 2ms. So when the on-time is 1ms the motor will be in 0° and when 1.5ms the motor will be 90°, similarly when it is 2ms it will be 180°. So, by varying the on-time from 1ms to 2ms the motor can be controlled from 0° to 180°. And in our case here we will use only 12 servos instead 18 and that means every leg has two servo.

3.2. Arduino Mega board:

This is an open source and open hardware micro controller with an Atmel AVR processor (ATmega2560). It is based on JAVA language and it is programming Language. It serves as a master that sends/receives commands and data from the drive circuit and the force sensors. It solves the Inverse Kinematics equations and sends them to the servo motors driver. It has four Tx/Rx pins that provide the proper interface between the microcontrollers. It has 14 PWM pins, 16 Analog input pins and 30 Digital pins. It also supports I2C (TWI) and SPI communication.

And here more features:

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by boot loader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

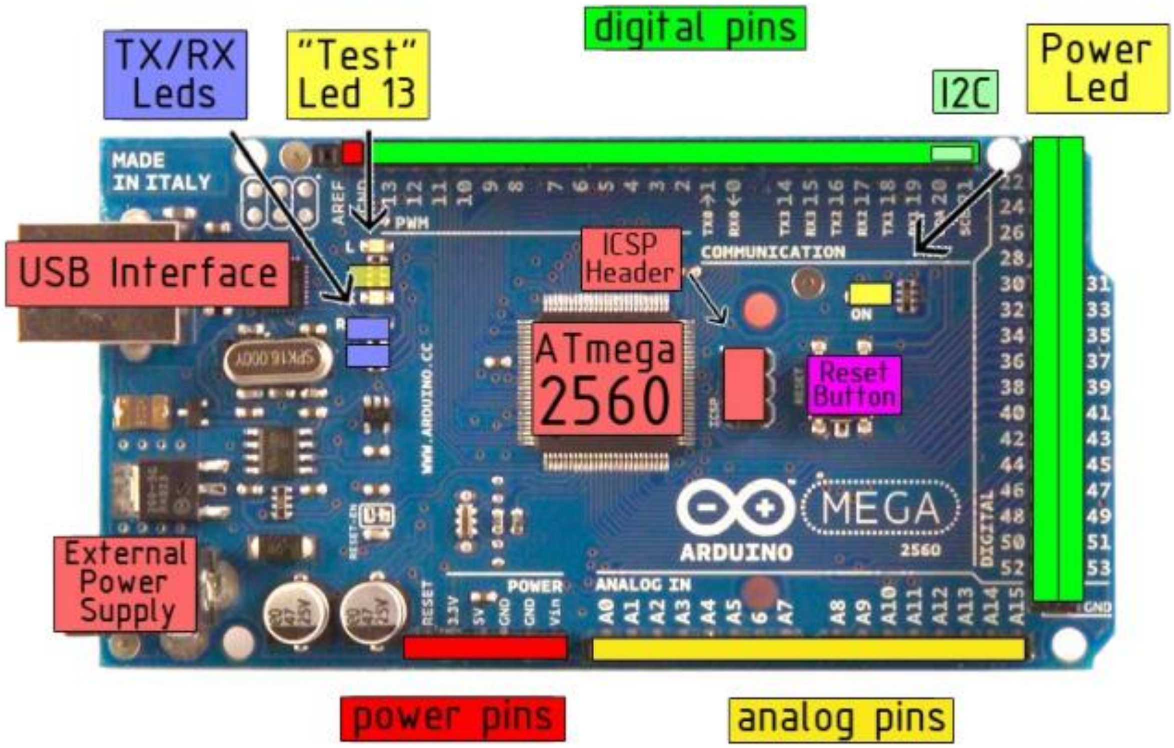

Figure 12: Arduino Mega

3.3. RF radio module:

The 433MHz wireless module is one of the cheap and easy to use modules for all wireless projects. These modules can be used only in pairs and only simplex communication is possible. Meaning the transmitter can only transmit information and the receiver can only receive it, so you can only send data from point A to B and not from B to A.

And the features of this module are:

Transmitter:

- Product Model: XD-RF-5V
- Operating voltage: DC5V
- Quiescent Current: 4MA
- Receiving frequency: 433.92MHZ

- Receiver sensitivity: -105DB

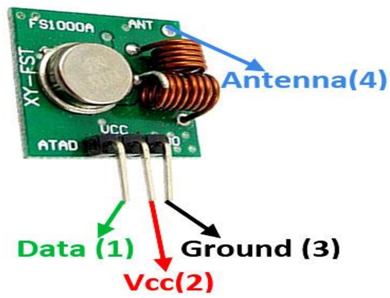

Figure 13: RF Module - Receiver

Receiver module:

- Product Model: XD-FST
- Launch distance :20-200 meters (different voltage, different results)
- Operating voltage :3.5-12V
- Operating mode: AM
- Transfer rate: 4KB / S
- Transmitting power: 10mW
- Transmitting frequency: 433M
- Pinout from left → right: (DATA; VCC; GND)

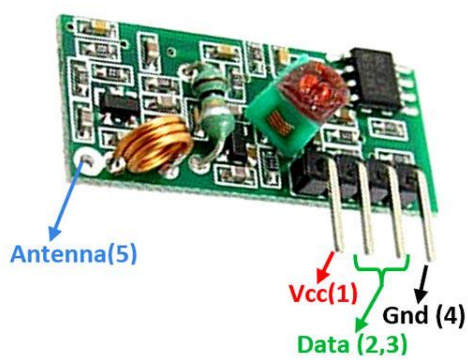

Figure 14: RF Module - transmitter

3.4. Ultrasonic sensor HC-SR04:

The HC-SR04 is an ultrasonic proximity sensor that tells you whether an object is in front of it, and also provides the distance between the sensor and the object. These sensing abilities make it particularly useful for robots that need to know how far they are away from an object or obstacle.

The HC-SR04 gets triggered by a ten microsecond high signal on the trigger pin. Once it gets pulled low again, the module sends out eight 40 kHz sound pulses. If an object is present in the detection range, the sound pulses get reflected by that object, and the module receives the echo. The time between sending the eight pulses and receiving the echo can be used to calculate the distance to the object that reflected the sound.

And here the specifications of it:

Working Voltage DC	5 V
Working Current	15mA
Working Frequency	40Hz
Max Range	4m
Min Range	2cm
Measuring Angle	15 degree

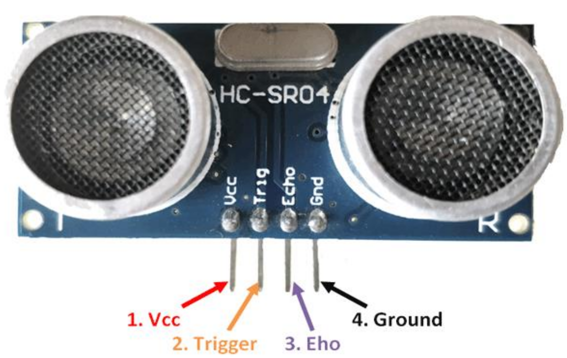

Figure 15: HC-SR04 Ultrasonic module

3.5. Joystick:

The Analog Joystick is similar to two potentiometers connected together, one for the vertical movement (Y-axis) and other for the horizontal movement (X-axis). The joystick also comes with a Select switch. It can be very handy for retro gaming, robot control or RC cars.

The home position for the stick is at (x, y: 511,511). If the stick is moved on X axis from one end to the other, the X values will change from 0 to 1023 and similar thing happens when moved along the Y axis. On the same lines you can read position of the stick anywhere in upper half hemisphere from combination of these values.

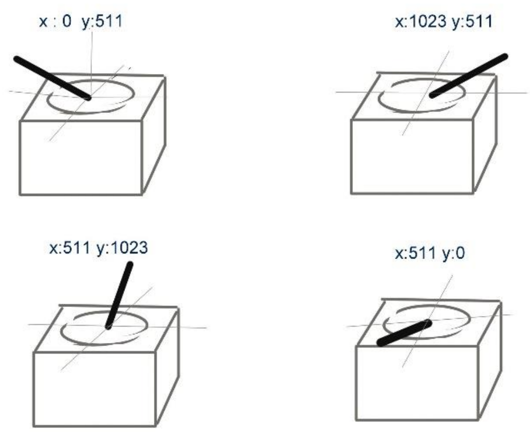

Figure 16: schema shows the directions of joystick

3.6. Battery:

Actually, when you want to use a battery for your robot you will find many and many choices in front of you but in our case here, we will use the most popular and commonly the 18650 battery cells. The 18650 battery is a Li-ion battery rechargeable named after its 18mm × 65mm cylindrical size (diameter × height).

And here some specifications about it:

Voltage	3.7V	nominal
Capacity	1200-3600mah	per cell

Operating voltage	2.5-4.2V	range
Charging voltage	4.2-5V	5V max

4. The body of the robot:

To design a Hexapod, you can't only use any design you find you need to do some specifications and studies to get the right structure that works perfectly for your robot.

So, in order to design the structure of the robot we can use many programs (illustrator, Photoshop, Solidworks etc…).

There are many different types of materials that you can use in your robot but you have to do calculation to make your Hexapod light, flexible and unbreakable. For example, if you use a material like iron the hexapod will be very strong but it is too heavy and this will affect the servos and the robot will not move. for this you have many choices like Forex, Plexiglas, and PMMA. These materials are very similar to glass and flexible and not easy to break.

After this you need to cut all the pieces that you designed and to do it you have to be very careful from the measurements and the places of every piece in your robot. You can use CNC machine or any machine cuts very precisely or you can use the 3D printer.

5. Conclusion:

In this chapter we talked about the benefits of six legs and why we choose it instead of four or more than six. although we said that there is more than one gait used for this robot to be exactly like insects and react similarly like them.

After that we talked about the necessary components that used for robots like Hexapod, why exactly choose them and some specifications about those components.

Chapter III: robot implementation and test

1. Introduction:

In this chapter we will do some tests for our Hexapod from speed and maneuverability and how can we improve them. Also, we will go deep to know how we can improve our robot to develop it to catch up high levels in autonomy.

2. Design :

2.1. The Design of the Hexapod body:

As we said before in the previous chapter there are many types of materials that you can make your robot structure and we did a comparison between those materials and we chose the PMMA material that not much expensive, flexible and not easy to break it.

The second step is to do a design that compatible with our needs and only with two servos in one leg. About the design as we mentioned before there are a lot of programs that you can use to design your robot pieces and, in our case, we used adobe illustrator and here is our design below:

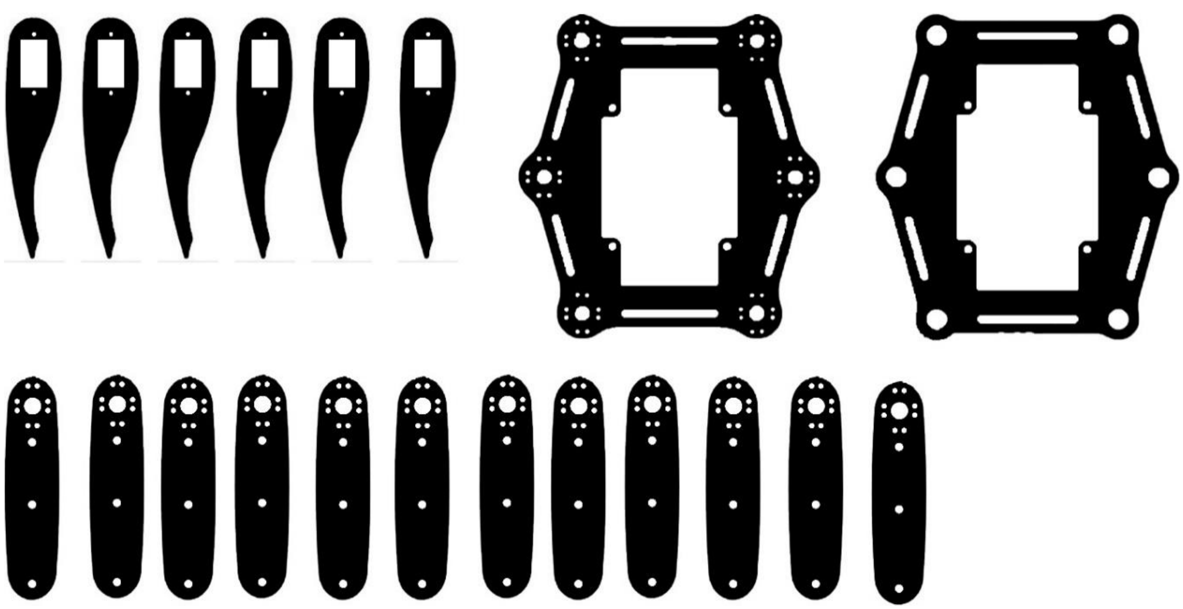

Figure 17: pieces of Hexapod designed with Adobe Illustrator

The final step you have to cut all these pieces above, here we used the CNC machine to cut it very precisely.

2.2. Components:

- 12 servo motors mg90s
- 2 battery Li-ion 18650
- 2 Arduino Mega
- RF radio module
- 2 Joysticks

3. Control of the Hexapod:

So in this part here after we created our design and do the necessary specifications we will collect all the pieces of the robot. In our project we walked through two main steps to get the finale result. The first step is how to control the Hexapod with a wireless controller and the second step is how to let the robot self-controlled.

3.1. Design of a wireless controller:

So to control the Hexapod with a wireless controller we made a small controller. This controller contains at “RF radio module”, “joysticks”, “Arduino mega” and “buttons”. We configured joysticks and buttons with Arduino and gave each component its job to move the Hexapod correctly. And the RF module send and receive data from the controller to Hexapod.

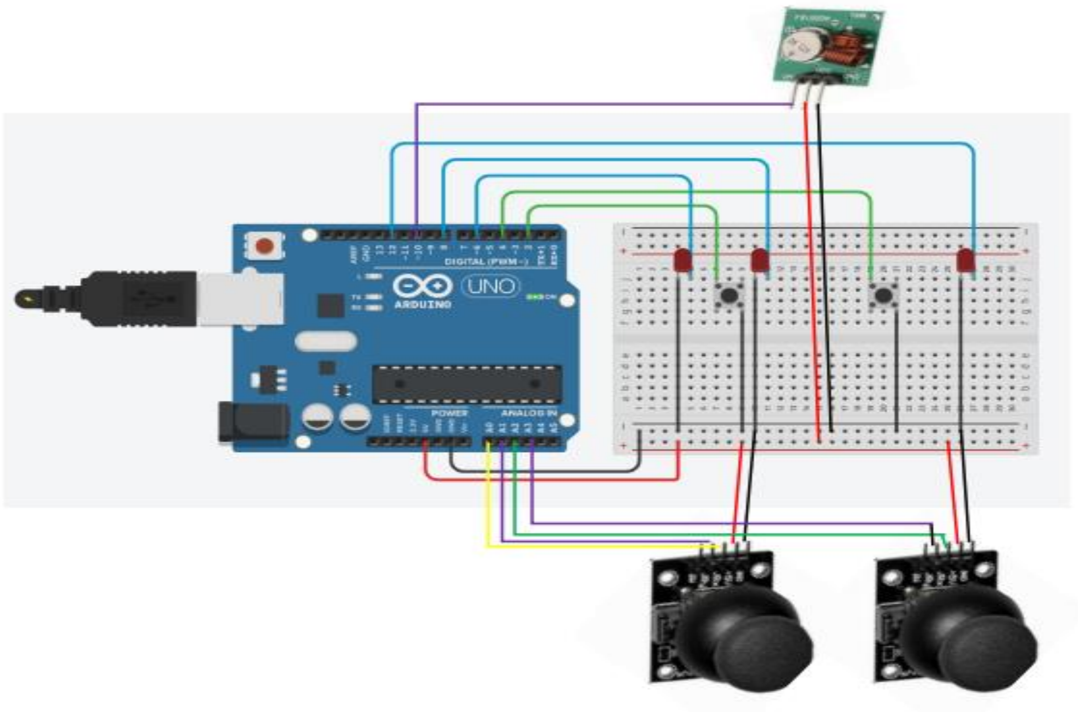

Figure 18: schema for the wireless controller

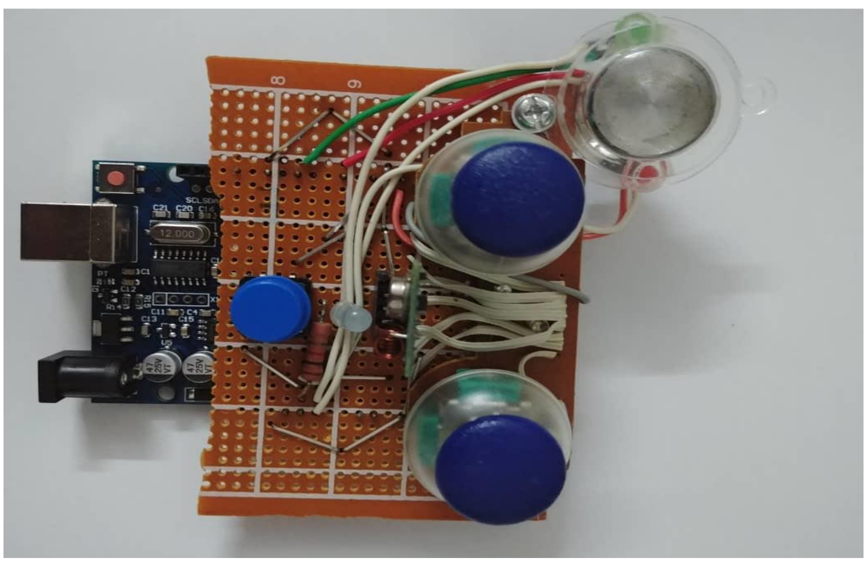

Figure 19: wireless controller

Arduino algorithm for the controller:

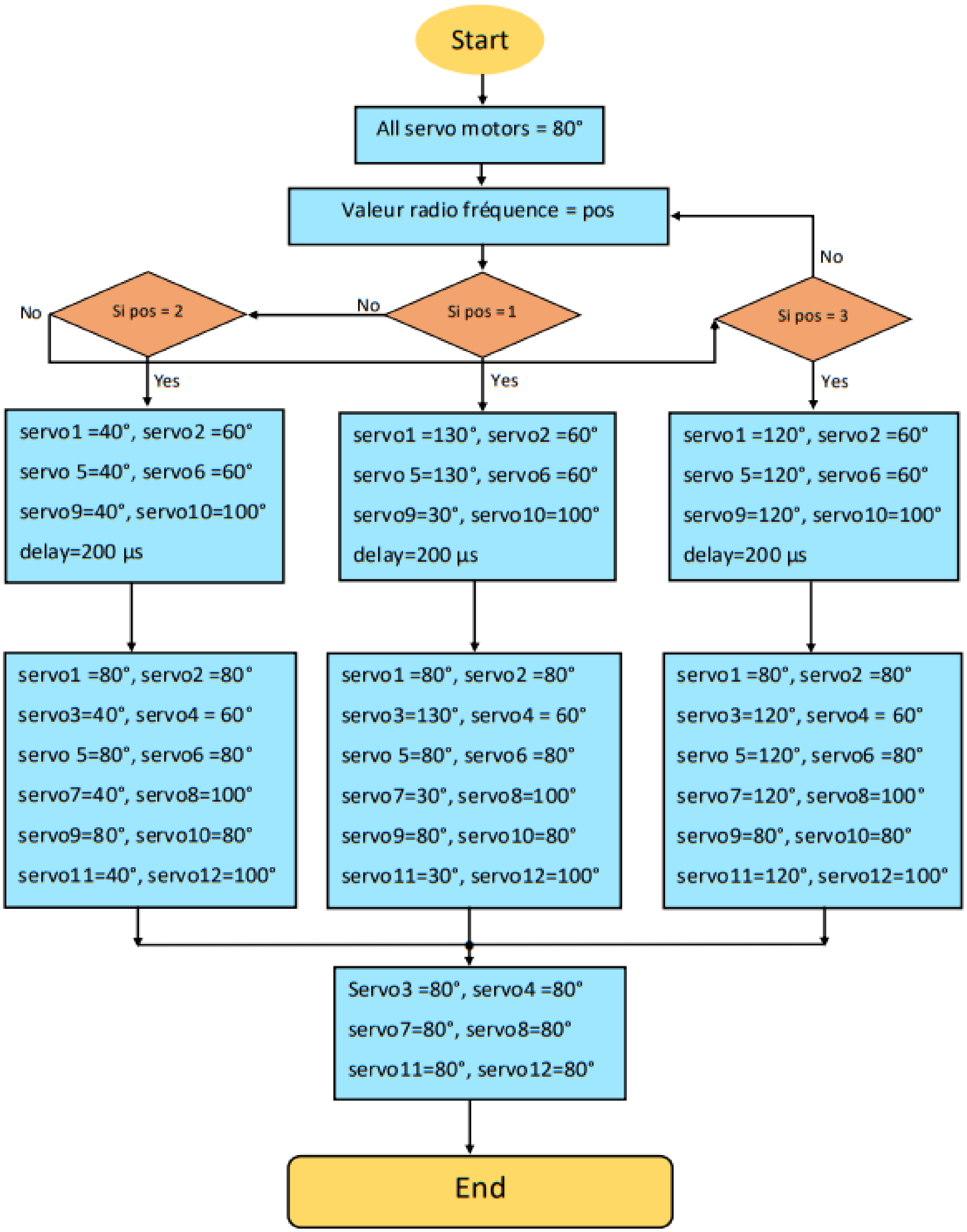

Figure 20: algorithm for controlling Hexapod with tripod gait

3.2. The Hexapod autonomy level:

After the classifications of autonomy level, we can say that our Hexapod belongs to level one and this means not a high level of autonomy and this because you still have to watch it and sometimes you have to set it to its path and all of This is due to the fact, we didn’t equip it with those components that makes it in a high level, we only used the ultrasonic sensor that gives it the ability to stop if it faces some obstacles and avoid them.

3.3. Obstacle’s avoidance:

As we mentioned before our Hexapod belongs to only level one and actually that means it can’t be alone all the time so we have to be in the line of sight with it. But in our case, we will not use it for complicated tasks and we will give it one job [18]. In this level the Hexapod only has to walk and when it finds a closed road it will stop and changes its direction. So the all operations is when Hexapod walks it will not stop until it detects for example a wall in front of it away 10 centimeters, in this case the Hexapod has to stop and go back a little and changes its direction and walk ahead again.

3.4. Arduino autonomous algorithm:

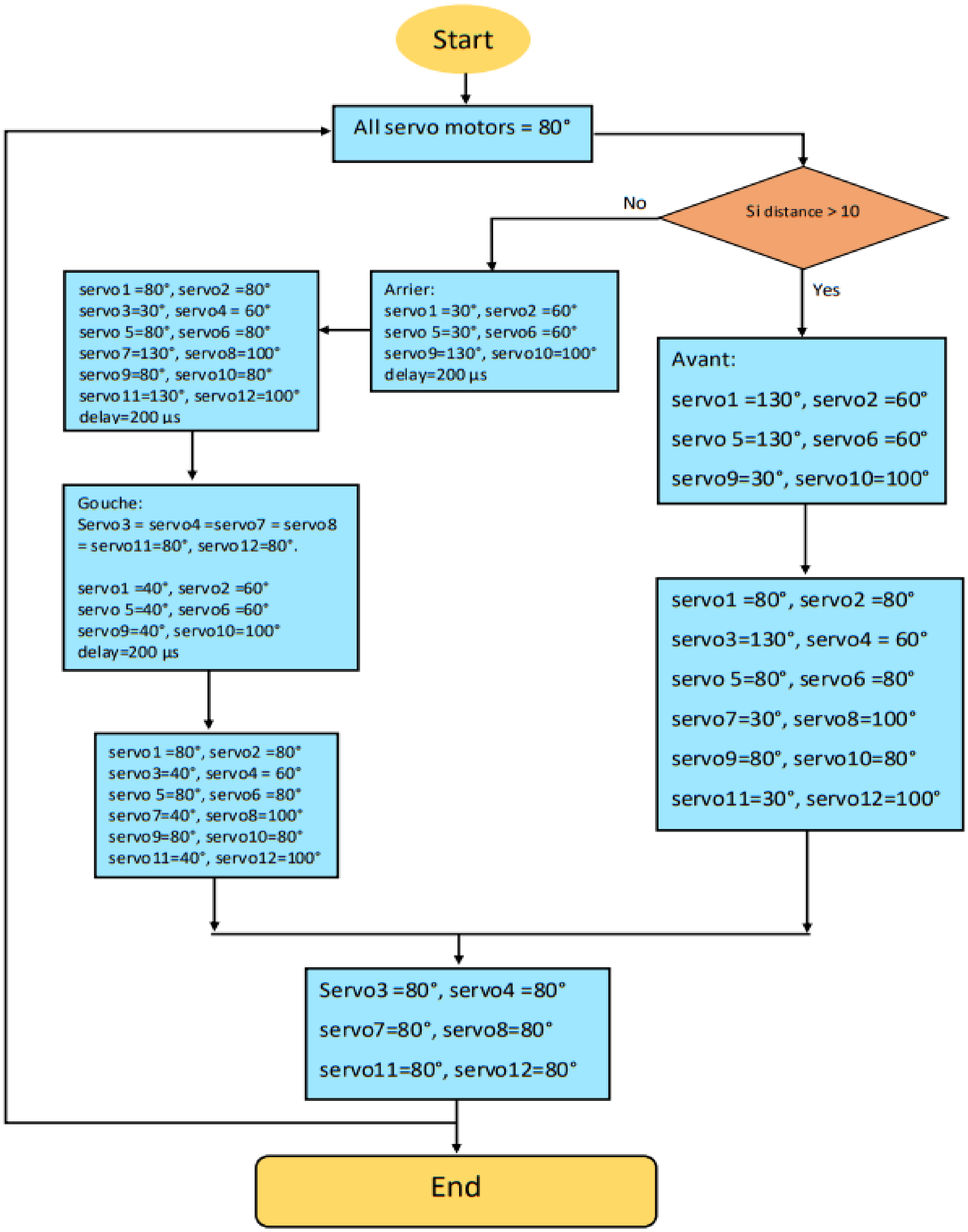

Figure 21: algorithm for autonomy controlling

4. Assembly and tests:

4.1. Assembly :

The next figure show the final assembly of the hexapod robot

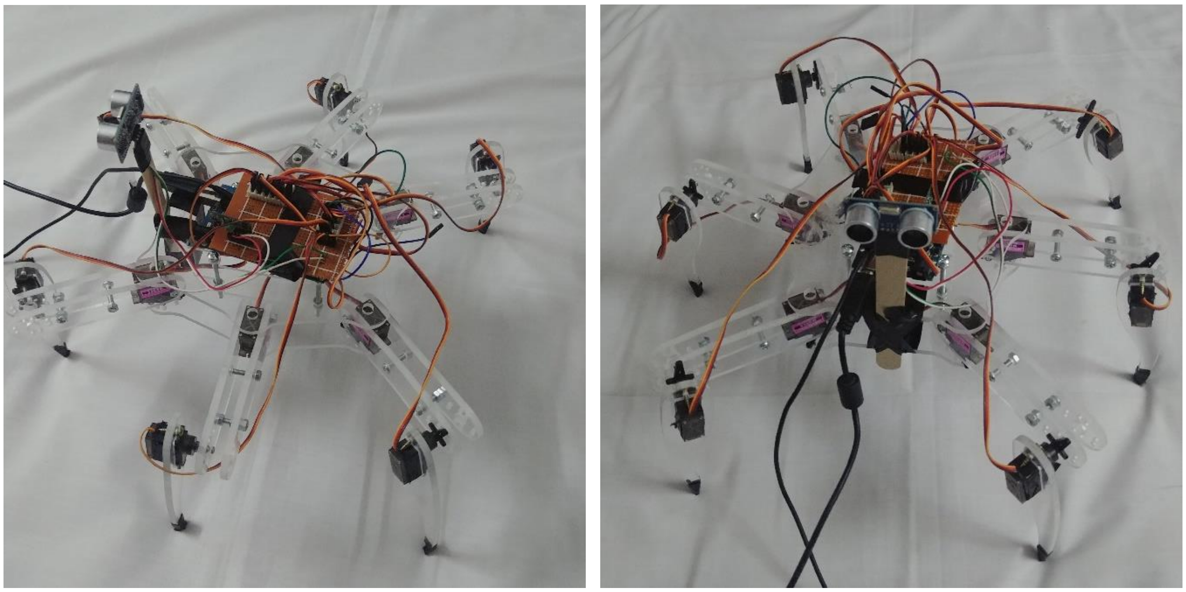

Figure 22: Hexapod after assembling

4.2. Hexapod tests:

After we have to complete our Hexapod we have to put it in a little hard environment and see it how it does. From these tests speed, maneuverability and noise etc…

4.2.1. Speed test:

The speed of Hexapod it depends on a lot of things, the first thing is do the servos can bare the weight of the robot body or not because this weight has an effect on the servos. If the structure made from iron or something heavy the servos can't rotate well in the right time and this will make the servos slow and maybe will effect on the gait of the legs. The second thing is the quality of the servos this thing is a big problem and this actually happened to us. The thing is these servos that we bought have a problem. The problem is the screw can't fix the servo well and the Hexapod do some steps you have to turn the screws again and this thing forced us to make the Hexapod walk slowly.

To solve this problem you have to buy bigger servos that looks stronger to fix this problem, from those servos MG996 and MG995. Those servos here are more effective than MG90s that we decided to work with. After this issue that we fall in we can say the speed of Hexapod can be approximately less than 0.3 km/h.

Another thing that can improve the Hexapod speed with is brushless motors. The brushless is much speed than servos and that because the magnetic field of the stator is rotated by using electronic commutation.

4.2.2. Maneuverability test:

So maneuverability from the things that the explorer robot has to have because the environments that it has to walk through force it to have it. But in our case our robot as we mentioned before only classified in level one because of its not equipped well and the problem that we faced because of servos we can say that the Hexapod is approximately has zero maneuverability.

The maneuverability of Hexapod can be improved and that to be done first we have to change the structure of the robot to another one more flexible and light as we can. Secondly we have to change the previous servos to servos more strong and solid.

Another thing that we can add to improve the maneuverability is to increase the number of servos for each leg and make it at least three servos in one leg, this thing gives the Hexapod more freedom and more gaits and speed which in turn helps it to be more flexible.

4.2.3. Noise test:

As the robots inspired from insects and its environments we eager to be like them in their walk or behaviors and we make no exceptions for the noise either. The robot has to be more silent as possible and this direct us to servos because the most noise that comes is from them. The servos in Hexapod not that loud but we can improve it but how?

We can change all those servos with different motors called brushless (without a brush). Brushless motors are widely used like the brushed once and that because the advantages that you can find only in these motors.

Brushless motors operate on the same principle of magnetic attraction and repulsion as brush motors, but they are constructed somewhat differently. Instead of a mechanical commutator and brushes, the magnetic field of the stator is rotated by using electronic commutation. This requires the use of active control electronics.

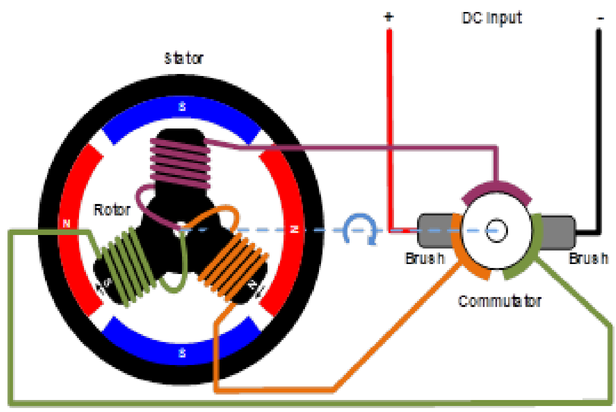

Figure 23: schema for a Brushed DC motor for inside

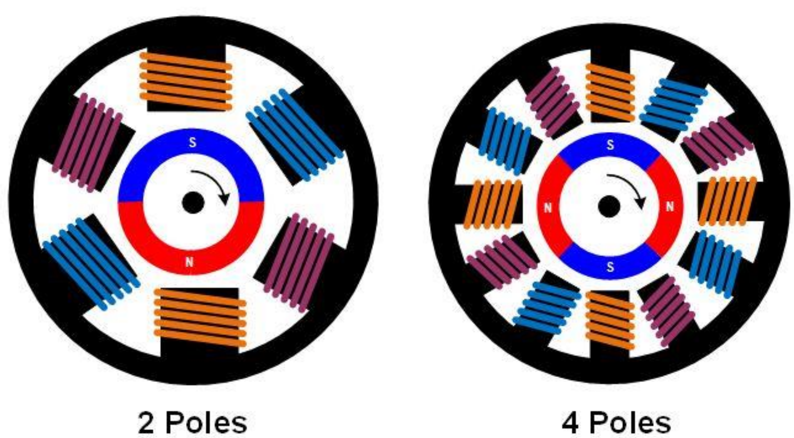

Figure 24: schema for a Brushless DC motor for inside

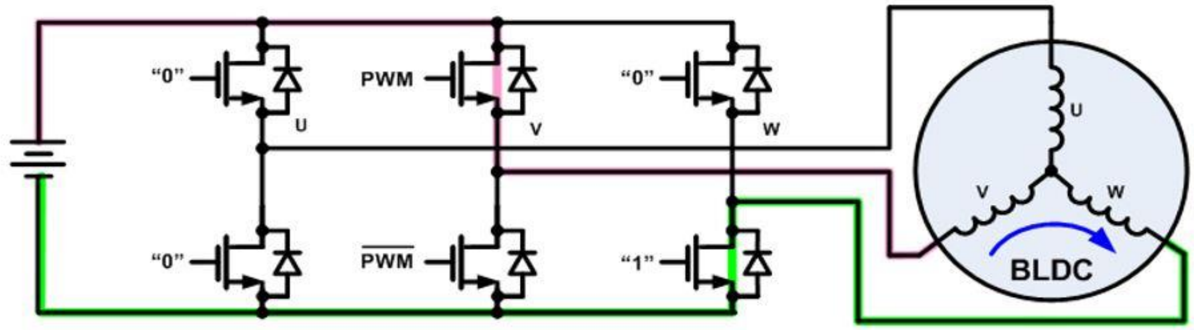

Figure 25: Power supply for Brushless DC motor

4.2.3.1. Advantages and disadvantages of Brushed and Brushless Motors:

	Brushed motors	**Brushless motors**
Life time	Short (brushes wear out)	Long (no brushes to wear)
Speed and acceleration	Medium	High
efficiency	Medium	High
Electrical noise	Noisy (bush arcing)	Quiet
Acoustic Noise & Torque Ripple	Poor	Medium (trapezoidal) or good (sine)
Cost	Lowest	Medium (added electronics)

5. Future improvement of the Hexapod:

As we said before our Hexapod only belongs to level one of autonomy but that doesn't mean it can't be developed. To develop this explorer robot we need to do a lot of changing in robot structure and add more features to the robot to upgrade its level to a higher one. For this development we will take the exploring robot ROVER "curiosity" as an example to see what are the important components that makes it can do this difficult job and in unknown place:

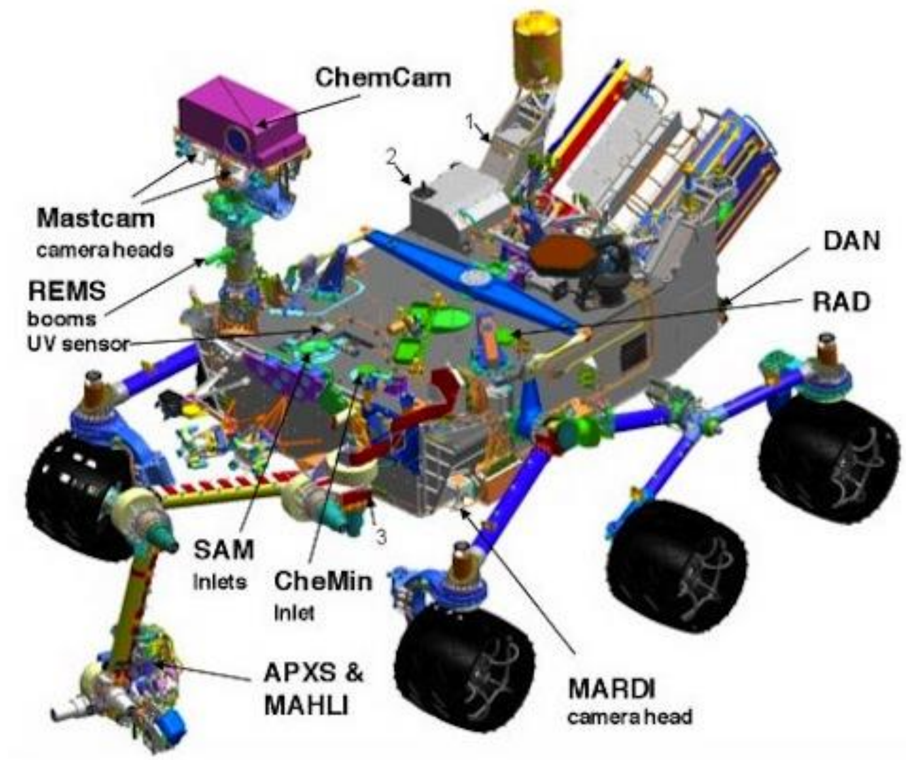

Figure 26: schema for ROVER components

MARDI (mars descent imager): Camera who will film under the rover during the descent once the heat shield ejected. Will be used to accurately locate the landing site and the first sites to visit.

MASTCAM (Mast Camera): set of 2 panoramic cameras (focal length of 34 and 100 mm). Eight filters between 440 and 1035 nm to make "True" and "false" color, "coarse" spectroscopy. Image of 1200x 1600 pixels. Storage capacity of 5500 images. Video at the 10 fps rate.

CHEMCAM (Chemistry Camera): laser + camera + spectrometers. The laser sends a beam of about 0.5 mm in diameter onto the rock (distance <7m). This produces a plasma that a camera photographs and specific analysis (240 to 850 nm). This gives "Quickly" and without moving the chemistry of several surrounding sites, which allows a choice for much longer detailed analyzes to be done.

MAHLI (MARS Hand Lens Imager): instrument will provide close-up views of rocks and soil samples near the rover. MAHLI sits at the end of Curiosity's long, flexible arm, and can image details down to about 12.5 micrometers, roughly half the diameter of a human hair. The instrument will also be able to see in ultraviolet light, which will come in handy during night exploration and funky psychedelic parties.

APXS (ALPHA-Particle-X-ray-Spectrometer): X spectrometer which analyzes X-rays re-emitted by the target excited by α-particles and hard X-rays. A particles and hard X-rays are emitted by a radioactive source (Curium 244). We can thus measure all the chemical elements with an atomic mass between 22 (Sodium) and 80 (Bromine), in particular Na, K, Si, Fe, Mg, Ca, S, Ni...

CHEMIN (Chemistry & Mineralogy): instrument will look at various minerals on the Martian surface. Specific minerals form in the presence or in the absence of water, revealing the history of an area and helping scientists to understand whether or not liquid existed there. Curiosity will drill into rocks to obtain samples for CheMin, pulverizing the material and transporting it into the instrument's chamber. CheMin will then bombard the sample with X-rays to determine its composition.

SAM (Sample Analysis at Mars): SAM is one of the most important instruments and the reason that Curiosity can be called a mobile laboratory. Taking up more than half of the rover's body, SAM contains equipment found in top-notch labs on Earth: a mass spectrometer to separate materials and identify elements, a gas chromatograph to vaporize soil and rocks and analyze them, and a laser spectrometer to measure the abundances of certain light elements such as carbon, oxygen, and nitrogen – chemicals typically associated with life. SAM will also look for organic compounds and methane, which may indicate life past or present on Mars.

DAN (Dynamic Albedo of neutrons): DAN instrument will look for water in or under the Martian surface. Water, both liquid and frozen, absorbs neutrons differently than other materials. DAN will be able to detect layers of water up to six feet below the surface and be sensitive to water content as low as one-tenth of a percent in Martian minerals.

RAD (Radiation Assessment Detector):

- Determine the level of protection needed for a possible human exploration of Mars.
- Determine the past and present impact on Martian chemistry.
- Measure isotopic effects.
- Evaluate the conditions allowing possible living organisms to survive in Martian soil (at what depth in the soil). Ultraviolet radiation data collected by the instrument will also be used for this purpose.

The Structure:

Here when we want to add all the previous components you can’t use the previous structure. Because the load is too high so we have to change the material to a solid one to get all those components. There are many materials that we can use for our new robot and the best choices are iron or aluminum.

Of course, when we change the hardware, we have to change also the servo motors to other stronger for handling that heavy and make the Hexapod walks normally and fast without any issues.

6. Conclusion:

In this chapter we did the final steps from making the design and group it all together to make the Hexapod doing it task that made for. Therefor how actually went from the first part from controlling the robot with a wireless controller to make it autonomous and control itself.

Also we mentioned some additional features that we can add to it make it better and increase its level in autonomy.

General conclusion

The goal of this project was to create a model and a controlling system for a hexapod robot. As the long-term goal was to navigate the hexapod in debris or rubble, a special walking gait was created using force sensors to navigate on rough terrain.

In chapter one we talked about some definition of robot and who made the first robot and some meanings as an introduction before we go deep through the project and for helping us to understand what is comes next.

Secondly in chapter two we started to go a little deep and mentioned what are the components that make a Hexapod robot and also see how scientists inspired walk gait from insects and makes it real in robotic field.

Finally in the last chapter we did some analytics and tests for our Hexapod to see if it does what it is made for or not. Also, some modifications and additional components that makes it better and more effective.

The overall conclusion of the project is that a control system that can successfully control the robot was designed, and the system was able to generate satisfactory gaits on flat ground.

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