Table of Contents:

Table the figures:

1 Introduction

1.1 Background to Proposal

Bioloid Beginner kit is like an advanced version of LEGO Mindstorms NXT and Meccano and is the ideal choice for many schools and beginners in robotics. They are perfect for education, hobby and competition. Bioloid Beginner kit is the introduction to the Bioloid modular robotic platform with the ability to update later with more servo and the frame set of the Comprehensive Kit.

Like his brother over 18 servo-motors (Bioloid Comprehensive Kit), the Bioloid Beginner Kit is the first robotic platform of its kind to be built servo-controlled intelligent technology that lets series feedback and sensory control of position, velocity, temperature, current and voltage of each servo-motor.

There are a total of 4 AX-12 servo Dynamixel, proximity sensors and light forwards and sideways, a microphone and a small speaker.

Bioloid Beginner Kit allows the novice user to build and configure a tour of construction following the printed manual supplied up to 14 different robot configurations.

1.2 Aim

The objective of this Project is to make an arm with robot BIOLOID, it take a glass. After, can put the liquid (normal is water) and distribute in two container with 50% of liquid each one.

1.3 Objectives

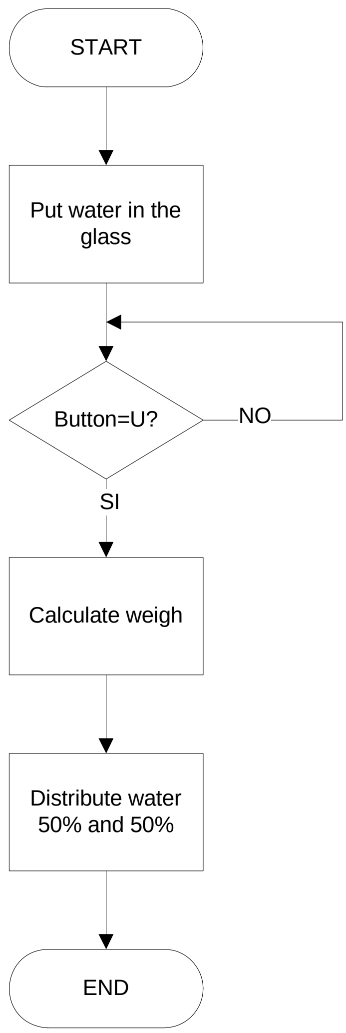
- Familiarize with the robots and programs
    - Have contact with the robots and programs, final of the project have knowledge for to make and programmer a robot
- Familiarize with the robot BIOLOID
    - Have contact with the robot BIOLOID, final of the project have knowledge for to make a robot BIOLOID
- Know to programmer with the program Bioloid
    - Have contact with the program BIOLOID that its name is Behavior Control Programmer and final of the project have knowledge for programmer it.
- Know to make a robot BIOLOID
    - Know to make all that to propose with robot BIOLOID

1.4 Block Diagram

The First stage is START and put water in the glass because after distribute the liquid in the containers.

The second stage is push the button U if we want to begin the program and calculate the weigh in the glass.

The third stage is distribute water 50% and 50% in the containers.



2 Introduction to Robotics

2.1 Introduction

Robot, computer-controlled machine programmed to move, manipulate objects, and accomplish work while interacting with their environment. The robots are capable of performing repetitive tasks more quickly, cheaply and accurately than humans. The term comes from the Czech word robot, meaning "forced labor", was first used in the 1921 play RUR (Robots Rossum's Universal) by the Czech novelist and playwright Karel Èapek. Since then, the word robot has been used to refer to a machine that does work to help people or make difficult or unpleasant tasks for humans.

2.2 History

The concept of automated machines back to ancient times, myths of mechanical beings living. Automata, or like machines, also appeared in clocks of medieval churches and eighteenth-century watchmakers were famous for their clever mechanical creatures.

Some of the first robots used feedback mechanisms to correct errors, mechanisms still in use today. An example of feedback control is a trough that uses a float to the water level. When water falls below a certain level, the float drops, opens a valve and let more water into the trough. Going up the water, the float also rises, and at a certain level the valve closes and cuts off the water.

The first real feedback controller was the Watt governor, invented in 1788 by the British engineer James Watt. This device consisted of two metal balls attached to the drive shaft of a steam engine and connected to a valve regulating the flow of steam. As increasing the speed of the steam engine, the balls away from the axis due to centrifugal force, thereby closing the valve. This caused a decline in the flow of steam to the engine and therefore the speed.

The feedback control, the development of specialized tools and division of work into smaller tasks that might make workers or machines were essential ingredients in the factory automation in the eighteenth century. As technology improved, specialized machines were developed for tasks such as placing caps on bottles or pouring liquid rubber into tire moulds. However, none of these machines have the versatility of the human arm and could not reach for objects and place them in the desired position.

The development of multijointed artificial arm, or manipulator, led to the modern robot. The American inventor George Devol developed in 1954 a primitive arm could be programmed to perform specific tasks. In 1975, American mechanical engineer Victor Scheinman, while a graduate student at Stanford University in California, developed a truly flexible multipurpose manipulator known as the Programmable Universal Manipulation Arm (PUMA, an acronym in English). PUMA was able to move an object and place it in any orientation in a desired location within its reach. The basic concept multijointed PUMA is the basis of most current robots.

2.3 How operate the robots

The design of a robot manipulator is modelled on the human arm, but with some differences. For example, a robotic arm may extend telescopically, is sliding cylindrical sections one another to lengthen the arm. Robotic arms also can be constructed so that they bend like an elephant's trunk. The clamps are designed to mimic the function and structure of the human hand. Many robots are equipped with specialized grippers to grab specific devices such as a rack of test tubes or an arc welder.

The joints of a robotic arm are usually driven by electric motors. In most robots, the gripper is moved from one position to another, changing its orientation. A computer calculates the joint angles needed to move the gripper to the desired position, a process known as inverse kinematics.

Some arms PNP, are equipped with servo drivers, or drivers by feedback, which receive data from a computer. Each joint of the arm has a device to measure its angle and send that data to the controller. If the actual angle of the arm is not equal to the angle calculated for the desired position, the servo controller moves the joint until the arm angle matches the angle calculated. The drivers and associated computers also must process the data collected from cameras that track the objects to be grasped, or censors information located on the clamps that regulate the gripping force.

Any robot designed to move in an unstructured or unknown environment requires multiple sensors and controls (for example, ultrasonic or infrared sensors) to avoid obstacles. The robots and NASA planetary vehicles need a lot of sensors and computers on board a very powerful to process the complex information that allows them to move. This is particularly true for robots designed to work in close proximity to humans, such as robots that assist persons with disabilities or serving meals at a hospital. Security must be essential in the design of robots for human service.

2.4 Uses of the robots

In 1995 some 700,000 robots worked in the industrialized world. More than 500,000 were employed in Japan, about 120,000 in Western Europe and about 60,000 in the U.S.. Many applications of robots are for dangerous or unpleasant tasks for humans. In medical laboratories, robots handle potentially hazardous materials such as blood or urine samples. In other cases, robots are used in repetitive, monotonous tasks in which performance might degrade over time. The robots can perform these repetitive precision for 24 hours a day without fatigue. One of the major users of robots is the automobile industry. General Motors uses around 16,000 robots for tasks such as spot welding, painting, machine loading, parts transfer and assembly. The assembly is one of the industrial applications of robotics fastest growing. Requires greater precision than welding or painting and sensor systems using low-cost, powerful computers and cheap. The robots are used for example in the electronics assembly for microchip mounted on circuit boards.

The activities that pose great danger to people, such as locating sunken ships, the search for mineral deposits or exploring undersea volcanoes, are particularly suited to robots. The robots can explore distant planets. The unmanned space probe Galileo, NASA, traveled to Jupiter in 1996 and performed tasks such as detection of chemical content of the Jovian atmosphere.

Robots are already used to help surgeons to install artificial hips, and certain specialized high precision robots can assist in delicate surgery on the eyes. Research on tele surgery using robots controlled remotely by expert surgeons, these robots could one day carry out operations on distant battlefields

2.5 Classification of the robot from the industrial viewpoint.

The main difference between a robot and a machine tool / robot is that the latter is specialized in their work, while the robot is more versatile and could be used as a fundamental part of a flexible production line.

Types of robots:

- **Intelligent Robots:** are manipulative or mechanical systems controlled by computers multifunctional able to relate to their environment or through sensors and make decisions in real time. Artificial Intelligence Concept.
- **Computer-controlled robots:** similar to above but lack the ability to interact with the environment around them.
- **Learning Robots:** merely repeat a sequence of movements performed with the intervention of an operator and then memorized it. Robots are also called Macro.
- Robot Manipulators: multifunctional mechanical systems which are simple control system can govern the movement of its elements in the following ways:
  - Manual: the operator directly controls.
  - Sequence Variable: it is possible to alter some of the characteristics of the cycles.

Note: The handlers are considered robots in Japan, but not in Europe and the U.S., only some of string variable.

2.6 Robotic Movement

The way in which a robot moves depends greatly on the environment the robot is designed to operate in, there are three main different types of environment, these are under water, in the air or in space and on land.

2.6.1 Under Water

Most of the robots used underwater are unmanned submersible robots, these robots are also known as Automated Underwater Vehicles (AUV).

Most AUV's use propellers to control their speed and rudders to control their direction of travel, however, more advanced underwater robots are being designed to move in a similar way to a fish, this would lead to underwater robots being made quieter, more manoeuvrable and also more energy efficient.

An example of this new technology is a robot called RoboTuna in figure 2.1. The RoboTuna project goal was to develop a better propulsion system for AUV's, it was designed to mimic the shape and motion and therefore extreme manoeuvrability of a small fish, it was controlled by six powerful 2 horsepower servomotors. Force

Figure 2.1: Fish

sensors were placed at various locations along the path of the controlling tendons and were used to calculate swimming efficiency as the robot was towed through the water.

2.6.2 On Land

Robots that are required to move on land can be designed to get around on legs, wheels or tracks depending on the specific function of the robot. Below are examples of real robots using each of the above methods, they are all also good examples of robots that do jobs that are too dangerous or not possible for humans.

Figure 2.2 is an example of a robot that uses legs, it is a robot called Dante II. Dante II is a tethered walking robot, it was designed for the exploration of volcanoes, the use of robotic explorers such as this one began a new field of study by enabling scientists to remotely carry out research and exploration in previously impossible conditions.

Figure 2.2: robot

Figure 2.3 is an example of a robot that uses tracks, it is a robot called Pioneer. Pioneer is a remote reconnaissance robot that was designed for clearing rubble, mapping and taking samples following the Chernobyl nuclear disaster. The design contained a tele-operated mobile robot that was used for sampling the area and a mapper for creating realistic 3 dimensional maps of the interior of the building as it was unsafe for humans to carry out these tasks. The robot also had an array of environmental sensors including radiation sensors to test where it was and was not safe for humans as well as core-borer for retrieving samples of structural materials.

Figure 2.3: robot

The most common method for a robot on land to get around is through the use of wheels as this is the most effective and efficient method of transportation under normal conditions.
Figure 2.4 is an example of a robot that uses wheels, it is a robot called Sojourner. The Sojourner was designed as a pathfinder rover for use on Mars.

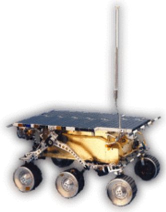


Figure 2.4: robot

2.6.3 In the Air/Space

Robots designed for use in the air use engines and thrusters to get around and devices such as wings, spoilers and air-foils to control direction of travel.

This is still a relatively new field of research; despite this a large amount of progress has been made as the use of robotics is an important factor in space exploration due to the fact that robots can be used to test environments that are not suitable for humans.

2.7 Classification from the point of view of the control of the movements

- **Without Servo-control:** the program that controls the movement of the various components of robot positioning is performed in a point to point in space.
- **With Servo-control:** this control allows for two different forms of work:
  - Government of the movements of the robot elements according to their axes. Shifts can be point to point or continuous path.
  - The movements are determined according to the position on the coordinate axes (x, y, z) and orientation of the robot hand or tool.

Note: servo feedback systems are comparing input with output

2.8 Impact of the robots

Create robotic manipulators manufactured goods of higher quality and lower cost. However, it also can cause loss of unskilled jobs, especially in industrial assembly lines. While creating jobs in the sectors of developing software and sensors, the installation and maintenance of robots and the conversion of old factories and the design of new factories, new jobs require higher levels of skill and training. The technology-oriented companies must face the task of re-train workers who lose their jobs due to automation and teach them new skills so they can have a job in the industries of XXI century.

2.9 Technology of the future

Machines will increasingly automated humans in the manufacture of new products, infrastructure maintenance and care of homes and businesses. The robots can build new highways, building steel structures for buildings, underground pipelines cleaning or mowing the lawn. There are already prototypes that perform all these tasks.

An important trend is the development of microelectromechanical systems, ranging in size from centimetres to millimetres. These tiny robots could be used to move through blood vessels to supply drugs or remove arterial blockages. They could also work inside of large machines for diagnosing potential mechanical problems in advance.

Maybe the most dramatic changes in the future robots will come from their reasoning capacity increasing. The field of artificial intelligence is rapidly moving from university laboratories to practical application in industry, and are developing machines capable of performing cognitive tasks such as strategic planning or experiential learning. The diagnosis of faults in aircraft or satellites, command a battlefield or the control of large factories increasingly borne by intelligent computers.

2.10 Robots in medicine

Robots have become more and more important in the medical field to the point that they are now seen as a critical component where extreme precision is necessary.

Robots are very often used whilst performing surgery thanks to their ability to perform major operations while only making small incisions. This means that the patient has a faster healing time and therefore a faster discharge from hospital; the use of robots in surgery also reduces the chance of infection and reduces the trauma to the patient. A good example of this is where a robot can be used to perform heart surgery without actually opening a patient's chest.

Robotic test instruments are another, now essential, component in the medical field. These instruments range from test equipment in laboratories which analyse blood and other samples to CAT scan machines which are used to produce a full body scan of the patient. The advantages of using these types of robotic machines are that they provide consistency and accuracy whilst reducing the chances of human error leading to misdiagnosis.

One of the major long term goals in the medical field is the replacement of missing limbs or damaged organs with mechanical alternatives. The aim of which is to develop effective implanted devices and replacement limbs with the ability to function for long periods of time.

2.11 Robots in war

As robotics has become more advanced, the use of robots in warfare has become an increasingly more attractive option to militaries due to the fact that they can be designed to do a great deal of damage and not cost any human life as they would be remotely controlled.

Robots in warfare are not always employed as killing machines however; one of the most useful applications is as remote reconnaissance vehicles, an example of this is a 'Predator drone' which is best described as an unmanned aerial system as it is considered to be much more than a vehicle as it has various features including four air vehicles with sensors, a ground control station and a satellite liked communication facility. Unmanned drones such as the predator have become an integral part of the United States air force as they are used to determine the risk of an area and to carry out risky surveillance without risking human life.

Robots are still not as widely used in warfare as they could be, this is due to ethical and moral objections relating to the weak AI that some if these robots would posses, the main limiting factor is formalization, this means that if a task cannot be formalized by a robot then it cannot be solved, no matter how simple it may seem. An example of this is a robotic optical instrument which may have a greater ability to 'see' then a human eye; however, if this robot does not possess the relevant software to interpret what it sees then it will not be able to act on it.

2.12 Advantages of a robot

2.12.1 Speed

A robot can be developed to work at a very high speed; the main advantage to this comes in the industrial field where a robot could perform the same task as a human employee at a much greater speed. In an assembly line a human could be replaced with a robot which would perform the task faster and more frequently, therefore producing a higher quantity of the product.

For example, in a car manufacturing plant a robotic arm is used to attach the doors to cars as they pass by on a conveyor belt, this is a lot faster than if a human was to do it and as a result more cars will get there door attached in a given period of time.

2.12.2 Productivity

A robot would increase productivity for a company as detailed in the Speed section above, however another major way in which a robot would increase productivity would be that a robot would not suffer from fatigue which would lead to a reduction in the number of mistakes made and ensure a consistent high quality of product.

Also, a robot would be able to continue working constantly without the statutory requirement for a break which would allow for increased productivity.

2.12.3 Accuracy

As a robot is computer programmed it can perform tasks to a great degree of accuracy, this allows for a task to be carried out with a low margin for error and consequently leads to a better product or a more efficient process.

The superior accuracy also enables a robot to work effectively with little room to manoeuvre which has led ground breaking work to be possible in micro and nano electronics which has resulted in innovative designs and revolutionary method's in countless walks of life from industrial to medical which would not have been possible without the use of robotics.

2.12.4 Conditions

One of the biggest advantages to the use of robotics is that a robot can be used to task under conditions that are deemed too dangerous or in places that are inaccessible to humans. This is due to the ability to remotely control a robot and the fact that robots have become so advanced that they can now mimic a large majority of human functions. Another factor is the advancements made in material technology leading to robots being constructed out of more durable materials allowing them to work effectively in these conditions.

Robots controlled remotely by a user or a computer are known as tele-operated robots, they have become essential in many fields, most prominently in scientific research where a robot can now be employed to observe and sample areas that it would not be possible for a human to get to, an example of where considerable progress has been made is in the understanding of space.

2.13 Disadvantages of a robot

2.13.1 Expense

In industrial cases a robot is said to be cost effective due to the increased productivity and therefore increased turnover it would provide for the company in the long term. Despite this, a robot would still incur a high initial expense which would not be possible for smaller companies to afford and therefore lead to only larger companies being able to afford certain robotic machinery and allow them to monopolise the industry.

2.13.2 Social impact

The social impact of the advancement in robotics is that jobs previously being done by several humans can be potentially done by a single robot which would therefore lead to unemployment, this is becoming more and more evident to employers as the cost-effectiveness of a robot is increased, coupled with its ability to do the job to a higher standard make it an increasingly more attractive option.

2.13.3 Artificial intelligence

Although major breakthroughs have been made in artificial intelligence, it is important to understand that there are some drawbacks, this has been hugely over dramatised in popular media however these drawbacks do exist. The more intelligence a robotic system processes, the less control the operator has and therefore the robot can feasibly make mistakes of their own.

A good example of this is in the military where robots have been designed to adapt to their environment and in some cases to select their own targets based on intelligence, this poses a problem as only a slight error in programming or communication could result in a catastrophic mistake. Although this scenario is highly unlikely as these types of robots undergo rigorous widespread testing, it serves as an example of what could conceivably go wrong.

2.13.4 Malfunction/Mechanical failure

Before being put on the market or put into practice, a robot must undergo extensive testing to ensure that it is safe and reliable. Despite the broad testing procedure there is always a chance of the robot suffering a mechanical failure or a malfunction. This could represent a problem for example in the manufacturing industry, if there is a fault with an assembly robot then that could halt production until the robot is fixed. Many large companies combat this problem by having a replacement robot on standby to take over, this however is not practical for smaller companies and therefore a mechanical failure to a fundamental robot is a potential disaster.

2.13.5 Degree of freedom

The number of degrees of freedom that a robotic manipulator possesses is the number of different ways in which the robot arm can move.

In many cases, the number of degrees of freedom is equal to the number of joints the manipulator has. This is because the manipulator is often an open kinematic chain and each join position is usually expressed as a single variable.

A robot arm strongly resembles a human arm, the joints of which can roughly be associated with the joints of a manipulator including shoulders, elbows, wrists and in some cases even fingers.

More advanced industrial robots are usually designed to work with six degrees of freedom which means that the manipulator can move in six independent directions. However, a one of the most innovative robotic manipulators is the SCRARA robot which was designed to use 4 axes and therefore has 4 degrees of freedom. The SCARA robot is shown in the figure below.

Figure 2.5: degree of freedom

If a robot is designed to be fixed to a surface as in the figure below, one degree of freedom is lost as the robot cannot rotate about this joint it is just there to hole the robotic manipulator in place.

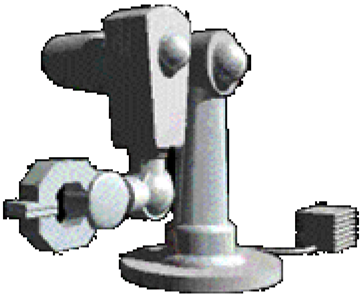


Figure 2.6: Degree of freedom

3 Comparisons

It has compared the Bioloid with two similar kits, that are Lego and RoboBuilder.

3.1 Programmes

3.1.1 Programmes of Bioloid

Robots require software and Bioloid robotic kits come with 3 powerful software tools; a behavior control programmer, a motion editor and a terminal application.

3.1.1.1 Behavior Control Programmer

is an application that sets rules for the robot's behavior. You can string together series of motions created in Motion Editor, or create looping and branching behavior patterns based on sensor values. All of this is achieved via a graphical sequencer interface. [2]

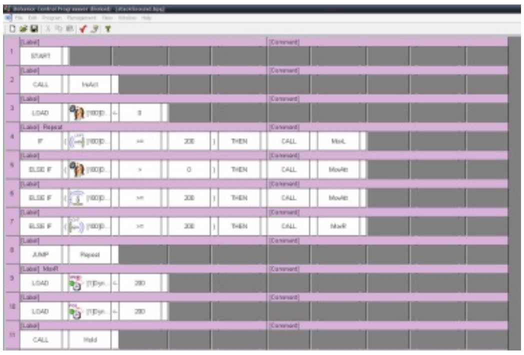


Figure 3.1: Behavior Control Programmer

3.1.1.2 Motion edition

is a 3D interface for setting servo positions and motion sequences. Motions created in this program can be called and used by the Behavior Control Programmer.[3]

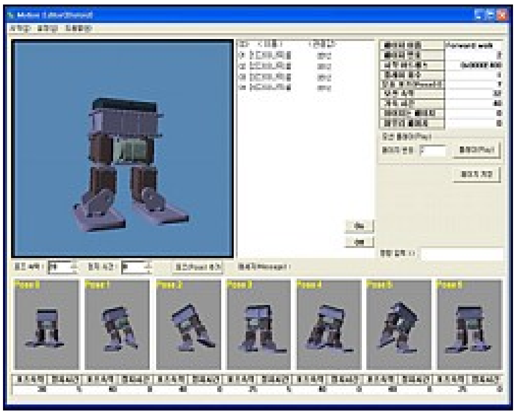


Figure 3.2: Motion edition

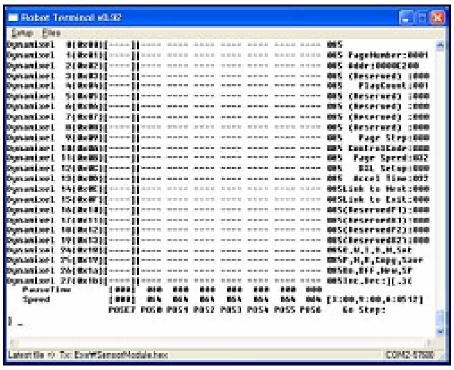


Figure 3.3: Robot Terminal

3.1.1.3 Robot Terminal

is used for lower-level management of Bioloid components, mostly for advanced users. It is a serial communication terminal that is useful for transmitting specific commands and troubleshooting the Dynamixel network. [4]

3.1.2 Programmes of RoboBuilder

3.1.2.1 Motion Builder

Movements "motions" are determined by the positions of the servos that can be adjusted using graphical controls, directly entering numeric values, or a scene can be created by learning through the method of "position and capture", where the robot is positioned manually in the desired position by moving your joints, and records and saves every position. You do not need programming skills to generate complex movements.[5]

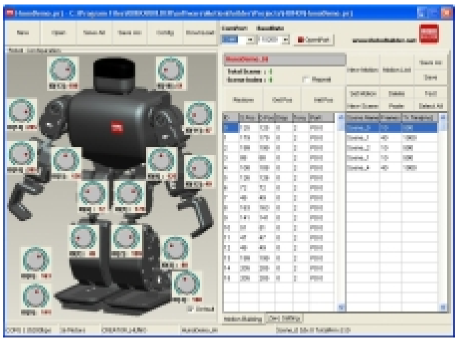


Figure 3.4: Motion Builder

3.1.2.2 ActionBulider

ActionBuilder allows the user to program the logic and behaviour of the robot by sentences such as "if-then" to determine the actions of the robot. Allows states to use as criteria the distance sensor, sound sensor, the states of the actuators, the buttons on the remote control or the buttons on the controller module. These conditions are used to trigger a move, waiting times, or to jump to another line of the program. [6]

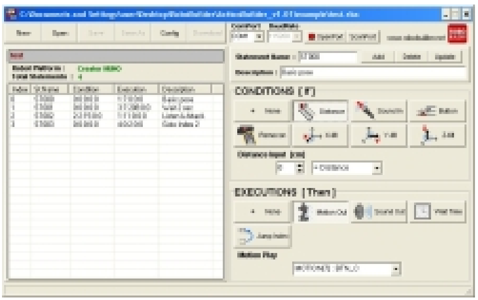


Figure 3.5: Action Builder

3.1.2.3 Programmer wCK

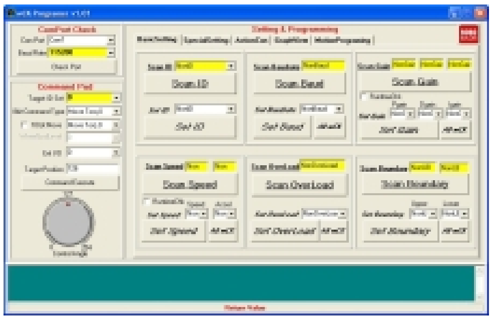


Figure 3.6 Programmer wCK

This application is a graphical user interface to all the advanced features of the actuator modules Vi. It is indicated for advanced users as it contains very dense and complete information to learn through their functions such as intelligent and optimized behaviour of the modules and adjust the actuators WCK PID control. [7]

3.1.3 Programmes of LEGO

3.1.3.1 NXT-G

NXT-G is an intuitive, icon-based drag-and-drop programming language designed for an easy introduction to programming for new users and experienced users. By choosing program blocks that work with the motors and make the sensors react to inputs, you simply build up your program block by block, and you can create programs that range from simple to complex.

The LEGO MINDSTORMS NXT toolkit comes with programming examples and a user-friendly walk-through introduction to the different programming blocks. [8]

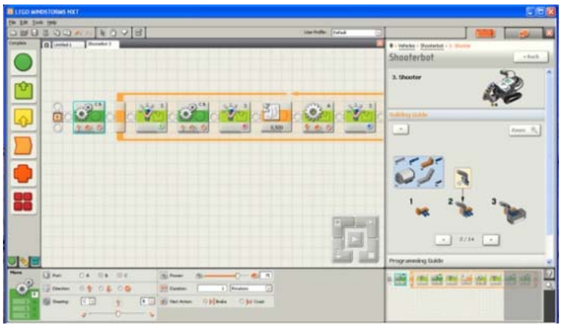


Figure 3.7 NXT-G

3.2 Motors and sensors

3.2.1 Bioloid

3.2.1.1 AX-S1: Sensor Module for Bioloid:

The Bioloid kit includes a sensor module with various functions (distance sensing, sound detection, etc) and unlike conventional remote controlled toys, autonomous programmable robots with intelligence can be buit with the Bioloid robot construction kit.

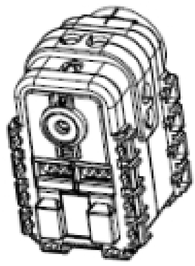


Figure 3.9: AX-S1

3.2.1.2 Dynamixel: DC Servo Module for Bioloid:

Unlike conventional R/C servos that use PWM, the Dynamixel DC servo modules used for the Bioloid kit are special bilateral servos operating on a network with feedback functions. It has a wide range of motion (300 degrees) with an option for continuous rotation for use as wheel actuators. [9]

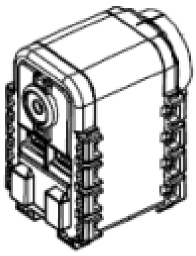


Figure 3.8: AX-S1

3.2.2 Robobuilder

3.2.2.1 Servomotores wCK en bus "Daisy-Chain" series con control PID

How the Bioloid robotic modular, servo actuator system in series provides valuable feedback of information of speed, position and torque. Each actuator can be programmed with the boundaries of these variables, and PID control algorithms are fully customizable.

Figure 3.10: wCK

RoboBuilder is the first non-industrial robotic kit with PID controllers in each servo.

With a simple command, the actuators can be switched between angular control (servo) the mode of continuous rotation (DC motor), allowing to assemble joints and wheel with the same actuator modules. Each actuator (unlike other actuator of other kits) even incorporate two TTL digital output ports and analog input port 0.5V, so the advanced users can extend their capabilities and create robotic applications more complex.

In the transparent module actuators, digital output ports are used to control bright LED's and cause visual effects of light in the darkness[10].

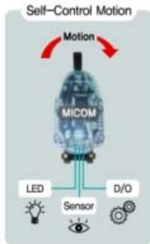


Figure 3.11: wCK

3.2.3 LEGO

3.2.3.1 Sensor color

The new color sensor is not included in the earlier version of LEGO Mindstorms NXT has been improved and can detect different colors real. Robots can "feel" with two pressure sensors, while through the "eyes" are capable of measuring ultrasonic distance and movement. [11]

Figure 3.12: Sensor Color

3.3 What can we build?

3.3.1 Bioloid

The following are robots than can be created from a Bioloid.

Crossing gate		Robot Arm	
Universal Gauge		Cliff Detection Car	

Sound-Level Meter		Greeting Penguin	
Crocodile Mouth		Attacking Duck	
Pan Tilt		Obstacle Detection Car	
Parking Gate		Clapping Penguin	
Melody Car		Waking Droid	

3.3.2 LEGO

4 building and programming challenges are included on the software CD.

Shooterbot

Color Sorter

Alpha Rex

Robogator

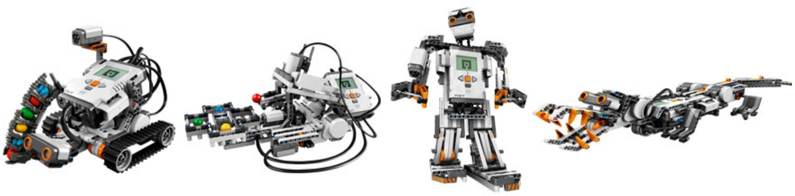


Figure 3.13: LEGO

3.3.3 RoboBuilder

Four building and programming challenges are included on the software CD.

1. Snake
2. Digger
3. Vehicles
4. Your own creation

Figure 3.14: RoboBuilder

4 Introduction to Bioloid

4.1 What is Bioloid?

The **Robotis Bioloid** is a hobbyist and educational robot kit produced by the Korean robot manufacturer Robotis. The Bioloid platform consists of components and small, modular servomechanisms called Dynamixels, which can be used in a daisy-chained fashion to construct robots of various configurations, such as wheeled, legged, or humanoid robo0074s. The Bioloid system is thus comparable to the LEGO Mindstorms and VEXplorer kits. The platform is currently in use by the U.S. Naval Academy in their Mechanical Engineering courses, and is also popular in the RoboCup internationalrobotics competition [12]

The Kit Bioloid is very practice for a final year project, because is possible build everything that you propose.

In the kit there are:

- Dynamixel AX-12 Actuator
- Dynamixel AX-S1 Sensor
- CM-5
- Cables
- CD with programme Software

4.2 The CM-5 Module. Controller for driving the Dynamixel

CM-5 is the dedicated central controller module for the Bioloid, Robots are built by connecting Dynamixel modules to the CM-5 module.

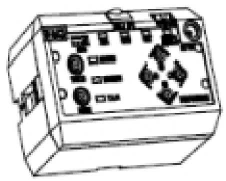


Figure 4.1: CM-5

This is the brain Bioloid platform and is based on the Atmel microcontroller ATMega128. Contains rechargeable battery. The controller board is embedded in a housing with LEDs and buttons to manually activate and monitor operations with leds the different states of the robot.

The Bioloid CM-5 comes with the preinstalled firmware that enables interoperability with the PC software provided in the kit (Motion Editor and Behaviour Control), and communicate with the PC using the supplied serial cable to load in the CM-5 programs that control the robot. [13]

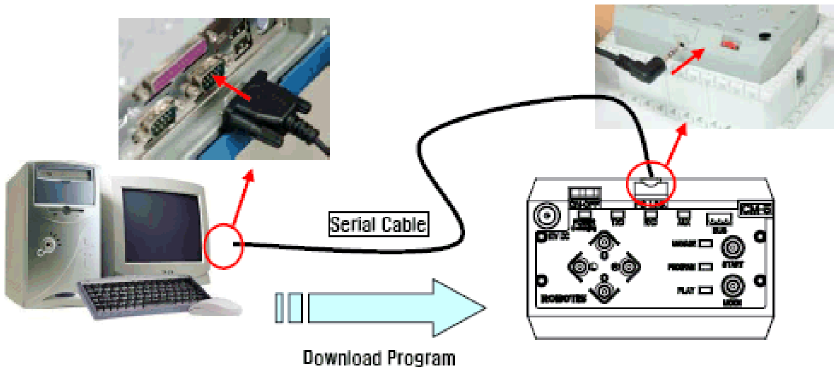


Figure 4.2: Connected

Operation modes:

- Manage mode: This is used when you want to know the status of the CM-5 unit or the Dynamixels, or when you want to test the motion. This mode should only be used by advanced users who are very confident with operating the robot.
- Program mode: The mode used for editing the motion.
- Play mode: The mode used for running the behavior control program created.
- Standby mode: The mode before running the other three modes.
- Charging mode: In standby mode, if the SMPS is connected, battery charging will begin when you press the ○U button. (ref PDF Bioloid User's Guide) [14]

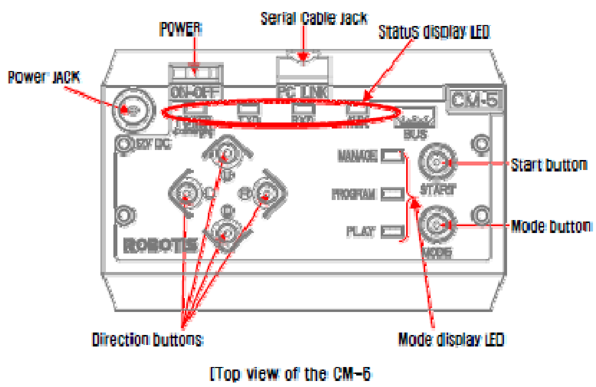


Figure 4.3: CM-5

4.3 Dynamixel AX-12 Actuator

Figure 4.4: AX-12

Each actuator Dynamixel AX-12 + included in the kit allows continuous rotation, and has a microcontroller that means 50 commands, most of which set or read parameters that define its behavior. The typical radio control hobby servo means the order only "objective angle (given by a PWM signal), but the actuators Dynamixel let you use them as a professional actuator sensors: the software that runs on the CM-5 can react to environment using information read from the sensors of the AX-12 +. This information can be read current position, the current drawn or the variation of the temperature of the servo under load in the same, allowing sophisticated feedback control that supports controlling the torque at each joint of the robot. This has applications eg in biped robots, because without inclinometers or accelerometers, are available equilibrium effects

Precision Control Position and speed can be controlled with a resolution of 1024 steps.

Compliance Driving The degree of compliance can be adjusted and specified in controlling position.

Feedback Feedback for angular position, angular velocity, and load torque are available.

Alarm System The Dynamixel series robot actuator can alert the user when parameters deviate from user defined ranges (e.g. internal temperature, torque, voltage, etc) and can also handle the problem automatically (e.g. torque off)

Communication Wiring is easy with daisy chain connection, and it support communication speeds up to 1M BPS.

Distributed Control Position, velocity, compliance, and torque can be set with a single command packet, thus enabling the main processor to control many Dynamixel units even with very few resources.

Engineering Plastic The main body of the unit is made with high quality engineering plastic which enables it to handle high torque loads.

Axis Bearing A bearing is used at the final axis to ensure no efficiency degradation with high external loads.

Status LED The LED can indicate the error status to the user.

Frames A hinge frame and a side mount frame are included.

Torque set up: Torque can be set up by 1023 steps from maximum torque to free run state[15]

4.4 Dynamixel AX-S1 Sensor module

Sensor Module AX-S1 is encapsulated within the same housing that the AX-12 servos and connect to the same bus number, but do not contain a motor.

Figure 4.5: AX-S1

The AX-S1 Sensor Module is the eyes, ears, and voice of your robot. It contains three IR sensors for object detection and line following, a microphone for sound detection, and a piezo speaker for generating tones.

Precision Control Capability to read sensor that has been detected through 1024 steps resolution.

Feedback Feedback capabilities for the values of infrared distance sensor, light sensor, sound sensor.

Alarm System Alarm system that detects out of the range values of internal temperature, torque, service voltage were preset by users (Alarming)

Communication Wiring is easy with daisy chain connection, and it support communication speeds up to 1M BPS.

Distributed Control Position, velocity, compliance, and torque can be set with a single command packet, thus enabling the main processor to control many Dynamixel units even with very few resources.

Engineering Plastic The main body of the unit is made with high quality engineering plastic which enables it to handle high torque loads.

Frames Hinge and side mount frame are included as basics. AX-S1 is compatible with AX-12 frames 100%, making it possible to use in various ways. Be cautious as unlike AX-12, Horn part of AX-S1 does not turn, so assemble frame in correct angle with the usage purpose in mind.

Infra-red Sensor It is embedded with three directions infrared sensor, making it possible to detect left/center/right distance angle as well as the light.

Remocon Sensor It has built-in remote control sensor in center, making it possible to transmit and receive infrared data between sensor modules.

Internal Mic It has built-in micro internal microphone, making it possible not only to detect current sound level and maximum loudness but also an ability to count the number of sounds, for instance, the numbers of handclapping

Buzzer Built-in buzzer allows the playback of musical notes and other special note effects.[16]

5 Construction of Hardware

5.1 Pieces and conections

The Dynamixel's are connected to the CM-5 module through the use of cables, figure 5.1 below shows the different cables contained within the kit.

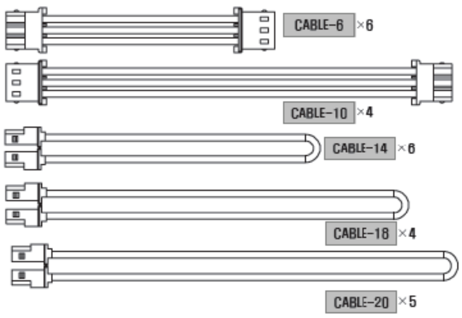


Figure 5.1: cables

The frames are connected together and to the Dynamixels mechanically through the use of nuts and bolts, the various sizes of bolts are shown in figure 5.2 below.

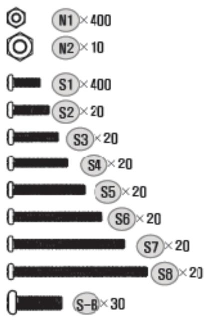


Figure 5.2: Screws

The three main pieces of hardware contained in the Bioloid beginner kit, the CM-5 module and the AX-S1 and AX-12 Dynamixels are connected together in the construction of a robot using a series of frames and cables.

Figure 5.3 below shows the different types of frames contained within the Bioloid kit; these are used to attach the Dynamixels together in countless different ways to construct all types of robots.

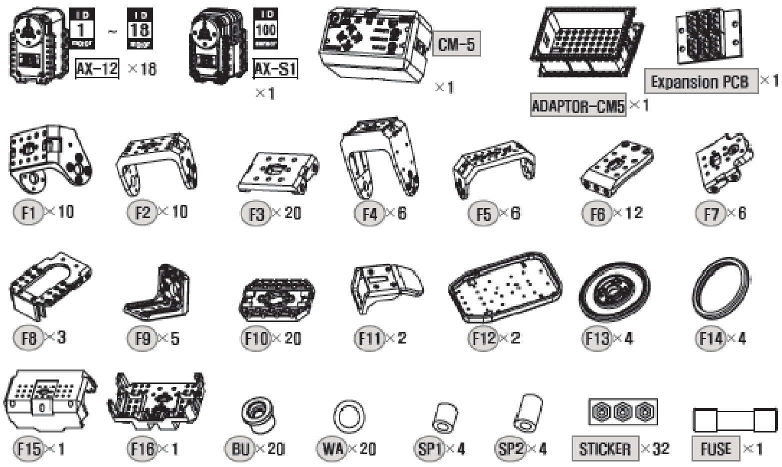


Figure 5.3: Hardware

When the Dynamixels are connected by the 'daisy chain' method, they are connected pin to pin using the cables; the pin assignment for the Dynamixels is shown by figure 5.4 below.

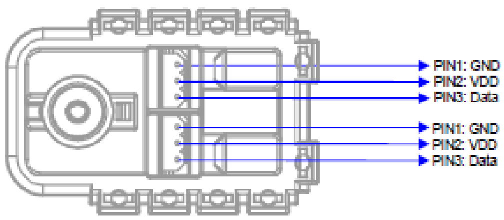


Figure 5.4: Pin Assignment

The wiring is very simple and it is possible to connect many Dynamixel units together, and to the CM-5 in the form of a 'daisy chain' allowing for simple control of complex assemblies by a single bus, this is shown in figure 5.5 below.

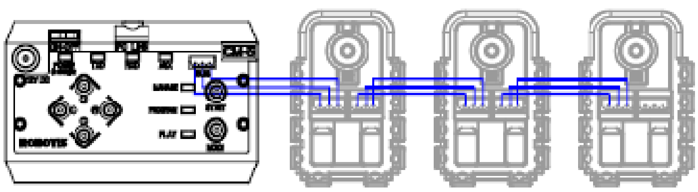


Figure 5.5: Connected

Main Controller To operate the Dynamixel actuators, the main controller must support TTL level half duplex UART. A proprietary controller can be used, but the use of the Dynamixel controller CM-5 is recommended. (ref PDF AX-12)

PC LINK A PC can be used to control the Dynamixel via the CM-5 controller. (ref PDF AX-12) [19]

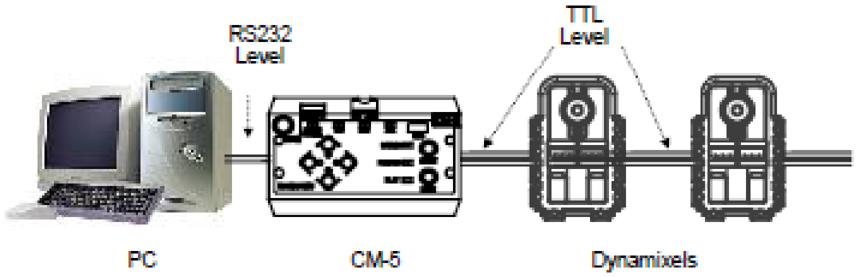


Figure 5.6: Connected

5.2 Construction of the robot arm

5.2.1 Robot arm specification

The robot arm was constructed using four motors Dynamixel AX-12 Actuators, five cables and the CM-5.

This design was chosen for their easy mobility that had distributed between the two places the water of the glass.

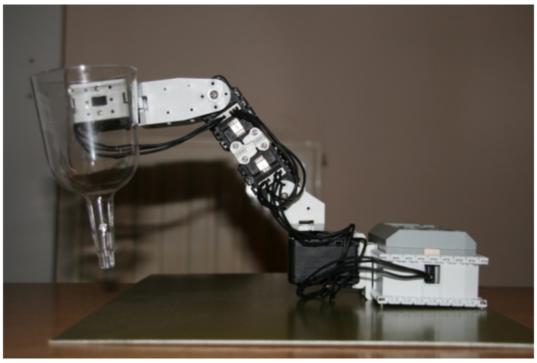


Figure 5.7: Robot

5.2.2 Steps for assemble the robot Bioloid:

Step 1:

The first step to assemble the robot Bioloid was fixed to the motor 1 in the CM-5 with screws. Was fixed with four screws in the motor and CM-5. The motor is mounted F1 part and then put the motor 2 in it.

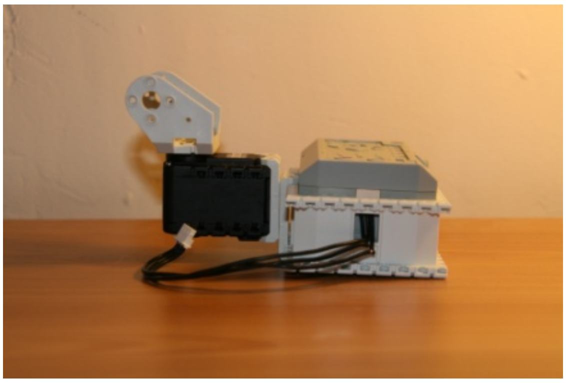


Figure 5.8: Robot step1

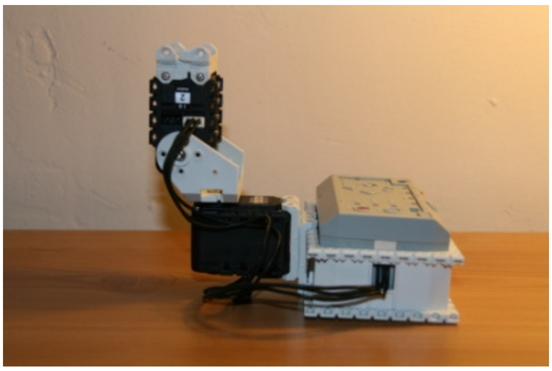


Figure 5.9: Robot step2

Step 2:

The second step to assemble the robot Bioloid was fixed the motor 2 in the F1 part with screws. The motor 2 is mounted two F3 parts and then put the motor 3 in it.

Step 3:

The third step to assemble the robot Bioloid was fixed the motor 3 in the F3 part with the screws.

The motor 2 and 3 was fixed one above the other.

Figure 5.10: Robot step3

Step 4:

The fifth step to assemble the robot Bioloid was fixed the motor 4 in the F4 part with the screws.

The F4 is a bit longer than the F1 or F2. This is because the arm has more elongated.

Figure 5.11: Robot step4

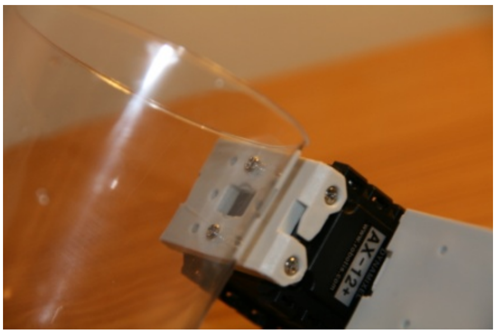


Figure 5.12: Robot step5

Step 5:

The sixth step to assemble the robot Bioloid was fixed the glass with the F1 and the screws. The F1 was fixed in the motor 4.

Step 6:

The seventh and the last step to assemble the robot Bioloid was fixed the motor 4 with the motor 3 across the part F4.

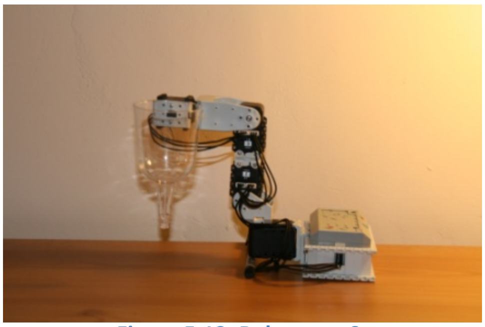


Figure 5.13: Robot step6

Step 7:

Was connected the cables with every motor. Was connected the cables from CM-5 to motor 1, motor 1 to motor 2, motor 2 to motor 3, motor 3 to motor 4.

Figure 5.14: Robot step7

Step 8:

Was take the big board and made four holes to grab the robot on this board. After, with the screws was steed in the board.

Figure 5.15: Robot step8

Figure 5.16: Robot step9

In this assembly, we use the 4 motors that come with the kit, do not use any sensor because what we have to know is the motor torque to lift the glass of water.

6 Kinematics

Kinematics is the branch of mechanics that describes the motion of an object without reference to the causes leading to the motion, such as force or mass.

The objective of forward kinematics is to calculate the Cartesian location at the end effecter from measured values of the joint angles.

However, it is more useful to consider the branch of mechanics known as Inverse Kinematics, in which the joint angles required to place the effecter in a pre defined position are estimated.

This solution allows for the output of the plotter to be set and the required joint angles to be estimated through a series of calculations.

6.1 Robot Forward Kinematics

6.1.1 Arm solution

Humans solve the inverse kinematics problem countless times a day without even thinking about it, whenever reaching out to grab something the joint positions of the shoulder, elbow and wrist are moved to the angles required in order to place the hand into the desired position.

This can be related to a robotic arm where the joints are the actuators and the hand is the effecter, the figure below shows the schematic of a very simple example of a robot lying in the X-Y plane, the robot has one link of length l, one joint with the angle Ø and the goal position for the effecter is X_{hand}.

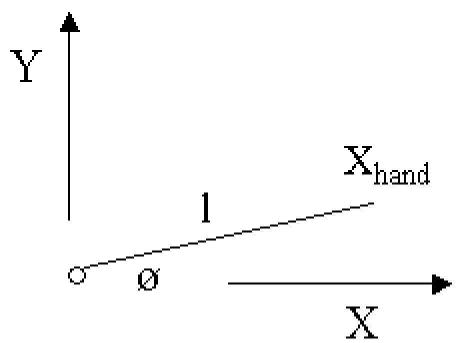


Figure 6.1: Kinematics

When X_{hand} and l are known, to solve this simple problem, the forward position equation is manipulated to make Ø the subject as shown below:

$X_{hand} = l\cos Ø$ (*forward position solution*)

$\cos Ø = X_{hand}/l$

$Ø = \cos^{-1}(X_{hand}/l)$

The figure below shows a more complex inverse kinematics problem which can be related to a robotic manipulator with several degrees of freedom. It requires the coordinates of the required point to be known for the X and Y plane as well as the angle of the required point.

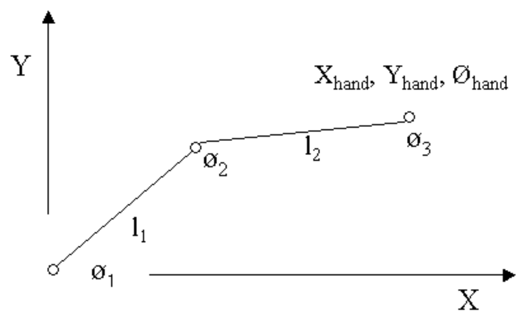


Figure 6.2: kinematics

In order to solve this problem, an imaginary line needs to be drawn from the robots first point to its last as shown in figure x, the properties of this line being as follows:

- B – length of the imaginary line
- q_1 – the angle between the x axis and the imaginary line
- q_2 – the interior angle between the imaginary line and the first link, L1

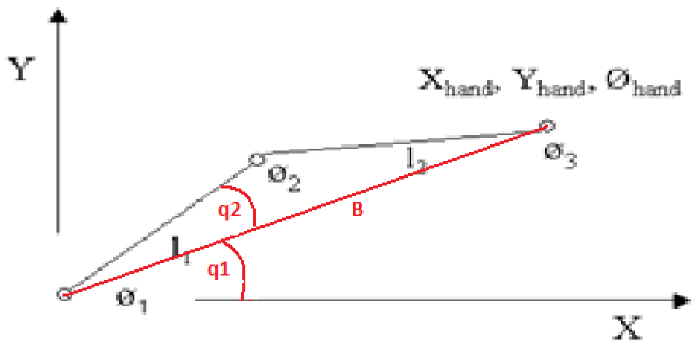


Figure 6.3: kinematics

Once these values have been defined, the following set of equations can be developed in order to calculate the angles at the actuators for the required output position.

Using Pythagoras' Theorem to find the length of B it could be said that:

$\boldsymbol{B^2 = X_{hand}^2 + Y_{hand}^2}$.

Next, using the law of cosines to find the angles q_1 and q_2 it could be said that:

$q_1 = ATan2(Y_{hand}/X_{hand})$

$q_2 = acos[(l_1^2 - l_2^2 + B^2)/2l_1B]$

Next, the values of the angles of the actuators, $Ø_1$, $Ø_2$ and $Ø_3$ could be found:

$Ø_1$ could be found from adding the values of q1 and q2 together: $Ø_1 = q_1 + q_2$

$Ø_2$ could be found from using the law of cosines: $Ø_2 = acos[(l_1^2 + l_2^2 - B^2)/2l_1l_2]$

$Ø_3$ could be found by subtracting the values for $Ø_1$ and $Ø_2$ from the measure value of $Ø_{hand}$:

$Ø_3 = Ø_{hand} - Ø_1 - Ø_2$. [19]

6.2 Aplication in the robot

It has been picked as grade 0 to 150 degrees, where is the rest of the engines. Depending on the engine is forward or backward, we will add or subtract 150.

ID1

This motor can say that is 150 degrees

ID2

$X_1 = 45$

$L_1 = 84$

$$ØID_2 = cos^{-1}\left(\frac{X_1}{L_1}\right) = cos^{-1}\left(\frac{47}{84}\right) = 55{,}97$$

ID3

$$ØID_3 = cos^{-1}\left(\frac{X_2}{L_2}\right) = cos^{-1}\left(\frac{47}{69}\right) =$$

ID4

This motor can say that is 225 degrees.

$\emptyset_{ID1}$ was measured to be **0°**

$\emptyset_{ID2} = cos^{-1}\ (X1/L1) = cos^{-1}\ (47/84) =$ **55,97°**

$\emptyset_{ID3} = cos^{-1}\ (X2/L2) = cos^{-1}\ (47/69) =$ **47,06°**

$\emptyset_{ID4} =$ **225°**

The next step is to determine the angle plus or minus 150 degrees, depending on if you turn left or right:

$\emptyset_{ID1} = 150° + 0 = 150°$

$\emptyset_{ID2} = 150° + 50.4 = 200.4°$

$\emptyset_{ID3} = 150° + 44.6 = 194.6°$

$\emptyset_{ID4} = 150° - 53.4° = 196.4°$

7 Torque

7.1 Introduction to torque

Torque, also called **moment** or **moment of force** (see the terminology below), is the tendency of a force to rotate an object about an axis,[1] fulcrum, or pivot. Just as a force is a push or a pull, a torque can be thought of as a twist.

Loosely speaking, torque is a measure of the turning force on an object such as a bolt or a flywheel. For example, pushing or pulling the handle of a wrench connected to a nut or bolt produces a torque (turning force) that loosens or tightens the nut or bolt.

The terminology for this concept is not straightforward: In physics, it is usually called "torque", and in mechanical engineering, it is called "moment" However, in mechanical engineering, the term "torque" means something *different*, described below. In this article, the word "torque" is always used in the physics sense, synonymous with "moment" in engineering.

The symbol for torque is typically τ, the Greek letter *tau*. When it is called moment, it is commonly denoted M.

The magnitude of torque depends on three quantities: First, the force applied; second, the length of the *lever arm* connecting the axis to the point of force application; and third, the angle between the two. In symbols:

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$$
$$\tau = rF\sin\theta$$

Where:

- $\boldsymbol{\tau}$ is the torque vector and τ is the magnitude of the torque,
- $\mathbf{r}$ is the displacement vector (a vector from the point from which torque is measured to the point where force is applied), and r is the length (or magnitude) of the lever arm vector,
- $\mathbf{F}$ is the force vector, and F is the magnitude of the force,
- $\times$ denotes the cross product,
- θ is the angle between the force vector and the lever arm vector.

[20]

7.2 Examples Torque

7.2.1 Tighten nut.

When a person presses a screw with a wrench, is applying a torque to the screw. As in the case of force, if all the torques are equal, it can't tighten the screw. If she applied torque is greater than the torque due to friction against the screw, the screw roll (fits).

The torque and power are linked directly. When the person pushes (a force) on the edge of the key, it applies more torque best fits the screw. However, it is only the force that makes the difference. The more distant the screw she holds the key, the more torque applied, and best fits the screw.

Therefore, the torque should be related to the applied force and distance to the center of rotation where the force is applied. This distance is called the moment arm.

7.2.2 Pedal on the bike.

Pushing the bicycle pedal torque transmitting a tire rolls. If you apply a torque that exactly neutralizes all other torques (frictional torques, etc.) Will not accelerate or decelerate the speed of the tire (pedal).

(The sum of torques = 0, therefore the angular acceleration = 0)

If the frictional torque, etc. are larger than the one applied torque will reduce the speed of the tire (pedal).

(Torques are added <0, therefore the angular acceleration <0)

If the applied torque is greater than the frictional torque, etc., The tire (pedal) will accelerate.

(Torques are added> 0, therefore the angular acceleration> 0)

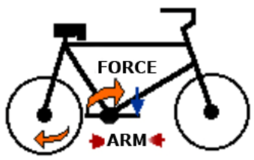


Figure 7.1: Bike

7.3 Application in Robot

Actually, the torque on a motor is determined by the equation:

$$\boldsymbol{T = Fl}$$

Where "T" is the motor torque, "l" is longitude between motor 2 and point where is the mass.

Then:

F=Mg

Where "g" is at gravitational force and "M" is the mass.

Then:

$$\boxed{\boldsymbol{T = Mgl}}$$

As "l" and "g" is defined by physical constants, that $g = 9.8\, ^{m}/_{s^2}$ motor torque is proportional to the current.

Then T is proportional to current of the motor 2

It can say that **T~I** ⇨ **I~M** ⇨**M= water weight**

So the ability to read the motor current allows you to determine the torque of the motor.

The units in the international system of measurements of torque is Nm (newton-meters).

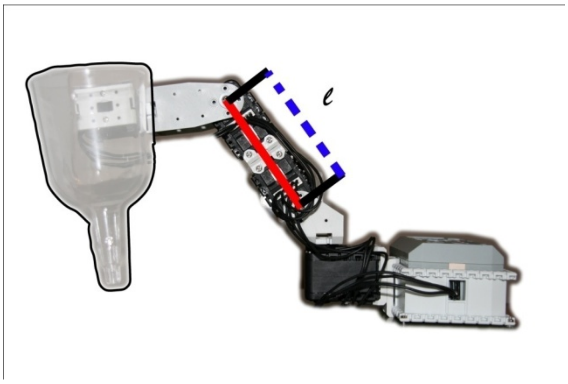


Figure 7.2: Robot longitude

In this arm, the formula can be applied to the motor 2. The length that we use with motors 2 and 3, plus the motor 4, we know how long it has, then we can calculate the intensity needed by the motor 2 to lift the weight to be, in this case the glass with water .

7.4 Goal Position of the motors

In the fours motors there is a margin for move of the motors:

When the AX-12+ is used as a joint, it rotates from 0° to 300° controlling the speed and position. The position value from 0 to 1023 is determined. For example, the position value 0 is 0°, 512 is 150°, and 1023 is 300° as shown below.

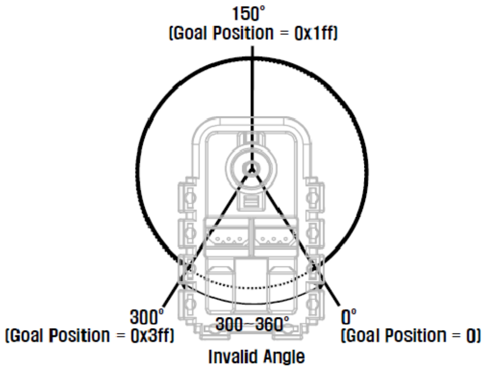


Figure 7.3: Goal Position

Every motor have to do movements because can distribute the water in the different glasses.

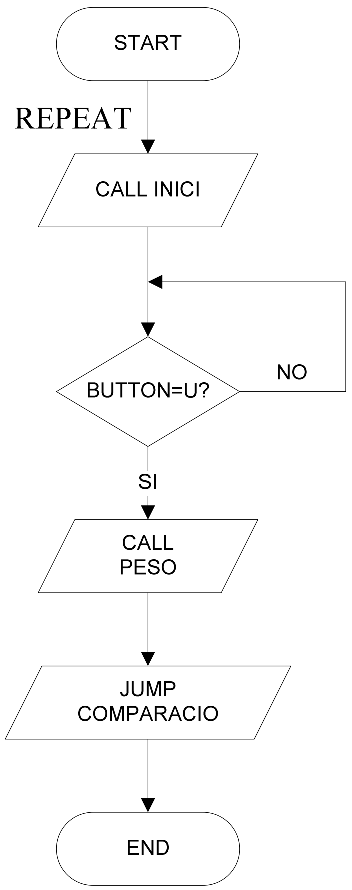
This is all movements of the motors:

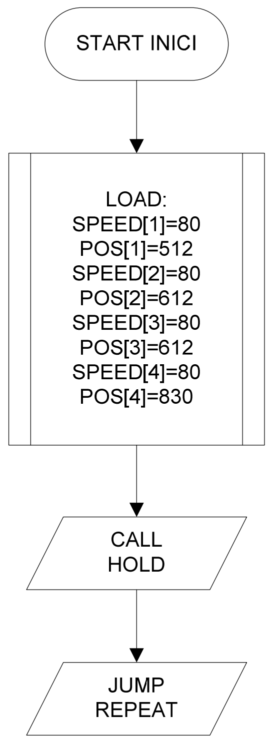
Motor 1 Positions: Inici: 512 Mov Left: 700 Mov Right: 220	**Motor 3 Position:** Inici: 612 Mov Left: 512
Motor 2 Positions: Inici: 612 Peso: 580 Mov Left: 512	**Position Motor 4** Inici: 830 Mov Left: Depens of the torque Up: 830 Mov Right: 400

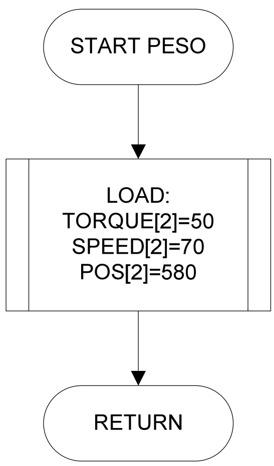
Torque

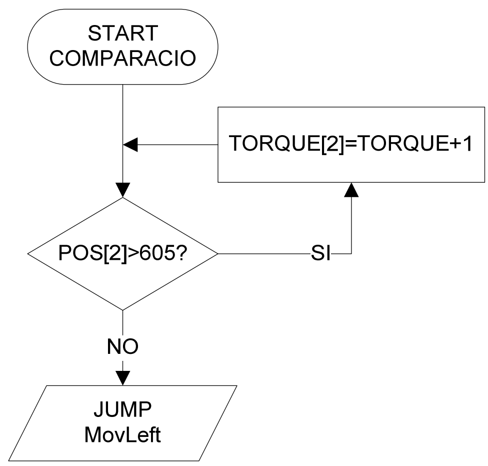
8 Operation of the program written

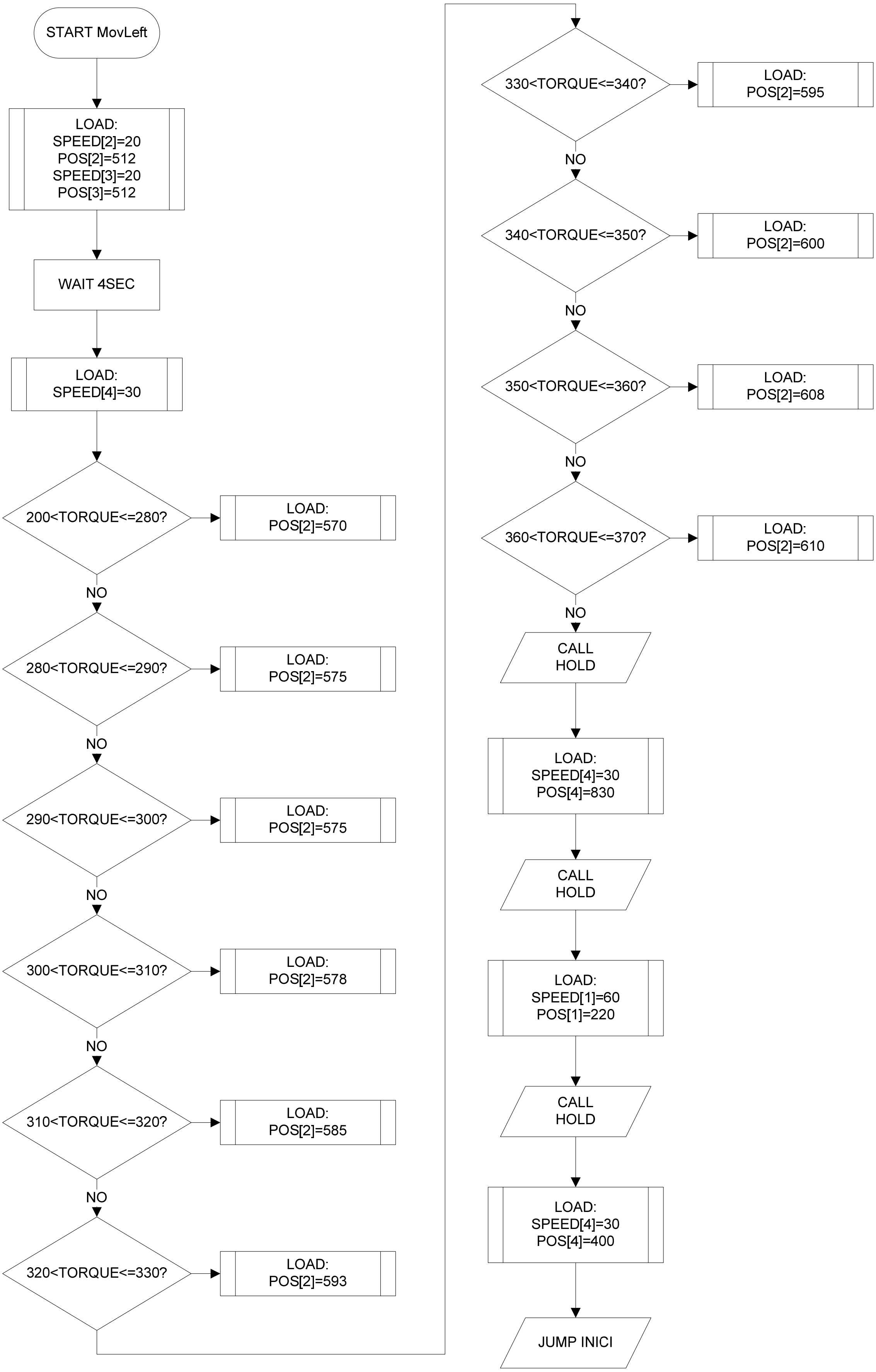
8.1 Diagram Block



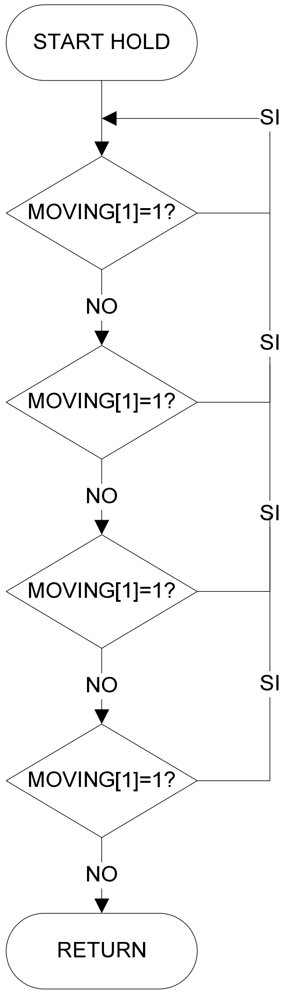








Operation of the program written



8.2 Program written

The program is written with the Behavior Control Programmer Bioloid. Program was chosen by the facility that has the time to write a program or give orders to the Bioloid robot. It is very simple yet very practical use.

To see how much water is in the glass of the robot Bioloid, has followed the following method:

1- The robot does not matter as they stand, the first call to "Inici" which is its initial position

Figure 8.1: Program written

Figure 8.2: Program written

2- When you it put the water wished (within limits) in the glass, press the key "U" to start the process.

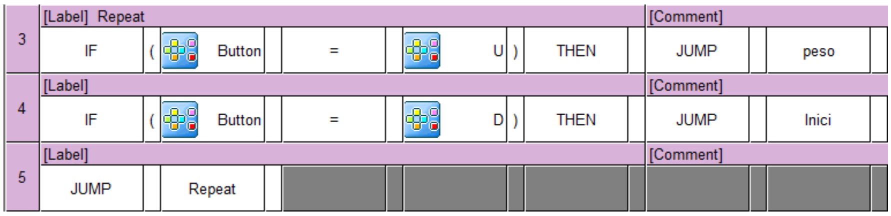


Figure 8.3: Program written

3- We put the engine torque 2 at 50 und at the same time, we try to lift the cup with the motor 2 to a certain point, if not yet reached that point because it has enough current to lift, let the engine by increasing the tap 2 until the desired point

Figure 8.4: Program written

4- We move the robot arm to the left to prepare, and make the initial distribution of wáter.

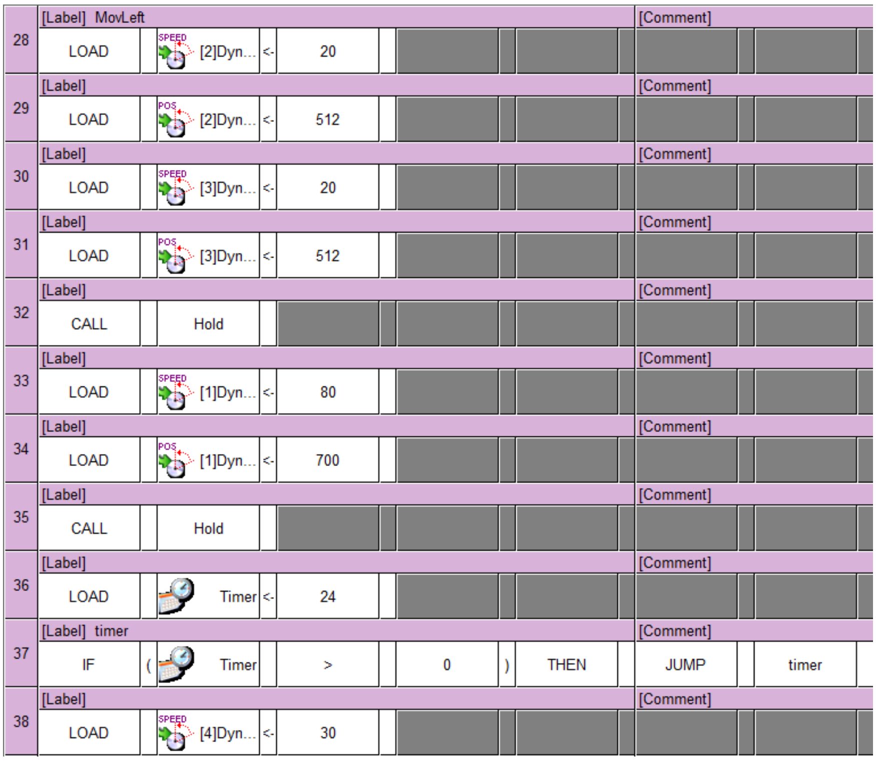


Figure 8.5: Program written

5- We compare the torque has been calculated at the time to lift the cup with a certain calculated parameters before in order to distribute the water.

6- Depende del torque que se ha calculado se usó un punto de inclinación u otro.

If TORQUE <=280 then position motor 4 is 570

If 280<TORQUE <=290 then position motor 4 is 575

If 290<TORQUE <=300 then position motor 4 is 575

If 300<TORQUE <=310 then position motor 4 is 578

If 310<TORQUE <=320 then position motor 4 is 585

If 320<TORQUE <=330 then position motor 4 is 593

If 330<TORQUE <=340 then position motor 4 is 595

If 340<TORQUE <=350 then position motor 4 is 600

If 350<TORQUE <=360 then position motor 4 is 608

If 360<TORQUE <=370 then position motor 4 is 610

If 370<TORQUE <=380 then position motor 4 is 618

If TORQUE >380 then position motor 4 is 618

7- Where has half the water in the container, goes to the other site to just put the water that remains.

67	LOAD	SPEED [4]Dyn...	<-	30
68	LOAD	POS [4]Dyn...	<-	830
69	CALL	Hold		
70	LOAD	SPEED [1]Dyn...	<-	60
71	LOAD	POS [1]Dyn...	<-	220
72	CALL	Hold		
73	LOAD	SPEED [4]Dyn...	<-	30
74	LOAD	POS [4]Dyn...	<-	400
75	CALL	Hold		

Figure 8.6: Program written

<u>Details of the program:</u>

1- When there is a motor moving, then run this loop, because if any motor is moving, it can`t jump the another step

	[Label]						[Comment]	
92	[Label] Hold IF	(MOVING [1]Dyn...	=	1	)	OR		
93	CONT IF	(MOVING [2]Dyn...	=	1	)	OR		
94	CONT IF	(MOVING [3]Dyn...	=	1	)	OR		
95	CONT IF	(MOVING [4]Dyn...	=	1	)	THEN	JUMP	Hold
96	RETURN							

Figure 8.7: Program written

9 Can it be extended?

Yes, it can be extended in many ways, and then can see some of them:

One could be, with a remote control, control the arm, and put in place when we want.

RC-100 is the wireless remote controller for robots introduced by robotised Biol. The box is semitransparent. You can check the status of movement through an LED. It was elegant and ergonomically designed boomerang shaped to be secured comfortably with easy access to all buttons. Has an automatic power save that automatically shuts down the remote controller when it has not been used for some time.

Figure 9.1: Control

Another can be, put a board that can simply connect the PC by wireless:

Zigbee: ZIG-100 is a device used for wireless communication of Bioloid. Zigbee is a technique for communication frequently used for PAN[Personal Area Network] like Bluetooth. [18]

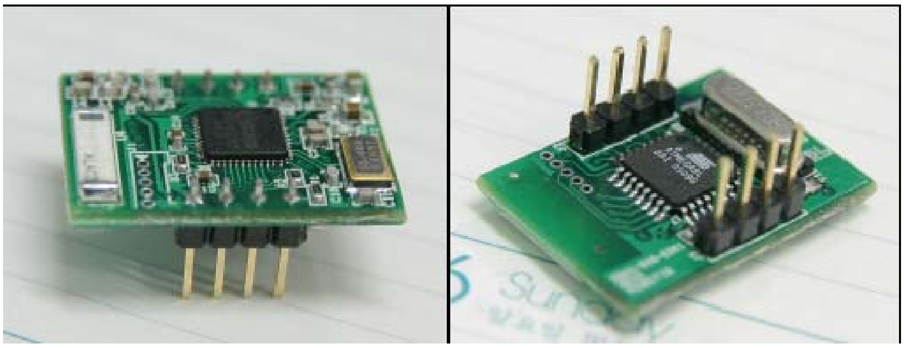


Figure 9.2: Control Zigbee

CM-5 and ZIG-100: For the communication between the Zigbee and Bioloid, the ZIG-100 should be mounted in the CM-5. You have to disassemble the CM-5 and insert ZIG-100 module in a place of ZIGBEE on the circuit board. To transmit and receive data, more than two sets of CM-5s and ZIG-100 are required. [18]

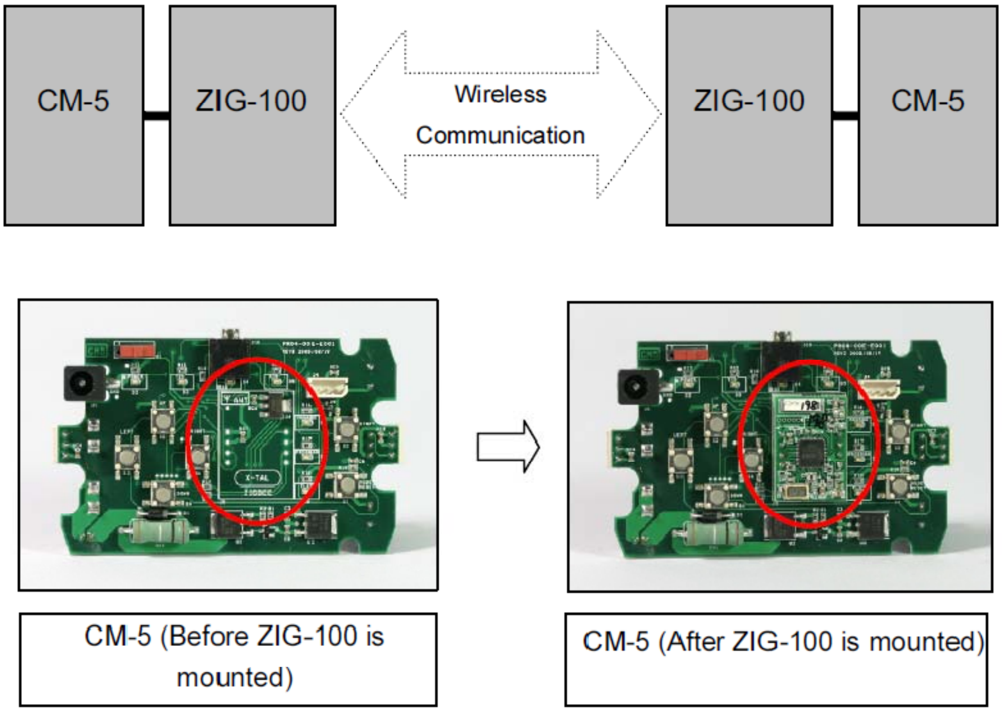


Figure 9.3: Control CM-5 and ZIG 100

10 Conclusions

In this project, one reached the conclusions that I have drawn is that the robotic assembly of kits can be many things, and if we know a lot of programming and devoted many hours to program their own kits, we can all what we propose.

One of the conclusions that I could do this is to remove the arm assembly, has no purpose at the time to market it, because you cannot find any reason to put water into a cup and divide it by 50% in each site differently.

The last conclusion I've found this project, is you learn to program with any kit with any program, because the end, all programming is very similar with all these kits, in this case the Bioloid.

Finally satisfied that I have found is learn to draw is that assemblies with motors of any kind, and any kit for the Bioloid robot wore a full month of the engines of the family of these kits.

11 ASSESSMENT

12 Reference guide:

[1] http://www.robotics.utexas.edu/rrg/learn_more/low_ed/dof/ ROBOTIS 16-06-2010

[2] http://ro-botica.com/bioloid_comp.asp ro-botica 18-06-2010

[3] http://ro-botica.com/bioloid_comp.asp ro-botica 18-06-2010

[4] http://ro-botica.com/bioloid_comp.asp ro-botica 18-06-2010

[5] http://ro-botica.com/bioloid_comp.asp ro-botica 18-06-2010

[6] http://ro-botica.com/bioloid_comp.asp ro-botica 18-06-2010

[7] http://ro-botica.com/bioloid_comp.asp ro-botica 18-06-2010

[8] http://ro-botica.com/bioloid_comp.asp ro-botica 18-06-2010

[9] PDF "Dynamixel Robotis AX-S1" 14-06-2006

[10] http://ro-botica.com/robobuilder_5710K_E02.asp ro-botica 18-06-2010

[11] http://ro-botica.com/mindstorms.asp ro-botica 18-06-2010

[12] http://www.robotis.com/zbxe/main ROBOTIS 18-06-2010

[13] http://www.robotis.com/zbxe/main ROBOTIS 18-06-2010

[14] http://www.robotis.com/zbxe/main ROBOTIS 18-06-2010

[15] PDF "*Dynamixel Robotis AX-12*" 14-06-2006

[16] PDF "*Dynamixel Robotis AX-S1*" 14-06-2006

[17] PDF "*Dynamixel Robotis AX-S1*" 14-06-2006

[18] PDF "*Robotis Bioloid User's Guide*" 14-06-2006

[19] http://www.learnaboutrobots.com/forwardKinematics.htm 14-06-2010

[20] http://en.wikipedia.org/wiki/Torque 14-06-2010

13 Reference Figures:

Figure 2.1	http://ro-botica.com 14-06-2010
Figure 2.2	http://ro-botica.com 14-06-2010
Figure 2.3	http://ro-botica.com 14-06-2010
Figure 2.4	http://ro-botica.com 14-06-2010
Figure 2.5	http://www.robotics.utexas.edu/rrg/learn_more/low_ed/dof/ 14-06-2010
Figure 2.6	http://www.robotics.utexas.edu/rrg/learn_more/low_ed/dof/ 14-06-2010
Figure 3.1	http://www.robotis.com/zbxe/main 14-06-2010
Figure 3.2	http://www.robotis.com/zbxe/main 14-06-2010
Figure 3.3	http://www.robotis.com/zbxe/main 14-06-2010
Figure 3.4	http://ro-botica.com/robobuilder_5710K_E02.asp 14-06-2010
Figure 3.5	http://ro-botica.com/robobuilder_5710K_E02.asp 14-06-2010
Figure 3.6	http://ro-botica.com/robobuilder_5710K_E02.asp 14-06-2010
Figure 3.7	http://ro-botica.com/mindstorms.asp 14-06-2010
Figure 3.8	PDF "*Robotis AX-S1*" 14-06-2010
Figure 3.9	PDF "*Robotis AX-S1*" 14-06-2010
Figure 3.10	http://ro-botica.com/robobuilder_5710K_E02.asp 14-06-2010
Figure 3.11	http://ro-botica.com/robobuilder_5710K_E02.asp 14-06-2010
Figure 3.12	http://ro-botica.com/mindstorms.asp 14-06-2010
Figure 3.13	http://ro-botica.com/mindstorms.asp 14-06-2010
Figure 3.14	http://ro-botica.com/mindstorms.asp 14-06-2010
Figure 4.1	PDF "*Robotis Bioloid User's Guide*" 14-06-2010
Figure 4.2	PDF "*Robotis Bioloid User's Guide*" 14-06-2010
Figure 4.3	PDF "*Robotis AX-12*" 14-06-2010
Figure 4.4	PDF "*Robotis AX-12*" 14-06-2010
Figure 4.5	PDF *"Robotis Bioloid User's Guide"* 14-06-2010
Figure 5.1	PDF *"Robotis Bioloid User's Guide"* 14-06-2010
Figure 5.2	PDF *"Robotis Bioloid User's Guide"* 14-06-2010
Figure 5.3	PDF *"Robotis Bioloid User's Guide"* 14-06-2010
Figure 5.4	PDF *"Robotis Bioloid User's Guide"* 14-06-2010

Figure 6.1	http://www.learnaboutrobots.com/forwardKinematics.htm 14-06-2010
Figure 6.2	http://www.learnaboutrobots.com/forwardKinematics.htm 14-06-2010
Figure 6.3	http://www.learnaboutrobots.com/forwardKinematics.htm 14-06-2010
Figure 7.1	http://en.wikipedia.org/wiki/Torque 14-06-2010
Figure 7.3	PDF *"Robotis Bioloid User's Guide"* 14-06-2010
Figure 9.1	PDF *"Robotis Bioloid User's Guide"* 14-06-2010
Figure 9.2	PDF *"Robotis Bioloid User's Guide"* 14-06-2010
Figure 9.3	PDF *"Robotis Bioloid User's Guide"* 14-06-2010