FUTURE

Mansoura University
Mansoura - Egypt

2014 MATE International ROV Competition

FUTURE

ROV Solutions

Willy

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Abstract

Our company, “Future “is constructed specifically for the purpose of taking part in the MATE International ROV competition. As a Team this is our second year of building specialized Remotely Operated Vehicles (ROVs) .Today, in 2014 "Willy" was designed carefully in order to compete in the 2014 MATE international ROV competition. Willy has an elegant design to compete the mission objectives. Its design, refinement, and construction are the result of the collective imagination, innovation, and effort of the Future team members.

Main Features of Willy includes that it is designed especially for the seabed exploration purposes and scientific shipwreck exploration, with dimensions of 67cm length, 54 cm width and 17.5 cm height and relies on 6 thrusters. It is equipped with instruments to collect samples from underwater microbial mats ,powerful cameras to collect photographs and make photo mosaic ,powerful thrusters to hold 10 kg weights under water ,special propulsion system that makes the best from the thrusters and consume less power at the same time, Image processing software that can calculate the distances using the camera and two laser pointers with high accuracy independent on any pre-known dimensions of competition arena as well as precise control of ROV motion (6 degree of freedom motion).

Our goal is to provide an inexpensive, multipurpose ROV. During the design and building process, company members learned essential technical skills and utilized “outside the-box” brainstorming techniques to ensure a quality end product. The design and fabrication of the ROV and traveling to the MATE Competition cost approximately 7000 L.E. this year. This detailed report will take you through the design and construction process step by step, as well as expenses, safety consideration and future modification.

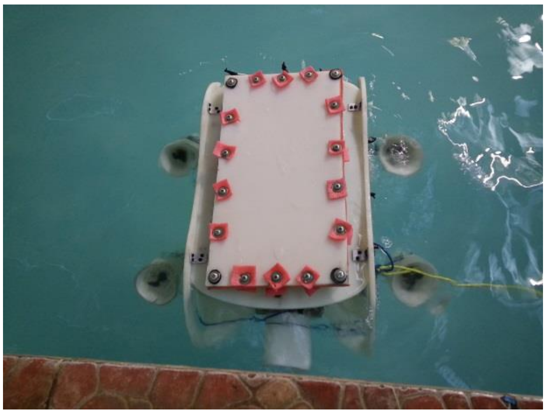


Figure 1-Willy in water

Mentor: Dr. Mostafa El-Hussieny.
Documentation: Salma Helal.

Budget

Electronics	Component	Price	Quantity	Cost	Total
	Thruster driver	80	6	480	
	Dual relays motor driver	35	1	35	
	24V Power Converter	80	1	80	
	12V,6V,5V Power Converter	40	1	40	
	Arduino Breakout Board	30	1	30	
	Spiral Wrap	22	2	44	
	20 m Power Tether	4.5	20	90	
	Lasers	10	2	20	
	20 m Ethernet Cable	0.75	20	15	**834**
Control					
	Arduino Mega	210	1	210	
	USB hub	75	1	75	
	20m USB Cable	155	1	80	
	20m Coaxial-power cable	4	20	80	
	Camera	420	1	420	
	HD Camera	175	1	175	
	Ethernet Shield	250	1	250	
	3Axis Mag. Acc.	240	1	240	**1530**
Mechanical					
	Polyethylene Sheet (1m2)	310	1	310	
	Motors (24v)	50	8	400	
	Thrusters Sealing cases	50	6	300	
	Camera sealing case	100	1	100	
	Motor couplings	10	6	60	
	Glandes (Size 7)	3	6	18	
	Glandes (Size 9)	3.5	30	105	
	Glandes (Size 11)	4	1	4	
	Hinged pipe clamps (1/2 in.)	2	6	12	
	Hinged pipe clamps (4 in.)	5	4	20	
	O Rings	26	10	260	
	Oil Seal	4	20	80	
	Bearing	3	26	78	
	Ties	10	1	10	
	Servo motor (30Kg.cm)	320	1	320	
	Servo sealing case	100	1	100	
	Polyethylene machining	165	1	165	
	Thrusters Nozzels	50	8	400	
	6 in. PVC pipe	60	1	60	
	4 in. PVC pipes	30	2	60	

Sero motor (20Kg.cm)	250	1	250	
Silicon	46	1	46	
Polyethylene sealing housing	40	1	40	
Nuts and bolts	50	1	50	
Sealing adhesive tape	3	10	30	
Propellers	35	8	280	
Servo motor couplings	25	2	50	
Foam sheet (1m2)	8	3	24	
Sponge sheet	12	1	12	
Stanless steel rod (8mm)	10	2	20	
Sealing Polyethylene end caps	200	2	400	
Camera housing	50	2	100	
Mechanism forging	100	1	100	
Double face adhesive tape	10	1	10	
Tools	50	1	50	
Laser sealing cases	30	2	60	**4384**
Total Cost				**6748**

Donator	Amount
EADT (Egyptian Association for Development and Technology)	1000
Eng. Tarek Heggy	200
Total	1200

Design Rationale

A. Frame

The frame is used to assemble all components of ROV together. Our ROV's frame consists of two vertical sides and two horizontal sheets all made of Polyethylene (as shown in figure X), as polyethylene is known for it's resistance to stress, positive buoyancy and ease of machining.

Figure 2 - Willy's frame

Our work was done step by step to reach the desired aim. First, we designed the frame on a piece of paper then, we used SolidWorks to give us a clear view of the ROV's appearance, to pay our attention to any measurement mistakes as well as to help us get a rounded estimation of the center of gravity position and the volume of the ROV, to determine whether the ROV will be stable underwater, sinking or floating, and help us reason out how much weight or buoyancy our ROV may need.

We also used CNC machines to cut the sheets just as we designed.

The sheets were freed at maximum to decrease the drag force and weight while moving.

The frame was constructed by connecting 4 sheets together, using brackets and using screw nuts and bolts. All components of the ROV are fastened to the two horizontal sheets using clamps and/or screw nuts and bolts. The upper sheet is used to fasten the Electronics Unit housing and main vision system. The lower sheet is used to fasten the propulsion system navigation mechanism, mission props and bottom-vision camera.

B. Housing

great concern was given to design, machine and operate .We paid more attention to reach a successful waterproofed housing.

Actually, waterproofing was one of the main challenges we had but eventually, we managed to design and fabricate well-sealed thruster, electronics, camera, light and laser housings.

a. Electronics Unit Housing

The Electronic Unit is the heart of the ROV system, so forbidding any leakage to this important system was inevitable.

First, we designed an Aluminum box that was later casted with specific dimensions and specifications. However, this design caused high drag force to move up and down. Also, heavy weight, expensive finishing and large area exposed to water leakage threat; all three reasons made us change the

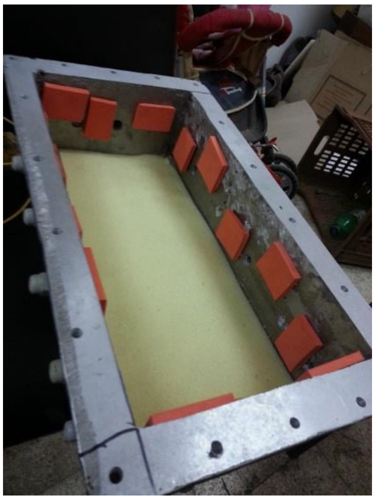


Figure 3 - Aluminum electronics housing

The new design consists of 3 parts: a 6' PVC pipe, two polyethylene caps and electronic circuits (PCB).

O rings are used to seal the pipe from water. Glands are installed into one cap so that all cables go to and from it. On the other face of this cap, other glands are used to double-seal the pipe. For the electronics, levels of PCBs are connected to the end cap using screws. This allowed us to easily remove the electronics from the pipe without having to loosen the glands or remove connectors as with the previous design.

This housing design can withstand the 6 meter depth of this year's competition.

b. Thruster Housing

We used uninsulated DC motors. Therefore, we needed to put them in waterproofed housings that seal the electric connections and prevent water from getting inside the case from around the shaft. Consequently, we designed polyethylene housing that consisted of 2 parts: the case body and

Figure 4 - Thruster

the nozzle. The case body is a hollow pipe with one end blocked; and the other is end screwed so that a screwed cap can close the housing. The nozzle plays two roles, one is the protection of propeller from hazardous objects and the other is that it is the other end cap of the motor housing. Oil seal and bearing are hard installed in the nozzle and O ring is used to seal the assembly of nozzle and motor case. The other end of the motor case has a gland which insulates the cable of the motor.

Figure 5 - Camera hosuing

c. Camera, light and laser housing

All three have similar housing approaches as with the motor housing. O rings, glands and polyethylene cases are used.

Propulsion System

Our propulsion system consists of 6 thrusters. 4 of them are for heaving, surging, pitching and rolling. The other two are used for swaying and yawing. Each thruster consists of 3 parts: a motor, a propeller and a case. We used spare-part motors that are taken from used and old photocopiers. As a result, we don't have detailed specs of each motor. The behavior is not the same, efficiency and speeds are also variant. Each motor is coupled with a 9 cm stainless steel rod that suits in the propellers. We used "Traxxas Propeller Left 4.0mm Villain EX". This propeller also lacks details. Due to these problems, we used identification methods to get some information about them. From that we came to know that each thruster operates on 24v, draws about 3 Amps in water, has speed of about 1500-1800 rpm and gives thrust of about 1 kg each. So, how can only 4 thrusters be used to surge, heave, pitch and roll? Actually, this is done

Figure 7 - Traxxas Propeller

Figure 6 - DC motor of a thruster

by utilizing a dedicated mechanism that can rotate each thruster about its center of gravity 90o and 180^{o}.

a. Navigation Mechanism

Figure 9 - 30Kg.cm Servo motor

two crank shafts (each one holds two thrusters) are linked together with a connecting rod, so that the two cranks rotate synchronized. One crank shaft has a gear with radius 'X'. A 30 Kg.cm-torque servo motor is used to drive the whole mechanism. It is waterproofed inside a polyethylene case with oil seal and bearing around the shaft. Coupling with staple penetrating through the servo motor shaft is used so that the coupling is firmly attached to the servo shaft and will not loosen under high torques. An identical 'X'-radius gear is attached to the coupling shaft, so that when the servo is installed in the mechanism, the two cranks rotate the same angle as the servo does. This allows us to rotate the cranks (and consequently, the thrusters) at precise

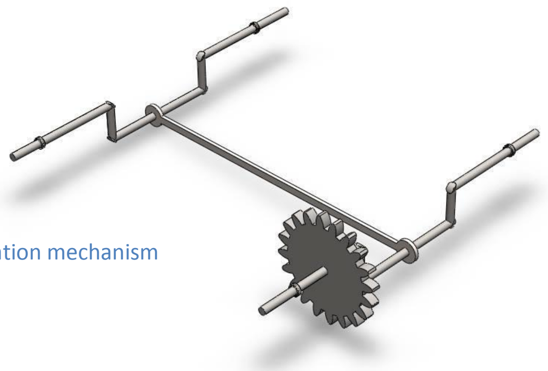


Figure 8 - Navigation mechanism

angles. A hinged clamp is welded to the end of each crank. These clamps are used to fasten the thrusters to the mechanism. The initial position of the mechanism is worth noting; the crank's C-like part is initially pointing downwards at the direction of gravity force; so, the servo motor doesn't have to resist unnecessary torque at initial position.

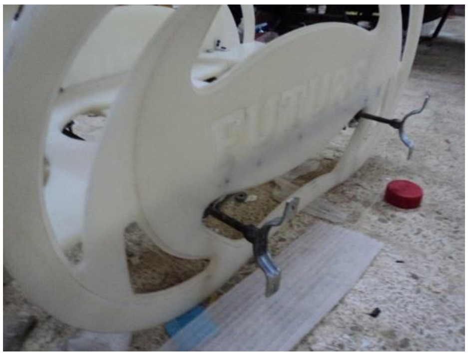


Figure 10 - Thrusters clamps

Actually, the required torque to drive the mechanism is about 16 Kg.cm; however, 30 Kg.cm servo motor was chosen to drive the mechanism. This is to be in the safe zone and to allow quick, smooth and safe motion.

Figure 11 - Thrusters mounted in the mechanism

This mechanism reduces the number of thrusters needed to achieve 6 DOF motion and reduces the power consumption of our ROV.

b. Side Thrusters

This year's mission requires the ROV to take many photos. All photos should lay on the same plan and must be taken quite perpendicular. So, a concept of setting the ROV initially in one perpendicular position and sway horizontally so that the ROV's direction is parallel to the surface so it can take photos which will be of the same size (for photo mosaic, specifically) - was applied. We used two sideway thrusters (one on the front and the other on the back) to achieve sway motion. Also, this structure allows us to achieve a couple moment so that the ROV can yaw around its center. This feature gives the ROV more maneuvering capabilities as we can surge/heave and yaw simultaneously.

c. Safety

Safety is a very important concern to us. This year, our company carried out dedicated safety procedures. First, ALL of our thrusters have shrouding (nozzle) with a net on the opening to prevent both human and inhuman objects from touching the propeller. Second, we gave great care to the smoothness of our design; the frame, the housings and payload tools are all designed smoothly with no sharp edges. Third, all electrical connections are

Figure 12 - Nozzles

enclosed in waterproofed housings, so no free wires are available. Forth, Willy is positively-buoyant so that if went wrong, it will float on the surface of the pool and will not sink and cause any damage. For the electronics, an ON/OFF switch controls the power of the ROV system. Switching this switch off will cut the power of the ROV and it will float to the surface (in emergencies). 30 Amps fuse lies on the positive terminal of the power cable of the ROV and another 30 Amps fuse is inserted in the power circuit. To avoid the problem of loosen and exposed wires, we used sockets and pin headers to reduce the number of individual, chaotic and flying wires. We also used heat shrinks to insulate any soldered wires and prevent unpredictable contact between exposed wires.

Electronics

A. Electronic Unit

The electronic unit is the driver for all electronic components of Willy's system. Power regulation, thruster driving, communication, light, laser, camera power and signals are all performed by the electronic unit.

a. Thruster Driver

We designed our thruster driver to be easily programmed to enable full control on thrusters. We used H-Bridge structure which is built with four solid state switches (N-CH IRF3205 and P-CH IRF4905 MOSFETs). Operational amplifier LM358 is used as MOSFET driver. The motor driver receives only digital signals for direction and brake, and a PWM one for speed. These signals control 4052 CMOS multiplexer to send orders to MOSFET driver. All input signals are buffered using PC817 opto-coupler that isolates the micro-controller ground from the thruster supply voltage to increase reliability. Fly back diodes were added around the motor terminal to limit the

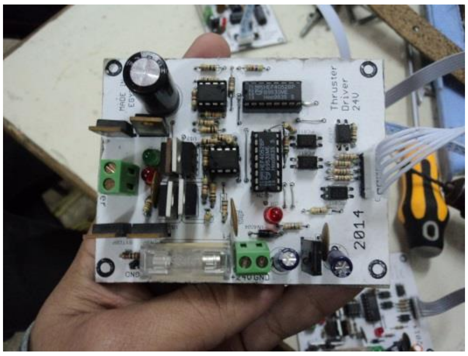


Figure 13 - Thruster driver

back EMF of the motor, preventing it from damaging the MOSFETs. We used ultra-fast schottky diode that is excellent with fast switching and has only voltage drop by 0.1V. The circuit is working with 24V input voltage and can stand 7A current without a heat sink, so we decided not to use one to reduce it's size. The schematics are shown in Appendix A.

b. Power Conversion

Figure 15 - Power conversion circuit

Willy is supplied with three DC-DC converters designed by the company to convert the DC 48V provided by the organizer, into the voltages required to supply the electronics components (24V, 12V, 6V, 5V). The maximum load of the 24V is 30A, the 12V is 8A, the 6V is 8A, and 5V is 5A.

The 24V is designated to power the motors, the 12V to power cameras, and 6V to power the RC servo motors. The DC-DC converters are based on DC linear regulation theory with common collector configuration of power transistor to boost the output current. We made them in two boards; one of them for 24V conversion, and the other for 12V, 6V, and 5V conversion. All transistors are biased to function in their safe operating area. Heat sinks are added to power transistors for heat dissipation. The schematic is shown in Appendix B.

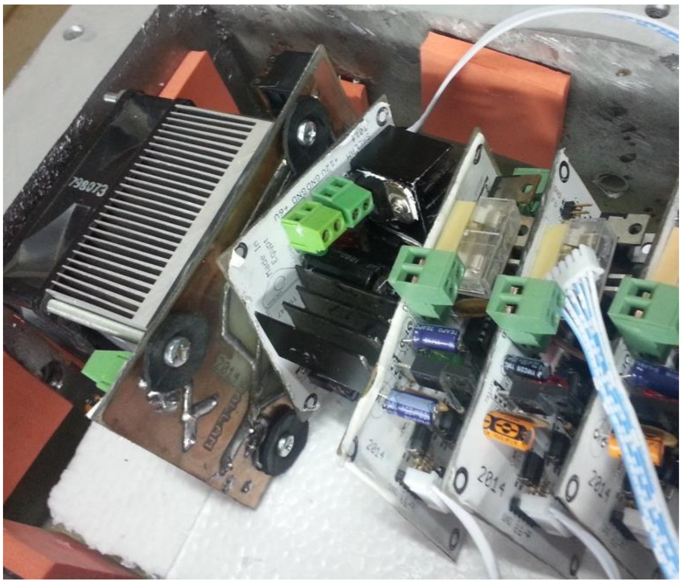


Figure 14 - Electronics in housing

B. Vision System

This year, our company decided to use two cameras: (A) camera is an A4Tech 1080 Full HD USB WebCam (figure X) and the second camera (B) is a CCTV analog camera.

Figure 16 – A4Tech Full HD camera

A is the main camera. This camera is fastened by clamps to a 20 Kg.cm servo motor that rotates the camera in 0-180o range. This allows us to observe broader area with one camera; specifically, observe the front manipulator, take photos at perpendicular position, count zebra muscles (Task 2) and calculate dimensions. Camera B allows us to observe the deployment of conductivity sensor, retrieving microbial mat and carrying payloads with the bottom arm.

Camera A is connected to USB hub with external power – inside the ROV. Thus, it is powered from the MATE power supply but only sends video stream through the USB hub cable to the surface. However, camera B is powered directly from power conversion unit (12 volts terminal), transmitting its video stream through a coaxial cable to a display monitor on the surface.

We used LED torches to illuminate the dark areas in the mission arena (specifically, inside the shipwreck).

C. Tether

This year, our tether contains three cables: DC power cable, 20m USB cable and coaxial cable.

The power tether is 20-m long. It has a pair of 2.0-mm in diameter of copper wire, which have impedance 0.6-ohm, that makes 18V voltage drop across the tether if 30-A flows through it – which is perfect for our system. A 20 m USB cable is used to control, communicate and command (C3) the ROV. After 10 m, a fixed repeater empowers and enhances the signal so that it can reach the destination without distortion.

A coaxial with power-ground terminals shielded cable is used to transmit analog video stream. A conversion to Video RCA cable is used to display the video stream on TV display.

Control System

The control system is responsible for sending and executing the pilots commands to the ROV. An interface on the computer sends commands to a microcontroller inside the ROV which interprets the command and sends signals to different electronic component to control electric and mechanical devices.

A. Hardware

We used Arduino Mega 2560 R3 kit with ATmega2560 microcontroller embedded as the main and only microcontroller kit in our system. We chose this microcontroller because it supports up to 54 digital pins and up to 16 analog pins. This number is required as the number of components to control in our system is large.

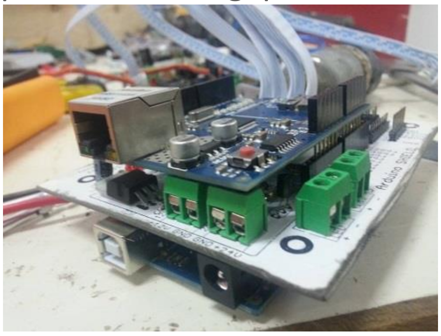


Figure 17 - Ethernet Shield mounted on Arduino Mega shield

Collect all pins relating to one thruster in one pin headers line. This organizes the connection and reduces the mess of multiple, loose, and flying wires. The shield also regulates input voltage to toggle laser and light.

The Arduino is powered by a USB cable connected to the external powered USB hub embedded in our ROV. This allows us to program and control Arduino from a single cable (USB hub cable), just by knowing Arduino COM port on the PC.

The host PC communicates with Arduino through RS232 serial protocol; which is done easily with the help of USB cable right connected from Arduino to the PC.

The user interface on the PC receives the commands from pilot, constructs a packet of information and sends it to Arduino via USB cable under serial protocol. Arduino detects the connection, receives the packet, reads it, extracts the commands and executes them. The System interconnection system is shown in appendix C.

B. Software

From the beginning, a question arised "What are the most important things the pilot may need on the GUI?". The answer of this question was the guide all the way in our development process.

First, a large camera display was essential to control the ROV. Second, a timer to know how much time has passed was also important to the pilot. Easy interface for shipwreck identification was developed. A list of all the tasks and steps required were listed in the planned sequence. Speed meter was developed to give indication of how much power the pilot gives to thrusters.

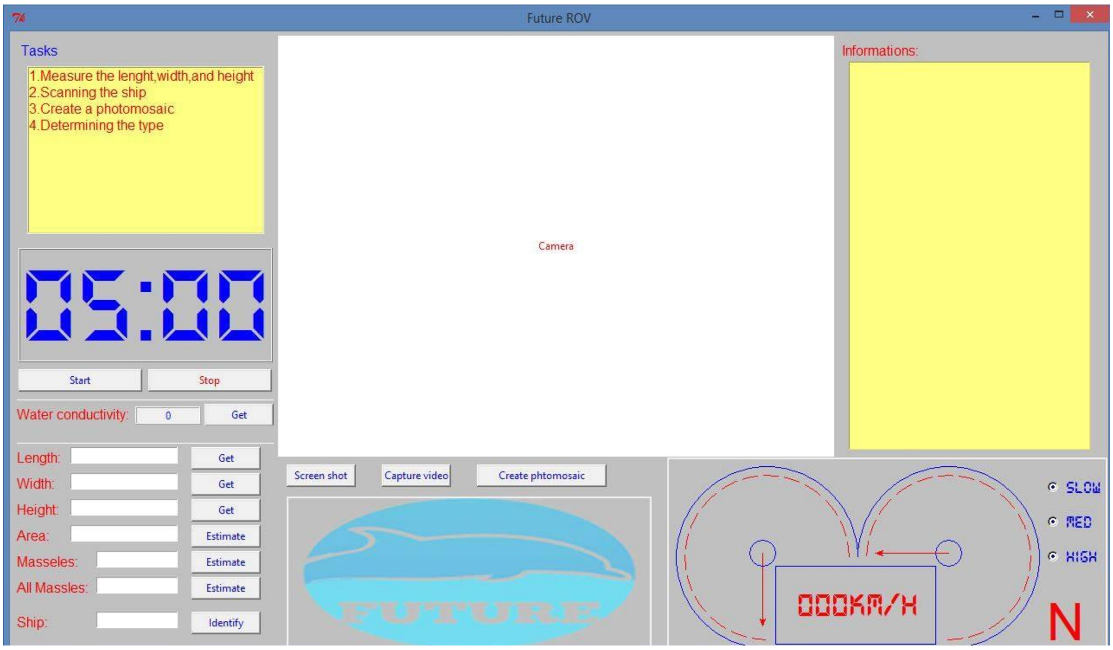


Figure 18 - GUI

Also, a tool box for image processing was developed to allow immediate task accomplishment.

The interface first initializes the Joystick, camera and Arduino connections. Then it starts the GUI, listen to joystick inputs and pilot interaction. When joystick event is triggered, the program constructs a message with specific protocol which contains the commands to Arduino. After that, it encapsulates it in specific header and sends it through the Arduino COM port.

We used Python 2.7 as the main and only programming language.

Python is an open source, easy to use and a learn programming language with a large number of supporting libraries. We used Pygame library to communicate with the joystick, Pyserial to communicate with Arduino, and OpenCV to display USB WebCam video stream and do image processing.

Payloads tools

A. Task 1

In this task, Willy is supposed to survey a shipwreck, measure its dimensions, take photos of 3 targets, construct a photomosaic of the shipwreck and identify it.

This task depends excessively on a good camera. We used A4Tech 1080 Full-HD WebCam for this task. It is powered through USB cable and transmits video streams via the USB cable to the host on board. To measure the dimensions of the shipwreck, we used 2 red laser pointers at the sides of the ROV with a known distance between them to make a reference for the camera when it captures a photo showing the two laser points (which have known distance in between) and the object we want to measure on the same plan. Let the true distance between the two laser pointers be X, the number of pixels between the two points be Y, and the number of pixels between the two points of the object to be measured be Z, then:

$$\frac{X}{Y} = \frac{?}{Z}$$

'?' is the true length of the required object.

In this task, we have to use a manipulator to lift a ceramic plate with the ship building date stuck on.

We designed our own manipulator which consists of the following parts:

i. Polyethylene axe which has an internal screw (5 cm hole) attached to the screw axe of a motor with a gearbox.

Figure 19 - Polyethylene axe with internal screw

ii. a support for the three jaws that consists of two parts. The 1st part is a polyethylene screw axe aligned with the 1st main axe and the jaws support which is cut with CNC machines.

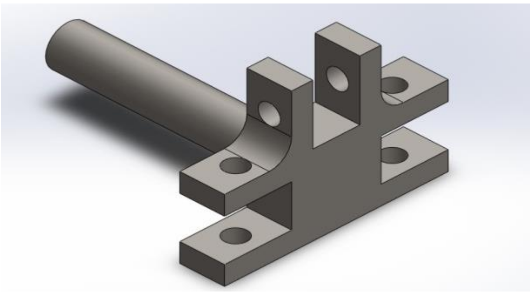


Figure 20 - 3 jaws Support

iii. The whole robotic arm support which is fixed to the ROV and has another part just like the jaws support to create the desired motion of the jaws.

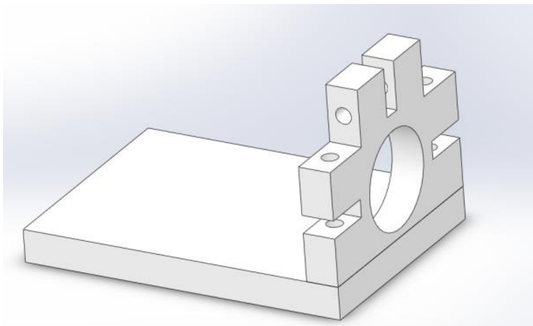


Figure 21 - mounting base

iv. Three links that attach the three jaws to the robotic arm support. Now the jaws are fixed from one point (connection between links and jaws) and moving from another point (the connection between the jaws and jaws support) this mechanism clearly converts the linear motion of the screw axe to rotational motion that makes the jaws open and close.

Figure 22 - Link

v. The jaws which are made from polyethylene supported with steel links and are cut with the help of CNC machines as shown in the figure.

And with assembling all these five parts we get the robotic arm which works mainly on a mechanism that converts linear motion to rotational motion and can produce a huge torque with the help of the gearbox also the screw mechanism make the arm self-locking so whatever the load is, the only driver of the mechanism is the motor and not the load in any case.

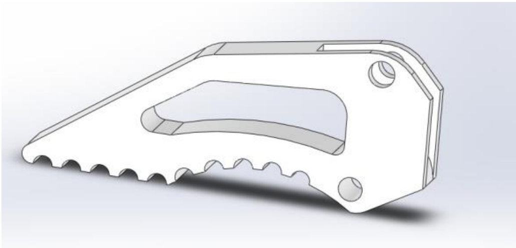


Figure 23 - Jaw

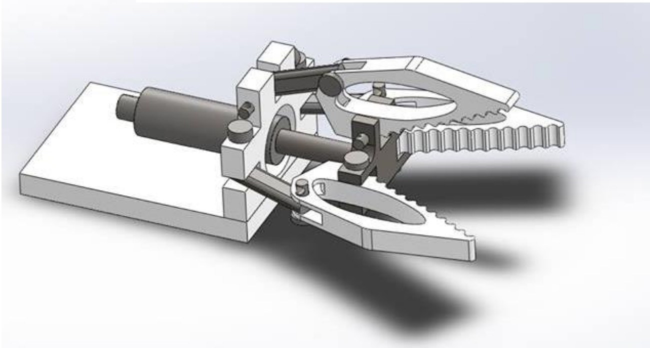


Figure 24 - Robotic Arm

B. Task 2:

In this task, we are supposed to deploy a conductivity sensor that measures the conductivity of saline water. Also, we have to retrieve an agar sample from a cup. Finally, we have to remove sensor string and deploy a new one.

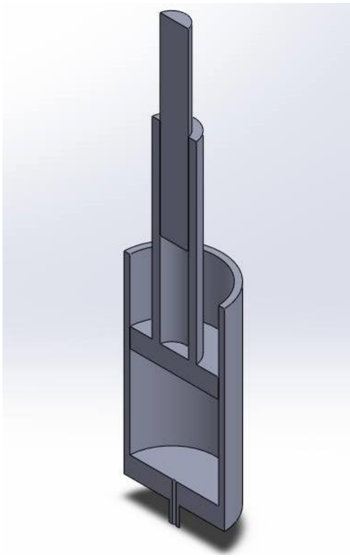


Figure 25 - Section view of the device

We designed and implemented a special conductivity sensor. The main idea is that; if we put two strips of metal in an electrolyte and expose them to a voltage difference; current will flow in the system. The conductivity is the reciprocal of resistance. So, if we can measure the current with the voltage known, we will be able to calculate the resistance; consequently, the conductivity. A circuit was designed to change the output current to voltage so that it can be fed to Arduino, that can transmit the values to the host PC using serial communication.

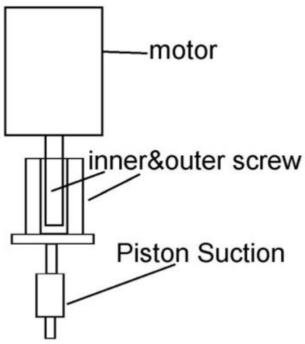


Figure 26 - illustrative diagram of the device

The main concept of the suction process is to make a pressure difference between the sample and a scaled container with a piston.

The piston moves with a motor-screw mechanism that converts the rotational motion of the motor to linear motion that pushes and pulls the piston to suck a specific amount of the sample. We used the front and the bottom arms to manipulate objects, such as the sensor string that should be replaced.

C. Task 3

In this task, we should retrieve some objects from pool bed including, plastic bottle, PVC bottle, debris string and an anchor.

The objects will be griped and taken to surface using the front manipulator. For the heavy anchor, the bottom arm will grip it and the 4 thrusters will be helping to lift the anchor up.

Challenges

Despite all the problems that were encountered and the troubleshooting that was required, as a team and after 3 months of hard work and dedication we were finally able to produce our first ROV (Willy) and today we proudly introduce it to the world. Valuable experience was gained while designing the ROV. With an entirely development team, Future opted to use a simple mechanical relay-based control scheme. This gave insight towards the overall engineering process and will be useful in future scheme endeavors.

One of the most challenging problems we've encountered was the operation of the navigation mechanism. Although it is quite simple, it was the first time that we try to waterproof a servo motor. It is not an easy job. Also, mounting the components at their positions was very sensitive. Any difference in length or depth could make a problem. We overcame this problem by trying multiple times to put an accurate design, take care at fabrication process and use the right tools.

Lessons Learned

We learned that; when you build something, accurate design and careful calculations are inevitable. It saves time, money and effort. In our journey in this competition, we made many mistakes all because we lacked of good design that takes care of details and future possibilities. We managed to build our ROV properly only when we put a good design, made careful calculations, use simulation software (like SolidWorks) and consider what will happen in assembly process. We also learned that parallel work is better than serial. When we distribute our work on all team members, we can finish more work at the same time. We learned that the spirit of the team is the most important thing at all as well. If the team members don't go along with each other, nothing will be done.

Future Improvements

This year we used polyethylene in almost everything. This is quite good because it is inexpensive and durable. However, some parts of the ROV system needs to be made with other material; such as Aluminum. Aluminum thruster housings are our next choice, as it can dissipate heat faster and do as heat sink. We also plan to design our own propellers. We need to replace our motors with identified ones. Brushless motors are good choice and may be considered.

Reflections

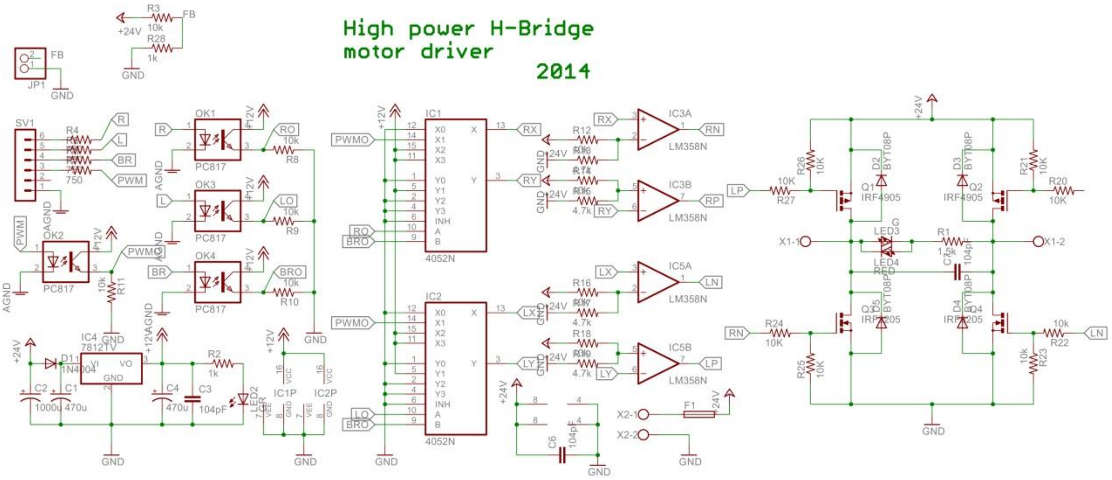
MATE ROV competition is a very unique experience. It gathers all these engineers from different departments and interests to do only one project. This is the case in real life, so it gives us a future experience that cannot exist in another competition. Not only technical experience, but also soft skills such as project management and team work. We all agree that this competition has raised our potentials and perspective greatly. So, thanks to MATE, thanks to Hadath.

Acknowledgment

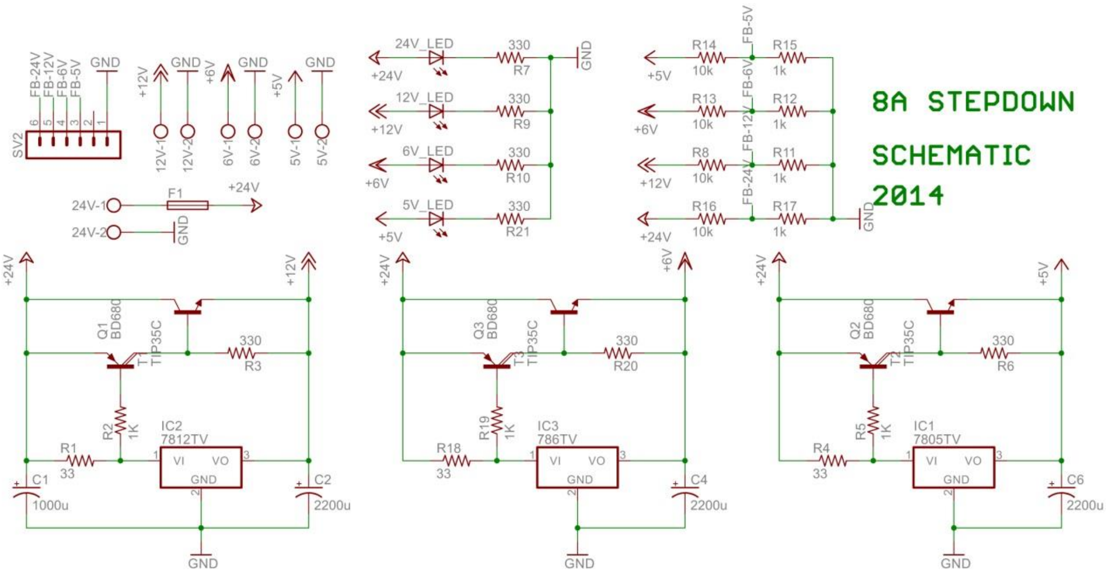
Special thanks to Eng. Tarek Heggy for his generous contribution to our team.

Also, we would like to thank Eng. Amr Mohammed Always for his help and support all the way. We cannot say how grateful we are for Eng. Sameh Galal for his always support and help.

Appendix A.



Appendix B.



Appendix C.