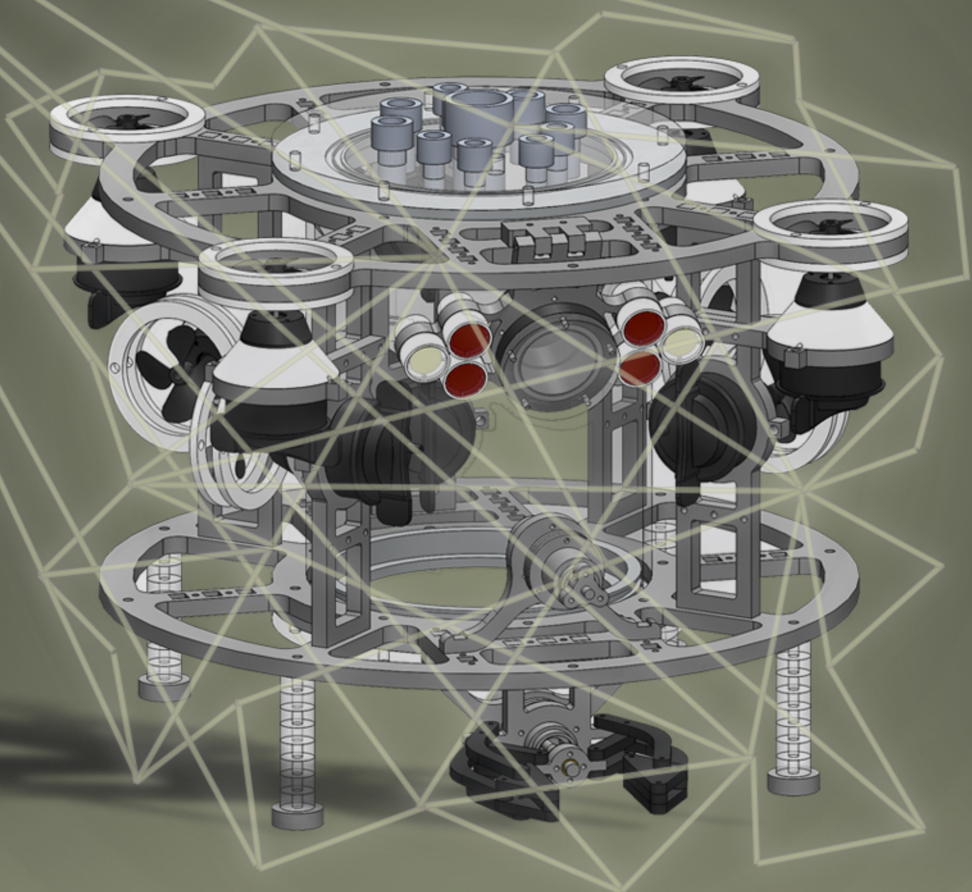
INVICTUS

MATE 2017 International Competition

EXPLORER Class

TECHNICAL REPORT



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ABSTRACT

The port of Los Angeles and Long Beach are on a transformative journey. They plan to significantly lower the cost of maritime goods by transporting them to and from ships using Hyperloop tunnels, repair their renowned light show fountain and survey the ocean's floor from polluted sediments and risky containers. To achieve these goals, they are in need for a Remotely Operated Vehicle that can operate in the busiest port complex in the United States.

Invictus is here to answer the port's call. The company was founded two years ago with a mission to provide the industrial and research sectors with low-cost high-quality ROVs. Our company comprises of passionate makers from the Mechanical, Electronics and Computer Engineering departments. With two ROVs under our belt, our newest ROV, *Eddy* is our best yet. *Eddy* was especially designed to maneuver with great speed and ease in the small port area. It has an acrylic electronics housing and 10 high quality Johnson bilge pump motors. Our chassis was manufactured using various manufacturing techniques such as CNC milling, Laser cutting, 3D-printing and electroplating.

This report illustrates how the company designed and built *Eddy* to be able to efficiently achieve the required tasks.

Invictus 2017 company group photo

TABLE OF CONTENTS

ABSTRACT 2
TABLE OF CONTENTS 3
DESIGN RATIONALE 4
- Design Process 4
- Design Evolution 4
- Mechanical Design 4
- Insulation Housings 6
- Electronics Housing 6
- Electrical Design 8
- Software and Control 11
- Mission-Specific Tools 12

TESTING & TROUBLESHOOTING 14
SAFETY 14
LOGISTICS 15
- Company Structure and Teamwork 15
- Project Management 16
- Budget and Project Costing 17

CHALLENGES 19
LESSONS LEARNED 20
REFLECTIONS 20
FUTURE IMPROVEMENTS 21
ACKNOWLEDGMENTS 21
REFERENCES 22
APPENDICES 23
- Appendix A 23
- Appendix B 24
- Appendix C 25

DESIGN RATIONALE

Design Process

Our company put a number of factors in mind when approaching the design process. The fact that our vehicle is set to operate in a busy port where space and maneuverability are limited called for a compact, highly hydrodynamic design.

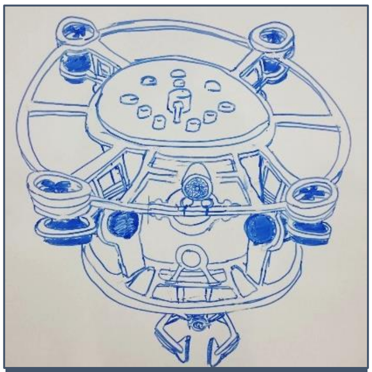


Figure 1 - Free hand whiteboard sketch of Eddy

Another factor that heavily influences our company's designs is our mission to provide our customers with cheap and efficient ROVs. Hence, heavy consideration was paid to the available materials in the market and the different manufacturing techniques available in our locality.

Design Evolution

Figure 2 - 3D CAD of Eddy using SolidWorks

For our first step, our company considered last year's design, preserved its lightweight, compact and hydrodynamic nature, evaluated its weaknesses and modified the design accordingly. Consequently, our newest ROV, *Eddy* preserves our older ROV's shape but features a number of key changes to greatly boost performance.

To help the company's different departments easily view the design and suggest any beneficial modifications, a computer aided design (CAD) was created using SolidWorks and viewed at a company-wide meeting, where members of the company's different teams voiced their opinions and suggested improvements. Finally, the designs were converted into Drawing Exchange Format (DXF) and Standard Tessellation Language (STL) files in order to be sent to our CNC router, laser cutter and 3D printer.

Mechanical Design

Frame

Most ROVs feature a horizontal electronics housing enclosed in a rectangular frame, which does not fare well when measured using a circle. The rectangular design means the vehicle has to be too small and compact, which leaves a lot of space unused and makes working on the ROV quite difficult. Our frame, however, features a vertical acrylic tube that is mechanically sealed and bounded by two PVC rings. This enables us to make use of every centimeter inside the entailed circular limit.

The links that connect the top and bottom rings house our motors, cameras and different mission tools. Using the table of fits and tolerances, we were able to create parts that easily but robustly fit into each other, eliminating the need for an inventory of nuts and bolts.

Thrusters

Our vehicle employs 10 Johnson bilge pump motors. This was extremely convenient – and much cheaper than buying specialized ROV thrusters such as the $140 BlueRovotics T100 thruster – as they are designed to be submerged. We simply replaced its impeller with 4-bladed propellers – their detailed specifications are shown in Table 1 –. This is the same number of thrusters our old vehicle used; 4 heaving, 4 surging and 2 boosting motors. However, this year, our company chose to use Johnson bilge pump thrusters as they provide superior thrust than their predecessors.

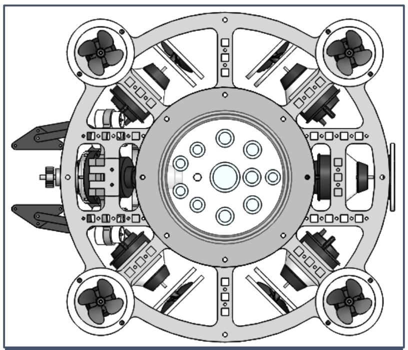


Figure 3 - Thrusters' Positioning

No. of Blades	4
Diameter	60mm
Hub Diameter	10mm
Blade Area Ratio (Proj.)	0.65
Hub Length	15mm
Rake Angle	7.5°
Skew Angle	13°
Pitch (at 0.7R)	76mm
Pitch Diameter Ratio	1.2

Table 1 - Specifications of the chosen Propeller

As shown in Figure 3, our surging motors are positioned with a 45° vectored layout. These motors, along with 2 booster motors propel the ROV in the horizontal direction. For vertical motion, our heaving thrusters are laid out differently than last year's ROV to increase hydrodynamic performance. As opposed to last year, the 4 motors have been pushed further away from the center of the vehicle, to decrease drag and increase their output thrust.


Figure 4 - 4-Bladed propeller

Buoyancy

Eddy relies on the acrylic electronics housing as its central piece for providing buoyancy. Our vehicle occupies a volume of approximately 14,500 cm^3, which generates a floating force of 14.5 Kg-force. Since our vehicle weighs nearly 13.8 Kg, we were in need of adding weights that sum up to about 700g to make our vehicle neutrally buoyant. Moreover, the PVC rings in our frame have a dozen places where weights and foam can be added to readily adjust the vehicle's buoyancy.

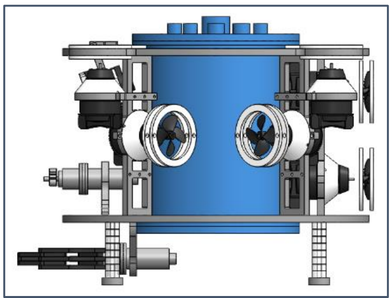


Figure 5 - The vertical insulation box

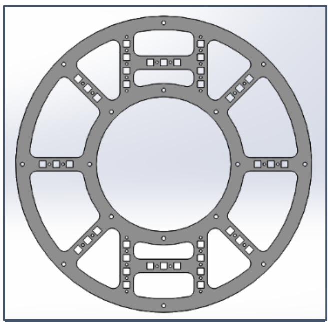


Figure 6 - The lower PVC ring

Insulation Housings

Camera

Due to the fact that high quality waterproof cameras are costly, our company was faced with an interesting build/buy decision; spend a large percentage of the firm's financial resources on one, or buy an HD security camera and seal it ourselves. We chose to use PA6G Artilon to house the camera and a transparent 8mm thick acrylic sheet as a lens cover.

Figure 7 - Sealed camera and LEDs

Red and White LEDs

A cylindrical part was 3D-printed to waterproof our different LEDs which are used extensively in this year's tasks. We designed the cylindrical part such that the LED's face be covered by a thin acrylic sheet, and its back sealed by pouring clear epoxy.

Gripper's DC Motor

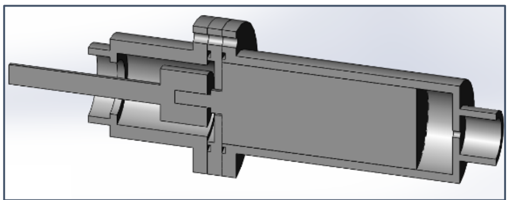


Figure 9 - CAD model of the sealed motor

Figure 8 – Mechanical spring shaft seal

To design a reliable gripper, we were in need of deciding on a reliable submersible motor that is capable of gripping the different objects robustly. Since the torque generated by a bilge pump wasn't enough for our gripper's design it was a must to seal a high torque geared DC motor. We chose an 8.8 kg.cm torque and 250 rpm speed DC motor to rotate the lead screw controlling our gripper. The motor is sealed in an aluminum housing, using mechanical single-spring shaft seal – as shown in Figure 8 – to waterproof the rotary shaft of the motor.

Electronics Housing

At the heart of our vehicle, a transparent cylinder – reminiscent of the Hyperloop – houses our electronics. It has a 200mm external diameter, 5mm wall thickness, and 270mm length. Acrylic was chosen as it is transparent and lightweight.

Two Aluminum flanges enclose our vertical acrylic cylinder. Each one has 2 radial grooves that house O-rings which are responsible for the sealing between the flanges and the acrylic tube, and another 2 surface O-rings that seal between the flanges and the acrylic endcaps.

Two Acrylic endcaps complete the mechanical sealing of our Electronics housing. The bottom one is void of cables.

Figure 10 – Assembled Electronics Housing

The top carries all the cables penetrators, both are cut out of a 10mm thick Acrylic sheet using a CNC laser cutting machine. A surface O-ring was used to seal on the Endcap surface, and Loctite Marine Epoxy was cast to seal inside the penetrator and around the cable.

The features of our new insulation box are:

1- **Durable:**

Aluminum was selected for the flanges because of its low density and high rigidity, while PMMA Acrylic was used to make the tube and the endcaps as it provides durability and high solidity. Acrylic happens to have high hardness whilst being lightweight, a highly desirable trait. The tube and endcaps are sealed together using O-rings of Buna-N/NBR rubber, O-rings are installed in suitable grooves to ensure totally mechanical sealing.

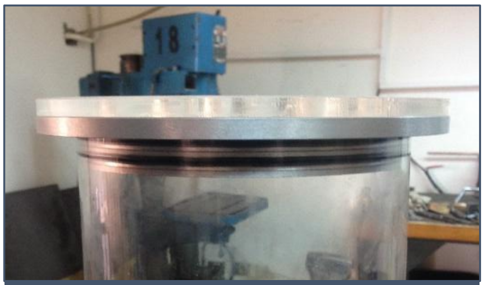


Figure 11 – O-rings sealing

2- **Modular:**

Last year, our company encountered a considerable amount of trouble whenever we wanted to check on or replace any cables sealed inside the insulation cap. It was too difficult to modify the insulation system as we used Scotch-cast to seal our cables. As a result, we decided on a modular insulation system that would help us easily modify anything in the control box.

Figure 12 - Cables Penetrators

Eddy's insulation system consists of: Acrylic Tube, Sealing Aluminum Flanges, Acrylic Endcaps and Aluminum Cable Penetrators; These components achieve a complete mechanical sealing on the electronics housing.

3- **Transparent:**

Our insulation system employs transparent PMMA Acrylic materials in two locations: The Acrylic Tube and Endcaps, which is a key factor, as it enables us to monitor the electronic components inside, as a means of debugging or detecting electronic component failure.

4- **Maintainable:**

In order to be able to test the effectiveness of our insulation system, we plugged a metal tyre valve in our Acrylic Endcap. This enabled us to readily compress air into, or evacuate out of the insulation box and monitor the pressure gauge, to ensure that our box is totally sealed, and identify the source of any leakage.

Figure 13 - Tyre Valve

Electrical Design

Tether

The tether was designed to be cost effective and reliable. It consists of one pair of 3 AWG wires (6 mm) for main power, three 75 ohm coaxial cables for three real time camera feeds and a CAT 6 Ethernet cable with molded insulator for communication and protection against water ingress. Also a pair of 12 AWG (2 mm) wires is used for powering the control station. Wrapped along our tether are lengths of hydrophobic closed cell foam caulking that adds enough buoyancy to the tether for improved maneuverability.

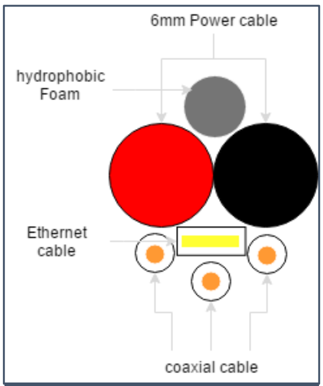


Figure 14 - Customized Tether

Topside Electronics

Our control system - as shown in Figure 15 - utilizes four Arduino boards known as MCU 1,2,3,4. It begins with a Logitech 3D Pro Extreme USB joystick, chosen for its ergonomic design, versatile functionality, and its intuitive control. MCU1 reads the joystick data through a USB host controller on a USB host shield (a stackable board system for the Arduino hardware). It is then sent over a serial connection to MCU2 which is dedicated to processing the control mixing algorithms and outputting raw thruster throttle and direction data. It also outputs data for controlling the lighting system, auxiliary relay and both manipulators. Output data is sent to the ROV over a serial connection. MCU2 also receives sensor data from the ROV to be used for feedback for closed-loop control in pilot aiding functions. Received data including the Bluetooth stream is sent to MCU3 for generating a PAL composite video signal to be displayed on the split screen.

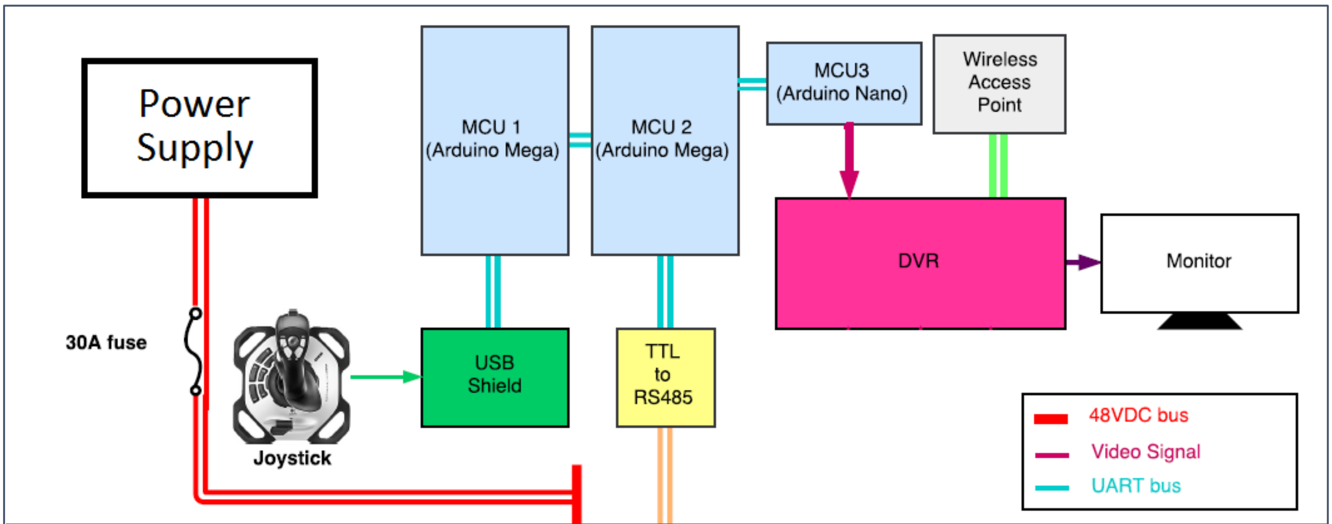


Figure 15 - Topside Electronics Interconnection Diagram

All serial data communications are packet based with checksum error tracking for maximum reliability while maintaining simplicity. All serial connections run at a baud rate of 230400 bps for fast transmissions and minimum data loss. Serial communication between the control station and the ROV is a point to point connection utilizing the RS485 physical layer which utilizes the twisted pairs in the Ethernet cable of the tether for noise and interference immunity and the fact that it uses a current loop signaling scheme allows for reliable full duplex communication up to 1200 meters. The digital video recorder "DVR" is connected to a Wi-Fi access point installed inside the station providing remote monitoring of the cameras' feeds to record and analyze the video stream. Since the DVR housing has extra space, we placed all the station boards inside it. Resulting in a compact, robust control station. The output multiplexed video signal is displayed on the monitor.

Figure 16 - DVR casing before modifications

Figure 17 - DVR casing after adding station boards inside

Figure 18 – Camera feeds

Onboard Electronics

We designed a modular tray system for the onboard electronics where there are three trays in our system, top to bottom, uniboard PCB tray, motor control tray and the power conversion and distribution tray.

We use a custom-made printed circuit board "PCB" for the uniboard that connects the onboard electronics together. The uniboard concept has proved very reliable with vibrations and rough handling from last years' experience.

Figure 19 - Onboard

Figure 20 - DC Converters fixation and wiring at the lower tray

The 48V input power connects to the power conversion and distribution tray through polarized terminal connectors (rated at 50 A and 450 V) for reverse polarity connection. Isolated metal screw terminal blocks distribute the 48V input power to four Murata industrial isolated DC-DC converters - as shown in Figure 20 -, three ¼ bricks capable of delivering 12V 35A each for the motors and one 1/8 brick capable of providing 12V 10A for the rest of the electronics.

In order to be specify the requirements of the DC to DC conversion system, the control department calculated our vehicle's power budget - as shown in Table 2 -. The maximum possible number of thrusters operated at any given time is hardcoded to be 6 thrusters, those consume 720 Watts. The total power consumed by the electronics boards is 71 Watts.

Device	Voltage (V)	Max. Current (A)	Max. Power (W)	Quantity	Total Max. Power (W)
Thrusters	12	10	120	6	720
Geared Motors	12	5	60	2	120
Cameras	12	1	12	3	36
LEDs	12	0.33	4	7	28
Control Boards	5	0.35	1.75	4	7

Table 2 – Power Budget

Although these converters cost about four times as the RCNUN converters, they are much lighter and less bulky with increased efficiency and they can be connected to share the same load allowing the full current capacity of each converter to be available to the system unlike the RCNUN converter. The total cost per weight for the RCNUN converter is almost five times as much as the Murata DC-DC converters. All three 35A DC-DC converters are connected in droop load sharing mode with remote feedback wires to compensate for voltage drops across the wires. The converters operate at a nominal efficiency of 95.2%, which means that they only require passive cooling heatsinks. The 35A converters can be monitored and configured over PMbus if required.

	RCNUN (RC481220)	Murata (DBQ0135V2)
Output Current	20 Amps	35 Amps
Efficiency	91%	95.2%
PMBus	✗	✓
Load Sharing	✗	✓
Dimensions	74 × 74 × 32 mm	58.4 × 36.8 × 12.2 mm
Weight	335g	66.8g
Total Weight	335×6 = 2.01 Kg	66.8×3 = 0.2 Kg
Cost	$20	$86
Total Cost	20x6 = $120	86x3 = $258
Cost × Weight	241.2	51.6

Table 3 - Comparison between past and current DC Converters

Table 3 compares the most abundant DC-DC converters in the market with the Murata DC-DC converters we currently use.

For continuing with the modularity of the system, we made kits for each converter which includes 3.5 mm bullet connectors soldered to the inputs and outputs and 5 mm acrylic plates for adding secure mounting points.

The second tray holds a custom-made vertical PCB that has female connectors that the H-bridge DC motor driver boards plug into and it connects to the uniboard through four 6-pin data cables. We use six 10A dual-channel H-bridge driver boards with high current MOSFET drivers allowing for short switching times and thus high efficiency and low power dissipation to the extent that no cooling heatsinks are required at all. They are wired so each board controls two motors that are less likely to operate at the same time to minimize stresses on the connecting wires and the PCB traces. Each H-bridge driver board has LEDs and testing buttons for easier debugging and testing.

Figure 21 - The custom made board that carries motor drivers

The top tray has the uniboard which holds the RS485 transceiver module, an Arduino MEGA 2560 (MCU4), a DPDT relay and a 10 DOF inertial measurement unit "IMU" board. It also has 12V connectors to power the cameras, control station and lights and connectors for the Bluetooth transceiver, external pressure sensor, H-bridge drivers and a two-channel relay module for controlling the lights. The uniboard also has two indicator LEDs that we use to indicate communication errors.

MCU4 receives thruster throttle and direction and passes them to a soft start function to avoid tripping the overcurrent protection in the converters and provide smooth operation. Upon startup, it configures the IMU's internal digital motion processor "DMP" to access the connected 3-axis digital compass and to apply a factory tuned Kalman filter so it is ready to directly read pitch and roll angles and uses them to compensate the compass for tilt and output a corrected heading. It also reads the pressure and temperature sensors and the Bluetooth module. Feedback data is then assembled into a packet that includes a checksum and is transferred to the control station.

All connections are color coded and power delivery connectors are polarized, see Appendix A for wiring color map. Motors are connected to their respective H-bridge drivers with XT60 connectors for robustness and cameras are connected to their respective coaxial cables with BNC connectors. An Ethernet plug connects the Ethernet cable to the RS485 transceiver board, only two twisted pairs are used and the other two are redundant. 2.1 mm barrel connectors deliver power to the LED lights, cameras and control station.

Figure 22 - XT60 Connectors

Video System

As shown in the Figure 23, Camera feeds including two analog high definition “AHD cameras” and one analog 700TVL camera are fed into the DVR for displaying all cameras and the data monitor MCU3 on a four by four split screen for a better piloting experience.

We use separate cables, one for each camera instead of multiplexing all cameras on one cable for redundancy. We chose to receive the video signal through the analog cables directly as it has very little latency compared to sending the video over an Ethernet connection.

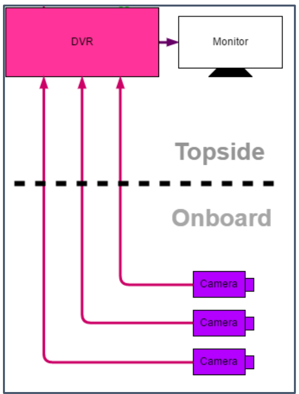


Figure 23 - Video Signals Interconnection Diagram

Software and Control

We chose Arduino boards as they are an open source AVR microcontroller-based development platforms that are easy to program in C++ with a very large community of developers and DIYers and a very affordable price tag.

We use an open source joystick library to read joystick button states and axes values on a dedicated Arduino (MCU1) so it can handle its interrupts without disrupting the rest of the system and introducing unnecessary delays. MCU1 interfaces with a USB host controller over serial peripheral interface “SPI” connection. Another library called Easy Transfer “ET” is used to assemble the data into a packet and send it to MCU2. Included in packet are two variables, one of them is a Boolean number that toggles with every transmission and the other one is the string “ROV”, used for tracking communication errors. All communication errors are detecting by checking for the string and the change of the Boolean variable and if they are missing for 100 transmissions then the system is halted until the communication error is resolved. This method of communication error tracking along with the checksum checks the ET library provides to reject corrupt data proved to be bulletproof so it’s used in the whole system.

MCU2 is responsible for the communication to MCU4 on the ROV using the same ET library. The USB joystick data is processed to extract each axis value. Each axis gets a specific amount of dead zone assigned to it to create a neutral position in the joystick's physical center. The X, Y and twist axes are used in 4 equations, the output of each corresponds to the speed and direction of one of the surging motors to provide a resultant thrust vector in the all directions on the XY plane.

The point of view "POV" hat on top of the joystick is used to command the ROV to pitch and roll and the slider axis is used to control the overall speed of the rolling and pitching actions by controlling the speed of the heaving thrusters. Two buttons in accordance with the slider axis control the diving and surfacing action through the heaving thrusters too. The trigger button is used to activate the two extra boosting thrusters for the forward motion. Two buttons control each manipulator and another two control the lights. For all motor functions, a soft acceleration function is implemented to start the motor from full stop or accelerate it from a previously achieved speed to avoid tripping the overcurrent protection of the DC-DC converters by the inrush currents.

The pilot aiding functions are implemented on MCU4. When the connection is lost, all moving parts are shut down immediately until the connection is re-established. The processed thruster data is used to set the thruster motor speed and direction as well as set the LED lights' states and control the manipulator. MCU4 uses inter integrated circuit "I^2C" serial bus to connect to the on board sensors including the 10 DOF IMU, internal pressure and temperature sensors and external pressure and temperature sensors. It also connects to the Bluetooth module with a serial communication.

Data sent back from the ROV gets passed through to MCU3 that uses the TVout library to generate a PAL video signal to display that data on one of the four quadrants of the DVR display. The data is laid out in an easy to read way on the screen and a heading main direction (N, NE, E, SE, S, SW, W, NW) is displayed too.

Mission-Specific Tools

Task 1: Commerce: Hyperloop Construction

Gripper

To be able to grab items from the pool bed with ease, our ROV features a gripper in the bottom of our vehicle. Made up of PVC parts that are readily bolted together and powered by a mechanically-sealed DC geared motor.

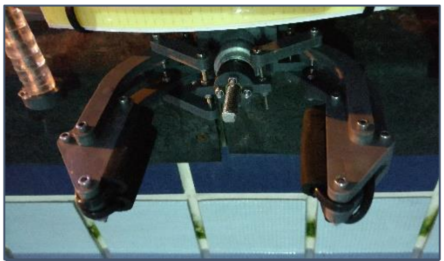


Figure 24 – Gripper

Vision System

Inserting the rebar reinforcement rods into the baseplate dictates a vision system that allows the pilot to view the gripper and the object it's holding, a view that includes the gripper with respect to different objects horizontally and another, vertically.

Task 2: Entertainment: Light and Water Show Maintenance

Valve Rotator

To quickly accomplish one of the main steps of task 2, our vehicle includes a separate motor with a single nail; to be inserted into the valve and readily rotate it.

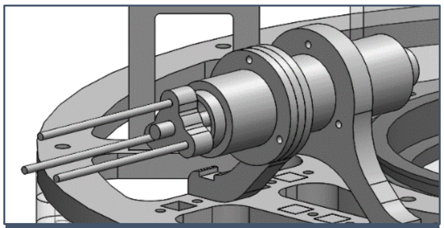


Figure 25 - Valve Opener

Task 3: Health: Environmental Cleanup

Simulated Raman Spectrometer

To shine a red light on the agar, our company approached a simplistic design; a white LED with a red-colored transparent acrylic cover.

Agar Extractor

Our company brainstormed multiple ideas for extracting Agar. We wanted a simple mechanism that would suck the Agar out and then automatically lock. Finally, the best answer proved to be the simplest one. We simply cut a PVC tube into a cylinder with a volume of 300ml. We insulated a safety valve at the other end of the cylinder. Our vehicle inserts the extractor into the cup, where the Agar is sucked inside, displacing the water. No more water can enter or Agar can escape due to the action of the safety valve.

Figure 26 - Agar Extractor

Task 4: Safety: Risk Mitigation

LED Strip

To ensure that our vehicle shines a substantial amount of light on the light sensor coupled with the Bluetooth module, we added 2 white LEDs housed in a 3D printed part and LED strip fixed on the lower ring of the frame.

Bluetooth Receiver

Our company created 3D-printed cylindrical housing with two internal rails for the Bluetooth module to rest upon. We then poured Epoxy till it filled up the entire cylinder. We then tested our housing underwater several times. It performed nominally, extracting data from a master Bluetooth module we sealed in the same manner and placed underwater.

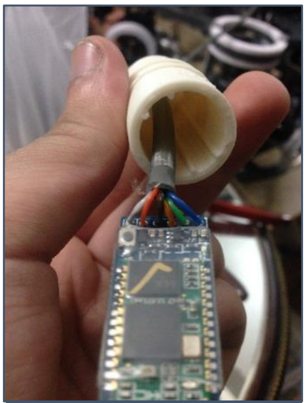


Figure 27 - Bluetooth module sealing procedure

TESTING & TROUBLESHOOTING

Our electronics housing has an array of troubleshooting and debugging techniques; our H-bridges have 3 indicator LEDs for each motor that display the current status. The fact that our electronics housing is transparent allows us to readily change our code and test it without moving a single motor or removing the aluminum end caps.

As shown in Table 4, the first LED shows whether or not it is powered up. The remaining two light up to indicate the current given direction. Also, the illumination intensity of the LEDs varies according to the PWM signal applied.

Power LED	CW Direction LED	CCW Direction LED	Status
OFF	OFF	OFF	H-bridge OFF
ON	OFF	OFF	H-bridge ON, No PWM signal
ON	ON	OFF	CW rotation of motors
ON	OFF	ON	CCW rotation of motors

Table 4 – Debugging H-Bridge LEDs states

To help us debug the crucial problem of communication between our Control station and the ROV. Instead of constantly connecting all Arduino boards to a single laptop and monitoring the feed, our custom-made printed circuit board (PCB) has two LEDs that light up in three conditions, as shown in Table 5.

Green LED	Yellow LED	Status
ON	OFF	Initializing
OFF	ON	Data packet from Control station is corrupted
ON	ON	No communication with ROV

Table 5 - Communication debugging LEDs states

SAFETY

Safety Philosophy

"Human over machine", at Invictus safety comes first and is always taken very seriously. The company always makes sure that members follow safety protocols and that they work safely in all environments. Safety instructions are always considered during designing, building, handling and testing of the ROV.

Figure 28 - Mechanical team member Abdallah

Lab Safety Protocols

Specific safety protocols are implemented while working in our labs. Appropriate safety equipment, such as safety goggles, ear protection, gloves and footwear were used when handling power tools. Using fixed tools instead of moving ones like drilling and cutting tools to avoid any injuries.

A ventilation fan was also used when soldering, removing the particulate matter and fumes from the lab, keeping the air in the lab cleaner and safer for the company members.

Safety in Handling the ROV

For the safety of our crewmembers, at least two must be present when lifting or transporting the ROV and must be wearing safety gloves and footwear. In addition, all members must have their hands off the ROV before power is applied. Most importantly, a safety checklist – Refer to Appendix C – must be rigorously followed during every water test to ensure both the safety of crewmembers and the optimal running of the system.

Safety Features

- Short circuit and overcurrent protection on all DC-DC converters and H-bridges on-board the ROV.
- Over-temperature protection on DC-DC converters, H-bridges and microcontroller boards.
- PMBus (Power Management) compliant DC-DC converters allow detailed system monitoring.
- Inrush current protection and software motor soft start and controlled acceleration.
- 30A fuse for ROV.
- Use of certified off the shelf equipment for the control station.
- Emergency stop switch.
- Polarized connectors and color coded cables for power and signal transmission across the whole system.
- Isolated DC-DC converters.
- Isolated RS-485 communication interface cards.
- AC powered control station for complete system isolation.
- Sensor and system status display on the control station, includes temperatures and pressures.
- Software lock out on all moving parts when connection is lost to prevent any injuries until control is regained.
- Curved, smooth edges on the ROV.
- Thruster shrouds.
- Lights were added for increased visibility at night.
- Warning labels on moving parts.
- Warning labels on electrical systems.
- Cap nuts used on exposed bolt threads.

LOGISTICS

Company Structure and Teamwork

Invictus holds frequent meetings on a strategic and operational levels. Strategic meetings are held by the CEO, CFO and the different team leaders to decide where the company stands on a financial and technical level by comparing the spending with the project costing and the current progress with the Gantt chart. Operational meetings are held by the team leaders and entail conveying and distributing the operational objectives as S.M.A.R.T. tasks with deadlines to the company employees.

Any technical problems that arose and would signal deviations from the plan were discussed between the employees and their team leader until an optimum solution was agreed upon. Project crashing techniques such as allocating more manpower and resources were employed to help the firm adhere to schedule.

The company is split into two departments. A control department and a mechanical one, each employee's skills and experience are assessed and the employee is assigned to a specific team. Cross-team work was facilitated by the fact that our employees have worked in various projects and attained practical knowledge beyond the scope of their major.

Project Management

Our company met after the 2016 regional competition and decided to preserve our vehicle's design philosophy having won 9th place. We laid out a Gantt chart that would feature a more pressed schedule for the design process -in order to finish the vehicle early- and have more time for testing, debugging and modification. Consequently, the company planned to dedicate a minimum of 200 hours for testing and training and actually clocked in 360 over a period of 5 weeks as illustrated in the Gantt chart.

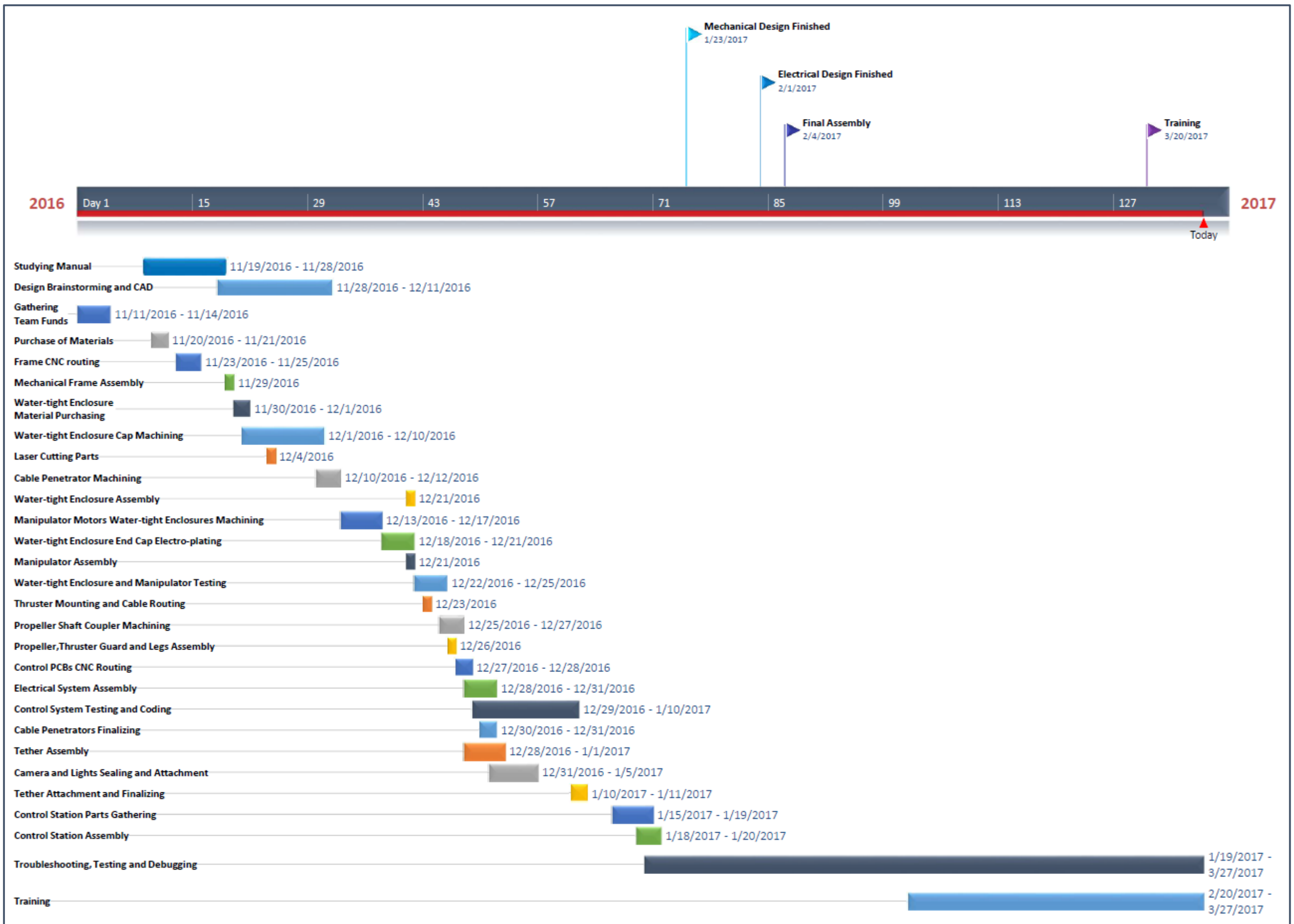


Figure 29 - Gantt Chart that illustrates tasks breakdown and timeline

Budget and Project Costing

Our company proposed a budget for our new vehicle based on a number of factors. We calculated the total amount spent on our 2016 vehicle ($ 1,200.00), reviewed the competition manual and added the amount of money required to prototype and manufacture new mission-specific tools. Next, we estimated the income generated from selling some parts $ 500.00, and accounted for the fact that the winner of the Regional competition is financially rewarded by our university, The Arab Academy for Science and Technology. Our university would pledge a total amount of $ 1,000.00 for vehicle development as well as $ 6,000.00 to cover our travel and accommodation expenses. Our team planned the design and build process accordingly.

Invictus is set to represent AASTMT in the International competition. Consequently, our university provided us with the aforementioned funds to develop our vehicle and cover our travel costs. We were able to sell old components for a total of $ 650.00. In conclusion, this year's vehicle costed a total of ($ 1,866.20) which is 89% of our proposed vehicle budget. This can be attributed to the fact that our company was able to re-use multiple components from our previous vehicle.

Eddy 2017 Project Budget			
General Expenses	ROV Components	$	(1,200.00)
	Machining Costs	$	(60.00)
	CNC Cutting Costs	$	(30.00)
	3D Printing Costs	$	(30.00)
	PCB Fabrication	$	(20.00)
	Prototyping	$	(100.00)
	Tools	$	(150.00)
	Rework	$	(100.00)
	Shipping and Customs Fees	$	(150.00)
	MATE Registration Fees	$	(250.00)
Total General Expenses		**$**	**(2,090.00)**
Travel Expenses	Students' Airfare (8 members, $ 700.00 each)	$	(5,600.00)
	Accommodation	$	(4,000.00)
	SUV Car Rental	$	(500.00)
Total Travel Expenses		**$**	**(10,100.00)**
Grand Total Expenses		**$**	**(12,190.00)**
Income	Arab Academy for Science and Technology ROV Support	$	1,000.00
	Arab Academy for Science and Technology Travel Support	$	6,000.00
	Hamza Associates Travel Support	$	1,200.00
	Sold Components from 2016 Competition	$	500.00
	Team Members Dues (8 members, $ 450.00 each)	$	3,500.00
Total Income		**$**	**12,200.00**
Surplus / (Deficit)		**$**	**10.00**

Table 6 – Invictus 2017 Project Budget

	Item	Notes	Type	Amount	Qty.	Total
Mechanical Body	PVC Sheet	Used to build the frame	Purchased	$ 57.90	1	$ 57.90
	Acrylic Parts	Used in minor parts	Purchased	$ 12.00	1	$ 12.00
	Assembling Components	Bolts, Nuts and Zip Ties	Purchased	$ 25.00	1	$ 25.00
	CNC Router Cutting	*Done by AAST Workshops*	*Donated*	*$ 30.00*	*1*	*$ 30.00*
	Laser Cutting	---	Purchased	$ 5.00	1	$ 5.00
	Geared Motors	To actuate grippers	Purchased	$ 10.00	2	$ 20.00
	Aluminum Housings	Seals geared motors	Purchased	$ 14.50	2	$ 29.00
	O-Rings	To seal enclosures	Purchased	$ 24.75	1	$ 24.75
Thrusters	Johnson Bilge Pumps	---	Purchased	$ 28.90	10	$ 289.00
	Propellers	4 Blades, 60mm Diameter	Purchased	$ 2.30	10	$ 23.00
	Copper Rods	Used to machine couplings	Purchased	$ 8.00	1	$ 8.00
	Acrylic Guards	To guard the propellers	Purchased	$ 10.00	1	$ 10.00
	Machining for Couplings	*Done by AAST Workshops*	*Donated*	*$ 1.50*	*10*	*$ 15.00*
	Laser Cutting for Guards	---	Purchased	$ 3.50	1	$ 3.50
	3D Printed Parts	---	Purchased	$ 3.00	4	$ 12.00
Tether	Primary Power Cables	48V to the vehicle	Purchased	$ 27.00	1	$ 27.00
	Secondary Power Cables	*12V to the station*	*Re-used*	*$ 5.00*	*1*	*$ 5.00*
	Coaxial Cables	Transmitting video signals	Purchased	$ 6.50	3	$ 19.50
	Ethernet Cable	Used for RS485 signal	Purchased	$ 12.00	1	$ 12.00
	Hydrophobic Foam	To adjust its buoyancy	Purchased	$ 75.00	5	$ 375.00
Control Box	Acrylic Tube	Containing all electronics	Purchased	$ 32.00	1	$ 32.00
	Aluminum Flanges	Seals radially with the tube	Purchased	$ 15.00	2	$ 30.00
	Aluminum Penetrators	Seals the cables	Purchased	$ 2.15	13	$ 27.95
	Acrylic Caps	Carries the penetrators	Purchased	$ 18.00	1	$ 18.00
	Machining for Flanges	*Done by AAST Workshops*	*Donated*	*$ 10.00*	*2*	*$ 20.00*
	Laser Cutting for Caps	---	Purchased	$ 8.00	1	$ 8.00
Onboard Electronics	DC-DC Converters	Murata 420W Converters	Purchased	$ 86.60	3	$ 259.80
	Motor Drivers	Cytron 2-Channels Drivers	Purchased	$ 14.50	6	$ 87.00
	Arduino MEGA 2560	Controls the vehicle	Purchased	$ 23.00	1	$ 23.00
	IMU	Gets vehicle's orientation	Purchased	$ 9.80	1	$ 9.80
	Pressure Sensor	Gets vehicle's depth	Purchased	$ 21.50	1	$ 21.50
	PCB	The uniboard	Purchased	$ 12.00	1	$ 12.00
	Relays Module	*---*	*Re-used*	*$ 2.00*	*1*	*$ 2.00*
	RS485 Modules	Communication protocol	Purchased	$ 14.50	2	$ 29.00
	Wires and Connectors	---	Purchased	$ 10.00	1	$ 10.00
Cameras	Security HD Cameras	Analog High Definition	Purchased	$ 16.10	2	$ 32.20
	Waterproof Fishing Camera	*Analog Signal*	*Re-used*	*$ 34.50*	*1*	*$ 34.50*
	LED Cold White Lights	---	Purchased	$ 1.60	9	$ 14.40
	Artilon PA6 Enclosures	---	Purchased	$ 11.00	1	$ 11.00
	Acrylic Transparent Caps	---	Purchased	$ 7.00	1	$ 7.00
	Machining for Enclosures	*Done by AAST Workshops*	*Donated*	*$ 5.00*	*2*	*$ 10.00*
	Laser Cutting for Caps	---	Purchased	$ 2.00	1	$ 2.00
Piloting Station	DVR	To display cameras' feeds	Purchased	$ 36.00	1	$ 36.00
	Logitech Extreme 3D Pro	To control the vehicle	Purchased	$ 28.90	1	$ 28.90
	Arduino MEGA 2560	Controls the station	Purchased	$ 23.00	2	$ 46.00
	Arduino Nano	*Displays on-screen feedback*	*Re-used*	*$ 9.00*	*1*	*$ 9.00*
	Wi-Fi Access Point	*Transmits video wirelessly*	*Re-used*	*$ 10.00*	*1*	*$ 10.00*
	Monitor	Displays video and data	Purchased	$ 32.50	1	$ 32.50
Travel	*Airfare*	*Flight tickets for team members*	*Donated*	*$ 760.00*	*8*	*$ 6,080.00*
	Accommodation	*House rental through airbnb*	*Donated*	*$ 2,660.00*	*1*	*$ 2,660.00*
	Transportation	*SUV car rental*	*Donated*	*$ 480.00*	*1*	*$ 480.00*
	Meals	*---*	*Donated*	*$ 200.00*	*8*	*$ 1,600.00*
	Total ROV Costs			**$**		**1,866.20**
	Total Travel Costs			**$**		**10,820.00**
	GRAND TOTAL			**$**		**12,686.20**

Table 7 – Invictus 2017 Project Costing Sheet

CHALLENGES

Technical

Figure 30 - VideoRay Tether

Our previous vehicle used a VideoRay™ cable. This was extremely advantageous as it was a single, neutrally buoyant cable that carried all our power and control signals from the control station. We chose not to use it in this year's design however as our company noticed that because cables inside the VideoRay tether had a very small cross-sectional area, a huge voltage drop used to happen, resulting in inconsistent DC converter performance and poor thrusting power. Replacing the video ray with an equally lightweight and buoyant cable was challenging.

Figure 31 - Customized Tether

Our control department consulted with the mechanical at a company-wide meeting and came up with a simple solution; eliminating the voltage drop by increasing our tether's cross-sectional area and using individual wires instead of a single cable made up of multiple ones. As a result, the mechanical team designed our penetrators in-house and the control team modified last year's design and came up with the vehicle's current electrical system and software accordingly.

Non-Technical

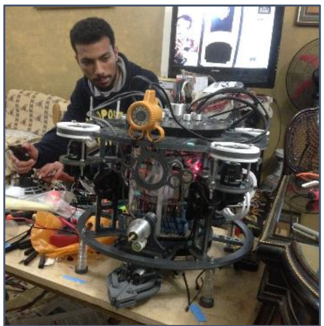


Figure 33 - Working on the ROV at Abdelrahman's Home

Testing our ROV proved especially challenging this year, as the only pool we could use for training was always reserved for our university's maritime department during mornings. This meant that we started training at night and often finished a few hours before sunrise of the following day. This proved even more inconvenient as our college campus is far away from the city, and by the time we finish training, some company members still had a distance of 22Km to travel before they are home. A company member who lived close-by, Abdelrahman Nasser, was generous enough to host anyone who was too tired to make the trip at night.

Figure 32 - Testing the ROV at midnight

LESSONS LEARNED

Technical

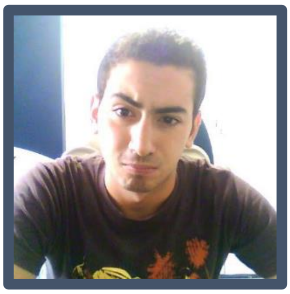
This year, our company was able to gain a new skill by trying mechanical sealing for the first time, this was especially challenging as no member in our company has tried any type but chemical sealing before. Our mechanical team began by sealing the DC motors that move the gripper and the valve rotator and then testing them to verify the quality of the seal.

Interpersonal

This year, we learned a lot about organizational structuring and work motivation; we said goodbye to 5 members and welcomed a new one, this was especially challenging as we were used to the company structure and everyone knew their roles quite well. We were able to benefit from this as we learned how to readily incorporate new members in our company, train them extensively about the company's culture and objectives and find ways to motivate them by entrusting them with challenging tasks.

REFLECTIONS

Mohamed Samir, former Mechanical Team Leader



Working on this project as part of this team has altered the course of my college experience. From going there, sitting for my classes then getting back home, to actually making use of concepts and theories and projecting my perception of them to real solutions for very real problems. It has taught me a lot in many aspects and brought out the best in me. If anything amounts a lot to making me confident and ready to face life as a graduate, it is -thanks to MATE, Hadath and all the support we have got from AAST, my teammates and mentors- this competition.

Hossam Samir, his brother and the current Mechanical Team Leader

There are not enough words to describe the gratitude I have for the organizers of this competition; MATE Center and ROV Egypt. Working on this ROV instilled in me a hunger to push myself out of my comfort zone and strive to do something innovative and different. Gaining an immense body of knowledge and practical skills along the way. Being a member of this team is simply a roller coaster that keeps going up! They taught me all the makers of a successful engineer; perseverance, time management and strong, clear communication.

FUTURE IMPROVEMENTS

Orientation-and-Depth Hold Mode

During testing, it was difficult for pilots to achieve simultaneous vertical and horizontal alignment when performing the pick and place missions such as placing the rebar rods into the frame in Task 1 and reconnecting the power cable in Task 2. So, it was apparent that the utilization of PID control is a crucial requirement in the correction of the ROV's position and orientation while in pilot-assisting mode.

Our team is considering enhancing it by developing an algorithm that allows the pilot to press a button that activates a "orientation-and-depth hold" mode, where the ROV registers its current position and orientation and autonomously corrects any deviations from it.

ACKNOWLEDGMENTS

Invictus would have not been founded nor able to overcome the challenges it faced without the help of these organizations and individuals:

- **MATE Center -** for creating such a highly competitive and professional competition, that allows makers to explore their passions and develop their engineering skills along the way.
- **Arab Academy for Science and Technology -** for funding our project, travel expenses and supporting us, and also for hosting this year's regional competition.
- **Regional Informatics Center (RIC) -** at AAST Alexandria.
- **Industry Service Complex (ISC) -** at AAST Alexandria.
- **Dr. Mamdouh Hamza (Hamza Associates) -** for his generous donation that funded two of our members' airfare.
- **Our supervisor, Prof. Mohamed Abbas Kotb -** for his constant concern for us to perform better.
- **Prof. Amr Ali Hassan and Prof. AbdelMoneim AbdelBary -** for their relentless support and continuous encouragement.
- **Dr. Ahmed ElShennawy from the RIC -** for organizing the AAST local qualifications stages.
- **Eng. Amr Khamis and Eng. Riham Abdallah from the Mechatronics Lab -** for walking us through all the troubles we encountered.
- **Eng. Sayed Hassan, Eng. Mohamed Ashour and Eng. Salah Edrees from the Manufacturing Workshops -** for using their time and experience in machining and assembling.
- **Eng. Hussein Fahim and Eng. Mohamed Abo-Senna -** as they never spared any efforts in assisting us.
- **Torbini ROV Team -** for sharing their inspirational journey and success in last year's international competition.
- **Our current mentors who were former team members, Mohamed Samir and Ahmed Salama.**
- **Former team members, Mahmoud Ghareeb, AbdelRahman Ramadan and Moamen Yasser.**
- **Our friend, Mohamed Galal -** for working and training with us into the small hours of the night, supporting and assisting in multiple difficult jobs.

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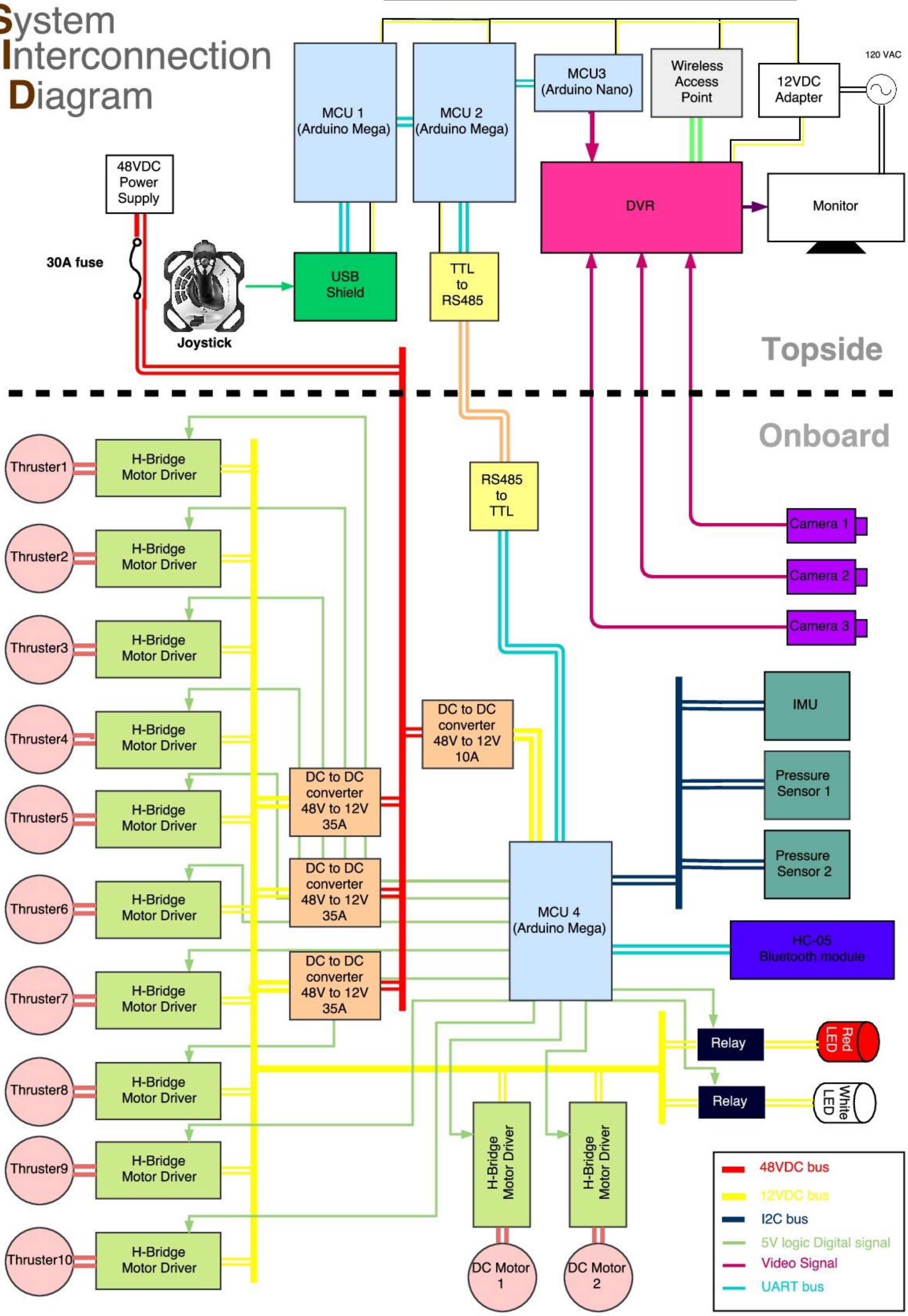
Max onboard drawn power	911 W
Min DC-DC Converters Efficiency	92%
Power Conversion Losses	79 W
Tether's Transmission Power Losses	150 W
Full load drawn Current at 48VDC	23.75 A
Full load Current x 150%	35.6 A
Used Fuse	30 A

APPENDICES

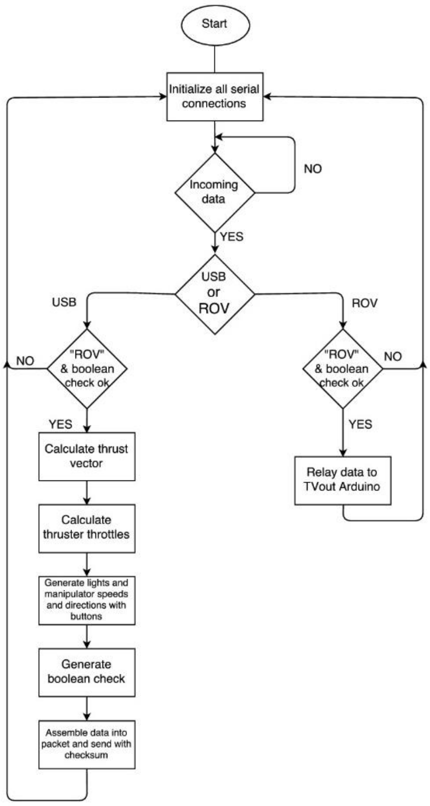
Appendix A

System Interconnection Diagram

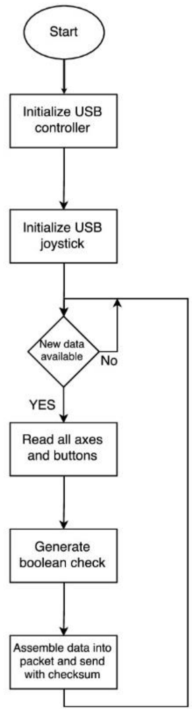


Appendix B

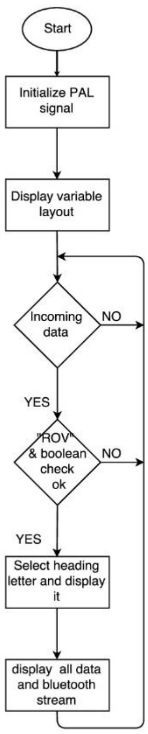
MCU2



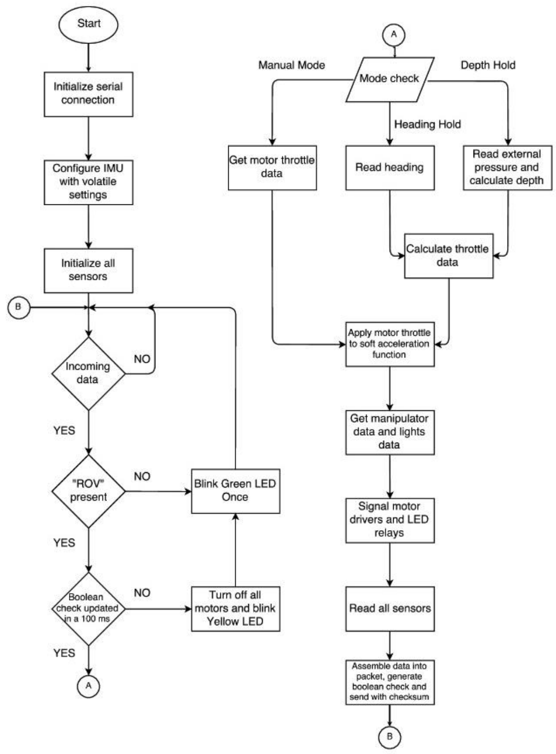
MCU1



MCU3



MCU4



Appendix C

Safety Checklist

Procedure	Check Mark
Pre-Power Checks	
All crewmembers are wearing safety gear	
Power is disconnected before conducting safety check	
Check fuse is not blown	
All mechanical structures fastened securely	
All sharp edges covered and cap nuts installed	
Propellers, shafts and manipulators clear of obstructions	
Video gear clear of obstructions	
Cables are tied down and electrical connections are waterproofed	
Check all seals are installed correctly	
Check electronics enclosure end caps are fastened correctly	
Check Pressure valve needle is fully screwed in	
Check operating environment is clear of obstruction	
Call out “Safe”	
Pre-Water Checks	
Connect tether to control station and power the system	
Check video system	
Pressurize the electronics enclosure for the rated depth for the called dive	
Check internal pressure reading at control station is correct for the dive	
Power down the system and call out “Water Ready”	
Two crewmembers and the tether man lower the ROV in the water	
Call out “In Water”	
In-Water Checks	
Check for bubbles	
Power up the system and check warning lights	
Check internal pressure is stable at surface	
Call out “Pilot In Command”	
Recovery Checks	
Check ROV is at surface, facing away from pool wall	
Power down the system and call out “Crew In Command”	
Two crewmembers and tether man lift the ROV from the water onto land	
Safety officer signature:	