Design And Development Of A Remotely Operated Vehicle - Arkaja 3.0

ABSTRACT:

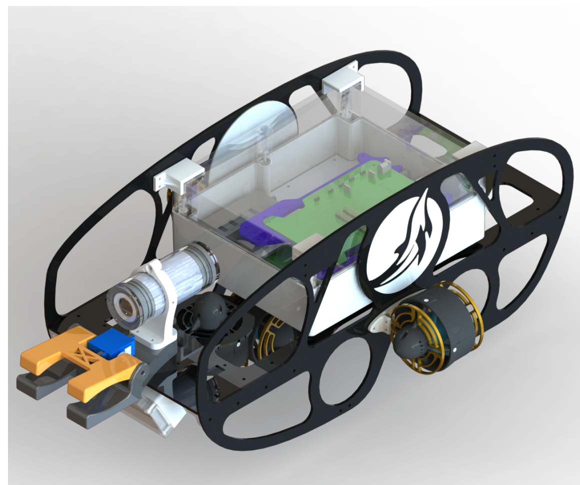
Our team at the Delhi Technological University has made significant advances in developing Arkaja 3.0, our latest Remotely Operated Underwater Vehicle developed for AMU ROV. Successful long-distance serial communication through RS485 protocol and specially designed custom PCBs are the major developments for the embedded subsystem. This year, we also moved from the earlier cylindrical to a cuboidal hull, which led to easier debugging of the system, as it takes much less effort to access the electronics inside the hull. Overall, Arkaja 3.0 is the most compactly designed vehicle developed by our team, which is also robust and reliable for completing all the required tasks.

I. COMPETITION STRATEGY

To successfully complete all the tasks special emphasis has been laid on controls and vision of the ROV. Along with that, the design has been made keeping in mind the parameters like mobility and dimensions. For the maneuvering task, Arkaja 3.0 has 6 thrusters (Yaw, Depth, and Surge) and 5 degrees of freedom. The communication lag between the vehicle and the shore is very less. For these reasons, we are expecting a high success rate for the first task. Arkaja 3.0 has two cameras; one at the bottom and the other at the front. Both the cameras have a high field of view which will enable us to see and touch the correctly marked balloon. Using depth control the vehicle can easily pass through the gate. For these reasons, we are expecting a high success rate for the vision and control task. The pressure sensor gives a continuous depth estimate of the vehicle and using this value a PID controller ensures that the vehicle always stabilizes at the correct height. With depth control, Arkaja 3.0 can maneuver through the first gate. As the second gate is half blocked, cameras will be utilized to find an opening for the vehicle so that it can proceed towards the balls. Arkaja 3.0 has a mounted net that can catch and hold the balls as the vehicle travels below the target zone.

II. DESIGN RATIONALE

MECHANICAL SYSTEMS

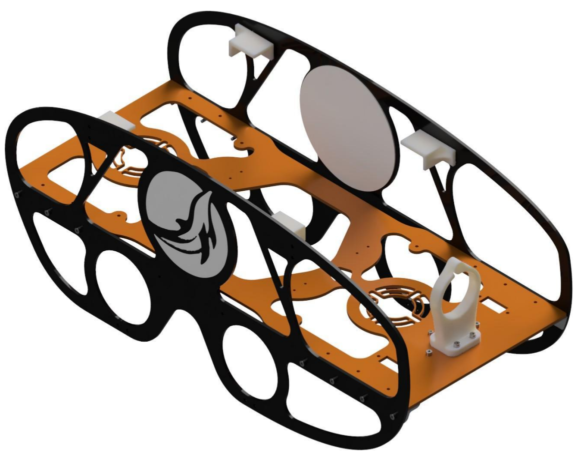


Arkaja 3.0

Prototype of Arkaja 3.0

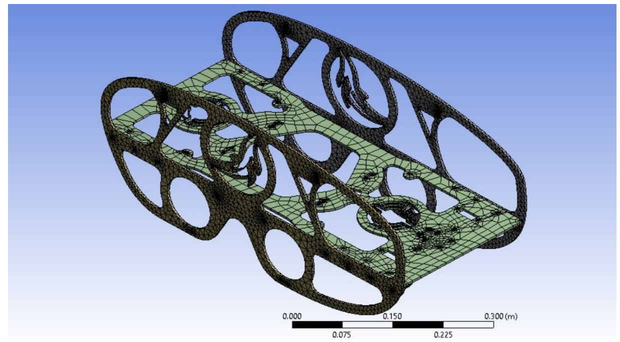
1. Mechanical Frame

The design of the frame has been kept simple to minimize assembly time and weight while simultaneously providing more than enough structural strength to ensure the safety of hulls and thrusters. The frame is assembled using three sheet metal parts: base plate, left plate, and right plate. These three plates are secured using 3D printed ABS L-brackets . The material used for the frame is Aluminum 6061-T6 alloy, which has a density of 2700 kg/m3. This alloy was chosen for its low density compared to steel, good strength, and relatively lower cost of the material. The sheet metal is cut using water-jet cutting. This process is selected for its precision in cutting which ensures proper cutting of the frame's various irregular cavities and edges. The bottom plate houses the electronics hull, front camera hull, bottom camera hull, and 4 thrusters. The electronics hull is secured at the center using 3D printed hull brackets (attached to side plates), the front camera is also mounted using 3D printed mounts towards the front.

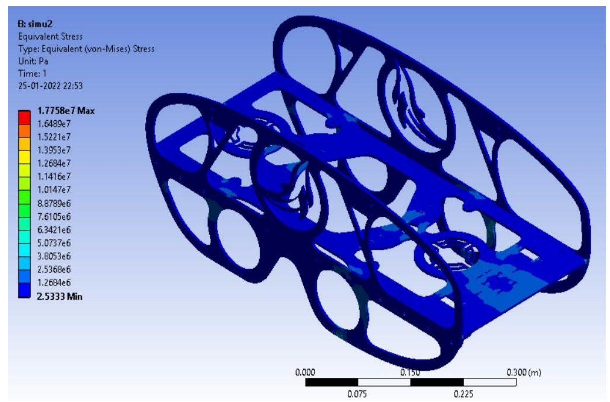


Mechanical Frame Of Arkaja 3.0

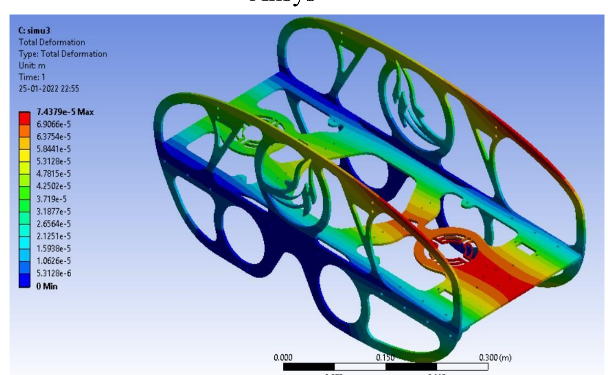
The frame of Arkaja 3.0 has sufficient rigidity and reliability. Upon structural analysis of the frame in Ansys software, the maximum stress generated in the frame was found to be well less than the yield stress of Aluminum 6061-T6 alloy.



Mesh of Arkaja 3.0 frame generated in Ansys



Von Mises Stress analysis of Arkaja 3.0 frame in Ansys



Deformation analysis of Arkaja 3.0 frame in Ansys

2. Waterproof Hulls

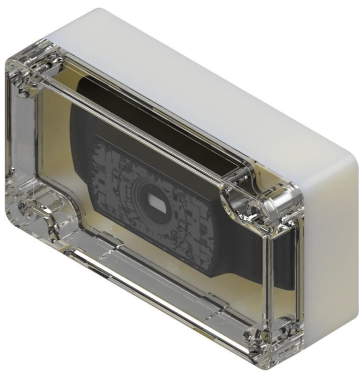
Arkaja 3.0 has two cuboidal and one cylindrical waterproof hulls housing onboard electronics and vision cameras.

Electronics hull: A cuboidal 1554YA2GYCL hull is used for housing the electronics stack of the ROV. The base of the hull and the lid are made of polycarbonate. The hull also has 16 precisely cut holes of 10.2 mm diameter each for mounting water-proof connectors.

1.

These holes provide a watertight passage for various wiring going from hull to thrusters and cameras along with wiring for power supply and onshore communications. A cuboidal hull provides an easier and space-efficient stacking of electronics such as PCBs and PDBs compared to cylindrical hulls. Also, since wiring connections come out of the hull body and not the lid, opening and closing of hulls are easier allowing faster debugging.

Bottom camera hull: The bottom camera of Arkaja 3.0 is housed inside a cuboidal 1554 C2 GYCL hull made of polycarbonate.



Bottom Camera with Hull

In both cylindrical hulls, a molded gasket with IP68 rating is being used to provide waterproof sealing.

Front camera hull: The front camera of Arkaja 3.0 is housed in an inhouse produced cylindrical hull having a clear acrylic body and end caps with Aluminum flanges. Waterproof sealing is ensured by sandwiching 4 radial O-rings between the inner hull wall and flanges and 2 facial O-rings between each flange and end cap.

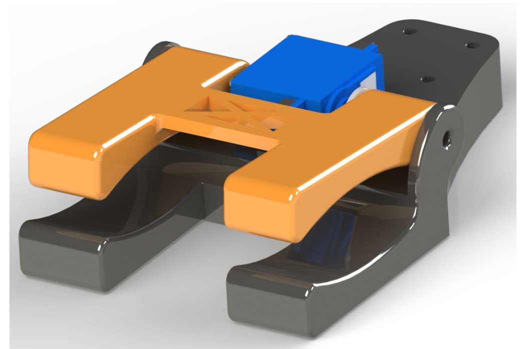
3. Propulsion System

For the ROV, T-200 thrusters by Blue Robotics are used. A total of 6 thrusters are installed in the vehicle providing 5 degrees of freedom: surge, heave, sway, pitch and yaw. These 6 thrusters have a configuration as follows:

3. 2 heave thrusters are placed on the base plate to control the heave and pitch of the vehicle.
4. 2 sway thrusters are placed on the bottom plate to control the sway and yaw of the vehicle.
5. 2 surge thrusters are placed on the side Plates for controlling surge of the vehicle.

6.

4. Gripper



Gripper for Arkaja 3.0

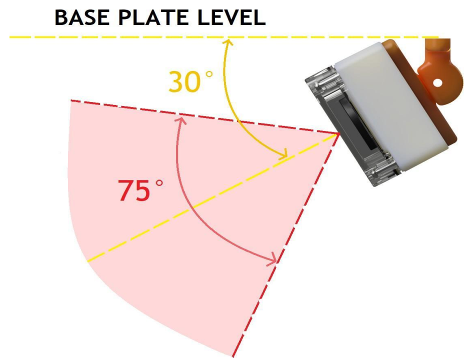
The design of the gripper focuses on reliability, simplicity, and practicality. The outcome of the design process is a 2-claw vertically oriented gripper. It features two claws with multiple coupler links. The lower part of the gripper is stationary to obtain better structural strength by eliminating features required to achieve movement. The servo motor provides torque to the upper claw which rotates and presses on the gripping object. The design allows for gripping of an object up to 70 mm long by providing multiple points of contact which greatly increase stability. The entire assembly is manufactured using 3D printed ABS plastic. In comparison to our previous 2-claw gripper with two coupler links, this gripper is able to hold objects of longer dimensions and greater mass.

7. 3 D Printed Mounts

Front camera mount: In Arkaja 3.0 the front camera hull has been secured using a custom 3D printed mount

Front Camera with Hull

Front Camera Mount with Hull withdrawal



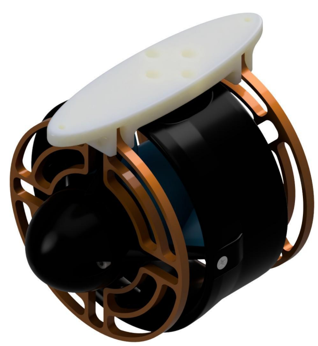
Orientation of Bottom Camera Hull with respect to Vehicle Baseplate and Camera Field Of View depiction

Bottom camera mount: The bottom camera hull has been installed on a custom made 3D printed ABS mount. The component has a two piece design in the shape of a fixed elbow. The piece directly fixed to the hull fixed in a slot shaped to position the camera hull at a 30 degrees incline downwards.

Bottom Camera Mount with Hull

We intend to use the bottom camera for preventing the vehicle from touching the pool floor and lower side of the half blocked gate in the ball collection task. Hence this particular tilt angle is chosen to keep the field of view of the camera (75 degrees) entirely in our region of interest which is the lower half of the region on the front side of the vehicle.

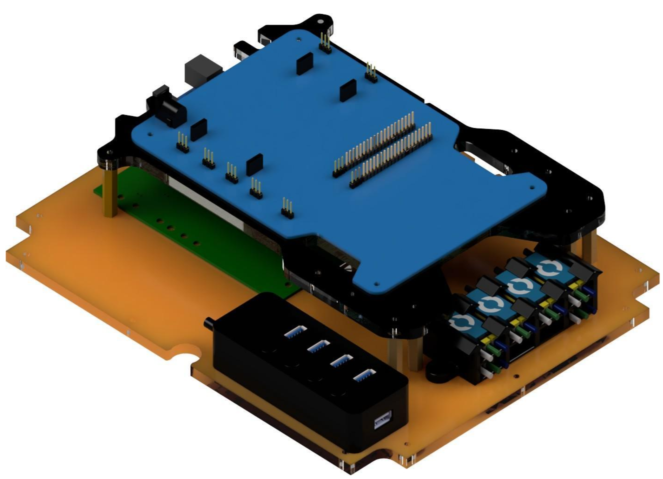
Thruster Mounts and Shrouds Assembly: Thruster mounts of Arkaja 2.0 are made by 3D printing ABS. These mounts are designed in a manner that combines thrusters and their shrouds as a single unit or subassembly. Thruster shrouds are protective mesh-like covers attached on both ends of the thruster nozzle. These subassemblies are easier and faster to install compared to shrouds being placed separately. Each surge and sway thruster has two shrouds attached with it while each heave thruster has one shroud, with the other inbuilt on the base plate.



Heave Thruster with Mount and Shroud

ELECTRICAL AND EMBEDDED DEPARTMENT

The main power comes to our ROV from the 48V power supply through XT60 connectors.Then, 12 AWG Silicone wires carry this power through a Double Pole Single Throw (DPST) Kill switch to a 25A inline fuse as per safety regulations. From the fuse, we get two output wires which go into the tether and then inside the ROV. These wires then go into the power distribution board (PDB) powering the microcontroller, all the sensors, and the thrusters. The microcontroller along with the sensors and rs485 transceiver are connected to each other on a single PCB, this reduces the wiring and makes the system more modular. The electronics department also designed the algorithm for communication with the vehicle from the shore using the RS485 protocol.



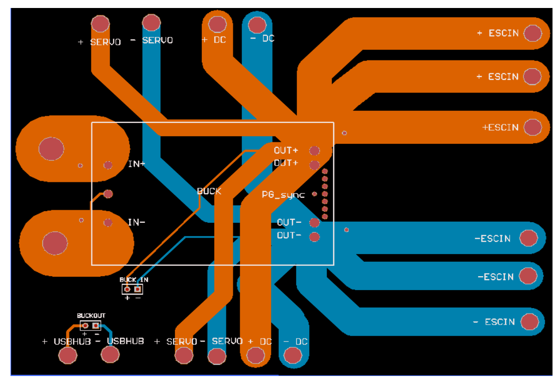
Electronic Assembly in Arkaja 2.0

1. Power Distribution System

A PCB was specifically designed and manufactured for the purpose of Voltage conversion from 48V to 12V and also for Power distribution. A 48-12V quarter-brick converter was implemented for voltage conversion because of its high output power (900W) and compact size. The quarter-brick converter is mounted on the PDB. The PDB has outputs for ESC's (Electronic Speed Controller), microcontroller PCB, and for the USB hub used in the imaging system. The outputs for ESC's from the PDB are combined into a single output and then are fed into the microcontroller PCB (Arduino Mega Shield).

On the microcontroller PCB, the input 12V power is split into 6 outputs for 6 ESCs. One 12V rail is stepped down to 5V to power the Arduino Mega.
The cameras through the USB hub are powered using another 12V rail which is stepped down to 5V. The trace widths were chosen using the IPC recommended trace width chart. PDB reduced a lot of wiring and the electrical system became much more manageable. Fault detection and debugging also became quicker due to the introduction of a PDB.

Power Distribution Board schematic



Power distribution board

S.No	Component	Current rating	Operational Voltage
1	Thruster	6A	12V
2	Arduino	0.6A	5V
3	Pressure Sensor	1.25mA	5V
4	Camera	0.5A	5V

Operating requirements of various major components in Arkaja 2.0

$I_{Tot} = \Sigma(I_{Drawn} \times N)$
$(6 \times 5) + 0.6 + 0.00125 + 0.5 \times 2 + 0.0005 \times 2 =$
31.6002 A (Total maximum current drawn) $I_{Over} =$
$I_{tot} \times 1.5$
$= 50.55 \times 1.5 = 47.4033$ A
$I_F = 25$A (Rating of the fuse) $P_{Tot} =$

$\Sigma\ (V_{Load}\, I_{Drawn}\, N)$

$= (72) \times 6 + 3 + 0.00625 + 5 + 0.005$

= **440.0112W** (Total maximum power Consumed)

2. DC-DC Converters

UBEC: 12V - 5V, 3A UBEC converter is used for supplying power to the USB hub. The USB hub powers up a Logitech C390e camera and a Microsoft camera. There is no need for any heat sink or forced cooling. Another buck converter is utilized for powering the Arduino from the 12V rail.

Quarter Brick Converter : A 48V - 12V High power (900W) quarter-brick converter BMR4800102 from Flex Power Modules is implemented in our system. It has a high-temperature tolerance of 125 C and is extremely compact. With features like adjustable output, Overvoltage protection, over-temperature protection, inbuilt baseplate helping in cooling the brick, and an efficiency of 96.9% made this quarter buck the best choice for our application.

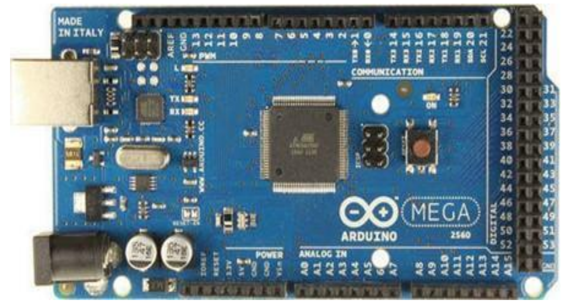
Quarter brick BMR4800102

3. Kill Switch

A generic double pole single throw switch is used as the killswitch. The switch is connected to the input of the 48 - 12V buck converter and is used to deactivate the power circuitry of the vehicle in case of an emergency or critical failure.

4. Control System

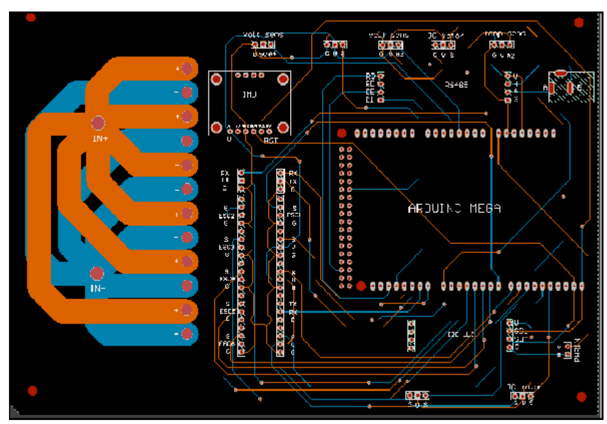
Microcontroller : Arduino boards were used because of their open-source AVR microcontroller-based development which can be programmed easily. Specifically, Arduino MEGA (2560) 32-bit was used because it has several analog-digital and serial communication pins for sensors, motors, and other actuators.



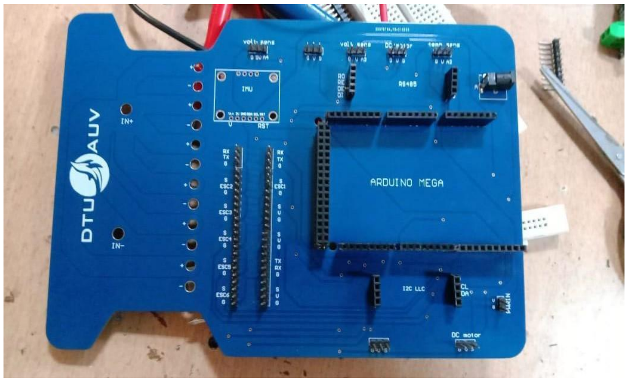
Arduino Mega

A microcontroller PCB (Arduino Mega shield) was designed to mount the Arduino and attach all the sensors to it. The PCB has ports for different components like the RS485 transceiver, logic level converter for the pressure sensor, 6 ESC's, temperature,. current and voltage sensors. The shore RS485 transceiver is connected via an ethernet cable with the RS485 board in the vehicle. This reduces the amount of wiring required and also allows easy debugging. It also has power outputs to run 6 BlueRobotics T200 thrusters.

The PCB also allows the connection of an additional Arduino Mega motor shield if extra pins are required. The current, temperature, and the voltage sensor are useful for debugging the electronic stack in case of a fault.



Microcontroller PCB Schematic



Microcontroller PCB

Controller : On the surface, we have a Redgear gaming controller connected to the laptop. This controller serves as the entire control unit for the ROV. It is connected with an Arduino UNO board and an operator can give commands to the ROV via RS485 communication.

PID Controller : For tasks requiring depth stability, A PID loop has been implemented. For the depth sensing, we have employed BlueRobotics Bar30 Pressure Sensor, connected to the Arduino via logic level converter on the microcontroller PCB. The required depth value can be hanged using the controller and this required depth value is the target value for the PID loop

5. Tether

For our tether we utilized 10mm diameter and 10m length Spiral Wrapping Band by robu.in. It is very flexible and durable and allows wire breakout at any point, it is quick and easy to apply and remove. The wires inside the tether are 4mm copper diameter and two ethernet CAT 6 cables for image and control signals respectively.

Power loss :

R_{Copper} = 4.3 Ohm/km

L_{Tether} = 15m x 2

$R_{Total} = R_{Copper} \times L_{Tether}$ (Total resistance of the cable)

= 4.3 x 30/1000 = 0.129 Ohms.

$V_{Drop} = I_F \times R_{Total}$ (Voltage drop in the tether)

= 0.129 * 25 = 3.225V

$P_{Drop} = I_F^2 \times R_{Total}$ (Power loss due to tether resistance)

= 0.129 x 25 x 25 = 80.625 W

$\eta_{Cable} = (P_{Tot} - P_{Drop})/(P_{Tot})$ = 86.042 % (Efficiency of the cable)

6. Imaging System

Two high FOV cameras are being used, namely C930e Logitech and Microsoft Live Cam for vision, one covers the front view and the second one covers the bottom view. The cameras derive their power from a USB hub which is in turn powered by the PDB using the 12V-5V UBEC. The image feed of the two cameras is carried over to the shore using a single ethernet CAT 6 cable. The image is processed on the shore on a GUI.

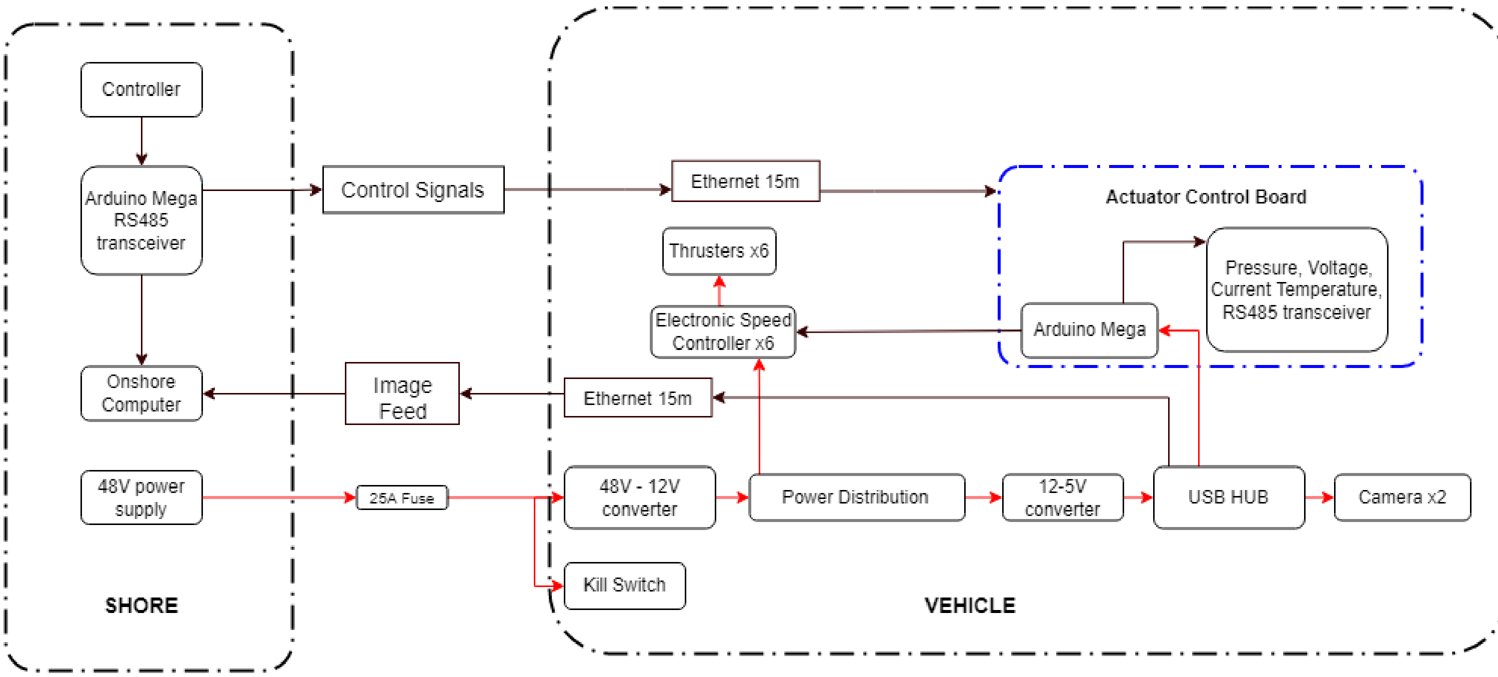
7. Depth Control

Earlier, to improve the modularity of the ROV, we had moved away from wired connections toward the use of the much more convenient PCBs.
Now, we have employed a BAR 30 pressure sensor, which can determine the depth at which the ROV is below the water level.
The depth calculated by the pressure sensor for the vehicle can be used as the current position for the PID loop to be executed. This can be achieved with the shore-side PCB determining the required depth, which is the set position.
The above algorithm is used to obtain better results in depth control of the vehicle, hence, smoother control of the vehicle.

SOFTWARE DEPARTMENT

1. Graphic User Interface (GUI)

The software team lead the development of GUI, with the help of a custom-designed GUI, we scale the accessibility of our bot to include even the most naive user, so that monitoring it becomes as easy as running a mobile application. Arkaja 3.0 uses two high-field-of-view cameras, namely the C930e Logitech and the Microsoft Live Cam, for vision, with one covering the front view and the second one covering the bottom view. The GUI is designed so as to provide a processed image of this live feed on the shore. A simultaneous feed from both the front and the bottom cameras will be available at our fingertips. . We can also switch between the front and the bottom cameras. This, coupled with information about certain parameters that govern the mobility of the bot, gives us the capability to perform different tasks and maneuver the vehicle while avoiding various obstacles. The GUI adds the capabilities in ROV to perform difficult tasks underwater.



Hardware architecture of Arkaja 2.0

III.ACKNOWLEDGEMENTS

We would like to thank and express gratitude to everyone who contributed to the completion of our project. We'd like to thank our Faculty Advisor, Mr. Ajeet Kumar, for his helpful guidance throughout the duration of this project. We would also like to thank our experienced and knowledgeable DTU AUV alumni network whose advice in matters like management of the scheduled timeline of our project and design considerations, assisted us in working efficiently. Finally, we would like to thank our sponsors - - Bulgin, 3D paradise, Xsens, Vectornav, Hitec, Solidworks, Adani, Ion exchange, Blue robotics, Total phase, Protocase, Fischer, Mathworks, SubCtech, RJE, Altium, Ansys - for helping us financially and aiding us with important tools and resources, which was essential for completion of this project

IV. REFERENCES

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V. APPENDIX

APPENDIX A: COMPONENT SPECIFICATIONS AND BUDGET

Component	Vendor	Model/Type	Specs
Buoyancy Control	NA	NA	NA
Frame	In House	Plane truss structure 3D printed attachments	4mm Aluminum 6061 T6 sheets 3D Printed ABS
Waterproof Housing	Hammond Hammond	1554YA2GYSL 1554C2GYCL	IP68 rated, Polycarbonate IP68 rated, Polycarbonate
Waterproof Connectors	Blue robotics	Potted Cable penetrator	Quantity: 20,M-10 thread, 6mm cable
Thrusters	Blue robotics	T200	Quantity: 6,Operating Voltage:7-20V, Full Throttle Current(@20V):32A
Motor Control	Blue Robotics	ESC for T200	Quantity:8,7-26 volts (2-6S)
High-Level Control	Arduino	Mega 2560	6-20V,54 digital I/0 pins,16 analog pins, Clock speed:16MHz
Vision	Logitech Microsoft	C930E Lifecam HD 3000	Full 1080p HD video at 30 frames per second Full 720p HD video at 30 frames per second
Regulator I	Robu	LM2596S	Quantity : 1, Input Voltage : 3-40V, Output Voltage :1.5-35V(Adjustable) Output Current : 2A
Regulator II	Robu	Bluesky Mini	Quantity 1 Input Voltage : 7-25V Output Voltage : 5V (constant) Output Current : 3A
Pressure sensor	Blue Robotics	BAR30	300m depth
Current sensor	Robu	ACS712	Measure Current Range: -30A ~ 30A
Voltage sensor	Robu	Voltage detection sensor module	Voltage detection range: 0.02445V - 25V DC

Temperature Sensor	Adafruit	MCP9808	Temperature range : -40 C - 125 C
RS485 Transceiver	Maxim	MAX485	Quantity = 2 Max Speed = 2.5Mbps Current Draw = 120 uA
Testing time: in-water	7 hours		
Inter-vehicle communication	RS485 Protocol		
Programming Language(s)	C/C++		