RoboSub 2024 Technical Design Report

University of Brasilia (All Blue)

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***Abstract*—For RoboSub 2024, All Blue Team focused on developing an AUV capable of performing all competition tasks satisfactorily. To achieve this goal, control algorithms were implemented to ensure autonomous navigation and interaction with objects. Equipped with 8 thrusters, Iara features 6 degrees of freedom and its IMU enables Style maneuvers. Structural and hydrodynamic analyses were conducted to reach the final design of the AUV: aluminum cylinders enclosed in extruded aluminum profiles. The electrical architecture was designed to integrate sensor data with the Pixhawk Flight Controller, easing the control by actuators. Visual Servoing techniques enabled the development of a navigation algorithm based on camera images, crucial for SLAM methods as well.**

I. Technical Content

A. Competition Strategy

Started earlier this year, All Blue, in its first year of competition, aims to develop a project that ensures satisfactory performance, achieving a first functional and safe AUV capable of performing tasks ranging from the simplest to almost all complex tasks proposed in RoboSub 2024. Our AUV, Iara, is the result of initial learning and represents the beginning of a long history of development and improvement of AUVs.

Our strategic vision for the competition consists of completing the initial tasks as reliably as possible to secure the necessary points and progressing to more complex tasks as these points are ensured.

The main tools enabling Iara to perform the proposed tasks include its ability to execute SLAM with its stereo cameras and apply visual-based control algorithms, combining image-based and position-based servo control approaches to achieve a more robust system. More detailed descriptions will be provided in the following sections.

1) Enter the Pacific — Gate

The first task to be completed by Iara will be the gate. After submerging, the search for the gate will begin, using a local scan until a detection is made by the neural network. Once this is done, the servo control algorithms will be used to bring Iara to the desired reference pose, stopping upon reaching a maximum error threshold. At this point, maneuvers are performed to earn extra points, and the task is completed by passing through the cold side.

2) Hydrothermal Vent — Buoy

Taking advantage of its additional downward-facing camera, Iara will follow the path to proceed to the Buoy. Once again, using servo control, the desired pose is first reached, and then circumnavigation begins. This is done through independent position and attitude control, where one aims to complete the circle around the Buoy and the other keeps it always in the field of view. The turn is made counterclockwise, consistent with the choice made at the gate, to maximize point acquisition.

3) Ocean Temperatures — Bin

For the Bin task, after Iara initiates its scan and successfully identifies the target using its downward-facing camera, the necessary alignment and approach will be carried out through depth control. A depth threshold has been established to minimize the risk of any collisions and also to reduce errors when dropping the markers.

4) Mapping — Torpedoes

With the aid of hydrophones, the goal is for Iara to reach the torpedo task, and with the help of the front cameras, position itself adequately so that the firing line aligns with the target hole. We expect that our computer vision algorithms and the construction of the torpedo launchers will allow Iara to hit at least two of the larger holes.

5) Collect Samples — Octagon

Once again, with the aid of hydrophones, the goal is for Iara to reach the octagon task and perform the surfacing. We expect that with the help of the pinger and the reference image from the bottom camera, the surfacing can be done correctly. Despite the robotic actuator being part of the project, it was initially decided not to perform the sample collection due to reliability and the time spent on this task.

B. Design Strategy

1) Mechanical Sub-System

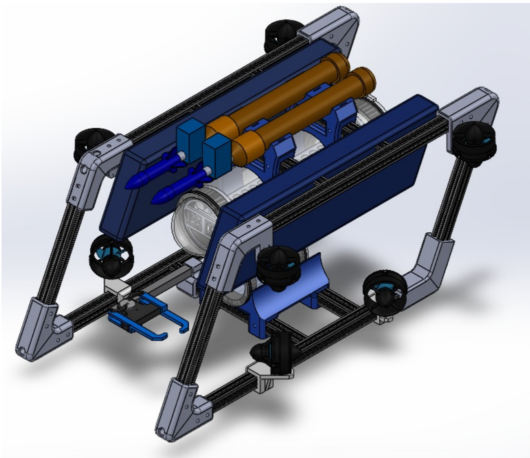

Fig. 1. Full SOLIDWORKS Assembly of Iara

a) Torpedo Launcher

The torpedo launcher challenge involved developing a mechanism capable of generating the necessary force to achieve a good distance in water. Opting for an economical and effective solution, a device was created using the principles of a PET bottle rocket, employing a pressure container. Thus, compressed gas inside the bladder tank creates high internal pressure. The expelled gas generates propulsion force upon release, propelling the torpedo forward. The pressurized container was constructed using sealed PVC pipes to prevent air leaks. An air pump connected to a barometer was used to compress the air, increasing the internal pressure of the tank. Through the barometer, tests were conducted adjusting the amount of air and pressure to achieve an optimal balance between propulsion force and safety, determining that 50 psi is necessary for the torpedo task. A water and pressure-resistant solenoid valve controlled by the microcontroller was installed to release the compressed air. The torpedo was 3D-printed with a cylindrical hydrodynamic profile and a conical tip. Ballast was added to the tip to adjust the density and consequently the torpedo's buoyancy.

b) Dropper

For the dropper task, we opted for a mechanism with neodymium magnets. This approach allowed us to avoid using expensive underwater parts, as well as avoiding openings in the cylinder that could cause potential leaks.

We were able to stabilize the markers on the outward part of the main hull, pointing directly down. There is a need to easily drop the marker, and once you release the marker, it should fall straight down. To make this happen, physical barriers to prevent unwanted rotation during deployment were used. The marker structure was 3D-modeled and 3D-printed with a space to place the neodymium magnet.

c) Gripper

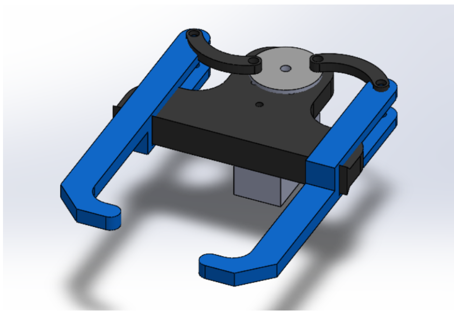

Fig. 2. SOLIDWORKS gripper CAD

The gripper design (Figure 2) was carefully considered, taking into account the geometry of the objects to be caught in the Collect Samples - Octagon mission. Since their shapes vary, to ensure the capture of the cylindrical samples an intersecting two-finger design was implemented to enhance grip and secure the objects in place. It was also taken into account the maximum size, which is restricted by the collection baskets and by the samples. This system operates using underwater servomotor and transmission gears that open and close the gripper as the AUV ascends and descends, as needed. The gripper is positioned near the main hull to allow the camera's field of view to track both the samples and the gripper simultaneously.

2) Electrical Sub-System

a) Embedded system

For the AUV to perform tasks autonomously, it is necessary to have an embedded system capable of processing received data and controlling its movements and actions. To achieve this, two embedded system boards were chosen: a Pixhawk and a Jetson Nano.

The Pixhawk is a control board used in unmanned aerial vehicles (UAVs), as well as in autonomous ground and aquatic vehicles. The operation of the Pixhawk involves collecting data from multiple sensors, such as gyroscopes, accelerometers, magnetometers, barometers, and GPS, which provide information about the vehicle's pose and velocity [1]. The controller processes this data in real time and adjusts the vehicle's actuators, such as motors and servos, to maintain stability and follow the programmed flight plan.

On the other hand, the Jetson Nano is a computing platform developed by NVIDIA, designed to offer artificial intelligence (AI) processing capabilities in a compact and affordable format. It is especially suitable for applications requiring real-time AI processing, such as computer vision, robotics, and the Internet of Things (IoT) [2]. The board supports the use of peripherals, offering a connectivity interface that includes USB ports, Ethernet, GPIO, I2C, SPI, and UART [3].

b) Electrical Architecture

The entire AUV system is powered by three 4-cell batteries, each providing 14.8V. The batteries are connected in parallel to pass through a power management board. For this connection, two bus bars are used, to which the battery terminals and the terminals of the cable leading to the board are connected. Only a few components are indirectly powered, such as the ADC converter and the pressure sensor, which are powered by the Pixhawk, and the cameras, which the Jetson Nano powers. Figure 5 shows the block diagram of the power architecture of the entire AUV system.

The communication system includes various data transmission methods, including the use of I2C, USB, and PWM. There is communication between the embedded systems and the peripheral sensors used for data capture, processing, and control. Additionally, there is communication between the embedded system, where the navigation controller and the compact computer exchange information and parameters. Figure 6 shows the block diagram of the communication architecture of the entire AUV system.

c) Power Distribution

The AUV requires a lot of power for various sensors, actuators, and other components to operate simultaneously. To meet this demand, three batteries were chosen as the power source, as mentioned before, and a power management board is necessary to ensure the correct operation of the entire system and provide additional safety. The OpenROV Power Management Board was selected; it is a board designed to manage the distribution of electrical power in underwater vehicles such as ROVs (Remotely Operated Vehicles).

This board regulates the input voltage, converting it to applicable voltages such as 12V, 5V, or 3.3V, which are then distributed to motors, controllers, sensors, cameras, and communication systems. In addition to providing regulated power, the board offers protection against overcurrent, short circuits, and overvoltage, preventing damage to the connected components.

Beyond regulation and protection, the OpenROV Power Management Board allows for real-time monitoring of the battery status and power consumption, which is crucial for safe and prolonged operations. This is particularly important for underwater vehicles, where maintenance and access to components may be limited during operation.

d) Propulsion System

The AUV propulsion system is based on 8 thrusters strategically distributed for surge, heave, sway, yaw, pitch and roll movements. The motors used are New T200 Brushless along with ESCs (Electronic Speed Controllers) F390 30A. Each ESC is responsible for controlling one thruster, receiving PWM (Pulse Width Modulation) signals from the Pixhawk Flight Controller.

The ESC used allows for speed and rotation direction control of the motors, enabling the reversal of the AUV's movements at any time [4]. These features bring agility to the movements and provide a greater degree of freedom for the submarine.

Of the 8 thrusters, half are clockwise-rotating (CW) and the other half are counterclockwise-rotating (CCW). Although designated to rotate in a specific direction for forward movement, the propellers also operate in reverse mode, providing less thrust. This ensures Iara's maneuverability and guarantees its 6 degrees of freedom.

e) Torpedo Launcher

To activate the solenoid valve coupled to the torpedo, a circuit was built using a MOSFET transistor as a switch. Since the solenoid behaves like an inductor, a flywheel diode was required to prevent reverse current spikes when the switch is open. It was necessary to use a MOSFET with a threshold voltage lower than 3.3V, given that this is the Pixhawk's PWM signal voltage. Therefore, we chose the BUZ11 MOSFET, which has a minimum threshold voltage of 2.1V. In the circuit, a pull-down resistor was also used to ensure that the switch does not close when the Pixhawk signal is LOW.

f) Dropper

As mentioned earlier, the marker will be fixed using neodymium magnets. For the marker to be released, the magnet holding the marker must be removed and moved away from the marker itself, reducing the magnetic force, and causing the gravitational force to become greater and the marker to fall. A simple mechanism using a 9-gram servo motor was assembled, where the servo is fixed to the cylinder on the inside and is responsible for moving the magnet until the marker falls. Various tests were conducted, and the 9-gram servo was chosen because it was the lowest-cost option that provided the necessary torque and was easily found and replaceable.

g) Gripper Drive

The Aquatic Servo D30-EDU was chosen to be used in the AUV gripper. Its robust and corrosion-resistant construction ensures durability and reliability in aquatic environments. The D30-EDU offers precise position control, essential for underwater manipulation and exploration tasks, and is compatible with various control systems. Its control will be handled via Pixhawk using a PWM signal, receiving commands to open and release the gripper as needed. Powered by a 7.4 V supply, the motor can achieve an angle from 0° to 270° depending on the command.

h) Inertial Measurement Unit

For the inertial control of the AUV, it is necessary to acquire inertial data from the vehicle using sensors such as accelerometers and gyroscopes. Since the Pixhawk flight controller already has an integrated Inertial Measurement Unit (IMU) in its circuit, the use of additional sensors was deemed unnecessary.

i) Pressure Sensor

We use an MS5837 - 30BA pressure sensor that measures up to 30 bar (300m depth). Its I2C interface enables direct connection to the Pixhawk, requiring a power supply of 1.5V - 3.6V. The sensor can be installed in the watertight cylinder and estimates the AUV depth with a 2mm resolution.

j) Hydrophone

The hydrophone was the chosen sensor for detecting the sound signals emitted during the competition. For correct detection and estimation of the direction of the received signal's origin, triangulation of the signal is necessary, and therefore, it was decided to use four hydrophones simultaneously.

The hydrophones were developed by the team and are based on the characteristics of piezoelectric material, which becomes electrically polarized when it undergoes mechanical deformation. This polarization generates an electric current that represents the mechanical deformation experienced. Thus, it is possible to analyze the current generated by a piezoelectric material and determine the level of deformation the material has undergone. Knowing that sound waves can cause slight deformations in such material, depending only on the material's resonance frequency and the frequency of the emitted sound, it is possible to identify a sound signal.

To enhance the signal detection results, filters, and signal amplifiers were developed using basic electronic components such as resistors and capacitors. Additionally, an ADC conversion board is used so that the analog signal emitted by the piezoelectric material is converted into a digital signal that can be interpreted by the Pixhawk.

k) Kill Swich

The M10 ROV rotary kill switch is directly connected to the power management board and has a maximum current of 500mA. By turning the switch counterclockwise, the battery supply to the internal circuit is interrupted. The M10 is attached to the main hull through a penetrator, making it easily accessible in emergencies and ensuring the watertightness of the cylinder.

3) *Software Sub-System*

a) Simulation Environment

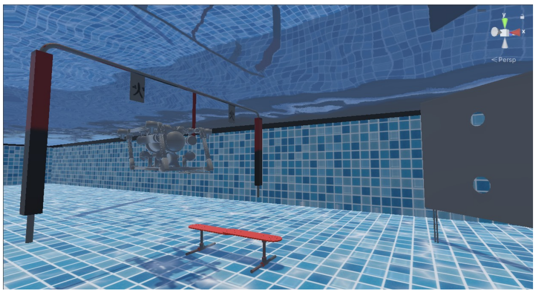

Fig. 3. Simulation environment developed in unity

We have built a new, robust Unity/ROS-based technical testing environment. It consists of an accurately rendered version of the competition pool and props, as well as all the hydrodynamic physics involved. This simulation makes it possible to implement and test new features before risking breaking anything in the real world.

Our simulation framework is integral to the construction and development of AUV. Utilizing the Unity game engine for high-fidelity visualization and the Robot Operating System (ROS) for control and sensor integration, we establish a comprehensive virtual testing environment. This approach accelerates development timelines while ensuring the reliability and performance of the AUV in real-world deployment.

b) Computer Vision

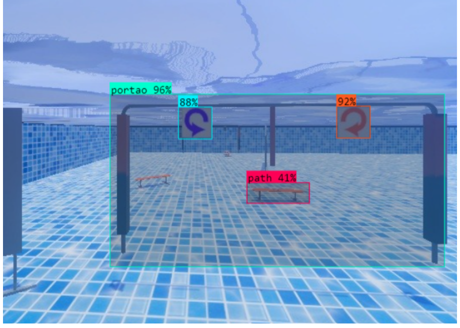

Fig. 4. Object detection performed in simulation

The Iara vision system was developed to assist in decision-making during tests. We utilize the SSD MobileNet V2 neural network due to its speed and precision [5], implemented on the Jetson Nano platform. The network output provides three important parameters: the predicted class, bounding boxes, and confidence scores, as shown in Figure 4. Our focus lies primarily on the first two. Consequently, we feed this information into a state machine to identify objects present in a scene. By combining bounding boxes with class information, we apply Visual Servoing (VS) techniques.

These techniques leverage visual feedback from the AUV's cameras to perform the image-based control, known as VS. Once the neural network obtains the image of the target task, this method extracts critical scene features to determine how the AUV should move, implying a control law which minimizes the difference between the current captured scene and the desired scene as we converge toward a reference state.

c) Mapping and Navigation

For the mapping and navigation of our AUV, we utilize the Simultaneous Localization and Mapping (SLAM) algorithm known as RTAB-MAP, available in the Noetic version of ROS [6]. It was chosen due to its real-time appearance-based approach, support for various sensors, and capability to handle large environments. Stereo cameras serve as the primary visual data source for our AUV. They capture real-time images processed by RTAB-MAP to generate a 3D map of the environment. This 3D map is crucial for autonomous navigation, providing the AUV with a detailed representation of its surroundings to identify obstacles and define safe routes [7].

To enhance mapping and navigation accuracy, RTAB-MAP integrates stereo camera data with additional sensor inputs, such as a pressure sensor for depth data and IMU for orientation data. Path planning relies on the 3D map, incorporating obstacle positions and underwater environment structure to compute precise and safe trajectories that avoid collisions and ensure navigation efficiency.

d) Control subsystem

The control subsystem is responsible for ensuring proper attitude regulation and accurate trajectory tracking. For this purpose, we use the vehicle's dynamic and kinematic models for closed-loop estimation and control. The dynamic modeling is based on [8], which describes the dynamics and main external forces for aquatic vehicles, considering the evolution of acceleration and velocity in the AUV's frame of reference. The kinematic model, on the other hand, relates the AUV's frame of reference to the external frame of reference, considering rotations parameterized by quaternions.

The control system was developed based on Computed Torque Control (CTC), as described in [9]. Position control is performed independently of attitude, which is one of the main advantages of having a fully actuated vehicle. Unlike the position error, which directly considers the difference between the desired and estimated positions, the orientation error is computed using the appropriate algebra for control with quaternions [10].

To estimate the states in real time and use this information for feedback in the control system, we employ an Unscented Kalman Filter (UKF). The estimated values are also used in the mapping algorithms. Additionally, we use a UKF for offline estimation of the dynamic model parameters of Iara.

The control architecture is composed of many layers, mainly an inner and outer loop. In the outer loop, references obtained through planned trajectory parameters or visual servoing (position-based visual servoing and image-based visual servoing) are used to define angular and linear desired velocities using kinematic models (which relate derivatives of quantities, usually generalized coordinates, in external frames and the vehicle frame). The obtained desired values for velocities are fed as references to the inner controller designed based on the vehicle equations of motion (written in the vehicle frame). In the special case of image-based visual servoing, velocities are imposed through inversion of the image interaction matrix (also known as the image jacobian) and already expressed in the local vehicle coordinates.

C. Testing Strategy

Due to the tight schedule from the team's foundation to the complete development of our AUV, we did not have significant time intervals for extensive pool testing, as, for most of the time, Iara was not in a condition to be submerged. For this reason, developing an accurate simulation environment was crucial for strategizing and developing algorithms. We had access to the pools at our university's Olympic Center for water testing, where we could use the Olympic pool, similar to the one in the 2024 competition, as well as an Olympic diving pool.

We chose to build an integrated environment that includes Unity, Robot Operating System (ROS), and Software in The Loop (SILT) to simulate sensor and actuator information, process navigation and control algorithms, and verify the combined behavior with the chosen flight controller, Pixhawk 1, using the ArduSub firmware. We focused particularly on developing sensors to be as close to reality as possible, knowing that many of the algorithm and sensor validations would need to be done without being in the water.

For real-world testing, we utilized the network created in simulation with ROS to connect with Iara via Ethernet cable, allowing us to monitor and potentially control the AUV. This way, we could initially test the functioning of all sensors and motor controls. For autonomous tests, we used ROS data logging, rosbag, for subsequent analysis of the AUV's performance. This allowed us to evaluate its overall performance and calibrate algorithms that require real data, such as the UKF for state estimation and dynamic model parameter estimation.

Acknowledgment

We would like to express our deep gratitude for the support we have received in our first year of creation and development at All Blue. Since our foundation late last year, none of this would have been possible without the support of the University of Brasília (UnB), specifically the Faculty of Technology (FT).

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APPENDIX A
COMPONENT SPECIFICATIONS

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost(if new)
Thruster	ROVMAKER	New T200 Brushless ROV Thruster - Regular Version for CW	–	Purchased	4 units - $556.00 USD
Thruster	ROVMAKER	New T200 Brushless ROV Thruster - Regular Version for CCW	–	Purchased	4 units - $556.00 USD
ESC	ROVMAKER	30A Self Starting Electronic Speed Controller	–	Purchased	8 units - $159.20 USD
Enclosure Vent and Plug	ROVMAKER	M10 Enclosure Vent and Plug	–	Purchased	1 unit - $8.90 USD
Cable Penetrator	ROVMAKER	M10 Big Cable Penetrator	–	Purchased	20 units - $98.00 USD
Air Tightness Detection Kit	ROVMAKER	–	–	Purchased	1 unit - $49.00 USD
Cable Penetrator	ROVMAKER	M10 Solid Penetrator - Aluminum Alloy	–	Purchased	5 units - $17.50 USD
Cable Penetrator	ROVMAKER	M16 Cable Penetrator	–	Purchased	1 unit - $9.80 USD
Waterproof PMMA Tube / Pipe	ROVMAKER	–	Out Diameter:160mm Length:500mm	Purchased	1 unit - $40.08 USD
Waterproof PMMA Tube / Pipe	ROVMAKER	–	Out Diameter:130mm Length:200mm	Purchased	1 unit - $12.35 USD
O-Ring Flange	ROVMAKER	–	160mm	Purchased	2 units - $79.98 USD
Underwater Optical Arcylic Dome Lens	ROVMAKER	–	160mm	Purchased	1 unit - $54.99 USD
Acrylic End Cap	ROVMAKER	–	160mm, 15 holes	Purchased	1 unit - $11.99 USD
Acrylic End Cap	ROVMAKER	–	130mm, 0 holes	Purchased	1 unit - $9.99 USD
Acrylic End Cap	ROVMAKER	–	130mm, 5 holes	Purchased	1 unit - $9.99 USD
O-Ring Flange	ROVMAKER	–	130mm	Purchased	2 units - $65.98 USD
Openrov Power Management Board	ROVMAKER	–	–	Purchased	1 unit - $59.00 USD

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost(if new)
Underwater Switch	ROVMAKER	M10 and M8 Underwater Switch	–	Purchased	1 unit - $20.39 USD
Lipo Battery	Helitec	Gens Ace	5s 18.5v 5000mah 50c C/ Xt60	Purchased	3 units - $514.89 USD
Jetson Nano	Waz	–	(4GB) (945-13450-0000-100)	Purchased	1 unit - $357.56 USD
Cameras	Uctronics	Arducam	100 FPS Global Shutter OV9782 UVC	Purchased	3 units - $162.02 USD
Depth Sensor	Full depth	300m Absolute Depth Sensor With MS5837-30BA	–	Purchased	1 unit - $30.45 USD
Depth Sensor Development Board	Full depth	–	–	Purchased	1 unit - $14.05 USD
Converter	Eletroshields	16-bit analog-to-digital converter ADS1115IDGSR	–	Purchased	1 unit - $44.52 USD
Nanoshield ADC	–	–	–	Purchased	1 unit - $14.28 USD
Battery Charger And Balancer	Mercado Livre	Lipo Imax B6ac With Source	–	Purchased	1 unit - $ 53.63 USD
MTI-3-DK	Br.mouser	–	–	Purchased	1 unit - $449.00 USD
CAT6 Shielded	–	–	50m	Purchased	50m - $35.67 USD
PLA Filament	–	–	–	Purchased	6 units - $99.22 USD
PETG Filament	–	–	–	Purchased	4 units - $74.67
Underwater Flashlight	–	–	–	Purchased	2 units - $146.62
Total					**$3,815.72 USD**

APPENDIX B
IARA ELECTRICAL ARCHITECTURE

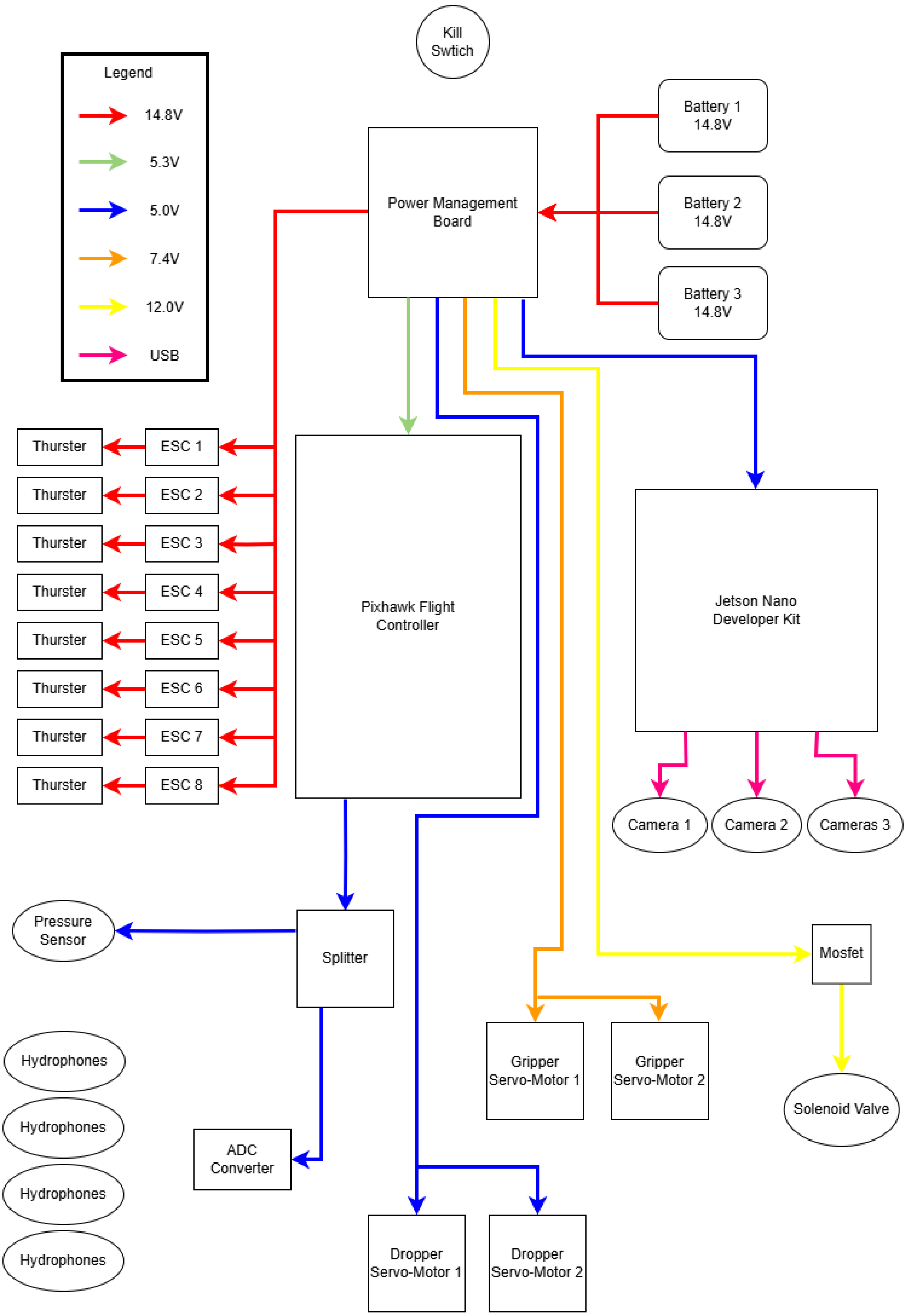

Fig. 5. Power architecture block diagram.

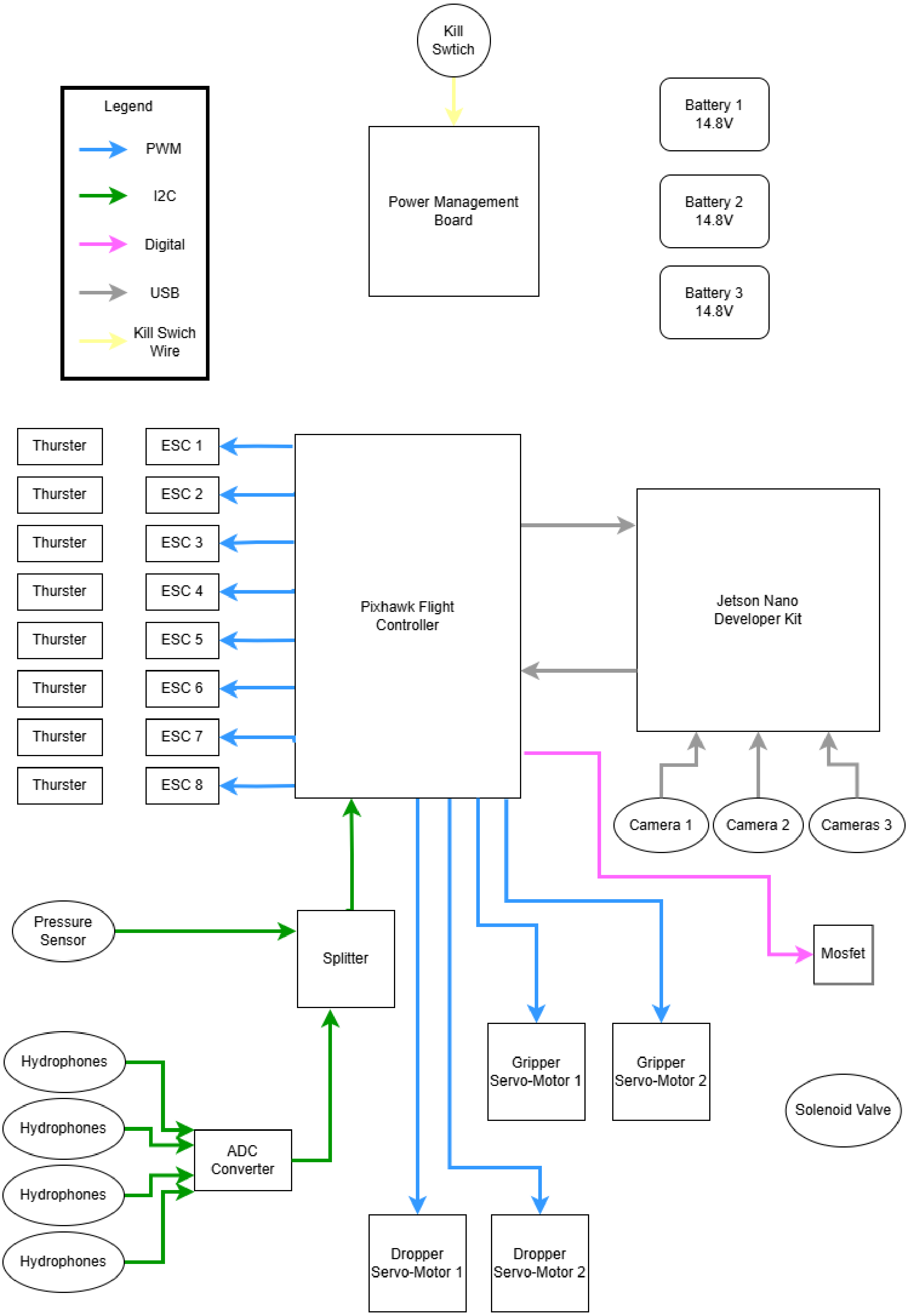

Fig. 6. Communication architecture block diagram.