Small-Scale ROV Onboard Electronics: System Architecture and Integration Design

Section 1: High-Level System Architecture and Design Philosophy

This document presents a comprehensive design for the onboard electronic systems of the small-scale Remotely Operated Vehicle (ROV) detailed in the project proposal.[1] The architecture is engineered to meet the dual requirements of robust, real-time vehicle control and high-level computational capacity for Machine Learning (ML) research. The design philosophy prioritizes modularity, reliability, and the leveraging of mature, open-source ecosystems to mitigate development risk and accelerate the path to a functional research platform.

1.1 Core Architectural Philosophy: A Hybrid Computation Model

The project's objective to create a testbed for novel ML control pipelines necessitates an architecture that can simultaneously manage two distinct computational domains: the deterministic, low-latency world of vehicle stability and the resource-intensive, high-level processing required for tasks like real-time video analysis and object recognition.[1] Attempting to manage both domains with a single processor, such as the Raspberry Pi 5, would introduce significant compromises. A general-purpose operating system like Linux is not a Real-Time Operating System (RTOS) and cannot guarantee the precise timing required for stable, closed-loop motor control, especially under high CPU load from an ML algorithm. Consequently, this design adopts a well-established dual-computer, or hybrid, architecture. This model segregates responsibilities between two specialized processing units:

1. **Flight Control Unit (FCU):** The **Pixhawk 6** will serve as the dedicated, real-time FCU.[1] Running the specialized ArduSub firmware, its sole responsibilities are to read and fuse data from its onboard Inertial Measurement Unit (IMU) and barometer, execute the core attitude and depth stabilization control loops, and generate the precise Pulse-Width Modulation (PWM) signals required to command the six thruster Electronic Speed Controllers (ESCs). This offloads all critical vehicle stability tasks to a dedicated, reliable

hardware and software environment.
2. **Companion Computer:** The **Raspberry Pi 5** will serve as the high-level companion computer.[1] Its role is to handle all non-real-time tasks, including processing the high-definition video stream from the camera, running ML inference models for object detection, managing communication with the topside control station via the tether, and issuing high-level motion commands (e.g., "move forward at 0.5 m/s," "hold current depth") to the Pixhawk 6.

This separation of concerns is a cornerstone of modern robotics design. It ensures that even if the companion computer experiences high load or a software fault, the FCU continues to operate independently, maintaining vehicle stability and preventing a catastrophic loss of control.

A significant advantage of this hardware architecture is its alignment with a mature, robust, and widely supported software ecosystem. The project proposal correctly identifies software integration as a high-likelihood, medium-consequence risk.[1] Rather than developing a custom software stack from the ground up, this design leverages the "Blue Robotics Stack." This consists of

BlueOS, a specialized Linux distribution designed to run on the Raspberry Pi companion computer, and **ArduSub**, the ROV-specific firmware variant for the PX4/ArduPilot flight controllers like the Pixhawk 6.[2]

By adopting this integrated stack, the project inherits pre-built, optimized solutions for:

- **MAVLink Communication:** The standardized protocol for communication between the companion computer, the FCU, and the topside control station.
- **Video Streaming:** Low-latency H.264 video streaming from the Raspberry Pi camera to the topside is handled automatically by BlueOS.[3]
- **Topside Control:** Seamless integration with QGroundControl, a comprehensive and feature-rich Graphical User Interface (GUI) for vehicle operation, parameter tuning, and data display.
- **Peripheral Management:** Drivers and interfaces for a wide range of common sensors and actuators are included.

This strategic decision effectively transforms the software integration challenge from a ground-up development effort into a configuration and tuning exercise. It mitigates one of the largest project risks and allows the engineering focus to remain on the primary project goal: the development and validation of ML pipelines, which can be integrated as new services or applications within the BlueOS framework.

1.2 Primary Subsystem Division

To manage the complexity of the design and assembly process, the complete electronic architecture is logically divided into three primary, interconnected subsystems. This modular approach simplifies analysis, testing, and potential future upgrades.

1. **Power Subsystem:** This is the foundational subsystem responsible for storing,

distributing, and regulating all electrical energy for the vehicle. It encompasses the main battery, safety circuits (including the kill switch), high-current power distribution to the propulsion system, and voltage regulation for sensitive electronics.
2. **Control & Computation Subsystem:** This is the "brain" and "nervous system" of the ROV. It includes the Pixhawk 6 FCU, the Raspberry Pi 5 companion computer, and the entire propulsion chain, from the ESCs to the six BlueRobotics T200 thrusters.
3. **Communications & Payload Subsystem:** This subsystem forms the ROV's link to the operator and its primary means of perceiving the underwater environment. It includes the Fathom-X tether interface boards for data transmission, the Raspberry Pi Camera Module 3, and the onboard illumination system.

1.3 Data and Control Flow Topology

The flow of data and commands through the system follows a clear, hierarchical path, ensuring predictable and reliable operation.

- **Operator Command Path (Topside to Thrusters):**
    1. The operator interacts with the **QGroundControl GUI** on a topside computer, manipulating a joystick to command vehicle motion.
    2. QGroundControl translates these inputs into **MAVLink command packets**.
    3. These packets are sent as standard Ethernet traffic from the computer's USB port to the topside **Fathom-X Tether Interface (FXTI)** box.[4]
    4. The FXTI modulates the Ethernet signal for transmission over a single twisted pair within the tether to the ROV's onboard **Fathom-X board**.[5]
    5. The onboard Fathom-X demodulates the signal back into standard Ethernet and passes it to the **Raspberry Pi 5**.
    6. **BlueOS** running on the Pi 5 receives the MAVLink packets and forwards them over a serial (UART) connection to the **Pixhawk 6 FCU**.
    7. The **ArduSub firmware** on the Pixhawk interprets the high-level MAVLink commands (e.g., SET_ATTITUDE_TARGET).
    8. The FCU's control algorithms calculate the precise thrust required from each of the six thrusters to achieve the commanded motion, sending corresponding **PWM signals** to the six **ESCs**.
    9. The ESCs translate the PWM signals into the appropriate three-phase power for the **T200 thruster motors**, generating thrust.
- **Data Return Path (ROV to Topside):**
    1. Vehicle telemetry (attitude, depth, heading, battery status) is continuously packaged into MAVLink packets by the Pixhawk and sent to the Raspberry Pi 5 via the UART link.
    2. The Raspberry Pi Camera Module 3 captures video, which is encoded into an H.264 stream by the Pi's hardware encoder.
    3. BlueOS multiplexes the MAVLink telemetry and the H.264 video stream into the

Ethernet data stream.
4. This combined data stream is sent back to the topside via the Fathom-X tether link, where it is displayed in the QGroundControl GUI.

This architecture ensures a clean separation of duties and a robust, multi-layered control structure.

Section 2: Power System Design and Energy Budget Analysis

The power system is the most critical element of the ROV's design. An improperly designed power system can lead to poor performance, insufficient operational endurance, and significant safety hazards. This section details a comprehensive analysis of the vehicle's power requirements and presents a robust design for the entire power subsystem, from the battery to the individual electronic components. The primary design driver is the project requirement for a one-hour operational runtime.[1]

2.1 Comprehensive Power Budget Estimation

To accurately specify the power system components, a detailed power and energy budget must be established. This budget must account for two distinct operational scenarios: the *peak power draw*, which dictates the requirements for wiring, connectors, and the battery's discharge capability; and the *average power consumption*, which determines the total energy required and thus the battery's capacity for the desired one-hour runtime.

The peak power draw occurs during maximum maneuvering, when multiple thrusters are commanded to full power simultaneously. The average power consumption represents a more typical operational profile of cruising, hovering, and performing inspection tasks. A crucial piece of data from real-world ROV operations indicates that a similar vehicle has an average current draw of approximately 20 A, with brief spikes into the 60-90 A range.[6] This real-world average will be used as the basis for our energy calculation, providing a much more realistic estimate than a theoretical average.

The power requirements for each major component are as follows:

- **Raspberry Pi 5:** While idle consumption is around 2.5-4 W, under the heavy load of ML processing, this can spike to 12 W.[7] For full performance and to supply adequate power to its USB peripherals, it requires a power supply capable of delivering 5V at 5A (25 W).[8] An average consumption of 8 W is a reasonable estimate for our operational scenario.
- **Pixhawk 6:** The flight controller itself has a modest power draw. The main consumption comes from powering connected peripherals. The combined output current is limited to 1.5 A for most port groups.[10] A conservative budget of 5 W is allocated for the FCU and its directly connected sensors.

- **BlueRobotics T200 Thrusters (x6):** This is the largest power consumer by a significant margin. At the nominal operating voltage of 16 V, a single T200 thruster draws 24 A (390 W) at full throttle.[12] The theoretical peak power draw for all six thrusters is therefore 6×390 W=2340 W, corresponding to a current of 144 A at 16 V.
- **Lumen Subsea Light:** At maximum brightness, this light consumes 15 W.[13]
- **Fathom-X Tether Interface:** Maximum power draw is specified as 2.5 W.[5]
- **Ancillaries:** A budget of 5 W is allocated for the camera module and other miscellaneous electronics.

These values are consolidated in the following power and energy budget table.

Table 2.1: ROV Power and Energy Budget

Component	Voltage (V)	Current - Avg. Cruise (A)	Current - Peak (A)	Power - Avg. (W)	Energy for 1hr (Wh)
Raspberry Pi 5	5	1.6	5.0	8.0	8.0
Pixhawk 6 & Sensors	5	1.0	1.5	5.0	5.0
T200 Thrusters (x6)	14.8-16.8	20.0 (System Total)	144.0 (System Total)	320.0	320.0
Lumen Subsea Light	14.8-16.8	1.0	1.0	15.0	15.0
Fathom-X Board	5	0.5	0.5	2.5	2.5
Camera & Misc.	5	1.0	1.0	5.0	5.0
Subtotal				**355.5**	**355.5**
Total with 20% Safety Margin				**426.6**	**426.6**

The analysis concludes that the ROV requires a power source capable of delivering a sustained average power of approximately 356 W and a total energy capacity of at least **427 Wh** to meet the one-hour operational requirement with a reasonable safety margin. The system must also be designed to handle peak currents in excess of 150 A.

2.2 Battery System Specification and Selection

The choice of battery is dictated by four key parameters derived from the power budget: nominal voltage, total capacity (energy), continuous discharge rating (power), and physical constraints (weight and volume).

- **Voltage:** The T200 thrusters are optimized for a nominal voltage of 16 V, which corresponds directly to a **4S (4-cell series) Lithium battery chemistry**, which has a nominal voltage of $4 \times 3.7\text{ V} = 14.8\text{ V}$ and a fully charged voltage of $4 \times 4.2\text{ V} = 16.8\text{ V}$.[12]

- Capacity: Based on the 427 Wh energy requirement, the necessary battery capacity in Amp-hours (Ah) can be calculated:
  $$ \text{Capacity (Ah)} = \frac{\text{Energy (Wh)}}{\text{Nominal Voltage (V)}} = \frac{427 \text{ Wh}}{14.8 \text{ V}} \approx 28.8 \text{ Ah} $$
  A capacity of at least 29,000 mAh is required. The Blue Robotics 14.8V, 18Ah battery, while a high-quality option, would provide a runtime of approximately $(18\text{ Ah}/28.8\text{ Ah}) \times 60\text{ min} \approx 37.5$ minutes under the estimated average load, failing to meet the project's endurance requirement.15
- Discharge Rating (C-rating): The battery must be able to safely deliver the peak system current of over 150 A. The C-rating defines the maximum discharge current as a multiple of the battery's capacity. For a 29 Ah battery, the required continuous C-rating is:
  $$ \text{C-rating} = \frac{\text{Peak Current (A)}}{\text{Capacity (Ah)}} = \frac{150 \text{ A}}{29 \text{ Ah}} \approx 5.2\text{C} $$
  This calculation reveals that while the peak current is very high, the required C-rating for a large capacity battery is relatively modest.
- **Chemistry (Li-ion vs. LiPo):**
  - **Lithium-Polymer (LiPo):** Offer very high C-ratings (often 70C or more), excellent power density, and are available in a wide range of sizes.[16] They are ideal for applications with high peak power demands. However, they typically have a lower cycle life and require more careful handling and storage.
  - **Lithium-Ion (Li-ion):** Generally offer higher energy density (more capacity for a given weight/volume) and a much longer cycle life. Their C-ratings are typically lower than LiPo batteries, but high-quality packs can meet the >5.2C requirement identified above.[18]

Recommendation:
The recommended primary option is a 4S Lithium-Ion (Li-ion) battery pack with a capacity of at least 29,000 mAh and a continuous discharge rating of 10C or higher. While a 5.2C rating is the calculated minimum, selecting a 10C pack provides significant headroom, ensuring the battery is not stressed during peak maneuvers, which improves both safety and longevity. A Li-ion pack is preferred over LiPo for its superior energy density and cycle life, which is more suitable for a research platform that will see frequent use. The GenX Ultra+ 14.8V 4S3P 18000mAh pack is an example of a Li-ion pack, though its 5C rating and lower capacity would not meet the project requirements.18 A custom or higher-spec pack will be necessary.

2.3 Power Distribution, Regulation, and Monitoring

A robust power distribution architecture is essential to deliver the correct voltage and current to each component reliably and without interference. A critical design consideration is the isolation of the high-power, noisy propulsion system from the sensitive, low-power

computation and control electronics. A voltage drop or electrical noise induced by a thruster spinning up could cause the Raspberry Pi or Pixhawk to reboot, leading to mission failure.
To prevent this, a segregated, dual-regulator strategy will be implemented. This ensures that the two most critical processing units, the Pi 5 and the Pixhawk 6, are powered by independent, isolated voltage regulators.

1. **Main Power Distribution Board (PDB):** The central hub of the power system will be a high-current PDB. The battery's main terminals will connect to the PDB's input. The PDB will provide multiple high-current output pads, to which the six thruster ESCs will be directly connected. The PDB must be rated to handle a continuous current well in excess of 150 A.
2. **Dedicated Companion Computer Regulator:** The Raspberry Pi 5 has a demanding and specific power requirement of 5V at up to 5A.[8] To meet this, a **Blue Robotics 5V 6A Power Supply** will be used.[19] This is a high-efficiency switching Battery Eliminator Circuit (BEC) that converts the 14.8V from the PDB down to a stable 5V. Its 6A output capacity provides the necessary headroom for the Pi 5's peak demand.[19] This BEC will be used *exclusively* to power the Raspberry Pi 5, ensuring it has a clean, stable, and isolated power source.
3. **Dedicated FCU Power and Monitoring:** The Pixhawk 6 and other low-power 5V electronics (like the Fathom-X board) will be powered by a separate, secondary system. This system consists of two components:
   - **Power Sense Module (PSM):** The **Blue Robotics Power Sense Module** will be installed in-line with the main battery connection to the PDB.[20] This module uses a Hall effect sensor to accurately measure the total system voltage and current draw. This critical telemetry data is fed to an analog input on the Pixhawk 6, allowing ArduSub to monitor battery health, estimate remaining runtime, and trigger low-battery failsafes. It is crucial to note that the Blue Robotics PSM *does not* provide a 5V regulated output; it is for sensing only.[20]
   - **Secondary 5V BEC:** A small, secondary 5V BEC (rated for at least 3A) will also be connected to the 14.8V PDB output. This BEC will provide power to the Pixhawk 6's power input port and to the Fathom-X board. This completes the electrical isolation, as any power fluctuations on the Pi 5's 6A BEC will not affect the power supplied to the flight controller.

This dual-BEC architecture is a critical design choice that significantly enhances the robustness and fault tolerance of the entire electronic system.

2.4 System Safety Circuits: The Kill Switch

As identified in the project proposal, the safety of personnel around high-speed propellers is a high-consequence risk.[1] A reliable kill switch is not an optional feature; it is a mandatory safety device. The kill switch must be capable of interrupting the flow of current to the entire system, even under full load (>150 A). A simple mechanical toggle switch, like the Blue Robotics 5A switch, is entirely inadequate for this purpose and would be destroyed instantly.[21] The correct implementation is a high-current DC contactor or relay controlled by a low-power external switch. For a marine application, a **magnetic kill switch** provides an ideal, waterproof method of activation.[22]

The design will incorporate a normally-open DC contactor rated for at least 200 A at 24 VDC, placed in the main positive power line between the battery and the PDB. The coil of this contactor will be energized by a low-power circuit controlled by an externally mounted, waterproof magnetic switch. A lanyard with the corresponding magnet will be attached to the operator or a safe location on the surface. When the magnet is in place, the contactor coil is energized, closing the main power circuit and allowing the ROV to operate. If the operator pulls the lanyard, removing the magnet, the coil de-energizes, the contactor opens, and all power to the ROV is immediately and completely cut off. This provides a failsafe mechanism for emergency shutdown.

Section 3: Computation, Control, and Propulsion Integration

This section details the integration of the core computational, control, and propulsion components. These connections form the "nervous system" of the ROV, translating high-level commands into physical motion.

3.1 Autopilot and Companion Computer Interface

The communication link between the Raspberry Pi 5 companion computer and the Pixhawk 6 FCU is the primary pathway for control commands and telemetry. The standard protocol for this link is MAVLink, transmitted over a physical serial (UART) connection.

The Raspberry Pi 5 provides access to several UARTs via its 40-pin GPIO header. The Pixhawk 6 features multiple standardized telemetry ports (e.g., TELEM1, TELEM2), which are serial interfaces designed for this purpose.[10]

The physical connection will be made between one of the Raspberry Pi 5's configured UARTs and the TELEM2 port on the Pixhawk 6. This is a three-wire connection:

- Pi 5 TXD (Transmit) pin connects to Pixhawk RX (Receive) pin.
- Pi 5 RXD (Receive) pin connects to Pixhawk TXD (Transmit) pin.
- Pi 5 GND (Ground) pin connects to Pixhawk GND pin.

A common ground reference is essential for reliable serial communication. Within the BlueOS software and the ArduSub firmware parameters, the baud rate for this serial port will be configured to 921600 bps. This high speed ensures sufficient bandwidth for the rich stream of MAVLink messages, including commands, vehicle state, sensor data, and status updates, without creating a communication bottleneck.

3.2 Propulsion System Integration

The propulsion system consists of the six T200 thrusters and their corresponding Basic ESCs. The Pixhawk 6 acts as the central controller, generating the command signals for the ESCs. Each of the six ESCs will be connected to one of the main PWM outputs on the Pixhawk 6's I/O rail (typically outputs 1 through 6). The ESCs receive their high-current 14.8V power directly from the dedicated output pads on the PDB. The connection from the ESC to the Pixhawk is a standard 3-pin servo connector. This connector carries three signals:

- **Signal (White/Yellow wire):** This carries the PWM signal from the Pixhawk, which commands the thruster speed and direction (1100µs for full reverse, 1500µs for stop, 1900µs for full forward).[25]
- **Ground (Black/Brown wire):** Provides a common ground reference between the ESC and the Pixhawk.
- **+5V (Red wire):** The ESC's internal BEC provides a 5V output on this wire. This is a potential source of power conflict.

Crucial Implementation Note: To prevent the ESC's internal BEC from back-feeding power into the Pixhawk's power rail, which is already being supplied by its dedicated secondary BEC, the red +5V pin must be carefully removed from all six ESC servo connectors before plugging them into the Pixhawk. This ensures the Pixhawk is only powered by its clean, dedicated source.

Once wired, the ArduSub firmware must be configured for the correct vehicle layout. Using the QGroundControl interface, the frame type will be set to "Vectored-6DOF" (also known as the BlueROV2 frame).[26] This pre-configured setting correctly maps the joystick inputs for surge, sway, heave, roll, pitch, and yaw to the appropriate mixture of outputs for the six thrusters in their vectored configuration.

3.3 Vision System Integration

The vision system is central to the ROV's purpose as a research platform for ML-based perception. The selected Raspberry Pi Camera Module 3 provides a high-resolution image sensor suitable for this task.[1]

The Raspberry Pi 5 is equipped with two 4-lane MIPI Camera Serial Interface (CSI) connectors, designed for direct, high-bandwidth connection to camera modules.[27] The Camera Module 3 will connect directly to one of these CSI ports using the appropriate flexible flat cable.

One of the significant advantages of using the BlueOS software stack is its native support for the Raspberry Pi cameras.[3] Upon booting, BlueOS will automatically detect the connected camera module. It will then configure and launch a GStreamer pipeline to capture the video, perform hardware-accelerated H.264 encoding, and stream it over the network via the

Fathom-X link. This provides a low-latency, high-definition video feed to the topside QGroundControl station with zero custom software development required for basic functionality. This pre-built video pipeline provides the necessary input for any ML models that will be developed and deployed on the Raspberry Pi 5.

Section 4: Communications and Auxiliary Systems

This section details the subsystems that connect the ROV to the operator and enable it to perceive and interact with its environment.

4.1 Tethered Communications Subsystem

A reliable, high-bandwidth communication link is essential for teleoperation and for transmitting the data required for ML research. The project specifies the use of a Fathom-X module for this purpose.[1] The Fathom-X Tether Interface Board set utilizes the HomePlug AV standard to create a robust Ethernet-over-powerline style connection, but adapted for a simple twisted-pair of wires.[5] This technology enables a practical bandwidth of 80 Mbps over tether lengths exceeding 300 meters, which is more than sufficient for HD video and telemetry.[5]

The implementation requires two Fathom-X boards: one onboard the ROV and one at the topside control station.

- **Onboard ROV:** The ROV's Fathom-X board will be mounted inside the main electronics enclosure. It will be powered by the same secondary 5V BEC that powers the Pixhawk. An Ethernet patch cable will connect the Fathom-X board's RJ45 port to the Raspberry Pi 5's Ethernet port. A single twisted pair of wires from the main tether will be connected to the board's two-position screw terminal.
- **Topside Station:** The second Fathom-X board will be housed in a topside interface box, such as the Blue Robotics FXTI.[4] This board is typically powered via a USB connection from the operator's computer. The same twisted pair from the tether connects to its screw terminal.

This setup creates a transparent Ethernet bridge. From the perspective of the topside computer and the Raspberry Pi 5, they are simply two devices on the same local area network, connected by a very long Ethernet cable. This simplifies all network configuration and allows for standard IP-based communication (e.g., SSH, MAVLink over UDP, RTSP video streaming).

4.2 Illumination Subsystem

Effective illumination is critical for underwater vision, especially as ambient light diminishes rapidly with depth. The project requires a light to ensure camera viability.[1] The

Blue Robotics Lumen Subsea Light is an excellent choice, providing over 1500 lumens of brightness from a 15 W input.[13] It is designed for subsea use, operates on a wide voltage range (10-48V), and its brightness can be controlled via a standard PWM signal.[13]
One or two Lumen lights will be mounted on the ROV frame, typically flanking the camera to provide even, shadow-free illumination of the forward-looking scene.

- **Power:** The lights will be powered directly from the main 14.8V bus. Their power and ground wires can be connected to an auxiliary output on the PDB or spliced directly into the main power distribution wiring.
- **Control:** The yellow PWM signal wire from each light will be connected to one of the auxiliary PWM output pins on the Pixhawk 6 (e.g., AUX1, AUX2).

This control scheme allows the operator to adjust the light intensity directly from the QGroundControl GUI. A joystick button or slider can be mapped to the corresponding SERVO_FUNCTION in ArduSub's parameters, providing intuitive, real-time control over the scene's illumination. This is particularly important for ML applications, as it allows for consistent lighting conditions to be established, improving the performance and reliability of vision-based algorithms.

Section 5: Final System Architecture and Implementation Guide

This section consolidates all preceding design decisions into a practical blueprint for the assembly and wiring of the ROV's electronic systems. The following diagram description and wiring schedule serve as the master reference for implementation.

5.1 Consolidated System Architecture Diagram

The system architecture diagram provides a high-level visual representation of every component and their interconnections. It is organized by subsystem and uses distinct line styles to represent the different types of connections: power, control, and data.
Diagram Description:

- **Power Subsystem (Core):**
  - A **4S 29,000mAh Li-ion Battery** is the central power source.
  - The positive lead from the battery connects to the input of a **200A DC Contactor (Kill Switch Relay)**.
  - The output of the contactor connects to the main input of the **High-Current Power Distribution Board (PDB)**. The battery's negative lead connects directly to the PDB's ground input.
  - A **Magnetic Kill Switch** is shown externally, with a low-current control line energizing the coil of the DC Contactor.

    - The **Blue Robotics Power Sense Module (PSM)** is shown in-line on the main positive and negative leads between the contactor and the PDB, with its sense cable connecting to the Pixhawk 6's power port.
- **High-Current Distribution (14.8V):**
    - Thick red and black lines emanate from the PDB's output terminals to each of the **six Thruster ESCs**.
    - Separate 14.8V lines run from the PDB to the inputs of the **Blue Robotics 5V 6A BEC (for Pi 5)** and a **Secondary 5V 3A BEC (for FCU)**.
    - A 14.8V line also runs from the PDB to power the **Lumen Subsea Light(s)**.
- **Regulated Power Distribution (5V):**
    - A distinct 5V power domain is shown originating from the 6A BEC, with a line connecting to the **Raspberry Pi 5**'s power input (USB-C or GPIO).
    - A second, separate 5V power domain is shown originating from the 3A BEC, with lines connecting to the **Pixhawk 6**'s power input and the **Fathom-X Board**'s power input.
- **Control and Data Flow:**
    - **PWM Signals:** Dashed lines run from the **Pixhawk 6 PWM Outputs (1-6)** to the signal inputs of the six ESCs. Another dashed line runs from a **Pixhawk 6 AUX Output** to the PWM signal input of the Lumen Light.
    - **Serial (MAVLink):** A solid line with arrows indicates the bidirectional UART connection between the **Pixhawk 6 (TELEM2)** and the **Raspberry Pi 5 (GPIO UART)**.
    - **Ethernet:** A solid line represents the Ethernet connection between the **Raspberry Pi 5 (RJ45 Port)** and the onboard **Fathom-X Board (RJ45 Port)**.
    - **Video (MIPI CSI):** A wide ribbon cable is shown connecting the **Raspberry Pi Camera Module 3** to the **Raspberry Pi 5 (CSI Port)**.
    - **Tether:** A line representing the tether connects the onboard **Fathom-X Board (Terminal Block)** to the topside **Fathom-X Board**, indicating the single twisted pair used for Ethernet communication.

This diagram provides a complete, top-down view of the system, illustrating the modularity and segregation of the subsystems.

5.2 Master Wiring Schedule

To complement the system diagram and eliminate ambiguity during assembly, the following table provides a detailed, wire-by-wire connection schedule. This schedule should be used as a definitive checklist during the physical integration process.

Table 5.2: Master Wiring Schedule

ID	From Component	From Port/Pin	To Component	To Port/Pin	Wire Type/Gauge	Signal/Purpose	Notes

High-Current Power							
PW-01	Battery	Positive (+) Terminal	Kill Switch Relay	Input	8 AWG, Red	Main System Power	
PW-02	Battery	Negative (-) Terminal	PDB	Main GND Input	8 AWG, Black	Main System Ground	
PW-03	Kill Switch Relay	Output	PDB	Main VIN Input	8 AWG, Red	Switched Main Power	PSM Current Sense loop must be on this wire.
PW-04	PDB	ESC Output 1 (+/-)	ESC 1	Power Input (+/-)	12 AWG, Red/Black	Thruster 1 Power	Repeat for all 6 ESCs (PW-04 to PW-09).
PW-10	PDB	Aux Output (+/-)	6A BEC (for Pi)	Power Input (+/-)	18 AWG, Red/Black	Pi 5 Regulator Power	
PW-11	PDB	Aux Output (+/-)	3A BEC (for FCU)	Power Input (+/-)	20 AWG, Red/Black	FCU Regulator Power	
PW-12	PDB	Aux Output (+/-)	Lumen Light	Power Input (+/-)	20 AWG, Red/Black	Light Power	
Low-Current Power							
PW-13	6A BEC (for Pi)	5V Output (+/-)	Raspberry Pi 5	5V GPIO Pin / GND	18 AWG, Red/Black	Pi 5 Main Power	Connect to appropriate 5V and GND pins on GPIO header.
PW-14	3A BEC (for FCU)	5V Output (+/-)	Pixhawk 6	POWER1 Port (+/-)	22 AWG, Red/Black	FCU Main Power	
PW-15	3A BEC (for FCU)	5V Output (+/-)	Fathom-X Board	Power Input (+/-)	22 AWG, Red/Black	Comms Board Power	Can be spliced from PW-14.
Control Signals							
CTRL-01	Pixhawk 6	PWM Out 1	ESC 1	Signal	24 AWG	Thruster 1	Repeat for

		(S)		Input	Servo Wire	Signal	all 6 ESCs (CTRL-01 to CTRL-06). **Remove red wire from ESC connector.**
CTRL-02	Pixhawk 6	AUX Out 1 (S)	Lumen Light	PWM Signal Input	24 AWG, Yellow	Light Brightness Control	
Data Connections							
DATA-01	Pixhawk 6	TELEM2 (TX)	Raspberry Pi 5	GPIO UART (RXD)	26 AWG	MAVLink Data to Pi	
DATA-02	Pixhawk 6	TELEM2 (RX)	Raspberry Pi 5	GPIO UART (TXD)	26 AWG	MAVLink Data to FCU	
DATA-03	Pixhawk 6	TELEM2 (GND)	Raspberry Pi 5	GPIO GND	26 AWG	Serial Ground Ref	
DATA-04	Raspberry Pi 5	Ethernet Port	Fathom-X Board	RJ45 Port	Cat5e Patch Cable	Main Ethernet Link	
DATA-05	Raspberry Pi Cam 3	CSI Connector	Raspberry Pi 5	CSI Port 0	MIPI CSI Ribbon	Raw Video Data	
DATA-06	Fathom-X Board	Tether Terminal	Tether	Twisted Pair 1	24 AWG UTP	Ethernet over Tether	Connect to topside Fathom-X board.
Sensing & Safety							
SENSE-01	PSM	Sense Cable	Pixhawk 6	POWER1 Port (V, I)	JST-GH Cable	Voltage & Current Sense	Connects to V, I, and GND pins on power port.
SAFE-01	Magnetic Switch	Control Out (+/-)	Kill Switch Relay	Coil (+/-)	22 AWG	Relay Control	Powers the contactor coil to enable main

							power.

This comprehensive architecture and wiring plan provides a robust, reliable, and extensible electronic foundation for the QUT small-scale ROV. By leveraging a mature hardware and software ecosystem and implementing sound engineering principles for power distribution and system safety, this design will enable the project to successfully meet its objectives and serve as a valuable platform for future ML research.

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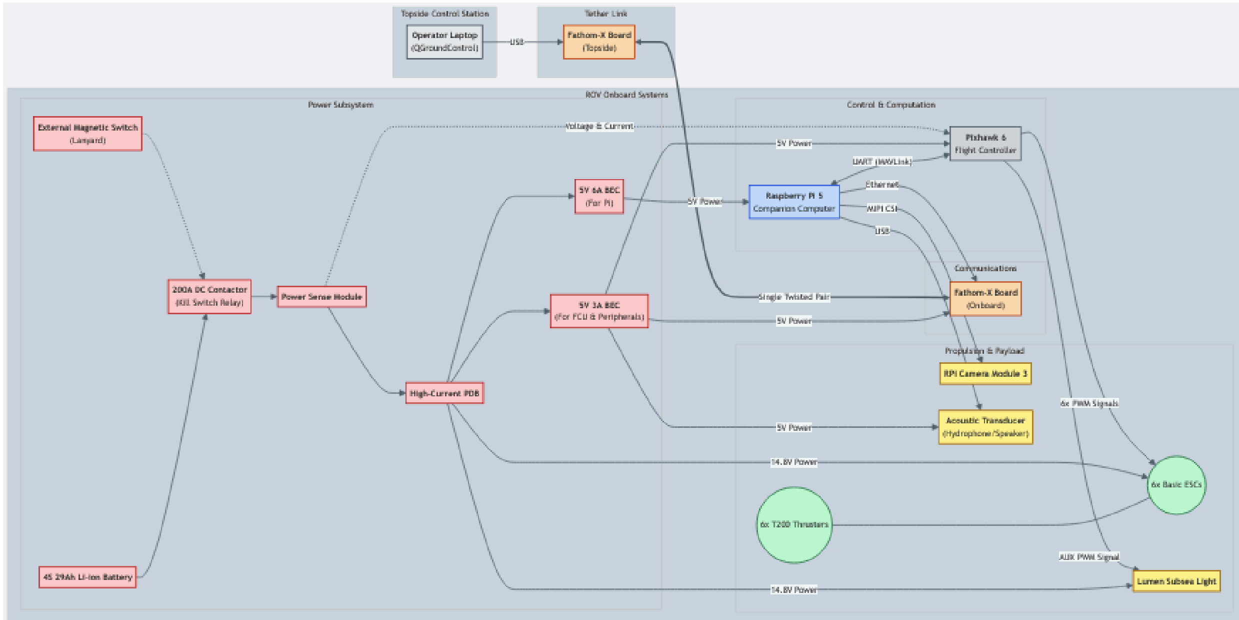
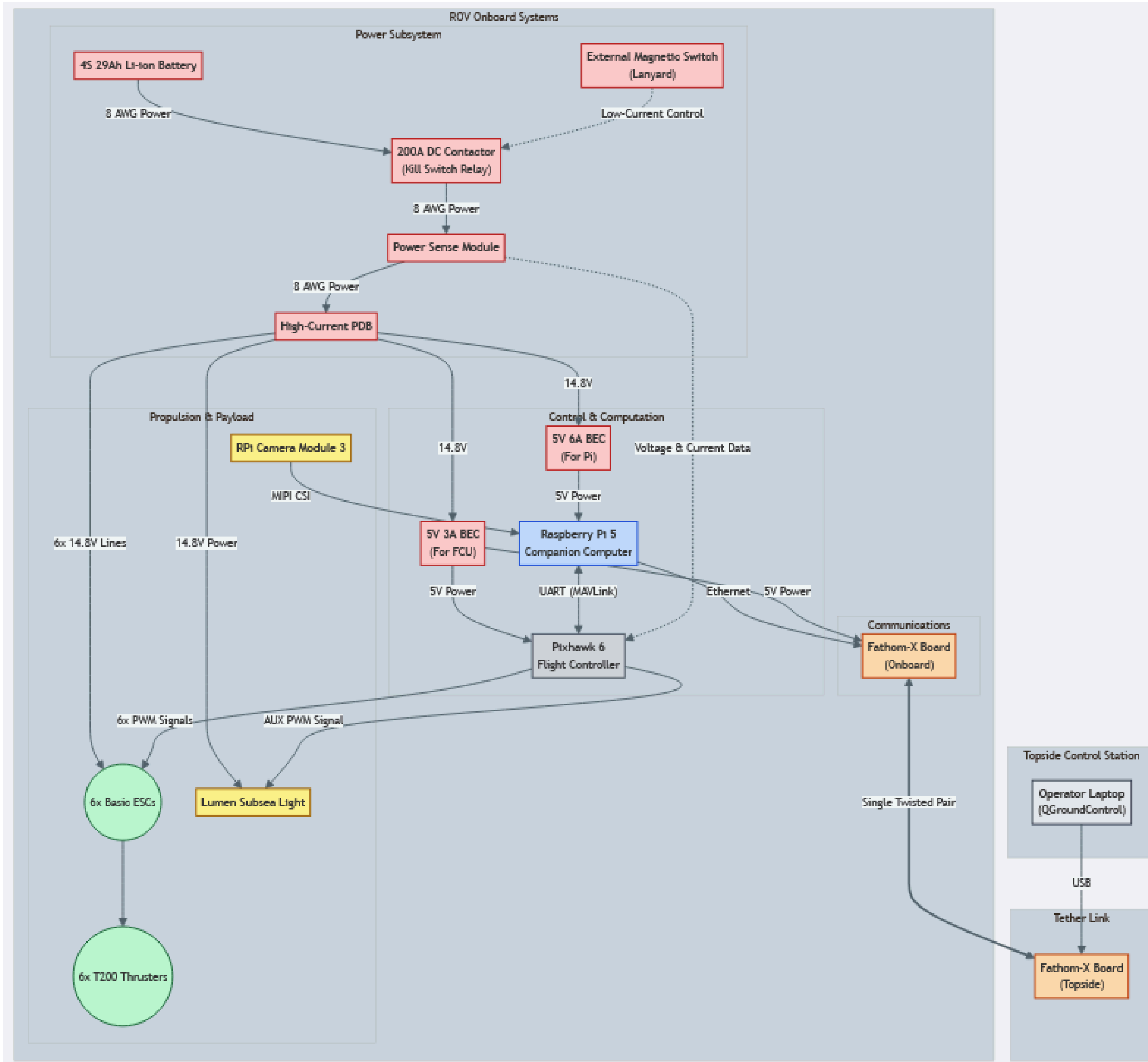


Topside Control Station
Operator Laptop
(QGroundControl)
USB
Tether Link
Fathom-X Board
(Topside)
ROV Onboard Systems
Power Subsystem
External Magnetic Switch
(Lanyard)
200A DC Contactor
(Kill Switch Relay)
Power Sense Module
High-Current PDB
4S 29Ah Li-ion Battery
5V 6A BEC
(For Pi)
5V 3A BEC
(For FCU & Peripherals)
Voltage & Current
5V Power
Control & Computation
Pixhawk 6
Flight Controller
UART (MAVLink)
Raspberry Pi 5
Companion Computer
Ethernet
MIPI CSI
USB
Communications
Fathom-X Board
(Onboard)
Single Twisted Pair
Propulsion & Payload
RPI Camera Module 3
Acoustic Transducer
(Hydrophone/Speaker)
6x PWM Signals
14.8V Power
6x Basic ESCs
6x T200 Thrusters
AUX PWM Signal
Lumen Subsea Light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