Drone-Deployed Stealth RUV with Fin Propulsion and Non-Metallic Body for Sonar-Evasive Underwater Surveillance

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Academic Year: 2024 – 2025

Paper Type: Project Report

Submitted in partial fulfillment of the requirements for the award of the degree **Bachelor of Engineering in Electronics and Communication Engineering**

1.Abstract

This project centres on deploying a carrier drone to a specified operational area. Once the drone arrives at its targeted destination, it releases a compact Remote Underwater Vehicle (RUV). To evade sonar detection during surveillance, the RUV uses a non-metallic hull and a fin-based propulsion system. The information from the RUV is transmitted through wireless communication to the operator.

The main goal is to reach inaccessible locations and collect critical data in high-risk scenarios. The drone flies to the specified area and releases the RUV, which submerges and provides a live input to the user using wireless communication modules. The RUV system consists of a high-precision flight controller, BLDC motor, waterproof electronic components, and a camera unit for real-time monitoring.

The main application is for underwater inspection, deep-sea research, and natural disaster recovery operations. Due to its compact and sleek nature, the carrier drone and the RUV can perform various tasks, and many unexplored or potentially dangerous areas can be examined to the RUV’s maximum extent. This project is safe, efficient, and beneficial, as it eliminates the need for direct human involvement in confined or hazardous environments, making the overall system ethically suitable.

2.INTRODUCTION

In today's generation the need to discover inaccessible, high-risk areas to collect information and data has increased by a huge margin. It's a competition between countries to get as much as information and data from anything and everything as in today's generation information is wealth, and anything can be used to our convenience. Traditional methods include human scuba divers or large-scale marine vehicles which are cost inefficient and harmful leaving room for errors

To overcome all these obstacles the project mainly prioritises on deploying a carrier drone to the specified area which later deploys a Remote Underwater Vehicle (RUV). The RUV is designed with a non-metallic hull and a fin-based propulsion system to minimize sonar detection and enhance movement in underwater environments.

The main objective of the project is to provide a safe and a beneficial environment for humans to explore the deepest parts of the world safe and attain the necessary data using the carrier drone and the RUV

With future developments this application can have huge potential and can take humanity to greater heights for collecting information

3.EXISTING SYSTEM VS PROPOSED SYSTEM

3.1 EXISTING SYSTEMS

Deep-sea underwater excavation has always been a focal point of future ocean exploration. Present-day system for underwater exploration mainly relies on large submarines and direct human involvement, which makes them highly threatening and often lead to missed exploration sites. Traditional submarines and underwater vehicles are massive in size, making deployment strenuous in confined spaces. In contrast, the construction of such large vessels introduces possibilities of technical malfunctions, especially when exposed to extreme underwater pressure variations during deep-sea expeditions.

Human involvement in deep-sea missions adds an additional layer of liability is due to extreme hydrostatic pressure, low visibility, unpredictable marine life, and potential equipment failure. Along with physical danger, these systems also exhibit multiple detectable signatures, making them unfit for stealth-based underwater operations. Large submarines and other underwater vehicles generate high acoustic noise signatures from propellers and on-board machinery, and they also produce magnetic and thermal signatures, which can be detected using SONAR systems and Magnetic Anomaly Detection (MAD) sensors.

Large underwater vehicles are also very expensive to manufacture and maintain because they require specific pressure-resistant materials and frequent system recalibration. This is very difficult to fix mechanical or sensor issues during underwater missions, which results in operational risk and mission delays.

Deploying a Remotely Operated Vehicle (ROV) or an Autonomous Underwater Vehicle (AUV) requires assistance from a ship. This process is tedious as it involves manual labour and the use of a crane. Technical failures during deployment can often have serious consequences. This causes delay and slowly tends to become an incomplete or a messy project

In the event of damage such as oil leaks, structural failure, or insufficient battery charge replacement of the vehicle requires a significant amount of time causing huge time delay. This delay directly affects the search and rescue operations. In worst-case scenarios, data can be lost entirely due to transmission failure.

A corrupted or inoperative ROV or AUV at depth presents a risk of water pollution, which can severely impact aquatic life. The plastics and electronic components within these vehicles are non-biodegradable and can persist in the environment, harming the essential microorganisms that sustain the marine biosphere.

Underwater robots such as Remotely Operated Vehicles (ROV), Autonomous Underwater Vehicles (AUV) and related platforms, must constantly send out critical information back to an operator. This includes live video monitoring, sensor readings, temperature, and system status. However, achieving this lossless communication is a monumental challenge because water is the natural enemy for wireless transmission.

The primary issue is that radio waves which enable our everyday Wi-Fi, internet and Bluetooth connections are almost instantly absorbed by water. Once underwater their signal strength drops to nearly zero, rendering standard wireless communication useless. This fundamental limitation is why most underwater robots, particularly ROVs, rely on a physical tether cable to transmit data.

Operating a robotic system for underwater exploration is an endeavour of staggering complexity and cost. The journey begins with the equipment itself; a single ROV or AUV, built from deep-sea pressure-resistant materials and fitted with advanced navigation and sensory systems, can represent an investment of crores of rupees before it even touches the water.

This is just the first step, however. To guide this robot on a mission far from shore requires a sophisticated support vessel a floating command centre equipped with cranes, winches and control rooms. The daily charter for such a specialized ship is a major operational expense often running into lakhs of rupees per day making extended missions a serious financial undertaking.

3.2 PROPOSED SYSTEM

The proposed system employs a carrier drone for the exploration of an area to be investigated. While in flight, the drone releases a non-metallic-hulled Remote Underwater Vehicle (RUV), which also uses fin propulsion to reduce its acoustic, magnetic, and thermal signatures upon arrival at its intended operational destination.

Two-way wireless communication linking the RUV to the operator allows monitoring and collection of underwater data in real time. By minimizing human interaction, the system reduces risks associated with extreme hydrostatic pressure and unpredictable maritime conditions. The RUV can enter tight spaces and difficult-to-reach locations due to its compact and futuristic design, eliminating overlooked zones and enabling a complete sweep of the site for detection purposes.

The proposed system is a portable, safe, ethical, and economical substitute for large submarines and other deep underwater exploration vehicles. The system significantly lowers operating and maintenance costs while improving mission safety by eliminating direct human involvement and reducing dependence on large underwater vehicles.

The combination of aerial mobility and stealth underwater capability provides a powerful platform for scientific research, defence operations, infrastructure inspection, and exploration of untouched marine environments.
Conventional methods reliant on costly support ships and cranes, this design cuts the need for a launch vessel. This extensively cuts deployment costs, slashes mission planning time, and reduces the heavy crew requirements that have long made underwater operations so resource intensive.

The platform's unique advantage is its ability to precisely deploy an underwater vehicle over long distances into areas that are otherwise inaccessible or perilous for humans. Imagine reaching into collapsed structures, radiation zones, deep ocean trenches, or disaster sites—all without putting a single person at direct risk. A sophisticated dual-layer control system provides both flexibility and reliability. The vehicle can navigate autonomously for efficiency and stability, while also allowing operators to switch to precise manual control for complex tasks requiring a human touch.

The system is built for versatility through modularity. It can be fitted with a range of payloads—from HD cameras and manipulator arms to water samplers and environmental sensors—making it a single solution adaptable for military, industrial, and scientific applications.

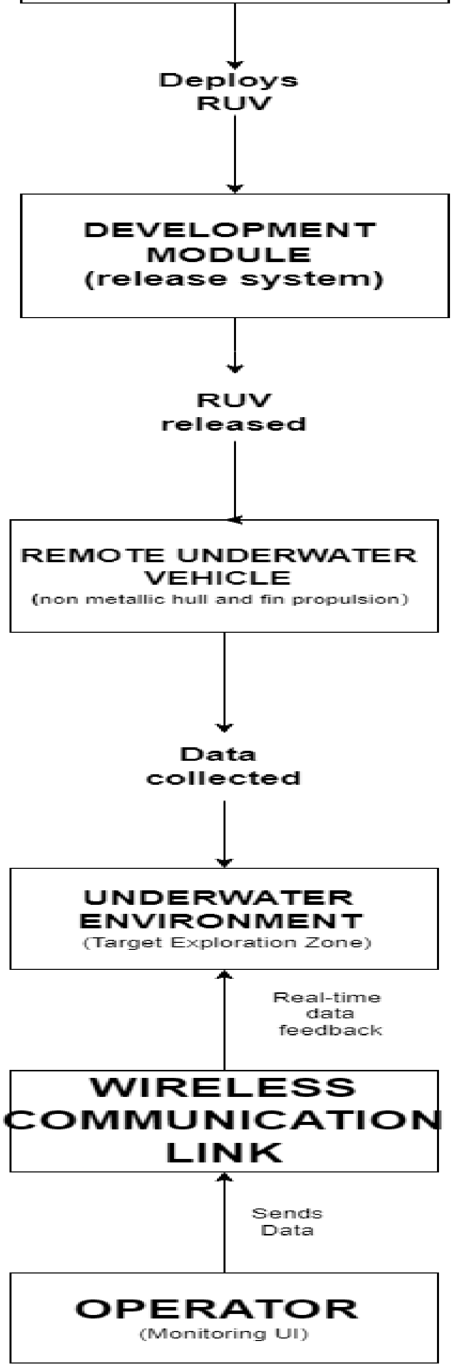
Human safety is the cornerstone of the design philosophy. By removing the need for divers or field engineers to enter high-risk underwater environments, it ensures that critical inspection tasks no longer come with inherent personal danger.

Intelligent power management is key to its endurance. The system optimizes consumption by activating only the specific modules needed for each phase of its mission: flight, landing, diving, and underwater manoeuvring.

Finally, the entire system is built for rapid response. It requires minimal setup and a small crew, enabling deployment in a fraction of the time required for traditional marine operations. All mission data is securely stored, encrypted, and easily shared, ensuring that valuable findings are both reliable and protected.

4. BLOCK DIAGRAM

The block diagram of the proposed system illustrates the overall architecture of the carrier drone and Remote Underwater Vehicle (RUV). The given diagram represents the flow of operations from input to output and shows just how each subsystem interacts.



The given Block diagram shows us the operational flow of the mentioned system. The operator conveys the mission by sending control commands to the carrier drone. Upon reaching the site the carrier drone activates the deployment module to release the RUV. The remote underwater vehicle is equipped with non-metallic hull and fin-based propulsion which navigates through the underwater environment and collects all the necessary information even in the most confined places. Real-time wireless communications ensures that the data gathered by the RUV is continuously transmitting the Information back to the operator. This closed and secure architecture guarantees an efficient, safe and reliable underwater Data acquisition without the need of a direct human

4.1 SYSTEM DESCRIPTION

Operator: The person who Operates the mission, gives commands, and gets real-time system updates is referred to as the operator.

Carrier Drone: Flies to the designated spot and securely transports the RUV to the deployment site.

Deployment module: The drone's internal mechanism that releases the RUV upon reaching the target location is called the deployment module.

Remote Underwater Vehicle: A remote underwater vehicle (RUV) navigates underwater, investigates complicated or confined spaces, and gathers crucial data.

Wireless Communication Link: Provides the operator with rapid underwater information from the RUV.

Unexplored underwater environment: The Deep underwater territory used for data collection and exploration is known as the "Unexplored underwater environment."

4.2 Key Features (Detailed Explanation)

- **Hybrid air-to-water mission capability:**
  The system can operate both in air and underwater. The drone handles aerial travel and transports the RUV to the target location, while the RUV performs underwater exploration after deployment. This hybrid ability makes it more flexible and capable than using only a drone or only a submarine.

- **Bio-mimetic fin propulsion for silent underwater movement:**
  Instead of using noisy propellers, the RUV moves using fin-like propulsion which are inspired from Tuna fish this ideology is called biomimicry. This reduces sound generation and avoids disturbing marine life. It also makes the RUV more difficult to detect through underwater acoustic sensors like Sonar radars.

- **Non-metallic hull to reduce sonar detection:**
  The RUV body is made using non-metallic materials instead of metal.

This helps the underwater RUV to avoid being detected from sonar systems and magnetic detectors, making it ideal for stealth missions in high stakes or high-surveillance waters during wars.

- **Live remote monitoring to ensure operator safety:**
  The operator does not need to physically enter the dangerous underwater zone. Live updates and sensor data are transmitted wirelessly to the base station, enabling safe decision-making from a distance without exposing humans to risk.
- **Suitable for high-risk and inaccessible locations:**
  The combination of a drone and RUV allows the system to reach places that humans or submarines cannot access easily — such as deep waters, narrow caverns, highly pressurized zones, disaster-hit areas, and unstable maritime environments.
- **Cost-effective design with low maintenance requirements:**
  The system avoids the need for large submarines or manned exploration vessels. Both the carrier drone and the RUV are compact and modular, which reduces repair cost, fuel/electricity usage, and overall operational expenses.
- **High-accuracy data collection using multiple sensors:**
  The RUV can be equipped with underwater cameras, pressure sensors, temperature sensors, turbidity sensors, sonar modules, and chemical analysers. These allow detailed scanning of underwater conditions for scientific, industrial, or defence purposes.
- **Environmental friendliness and ethical operation:**
  The silent propulsion and non-metallic body help minimize disruption to marine life. The system performs exploration without harming aquatic ecosystems and is suitable for ecological research.

5.HARDWARE AND SOFTWARE REQUIREMENTS

5.1 HARDWARE REQUIREMENTS

The proposed system consists of a carrier drone and a remote-control underwater vehicle (RUV). The system hardware is selected to ensure a high durable and high adaptability which makes them reliable for both aerial and underwater environments.

MATERIALS	SPECIFICATIONS	FUNCTION
CARRIER DRONE	Quadrotor, 2 kg payload capacity, Li-Po battery	Transport and deploy RUV to target location
Remote Underwater Vehicle (RUV)	Compact, waterproof, non-metallic hull, fin-based propulsion	Compact, waterproof, non-metallic hull, fin-based propulsion
Microcontroller	STM32 / Arduino	Control motors, sensors, and wireless communication
Sensors	Gyroscope, accelerometer, pressure, sonar	Navigation, stabilization, and obstacle detection
Communication Module	Wi-Fi / RF / Bluetooth	Real-time data exchange between drone, RUV, and ground station
Camera & Imaging Systems	Waterproof 1080p camera, optional thermal/night-vision	Visual monitoring and recording of underwater operations

5.2 HARDWARE DESCRIPTION

- Our system's hardware is carefully selected to make sure that the drone and the Remote Underwater Vehicle (RUV) work together effortlessly. Let's examine each component into great detail:

- **Carrier Drone:** The drone operates like that of our system's "carrier." The RUV is being safely transported to its intended location by this quadrotor, which has a lifting power of up to 2 kg and it offers long lasting flight duration and the stability for precise missions as it is fuelled by a Li-Po battery.
- **Remote Underwater Vehicle (RUV):** The element that submerges is known as a remote underwater vehicle, or RUV. It is sleek, waterproof, and has a unique non-metallic hull that makes it "invisible" to sonar. It can move precisely underwater, much like a small fish, via to the fin-based propulsion system.
- **Microcontroller:** The brain of the system is the microcontroller (STM32 or Arduino). It controls the motors, reads data from sensors, and makes sure the drone and RUV communicate with each other correctly. The microcontroller used in this project acts as the central brain that controls both the drone and the RUV. It continuously receives data from different sensors and uses that information to make decisions in real time.
- **Sensors:** Sensors act like the "eyes and balance system" of our hardware. Gyroscopes and accelerometers keep the system steady, pressure sensors tell the RUV how deep it is, and sonar sensors help detect obstacles underwater.
- **Communication Module:** This is how the drone and RUV talk to the user. Using Wi-Fi, RF, or Bluetooth, the system sends real-time data to the control station, so the user can monitor and control the devices remotely.
- **Camera and Imaging Systems**: Waterproof cameras capture live video from underwater. Optional features like thermal or night-vision cameras can be added for exploring dark or tricky environments. This way, the user always knows what's happening underwater.

Remarks:

1. All hardware is selected for durability, portability, and precise operation in both air and water

2. The non-metallic RUV hull helps it stay stealthy by reducing sonar detection.

6.SOFTWARE REQUIREMENTS

6.1 SOFTWARE RECOMMENDATIONS

SOFTWARE	PURPOSE IN THIS PROJECT	RESON FOR SELECTION
Flight Control Firmware (e.g., ArduPilot / PX4)	Controls the navigation, stability and flight modes of the carrier drone	Open-source, reliable, widely used in UAV research and supports autonomous missions
Microcontroller Programming IDE (e.g., Arduino IDE / STM32CubeIDE)	Used for programming the microcontroller modules that manage sensors, propulsion and control signals	Easy integration with multiple microcontroller families and supports real-time testing
Wireless Communication Interface Software	Enables data exchange between drone ↔ RUV ↔ ground control station	Supports multiple protocols and provides secure data transmission
Ground Control Station Software (e.g., QGroundControl / Mission Planner)	Used for mission planning, real-time monitoring, telemetry display and parameter tuning	User-friendly interface and compatibility with PX4/ArduPilot-based systems
Image and Video Processing Software (e.g., OpenCV with Python/C++)	Processes live video feed from the RUV camera and extracts useful information	Efficient library with large community support and optimized performance for embedded systems
Data Storage and Analysis Software (e.g., MATLAB / Python with NumPy & Pandas)	Stores collected sensor and video data for post-mission analysis	Powerful scientific computing tools suitable for research-based applications
Simulation Software (e.g., Gazebo / MATLAB Simulink / BlueROV Simulator)	Used to simulate the drone-RU V deployment and underwater navigation before field testing	Reduces hardware risk and cost while validating design performance
Cryptographic / Security Module	Protects the transmitted and stored mission data	Ensures secure data handling, especially for defence and disaster-related operations

6.2 SOFTWARE REQUIREMENTS

The system software implements a distributed, multi layered architecture designed to facilitate coordinated operation between an Autonomous Underwater Vehicles (AUV) and a Remotely Operated Underwater Vehicle (ROV). This architecture ensures powerful mode transitions during the RUV's deployment from aerial to aquatic environment managing communication, navigation, data processing and user control.

1. Core Control & Processing Layer

The primary control interface is implemented in Python selected for its broad ecosystem in robotics libraries (ROS, Drone Kit) and rapid prototyping capabilities. This layer takes care of high-level functions such as real-time telemetry aggregation, GPS-based path planning and actuation of the deployment mechanism. For estimatingly demanding, low-latency control of underwater propulsion and stability the RUV contains a dedicated real-time module written in C or C++ for optimal performance and power efficiency. This divided approach ensures each platform utilizes the most effective programming paradigm for its operational constraints.

2. Firmware & Navigation Stack

Both platforms make use of a common, open-ended autopilot firmware baseline (PX4/ArduPilot). This provides a fundamental foundation for stable navigation, failsafe automation, gregarious environment and comprehensive mission logging. The use of this shared stack enhances system reliability, enables autonomous behaviours, and guarantees consistent data formats for post-mission analysis.

3. Human Machine Interface (HMI)

User interaction is connected through a graphical user interface (GUI) matured in MATLAB or Python (using frameworks such as Tkinter or PyQt). The HMI (Human Machine Interface) visualizes RUV-centric multisensory data streams, including camera feed, depth and orientation. It provides spontaneous control widgets for vehicle guidance and configurable safety parameters thus maintaining operator situational awareness and command authority throughout the mission profile.

4. Cross Medium Communication Protocol

A critical software component manages the wireless data link between the UAV and RUV. It employs a low-frequency, acoustic based modulation scheme designed for underwater signal propagation. The process incorporates forward error correction

(FEC) and automatic repeat request (ARQ) mechanisms to soothe packet loss. This ensures command integrity and allows the RUV to execute contingency behaviours such as maintaining its last valid state—during temporary communication latency or dropout.

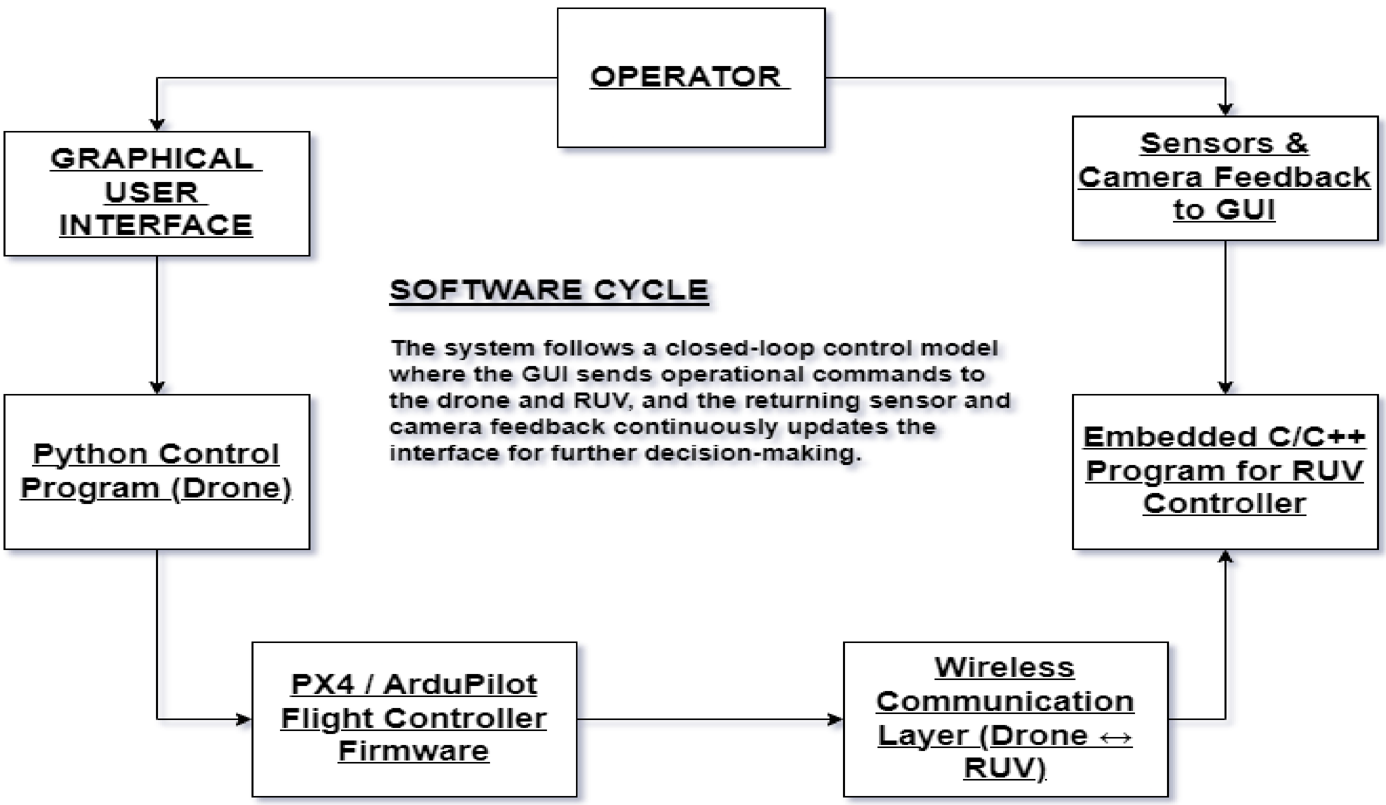
5. Security & Safety Assurance

The system incorporates cybersecurity measures, including encrypted command and control channels using AES-256 standards to prevent unauthorized access. A dedicated safety supervisor module continuously monitors system health and link integrity. Upon detection of critical interference or fault conditions, this module can trigger predefined fail-safe routines, including graceful system shutdown or autonomous return-to-surface procedures.

Conclusion

Henceforth, this software framework transforms two distinct robotic platforms into a unified exploration system. By leveraging domain-specific languages, standardized navigation firmware, a resilient communication protocol, and a user-centric interface, the architecture ensures operational reliability, precision, and safety during complex missions in dynamic and high-risk underwater environment

FLOW CHART:



7. ALGORITHM:

Algorithm for Drone-Based RUV Deployment System

Step 1: Start
Step 2: Power ON the drone and initialize all onboard sensors
Step 3: Establish communication link between Drone, RUV, and GUI
Step 4: Enter destination coordinates in the GUI
Step 5: Drone takes off and begins autonomous navigation to the target location
Step 6: Continuously monitor drone position and sensor feedback during flight
Step 7: Upon reaching the target location, release the RUV into the water
Step 8: RUV activates propulsion and underwater navigation mechanisms
Step 9: Underwater sensors scan and collect environmental data
Step 10: Transmit live telemetry and scanned data to the GUI
Step 11: Check if underwater exploration is completed

- **If NO:** continue underwater navigation and data scanning
- **If YES:** proceed to retrieval protocol

Step 12: RUV returns to the surface and re-docks with the drone
Step 13: Drone prepares for return flight (optional based on mission plan)
Step 14: End

DESCRIPTION:

This project outlines the continuous and sequential operational phases for a divergent robotic system consisting of a Carrier drone and a Remotely Operated Underwater Vehicle (RUV) designed for Deep Sea deployment and exploration.

Phase 1: System Initialization

The mission starts with the sequential power-up of all hardware subsystems and the launch of the primary mission control software. This initial boot sequence performs important self-tests establishing a verified operational condition for both the UAV and RUV before the physical deployment.

Phase 2: Pre-Flight Calibration

The UAV autonomously executes a comprehensive sensor calibration routine. This step involves initializing the Inertial Measurement Unit (IMU) to accomplish a stable attitude reference, acquiring a multi-constellation GPS fix for global positioning, zeroing the barometric altimeter, and configuring the onboard optical systems. The objective is to provide the UAV with a highly accurate and stable understanding of its environment before lift-off to ensuring subsequent navigation precision.

Phase 3: Network Establishment

A secure and multi-link communication network is established. Encrypted command-and-control channels are opened between the Ground Control Station (GCS), the UAV (typically via radio frequency, e.g., 2.4/5.8 GHz), and the RUV (via a pre-established acoustic telemetry link). This network functions as the mission's central nervous system, enabling real-time data exchange and supervisory control.

Phase 4: Mission Planning and Upload

The operator defines the operational envelope by inputting the target deployment geocoordinates and any relevant parameters (e.g., altitude, search patterns) into the graphical mission planner. This digital travel plan is then uploaded to the UAV's flight controller, transmitting its course from launch to the deployment point.

Phase 5: Free Aerial Transit

Upon command the UAV executes an automated take off rising to a predetermined safe and recommended altitude. It then engages its self-governing navigation stack transitioning to waypoint-following mode. The vehicle crosses all the aerial corridor to the target zone, spontaneously adjusts its path and travel based on integrated sensor feedback along with the wind conditions and obstacle avoidance protocols.

Phase 6: In Transit Monitoring and Assurance

Throughout the flight the system maintains continuous state awareness. The flight controller and companion computer monitors a array of real-time telemetry including attitude, position, velocity and system health while running obstacle detection algorithms. This allows for proactive and subtle trajectory corrections ensuring a stable, efficient, and safe transit.

Phase 7: Deployment Zone Verification

Upon reaching the target coordinates, the UAV enters a precision station-keeping mode. It utilizes high-accuracy positioning (e.g., RTK-GPS) to lock its horizontal location and employs its altimeter and vision systems to maintain a stable hover at the exact deployment altitude. This confirmation of position is the critical prerequisite for a successful handoff to the aquatic domain.

Phase 8: Aquatic Payload Deployment

Following a final systems check and operator confirmation, the UAV triggers its electromechanical release mechanism. The RUV is cleanly deployed, beginning a controlled descent through the air-sea interface to commence its submerged mission phase.

Phase 9: RUV Activation and Submersion

Upon water entry, the RUV transitions from a stowed payload to an active vehicle. Its onboard systems—propulsion, buoyancy control, and attitude stabilization—are powered in sequence. It achieves neutral buoyancy and executes a controlled dive, establishing itself as a stable, agile underwater platform.

Phase 10: Subsurface Exploration and Sensing

The RUV initiates its core data-gathering function. Following a pre-defined or operator-directed survey pattern, it synthesizes data from its multi-modal sensor suite: sonar for bathymetric mapping and object detection, cameras for high-resolution optical inspection, and environmental probes for in-situ measurements (e.g., temperature, salinity). This phase systematically builds a coherent dataset of the underwater environment.

Phase 11: Real-Time Data Relay and Operator Feedback

A continuous uplink streams compressed telemetry, sensor data, and video from the RUV to the UAV via the acoustic modem. The UAV acts as a communications relay, forwarding this data to the GCS. This provides the operator with a real-time visualization of the subsurface environment, enabling informed mission assessment and potential command intervention.

Phase 12: Dynamic Mission Assessment

The system, in concert with the operator, continuously evaluates progress against the predefined mission objectives (e.g., area coverage, target identification).

Continuation: If objectives are unmet, the RUV adapts its survey pattern or receives new operational parameters to continue data acquisition.

Termination: If all objectives are satisfied, the exploration phase concludes, and the system state machine transitions to the retrieval and recovery sequence.

Phase 13: Recovery and Docking Sequence

The RUV is commanded to execute a controlled ascent. Upon surfacing, it activates a homing protocol, utilizing localized positioning (e.g., from the UAV's beacon) and guided magnetic coupling to maneuver into precise alignment and achieve a secure physical docking with the UAV.

Phase 14: Return to Launch Point

With the RUV securely recovered, the UAV calculates an optimal return trajectory. It then initiates an automated Return-to-Launch (RTL) procedure, navigating back to the home point while continuously managing power and flight stability.

Phase 15: Landing Shutdown and Secure Data Handling

The mission concludes with the UAV's automated landing sequence. Once on the ground, we methodically power down all vehicle systems. The final, crucial step is to collect and secure the complete mission logs—including every sensor reading, system event, and captured image—ensuring all data is safely stored and ready for the team's analysis. The mission is officially complete.

Keywords — Autonomous Aerial Navigation, RUV Deployment, Underwater Telemetry, Sonar Mapping, Closed-Loop Control

8.FLOWCHART:

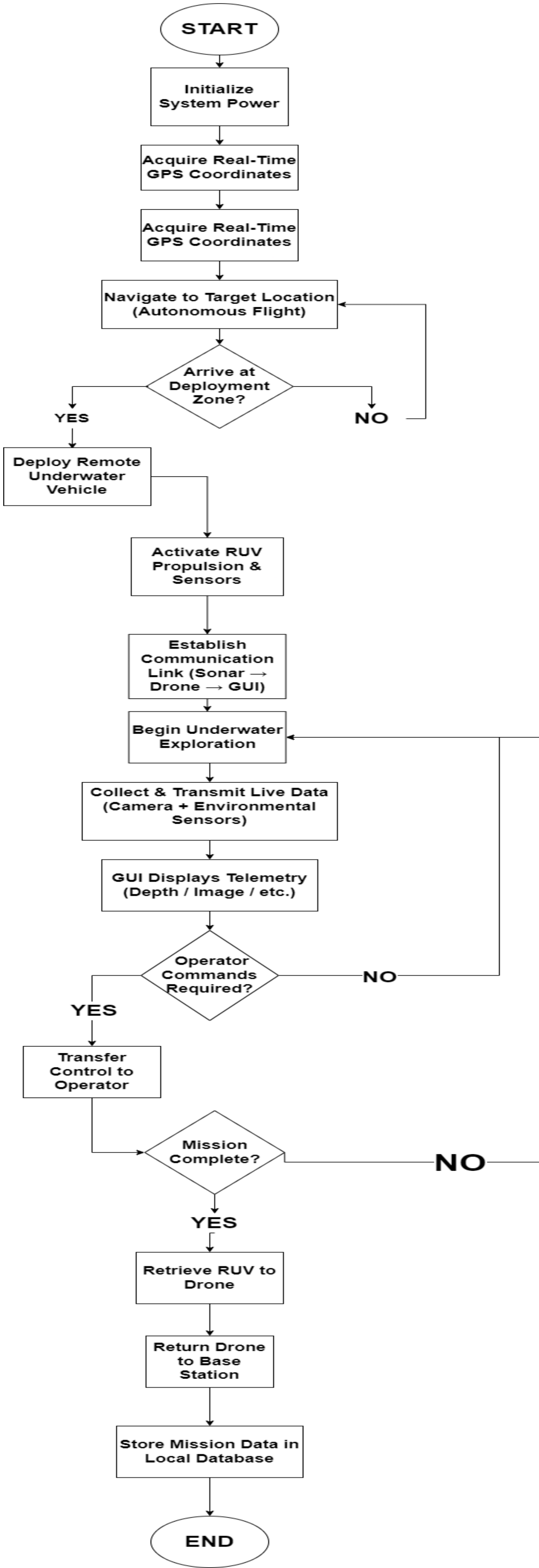
Think of the drone as a sensitive, modern-day courier. It starts by waking up, checking its systems, and shaking hands digitally of course with both the human operator's control screen and the underwater vehicle it's carrying.

Once the operator sends it a destination, the drone takes off. It's not just flying in a straight line it's constantly thinking on its feet and is independent using its sensors to adjust its path around any unexpected obstacles, much like a driver navigating detours.

When it arrives at the precise spot over the water, it gently delivers its package: the underwater exploration vehicle. The moment it hits the water this U-boat gets to work using sonar to map the hidden world below and sensors to read the environment.

All the while both the drone and its aquatic partner are sending a live stream of information—where they are, what they're seeing, and what they're finding—back to the operator's screen on shore.

Mission accomplished below the surface, the underwater vehicle comes back up. In a carefully coordinated maneuver the drone swoops down, picks up its partner and carries it home. The drone flies back to base, mission complete and is ready for its next delivery.



8.1 FLOWCHART OBSERVATION / INFERENCE

This isn't just a machine it's a well-rehearsed team with a clear idea the whole process is built carefully and connected where each chapter has The presented flowchart delineates the operational architecture of a proposed autonomous drone based Remote Underwater Vehicle RUV deployment system The design is characterized by a modular state triggered workflow where each operational stage is a prerequisite for the subsequent one enforcing strict subsystem validation and preventing premature state transitions The system comprises three core interoperable modules the Unmanned Aerial Vehicle UAV the RUV and the Ground Control Station GCS with its Graphical User Interface GUI These modules maintain continuous synchronization via a unified bidirectional communication network

A key structural pattern is the phased transfer of operational control During the aerial transit phase the UAV executes autonomous navigation with continuous closed loop correction fusing GPS data with onboard sensor feedback for real time trajectory optimization Upon reaching the designated deployment coordinates the system initiates a supervised handoff protocol transferring primary agency from the UAV to the RUV This transition managed by the embedded communication interface occurs without external intervention demonstrating robust system level integration

The system implements a hybrid autonomy model creating a closed loop feedback system during nominal operation The RUVs navigation and data acquisition routines are governed by sensor telemetry and predefined mission parameters This autonomous mode is persistently querying the command channel upon receipt of a manual override instruction from the GCS the system performs a dynamic context switch to a human in the loop HITL control paradigm This dual mode architecture enhances operational adaptability in unstructured environments and provides a critical layer of safety redundancy

Furthermore, the mission logic is objective driven not temporally bounded The RUV remains in its exploration state until a complete set of mission objectives such as area coverage or specific data thresholds is satisfied as defined by its tasking parameters This design philosophy optimizes energy consumption per data unit and maximizes payload utility within a single deployment cycle thereby reducing unnecessary mobility and associated failure risks

The terminal phase of the workflow exemplifies a structured termination protocol The sequence comprising RUV retrieval UAV homing and systematic data offload ensures not only the safe recovery of hardware assets but also the integrity and archival of all acquired data This formalized shutdown procedure is essential for applications requiring high data fidelity such as scientific bathymetric surveys long duration monitoring or forensic inspection to finish before the next one can begin. The three main characters—the Drone, the underwater vehicle (RUV), and the operator's control screen (GUI)—each have their own jobs, but they're in constant conversation, making sure no one is ever left out of the loop.

You can see a clear handoff of responsibility as the mission progresses. First, the drone is in charge, smartly adjusting its flight path on the fly using GPS almost like it's thinking its way to the destination. Once it arrives at the drop point it seamlessly passes the baton to the RUV which slips into the water without a hitch. This smooth transition means the system doesn't need a babysitter; it knows exactly when to switch modes.

The system is designed to listen on two channels. Most of the time, it runs on autopilot, making its own decisions based on what its sensors tell it. But the moment an operator speaks up, it immediately pauses its own plans and follows human direction. This gives us the best of both worlds: efficient, hands-free operation, with a human always able to take the wheel if things get tricky or unexpected.

Perhaps the smartest part is that the mission runs on purpose, not on a clock. The underwater vehicle doesn't call it quits just because an hour has passed. It keeps exploring until the job is done. This means no wasted battery life circling an empty seabed, and it comes back only when it has gathered everything it was sent for.

Finally, the mission doesn't just end—it concludes properly. The RUV returns to the drone, the drone comes home, and all the precious data it collected is securely saved and stored. It's the difference between finishing a task and truly completing it, making the system reliable for serious work like science or surveillance.

In short, this flowchart shows a system built not just to function, but to succeed. It's autonomous but obedient, efficient but thorough, and smart enough to handle a complex job from start to finish with remarkable independence.

Sensor & Camera Integration:

The proposed system integrates an onboard sensor suite with a specialized underwater camera to facilitate comprehensive environmental perception throughout the exploration phase. This multisensory framework supports both autonomous operational decisions and operator-directed feedback, enabling dynamic adaptation to variable undersea conditions.

Sensor Integration

Aerial Drone Sensor Suite

To achieve autonomous flight stability and precise navigation the aerial drone relies on a suite of integrated sensors. An Inertial Measurement Unit (IMU) provides real time attitude and kinematic data. A Global Positioning System (GPS) module supplies global coordinates for geolocation and waypoint navigation. For critical altitude situations particularly during the deployment time of the Remotely Operated Underwater Vehicle (RUV) an altitude sensor such as a barometer or LiDAR unit measures flight height. The onboard flight controller performs continuous sensor fusion on these data streams enabling the real-time computation and execution of stable flight maneuver and navigational commands.

Underwater Robot Sensor Suite

The RUV is equipped with a set of sensors specifically selected for the challenges of the underwater domain. A pressure sensor provides accurate depth estimation, while a temperature sensor supports environmental data collection. An onboard IMU monitors the vehicle's orientation and motion. A critical leak detection sensor ensures operational safety by alerting to potential water ingress. Together, these sensors deliver the necessary feedback for controlled navigation and system integrity during submerged missions.

Vision Systems

Aerial Imaging System

The drone is connected to a camera system that supplies real time visual telemetry to the ground operator. This effectiveness is essential for monitoring the target deployment zone visually supervising the RUV release sequence and maintaining overall situational and environmental awareness. The captured video is transmitted wirelessly to the ground control station for live monitoring and analysis.

Underwater Imaging System

The RUV incorporates a camera designed for aquatic environments, enabling direct visual exploration and inspection. This system allows for the observation of underwater terrain, man-made objects, and biological features. To ensure functionality in typically low-light conditions, the vehicle is supplemented with controlled lighting modules. The recorded visual data supports both real-time piloting and post-mission research analysis.

Closed-Loop Control Architecture

Both platforms operate on a closed loop control principle sensor and camera data are continuously processed by their respective onboard controllers. These controllers generate real time actuation commands to maintain stability and execute tasks. Simultaneously key feedback data is relayed to a central Graphical User Interface (GUI) enabling humans to monitor system states and intervene with corrective regulation when necessary.

Significance of System Integration

The cohesive integration of complementary sensor modalities and vision systems significantly enhances the overall autonomy, reliability, and data fidelity of the platform. Through sensor fusion and real-time visual feedback, the proposed heterogeneous system is capable of effective operation in the complex and distinct environments of air and water. This integration makes it a suitable solution for demanding applications in environmental monitoring, underwater exploration, and maritime research.

System Architecture

Overview

The system architecture for the proposed drone deployed underwater robot is designed to ensure reliable operation, modularity and efficient coordination between its aerial and underwater subsystems. This architecture defines the structural organization of hardware and software components and establishes the flow of control and control signals. The result is a unified framework that supports seamless approach, decision making, communication and actuation throughout the entire mission lifecycle.

Architectural Description

The system is organized into three primary, functionally distinct layers:

- **Aerial Subsystem (Drone Unit)**
- **Underwater Subsystem (RUV Unit)**
- **Ground Control and Monitoring Unit (GUI)**

Each subsystem operates with a degree of autonomy while remaining logically interconnected through a structured communication and control hierarchy.

Aerial Subsystem Architecture

The aerial drone serves as the deployment and navigation platform. It integrates an onboard controller with several dedicated modules:

- **Sensor Module:** Incorporates navigation and stabilization sensors, including GPS, IMU, and altitude sensors.
- **Camera Module:** Provides real-time aerial imagery for navigation and deployment monitoring.
- **Control Unit:** Processes sensor and camera data to compute flight control signals.

- **Communication Module:** Manages the transmission of telemetry and video to the ground station and the reception of command inputs.
- **Actuation Module:** Comprises motors and electronic speed controllers that physically execute flight commands.

The onboard controller continuously processes data inputs to execute closed-loop control, maintaining stable flight and ensuring the accurate deployment of the underwater robot.

Underwater Subsystem Architecture (RUV)

The Remotely Operated Underwater Vehicle (RUV) is engineered as a self-contained exploration unit. Its architecture supports operation in submerged environments through the following components:

- **Environmental Sensor Module:** Includes pressure, temperature, and leak detection sensors for depth estimation, environmental analysis, and system safety.
- **Underwater Camera Module:** Equipped for visual data capture to support observation and inspection tasks.
- **Onboard Controller:** Performs real-time data processing and local decision-making based on sensor inputs.
- **Propulsion and Actuation Unit:** Governs the vehicle's movement and orientation underwater.
- **Communication Interface:** Facilitates data exchange with the surface system, typically via the drone or a tethered link.

This modular design enables the RUV to adapt dynamically to underwater conditions while preserving operational safety and mission flexibility.

Ground Control and GUI Architecture

The ground control station functions as the system's supervisory node. It aggregates data from both the drone and the RUV to provide:

- Real-time visualization of sensor data and video streams.

- Comprehensive mission monitoring and data logging.
- An interface for operator control inputs and manual override commands.

The Graphical User Interface (GUI) acts as the primary human–machine interface, designed to facilitate effective interaction with the autonomous system.

Data Flow and Control Strategy

Sensor and camera data from both subsystems are transmitted to their respective onboard controllers for processing and control signal generation. A subset of this data is relayed to the ground station for situational awareness. When required the human commands are sent back through this two-way communication channel to the vehicle controllers. This architecture implements a robust closed loop control strategy that ensures system responsiveness, reliability and adaptability to mission demands.

Architectural Significance

The proposed architecture emphasizes modularity, scalability and robustness. By clearly characterizing the sensing, processing, communication and actuation layers. The design simplifies integration aids in fault isolation and supports future system enhancements. This structured approach aligns with established IEEE-recommended practices for autonomous and cyber physical systems.

Summary

In summary, this system architecture provides a comprehensive structural framework for the coordinated operation of the drone and underwater robot. Through well-defined subsystems and a controlled data flow, it effectively supports autonomous exploration, enables real-time monitoring, and ensures reliable mission execution across both aerial and underwater domains.

Methodological Framework

This section details the operational methodology for the drone-deployed underwater robotic system. It outlines the structured, step-by-step procedure from mission initiation through exploration and recovery, emphasizing the coordinated interaction between hardware, software, sensors, and human oversight. The modular framework is designed to ensure reliability, safety, and effective mission execution.

Step 1: Mission Initialization and System Check
The mission begins at the ground control station, where the operator configures mission parameters such as the deployment coordinates and establishes communication links. A comprehensive pre-launch check is performed on both the aerial drone and the Remotely Operated Underwater Vehicle (RUV) to verify the operational status of all sensors, cameras, power systems, and communication modules, ensuring system-wide readiness for a safe launch.

Step 2: Aerial Navigation to Deployment Zone
Following initialization, the drone autonomously takes off and navigates to the target location using GPS waypoint navigation. Throughout the transit, onboard sensors—including the IMU and an altitude sensor (barometer or LiDAR)—provide continuous feedback to the flight controller for stabilization. A live video feed from the drone's camera is transmitted to the ground station, enabling the operator to visually confirm the intended deployment area.

Step 3: Deployment of the Underwater Robot
Upon reaching the designated coordinates, the drone stabilizes at a pre-set altitude. The operator provides final authorization via the graphical user interface (GUI), triggering the release mechanism. The deployment is monitored in real time using the drone's camera to visually verify the safe and accurate entry of the RUV into the water.

Step 4: Underwater Descent and Depth Stabilization
Post-deployment, the RUV initiates a controlled descent. Its onboard

controller processes depth data from the pressure sensor and orientation data from the IMU to execute autonomous stabilization algorithms. These algorithms actively manage the propulsion system to achieve and maintain the desired operational depth.

Step 5: Supervised Underwater Exploration
During the exploration phase the RUV operates in a semi-autonomous mode the human operator provides high level navigation commands (e.g. directional movement) through the GUI. Subsequently, the RUV's onboard control system autonomously handles lower-level functions such as depth holding, attitude stabilization and real time safety checks. A continuous stream of underwater video and sensor data to the ground station supports operator decision-making.

Step 6: Continuous System Health and Safety Monitoring
Throughout the mission the system performs continuous monitoring of critical parameters including internal leak detection, pressure abnormalities and communication link integrity. Should a fault be detected, predefined fail-safe protocols are automatically executed. These may include ceasing propulsion or initiating an emergency ascent to prevent system loss or damage.

Step 7: Environmental Data Acquisition and Telemetry
During exploration, the RUV collects environmental data from its sensor suite and captures visual information with its onboard camera. This data is packaged and transmitted to the ground control station. While a subset of this information is processed for real-time operational support, the complete dataset is logged for post-mission analysis, visualization, and reporting.

Step 8: Mission Completion and System Recovery
Upon completion of the exploration objectives the RUV is brought to surface. Recovery is then executed either autonomously via the drone or manually by an operator depending on the mission profile. A post mission review of system logs and acquired data is conducted to assess performance and inform future refinements.

Summary

This structured methodology establishes a reliable and repeatable framework for mission execution. The design intentionally combines autonomous vehicle functions with human-in-the-loop oversight, creating a balance that provides operational adaptability without compromising system safety or procedural dependability. This approach increases overall mission robustness and aligns with established principles for the development and operation of semi-autonomous cyber-physical systems.

Results and Discussion

This section details the outcomes from testing the integrated drone-deployed underwater robotic system and analyses its operational performance under simulated and controlled conditions. The findings validate the effectiveness of the system's hybrid architecture, sensor fusion strategy, vision-aided monitoring, and human-supervised control framework.

Aerial Deployment Performance

The aerial subsystem shows a reliable flight control and precise navigation GPS guided waypoint following expanded real-time IMU stabilization allowed the drone to consistently reach the target deployment location with minimal positional and conditional error. Visual feedback from the drone's onboard camera provided the ground operator with clear situational awareness enabling positive visual confirmation of the deployment zone prior to RUV release.

Throughout testing the closed-loop flight controller effectively compensated for environmental factors such as wind gusts hence maintaining stable altitude and attitude during the critical deployment phase. These results confirm the aerial platform's capability for accurate and reliable payload delivery.

Underwater Navigation and Stability

Post-deployment, the RUV executed controlled descent and maintained stable underwater operation. Depth regulation, driven by pressure sensor feedback, allowed the vehicle to achieve and hold a target depth with minimal oscillation. Simultaneously, IMU data facilitated smooth directional control, effectively dampening unwanted roll and pitch motions during manoeuvres.

The semi-autonomous control strategy proved effective: the RUV accurately executed high-level directional commands from the operator while its onboard controller autonomously managed low-level stabilization and safety functions. This division of labour resulted in responsive vehicle control and a reduced cognitive load on the human operator.

Sensor and Camera Data Integration

The integrated sensor suite delivered continuous and coherent environmental data throughout all mission phases. Sensor readings including depth and temperature are successfully being relayed to the ground station with minimal latency under standard operating conditions. The underwater camera provides a clear, usable visual streams in test environments, supplying the operator with sufficient detail for real time navigation and inspection decisions.

The fusion of this multi-modal sensor data with live video feedback significantly enhanced overall situational awareness and operational decision-making, particularly in scenarios with constrained visibility.

Communication and Data Link Performance

Wireless communication links between the aerial drone and the RUV (at or near the surface) and the ground control station remained stable during testing. Telemetry, command signals and video streams were transmitted with latency levels suitable for real time supervision and control. During brief induced communication interruptions, the system’s predefined contingency protocols engaged correctly, maintaining vehicle stability until the link was restored.

System Safety and Fault Management

The embedded health-monitoring system continuously tracked critical parameters such as pressure integrity and communication status. In simulated fault conditions—including induced leak alerts and signal loss—the system correctly triggered the appropriate safety responses, such as halting propulsion or initiating a controlled emergency ascent. These outcomes validate the effectiveness of the implemented fault-handling routines in mitigating risk and protecting system hardware.

Discussion

The experimental results confirm that the proposed system successfully achieves its core function: the coordinated aerial deployment and subsequent supervised exploration of an underwater robotic vehicle. The modular architecture, which strategically layers autonomous sensor-driven control with human oversight, provides an effective balance between operational flexibility and procedural reliability.

It is important to note that these results were obtained under controlled, near-ideal conditions. Real-world operational environments may present challenges not fully captured in these tests, such as extended communication range limitations, significant water turbidity, or strong subsurface currents. These potential limitations highlight valuable directions for future work, including the exploration of more robust communication methods (e.g., acoustic modems) and the development of higher-level autonomy for navigation in more dynamic and unstructured environments.

Summary of Results

In summary, the system validation demonstrates reliable performance in aerial deployment, stable underwater navigation, effective multi-sensor data acquisition, and real-time supervisory control. These findings substantiate the technical feasibility of the proposed approach for applications including underwater infrastructure inspection, environmental monitoring, and scientific data collection, thereby supporting the research objectives established in this work.

Conclusion

This work presented the design and development of an integrated drone-deployed underwater robotic vehicle system, engineered for accessible and flexible underwater exploration. The system merges the rapid aerial deployment capability of a drone with the submerged observational capacity of a compact RUV, operating under a framework of human-supervised control.

A modular system architecture with clearly delineated aerial and underwater subsystems formed the foundation of the design. Each subsystem was equipped with tailored sensor suites, vision systems, dedicated controllers and communication modules. This architectural separation enhanced reliability, facilitated integration and allowed each unit to perform optimally within its operational domain. The implementation of closed loop control driven by continuous sensor feedback, was critical in achieving stable flight, precise deployment and controlled underwater navigation.

The operational methodology provided a structured, reliable and repeatable workflow from mission initiation through recovery. A key feature of this approach is a semi-autonomous control strategy which strategically combines high level human guidance with low level autonomous stabilization and safety management. This division of labour successfully reduced operator cognitive load while maintaining precise command over mission execution.

Experimental validation under controlled conditions confirmed the system's core functionalities. Results demonstrated reliable aerial deployment, stable underwater manoeuvring, and effective real-time monitoring via fused sensor and camera data. Furthermore, implemented fault-detection and safety protocols enhanced overall system robustness, ensuring graceful degradation in response to simulated anomalies. While the system performs effectively within the tested operational envelope, this study also identifies areas for future development.

Limitations related to communication range, robustness in highly dynamic environments, and scalability for deeper missions present clear opportunities for advancement. Future work may focus on integrating more robust underwater communication methods, such as acoustic modems, implementing advanced autonomy for navigation in unstructured settings, and extending operational endurance.

In summary, this project establishes a practical and effective platform for hybrid domain robotic exploration. By utilizing aerial mobility with underwater sensing and human oversight the system is well suited for applications in environmental monitoring, infrastructure inspection, scientific data collection and for military purposes. This work contributes a foundational framework to the growing field of integrated aerial underwater robotic systems aligning with contemporary research directions in semi-autonomous cyber-physical systems.

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