School of Engineering/ College of Engineering, Computing & Cybernetics

Concept of Operations for Multi-beacon ranging system for underwater robotics

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Date: 4th May 2025

Version 1.1

Date and document version

Version	Date	Notes
V1.0	04/03/2025	Original drafted Con-Ops
V1.1	24/03/2025	Updates to original Con-Ops which include Scope of the Project, Referenced Documents, Team Structure, Stakeholder Management Plan, Cost Management Plan

Contents

Purpose of Document

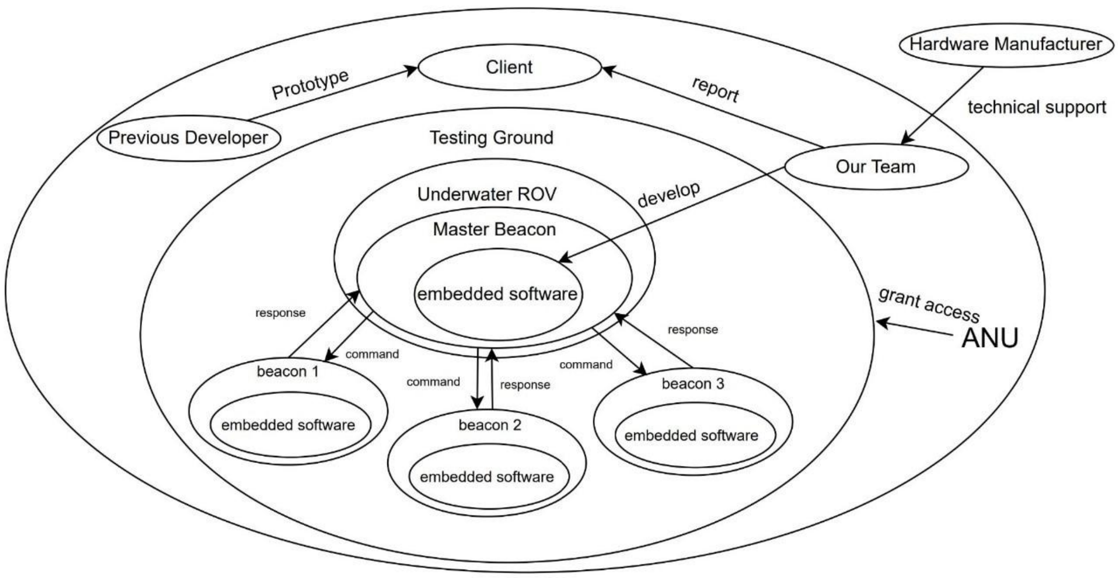
This project aims to develop a sonar system capable of measuring underwater range to three beacons, expanding on existing hardware that supports one beacon. The project involves upgrading the system, programming a microprocessor for precise timing, validating performance through experiments, and implementing a real-time data collection system integrating ranging signals, RTK-GPS, and IMU, mounted on a boat. The collected data will support 3D underwater range SLAM research.

In this document we will provide a high-level description of how the system will function from perspective of its users and stakeholders. We will clarify objectives and project scope, align stakeholders' expectations, guide system design, identify operational scenario, support the risk management and facilitate communication. It is mainly prepared for the stakeholders, decision makers, engineering teams and external contractors.

Scope of the Project

This project is based on the prototype developed by the previous developer. The client requires our team to continue to improve and verify the multi-beacon ranging system, covering the entire process of system development, testing and technical report submission. The core of the project focuses on the development of embedded software for the master beacon and the design and implementation of the response protocol for the slave beacon. With the existing hardware provided by the laboratory, the team will complete the system function verification at the ANU test site, focusing on verifying the stability of underwater communications and data accuracy. We also plan to obtain relevant technical support from the hardware manufacturer.

Because the project already has a hardware foundation, there is no need to purchase, design and long-term operation and maintenance support for hardware. All test experiments are limited to ANU authorized waters and require access granted by ANU to ensure compliance. Key deliverables include a runnable multi-beacon ranging prototype system, complete technical documentation and three phased audits. Change management will ensure that the development scope is consistent with the goals through regular evaluation. If there is any adjustment requirement, the team will decide after evaluation. The intellectual property rights of the experimental data and code belong to ANU, and the team reserves the right to use them for academic evaluation.



Conceptual graph for project scope

Goals

1. Extend the existing single-beacon sonar system so it can perform distance measurements to three underwater slave beacons simultaneously.

2. Combine the collected sonar data with RTK-GPS and IMU readings and integrate into the SLAM frameworks.
3. Develop and test communication protocols that can maintain consistent signal quality and reduce interference or data loss during underwater transmission.
4. Assess the accuracy, timing, and reliability of the system by conducting tests in both water tanks and an outdoor lake environment, using the results to guide further improvements.

Objectives

- Program the master beacon to manage multiple ranging sequences with precise timing control.
- Implement a time-based response protocol on the slave beacons to ensure they do not interfere with each other.
- Synchronize the data from sonar, RTK-GPS, and IMU for integration into SLAM datasets.
- Conduct controlled experiments to evaluate the stability of multi-beacon underwater communications.
- Document all hardware and software configurations, test procedures, and findings clearly for future development or academic use.

Scope Management Plan

To manage the project scope effectively, we would like to use the following approach

1. Have initial alignment meetings with the client to confirm the technical boundaries and constraints of the project
2. Any proposed changes will be logged and discussed with the client to ensure the changes align with their expectations
3. Include internal milestones reviews and client checkpoint to ensure the deliverables remain aligned with the expectations in each key phase.
4. We commit to a locked development scope by week 5 unless any critical technical issues arise that require adjustment.

Referenced Documents

In this section, any supporting documentation or resources is listed.

Project Management Plan

Deliverables

1. Project Initialization & Research Completion

    1.1 Requirement Analysis

    1.2 User Needs Analysis

    1.3 Stakeholder Analysis

    1.4 Previous Research Review

2. Recreating Distance Measurement Function

    2.1 Configure development environment

    2.2 Data reception and interpretation from master beacon

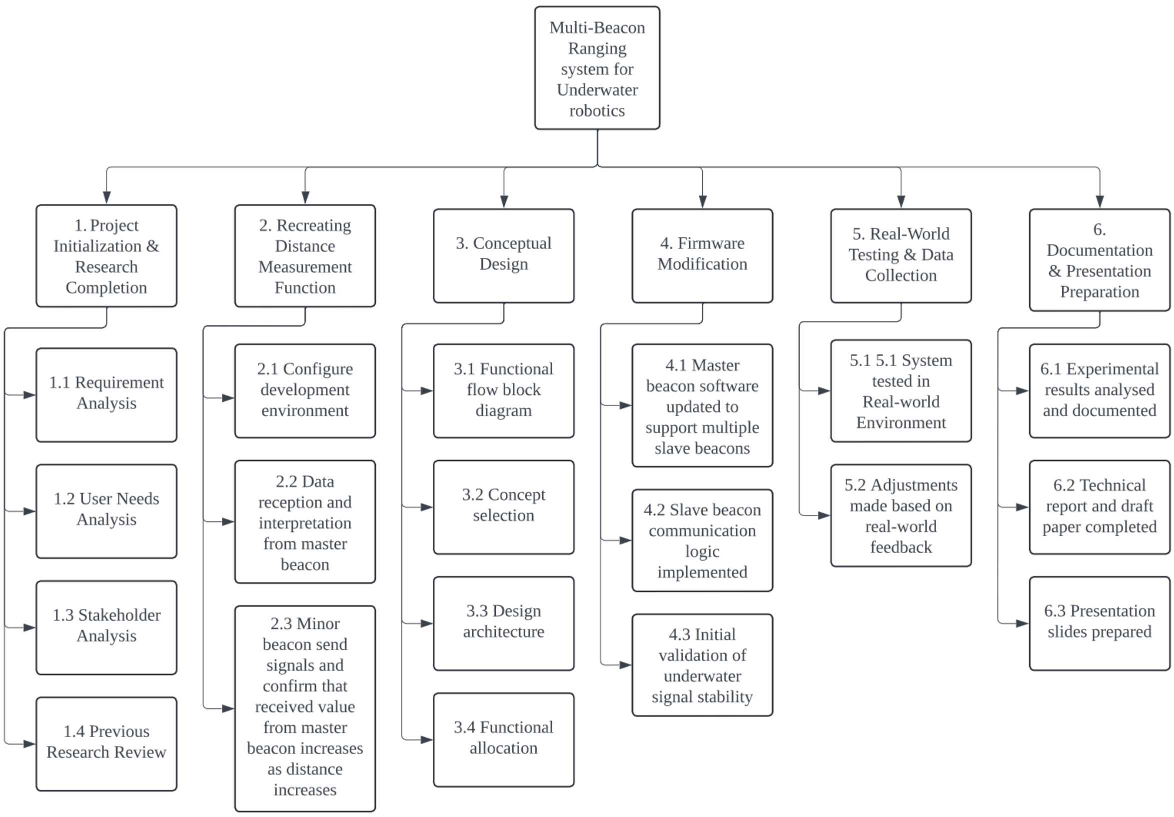
    2.3 Minor beacon send signals and confirm that received value from master beacon increases as distance increases

3. Conceptual Design
    - 3.1 Functional flow block diagram
    - 3.2 Concept selection
    - 3.3 Design architecture
    - 3.4 Functional allocation
4. Firmware Modification
    - 4.1 Master beacon software updated to support multiple slave beacons
    - 4.2 Slave beacon communication logic implemented
    - 4.3 Initial validation of underwater signal stability

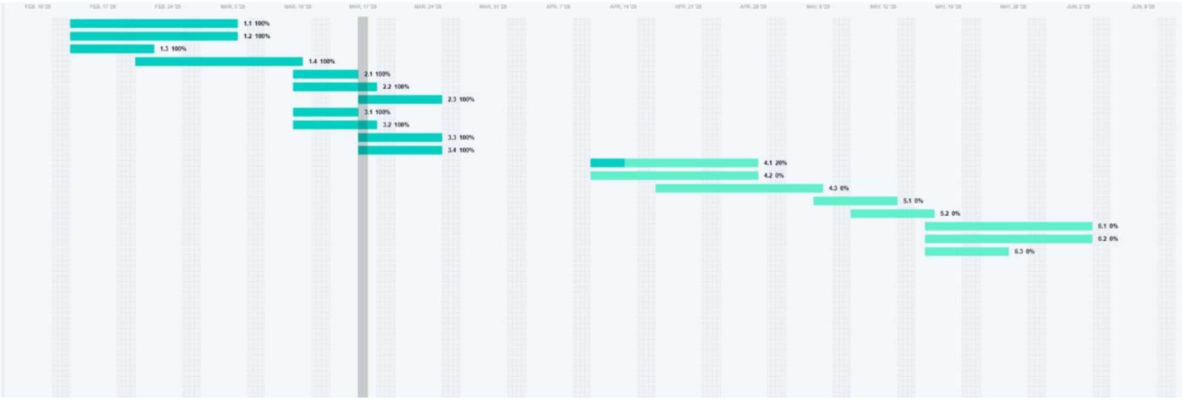
5.Real-World Testing & Data Collection
    - 5.1 System tested in Real-world Environment
    - 5.2 Adjustments made based on real-world feedback

6. Documentation & Presentation Preparation
    - 6.1 Experimental results analysed and documented
    - 6.2 Technical report and draft paper completed
    - 6.3 Presentation slides prepared

<u>Work Breakdown Structure (WBS)</u>



Timelines



Gantt chart of the project schedule

Risks Assessments

As part of our project planning, we conducted a preliminary risk assessment to identify and mitigate potential hazards associated with the design and testing phases. Each hazard was evaluated in terms of its likelihood and consequence, and the risk level was then determined using the ANU WHS Risk Matrix. Appropriate control measures were applied to mitigate each risk. After applying these controls, most of the residual risks were rated as low or medium. The team will continue to review risks as the project progresses and update controls where needed.

Consequence / Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	Medium (10)	High (14)	Extreme (21)	Extreme (22)	Extreme (25)
Likely	Medium (7)	High (13)	High (16)	Extreme (20)	Extreme (24)
Possible	Low (4)	Medium (9)	High (15)	High (18)	Extreme (23)
Unlikely	Low (2)	Medium (6)	Medium (8)	High (17)	High (19)
Rare	Low (1)	Low (3)	Low (5)	Medium (11)	Medium (12)

Risk Assessment Matrix

Risk Category	Hazards	Inherent Risk			Control Measures
		Likelihood	Consequence	Risk rating	
Technical	Multipath Propagation and Acoustic Distortion There are reflections from the seafloor or water surface which can cause multipath effects, leading to ambiguous or inaccurate distance measurements.	Likely	Major	Extreme (20)	• Develop echo suppression algorithms to filter out delayed reflections. • Conduct regular signal integrity testing to detect multipath effects early.
Technical	Signal Interference and Beacon Collision With multiple (three) beacons operating in the same frequency range, there might be signal collisions which could lead to inaccurate range measurements or even communication failure.	Likely	Catastrophic	Extreme (24)	• Implement time-division multiplexing (TDM) or frequency hopping techniques to reduce interference. • Ensure beacon transmissions are synchronized to avoid overlap.
Reliability	Power Consumption and Battery Life Running multiple beacons simultaneously increases the power demand, which could limit the operational time.	Likely	Moderate	High (16)	• Optimize beacon transmission intervals and use low-power modes for inactive beacons. • Establish guidelines for efficient power management during operations.
Reliability	Data Integrity and Loss Prevention If there are transmission errors or beacon failures, it could result in lost or corrupted data, which leads to inaccurate positioning.	Possible	Catastrophic	Extreme (23)	• Use Forward Error Correction (FEC) and Cyclic Redundancy Checks (CRC) to validate received data. • Implement real-time monitoring and alerts for transmission failures.
Security	Unauthorized Signal Spoofing Any unintended acoustic sources could spoof the beacon signals and this disrupt navigation and positioning of the ROV.	Unlikely	Catastrophic	High (19)	• Implement cryptographic authentication mechanisms to validate beacon signals. • Train personnel on detecting and reporting anomalies in acoustic signals.
Safety	Impact on Marine Life Sonar emissions might disturb some marine life, particularly the species that are sensitive to acoustic signals.	Possible	Minor	Medium (9)	• Adjust sonar frequencies to biologically safe thresholds. • Follow marine safety regulations and perform impact assessments. • Use noise-dampening equipment where applicable.
Other	Limited Access to Testing Facilities Availability of suitable underwater testing environments like a pool may be constrained and this can delay our progress in the later stages.	Possible	Moderate	High (15)	• Plan for alternative testing sites ahead of time. • Use simulation environments to replace real-world testing where feasible. • Schedule backup testing sessions to avoid delays.
Other	Difficulty Contacting Client for Feedback The client may be slow to respond to emails or messages, causing delays in getting feedback or approvals, which can affect project progress and decision-making.	Unlikely	Moderate	Medium (8)	• Establish multiple communication channels e.g. email, phone, video calls. • Assign a team member as the main point of contact to follow up regularly.
Other	Group Member Sick or Unavailable for Key Work A team member may fall sick or be unavailable due to personal reasons, leading to delays in completing assigned tasks and increased workload for others.	Unlikely	Moderate	Medium (8)	• Assign backup members for critical tasks in advance. • Maintain clear documentation so another team member can take over if needed. • Set early deadlines to allow buffer time for unexpected absences.

WHS hazard and risk assessment

Team Structure

Brian Ma	Version Control, Multi-Beacon Protocol Design
Xingyu Luan	Meeting Minutes, SLAM Data Integration
Yifan Wu	Liaising with clients, RTK-GPS Integration
Yuqiao Xin	Preparing Audit Presentation, IMU Integration
Xu Ben	Progression Tracking, Data Logging & Output Formatting
Yuk Lam	Risk Management, Multi-Beacon Ranging System Development
Xiang Peng	Landing Page Design & Development, Experiment Design

Responsibilities and Authorities

Stakeholder Analysis

Stakeholder	Power	Influence	immediacy	Vested Interest	Importance
Client	high	high	high	high	9
Australian National University	high	medium	low	low	7
Previous Developer	low	high	low	low	6
Hardware Manufacturer	low	medium	low	low	5

Need list

ID	Description	Importance	Stakeholder
N1	Locate underwater robot accurately	Essential	Client
N2	No cross talking between beacons	Highly Desirable	Client
N3	Real time tracking while robot is moving	Bonus	Client
N4	Avoid transmission error via signal encoding and processing	Bonus	Client
N5	Cause no damage to environment	Essential	ANU

Stakeholder Management Plan

Our project involves a small but critical set of stakeholders. Their input greatly influences the direction and validation of our work. We have engagement plan with different stakeholders as shown in the table below.

Stakeholder	Role/Interest	Communication Plan
Client	Supervise the project direction and ensure the outcomes align with the project goals	Primary: 1. Email for formal updates or approvals 2. Weekly in-person meetings to ensure our progress aligns with their expectations Alternative: Scheduled online calls when urgent clarification or design decisions are needed Consideration: If they are unavailable, we will continue our work based on previous guidance and document any pending decisions for later follow-up
Australian National University	Authorize access to the testing sites	Primary: Email for requesting the testing sites Alternative: In-person visits to the facilities office if required
Previous Developer	Provide the original system prototype	Email directly for any technical clarification or debugging advice
Hardware Manufacturer	Provide technical support on the sonar hardware	Contact via email or support portal for any technical support Consideration: As their response time may vary, we will plan to test in parallel to avoid any dependency bottlenecks

Cost Management Plan

Our project does not require a formal budget because most of the equipment including the beacons, development boards, GPS and IMU sensors, experiment setup, test tanks, testing boats are already provided by the university. As a result, there are no direct financial expenses expected.

However, we still aim to manage resources efficiently and responsibly as follows.

- Hardware: All testing and development will be done using the existing lab equipment. In case of any hardware issues, we will attempt to troubleshoot internally first. If replacements are needed, we will consult the lab supervisor to explore any available options.
- Software: We are going to rely on all free or ANU-licensed software, including STM32Cube software and Visual Studio Code to avoid any unnecessary software costs.
- Testing site: All experiments will be conducted on test sites with ANU approval. We will schedule testing sessions in advance to make the best use of facility access.

System Lifecycle Process

Milestones for Multi-Beacon Ranging System for Underwater Robotics

Milestone 1: Project Initialization & Research Completion (End of Week 2)

Clearly defined project objectives and scope
Team roles assigned
Understanding of previous research and existing one-to-one communication system

Milestone 2: Previous Prototype Validation & System Architecture Finalization (End of Week 4 for audit 1)

Recreating previous experiments and getting reasonable data for single-beacon system
One-to-three communication protocol designed
Signal synchronization & scheduling strategy selected
Data format and error handling methods defined

Milestone 3: Software & Hardware Implementation (End of Week 6 for audit 2)

Master beacon software updated to support multiple slave beacons
Slave beacon communication logic implemented
Initial validation of underwater signal stability

Milestone 4: Successful Simulation Testing (End of Week 8)

One-to-three communication tested in a simulated environment
Evaluated interference, latency, and data synchronization
Optimization of error correction methods

Milestone 5: Real-World Testing & Data Collection (End of Week 10 for audit 3)

System tested in a controlled water tank/lab environment
Performance metrics collected (latency, bit error rate, data loss)
Adjustments made based on real-world feedback

Milestone 6: Documentation & Presentation Preparation (End of Week 11)

Experimental results analysed and documented
Technical report and draft paper completed
Presentation slides prepared

Milestone 7: Final Optimization & Submission (End of Week 12)

Final system refinements and optimizations completed
Technical report and presentation finalized
Project deliverables submitted