School of Engineering/ College of Engineering, Computing & Cybernetics

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

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V1.0	04/03/2025	Original drafted Con-Ops

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.

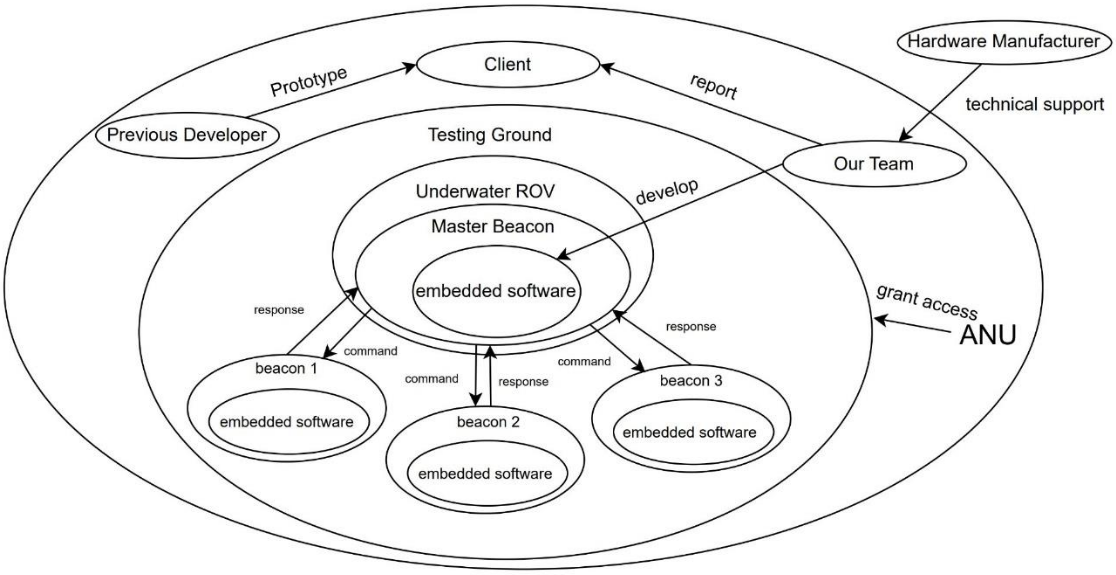
Scope of the Project

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.

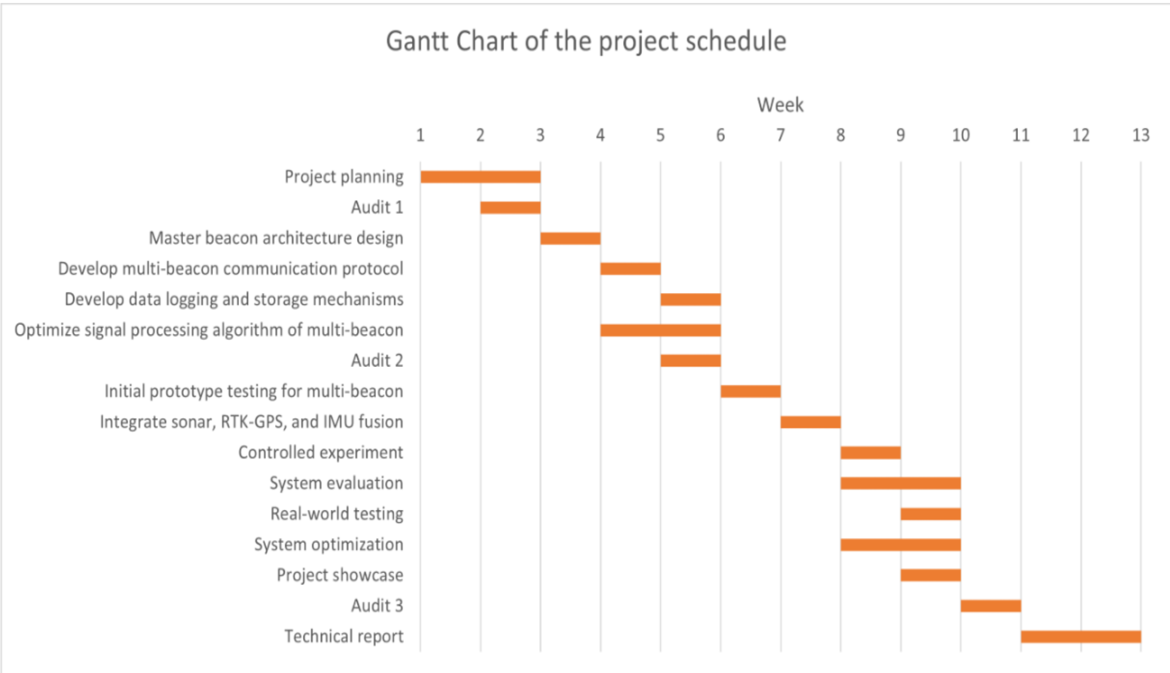
Because the project already has a hardware foundation, there is no need to purchase, design and long-term operation and maintenance support for hardware. All test experiments are limited to ANU authorized waters and require access granted by ANU to ensure compliance. Key deliverables include a runnable 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.

Referenced Documents

1. Conceptual graph for project scope



2. Gantt chart of the project schedule



3. Risks and mitigation

Technical risk

1. 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.

   Mitigation: Develop echo suppression algorithms that can filter out any delayed reflections.

2. 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.

   Mitigation: Implement time-division multiplexing (TDM) or frequency hopping techniques to ensure the beacons transmit signals in a controlled manner to reduce any interference.

Reliability risk

1. Power Consumption and Battery Life

   Running multiple beacons simultaneously increases the power demand, which could limit the operational time.

   Mitigation: Power can be managed by adjusting beacon transmission intervals, like low power mode can be used for inactive beacons.

2. 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.

   Mitigation: Forward error correction (FEC) and cyclic redundancy checks (CRC) techniques can be used to validate the received data.

Security risk

1. Unauthorized Signal Spoofing

   Any unintended acoustic sources could spoof the beacon signals and this disrupt navigation and positioning of the ROV.

   Mitigation: Cryptographic authentication mechanisms can be implemented to validate the beacon signals.

Safety risk

1. Impact on Marine Life

   Sonar emissions might disturb some marine life, particularly the species that are sensitive to acoustic signals.

   Mitigation: Comply with teg marine safety regulations by limiting sonar frequencies within the biologically safe thresholds.

Other possible risks

1. 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.

Mitigation: Prepare alternative test sites and backup testing sessions in advance and also develop simulation environments for preliminary validation.

Risk Matrix

Risk	Likelihood	Impact	Risk Rating	Mitigation
Technical				
Multipath Propagation	4	3	12	Echo suppression algorithms
Signal Interference	4	4	16	Time-division multiplexing (TDM)
Reliability				
High Power Consumption	5	3	15	Optimize transmission intervals
Data Integrity Issues	3	4	12	Validate received data
Security				
Signal Spoofing	2	5	10	Implement authentication mechanisms
Safety				
Impact on marine life	3	4	12	Comply with marine safety regulations
Other				
Testing Constraints	4	3	12	Secure alternative test sites

For likelihood,

1 - every unlikely to occur

2 - low chance to occur

3 - half chance to occur

4 - probably would occur

5 - very likely to occur

For impact,

1 – Negligible impact

2 – the consequences can be easily handled

3 – some time and effort need to be taken to handle the risk

4 – the consequences would be long term and it will be hard to mitigate

5 – the impact is critical, which can ruin the project

The risk rating ranges from 1 to 25, which

1 – 6 is low rating risks that not likely to happen, if they do happen, they are not going to be a threat to the project.

7 – 12 is medium rating risks that might happen at some point, we do not have to prioritize these risks but we should not ignore them as well.

13 – 25 is high rating risks that are critical to the project, which we should keep them in mind when we are planning our project.

Team Structure

Brian Ma	Version Control, Embedded Programming
Xingyu Luan	Meeting Minutes, Embedded Programming
Yifan Wu	Liaising with clients, Embedded Programming
Yuqiao Xin	Preparing Audit Presentation, Embedded Programming
Xu Ben	Progression Tracking, Embedded Programming
Yuk Lam	Risk Management, Embedded Programming
Xiang Peng	Landing Page Design & Development

Responsibilities and Authorities

Stakeholders:

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

The experiment equipment is well prepared by the school. So, we will get little communication with the previous developer and hardware manufacturer. We need to get in touch with the university for some authority. Do further adjustment through client's feedback. All communication work will be done through email.

Cost Management Plan

Due to almost all experiment equipment is well prepared by the school, there are no costs associated with this project.

System Lifecycle Process

Milestones for Multi-Beacon Ranging System for Underwater Robotics

1. **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
2. **Milestone 2: System Architecture Finalization** (End of Week 4 for audit 1)

   One-to-three communication protocol designed

   Signal synchronization & scheduling strategy selected

   Data format and error handling methods defined

3. **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
4. **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
5. **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
6. **Milestone 6: Documentation & Presentation Preparation** (End of Week 11)

   Experimental results analysed and documented

   Technical report and draft paper completed

   Presentation slides prepared
7. **Milestone 7: Final Optimization & Submission** (End of Week 12)

   Final system refinements and optimizations completed

   Technical report and presentation finalized

   Project deliverables submitted