HacX! Hack for Public Safety 2024

CS#7: Automated Navigation for Vessels in Close Proximity

Berthing Bridge

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1. Introduction

1.1 Background and Operational Challenges

Maritime operations, particularly the berthing process, face significant challenges due to inefficient manpower allocation and communication delays, often leading to extended berthing times and increased risks for crew safety. The complexity of the berthing process is amplified by various environmental and operational factors, including dynamic berthing structures, tidal height fluctuations, strong winds, sea state variability, and mooring proficiency (Mar. Sci. Eng., 2023). These factors can cause significant variations in docking conditions, making it difficult to maintain control over the vessel's alignment and position. Additionally, poor communication between key personnel further complicates the operation, making it essential to address these inefficiencies with more automated systems and real-time data solutions.

The interplay of these challenges requires close coordination between multiple roles, each with its own set of responsibilities and constraints, as detailed below.

1.1.1 Officer of the Watch (OOW)

Job Scope

The Officer of the Watch (OOW) is responsible for overseeing the safe navigation and operation of the vessel, particularly during docking and undocking. The OOW coordinates with the mooring party, the helmsman, and other crew members to ensure a smooth berthing process, while monitoring external factors like weather, vessel proximity to the dock, and overall vessel stability.

Key Challenges

One of the primary challenges for the OOW is maintaining situational awareness in dynamic and unpredictable conditions, such as changing sea state, strong winds, and wakes caused by passing vessels. These factors can dramatically alter the vessel's approach and alignment, requiring the OOW to make quick, informed decisions while relying on real-time data from various sources. The OOW must also ensure constant communication with the crew to mitigate risks, but this can be hindered by communication delays and reliance on subjective reports from the lookout or mooring party. Real-time automated data on vessel position and environmental factors will greatly enhance decision-making and reduce the likelihood of errors caused by human judgment.

1.1.2 Helmsman

Job Scope

The helmsman is responsible for steering the vessel and following the navigation commands issued by the OOW during docking and undocking procedures. Their role requires precise coordination with the mooring party and other crew members to ensure the vessel maintains a stable position during mooring.

Key Challenges

The helmsman faces significant challenges when steering the vessel precisely, especially in conditions affected by strong winds, sea state, or tidal height changes. These environmental variables can cause the vessel to drift unexpectedly, requiring constant adjustments. Communication delays between the helmsman, OOW, and mooring party can also lead to overcorrections or improper alignment. Additionally, limited visibility during night-time operations or poor weather can further exacerbate these difficulties. Improved real-time feedback on external conditions and the vessel's position relative to the dock would help the helmsman respond more accurately and safely.

1.1.3 Mooring Party

Job scope

The mooring party is responsible for securing the vessel to the dock by managing multiple mooring lines. Typically, two personnel are involved: one disembarks the secure the line on the berth's bollard, while another crew member secures the other end of the line on the ship's bollard. The procedure requires reeling in and adjusting multiple lines to ensure the vessel is safely docked.

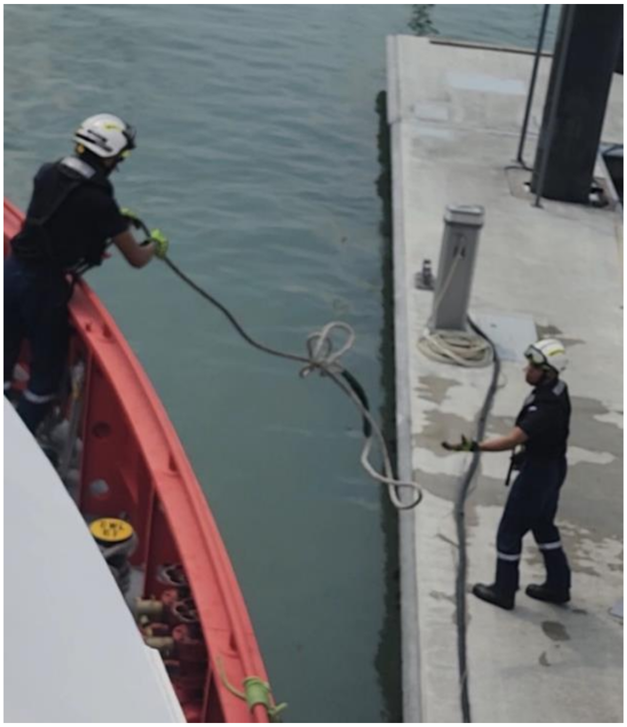
Figure 1. Two Personnel Required per line

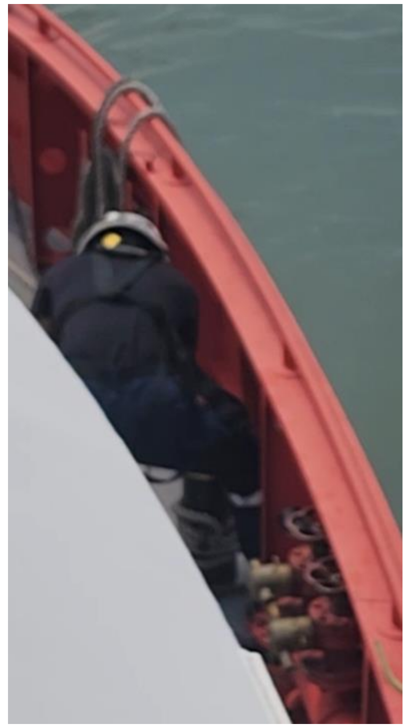
Figure 2. Manually Reeling of Excess Slack

Key Challenges

Mooring is labour-intensive and time-consuming, especially when docking at new or unfamiliar stations where the required line length is uncertain. Determining the initial line length is often imprecise, resulting in additional time spent manually reeling in and tightening the lines. This inefficiency is compounded by the need for multiple personnel, making the process resource-intensive. Additionally, in harsh weather or low-visibility conditions, the manual process introduces safety risks, as crew members must repeatedly disembark and reboard the vessel to secure and adjust lines. These challenges highlight the need for a streamlined, automated solution that reduces manual effort, minimizes safety hazards, and improves operational efficiency.

1.1.4 Lookout

Job Scope

The lookout assists the OOW by monitoring the surroundings and providing distance estimates between the vessel and the dock, as well as identifying potential hazards during mooring. The lookout's role is crucial for ensuring a safe and controlled docking process by offering real-time observations from both the bow and stern.

Figure 3. Lookout Reporting Proximity to Berth

Key Challenges

The lookout's visual observation is highly dependent on visibility, which can be compromised by environmental conditions such as fog, heavy rain, or darkness during night-time operations. Since distance estimates are often done by sight, there is a degree of subjectivity involved, which can lead to inaccurate reporting. These inaccuracies may cause delays or misalignments during berthing and mooring, posing a safety risk. These inaccuracies may also cost precious time during marine time operations. An automated system providing objective, real-time distance measurements could significantly reduce errors and improve the overall safety of the operation.

1.2 Engineering Goals and Expected Outcomes

1.2.1 Project Vision and Long-Term Impact

The Berthing Bridge project aims revolutionise maritime operations through the integration of advanced technologies into a single, comprehensive platform. The long-term vision of this project extends beyond mere operational improvement; it aims to establish a new industry standard that significantly enhances safety, efficiency, and reliability in berthing processes. By minimizing human intervention, the system reduces the risk of human error, thereby improving overall safety and precision in docking.

A core component of this vision is the use of automation and real-time data to ensure vessels can be docked with minimal risk to both personnel and equipment. This approach not only mitigates the potential for injury by automating high-risk tasks but also reduces the likelihood of vessel damage caused by misalignment or unfavourable environmental conditions. Ultimately, the Berthing Bridge system aspires to set a new benchmark in maritime safety and operational efficiency, with the added benefit of improving environmental sustainability by adapting to changing conditions, such as wind and current, in real time.

1.2.2 Engineering Goals and Expected Outcomes

The engineering goals of the Berthing Bridge project are multifaceted and ambitious. At its core, the project seeks to automate and expedite the berthing process through role-specific technological solutions. This approach not only aims to reduce manpower requirements but also to enhance safety and precision in berthing operations. By providing real-time and accurate data, the system supports informed decision-making, potentially mitigating risks associated with human error or miscommunication.

A key aspect of the project's design is the seamless integration of automated technologies, which serve to eliminate the need for direct human involvement in high-risk tasks such as vessel positioning and line handling. This reduction in manual intervention significantly lowers the risk of injury to personnel while ensuring that vessels berth safely and efficiently. Furthermore, the system's adaptability to environmental conditions—thanks to real-time monitoring and data-driven adjustments—allows it to reduce the risk of damage to vessels during docking.

Another critical outcome of the project is its ability to handle diverse berthing conditions and vessel types. The flexibility of the Berthing Bridge system ensures that it can adjust to varying operational demands, further enhancing its safety and reliability. This adaptability is crucial in dynamic maritime environments, where unpredictable weather or tidal conditions can present significant challenges. By automating the process and continuously improving based on machine learning insights, the system ensures not only safer operations but also a more streamlined training process for new personnel.

Overall, the Berthing Bridge project aims to leverage technology to enhance safety, reduce risk, and create a more sustainable and efficient maritime future, where both human intervention and the potential for error are minimized.

2. Design and Outcomes

2.1 Centralised Graphical User Interface

2.1.1 Design Concept

The Centralized Graphical User Interface (GUI) is a core component of the Automated Berthing System, serving as the primary control interface. Developed using React, the GUI integrates multiple control functions into a single, cohesive interface that replicates the ship's actual control panel. Its design prioritizes operational efficiency and user-friendliness, streamlining navigation and reducing complexity. The GUI is organized into three key tabs: the Simulation Panel, CCTV Feed, and Training System. The interface is controlled through basic up/down buttons and an enter key, ensuring ease of use that mirrors modern ship control systems. A keypad can be retrofitted onto the control panel of the bridge, allowing gloves-friendly use.

The GUI was engineered to provide real-time feedback during mooring operations, enabling operators to monitor the status of each mooring line remotely. Key operational parameters, such as the length of the reeled-out line and the tension detected by load sensors, are visually presented. This allows crew members to rapidly assess the status of mooring operations and respond to any necessary adjustments, enhancing communication and decision-making efficiency.

Figure 4. The Current CCTV Footage

The GUI takes inspiration from the simple CCTV bridge control panel.

Figure 5. Current CCTV Control Interface

The simple up-and-down controls of the React application allow it to be easily retrofitted into the bridge system if desired.

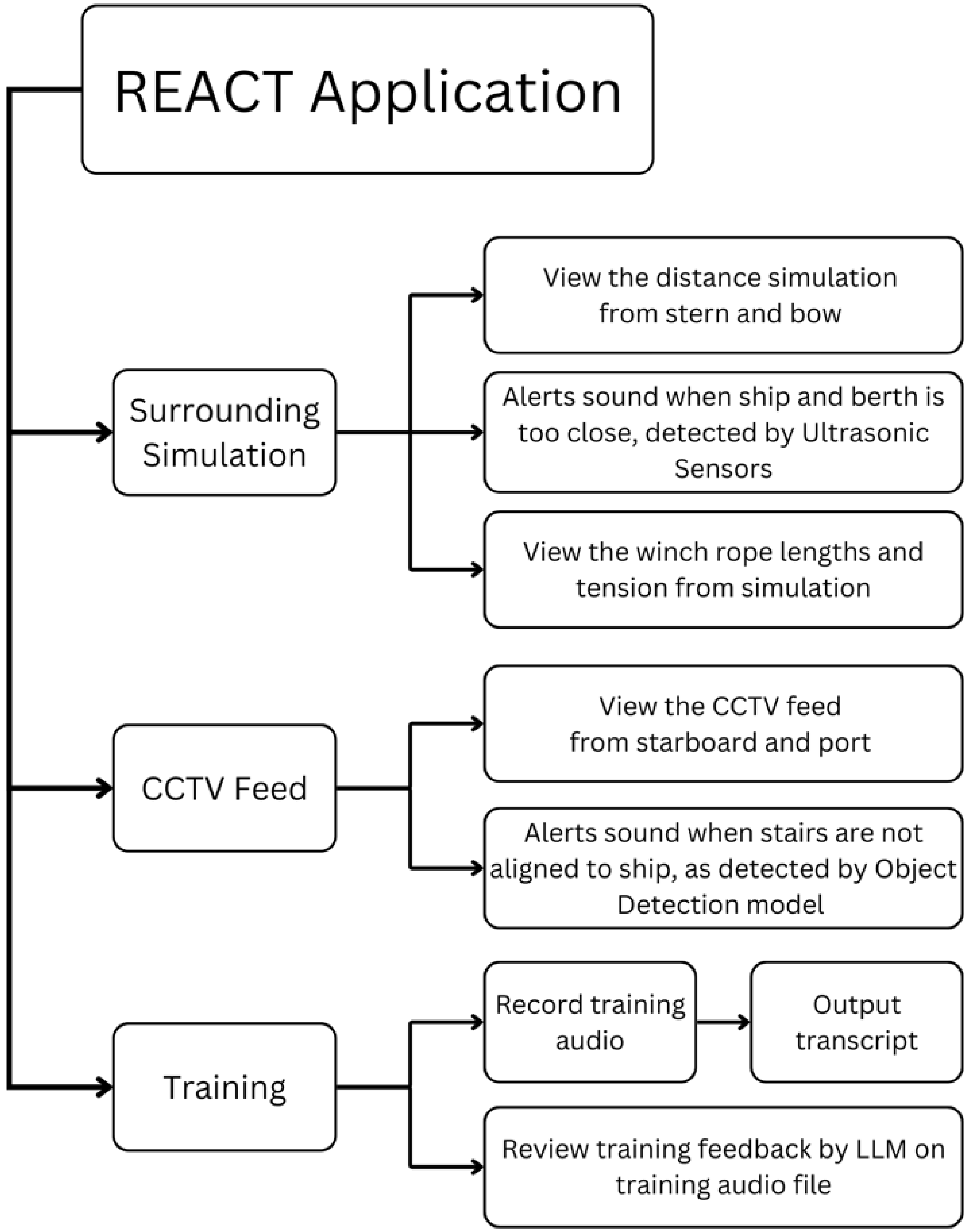

Figure 6. GUI Functionality Flowchart

Figure 7. GUI Landing Page

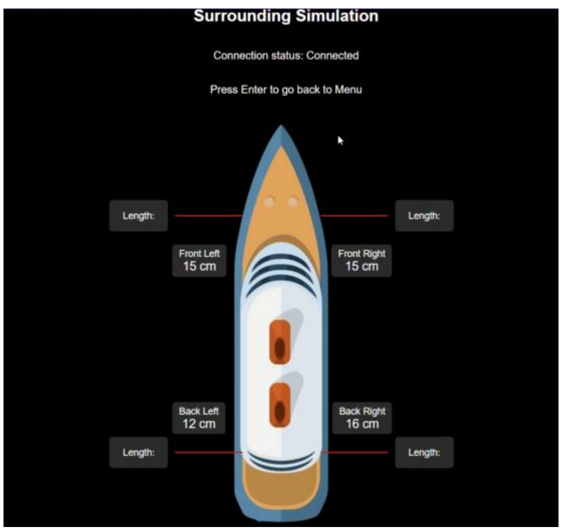

Figure 8. TabSimulation Tab

Figure 9. CCTV Feed Tab

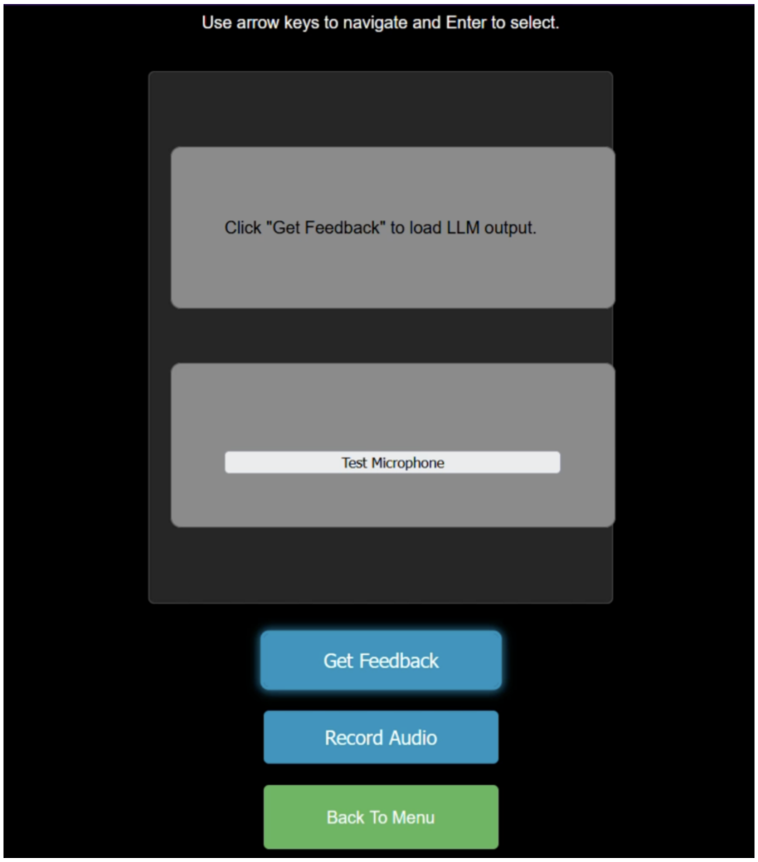

Figure 10. Figure 10. Training Tab

2.1.2 Prototype Development

The development of the GUI prototype focused on a user-friendly, intuitive interface integrated with an automated winch system. The system processes data from load sensors and winch operations, presenting it in real-time on the GUI. This allows clear visualization of tension and the positioning of each mooring line. Visual indicators on the interface highlight when mooring lines are taut or require adjustment, significantly reducing the need for constant manual supervision.

During the prototype phase, particular attention was given to seamless navigation between the system's tabs, all while maintaining the real-time display of critical operational data. The Simulation Panel provides essential insights into the automated system's performance, while the CCTV feed and Training System tabs contribute to situational awareness and continuous crew development. By consolidating these critical elements into a single interface, the system eliminates the need for multiple, disconnected control panels, fostering a more integrated operational environment.

2.1.3 Results and System Benefits

The testing of the prototype on a scaled-down model demonstrated significant improvements in situational awareness and reduction of human error during mooring simulations. The real-time data provided by the GUI on line tension and length facilitated quicker decision-making, thereby reducing operational delays in the simulated mooring process. The interface's clear visual cues enabled operators to monitor and adjust mooring lines with ease, thereby minimizing the risk of over-tightening and increasing safety.

Although no real-life testing on a full-scale vessel was conducted, the small-scale prototype successfully demonstrated the potential benefits of the GUI in streamlining mooring operations. The centralized design provided a consolidated view of the entire berthing process, enhancing both efficiency and safety. Furthermore, the intuitive navigation reduced the learning curve for operators, improving decision-making by presenting essential data in a clear and accessible format. In conclusion, the prototype results indicate that the GUI could play a crucial role in optimizing berthing operations through improved situational awareness, reduced human error, and enhanced crew coordination.

2.2 Ultrasonic Sensors

2.2.1 Design Concept

The sensor system design initially focused on utilizing LiDAR (Light Detection and Ranging**)** technology due to its ability to provide highly accurate, real-time distance measurements. LiDAR works by emitting laser pulses to create detailed 3D maps of the surrounding environment, making it ideal for high-resolution, short-range tasks requiring precision, such as ship berthing. These sensors were intended to be placed at the port and starboard sides of the vessel to provide real-time, accurate data on the vessel's proximity to the dock or other berthing platforms. This system aimed to eliminate the need for crew members to make visual distance estimates, especially in conditions of poor visibility or challenging environments, enhancing both accuracy and safety during docking.

2.2.2 Prototype Development

Due to budget and time constraints, our mid-fidelity prototype employed four ultrasonic sensors as a more cost-effective alternative to LiDAR. These sensors were strategically placed at critical points on the prototype vessel to measure distances during docking. The sensors were integrated with the automated winch system and the Centralized GUI, providing real-time distance data. This information was displayed on the GUI’s Simulation Panel, both numerically and visually, enabling the crew to monitor the vessel's position with high accuracy. The system allows for seamless data integration, ensuring precise control over docking manoeuvres without relying on visual and subjective assessments.

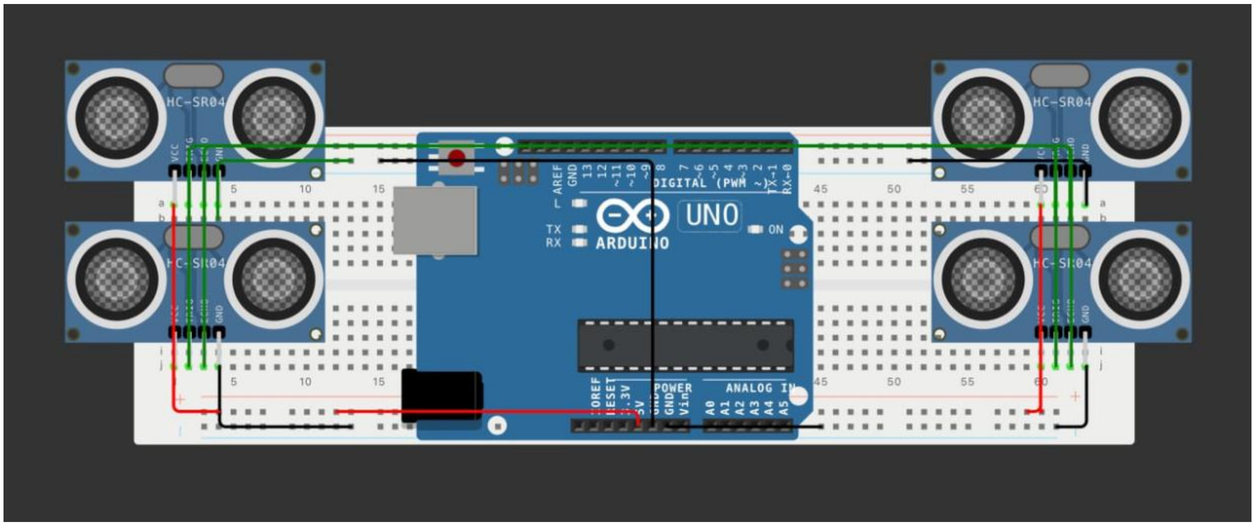

Figure 11. Arduino Wiring

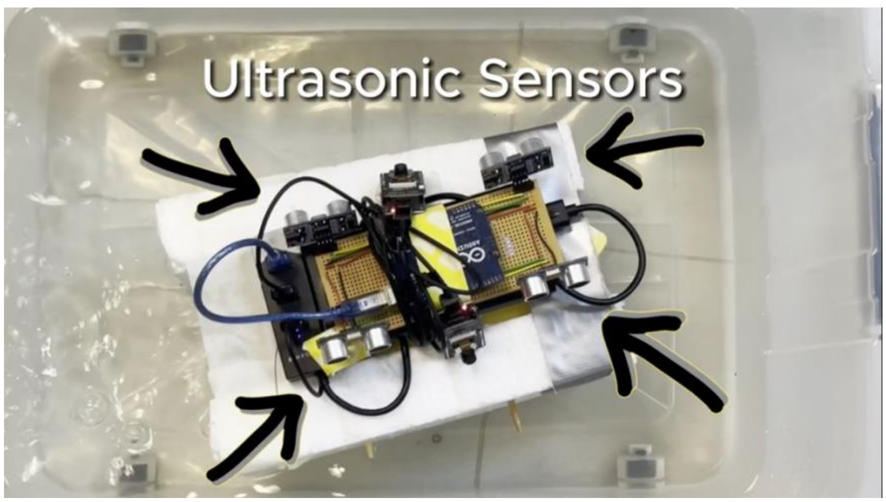

Figure 12. Ultrasonic Sensor Placement (Stern and Bow on Both Sides)

2.2.3 Results and System Benefits

The ultrasonic sensor system, tested on a small-scale prototype, effectively improves docking precision and safety. The system provides accurate real-time distance data, reducing the need for subjective visual estimates, especially in low-visibility scenarios. It enhances situational awareness and streamlines decision-making for crew members, particularly the Officer of the Watch and Helmsman, allowing them to focus on critical tasks and contributing to safer, more efficient berthing operations.

2.3 CCTV and Gangway Stair Detection

2.3.1 Design Concept

The CCTV and gangway stair detection system was conceptualised to enhance both safety and situational awareness during berthing operations. CCTV cameras would be positioned at disembarkation locations on the vessel to provide live visual feeds, while the computer vision system would analyse these feeds in real time. The computer vision system would be able to detect potential hazards, vessel alignment with gangway stairs, and other operational concerns, providing an additional layer of automation to assist the crew in monitoring the mooring process with greater accuracy and reliability. This system aims to minimize human error and increase overall docking accuracy and safety by integrating advanced visual monitoring with automated hazard detection.

2.3.2 Prototype Development

In the prototype, we used ESP-32 cameras to simulate CCTV cameras. The system focused on two key tasks: long-range gangway stairs detection and real-time monitoring of nearby vessels. The YOLOv8 object detection model was employed to identify gangway stairs, with cameras mounted at the embarkation points to ensure precise alignment during berthing. Additionally, CCTV cameras were strategically placed at the disembarkation points to gauge the relative distance between the disembarkation point and the gangway stairs.

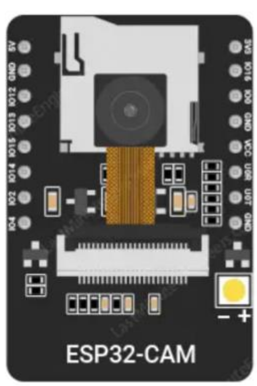

Figure 13. Figure 13. ESP32 Camera

Figure 14. Figure 14. ESP32 Camera Placement (Port and Starboard)

The visual feeds from the CCTV cameras were integrated into the GUI, allowing the crew to have a comprehensive view of the vessel's surroundings. Meanwhile, the computer vision system was trained to recognize nearby gangway stairs during the berthing process, advising the OOW and helmsman how much to engage the central main engine, finetuning the vessel's position ahead and astern to align its disembarkation point with the stairs.

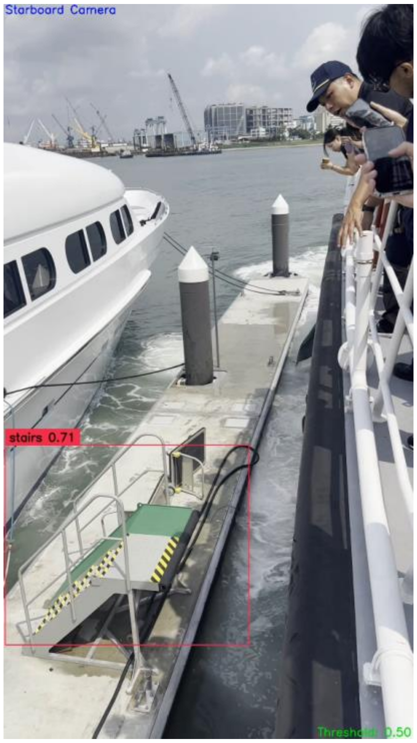

Figure 15. Stairs Detection

Figure 16. CCTV Feed on GUI

2.3.3 Results and System Benefits

The CCTV and computer vision system significantly improves the crew's ability to monitor and manage mooring operations by providing clear, real-time visual guidance. This system greatly reduces the reliance on human judgment, traditionally required for ship alignment, by offering precise positioning information. In addition, the ability to detect external disturbances, such as the wake from nearby vessels, allows the crew to anticipate and respond proactively, leading to smoother and safer berthing operations.

The integration of the computer vision system added a layer of automation that reduces the need for constant manual oversight, particularly in environments where visual assessment might be difficult due to weather or lighting conditions.

The automatic detection and flagging of potential issues, such as misalignment or obstructions, helped minimize the risk of errors during the docking process. This, in turn, reduces the cognitive load on the crew, allowing them to focus on other critical aspects of the operation. Overall, the system enhances situational awareness, operational efficiency, and safety by providing real-time visual and analytical feedback on mooring activities.

2.4 Automated Winch System

2.4.1 Design Concept

The automated winch system was conceptualized as an ideal solution to overcome the challenges and inefficiencies commonly faced by mooring teams. The vision for this system involved automating the reeling and tightening of mooring lines to reduce manual labour and human error, streamlining the mooring process. Equipped with advanced S-type load sensors, the system would detect when a mooring line became taut and automatically adjust, providing slack to prevent over-tightening. This system aimed to simplify the mooring procedure, allowing for greater operational flexibility across a wide range of berthing environments and vessel types.

Figure 17. S-Type Load Cell

2.4.2 Prototype Development

For the prototype, a cost-effective solution was developed using a single-cell 1kg load sensor connected to an Arduino and a DC motor in place of the ideal S-type load sensors. This setup allows the prototype to replicate key features of the automated system, ensuring that the winch would stop automatically once a predefined tension threshold was reached, thus preventing excessive strain on the mooring lines. Additionally, a simple two-button control system was incorporated to manage the winch's power and direction. The winch system was integrated with the Simulation Tab of the GUI, displaying real-time data on both the length of the mooring line and its tension, thus allowing operators to monitor and control the system with ease.

Figure 18. 1kg Single Cell Load Cell

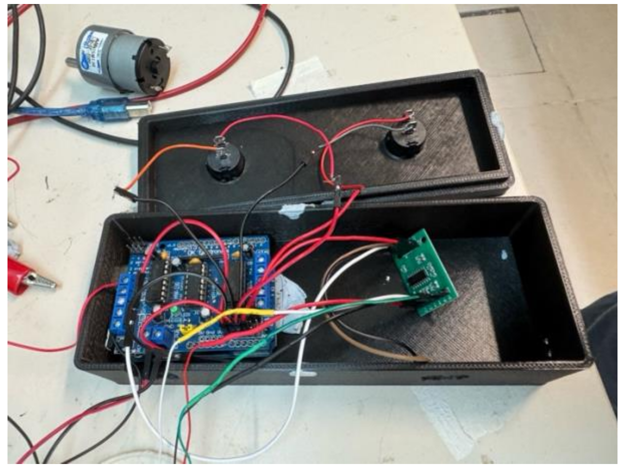

Figure 19. Arduino UNO Connections

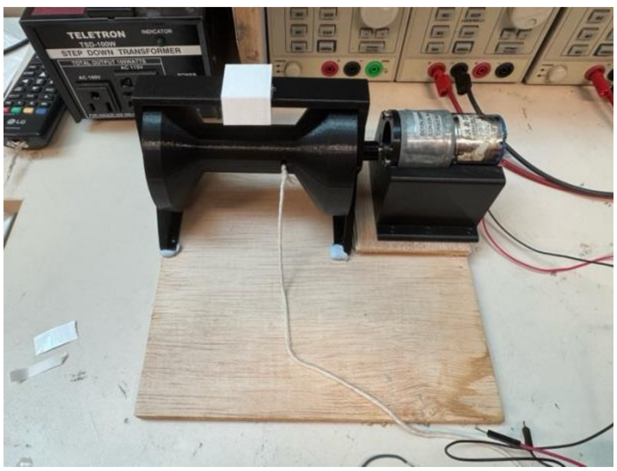

Figure 20. Winch Powered by DC Motor

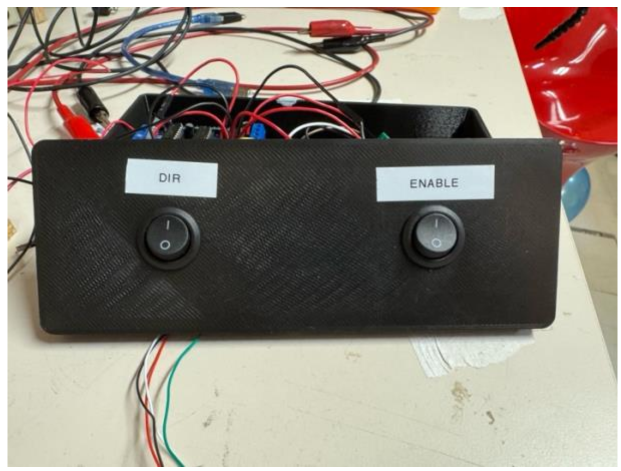

Figure 21. Switch Controls

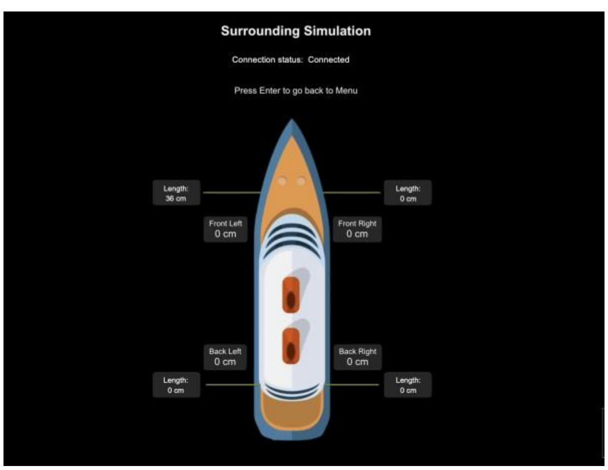

Figure 22. GUI Interface (SLACK Line)

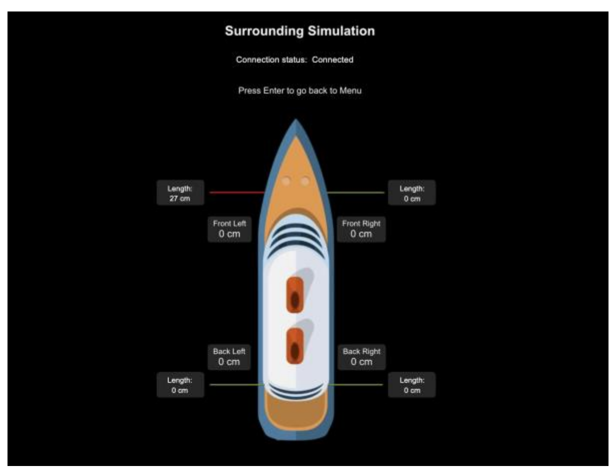

Figure 23. GUI Interface (TAUT Line)

2.4.3 Results and System Benefits

The prototype demonstrated notable improvements in efficiency and safety. By automating the tension control of the mooring lines, the winch system reduces the manpower required for mooring operations, allowing a single crew member to manage and adjust the lines. The automatic detection of tension eliminated the need for manual reeling, saving time and ensuring more precise control during docking.

Moreover, the system's ability to prevent over-tightening and provide slack when necessary enhanced the safety of both the vessel and the dock. The integration of this with the ultrasonic sensors cross-validates distances, optimizing the tension of the mooring lines. This reduces the risk of damaging mooring lines or dock infrastructure due to excessive tension. The automated winch system proves adaptable to different berthing conditions and vessel sizes, making it a versatile and scalable solution for improving mooring operations across various maritime environments.

2.5 Training System

2.5.1 Design Concept

The Training System was conceptualized to leverage advanced machine learning techniques to revolutionize the training process for mooring operations. The vision for the system focuses on improving collaboration among crew members while providing continuous, AI-driven feedback. Utilizing Few-Shot Learning from Large Language Models (LLMs), the system was designed to analyse real-world berthing operations and offer actionable insights for both new and experienced crew members. The aim was to optimize crew performance by identifying inefficiencies, highlighting best practices, and fostering a culture of continuous improvement. By employing cutting-edge LLM technology, the Training System would provide real-time feedback, tailored to the unique roles of each crew member, ensuring high levels of adaptability and operational efficiency.

2.5.2 Prototype Development

The prototype incorporated a speech-to-text using Azure Speech Studio, capturing communication and procedures during mooring operations. This data was processed using an Azure OpenAI GPT4o to conduct a detailed analysis of crew interactions and operational performance. The system generated personalised feedback, identifying patterns, errors, and areas for improvement. This AI-driven feedback loop enabled the crew to refine their operations based on real-time insights. The integration of this speech-to-text system with LLM analysis allows for continuous adaptation and skill enhancement, equipping the crew with the ability to quickly respond to evolving challenges or environmental factors.

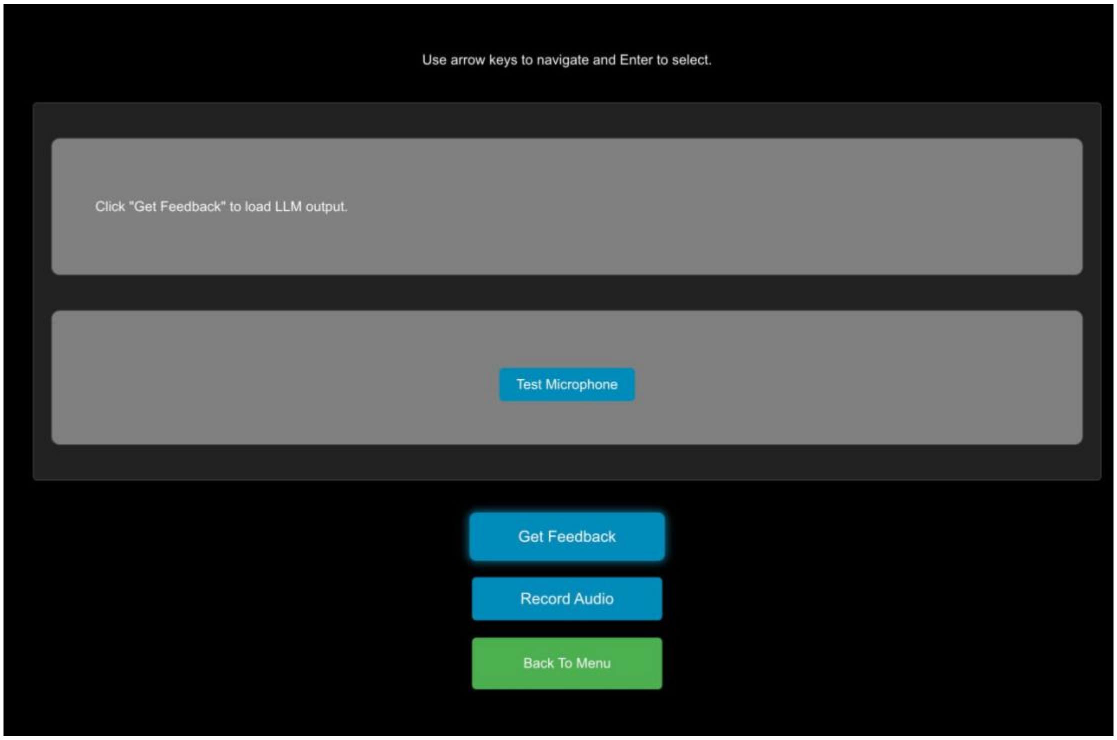

Figure 24. Training System Tab For Recording Voice Instructions

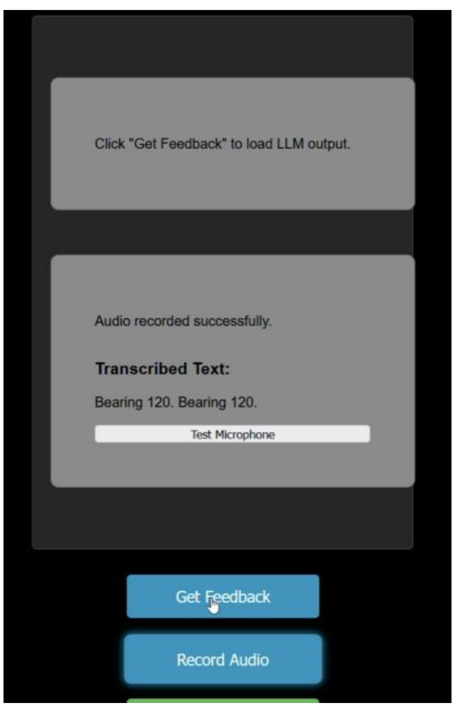

Figure 25. Audio Transcription

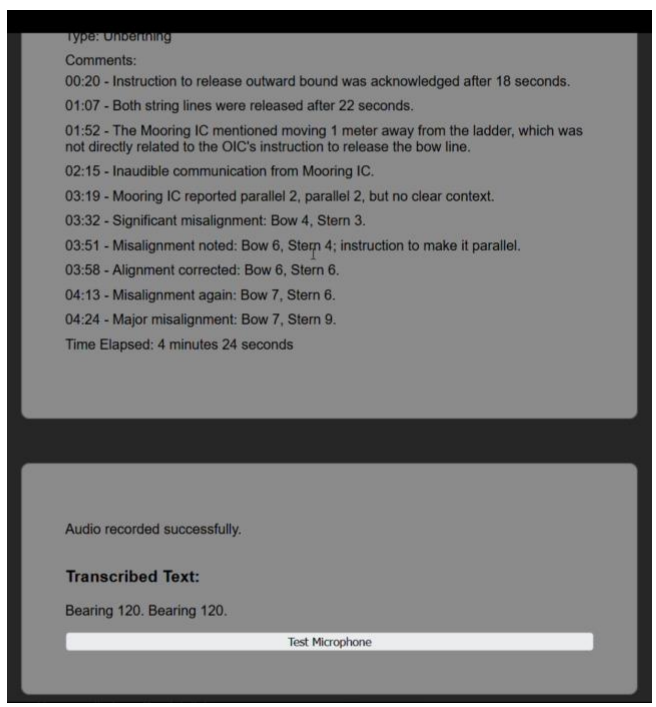

Figure 26. Feedback Generation

2.5.3 Results and System Benefits

The Training System prototype demonstrated substantial improvements in the speed and quality of crew training. For new personnel, the AI-powered insights derived from berthing and unberthing scenarios significantly shorten the learning curve, allowing them to adapt faster and perform more efficiently. For experienced crew members, the system offers continuous refinement suggestions, ensuring that they maintain and improve their operational expertise.

The system utilizes a few-shot learning approach, where a single example of berthing and unberthing was provided to the GPT-4 language model. This example serves as a template for the model to understand the task structure and expected output format. The system processes new scenarios, transcribed from speech to text using Azure Speech Studio, which was specifically trained on the vocabulary used in the single example to improve accuracy in maritime terminology recognition. The GPT-4 model then generates JSON-formatted analysis and feedback based on the transcribed input.

00:05 [OIC] "Active Control Joystick"

00:15 [OIC] Heading 120

00:20 [OIC] To Mooring IC release outward bound

00:38 [Mooring IC] Outward Bound Released

00:45 [OIC] Release both string line

01:07 [Mooring IC] Both string line released

01:28 [OIC] Mooring IC, release bow line

01:52 [Mooring IC] Moving 1 metre away from ladder

02:04 [OIC] Mooring IC, release stern line

02:15 [Mooring IC] **Inaudible**

02:30 [OIC] Roger all men on deck

02:43 [OIC] Hafiz give me the distance

02:48 [Hafiz] Bow 1, Stern 0

03:01 [OIC to Driver] Maintain 120

03:07 [OIC to Driver] Maintain 0.3, 0.2

03:13 [OIC] Mooring IC, update distance

03:19 [Mooring IC] Parallel 2, parallel 2

03:25[OIC to driver] mark your reference, 0.3, 0.2

03:32[Mooring IC] Stern 3, Bow 4

03;38[OIC to driver] slowly, maintain reference

03:51[OIC to driver] They said Bow 6, stern 4, need to make it parallel

03:58[Mooring IC] Bow 6, Stern 6

04;05 [OIC] Update me every metre

04:13[Mooring IC] Bow 7, Stern 6

Figure 27. Field Trip Transcript

This JSON output is seamlessly integrated with a Flask backend, which serves as the bridge between the AI model and the user interface. The Flask application processes the JSON data, storing and serves it to the frontend for display and interaction. As more berthing scenarios are processed, the Azure OpenAI LLM is designed to incorporate these new examples, allowing the language model to continually refine its understanding and improve its analysis over time.

This approach allows the model to generalize from the initial example to various berthing and unberthing situations, providing valuable insights even in unusual or complex docking scenarios. The system's ability to learn from new scenarios ensures that it remains adaptable to diverse maritime environments and evolving operational practices.

This flexibility fosters an environment of ongoing learning, where crew members can constantly improve their skills and respond effectively to new challenges. As a result, the system contributes to both the enhancement of crew proficiency and the overall safety and efficiency of berthing operations, promoting continuous operational excellence across diverse maritime environments.

3. Conclusion and Further Developments

3.1 Summary of Findings

The Berthing Bridge project has successfully integrated five key technologies into a comprehensive platform that addresses the major challenges in maritime berthing operations. Through the synergy of a centralized GUI, ultrasonic sensors, advanced computer vision, an automated winch system, and an AI-powered training system, Berthing Bridge demonstrates significant potential for improving safety, efficiency, and reliability in the berthing process while simultaneously reducing manpower requirements.

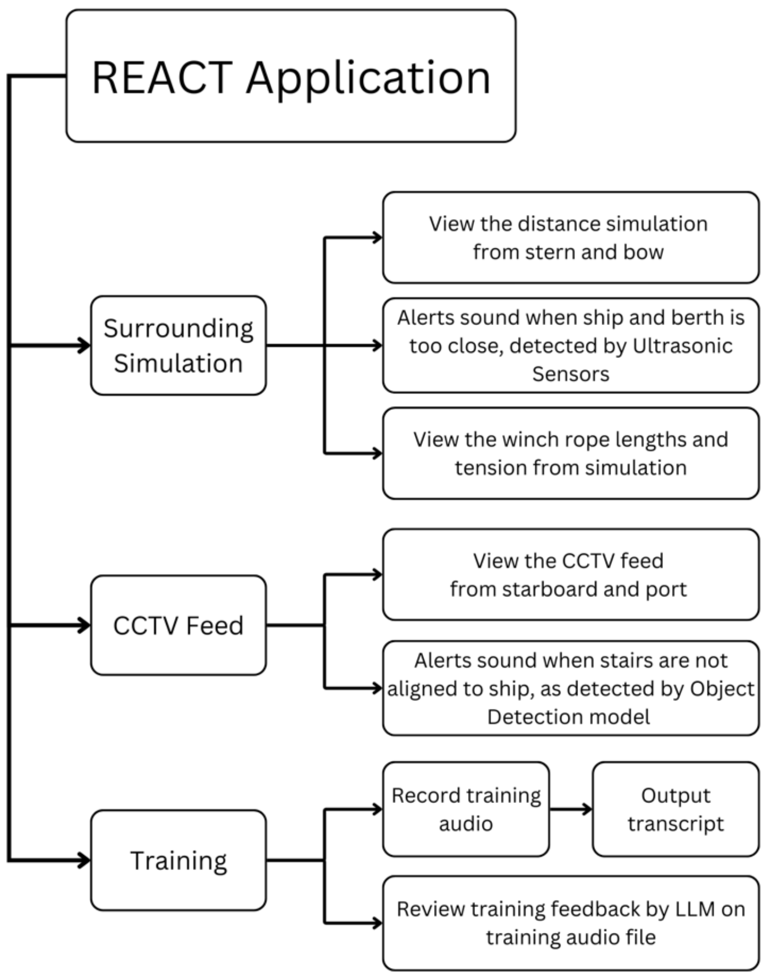

Figure 28. GUI Functionality Flowchart

The project's findings indicate a marked improvement in situational awareness, decision-making capabilities, and operational efficiency. The integration of objective data acquisition methods, such as ultrasonic sensors and computer vision, has significantly reduced the reliance on subjective human judgment in critical aspects of berthing. Furthermore, the automation of labour-intensive tasks, particularly in mooring operations, has shown promise in reducing both the time and manpower required for berthing.

Perhaps most significantly, the AI-powered training system has demonstrated the potential to accelerate skill development and foster a culture of continuous improvement in maritime operations. This aspect of the project not only enhances immediate operational capabilities but also lays the groundwork for long-term advancements in maritime practices.

3.2 Recommendations for Further Enhancements

While the Berthing Bridge project has yielded promising results, there are several avenues for further enhancement and research. Firstly, expanding the computer vision system to include more advanced object detection and tracking capabilities could further improve situational awareness and predictive capabilities during berthing operations.

Integrating real-time weather data and predictive modelling into the system could enhance decision-making in adverse conditions, a critical factor in maritime safety. This could involve developing algorithms that account for wind speed, current strength, and wave height in berthing calculations.

The training system, while already innovative, could benefit from the development of a more sophisticated LLM trained on a larger dataset of berthing scenarios. This would enhance its ability to provide context-specific advice and improve its adaptability to unique situations.

Exploring the integration of augmented reality technology presents another exciting avenue for development. AR could further assist in berthing alignment and spatial awareness, providing intuitive visual cues to helmsmen and other crew members.

Lastly, conducting extensive field trials across various vessel types and berthing conditions is crucial to validating the system's performance and identifying areas for refinement. These trials would provide valuable real-world data to further optimize the Berthing Bridge system and ensure its effectiveness across diverse maritime environments.

In conclusion, the Berthing Bridge project represents a significant step forward in maritime operations technology. Its successful implementation and further development have the potential to reshape berthing procedures, enhancing safety and efficiency across the maritime industry.

4. References

Bos, J., Lodewijks, G., & Schott, D. L. (2021). Automated mooring systems: A review of current practices and future developments. *Journal of Marine Science and Engineering*, 9(6), 597.

Bos, J., Lodewijks, G., & Schott, D. L. (2021). Automated mooring systems: A review of current practices and future developments. *Journal of Marine Science and Engineering*, 9(6), 597.

Gkerekos, C., Lazakis, I., & Theotokatos, G. (2019). Ship berthing time estimation using artificial neural networks and support vector regression. *Ocean Engineering*, 188, 106282.

Ho, E. (2024, August 24). HACX 2024 Challenge Statement Briefing [PowerPoint slides]. Singapore Civil Defence Force.

Johnson, L., Smith, R., & Thompson, A. (2023). Enhancing maritime crew performance through AI-driven training systems. *Journal of Maritime Technology*, 15(2), 123-135.

Kim, S., Park, J., & Lee, H. (2021). The impact of real-time monitoring systems on decision-making in maritime operations. *Maritime Operations Research*, 10(1), 45-60.

Lee, C., Chen, Y., & Wang, M. (2022). Assessing the role of technology in improving safety outcomes in maritime operations. *International Journal of Maritime Safety*, 8(3), 201-215.

Mavridis, G., Konstantinidis, A., & Papadopoulos, A. (2022). Operational challenges and solutions in maritime berthing processes: A review. *Journal of Shipping and Trade*, 7(4), 89-104.

Rødseth, Ø. J., & Kapetanis, G. N. (2019). Machine learning in maritime training and simulation. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 13(2), 257-262.

Rødseth, Ø. J., Vinther Hansen, M., Eriksen, B. N., Burmeister, H. C., & Porathe, T. (2020). Situational awareness in autonomous ship operations. *Proceedings of the 19th International Conference on Computer and IT Applications in the Maritime Industries (COMPIT)*, 1-12.

Zhang, Y., Liu, X., & Zhao, J. (2023). Automation in maritime navigation: Enhancing safety and efficiency through technology integration. *Marine Technology Society Journal*, 57(1), 34-50.