Technical Design Report of KMOU MACRO for RobotX Challenge 2024

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Abstract* — Korea Maritime and Ocean University is uniquely situated as the only university campus located on an island globally. This geographic advantage enables our team to conduct research on autonomous vessels in the adjacent maritime environment. We developed a comprehensive software architecture and the WAM-V platform specifically for the RobotX Challenge. Beyond conducting field experiments, we further validated the system using the simulation with a Hardware-In-the-Loop (HILS) framework. Detailed discussions on the Unmanned Surface Vehicle (USV) can be found in the paper.

I. INTRODUCTION

Team KMOU MACRO developed and integrated hardware and software systems designed specifically to meet the requirements of the Maritime RobotX Challenge 2024. Firstly, in the hardware system we used four cameras, PTZ(Pan-Tilt-Zoom) camera and 3D LiDAR for situational awareness of the USV. It calculated reliable control commands by combining sensor data. Also, GNSS and IMU were used for navigation system. Two system boxes are installed below the deck, and communication antenna was designed to be a foldable, to secure a landing and take-off space for the drone. In order to perform the task related to shooting, ball shooter was designed as a revolver type for fast and continuous reload and launch of the racquet ball.


Fig. 1: KMOU MACRO WAM-V

To execute tasks seamlessly, we implemented the Autonomous Management System (AMS), which operates based on a state machine that follows a specific sequence. The AMS integrates path planning, obstacle avoidance, and propulsion control. Additionally, the Ground Control Station (GCS), developed for comprehensive monitoring, allowed efficient task management during experiments by tracking system performance, device status, and logging states. To succeed in the RobotX Challenge, we conducted extensive tests in both simulated and real-sea environments, enhancing the system's robustness in our unique testing conditions.

II. TECHNICAL STRATEGY

A. *Competition Strategy*

First, obstacle detection through situational awareness is crucial for developing an autonomous control algorithm. Our team implemented object tracking to detect the location and color of obstacles using 3D LiDAR along with three IP cameras installed in a specially designed sensor package to increase the detection angles. Beneath the sensor package, we installed a PTZ camera to assist with specific tasks involving distant objects.


Fig. 2: PTZ camera and Sensor package

To optimize computational efficiency of the situational awareness algorithms, we separated the

PCs by sensor type, enabling parallel development. As the number of PCs increased, we robustly adjusted the bandwidth and communication methods of each sensor to prevent overall system latency. Additionally, by utilizing IP cameras and G-streamer, an open-source framework suitable for real-time video processing, we minimized camera latency within our system.

Second, all electronic equipment, except for the ball shooter system, was relocated below the deck to enhance the stability of drone takeoff and landing. A foldable mechanism was implemented for the communication antenna to prevent potential collisions with the drone. The antenna retracts during drone operations and returns to its original position once the operations are completed, controlled via a servo motor receiving PWM signals.

Third, we developed a low-level controller module to enhance the robustness of the propulsion system. The WAM-V is equipped with four thrusters: two side thrusters and two stern thrusters. Initially, a single controller was used to facilitate communication between the RC and PC. However, this configuration resulted in control instabilities, such as signal delays from the PC. To address this issue, we restructured the control system, utilizing an Arduino for thruster control and a Pixhawk for communication. The Pixhawk manages communication with the RC via RF and with the PC via serial communication, subsequently transmitting control signals to the Arduino to operate the thrusters. Although our system became more and complex, the integration of our controller module enabled us to manage the propulsion system with greater robustness compared to the single-controller setup.

Fig. 3: Low-Level Controller Box

Finally, we developed a ball shooter system designed for executing a task involving the launch of racquet balls. The system was designed and built with two primary objectives

1. Optimizing the ball-shooting mechanism
2. Establishing an effective reloading mechanism

To achieve these objectives, the ball shooter was designed based on an air gun mechanism, incorporating four reservoirs to compress and store air before its release. During the shooting tests, we observed that increasing the pressure made it more challenging to prevent air leakage.

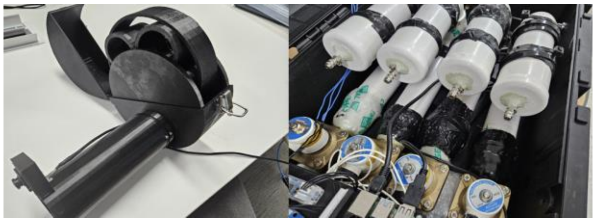


Fig. 4: Inner and Outer structure of the Ball Shooter

To address this issue, rather than relying on the method of compressing air on land and then opening the reservoir, we installed an onboard compressor. This allowed for real-time air compression, and even with leakage, the system could regulate pressure automatically through a control mechanism, significantly improving the shooting success rate. For the loading system, we devised a method inspired by the revolver mechanism. The system was designed to control the pneumatic reservoir replacement via relay control, enabling continuous shooting by switching the magazine as sequential. Lastly, we were able to keep our systems stable in the final stage.

B. *Design Strategy*

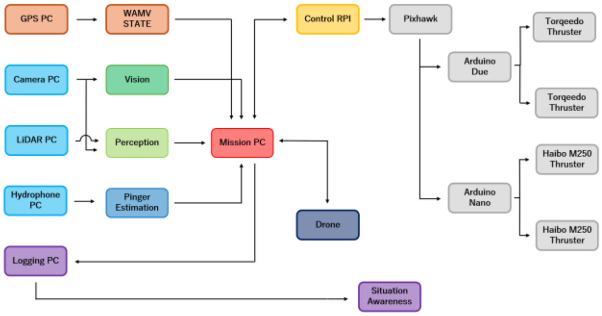


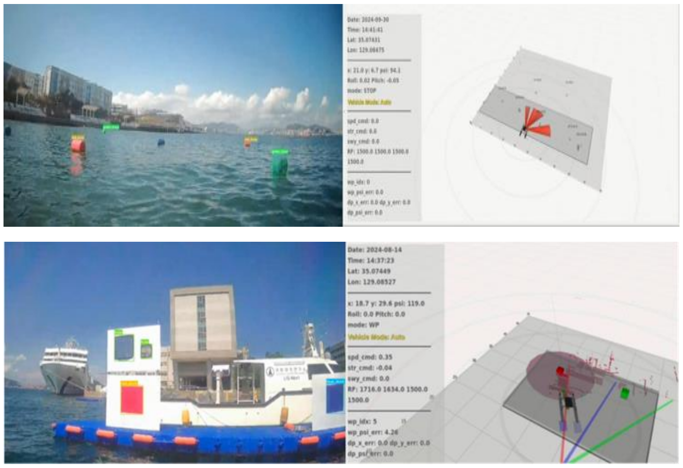
Fig. 5: Data Architecture

As shown in Fig. 5, the system is divided into navigation, situational awareness, performing mission, calculation control command, and computing propulsion command. Based on the results of situational awareness, appropriate path planning and tracking commands for the tasks are computed on a separate mission PC. To manage the eight tasks of the challenge, we made the system into a Mission node, which defines the overall state machine flow for each mission, and task, which are divided into sub-tasks to perform the state machine for each individual task. This approach allowed our team to assign specific task developers to work in parallel, improving the efficiency of mission execution for the competition.

1) *Situational awareness*

In situational awareness, LiDAR visualization data is represented as a type of point cloud. But point clouds increase the computational load of the object detection algorithm and make noise, which interferes with accurate object detection and real-time [1]. To solve this problem, we used three ways.

First thing is pre-processing. LiDAR used in the tasks cover up to 360° and maximum detection distance may result in the noise and less accurate data compared to data with closer coverage [2]. So, we adjusted the parameters for object detection to 180° and 50 m forward detection range for the mission.



Date: 2024-09-30
Time: 14:41:41
Lat: 35.07431
Lon: 129.08475
x: 21.0 y: 6.7 psi: 94.1
Roll: 0.02 Pitch: -0.05
mode: STOP
Vehicle Mode: Auto
spd_cmd: 0.0
str_cmd: 0.0
swy_cmd: 0.0
RF: 1500.0 1500.0 1500.0 1500.0
wp_idx: 0
wp_psi_err: 0.0
dp_x_err: 0.0 dp_y_err: 0.0
dp_psi_err: 0.0

Date: 2024-08-14
Time: 14:37:23
Lat: 35.07449
Lon: 129.08527
x: 18.7 y: 29.6 psi: 119.0
Roll: 0.0 Pitch: 0.0
mode: WP
Vehicle Mode: Auto
spd_cmd: 0.35
str_cmd: -0.04
swy_cmd: 0.0
RF: 1716.0 1634.0 1500.0 1500.0
wp_idx: 5
wp_psi_err: 4.26
dp_x_err: 0.0 dp_y_err: 0.0
dp_psi_err: 0.0

Fig. 6: Buoy EC detection result (top), DBSCAN-based panel detection result (bottom)

Secondly, Euclidean clustering (EC) is a generalized LiDAR-based object detection algorithm that clusters point clouds based on Euclidean distance. EC algorithm is advantageous to represent simple shape like buoys and use lower computing power. In this paper, these constraints (Euclidean tolerance, min cluster, and max cluster) are parameterized according to each mission.

To dock WAM-V to the target panel, DBSCAN (Density-based spatial clustering of applications with noise) was used. The reason why we used DBSCAN [3]is a density-based clustering technique that is advantageous for detecting dense objects or objects with complex geometries. When WAM-V attempts to detect an object for docking near a panel, it uses DBSCAN to detect the panel.

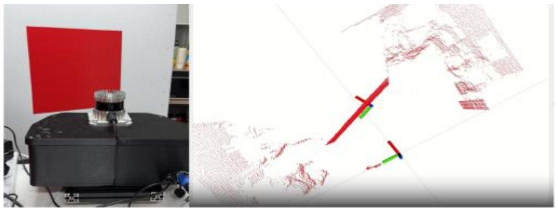


Fig. 7: RANSAC-based panel TF result

After docking, the RANSAC (RANdom SAmple Consensus) algorithm was used to measure the tilt of the panel and generate a coordinate system centered on the panel, which was then used to update the target location and heading.

Furthermore, we used cameras for situational awareness. These were mainly used to recognize the color of marine buoys, LED tower, panel and dock site. The YOLOv8[5] model was used for object recognition. The entire process of tracking the sea buoy in Task 3 using sensor fusion is shown in the diagram in Fig8. Tracking is performed based on LiDAR's detection information, and camera detection information is matched with the 3D projected frustum [6] to derive 3D tracking information including color.

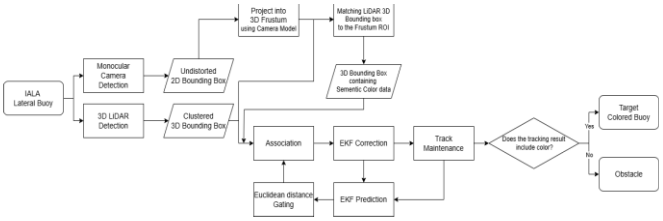


Fig. 8: Tracking architecture

Internal parameter information was acquired by correcting the camera's distortion, and external parameter information was acquired through calibration between the camera and LiDAR. Projection is performed and then the corresponding frustum and LiDAR Cluster information are matched to derive 3D object information with semantic data and updated based on the LiDAR Cluster information entered as the observed value of the Extended Kalman Filter [7] and the Euclidean distance.

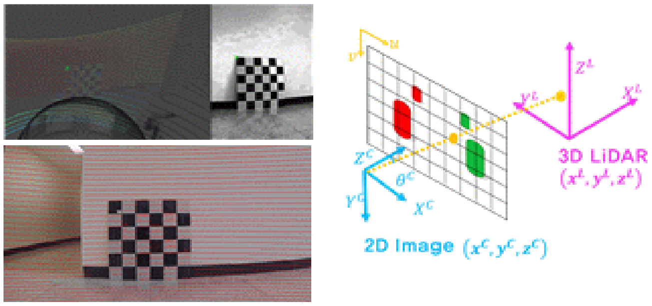


Fig. 9: Camera-LiDAR Calibration

Gating is performed by applying Global Nearest Neighbor [8] (GNN) to the derived tracking values and assigning tracking to the observed values. By stacking the colors of the LEDs using a buffer, we determine the representative color that is most frequently detected for each element at one-second intervals, estimating the consecutive three colors. With estimating the representative color for each time periods, we can prevent misidentification of colors due to false detections.

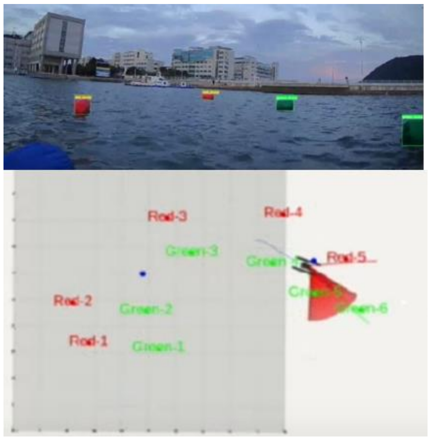


Fig. 10: Path Mapping through Tracking

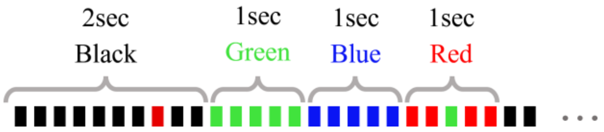


Fig. 11: Color Sequence Estimation Process

We also used hydrophones to detect pinger's sign. These hydrophones are mounted on the bow of the hull using PVC pipes and aluminum profiles. A DAQ system is used to convert the acoustic signals captured by the hydrophones into digital signals, enabling signal processing on a PC.

During Task 2, two hydrophones were used to detect its signal, and signal processing was applied to estimate the Direction of Arrival (DOA) to select the correct gate containing the pinger. The measured signal is passed through a Band Pass Filter (BPF) to isolate the signal within the frequency range. The maximum value of the signal is likely caused by the pinger signal, so the signal is cropped around this peak. Within this cropped range, the first point where the signal exceeds a predefined threshold is measured. The time difference between these points in each signal is then used to calculate the Time Difference of Arrival [9] (TDOA). Using triangulation, the Direction of Arrival (DOA) is estimated by the TDOA. Next, in the gate inference state, Bayesian inference is applied using the previously estimated DOA [10], the candidate gate positions, and the vessel's position and heading at the time the signal was detected. This inference is repeated until the probability of the pinger being located at a specific gate exceeds certain threshold. Once this threshold is reached, the gate is confirmed, and the gate inference process is completed.

2) Path planning

To successfully execute the tasks of the RobotX competition, efficient path planning is essential. Accordingly, we developed several path planning algorithms, as outlined below.

1. Fine Path: This algorithm generates waypoints at consistent intervals from the current position to the target location

2. U-Turn Path: This algorithm constructs a U-shaped turning path based on a specified coordinate

3. Circular Path: This algorithm creates a circular trajectory with a fixed radius around a designated coordinate.

3) Ball shooter

To perform shooting process, not only the shot success rate but the mission success rate is important. So, we devised the whole shooting process and made the state machine of ball shooter.

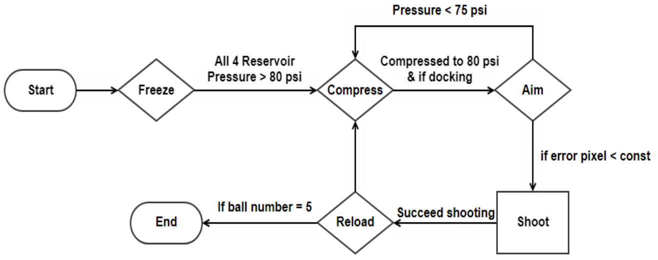


Fig. 12: State Machine of Ball shooter

When ball shooter is activated with mission, it maintains the initial position. After freezing mode, the air is compressed into four reservoirs individually. All reservoirs preserved the air compressed and that's measured by pressure transmitter with Arduino. Next step is "Aim" when docking precisely. Using the USB camera, which is located on the tip of gun barrel, the target hole can be captured and follow it during docking. We used YOLOv8 model to learn about target hole and performed visual servoing [11] using two motors to aim at the center pixel of the resulting bounding box. If the pressure condition is satisfied, Raspberry Pi 4 controls the relay module with designed algorithm. Until all balls were shot, aim-shoot-reload state is repeated during the mission.

Two motors for two-dimensional movements are controlled by command about pixel error between target hole and aiming point. But there were awkward movements and overshoot that occurred by payload of the structures. To overcome unnatural motions, simple smooth control was used. Besides that, attitude of WAM-V was changed by environmental forces, and it disturbed the aiming. We used PID controller to operate robustly.

4) Drone

We created a state machine to execute the process of takeoff, mission execution, and landing. ROS2 was used to communicate between WAM-V and the drone, and Micro-XRCE-DDS Protocol [12] was used to receive sensor data from Pixhawk. And the drone was controlled with position control in offboard mode.

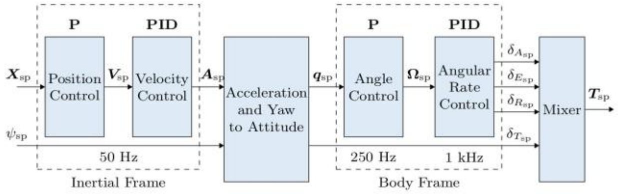


Fig. 13: Multicopter Control Architecture [12]

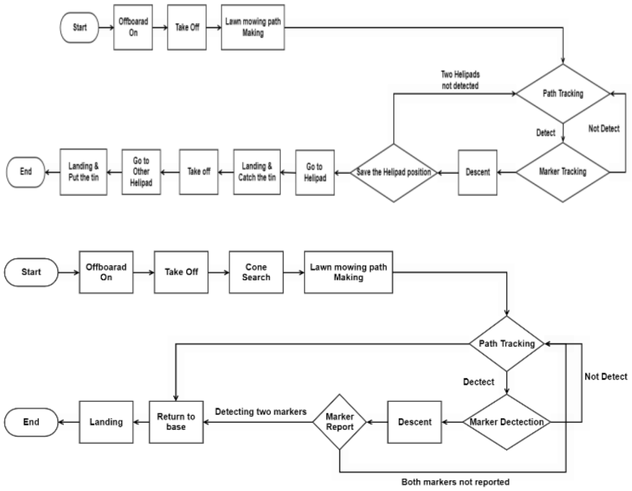


Fig. 14: State Machine for catching a tin(top), State machine for marker reporting(bottom)

We also detected the Helipad and R and N markers using the Grid Based Coverage Path Planning technique for exploration.

For the landing system, Aruco Markers were utilized to estimate the three-dimensional position and attitude of the drone camera, and control commands were generated from the position error of the markers and camera.

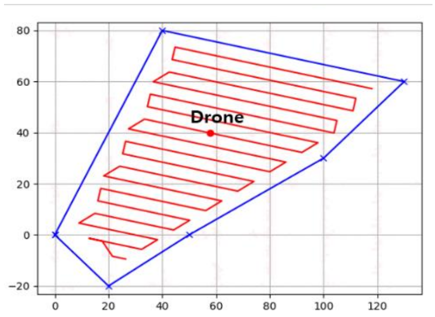


Fig. 15: Grid Based Coverage Path Planning

C. Testing strategy

Equally important is the execution of the experiments. Although we have designed and prepared the WAM-V for the competition, one crucial step remains. We developed a sequential testing plan to identify and evaluate each stage systematically.

Before conducting sea trials, we aimed to validate our system in a controlled environment first. Therefore, we tested the simulation environment using the Virtual RobotX (VRX) simulator. Our participation in VRX 2023 competition facilitated this process, as we were able to replicate the competition environment and perform the experiments efficiently. Through this approach, we gained a comprehensive understanding of the tasks involved and developed strategies to address the challenges encountered.

Fig. 16: VRX environment for RobotX tasks(left), Hardware In the Loop Simulation setup(right)

We aimed to verify the seamless operation and communication of hardware components with each PC. To achieve this, we implemented a Hardware-in-the-Loop Simulation (HILS) system within the VRX environment, as shown in Fig. 16. By integrating the hardware components (controller, sensors, PC, actuators) into the simulation, we were able to validate the system. This approach allowed us to identify and resolve issues related to communication, logic, and hardware states without the need for water-based testing.

Once all systems were validated, we planned to conduct tests under real sea conditions. This pre-planned approach minimized errors during daytime field experiments. In case of any issues encountered during the tests, we could promptly address them by verifying and adjusting algorithms and logic in the simulation environment during nighttime sessions.

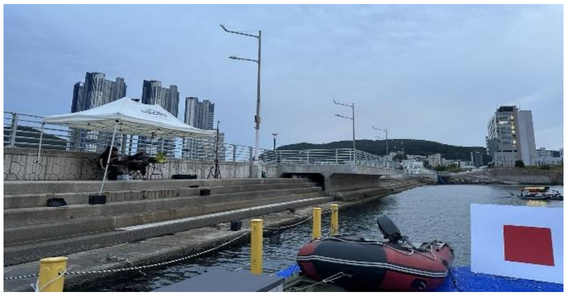


Fig. 17: Test site located in the KMOU campus

Furthermore, we implemented a Ground Control System (GCS) software to provide real-time monitoring of the vehicle and task status at a glance. This system enables team members to oversee the entire process, including device status and sensor data. Developed using rviz2 in ROS2, the GCS comprises four screens, each of which will be explained in detail below.

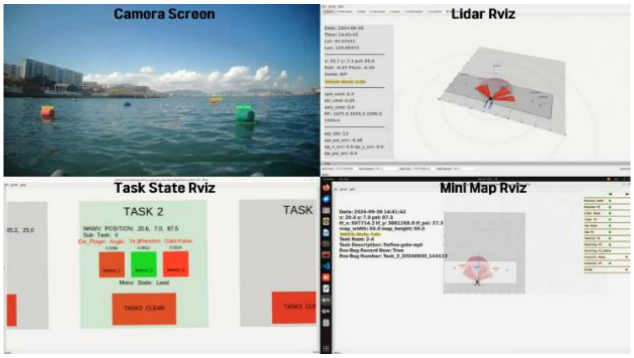


Fig. 18: Ground Control System

1) Camera Screen

Show a real-time video feed from IP Cameras and inference results such as object detection which helps in identifying targets.

2) Lidar Rviz

Display a LiDAR data from a perspective that follows the WAM-V, including clustering results shown relative to the mission coordinate system.

3) Task State Rviz

Display the progress of each task, including sub-task numbers, and visualizes the necessary information required to perform the mission.

4) Mini-Map Rviz

Display a top-down mini-map with sub-task descriptions, logging status and identified object in each task. Additionally, it visualizes the status of each PC and the Node states on the right side.

III. ACKNOWLEDGMENT

Team KMOU MACRO achievements would not have been possible without the support. The team wishes to acknowledge its sponsors: HD Hyundai, Avikus, KRISO(Korea Research Institute of Ships & Ocean engineering), LIG Nex1.

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APPENDIX A: COMPONENT LIST

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of Purchase	Reasoning
Waterproof Connectors	Elec Solution	LP-16-C08PE	https://smartstore.naver.com/elecsolution/products/6888756573?NaPm=ct%3Dm1z07ago%7Cci%3Dcheckout%7Ctr%3Dppc%7Ctrx%3Dnull%7Chk%3D704b97317e2d33e7d35b7e2e1e988fe6f877e751	Purchased	$9.00	2024	Waterproof
Propulsion	Torqeedo	Torqeedo Thruster Cruise 3.0	https://www.torqeedo.com/us/en-us/products/outboards/cruise/cruise-3.0-r/M-1260-00.html?srsltid=AfmBOorgBkEKHxQM_quhV3kZuSaLcf5sQyYyJiPvLuqHKkQrZnLm8T8D	Purchased	$4,654.70	2024	Propulsion
Propulsion	Haibo	Haibo Hand Control Electric Trolling Motor	http://www.haibomotor.com/SW_Transom-mount_show_12.html	Purchased	$219.00	2024	Propulsion
Power System	badaroyacht	24V 100AH LITHIUM IRON PHOSPHATE BATTERY	https://www.toolpark.co.kr/goods/goods_view.php?goodsNo=1000007425	Purchased	$743.11	2024	Propulsion battery
Power System	ecoflow	EcoFlow DELTA 2	https://manuals.ecoflow.com/us/product/delta-2-portable-power-station?lang=en_US	Purchased	$891.73	2024	Electric system power
Motor Controls	Robotis	XM430-W350-R	https://www.robotis.com/shop/item.php?it_id=902-0118-000&NaPm=ct%3Dm1yzo5c6%7Cci%3Dcheckout%7Ctr%3Dppc%7Ctrx%3Dnull%7Chk%3D60699b61d4e1c25d7251b28b137d57bd89695f3c	Purchased	$216.00	2024	Antenna folding motor
Motor Controls	Robotis	XL430-W250-T	https://www.robotis.com/shop/item.php?it_id=902-0135-000&NaPm=ct%3Dm1yzpyg1%7Cci%3Dcheckout%7Ctr%3Dppc%7Ctrx%3Dnull%7Chk%3D660a16417ee683fd1fee9937b570092515d9445a	Purchased	$40.00	2024	Targeting and loading motor for ball shooting
CPU	Intel	NUC13ANKi7	https://download.intel.com/newsroom/2023/client-computing/Intel-NUC-13-Pro-Tech-Product-Spec.pdf	Purchased	$862.00	2024	Computer
CPU	Asus	ASUS ExpertCenter PN64 i7-13700H M.2	https://www.asus.com/displays-desktops/mini-pcs/pn-series/asus-expertcenter-pn64/techspec/	Purchased	$1,040.35	2024	Computer
Teleoperation	Ubiquiti	airMAX AC Antenna (Model:AM-5AC21-60)	https://dl.ubnt.com/datasheets/airMAX_ac_Sector/airMAX_ac_Sector_Antennas_DS.pdf	Purchased	$199.00	2024	Communication
Teleoperation	Ubiquiti	airMAX Antenna (Model:AM-5G19)	https://dl.ubnt.com/datasheets/airmaxsector/airMAX_Sector_Antennas_DS.pdf	Purchased	$139.00	2024	Communication
Teleoperation	Ubiquiti	airMAX Omni Antenna (Model: AMO-5G13)	https://dl.ubnt.com/datasheets/airmaxomni/amo_ds_web.pdf	Purchased	$165.00	2024	Communication
Teleoperation	Ubiquiti	airMAX Antenna (Model: AMO-5G10)	https://dl.ubnt.com/datasheets/airmaxomni/amo_ds_web.pdf	Purchased	$125.00	2024	Communication
Teleoperation	Ubiquiti	airMAX Rocket Prism 5AC (Model: RP-5AC-Gen2)	https://dl.ubnt.com/datasheets/RocketAC/Rocket_Prism_AC_Gen2_DS.pdf	Purchased	$249.00	2024	Communication
GNSS	CUAV	CUAV C-RTK 2 HP GNSS	https://www.cuav.net/en/c-rtk_2hp/	Purchased	$269.00	2024	Navigation
Inertial Measurement Unit (IMU)	Micro Strain	MICROSTRAIN 3DM-GX5-IMU	https://microstrain.com/sites/default/files/GX5%20%20IMU.pdf	Purchased	$1,571.00	2024	Navigation
Camera(s)	Hanwha vision	QNO-6012R (2M H.265 IR Bullet)	https://www.hanwhavision.com/ko/products/camera/network/bullet/qno-6012r/download/#	Purchased	$400	2024	Perception
LiDAR	OUSTER	os1-32-U Mid-range digital lidar sensor	https://data.ouster.io/downloads/datasheets/datasheet-rev7-v3p1-os1.pdf	Purchased	$4,800.00	2024	Perception
Hydrophones	Aquarian Audio	AS-1	https://www.aquarianaudio.com/as-1-hydrophone.html	Purchased	$409.00	2024	Pinger estimate
Teleoperation	Radio Master	TX16S Mk2 Max	https://www.rcme.co.kr/shop/goods/goods_view.php?goodsno=100048067	Purchased	$490.00	2024	Radio controller
Teleoperation	Radio Master	R88 V2 Receiver	https://www.rcme.co.kr/shop/goods/goods_view.php?goodsno=100020533	Purchased	$24.00	2024	Receiver

Component	**Vendor**	**Model/Type**	**Specs**	**Custom/ Purchased**	**Cost**	**Year of Purchase**	**Reasoning**
Amplifiers	Aquarian Audio	PA-4 Hydrophone Preamplifier	https://www.aquarianaudio.com/pa4.html?variation_id=101	Purchased	$109.00	2024	Pinger estimate
DAQ	National Instrument	cDAQ-9181	https://www.ni.com/ko-kr/shop/model/cdaq-9181.html	Purchased	$676.00	2024	Pinger estimate
DAQ chassis	National Instrument	NI-9263	https://www.ni.com/ko-kr/shop/model/ni-9263.html	Purchased	$855.00	2024	Pinger estimate
SBC	Raspberry pi	Raspberry pi 4 8 GB	https://datasheets.raspberrypi.com/rpi4/raspberry-pi-4-datasheet.pdf	Purchased	$75.00	2024	Computer
MCU	Arduino	Arduino Due	https://store.arduino.cc/products/arduino-due?srsltid=AfmBOooBrI0NmYMxMNS7zewJTuhbGSe2VzXyH4KJT9-hrZFrTiyogB-Q	Purchased	$56.00	2024	Thruster controller
MCU	Arduino	Arduino Nano	https://store.arduino.cc/products/arduino-nano?srsltid=AfmBOor18E95YEB10y1WQV0sqkr5JT4qfAJ1n7OFAG6OVsZtEQ40mGKe	Purchased	$30.00	2024	Thruster controller
GNSS Antenna	Amotech	u-blox GNSS Multiband	https://mm.digikey.com/Volume0/opasdata/d220001/medias/docus/3098/AS-ANT2B-ANN-L1L2-50SMA-00.pdf	Purchased	$63.00	2024	Navigation
Reservoir	-	Ball shooter reservoir	-	Custom	-	2024	Pressurized tank for ball shooting
Revolver	-	Ball shooter revolver	-	Custom	-	2024	Structure for ball shooting
Flight Controller	Holybro	Pixhawk 6X	https://xcopter.com/product/detail.html?product_no=35780&gad_source=1&gclid=Cj0KCQjwjY64BhCaARIsAIfc7YYSxMNqHTWXPQ6aLHTnTbFlbYuS108WeNGH6dvFBNr8MpgrhU7Gk1caApV2EALw_wcB	Purchased	$400.98	2024	Drone Flight Control
SBC	Raspberry pi	Raspberry pi 5 8GB	https://www.raspberrypi.com/products/raspberry-pi-5/	Purchased	$115.80	2024	Drone Mission pc
Camera	SJCAM	SJ4000 WIFI	https://www.sjcam.com/cameras/action-cameras/sj4000-wifi/	Purchased	$56.35	2024	Drone camera
Range Finder	Benewake	TF-02 Pro	https://www.mouser.com/datasheet/2/1099/Benewake_10152020_TF02_Pro-1954040.pdf?srsltid=AfmBOopGoPcKRmvSeLNlnoT-TYGhXhlImluUyLKqtE9El0DxGRr-TMj7	Purchased	$141.95	2024	Drone range finder
Motor	RCVICTOR	2212 920kv Brushless motor	https://tophobby.co.kr/product/2212-920kv-brushless-motorcwccw/3451/	Purchased	$9.64	2024	Drone motor

APPENDIX B: TEST PLAN & RESULT

Team KMOU MACRO prepared for the Maritime RobotX Challenge 2024 from May to October. We scheduled whole period before sending WAM-V and detailed by dividing goals to three steps: 1. Setup UGV and fundamental devices, 2. Test in VRX and interwork between software and hardware (HILS), 3. Construct testbed and execute the experiment at sea.

1. *Setup UGV and fundamental devices*

Initially, the team divided the work between designing the system box for software operation and the create propulsion system. The system box design team first integrated communication equipment, PCs for performing tasks, and various sensors, then mounted them on a small UGV for verification. During this process, severe latency issues arose due to bandwidth and communication settings, which required stabilization efforts. The propulsion system team initially attempted to control four thrusters using Arduino but encountered signal delay issues and instability when linking with ROS2. To solve these problems, a Pixhawk was added, and sufficient tests were conducted on ground, which significantly improved the system's performance. And then, the propulsion system was then mounted on the WAM-V platform, and numerous maneuver tests were performed.

Fig. 19: UGV with sensor box and system box

2. *Test in VRX and interwork between software and hardware (HILS)*

Finally, the propulsion system and system box were integrated, and the overall system was verified through Hardware In the Loop Simulation (HILS) using VRX. At that time, there were bandwidth issues between the RF controller and the router, but they were easily resolved based on previous experience. Also, HILS was used to develop the software for task execution before conducting sea trials. During software development, the system was divided by tasks, and state machines were separated to enable parallel development.

3. *Construct testbed and execute the experiment at sea.*

The systems were developed that displayed the states of the thrusters and all sensors on the GCS, enabling forced shutdowns in case of suspected sensor malfunctions, which helped mitigate risks. Subsequently, we created a similar testbed near Korea Maritime and Ocean University by installing buoys, docking panels, and a LED tower. In the early sea trials, we executed the algorithms developed using HILS, and issues arising from sensor uncertainty were addressed through additional sea trials.

Since none of us majored in the field of aerial vehicles, we used Pixhawk which was designed as a drone controller. However, at the first time we used Pixhawk's Offboard mode, it failed to receive many satellites and to arm due to ‘No Offboard Signal’ error. So, the problem was solved by placing the antenna jig higher on the drone to improve GNSS reception.

Before conducting drone experiments, we added a hardware forced shutdown feature for safety. We carried out tests in unpopulated areas until stable flights were consistently achieved. Once sufficient ground missions were completed, we integrated the drone with the WAM-V for sea trials. To minimize the equipment on the deck, we fabricated an aluminum profile jig to position the propulsion battery and system box power bank below the deck.

Additionally, we installed a net on the WAM-V to prevent the drone from falling into the sea. Throughout all experiments, at least two team members were on standby in a lifeboat to respond to any potential accidents.

Fig. 20: WAM-V Test conducted in KMOU campus

4. *Result*

Finally, we designed a robust controller through sea trials and checked that all tasks were performed smoothly, even in maritime environments with waves, currents, and wind. In the latter part of the experiments, we utilized the scoring system from Maritime RobotX 2022 to enhance the completeness of our mission performance, and we expect excellent results in this competition.