Technical Design Report

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***Abstract*—The AGH Solar Boat Team presents their approach for the RoboBoat 2024 competition, emphasizing visual detection technology for navigation. The boat integrates vision, GPS data, and depth measurements for efficient task execution.**

Tasks such as navigation, docking, and collection/delivery octagon utilize a custom neural network, depth measurements, and hardware commands for precise control. The Return to Home task incorporates GPS positioning and waypoint navigation with IMU data.

The design features a catamaran structure with basalt fiber floats for lightweight and corrosion resistance. Computational fluid dynamics simulations optimize hydrodynamics. The power and control system include three circuits for safety and reliability.

Communication involves a commercial RC controller and telemetry system. Sensors include the ZED2i camera and SBG Ellipse-D IMU. The system architecture is organized into three layers for scalability.

Testing strategies include dry tests, water tests, and simulation tests to validate hardware robustness and refine algorithms. Gratitude is expressed to AGH University, advisors, collaborators, and team members for their contributions to the project.

I. TECHNICAL CONTENT

A. Competition Goals

This year, team has made the decision to undertake all of the tasks. The implementation of visual detection technology plays a pivotal role in all of the tasks, except Return to Home. In these scenarios, our algorithm adeptly identifies buoys based on size, color, and shape, steering the boat with precision. The strategic use of mirrored reflections enhances control when faced with a single buoy. The navigation process between tasks involves the integration of both vision and GPS data.

*1) **Navigation Channel, Follow the Path and Speed Challenge**:* The methodology employed for these tasks relies on the visual detection of buoys varying in size, color, and shape. In the Navigation Channel and Follow the Path tasks, the algorithm identifies the nearest pair of red and green buoys, taking into account the detection area, and directs the boat toward the midpoint between them. Should the ASV observe only a single buoy, the algorithm will generate a mirrored reflection of it to facilitate easier control.

The same strategy is implemented in the Speed Challenge, where the detector initially identifies the sole existing gate and then proceeds to locate the yellow buoy. Subsequently, it guides the boat in a manner ensuring that the yellow buoy consistently remains on the left side before navigating towards the ”mirrored” gate.

*2) **Docking & Duck Wash**:* Our custom neural network will be employed for the identification of both the docking platform and the shapes present on it. Additionally, we utilize depth measurements from the ZED2i camera to halt the boat at a specified distance before the detection of the required shape. Initially, the detector will recognize the dock, guide the boat towards it, then identify the shape and steer towards it until the distance equals a predefined threshold.

In the case of Duck Wash, our plan involves a similar approach, with the additional incorporation of a command to the hardware for activating and deactivating the nozzle. This strategic inclusion allows us to control the water flow during the Duck Wash task. The seamless coordination of hardware commands with visual and depth-based navigation reinforces the versatility and robustness of our autonomous boat's functionality in diverse scenarios.

*3) **Collection & Delivery Octagon**:* For Collection Octagon, the neural network will identify the octagon. Subsequently, the ASV will approach it until it reaches a specified threshold, prompting the issuance of a command to the robotic arm to retrieve ducks and balls. The algorithm for the Delivery Octagon shares a similar structure, with the key distinction being that the arm releases the collected items. In both scenarios, precise coordination between the neural network, ASV navigation, and robotic arm commands ensures efficient and accurate execution of the tasks. The design also incorporates real-time feedback mechanisms to adapt to dynamic environmental conditions, enhancing the adaptability and reliability of the entire collection and delivery process. This holistic approach underscores our commitment to creating a versatile and resilient autonomous boat system for the RoboBoat 2024 competition.

*4) **Return to Home**:* Our plan involves introducing a waypoint at the commencement of the Navigation Channel, subsequently utilizing GPS position and steering toward the waypoint to facilitate a return to the starting point. This is implemented with the use of cartesian coordinates with our (0,0) point designated as the starting position before entering the Navigation Channel. This strategic utilization of waypoints and coordinates not only ensures precise navigation through the channel but also provides a systematic approach for Barka's autonomous operations. The integration of IMU data and feedback loops allows the autonomous boat to adapt to unforeseen challenges, showcasing the adaptability and resilience of our navigation strategy.

B. Design Strategy

*1) **Hull Design**:* The design featured a catamaran structure for easy disassembly, facilitating convenient transport suitable for air travel.

Basalt fiber was chosen as the primary material for the floats due to its corrosion resistance, low weight, and superior mechanical strength compared to traditional fiberglass. The floats also incorporated a polyethylene core to ensure high rigidity and bending strength, contributing to the overall structural integrity of the boat.

The construction process involved creating positive molds for the floats using MDF panels and resin, followed by negative molds made of gelcoat and fiberglass. Composite materials were used for the deck and bulkheads.

To optimize hydrodynamics, computational fluid dynamics simulations and finite element method analyses were conducted, aiming to enhance the boat's performance in various water environments.

The connection between floats and deck was established using aluminum profiles and 3D-printed components, allowing for both structural stability and ease of disassembly during transport.

The use of standardized aluminum T-slot profiles in conjunction with hammerhead nuts (T-slot nuts) allows for the versatile configuration of structures and easy addition of elements, such as sensors.

The lightweight properties of basalt fiber and polyethylene contributed to the boat's overall efficiency, enhancing both performance and environmental sustainability.

Environmental considerations were paramount in the construction, with the boat designed to minimize its carbon footprint. The transparent nature of basalt fiber to magnetic fields prevented interference with measurement equipment during environmental research.

We used thrusters from Blue Robotics T200 to propel the boat. In the future, we plan to replace them with propeller nacelles designed by us.

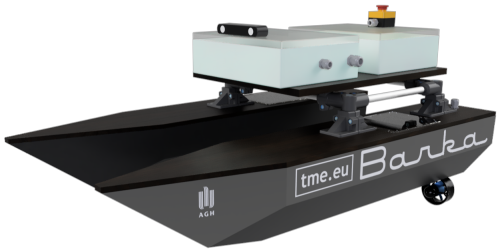

Fig. 1. Render of Barka

*2) **Electrical Strategy**:* Last year's competition illuminated the shortcomings of certain solutions, prompting a comprehensive overhaul of the boat's electrical system this year. We divided the entire system into three circuits: power, controls, and PV. Our primary focus was on the safety and reliability of the system. Additionally, the modularity of the components used and ease of access to electronic elements were significant considerations for us.

*3) **Power Circuit**:* In comparison to the previous year, we have opted to discontinue the practice of powering the entire boat from two batteries housed within the compartment, instead relocating them to the floats. Additionally, with the objective of safeguarding the thrusters against excessively high currents, we have replaced the BLDC motor controller with a version featuring signal opto-isolation. The delivery of energy is facilitated through the Battery Management System (BMS), whose role encompasses protection against short circuits, battery overcharging or significant discharge, and excessively high current draw. Monitored battery parameters will be transmitted to the CAN 2.0 bus on the boat for real-time diagnostics utilizing a telemetry system.

*4) **Control Circuit**:* The power supply for control circuits is facilitated through a new, third battery located within the electrical box. Overseeing its operation, similar to the other batteries, is the BMS, which transmits voltage to both the Control Board PCB (Printed Circuit Board) and NVIDIA Jetson Orin computer. All printed circuits on the boat are interconnected via the CAN 2.0 bus to facilitate the exchange of data essential for the proper functioning of the boat.

*5) **Modularity of Used Elements**:* A crucial aspect for us is the compatibility of the components used. Hence, in the design of the BMS, we developed a single board that can manage both the batteries in the compartment and those in the floats.

*6) **Control Board**:* With the expanded functionalities of the boat compared to last year's competition, the incorporation of new electronic components was necessitated. To address this requirement, a new PCB has been developed with the following responsibilities:

- Communication with the radio receiver
- Handling new peripherals of the telemetry system
- Control of the stepper motors of the robotic arm
- Management of motor controllers

*7) **Jetson AGX Orin**:* The Jetson AGX Orin serves as a pivotal component in the project, acting as an advanced system-on-module (SoM) developed by NVIDIA. Featuring the potent Orin GPU architecture with dedicated AI accelerators, it excels in handling complex deep learning computations. Specifically designed for edge computing applications, such as robotics, autonomous vehicles, and smart cameras, the Jetson AGX Orin provides compact and energy-efficient computing power for real-time AI inference tasks.

*8) **Radio Control**:* We use a commercial RC controller RadioMaster TX16s to control the boat. Equipped with an ARM-based STM32 processor, we use the open-source Edge-TX software as firmware. The head gimbals are digital (based on HAL sensors) giving very fine control precision and reliability in various weather conditions. Input controls from the controller are sent over 868Mhz frequency in MavLink protocol.

*9) **Telemetry**:* The AVS is equipped with an independent telemetry system complete with a first-person vision (FPV) system, with on screen display system (OSD) overlaid on the video in PAL technology (parallel standard to NTSC). The signal is transmitted at 5.8GHz in the analog channel. The image is decoded by the receiver and displayed on the monitor in analog standard (e.g. AV). The information that this communication channel provides is battery voltages, current consumption, and power consumed, and this system can be expanded to include other parameters of any choice. The use of the FPV system improves the manual navigation of the boat and allows better supervision of the boat. This system is not related to the AI system and is a completely separate branch of the project.

*10) **Wifi Communication**:* Communication with the base station is facilitated through a 2.4 GHz WiFi connection, made possible by deploying two antennas—one on the boat and a sector antenna on land. The connection is established using the Ubiquiti Bullet M Series, ensuring reliable and efficient wireless communication between the mobile unit and the base station.

*11) **System Architecture**:* To enable scalability and simplify the incorporation of new functionalities, our project is organized into a three-layer system. This la strategy provides a clear and modular framework, streamlining the process of expanding and integrating additional features.

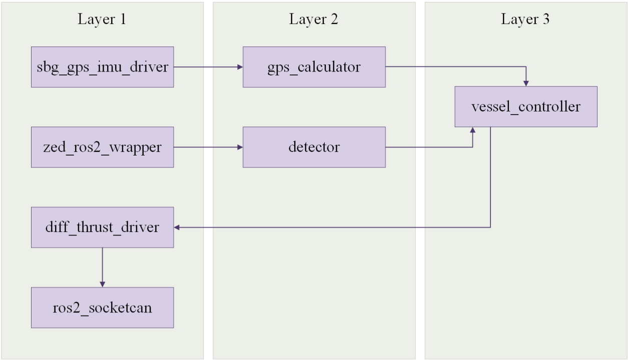

Fig. 2. Layerd system architecture

- Layer 1 - Hardware Drivers: This layer serves as the interface to hardware communication, encompassing messaging, CAN bus interactions, camera communication, and motor control calculations. Comprising four integral packages, it begins with the manufacturer-provided software for the ZED2i camera. Next is the ros2_socketcan package, dedicated to managing CAN bus communication. Subsequently, the diff_thrust_driver package takes charge of computing motor control signals, and finally, the sbg_imu_driver package handles the reception and forwarding of data from the SBG Ellipse-D sensor. This cohesive structure ensures seamless coordination and operation at the hardware level within the system.

- Layer 2 - Data Processing: This unit is tasked with real-time object detection and processing data from the IMU sensor. The goal is to provide information to the autonomous steering controller. To achieve efficient object detection, a neural network model using the You Only Look Once (YOLO) algorithm was chosen. YOLO excels in speed and precision by conducting object detection in a single iteration, making it suitable for real-time applications. The model processes RGB-D camera images, predicts object classes, and provides bounding boxes.

  The controller, responsible for autonomous steering, relies on information such as object position, class, and estimated distance from the depth map. The YOLO-based model's performance in detecting buoys is depicted in Figure 3. Additionally, this layer preprocesses IMU sensor data for input into subsequent layers of the software architecture.

  The neural network model undergoes thorough simulation testing for assessment and validation. This includes evaluating its ability to detect objects and ensuring that the data fed into subsequent layers is appropriately processed.

Fig. 3. Performance of the neural network model during the autonomy

- Layer 3 - Control: Within this layer, an important component is the implementation of a state machine that governs the selection of algorithms executed by the software. Taking information from the L2 layer and guided by various conditions, the state machine serves as the decision-making engine, determining the subsequent algorithm to be executed. This adaptive approach ensures that the software responds intelligently to the information provided, allowing for efficient and context-aware algorithmic execution. Furthermore, all of our algorithms for steering are housed within this layer. The integration of this state machine adds a layer of versatility to the system, enabling it to navigate through diverse scenarios and optimizing algorithmic choices based on real-time conditions.

C. *Testing Strategy*

As the majority of testing occurs in late autumn or winter, lake tests can only be conducted infrequently. Consequently, for water testing, we make use of the AGH University swimming pool to maximize our testing opportunities when outdoor water testing is limited. We also strive to conduct testing even in the absence of water access whenever possible.

*1) **Dry tests**:* To validate the robustness of our hardware, we perform dry tests within our workshop. Prior to the integration of the electrical system into the boat, we assess the tightness of all components. Following this, team members inspect each part of the system. Subsequently, comprehensive tests encompass the initiation of the boat, verification of correct signal transmission from the radio to the thrusters. The next step is to activate Jetson, which is the main component of the autonomous system. Upon activation, we check if all the needed information can be read and sent.

For evaluating waypoint navigation, we positioned waypoints in the parking lot near the workshop and manually maneuvered the vehicle. Subsequently, we examined the output sent to the thrusters and conducted a detailed analysis.

To assess the nozzle, we linked it to the boat and manually issued commands to initiate and cease water flow. The same procedure was applied to the robotic arm. Both functionalities feature simple control, having only two states.

*2) **Tests on water**:* On the water, we are able to test waypoint navigation, depth measurement, some solely vision-based tasks, robotic arm and water nozzle. We conducted tests on Bagry lake in Krakow and at AGH swimming pool.

We have the capability to conduct tests for the Follow the Path, Speed Challenge, Collection Octagon and Delivery Octagon tasks. Before the first tests on a water reservoir, we come and gather visual data to train our model specifically for that environment. For the initial two tasks, we arranged buoys to simulate gate markers, comprising red and green buoys, as well as establishing a designated course for the Speed Challenge. In the case of Collection and Delivery Octagons, a physical model representing a quarter of a cube, enclosed with PVC pipes, has been assembled to replicate the testing environment. This approach ensures that our testing scenarios closely mirror the competition conditions, allowing us to refine and optimize Barka's performance in a controlled setting before deployment.

To test waypoint navigation, we establish several waypoints within the system and observe the outcomes.

3) ***Simulation tests****:* In the Gazebo simulation, we created Roboboat 2024 tasks by integrating custom models into the VRX world. Prior to the incorporation of any new functionalities, the software underwent testing within the simulation environment. Tasks exclusively reliant on vision data were thoroughly tested and refined through the utilization of the simulation.

Simulation allows us to refine the logic in algorithms and make sure the detection processes work well. By testing in a virtual environment, we can check how strong and reliable the vision systems are in various situations. The algorithms and settings are adjusted constantly to make the boat work even better. Such flexibility speeds up our development process.

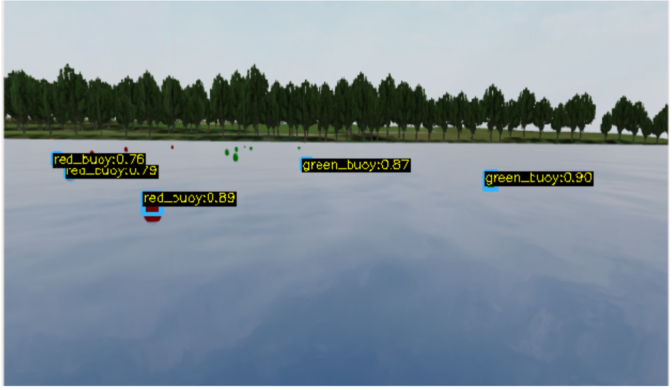

Fig. 4. Performance of the neural network model in real-time buoys detection during the simulation testing

II. CONCLUSION

In conclusion, our AGH Solar Boat Team has developed an advanced strategy for RoboBoat 2024, emphasizing precise navigation with cutting-edge visual detection technology. Our boat, integrating vision, GPS, and depth measurements, employs a custom neural network for accuracy in tasks like navigation and docking.

Designed with a lightweight and corrosion-resistant catamaran structure using basalt fiber pontoons, our approach is optimized through computational fluid dynamics simulations. The three-circuit power and control system prioritize safety, and communication is facilitated by a commercial RC controller and telemetry system.

Key sensors, including the ZED2i camera and SBG Ellipse-D IMU, enhance our boat's capabilities. The three-layer system architecture ensures scalability for future enhancements. Our testing strategies, spanning dry tests, water tests, and simulations, validate hardware robustness and algorithm refinement.

We extend our gratitude to AGH University, advisors, collaborators, and team members for their invaluable contributions. Our project not only positions us competitively in RoboBoat 2024 but also advances autonomous boat technology through collaborative efforts and innovative engineering solutions.

ACKNOWLEDGMENTS

We would like to express our sincere gratitude to AGH University for providing invaluable support and resources throughout the development of our autonomous boat project. Special thanks go to our esteemed academic advisors, Krzysztof Sornek and Wojciech Sajdak, for their guidance, expertise, and unwavering commitment to our success.

We extend our appreciation to the management of AGH swimming pool for their cooperation and generous permission to conduct in-water tests for our boat. Their collaboration has been instrumental in refining and enhancing the functionality of our autonomous system.

We also acknowledge the collaborative efforts of SimLE team for providing essential models for the simulation and extend our thanks to the VRX developers for creating a dynamic world in the simulation environment.

Last but certainly not least, we extend thanks to every member of our team who has invested time and passion into the project. Together, we have embraced challenges, learned, and innovated, making this journey a true testament to the power of teamwork and shared dedication.

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APPENDIX A
COMPONENT LIST

Component	**Vendor**	**Model/Type**	**Specs**	**Custom/ Purchased**	**Cost**	**Year of Purchase**
ASV Hull Form/Platform	-	-	Made of basalt fiber	custom	-	2023
Waterproof Connector	WEIPU	SP2110	SP2110/P2II-1N	purchased	10$	2023
Propulsion	Blue Robotics	T200	T200 Thruster with Penetrator	Purchased	donated	2022
Power System	Zeee	4S Lipo Battery	Zeee 4S Lipo Battery	Purchased	100$	2023
Motor Controls	Little-Bee	Mini 30A BLHeli_S 2-6S	2-6S Lipo, 30A, 7,5g	Purchased	35$	2023
CPU	Nvidia	Orin AGX	Jetson AGX Orin Developer Kit	Purchased	2500$	2023
Teleoperation	Tbs	Crossfire rx	TBS Crossfire Nano RX Pro	Purchased	30$	2023
Compass,	SBG Systems	Ellipse-D	SBG Ellipse-D	Purchased	3358$	2022
Intertial Measurement Unit (IMU)	SBG Systems	Ellipse-D				
Doppler Velocity Logger (DVL)	-	-	-	-	-	-
Camera(s)	Stereo Labs	ZED2i	ZED 2i	Purchased	589$	2023
Hydrophones	-	-	-	-	-	-
Algorithms				Custom		
Vision				Custom		
Autonomy				Custom		
Localization and Mapping				Custom		
Open-Source Software		VRX, OpenCV, ROS2, YOLOv8				