Istanbul Technical University RoboSub 2024 Technical Design Report

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Abstract—The Istanbul Technical University Autonomous Underwater Vehicle (ITU AUV) team presents Taluy, an innovative underwater vehicle designed for the RoboSub 2024 competition. Taluy integrates advanced mechanical, electrical, and software systems to meet the rigorous demands of the competition tasks. Key features include a redesigned chassis for optimal weight distribution and stability, custom electronic housing for enhanced durability, and mission-specific tools like marker droppers and torpedo launchers. The electrical system incorporates custom PCBs for power management, propulsion control, and sensor integration. Advanced AI-based computer vision and state-of-the-art navigation algorithms ensure precise task execution. The team's strategic approach focuses on maximizing points through efficient task performance and robust design, leveraging extensive testing and iterative improvements. This document details Taluy's design, development, and testing processes, showcasing the team's commitment to innovation and excellence in underwater robotics.

I. Competition Strategy

The team plans to enter the competition with the vehicle Taluy. Since the complexity of the nature of the problem in general, the team has planned to focus its limited efforts towards the strategy which aims to earn most points while gaining a lot of experience for the next year. Therefore this year, the team focuses on below tasks:

- Rough Seas - Coin Flip
- Enter the Pacific - Gate
- Path
- Hydrothermal Vent - Buoy
- Ocean Temperatures - Bin
- Mapping - Torpedoes
- Collect Samples - Octagon

For Rough Seas - Coin Flip and Enter the Pacific - Gate task, our vehicle Taluy, will commence by requesting a coin flip to determine its heading, aiming for additional points. The vehicle will initially submerge to the requisite depth, followed by either advancing directly towards the gate or rotating to align before proceeding, contingent on the coin flip result. Orientation management will be handled by an Inertial Measurement Unit (IMU) in conjunction with control algorithms. Object detection methods will be used both to detect the gate and exit the search mode; and to detect which side the vehicle is passing through. Advanced algorithms are being developed for stylish maneuvers during this mission to secure additional points. These include sophisticated control algorithms and sensors, such as an IMU, Doppler Velocity Logger (DVL), and pressure sensor, which will be employed to maintain vehicle's orientation and stability.

This year's strategy for the Path task is more streamlined and efficient compared to previous years. Unlike past competitions, the camera is now housed inside a tube, eliminating the need for additional sealing efforts. Real-time segmentation via artificial intelligence models is implemented to visualize and interpret the path accurately, replacing the previously used series of processes. These segmented images enable calculation of the angle and determination of the vehicle's direction. However, precise positioning relative to the path necessitates the use of additional sensors, such as a pressure sensor, DVL and IMU, alongside the camera.

For the Hydrothermal Vent - Buoy task, the vehicle will leverage advanced techniques to maximize points. Using sonar and camera systems, Taluy will precisely locate and track the buoy, maneuvering to either tilt it by at least 10° or navigate around it in the correct direction, avoiding rope manipulation. This ensures full points without using torpedoes, based on the team's strategic point calculation, which aims to conserve the two torpedo attempts for the Mapping - Torpedoes task.

For this task, a targeting algorithm will be employed, utilizing sensor data to calculate the optimal launch angle and trajectory for precise hits. Rigorous testing will ensure the reliability of the vehicle's navigation and targeting systems for effective buoy interaction and torpedo accuracy.

The vehicle will use its vision and control systems to complete the Ocean Temperatures - Bin task with high precision thanks to its downwards looking camera. Initially, Taluy will analyze the bin, featuring a split image of RED and BLUE separated by an invisible divider. To enhance the accuracy of bin detection, innovative neural monocular depth estimation models will be employed to identify the bin's shape. Using its cameras and image processing algorithms, Taluy will identify the correct side for dropping markers based on the results of the Enter the Pacific - Gate task. Upon determining the appropriate side, the vehicle will carefully maneuver to deposit markers into the designated bin section. The accuracy of marker placement will be ensured through precise control and positioning systems, aiming to maximize points based on the final resting position of each marker and adherence to the correct bin side.

For the Mapping - Torpedoes task, the vehicle will employ precise targeting and timing to maximize points. The forward camera and image processing systems (YOLO [1]) will identify the exact positions of the openings. The torpedo system will be calibrated to adjust for distance and trajectory, ensuring accurate passage through each octagon. Torpedoes will be fired at the two smallest holes on the map, starting with the smallest. The shots will be carefully evaluated through extensive testing and by utilizing the transformation from camera frame to world coordinates, using precisely calibrated extrinsic parameters.

II. Design Creativity

A. Mechanical

The vehicle is 865mm long and 620mm wide, consisting of three principal structural components: chassis, electronic housing unit, and mission equipment. Positions are determined for optimal weight distribution and stability. Aligning VCG and VCB prevents tilting, while LCB and LCG ensures trim. Stability is verified using MATLAB during design and modification.

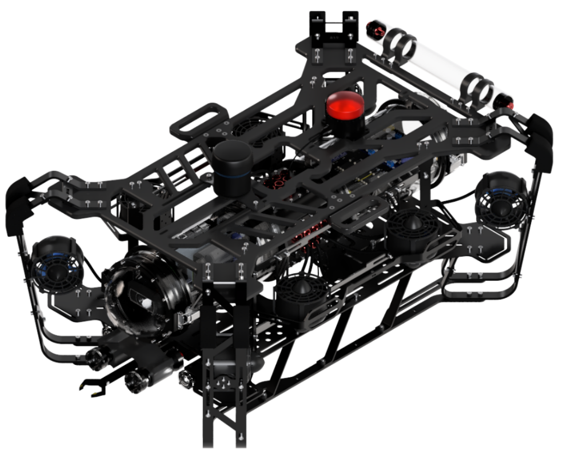

Fig. 1. Taluy

1) Chassis: The vehicle's resistance to land and water forces is crucial for tasks. The vehicle's weight is balanced with its internal volume. It has three main components: corner cage systems, bottom and top plates, and side cage systems. The corners use 5mm Aluminum 6061, bent via press brake, with adjustable thruster channels for X-Y movement. The top plate is HDPE; the bottom is 5mm Aluminum 6061. Side cages hold Z-axis thrusters and are made of stainless steel for strength. The bottom cage, supported by Z-shaped aluminum strips, carries mission equipment and increases payload capacity.

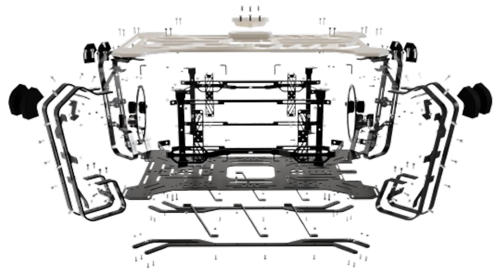

Fig. 2. Chassis

2) Electronic Housing Unit: This section houses motor controllers, cameras, battery, and other electronic components that must stay dry. It consists of two PMMA tubes, an Aluminum 6061 center flange, PMMA front and rear covers, and Aluminum 6061 front and rear flanges. Cylindrical tubes distribute water pressure efficiently. Acrylic is chosen for its pressure resistance, visibility for inspections, and cost-effectiveness.

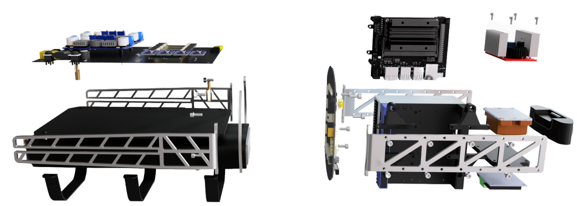

Fig. 3. Electronic Housing Unit

3) Mission Tools:

- Marker Dropper: The marker dropper launches markers using a servo motor for angular movement. Markers are held in the dropper and released by the servo motor's activation.

Fig. 4. Marker Dropper

- Torpedo Launcher: The team developed a torpedo system using a spring and electric solenoid lock mechanism. The spring-solenoid system was chosen for its reliability and simplicity. Magnetic and pneumatic systems were avoided due to potential technical failures and maintenance difficulties. The design ensures easy maintenance, quick adjustments, and precise torpedo launches, making it ideal for competitive conditions.

Fig. 5. Torpedo Launcher

- Gripper: The initial gripper designs utilized a bevel gear system actuated by a servo motor, however, 3D printing and design revealed issues with tolerances and sizes. Size adjustments and topology optimizations for necessary gaps were performed. Despite this, it was found that the bevel gear system was only suitable for vertical use. On top of that, the servo motor placement was problematic. This led us to the final version, where we adopted a parametric and modular design strategy. This new approach allowed for flexibility and easier adjustments. We emphasized the importance of maintaining gaps between the claws to grasp irregular geometries and handle difficult objects, aligning with our competition strategy.

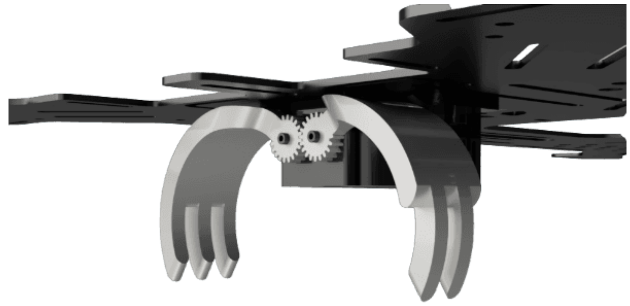

Fig. 6. Gripper

B. Electrical

Electrical systems of the vehicle consist of power delivery & distribution, low-level data processing and Input Output (IO) operations. To achieve such features few printed circuit boards are designed by the electrical subteam members and utilized across the vehicle.

a) Power System: The vehicle is powered by a $14.8V$ lithium-ion battery. The custom battery pack is assembled using 18650 cells, arranged in a $4S9P$ configuration, resulting in a total capacity of $27Ah$ at $14.8V$. This high capacity was selected to maximize operational time during testing. However, due to constraints related to competition duration and flight regulations, two $8Ah$ $14.8V$ lithium polymer batteries will be utilized instead. The weight discrepancy has been considered to maintain the stability of the vehicle and ensure it is consistent with test conditions. Based on sensor data, the average power consumption, accounting for converter inefficiencies, is approximately $400W$, as detailed in Table I. With this information, it is estimated that two $8Ah$ $14.8V$ lithium polymer batteries will provide a runtime of approximately 35 minutes, which is adequate given the 20 minute competition duration.

Component	Average Power	Observed Peak Power
8 thrusters	270W	1250W
Jetson AGX Xavier	40W	65W
Wayfinder DVL	3W	10W
Active Sonars	10W	15W
Sensors & Cameras	10W	15W
Total:	333W	1355W

TABLE I
Power Budget

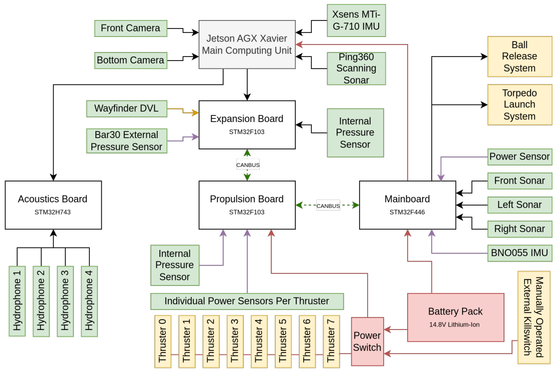

Fig. 7. Taluy System Integration Design

b) Propulsion System: The propulsion system is controlled by a custom-designed printed circuit board that utilizes an STM32F1 microcontroller and 8 Electronic Speed Controllers attached to the board. Additionally, individual power sensors are placed for each thruster to provide power data, which will be used to more accurately estimate the momentary thrust produced by the thrusters. Given that the vehicle uses brushless DC motors, the propulsion system is housed in an external enclosure to reduce Electromagnetic Interference (EMI) in the main hull, where sensitive components like the magnetometer and IMU are located. To comply with competition requirements and ensure safe operation, a kill switch system is integrated into the propulsion system. The power switch inside the propulsion system enclosure is electrically controlled by a manually operated external safety switch, monitored by the microcontroller to inform the main software system. This setup completely cuts power to the thrusters without relying on software, thereby enhancing safety by avoiding potential software failures. Communication between the propulsion system and the main software system is facilitated through CANBUS [2], a protocol renowned for its robustness and reliability in critical applications.

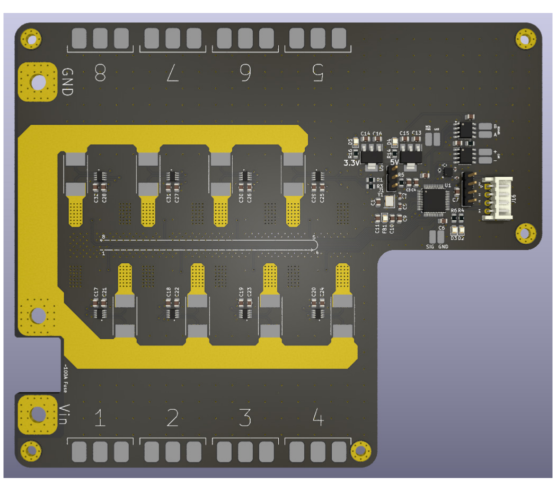

Fig. 8. Propulsion System Board 3D View

c) Sensor Integration: To enable seamless sensor integration, the mainboard processes data from various internal and external sensors while controlling the vehicle's actuators. It also manages power distribution throughout the vehicle using embedded $12V$ and $5V$ converters on a custom-engineered circuit board. This board controls the torpedo launching system and the ball release system, and like the propulsion system board, communicates via CANBUS, sharing the same bus for efficient and coordinated operations.

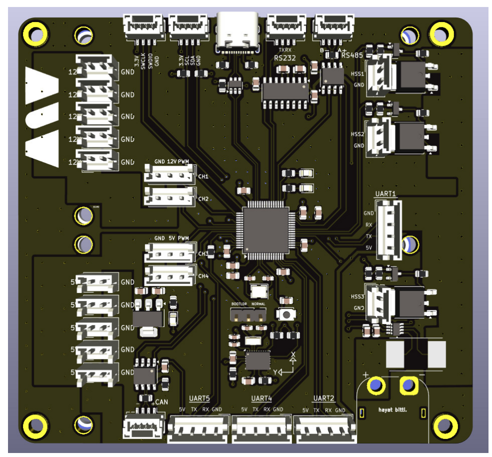

Fig. 9. Mainboard 3D View

d) Expansion Board: This year, a PCB has been designed to integrate directly with the NVIDIA Jetson AGX Xavier GPIO headers, primarily to enhance communication capabilities. This compact design reduces workload and saves space within the vehicle. The PCB includes built-in internal pressure and IMU sensors, and allows direct connections for both the pressure sensor and the Doppler Velocity Log (DVL). Additionally, a leak probe is directly attached to the card, significantly enhancing vehicle safety. Communication with the Jetson AGX Xavier is established through UART pins directly connected to the card. Additionally, this setup facilitates direct CANBUS communication with the mainboard and the propulsion system, ensuring efficient and coordinated operations across all components. Similar to previous systems, this can also be integrated into the same bus.

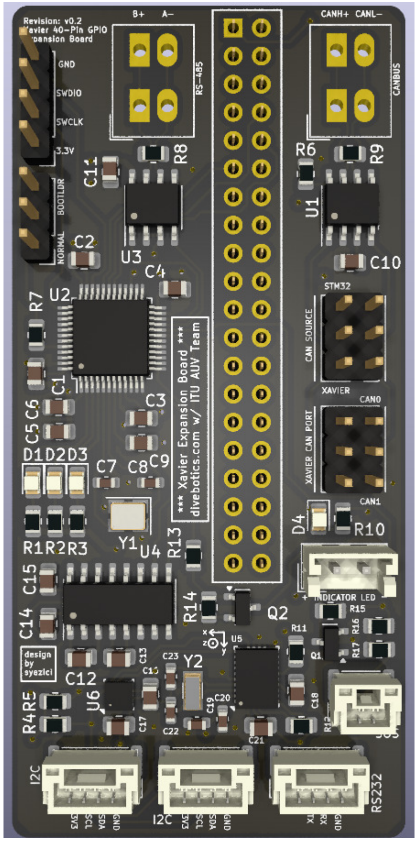

Fig. 10. ExpansionBoard 3D View

e) Acoustic Signal Processing Board: To detect the location of a wave source, an acoustic signal processing board was designed, positioned on the back tray of our vehicle. The primary function of this board is to use the phase difference of signals from four identical hydrophones to pinpoint the wave source. During development, challenges such as signal interference and space limitations for the PCB layout were encountered. To mitigate signal interference, the PCB is divided into five sections: a main piece housing the STM32H7 microcontroller and four external PCBs connected to the main board for hydrophone connections and filtering processes. The built-in Analog to Digital Converter in the STM32H7 provided high precision and a high sample rate, making it accurate enough to pinpoint the incoming sound wave's location.

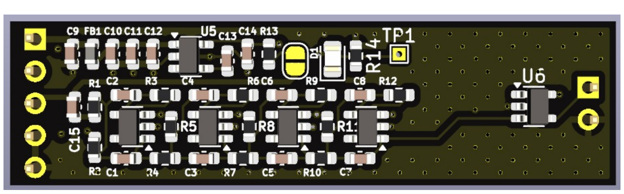

Fig. 11. Acoustic Signal Processing Board 3D View

C. Software

a) Control & Navigation: The control and navigation system is essential for the vehicle, providing stability and precise maneuvering. A PID control scheme, combined with an accurate mathematical model of the vehicle, is employed to ensure precise movement. The control system relies on sensor data from the DVL, IMU, Bar30 (pressure), and sonars.

The primary objective of the team is to achieve vehicle stability and effective mapping. To enhance performance, adaptive control is employed for dynamic parameter adjustment, along with sensor fusion algorithms for robust state estimation. The vehicle's sensing capabilities are improved using the Extended Kalman Filter (EKF) algorithm [3], which integrates inputs from the DVL, IMU, pressure sensor, and sonar to refine data accuracy. This year, the EKF algorithm was implemented using the ROS [4] robot localization [5] package, significantly enhancing observation capabilities and streamlining the debugging process.

b) State Machine: The mission sequence is executed by state machines, which are behavior models comprising a finite number of states. Depending on the current state and given data, the machine enforces state transitions and generates outputs. Individually designed finite state machines for each task aim to perform tasks as quickly as possible while making accurate decisions when encountering potential issues.

In the competition, state machines enable the vehicle to execute tasks efficiently and adapt to unexpected challenges, ensuring reliable and precise performance.

c) Computer Vision: This year, vision processing techniques have been upgraded to enhance object detection and depth estimation. YOLOv10[1] is employed for object detection, trained on a large, automatically generated and labeled dataset using a custom Blender plugin, facilitating efficient object detection in various tasks. Additionally, advanced AI models such as Segment Anything[2] and Depth Anything[3] have been integrated to estimate object distances from the camera, even without a dedicated depth camera. A new camera has also been added to the bottom of the vehicle to view the pool floor, aiding in the estimation of the vehicle's heading angle and orientation.

[1] YOLOv10: Real-Time End-to-End Object Detection
[2] Segment Anything Model (SAM)
[3] Depth Anything

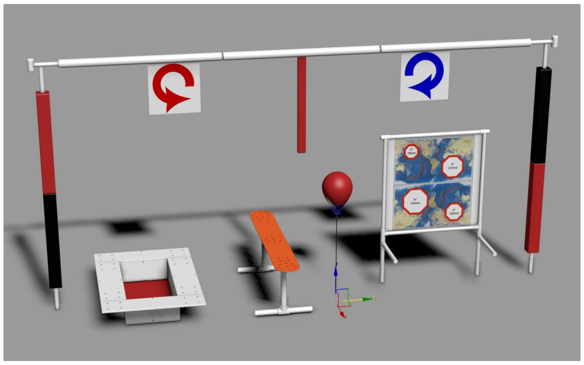

Fig. 12. 3D Models of Competition Props

III. Experimental Results

- Due to constant modifications on the vehicle, its buoyancy varied, causing issues before tests. To address this, an adjustable buoyancy tube was designed and placed at the rear, simplifying the process of balancing the vehicle prior to tests.
- This year, several changes were implemented to enhance the efficiency and effectiveness of the computer vision processes. One significant change involved replacing color-based masking with real-time segmentation models. A prime example is the use of Ultralytics' FastSAM (Fast Segment Anything Model)[4] for the 'path' task, enabling real-time segmentation. This approach has improved image processing accuracy and operational efficiency by generating extensive datasets.
- A custom-developed Blender plugin enables the automatic generation of large datasets under various conditions (e.g., blur, distance, environment, position). These datasets are automatically labeled by the plugin and custom-trained using YOLO v10. This automated workflow significantly enhances image processing capacity and detection capabilities, providing a substantial advantage in recognizing critical objects during tasks.
- Due to the high power operation of the vehicle's motors, overheating and EMI issues with the ESCs were encountered. To mitigate this, all ESCs were placed in a separate sealed box this year, rather than inside the vehicle's tube. This solution eliminated cable clutter within the tube and provided a liquid-cooled solution to the overheating problem by allowing the ESC box to be in direct contact with water. Although this addition introduced challenges in maintaining overall waterproofing with the second watertight compartment, extensive work and testing successfully resolved these issues.
- The previous model, Turquoise, had 6 thrusters and was unable to perform all 6 DOF motions. To enhance mobility, 2 additional thrusters were added to the new design. This new thruster configuration allows Taluy to execute sway motions.
- An expansion board was designed to directly connect several of the vehicle's sensors to the Jetson Xavier for data acquisition. This board utilizes all General Purpose Input Output (GPIO) pins of the Jetson, reducing electronic clutter and creating more space. Through this board, data from the Bar30, DVL, and BNO055 sensors can be read.

[4]FastSAM

Acknowledgment

The ITU AUV Team would like to thank faculty advisor Bilge Tutak for their consistent and encouraging support. Our team also extends special thanks to our mentor, Sencer Yazıcı, for his endless effort and dedication. The team appreciates all the assistance and kind donations from Ince Shipping, Altium and ITU that have enhanced the vehicle's capabilities. The highest praise goes to each member who has diligently worked to improve the vehicle thus far.

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TABLE II
Component Specifications

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost
ASV Hull Form/Platform	ITU AUV	Custom designed center hull	Acrylic tubes	Custom	$180
Waterproof Connectors	BlueRobotics	Wetlink Penetrator	link	Purchased	$250
Propulsion	BlueRobotics	T200	link	Purchased	$1600
Motor Controls	BlueRobotics	Basic ESC	link	Purchased	$38 ea
CPU	Nvidia	Jetson AGX Xavier	link	Purchased	$950
External Comm Interface	BlueRobotics	Fathom-X Tether Interface Board	link	Purchased	$250
Compass	Xsens	MTi-G-710	link	Purchased	Legacy
Inertial Measurement Unit	Bosch Sensortech	BNO055	link	Purchased	$15
Doppler Velocity Logger	Teledyne	Wayfinder DVL	link	Purchased	Legacy
360 Sonar	BlueRobotics	Ping 360	link	Purchased	$2650
1D Sonar	BlueRobotics	Ping Sonar	link	Purchased	$410 ea
Gripper Servo	Rovmaker	40KG Micro Servo	link	Purchased	$150
Camera(s)	Logitech	C922 Pro	link	Purchased	$100
Hydrophones	Aquarian Audio	H2C Hydrophones	link	Purchased	$600
Vision	Ultralytics	YOLOv10, FastSAM			
Localization and Mapping		ORB-SLAM localization algorithms			
Autonomy		ROS smach			
Open-Source Software		C, C++, Python, ROS			

Appendix B: Outreach Activities

Throughout the year, the ITU AUV Team has actively participated in various outreach activities to connect with the next generation of engineers and robotics enthusiasts. We mentored students at Cağaloğlu Anatolian High School, Adana Science High School, and Beşiktaş Anatolian High School, fostering their interest in underwater robotics and engineering.

We also participated in several industry events and expos, including ExpoMaritt, the Petroleum and Natural Gas Fair, and the Solarex Solar Energy Technology Fair. These gatherings allowed us to engage with leading companies and professionals in the field. At these events, we showcased our AUV, introduced it to interested individuals, and shared insights about the underwater ecosystem. These activities provided educational opportunities and helped raise awareness about the significance of underwater exploration and technology.

Fig. 13. Photograph From Petroleum and Natural Gas Fair

Participating in these events allowed us to expand our network and gain valuable knowledge from industry experts. The exposure and feedback we received were instrumental in our team's development. Engaging with professionals provided us with fresh perspectives and insights that we could incorporate into our projects, enhancing our work's overall quality and effectiveness.

These events also provided a platform for us to share our excitement for underwater robotics, inspire future engineers, and strengthen our commitment to advancing the field. By engaging curious minds and explaining our AUV's intricacies, we have motivated young students to pursue careers in STEM and strengthened our commitment to continuous learning and innovation.

Fig. 14. Our Stand in Antalya Science Fair

Fig. 15. Our Stand in Istanbul Technical University graduation day photo