AUVUA

Danger 'Zona Design Overview

Autonomous Underwater Vehicle – University of Arizona (AUVUA)
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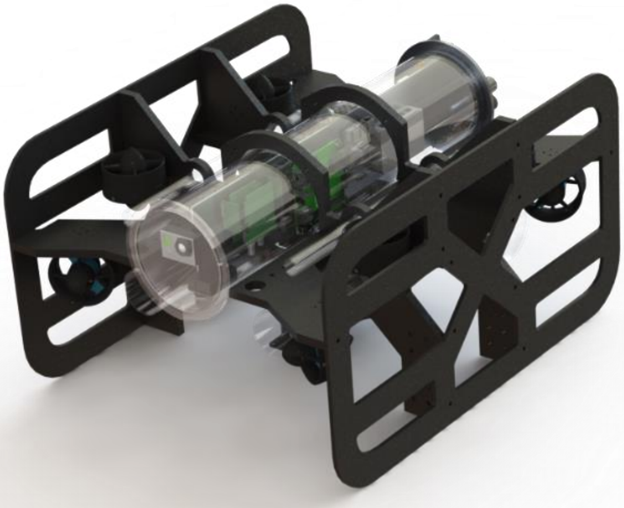
Abstract:
The autonomous underwater vehicle team at the University of Arizona has made significant progress in its third year. With a budget of $5000, AUVUA presents Danger 'Zona, the successor to BEARacuda. In addition to improved mobility, Danger 'Zona features two ultra-wide angle cameras and a pneumatics system for various actuators. The main design objective for this machine is interaction with game elements – new this year are torpedoes, markers, and claws, giving Danger 'Zona the capability to complete the 2018 RoboSub challenge.



Overview	
Size:	28"L x 22.5"W x 15"H
Weight:	Approx. 65lbs
Sensors:	2x GoPro Hero 3 White
	Teledyne RDI Explorer DVL
	Ratiometric depth sensor
	Humidity leak sensor
	Passive sonar array
	MPU-9150 IMU
Runtime:	Approx. 1.5 hours

System Overview

Danger 'Zona is the third installment in a series of increasingly capable underwater robots. The predecessor, BEARacuda, was successful in completing navigational tasks. The goal of Danger 'Zona is to augment that navigation with interactive elements, including torpedoes, claws, and markers. This year, the team consists primarily of eight members from mechanical, electrical, and software engineering backgrounds. The budget for the system was approximately $5000, so cost effective solutions are used throughout the design.

Mechanical Design

The mechanical subsystem includes the framing, housings, bulkheads, actuators, and waterproofing, along with accessories such as the torpedoes and markers. SolidWorks was used to design the primary structures, with COTS items either downloaded or modeled internally. Evaluation tools were used to determine the weight, center of mass, center of volume, and moments of inertia, while flow simulations were performed to characterize drag.

Though software often takes a front in autonomous competitions, the mechanical aspects of an AUV are easily overlooked. Danger 'Zona is lighter, smaller, and much more capable than its predecessor, all while retaining the desirable aspects of BEARacuda: maintainability, speed, and low cost. This was accomplished through material selection and more attention to detail in the planning phase.

Frame

AUVUA took a different route in frame design this year. High density polyethylene (HDPE) that is UV-resistant and marine grade (Starboard) was chosen for several reasons. Starboard is close to the same density as water, which reduces the need for added buoyancy. It is easily machinable on a router and relatively cheap.

Four unique parts are used: two outer runners protect the inside of the vehicle and add much needed torsional rigidity to the frame. Attached to the runners are the lateral and vertical supports. The vertical supports hold the main hull, battery hulls, torpedo tubes, and the four vertical thrusters. The lateral supports hold the four vectored thrusters and the marker tubes while connecting to the vertical plates and providing mounting points for adjustable weights/buoyancy. Finally, the sensor sled mounts to the underside of the vertical supports and secures the DVL and passive sonar compartments. Frame members are connected together via edge tapped holes.

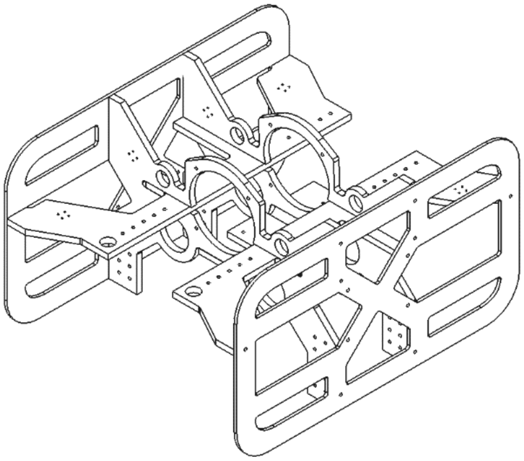


Figure 1: HDPE Starboard frame.

Main Hull

The main hull is the largest watertight compartment on the vehicle. It houses most of the electronic components (excluding the batteries) and was designed for rapid disassembly if required. A six inch outer diameter polycarbonate tube is used to allow visibility of electronic components as well as vision for internal cameras. One end of the tube is terminated by a polycarbonate cap which is chemically bonded to the tube. This provides a transparent surface for the forward facing camera to view through. At the aft end, an aluminum end cap is fitted inside the tube, using an o-ring bore seal to maintain a watertight interface up to the maximum depth of the acoustic trap of the TRANSDEC (16 feet). The front plate and rear hull support plate are tied together through the frame with multiple threaded rods.

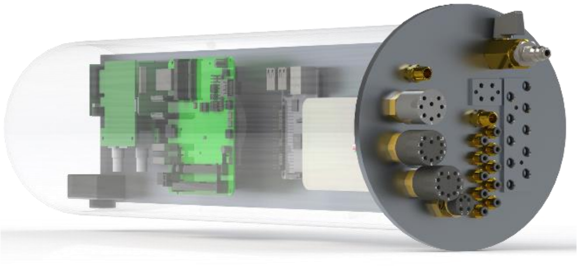


Figure 2: Left side of the main hull, including the fixed endcap and sensors/processing units.

The end cap at the rear of the hull is considered a permanent fixture of the vehicle. It acts as the primary bulkhead, allowing wires in and out of the main housing for transporting power and signals to and from external components. The electronic components are also attached to this end cap via a cantilevered electronics rack. This rack is built from aluminum sheet and is mounted vertically so that electronics can be accessed from either side. One half of the sheet is dedicated to power electronics and pneumatics, while the other is used for processing and sensors. 3D printing was employed for mounting ESCs, the air reservoir, and the network switch.

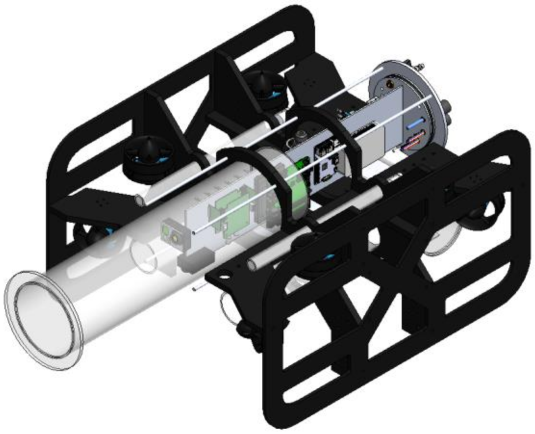


Figure 3: Compartment access.

Secondary Hulls

In addition to the main hull, five other enclosures are included on Danger 'Zona. Two 2.5 inch diameter battery tubes exist on either side towards the forward end of the vehicle. These hulls are constructed similar to the main hull, with a front-facing polycarbonate window and a rear aluminum endcap fitted with an o-ring. Two lithium polymer batteries are placed inside each tube so that they may be isolated from the main hull in case of failure. In each battery housing, two power wires join with the main hull end cap.

The third waterproof enclosure is recycled from last year's vehicle. This hull houses the hydrophones and localization board, and is easily removed from the vehicle. This compartment is to be shared with the Carl Hayden High School Robotics Team during competition, so it was designed to be modular and easily mounted. Two aluminum end caps seal a 5 inch length of polycarbonate tube. These end caps are pulled together using two 1/4 inch stainless steel rods.

Finally, two additional enclosures were created to house the DVL transducer and electronics box. The electronics box housing is constructed similarly to the rest of the housings, but the transducer head required an aluminum adapter ring to step the diameter up to 5 inches.

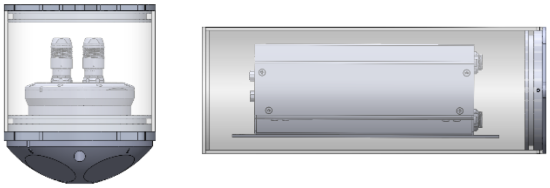


Figure 4: DVL housings.

Waterproofing

As with any underwater vehicle, there are several locations where waterproof seals are necessary. The bore seals on the compartment end caps use single EPDM O-rings which press against the inner surface of the hull tubes. Sufficient compression allows for tight fits which do not fail or leak during normal operation. Some end caps are designed with holes for wires to pass through. These holes are sealed in a similar way, with O-rings slipped around each wire and fitted into a counter-bored hole. The O-rings around these wires were sized to fit snugly inside the wire holes to facilitate wire removal if necessary. The DVL housing includes a special clamping retainer that applies a force on the o-ring inline with the cable. This was necessary to preserve the cable's integrity while allowing it to be removable.

The pneumatics system was an additional challenge this year. Push-to-connect NPT fittings are used to route tubing from the bulkhead to various actuators. Check valves are used to vent from the solenoids, prevent pressure buildup inside the main housing, and prevent backflow in the torpedo and marker lines.

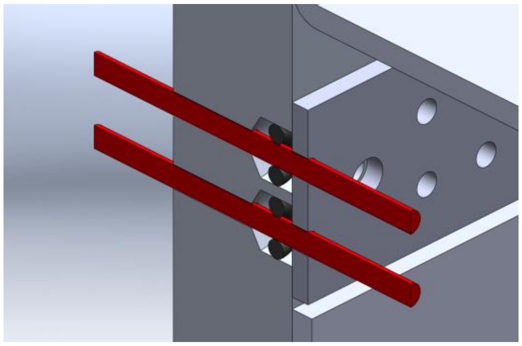


Figure 5: Wire waterproofing technique.

A retaining plate is fitted over each wire hole to constrain movement of the O-rings. This sealing technique is robust and easy to implement, allowing wires for additional actuators to be added without much design effort.

Thrusters

BEARacuda was an advancement in both thrust and cost using an old solution: trolling motors. However, the mass of each thruster was inconvenient and detrimental to weight distribution and buoyancy. Additionally, each thruster required epoxied connections, a custom mounting bracket, two holes in the bulkhead, and 3D printed propellers. The time sink did not match the cost savings.

Fortunately, the increasing demand for COTS parts in ROV and AUV applications has generated competition for cheaper, lighter, and more powerful actuators. Blue Robotics designed fully sealed, 4" diameter thrusters capable of 6 lbs of thrust in the T100 for $110. A high-performance model, the T200, sells for $160 and reaches 10 lbs. Each thruster is brushless, which allows us to utilize cheaper, smaller controllers.

Figure 6: Blue Robotics T100 thruster.

The thruster configuration is vectored in the horizontal plane with four thrusters placed symmetrically on the corners of the vehicle to provide omnidirectional movement. Four additional heave thrusters are placed on the corners as well. All eight thrusters allow for 6 degrees of freedom.

Torpedoes and Markers

With the addition of a pneumatics system, torpedoes and markers have become a priority. A simple design for firing was conceived using the same polycarbonate tubing and some small endcaps. Check valves and push-to-connect fittings are used to feed air into the back of the tube.

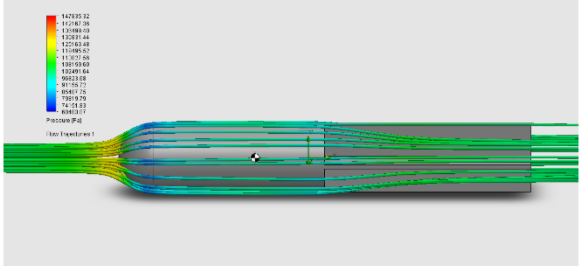


Figure 7: Flow simulation of simple torpedo design.

The torpedoes are milled from 1 inch diameter HDPE rod stock. With the short distances required, choosing a neutrally buoyant material simplified the design and manufacturing times immensely. The markers are aluminum rods turned down to a teardrop shape with buoyant fins. This ensures a straight and steady trajectory. A small magnet holds the markers in place prior to launching.

Material Selection

The system makes use of several different materials. High density polyethylene was used for a multitude of parts due to its neutral buoyancy and easy machinability. The frame and torpedoes both are made from HDPE. 6061 aluminum is used for endcaps, markers, and the electronics rack for its stiffness and weight.

The waterproof enclosures are constructed using polycarbonate tube. This material was chosen for its light weight and transparency. It is also shatter resistant, making it a good choice over other low strength plastic tubing. The team's experience making waterproof hulls using polycarbonate tubing made it an obvious design choice for use in the AUV's compartments.

This year's vehicle also takes advantage of 3D printing technologies. Several electronic components proved difficult to package, so printed structures were used to easily adapt these parts to the electronics rack.

Buoyancy and Stability

The system is slightly positively buoyant in order to prevent unwanted vertical movement when no thrusters are powered. The mass of the system must equal the mass of the water displaced in order for buoyancy and gravitational forces to cancel out. This year, the system is unconstrained in movement: all six degrees of freedom are controlled. In order to prevent uncoupled pitch and roll rotation, the system uses a mass distribution which is gravitationally stable. This is done by placing positively buoyant components (such as the hollow main housing) above negatively buoyant components (such as counterweights or batteries). Any deviation from the default vertical orientation will create a torque which will force the system to return to an upright orientation. For further stability, thruster positions can be adjusted to be inline with the vehicle's center of mass. Additionally, a buoyancy adjustment system is in place to correct for any deviations from the theoretical values. Therefore, when a thruster is powered, the vehicle is constrained strictly to movement in the thruster's plane of action. This allows for more predictable movement as well as increased stability for performing high precision tasks.

In its current configuration, Danger 'Zona has a displacement of approximately 65 pounds. The frame and endcaps weigh 15.2 pounds.

Electrical Design

The electrical subsystem is composed of power distribution, main computing, peripheral sensors, and power outputs, including high-current switches and motor controllers. Operating in an underwater environment, the system has to have a robust design to tolerate leaks, shorts, and other hazardous electrical phenomena. The final subsystem design meets all the aforementioned goals.

Power Distribution

Four 12 volt, 6.4 amp-hour lithium-polymer batteries tied in parallel provide up to 300Wh of energy to the sub, enough to operate continuously for over an hour. Two sets of two battery packs are located in individual auxiliary hulls and are connected to the system via a high power relay and 40 amp fuses. This isolation and protection helps prevent catastrophic failures from destroying other sensitive electronics.

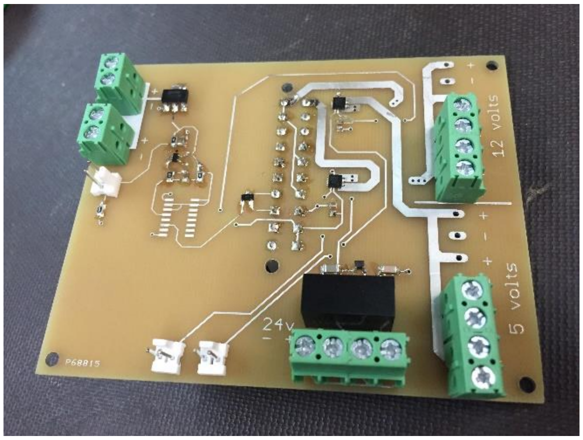


Figure 8: Prototype power board. ATX power supply is mounted on the back.

A power management board was designed with a large low-pass filter run through Schmitt triggers. The result is clean transitions during power-on/off and kill with little to no impact on other circuits. The power management board also relays current information for various power rails that the CPU can integrate to estimate the batteries' state of charge. An ATX power supply is used to create stable 12 volt and 5 volt rails in order to avoid undesirable changes in voltage. A 12 to 24 volt step-up converter is fed to the actuator board to power the pneumatic solenoid valves.

Actuator Control

The use of Blue Robotics T100 and T200 brushless motors called for 30 amp electronic speed controllers, which are controlled by pulse-width modulated signals. The addition of pneumatics to this year's model required an actuator control board with a PIC24F microcontroller with a high pin count. 30A current sensors were tied to the 12V lines feeding the motors to monitor their individual currents. The pneumatic solenoids plug into this board as well as the electronic speed controllers via 12V terminal blocks and PWM data pins.

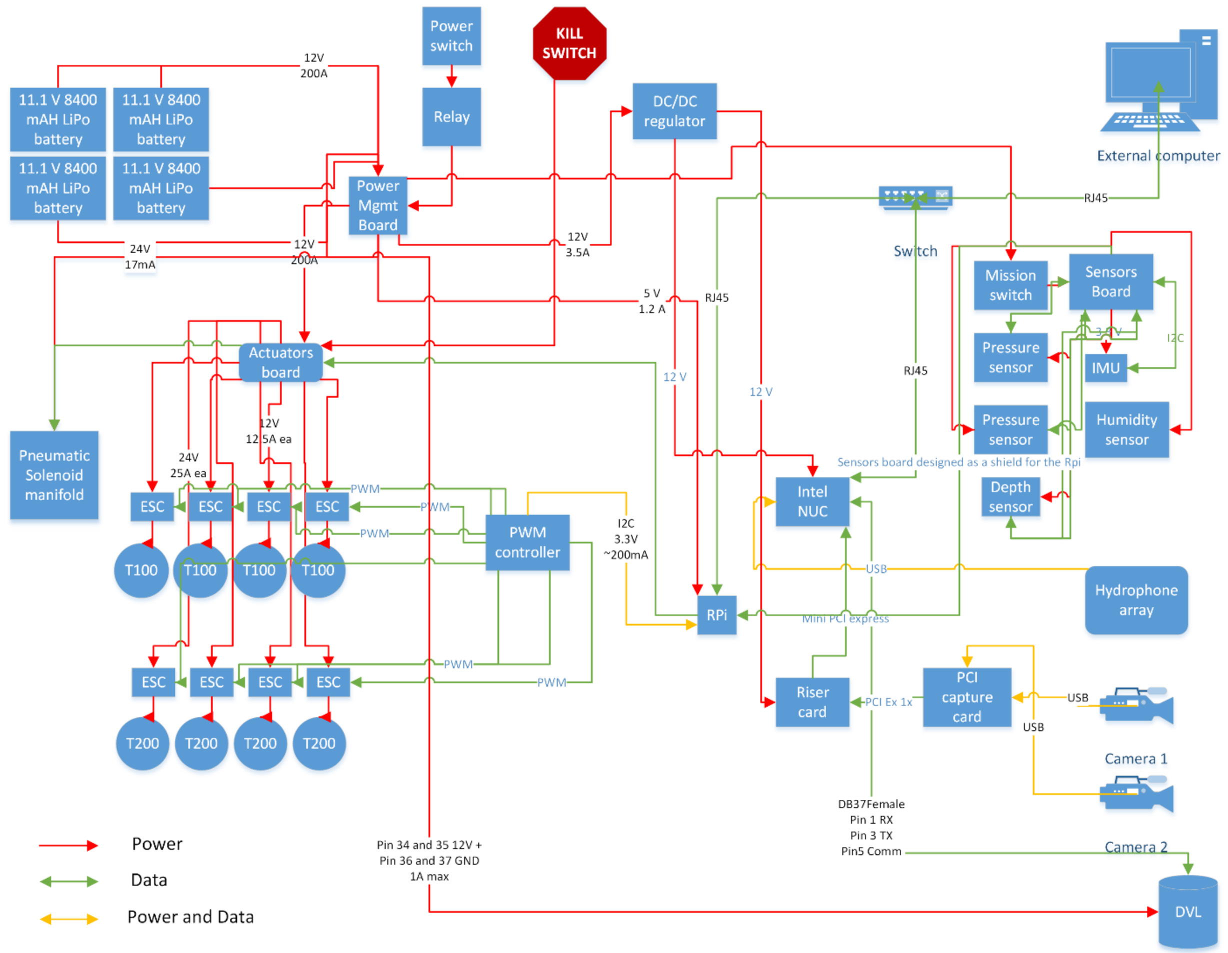


Figure 9: Danger 'Zona electrical block diagram

Tethered Operation

BEARacuda marked the transition from a KVM extender tether setup to a single Ethernet connection with a webserver on the vehicle for control. However, the user interface had not been created until this year. Additionally, an on-board network switch lets users connect directly to the Raspberry Pi that controls actuators and sensors.

Sensors

What sets AUVs apart from their ROV relatives is the amount of data collection and manipulation. The accumulation of sensory input is what allows an AUV to measure and act upon changes in its environment. Danger 'Zona employs a combination of sophisticated and low-cost sensors to achieve this goal.

Two GoPro Hero 3 Whites provide high-resolution and high-FOV visual feedback in the forward- and downward-facing directions. The field of view of large enough to stitch both images together. An MPXA4250AC6U pressure sensor provides linear depth measurement at sub-inch accuracy. The battery voltage, current, and state-of-charge are monitored by the power management board.

This year, Carl Hayden High School Robotics is sharing their Teledyne RDI Explorer DVL with AUVUA, which will facilitate in determining the AUV's exact location. The DVL is housed in a dedicated compartment on the bottom of the vehicle.

Pinger Localization

The final mission task of surfacing above a pinger presents a unique challenge for which there are no COTS solutions. Although it's possible to create a cheap, home-built hydrophone, a higher quality solution was desirable. AUVUA partnered with the Carl Hayden High School Robotics team in 2013 to build a localization module for mutual use between the two teams during the competition. Falcon Robotics purchased four Reson TC4013 piezoelectric hydrophones, while the AUVUA designed and fabricated a localization board that utilizes the hydrophones and interfaces easily with both platforms.

Software Design

Introduction

The software for Danger 'Zona was designed from the ground-up to be user-friendly and easy to adjust. BEARacuda marked an immense improvement in usability, allowing the team to quickly adapt code to complete mission objectives. Much of the code remains, but the primary goal this year was to restore it to a more refined state.

The software system of the AUV is composed of several main sections: the model, agent, and server, as well as a separate hardware interface process. The model contains a current world-view of the vehicle accessible globally by other components. The agent executes the mission, altering the path and tasks dynamically based on task outcomes and parameters. The server communicates to the users' browsers through websockets, collecting commands for movement, relaying telemetry data, and receiving updates to the mission path and vision filters. The simulator and hardware interfaces are interchangeable, allowing the team to test various mission scenarios before running them on a physical machine. A simple message library, ZeroMQ, is responsible for transferring information between the simulator/hardware and the main components.

Planning Agent

The majority of the artificial intelligence takes the form of a mission planning agent. This agent is responsible for loading and parsing the mission and tasks that then run sequentially. Tasks are hard-coded into the agent and parameterized and itemized in XML to achieve runtime adaptations for faster autonomous script testing. Tasks are threaded and capable of creating and executing additional tasks, allowing for a hierarchical, modular mission design. Each task can complete in four ways: success, failure, interruption, and time-out, giving more flexibility in the execution of the course.

Image Processing

The need for image processing is essential for underwater autonomy. Java bindings for OpenCV enable the team to include powerful, open-source vision algorithms with little effort. One unique algorithm uses RANSAC and affine transforms to create a map of the floor of the pool, which can then be referred to for measurements and location determination.

Peripheral Interface

The primary method for the host computer to interface with the physical world is through the Raspberry Pi peripheral controller. A Raspberry Pi B+ acts as a simple bridge, reporting digital and analog inputs and relaying commands to switch high power outputs. From a software perspective, the peripheral board maintains a constant communication line with the host processor to ensure a high level of safety. Once a safety layer has been put in place, the only remaining work is to switch digital outputs to the desired setting and collect, package, and send basic telemetry information.

Pinger Localization

The pinger generates a sinusoidal pressure wave at a constant frequency between 25kHz and 40kHz (in 1kHz increments, so 25kHz, 26kHz, 27kHz, etc. are all possibilities) for 1.3 milliseconds every two seconds. As such, the algorithm requires a peak detection scheme to identify the front of the wave. Once the wave front is detected, each hydrophone channel is recorded for the 1.3ms duration, then processed in the remaining two seconds until the next wave. Processing involves taking a high-point complex FFT of each channel, extracting the phase angle at the given frequency, and comparing phase shift between pairs of hydrophones. Basic trigonometry and physics are used to determine the heading and altitude to the pinger. Hydrophones are spaced apart by a maximum of the half-wavelength of the highest target frequency being measured (in this case, 40kHz).

Community Outreach

Members of AUVUA have spent numerous hours mentoring southern Arizona robotics teams: the Bit Buckets and the NERDS from Sierra Vista, who participate in the FIRST Robotics Competition and similar challenges. The team has shown BEARacuda at several community events, including a National Robotics week STEM outreach event at a local library. AUVUA met with middle- and high-school students at College Knowledge for Parents to promote higher education and its tangible results. AUVUA also visited Amphitheater middle and high school students in the MESA program, allowing students to drive BEARacuda and learn about opportunities in STEM.

Figure 10: AUVUA and the Amphi MESA & Robotics Group

Acknowledgements

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