# Turkish Naval Academy Autonomous Underwater Vehicle: Design and Implementation of the Reis

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**Abstract:**

Developed by the RoboSub 2015 Team, Reis is the first AUV in Turkish Naval Academy that's designed with the purpose of joining the competition. It has the capabilities to use its six thrusters, two cameras and other sensors such as inertial measurement units (IMUs), a depth sensor, an internal pressure sensor, and a hydrophone array to make its way through the missions. Mission planning and management algorithms run on a mainboard computer which is also responsible for processing the image acquired from the cameras.

## I. INTRODUCTION

Technology and military, which is among the world's most challenging professions, cannot be considered as separate. Undoubtedly, military personnel should have sufficient insight about the details of the high-tech systems they operate. Being aware of the crucial role of the technology in modern warfare, we know that modern warfighters should be willing to learn and exploit the technology, instead of being ill-disposed against it. Tactical leaders who efficiently take advantage of technology would have an edge over those who don't.

Project Reis's main objective is to give an opportunity to cadets, who take both engineering and military courses, to learn about modern-day technologies and put their worthwhile ideas into practice. Pairing up the user and the developer of technology by means of sponsorship and consultancy is also an essential mission for us.

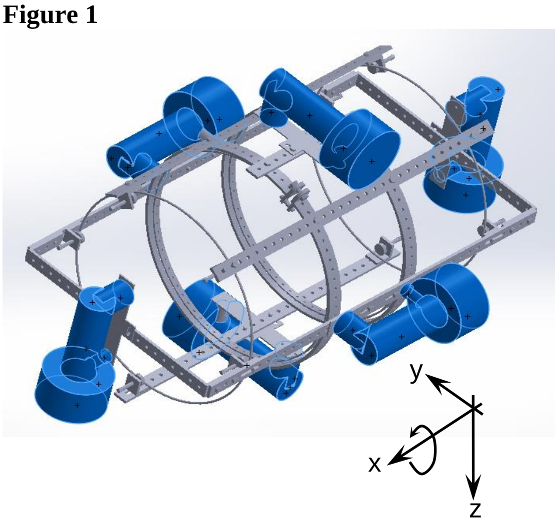
Reis is created by seven dedicated cadets who have been interested in robotics since high school years. Since then, members have participated in various competitions at several high schools and universities. With the support of Turkish Naval Academy and Our Commanders we have decided to take part in more assertive and challenging competitions. From this perspective, we considered that ROBOSUB is the most proper one for us. The facts that it requires skills across different disciplines, and provides an environment in which cadets can improve their military skills as leader, sub-leader and team members are our primary reasons in addition to cooperative learning and problem solving capabilities. Participating in such a great project would also provide a chance to interact with prominent people and well known institutions. All in all, the product of this effort is Reis; capable of completing the missions it is told to seek for.

## II. MECHANICAL SYSTEMS

### A. Frame

Main frame of vehicle consisting of outer and inner frames are designed with CAD software and produced from 316 stainless steel. Outer frame enclosures the main hull and supports the thrusters and other payloads such as torpedo and marker launchers, grabbers, hydrophones. Inner frame is for supporting the batteries and electronic circuitry. Figure 1 shows the design in CAD environment.

**Figure 1**




### B. Main Hull

Main hull is made of cylindrical acrylic tube with diameter 300 mm, height 400 mm and thickness of 4 mm. All electronic gadgets and batteries are included in this dry side cabinet. Back and front covers which are also made from acrylic have been specially designed and cnc machined. Water proof conditions were achieved by various O-rings. Cables are entering to main hull over cable records.

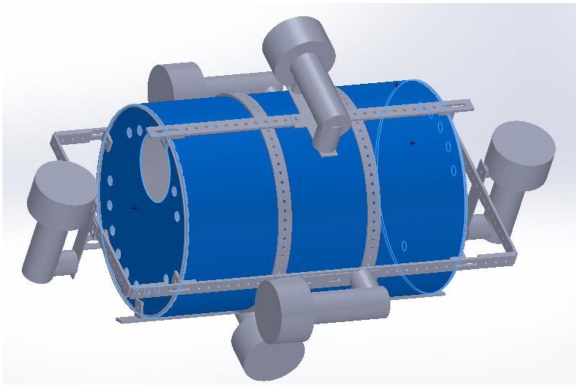


**Figure 2**

### C. Thrusters:

Propulsion is provided by six brushed motor, commercial, off-the-shelf Seabotix SBT150 thrusters (Figure 3).

**Figure 3**

Two thrusters symmetrically oriented in each of the main axis: surge, sway and heave. This scheme (see figure 2) provides the vehicle with control in the three linear degrees of freedom as well as three rotational degrees of freedom, namely roll, pitch, and yaw.

**D. Torpedo Launcher and Marker Dropper:**

Torpedo launchers are handmade and cast plastic pen case as projectiles, made to travel through the water approximately 3 meters. The torpedoes are triggered magnetically from the inner side of the main hull.

Markers are hung to a double hook under the vehicle and released by rolling the vehicle to certain angles of opposite directions. Markers were made from Pb with 75 g as shown in figure 4.

**Figure 4**

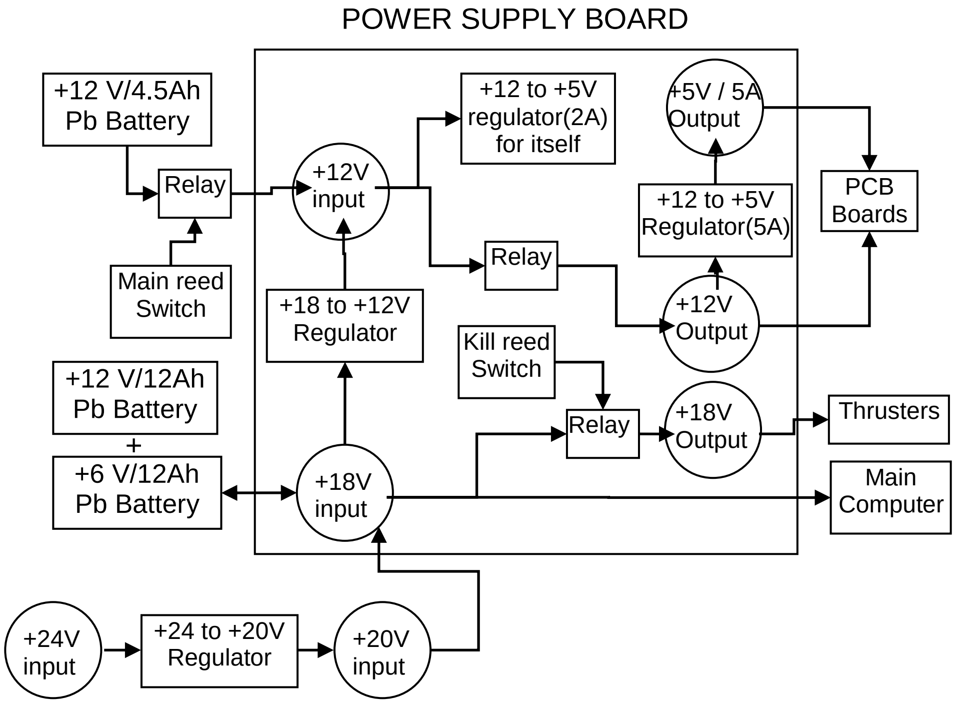
**D. Grabbing System:**

The grabbing arm is used to remove the lid over the bin. The arm is controlled by one water proof servo. So its motion is one degree of freedom. It only grasps and releases the lid's handle. This system will also be used at the recovery area mission. A 40 cm long rod mounted in front of the main hull will be used to open the door covering one of the small openings.

**ELECTRICAL SYSTEMS**

**A. Power System:**

The power to run DHO Reis is supplied by three Pb batteries which give the vehicle a run time of about 1 hour. A power supply board has been designed to manage the energy to the vehicle from two separated DC rails; one of them +12 V, and the other is +18 V. First rail, which is connected to a single +12V/4.5Ah Pb battery, provides +12 and +5 Volts for the electronic circuitry. The +5 Volt is obtained by means of a DC to DC stepdown regulator connected from +12V DC rail. Due to ripple rejection considerations which could be caused by reverse-induction, the +12 V battery supplying the electronic circuitry is isolated from the +18V DC rail which is only responsible for feeding the thrusters. +18V rail consists of serially connected +12V/12Ah and +6V/12Ah Pb batteries. Thrusters are connected to this rail. +18V battery set charges the +12V battery by a regulator. The +18V battery itself is charged from mains outside the vehicle as needed. See figure for the details of connections.



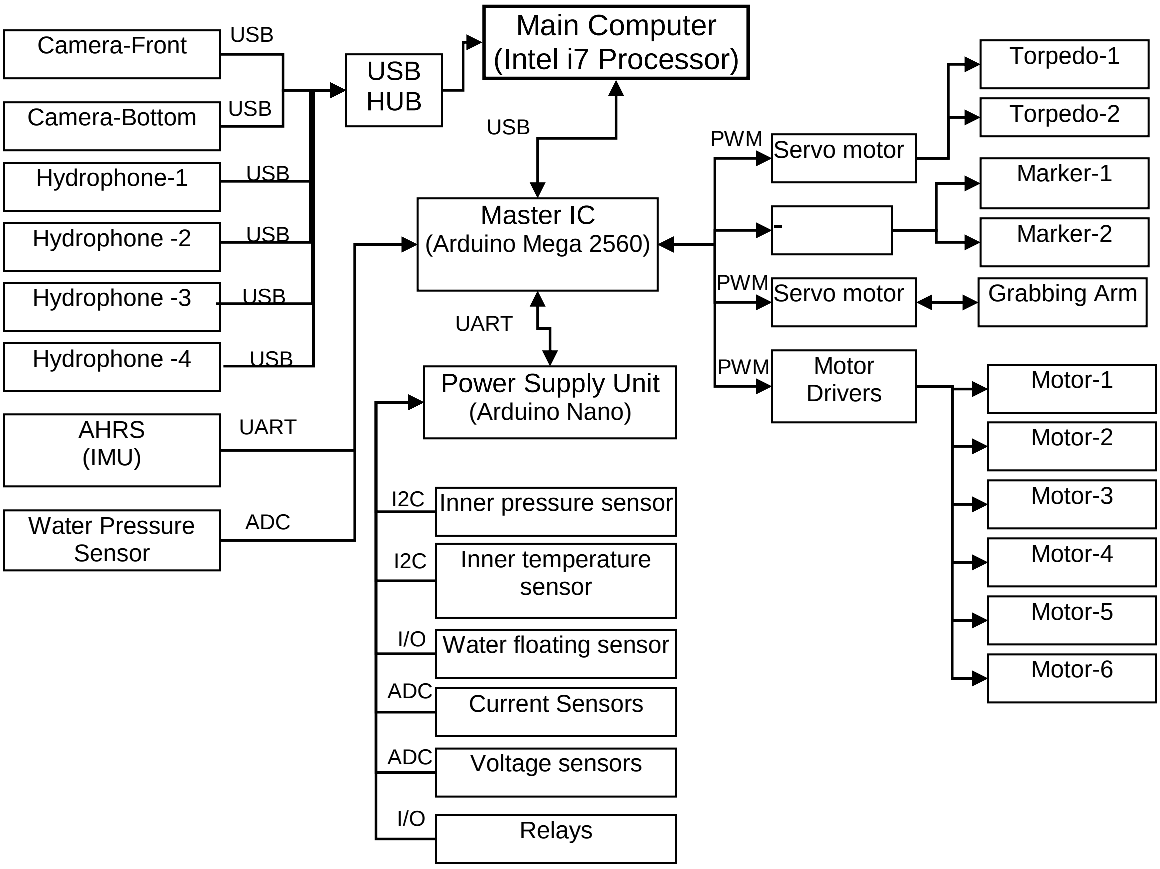

### B. Actuator Control:

Our current actuation system is comprised of six thrusters, two torpedo launchers and one grabbing arm. The thrusters are controlled through simple PWM pulses. Each brushed thruster is driven by 30A Mini VNH2SP30 Monster moto shield motor driver. Power for the thrusters comes directly from the +18V batteries, and their speed is set by the master IC (Arduino Mega) via PWM signals. Both a kill switch and a relay controlled by Arduino Nano are connected prior to motor driver boards, in order to stop the thrusters in case of an emergency.

### C. Software, Firmware and Sensor Communication

Communication between the main computer and the various actuators and sensors takes place through a serial communication bus which is supervised by an Arduino MEGA 2560 (the master IC). It delivers commands to all of the other microcontrollers, and allows any microcontroller with enough pins to interface with the whole electrical system. All the microcontrollers used are capable of standard communication protocols including I2C, UART and SPI. Cameras and Hydrophones are interfaced directly with the main computer over USB HUB rather than the master IC in order to provide flexibility and ease of use.

HARDWARE DESIGN AND
COMMUNICATION PROTOCOLS




### III. SENSORS

#### A. Cameras

Located at the bottom and in front, the two cameras provide vision to Reis. Logitech C310 webcam with adjustable gain for brightness, contrast, color intensity and white balance is used in front of the vehicle (Figure 5).


**Figure 5**

Logitech C270 (Figure 6) with the same features other than the resolution is used at the bottom.


**Figure 6**

#### B. Depth Sensor

The vertical position of the vehicle with respect to surface is measured using the pressure sensor MSI Ultrastable 300 series, which gives the pressure values from zero to 100 PSI in terms of current within the range of 4-20 mA which increases linearly with the depth from exact vacuum up to 60 meters in water. The current flowing over 10 Ohms resistor is converted to an analogue voltage signal by a custom interface board which is designed by the team for this purpose. In order to improve the sensitivity of depth, the voltage 63 mV-85mV over the 10 Ohms resistor is amplified by OP-AMPs and is stretched to 0 – 5 V indicating 0 - 10 meters respectively. The analog signal is then sent to 10 bit ADC port of the Arduino. As a result the sensitivity of the depth sensor is 0.94 cm/bit.

### C. AHRS Unit

Spatial orientation of the vehicle is measured from the CH Robotics' CHR-6dm (Figure 7) Attitude and Heading Reference System.

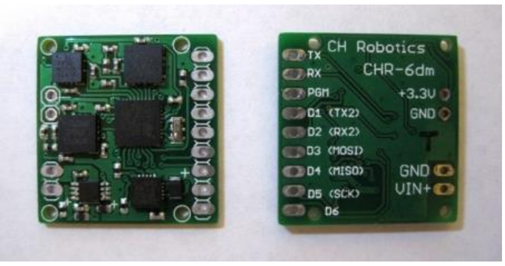



**Figure 7**

This sensor is a cost-effective orientation sensor providing yaw, pitch, and roll angles at 20 - 300 Hz. An Extended Kalman Filter (EKF) combines data from on-board accelerometers, rate gyros, and magnetic sensors to produce yaw, pitch, and roll angle estimates through fuzzy logic.

### D. Hydrophone Array

Aquarian H2A hydrophones (Figure 8) are used as the receiver for the pinger mission. Connected to the computer via ADC (analogue digital converter) the hydrophone array is used to produce the vector to the sound source (pinger in this case) and locate it.


**Figure 8**

### E. Voltage and Current Sensors.

Voltage and current sensors are essential for keeping track of battery levels and providing safety for the electrical system. Whenever the peak value of the limited current is exceeded, current flow is simply disabled to protect the system elements. 2 main switches are used for this purpose; one for the thrusters and the other for the electrical circuit.

### F. Temperature and Inner Pressure Sensors

Now discontinued Bosch BMP085 (Figure 9) pressure sensor is used to measure the interior pressure of the main hull.

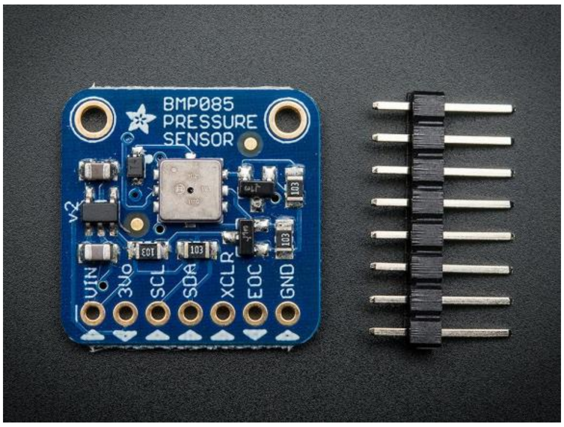



**Figure 9**

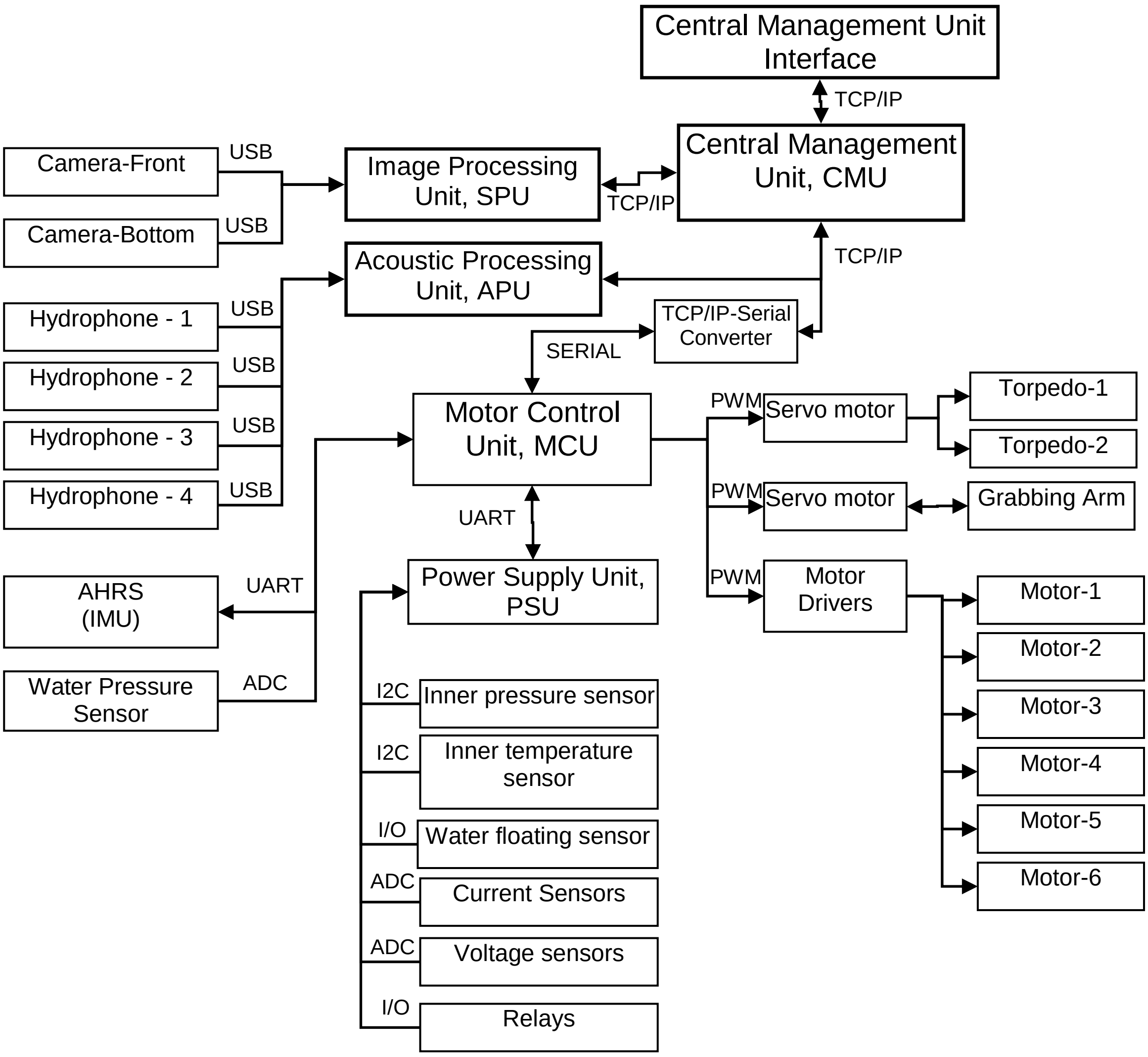
### G. Water Floating Sensor:

Water floating sensor is there to help in case of a leakage which can seriously damage the whole electrical circuitry. Emergency power cut is thought to be the only way to prevent such massive damage and rescue the vessel. Thus, the water floating sensor data may lead to partially recoverable power failures.

## IV. SOFTWARE

The operating system running CMU and IPU are two C++ programs which run on the same mainboard computer for discrete processes.

SOFTWARE DESIGN AND COMMUNICATION PROTOCOLS




## A. Computer

The core computing power of the system consists of a mainboard which runs an Intel i7 mobile processor having an HDD of 1 terabytes. This design which includes a Microsoft Windows 8 operating system proved to be helpful in establishing connections easily between the units via common drivers and software.

## B. Vision

Image processing is done at the Image Processing Unit (IPU) which receives the frames from front and bottom cameras. OpenCV C++ libraries are used for processing the frames along with Boost.Asio which provides multi-threading and precise timing for certain jobs such as logging. The unit mainly uses contour analysis and color binarisation techniques in order to provide a meaningful result to the CMU.

## C. Vehicle Logging and Simulation

Since the beginning of the project, the provision of the software team was that the logging system had to be comprehensive but at the same time it had to use minimal system resource as we had limited computing power which might have resulted in a bottleneck in between connections. Having these considerations in mind, the logging class structure is designed for the units which need careful examination in order to relate the system behaviour with the correct part of the code. Any other relatively unnecessary logging is excluded.

### D. Mission Planner

Central Management Software running on the main computer decides and plans the missions, using the data sent from Image Processing Unit and peripheral devices such as Motor Control and Acoustic Processing units. The Central Management Unit (CMU) then generates the signals to be sent to the Motor Control Unit (MCU).

As the CMU is responsible for the actual movement decisions of Reis, it is provided with the ability to request data from other units so that it can interpret these data in order to accomplish the missions. Simultaneous processing of the data is required for the CMU to do its job correctly. Thus, controlling the simultaneousness is also one of CMU’s constant tasks.

The communication protocol is based on TCP/IP so that no packet loss is tolerated and the connection is consistent. Whenever the server (CMU) sends a command to one of the clients, the evaluation of the command takes place after deserialization of the packet upon receiving.

CMU interface connection is established via the Ethernet adapter of the computer either by wire or WiFi. This interface turns debugging mode on and allows us to change mission related parameters in real-time. Microsoft Visual Studio 2013 is used as the development environment for both the C++ (units) and the C# (interface) programs.

## V. CONCLUSION

Concluding the idea behind creating our first Autonomous Underwater Vehicle (AUV) Reis it can be said that the long process of learning will lead to more efficient and capable designs. Starting Reis from scratch and building it in such a way that it has the abilities to observe its environment and decide the way it was told before without any human intervention was itself an exciting experience.

Reis is only the beginning of a promising project which can lead to many doors with every part of its modular structure from image processing to controlling of an underwater vessel. Expecting to take people’s attention to what unmanned technology could lead us to in the not-so-far future, DHO-Reis team hopes to find new ways to actually encourage people to join and be part of this promising technology.

## VI. ACKNOWLEDGMENTS

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