Introduction and Concept Design of the "AUVTECH" Istanbul Technical University Autonomous Underwater Vehicle

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Abstract: AUVTECH Vehicle is an Autonomous Underwater Vehicle (AUV) carrying an embedded intelligent system that can autonomously navigate beneath the surface of water based on inputs from image processing and digital signal processing. The combination of homemade electronic circuits along with mechanical parts hosts the software mechanism implementing the decisions and executions. The vehicle receives input data from its precise sensors like Inertial Measurement Unit, hydrophones and pressure sensor for odometry and decisions are made based on vision information coming from two cameras. Actuation and maneuvering mechanisms are applied through thrusters, robotic arm and torpedo pneumatics based on received inputs. The vehicle is fully operable in a diverse hydrodynamic environment such as water by applying and controlling all of its peripheral devices in a simultaneous manner. Such a field of operation makes the vehicle quite useful in missions involving the observation of aquatic life, undersea terrain shifts and geological transformations. AUVTECH Vehicle will be the first of its kind available publicly in Turkey, a country which is geographically almost surrounded by water from three sides. This work includes detailed explanation on how AUVTECH Autonomous Underwater Vehicle has been grown up and concludes further aims to be planned.

Keywords: Auvtech, AUV, unmanned underwater vehicle.

1.INTRODUCTION

The incorporation of digital and artificial intelligence into yet solely human engaged fields of life has pushed forward the quest for digital paradigm even further.

Recently, Autonomous Underwater Vehicles (AUVs) have come under the intense focus of interested academic circles thanks to the ongoing researches on versatile and challenging environmental phenomena existing in the fields of operations.

The hydrodynamic nature of the fields of operation for civilian AUVs brings up at least two major reasons, i.e. the observation of diverse aquatic life, and the geological shifts beneath the surface of oceans and water bounds.

The AUVTECH vehicle, to be built as the first of its civilian AUV around the country, will be a suitable, and for the moment, the merely choice addressing the concerns related with the aforementioned. Despite the fact that geographically peninsular Turkey is surrounded by open waters from three sides, publicly there have been no or negligibly small efforts spent on studying the marine life and underwater terrestrial surfaces by hiring a researching robot.

The team consisting of nine students from different disciplines at Istanbul Technical University has been nominated to be the first time runners for an international competition in order to prove the ability of AUVTECH vehicle in contributing to the existing marine challenges at home and abroad.

In 1999, a severe earthquake hit the north west of Turkey leaving behind huge damages and causalities which have been recorded as a national tragedy during the whole century. Unfortunately, the aftermath of this disaster still exist and threats the nation emotionally each time a region is hit by a swing.

Specialists, in particular, are concerned about the faulty lines beneath the water surfaces of Marmara Sea, claiming on an approaching date for another disastrous earthquake or a tsunami. This was the startup motivation behind the gathering of team members on the eve of 2012.

AUVTECH vehicle will be the first of its kind to publicly appear beneath the surface of Marmara Sea and would claim the guardianship for unreached underwater inhabitants and territories. However, it can serve as a model and prototype to reach and investigate any closer regions or even the farthest locations from home.

2. MECHANICS

The AUV consists of a frame, a main hull, actuators and external enclosures. All mechanical parts are built to be easily modifiable and can be restructured. Frame along with the main hull are bound together in such a way to maintain the stability. The actuators and external enclosures can extend over the frame as required.

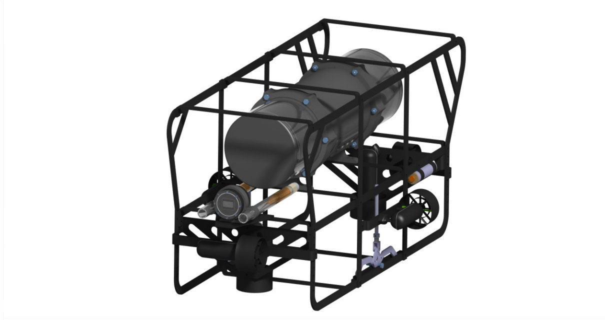

Figure.1 A Catia rendering of Auvtech

The whole vehicle was drawn in CAD software and was simulated using CFD and FEA software collections. After simulation, the necessary parts were fabricated using a five axes CNC machines at ITU Mechatronics Education and Research Center and at one of AUVTECH's sponsors' workshop where laser machines were available. The remaining parts were purchased and then small amendments were applied by the CNC.

2.1 Frame

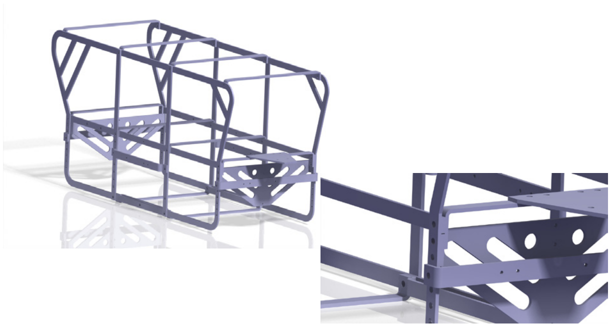

Figure.1 Frame and detail

The main idea behind the frame was to obtain an easy modifiable platform with other parts, therefore, the main hull, actuators and enclosures can be mounted with stainless steel bolts and nuts.

The frame is composed of 14 pieces of marine aluminum and 18 pieces of chrome. Chrome is used at the bottom of vehicle to improve the stability of vehicle. Parts of frame were fabricated in laser cutting machine and then were bended in hydraulic press braker.

2.2 Main hull

The main hull is the pressure vessel on the vehicle and contains electronic cards, sensors, batteries and embedded pc. The main hull is fabricated out of aluminum and Plexiglas. It is enclosed on both sides with end caps. The end caps, connective parts and middle part of the main hull are made of aluminum. The bow and stern part of the main hull are made of Plexiglas. The hull can be separated in three sections due to the easy accessibility into interior of the hull. It has three foundations aiming to keep the electronic cards, embedded pc and batteries unmovable inside the hull and to improve stability of the hull.

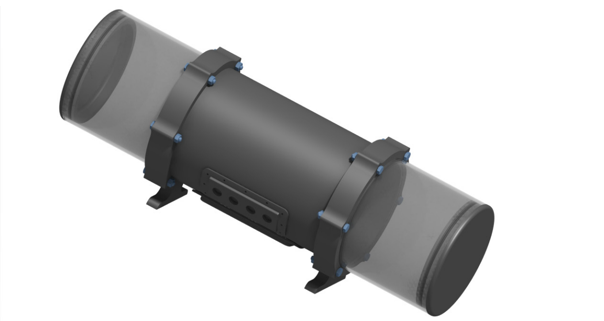

Figure.2 Main Hull

The main hull is simulated with FEA and CFD software and controlled via FSI analysis to observe unwanted stress, deformation.

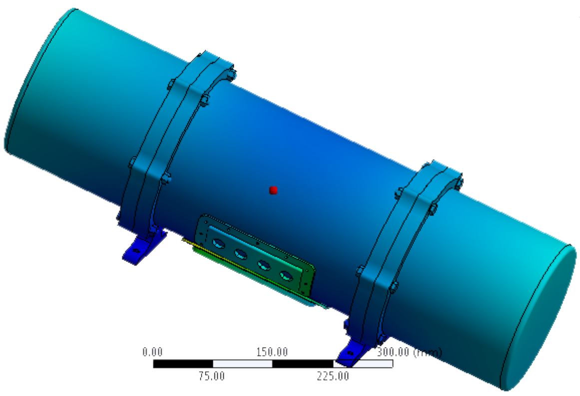

Figure.3 Main Hull structral analysis

External enclosures are connected with IP68 underwater connectors from enclosures to the bottom of the middle part in the main hull.
In particular, USB connectors are chosen for cameras and hydrophones enclosures to prevent noise interference.

2.3 Actuators

The vehicle has four actuators which are torpedo mechanism, marker, grabber and manipulator. All of the actuators function based on pneumatic system. Grabber is inspired from crab. Markers and torpedos have suitable hydrodynamic design to achieve fluent movement and manipulator can catch horizontal and vertical positions with only a linear actuator.
Each actuator is controlled by an independent solenoid valve.

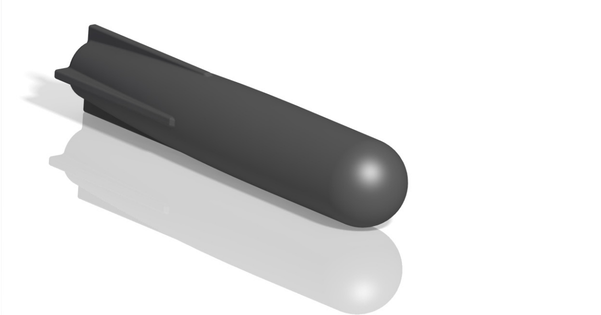

Figure.4 Torpedo

2.4 External enclosures

Cameras, hydrophones, manifold system and CO2 cartridge holder require external enclosures. All of the enclosures are fabricated out of Delrin. Delrin is a cheap lightweight material which can also be easily shaped with a CNC machine. Enclosures are closed with stainless steel bolts and are sealed using the O-Rings. Enclosures are connected with IP68 USB and power connector to the main hull.

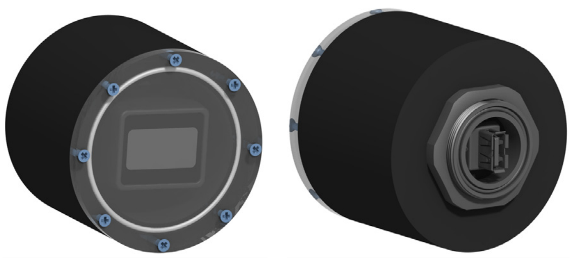

Figure.5 Camera Enclosure

3. ELECTRICAL SYSTEMS

The electrical system of Auvtech allows the computer to read inputs from sensors, to drive thrusters and to control the actuators through serial communication modules, microcontroller based electronic cards and power systems. Most of the electrical subsystems of Auvtech are custom designed, built and programmed.

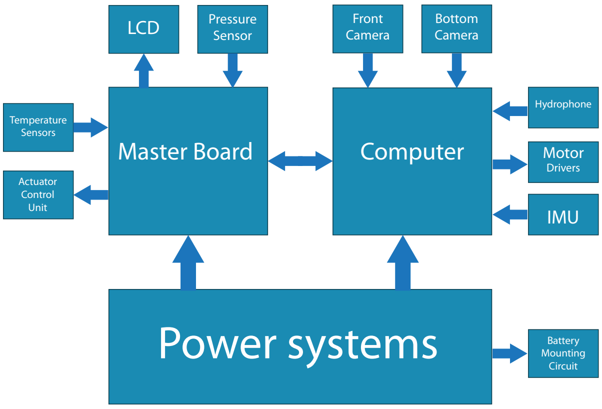

Figure. 6 Electrical sytem block diagram

3.1 Power System

The power system of the vehicle is based on three Lithium polymer batteries configured with six cells in series order. The total output voltage of the batteries is 22.2V and is stepped down to 12V and 5V by two commercial DC-DC converters. The output voltage of each cell and the total voltage of each battery can be observed by three battery voltage monitoring circuits.

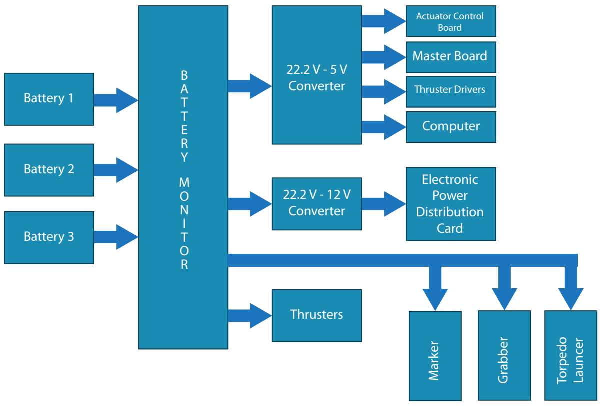

Figure. 7 Power system block diagram

The custom built electronic power distribution board in figure, is supplying regulated 5V to the electronic boards which needs 5V to operate.

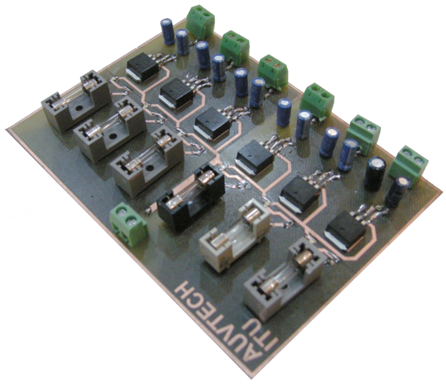

Figure. 8 Electronic power disturbution board

3.2 Master Board

Interface between the computer and other peripheral devices is supplied by a custom built electronic card named "Master Board". The computer communicates with Master Board through the USB port by using its USB/UART converter, and the communication between the computer, motor and actuator control boards is handled by I2C ports of Master Board. The I2C ports of this board minisied. The inputs from temperature and depth sensors are read through this board via the analog inputs. The temperature and mission information of the vehicle can be displayed on the LCD driven by Master Board. This board has extra I2C ports and digital outputs which can be used for additional installments such as connecting extra motor controllers or actuator controllers.

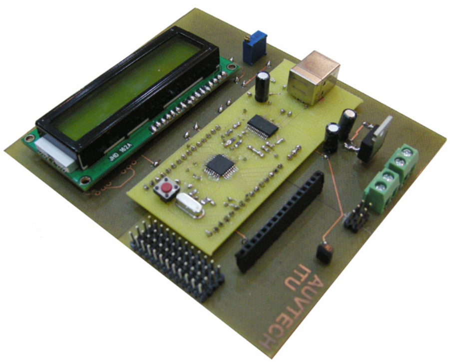

Figure. 9 Master Board

3.3 Motor Drivers

Auvtech has six Seabotix BTD150 brushed thrusters, and the control of each thruster is achieved by using commercial off-the-shelf H-Bridge motor drivers. Each motor driver can drive two thrusters independently and the motor drivers communicate with the Master Board through the I2C ports. The motor drivers are fed with 22.2V.

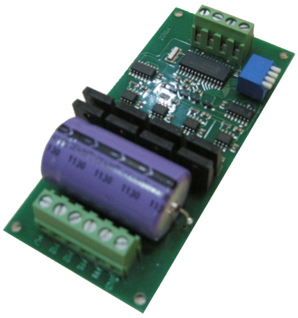

Figure.10 Motor driver

3.4 Actuator Controller

Auvtech vehicle is equipped with torpedo launchers, marker droppers, manipulator and grabbers which are controlled by pneumatic cylinders. The control of the each cylinder is done by microcontroller based custom built actuator controller board which can control up to eleven solenoid valves independently.

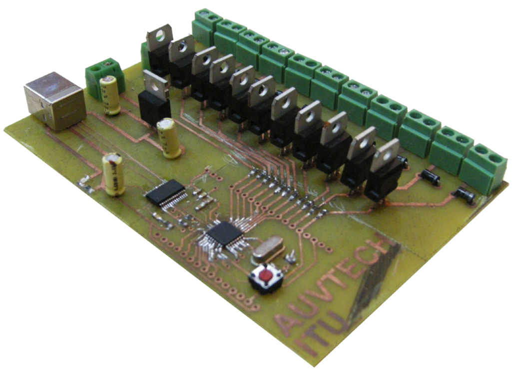

Figure. 11 Actuator controller board

Communication between the computer and actuator control board can be handled over USB port of computer or I2C port of Master Board. Through the USB port, the microcontroller of the actuator control board can be programmed repeatedly. The solenoid valves are fed with 22.2V from batteries and the actuator control board is fed with 5V from electronic power distribution board.

3.6 Kill Switch

Two custom designed magnetically controlled switches allow the operators of the vehicle to cut the connection between battery and thrusters and other components of the electrical system of the Auvtech. These switches based on two magnetic sensor, relays and mechanic parts.

3.5 IMU

The inertial measurement unit of the vehicle is an XSens MTi unit which provides 3D acceleration, rate of turn and magnetometer data through its sensors array. Moreover, the MTi has a signal processor which makes it possible to provide accurate measurements to the computer.

Figure. 12 XSens MTi Unit

3.6 Pressure Sensor

MSI Ultras table 300 pressure sensor has been used for the depth measurement of the vehicle. The pressure sensor has been connected to one of the analog inputs of the Master Board directly, and pressure measurement data is sent to the computer through the USB port of Master Board.

Figure. 12 Depth sensor

3.7 Passive Sonar System

The passive sonar system of the vehicle consists of three external sound card and three hydrophones. H2a hydrophones from Aquarian Audio are used to detect analog signals from acoustic pinger and the output of the hydrophones processed by external sound cards.

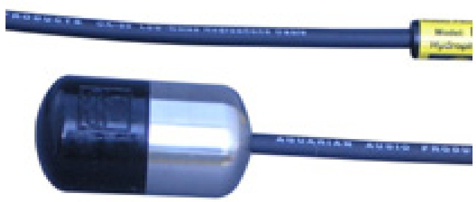

Figure. 13 H2a hydrophones

3.8 Cameras

The vehicle is equipped with two Microsoft LifeCam HD-5000 cameras, one of them is in the front and the other at bottom vehicle. These CMOS cameras have 66 degrees wide field angle. It can capture up to 30 frames per second in 24-bir color depth. Front camera is used for tasks like gate, training, obstacle course, et tu brute, feed the emperor grapes etc. Inferior camera is used for path, gladiator rings, emperor' s palace. Microsoft LifeCam HD-5000 cameras are cheaper than fire wire cameras and can focus automatically from 6 inch to infinity. Autofocus increases sharpness of shapes and decrease possibility of calculation errors.

Figure. 14 Microsoft LifeCam HD-5000 camera

4. SOFTWARE

The software collection used in AUVTECH vehicle consists of an underlying operating system, a core application along with lightweight runtime environments managing the simultaneously running mechanisms. The embedded SBC (Single Board Computer) hosts all of the software components in full compatibility considering the limited resources that it provides. A deployed version of Windows Embedded Standard 2009 (WES2009) was designed using Microsoft Windows Embedded SDK which provides a small footprint with features like auto logon and unbranded logo for a faster initial load. These features decrease the delay time in launching and restarting the system.

The implementation of all the software structure has passed through three design phases which are coding, simulation and debugging.

4.1 Core Application

The core software which acts as the brain of AUVTECH vehicle was designed using Microsoft Robotics Developer Studio. The smart simultaneous coordination and iteration features that are provided by this platform were the main reasons behind this choice. "The Concurrency and Coordination Runtime (CCR) and Decentralized Software Services (DSS) libraries were originally intended as a future programming model to enable developers to write applications for the increasingly prevalent multi - processor,
distributed scenarios into which computing technology is evolving" [1]. C# programming language which is the preferred coding language for MRDS, makes it easier and quicker to get used to the platform as this will be the first experience of the team running for a competition.

The core software designed with MRDS consists of services as the basic building blocks. The main feature in MRDS called DSS (Decentralized Software Services) is the host environment for the services comprising the core software application. Another feature of MRDS called CCR (Concurrency & Coordination Runtime) which is integrated with DSS, provides multithreaded and iterative mechanisms for those services in order to accomplish a mission in a simultaneous state. DSS and CCR together form the Runtime environment for running the entire collection of services (compiled as the core software) which is deployed into WES2009 on the SBC.

There are different services each incorporating the functionalities of different peripheral devices like IMU, Pressure Sensors, Thrusters, hydrophones as well as image processing methods. These services can communicate with each other and were bound together using DSS Manifest Editor in MRDS.

The core software also takes on the responsibility of planning and accomplishing the tasks and challenges defined in the competition arena. In order to accomplish those tasks, a behavioral FSM approach was implemented in the algorithms. The reason for this approach is the fact that it lets the system act on a combination of input data which can define a behavior in a block of code. This is an alternative to the traditional method of sequential data processing such as "Mod—Plan-Act".

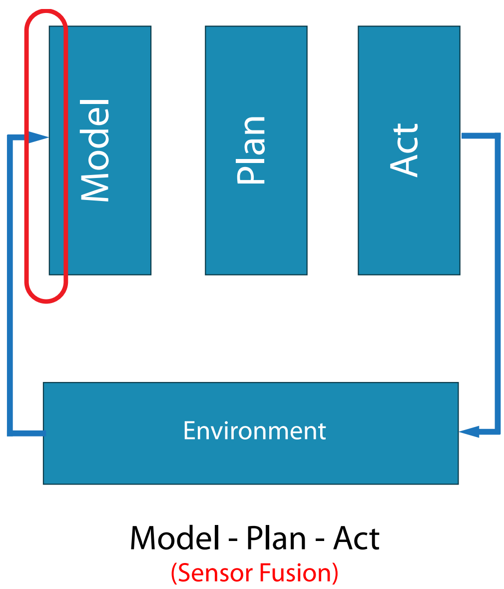

Figure. 15 Model - Plan - Act diagram

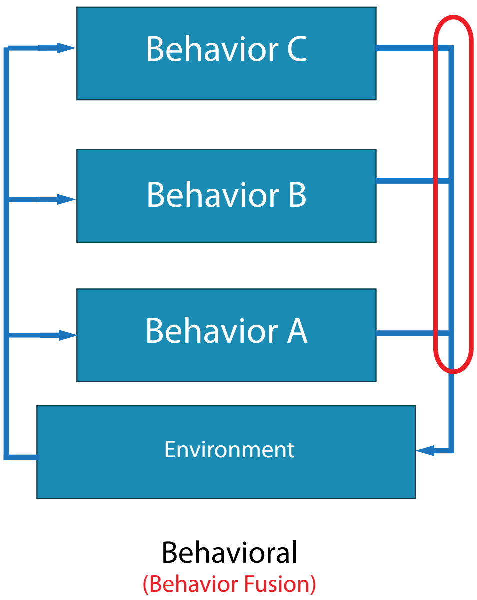

Figure. 16 Behavior diagram

"Model-Plan-Act fuses sensor data, while behavioral fuses behaviors" [2]. The behaviors are coded into algorithms in the core software application. These algorithms are individually implemented in the main holder class of the application. An algorithm is initialized for running in the main method of this class only when a vision method is triggered. Once image processing is running in the context, other actuating and maneuvering capabilities are launched as defined by the task planner arbiter.

The whole mechanism is run in parallel by receiving inputs in minor time sliced loops and by sending actuating and maneuvering commands through multi threaded wrappers. The core software application consisting of services and algorithms has been deployed into the SBC, handled by DSS and CCR Runtime and is integrated with the automation procedures functioning under WES2009.

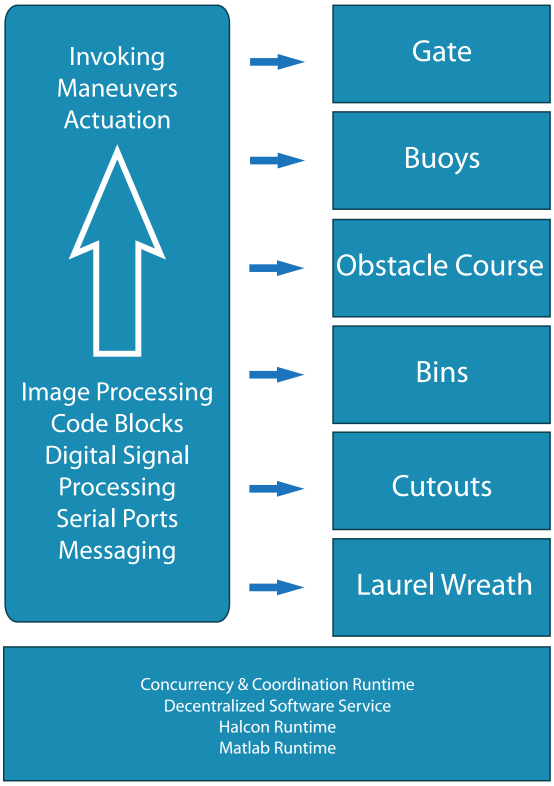

Figure. 17 DSS & CCR Runtime Diagram

The simulation of the competition arena has been designed using Google SketchUp and was imported into MRDS Simulation Engine. This simulation hold the purpose of behavioral testing of the vehicle since the actual challenges existing in the real world has not been yet achieved. The major issue was the handling of a hydrodynamic environment and CFD analysis which seem to be a laborious task. Hence, so far it has not been incorporated into MRDS Simulation Engine.

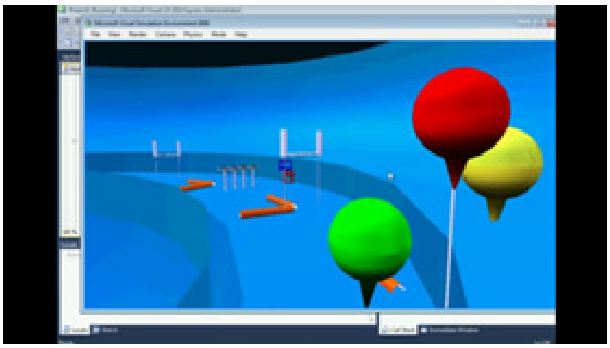

Figure. 18 MRDS Simulation

Prior to going actually into the debug phase, the communication of different peripheral devices had to be maintained in the application. Some peripheral devices like hydrophone had to communicate through a MATLAB interface and then be incorporated in the application using MATLAB Compiler Runtime. The same is true for the communication with image processing methods which are based on Halcon Runtime. Both of these are installed in the SBC and provide the essential communication which complements the real time response of the whole system.

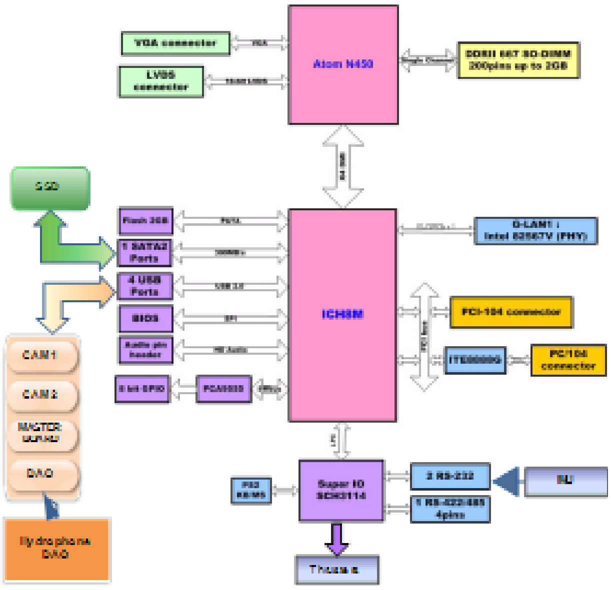

Figure. 19 The entire system

Controller implementation has been achieved using a PID controller which has been coded in C# and accepts processed inputs from IMU and Pressure Sensor generating optimized signals and hereby invoking respective commands to the mobility and actuation mechanisms of the system.

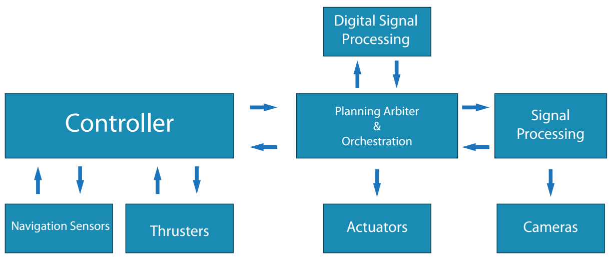

Figure. 20 Control System

4.2 Vision

Machine vision is coded in Halcon and exported via Halcon.NET to the core software. Halcon is the comprehensive industrial image processing software product with an integrated development interface. The Halcon full library can be accessed from C# and make image processing much easier.

Canny edge detection algorithm is applied to find edges of images [3]. Then, closed regions are created by region growing algorithm [4] and a filtering is carried out afterward according to the width and area. Regions are selected by its shape to determine the mission info and by the marked colors. Mission info can provide distance calculation from vehicle to the mission by comparing methods. To be able to measure the distance, cameras have to be calibrated. Mission info and calibration of cameras are two important parameters in order to measure the distance with a single camera. All components of the mission coordination can be calculated with respect to the vehicle. All these data (mission info, color and coordinate of mission etc.) are then fetched by the core planner software.

5. CONCLUSION & FUTURE WORKS

AUV technology has gone through stages where academic interest was followed by research investigation. Development of AUVTECH Autonomous Underwater Vehicle was carried out by intelligent students of Istanbul Technical University and the laboratory facilities.

The paper mainly included information about mechanics, electrical systems and software of the vehicle. Types of mechanical parts, diagrams of electrical systemes, collection of operating system and a core appplication have been clarified in details.

Eventually, an autonomous underwater vehicle designed and built successfully, especially for AUVSI Foundation and ONR's 15th International RoboSub Competition 2012. Also a closed form solution for hydrodynamic optimisation of AUV's will be considered for future work.

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