Vasa
An Autonomous Underwater Vehicle

http://www.projectvasa.com

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Abstract—Vasa is a custom made autonomous underwater vehicle developed solely at Mälardalen University, Sweden. It is built in a modular fashion, both mechanically and electronically. The development of Vasa started within a project course given at the university during autumn 2011. After the course, a part of the team continued to develop the robot in order to compete in the 15th Annual Robosub competition in San Diego, CA, USA. The primary goal was to create a system good enough to successfully complete a set of tasks in the competition. The team hopes that Vasa will be developed continuously afterwards and return to the competition annually.

Index Terms—Vasa, AUV, underwater robot, autonomous, RoboSub.

1 Introduction

Underwater robots offers endless possibilities in the field of naval exploration, warfare and navigation. This is because AUVs are without any direct control by a human operator. Vasa is totally autonomous and interprets the environment through cameras and sensors. In order to have greater development potential Vasa is designed to be modular in the fields of mechanics, electronics and software. With a modular design it is easier to expand the intent of usage for the robot as it is easy to construct and add new modules. Vasa is developed solely from students at Mälardalen University in Västerås, Sweden. The project goal is to compete in the 15th annual RoboSub competition. The team is confident that Vasa is of high value for the school and will increase the interest of robotics at Mälardalen University. Hopefully more teams from the university will compete in the upcoming years and the team has made sure to make it as easy as possible to continue the development of Vasa after the competition. Vasa is attractive because of its modular platform that makes it possible for anyone to customize it to fit any special needs.

Fig. 1. Vasa AUV

2 Team Organization

To achieve a qualitative and time efficient development the project members where assigned different roles. The team constellation mainly consisted of a project leader and three groups with a group leader in each one. The project leader was responsible for the development of the project as a whole. The purpose of the group leader was to delegate work load and synchronize the subgroup. The team was divided into the subgroups; mechanics, electronics and software.

3 Mechanics

The mechanical design of Vasa has been done with modularity and flexibility in mind. Two easily removable and openable hulls are attached to the frame surrounding the robot. The hulls contain all the electronics of the robot and the electronics are supported by a support system that allows for easy maintenance and upgrades. Thrusters and equipment are directly mounted to the frame.

Part	Description
A	Front hull
B	Rear hull
C	Battery
D	Power board
E	Backbone
F	High level CPU
G	Thruster
H	Camera
I	Markers
J	Gripper
K	Torpedos(under development)

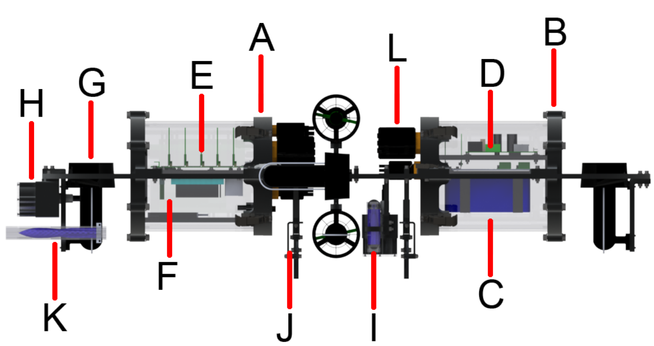

Fig. 2. Parts of Vasa

3.1 Frame

The frame is waterjet cut out of 10mm EN-AW 5754 aluminium [Fig. 3]. It surrounds the robot and acts as a mounting structure to the hulls and everything else mounted to the robot. A hole pattern surrounding the whole frame ensures easy mounting of equipment. Most equipment are attached to the frame with custom CNC-milled mounts.

Fig. 3. Frame of Vasa.

3.2 Thrusters

Six of-the-shelf Seabotix BTD150 brushed DC thusters are used for propulsion, steering and balancing.

3.3 Thruster Configuration

To be able to achieve all possible motions of the robot, a six thruster configuration was chosen. They are positioned in a way that enables the robot to move in six degrees of freedom:

The three linear motions are

- Heave - Vertical (up/down) motion
- Sway - Lateral (side-to-side) motion
- Surge - Longitudinal (font/back) motion

and the three rotational motions are

- Yaw - Rotation around vertical (up/down) axis
- Pitch - Rotation around lateral (side-to-side) axis
- Roll - Rotation around longitudinal (font/back) axis

When configured in this way, the robot has the ability to move in the best possible way to its target, no matter of its current position [Fig. 4]. When having six thrusters, they can be positioned in a number of ways to achieve the six degrees of freedom. The way chosen is a variation of the cubic formation that enables the robot to maintain its modular design together with the

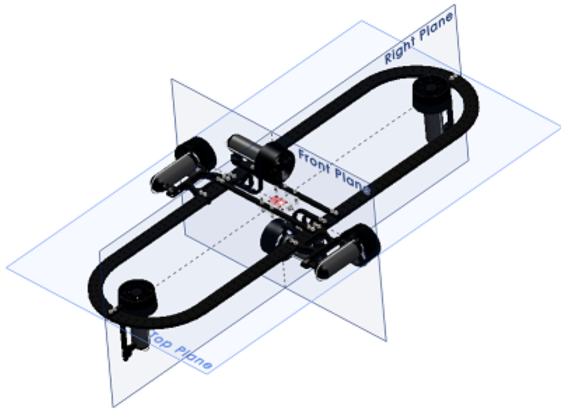

Fig. 4. Thruster configuration.

two main hull configuration and optimal sensor, gripper and marker positions.

All the thruster pairs have one singe intersection point and this point is moved slightly forward from the center of the frame. This is to be able to fit the downward facing camera and grippers in their near optimal positions.

3.4 Main hulls

The two main hulls contains most of the electronics and each consists of five major parts; two flanges, two lids and one plastic tube, see [Fig. 5]. The flanges and lids are made of EN-AW 5754 aluminium and were first cut by waterjet and then CNC-machined. Both flanges are attached to the ends of the plexiglas tube using an ms-polymer based adhesive (Tekton MSPolymer) that ensures a waterproof connection while still being flexible. Since aluminium and plastic reacts different on pressure and temperature changes a 1 mm space in every direction has been left between the flanges and the tube to allow the connection to flex. The flanges are connected to the lids with screws and bolts on one side and compression spring latches on the other side. NBR o-rings are used as the seal between the lids and flanges.

3.5 Electronics support system

The Electronics Support System (ESS) [Fig. 6] is CNC milled from polyoxymethylene (POM-H), also known as Delrin. There is one ESS mounted to the inner lid in each hull, and it is responsible for keeping all the electronics and inner components in place. The ESS consists of two circular plates at each end which are connected to each other with rods. These rods are mounted to grooves in the circular plates and acts both as the supporting structure and as mounting points. The grooves in the circular plates span over 83% of the faces of the plates which gives a lot of flexibility as the rods can be moved along the grooves to the optimal position. On top of the mounting rods smaller aluminium mounting plates are mounted, enabling the mounted components to be moved in a direction perpendicular to the mounting rods. More rods can easily be added if there is a need for more mounting points or additional components. On the outer end of the ESS two tabs mates with the outer lids, keeping the ESS in place during operation.

On the outer ends of each ESS a cooling fan supplies the electronics with air cooled by the cooling fins on the inside of the outer lids. The fans are permanently mounted to the ESS and comes out with it as it is removed from the hull.

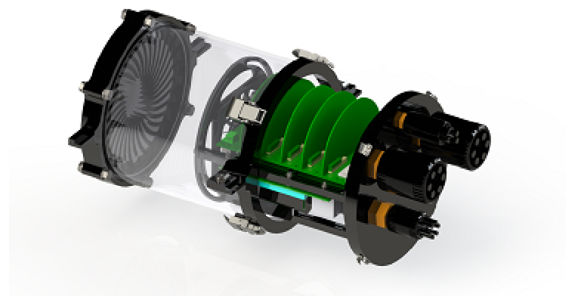

Fig. 5. Hull assembly.

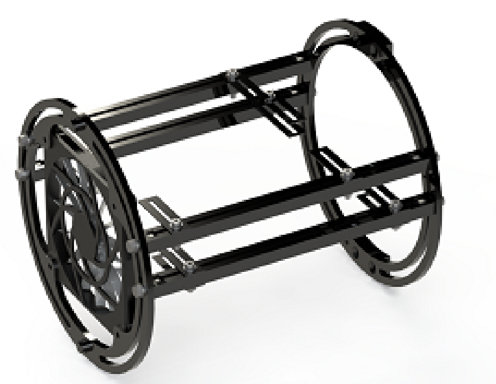

Fig. 6. Electronics support system.

3.6 Markers

Vasa has two markers that are supposed to be dropped in specific bins during the competition. The dropping of the markers are controlled by solenoids and the markers are mounted inside plexiglas tubes close to the downward facing camera to improve aiming accuracy. The markers [Fig. 7] are made of plastic and have four fins to keep them stable. A weight has been added to the front part of the markers to keep them negatively buoyant and sinking straight down. Marker tubes and solenoids are attached to aluminium mounts connected directly to the downward camera housing.

Fig. 7. Markers.

3.7 Grippers

The idea behind the gripper[Fig. 8] design is to grab the PVC structure in the competition but it can also be used as a general gripper to pick up other objects. There are two identical gripper mechanisms each powered by a solenoid. The solenoids are single-action and recover their natural, open position by spring power.

Fig. 8. Grippers.

3.8 Camera Housings

The camera housings are designed around the Point Grey Dragonfly2 board level camera with optics, see [Fig. 9]. The housing consists of three CNC-milled parts. The front and back part are made of EN-AW5754 aluminium and the lens is made of 3mm plexiglas with extra fine thickness tolerance. To waterproof the camera housing, two standard dimension NBR o-rings are used. There is also enough space to adjust the camera board mounting with spacers, so that the camera angle can be adjusted. The front camera housing is mounted directly to the frame in front of the forward hull and the downward facing camera is mounted between the hulls.

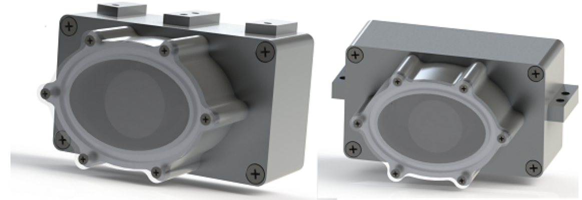

Fig. 9. Camera housings.

3.9 Connectors

To be able to interact with the environment many signals needs to go in to and out from the hulls. All external connectors are made by Seacon [Fig. 10] and the cables are spliced together with solder, heat shrink tube, silicon and vulcanizing tape. There are many free slots in the split connectors for future use.

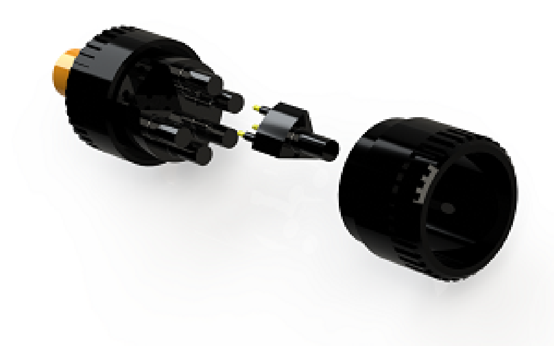

Fig. 10. Seacon connectors.

4 Sensors

Vasa is equipped with a pressure sensor and an IMU and shortly it will get updated with an active sonar as well as a passive sonar. The data from these units are sent over the CAN-bus which makes it possible for the CPU and the motor controller board to read the sensor data at the same time. Data from the IMU is used for stabilization and orientation. Two firewire cameras provide vision for the robot.

4.1 IMU

Vasa is fitted with a 9 degrees of freedom (DOF) Razor IMU sensor from Sparfun Electronics. This sensor is equipped with a three axis gyroscope, a three axis accelerometer and a three axis magnetometer. The IMU is connected to the sensor card through a UART interface.

4.2 Pressure Sensor

The robot also utilizes a pressure sensor, Series 2600 submersible depth sensor, from Omni Instruments. This is a submersible sensor which means that the sensor itself does not need any casing, so an analog feedback signal goes straight from the sensor to the front hull.

4.3 Cameras

Vasa is equipped with two Dragonfly 2 CCD cameras from Point Gray. These are board-level cameras and are using the IEEE 1394 (Firewire) communication standard. More details about the cameras are explained in [Section 6.3.1].

4.4 Active Sonar

The active sensor module is a Senix TSPC-30S1-232. This sensor has configurable outputs between analog signal and RS-232 serial communication.

4.5 Passive sonar

A passive sonar system uses H2c hydrophones from Aquarian audio products. These are designed to pick up signals from 20Hz to 100Khz. But as they are passive hydrophones, additional electronics is required to make it a useful sonar system.

5 Electronics

The overall electronics design is constructed to be modular with as few cables as possible as these were considered weak points. The electronics is divided into a set of cards which are all designed to handle specific tasks.

5.1 Batteries

The system is powered by a 18,5V (19-21V operational) Lithium polymer battery. Either one 5S1P 8Ah battery pack is used, or a 5S2P 16Ah pack may be used to double the run time.

5.2 Backbone

The backbone is a PCB card designed to function as a communication bus as well as a power supply. This board gives the advantage of having a modular design without the use of cables but rather slots (headers). [Fig. 11] illustrates the information accessible on each slot located on the backbone. This board can sustain each slot with 3.3V, 5V, -5V as well as battery voltage (19-21V). The board also contains the necessary media for transporting the signals on a CAN-bus.

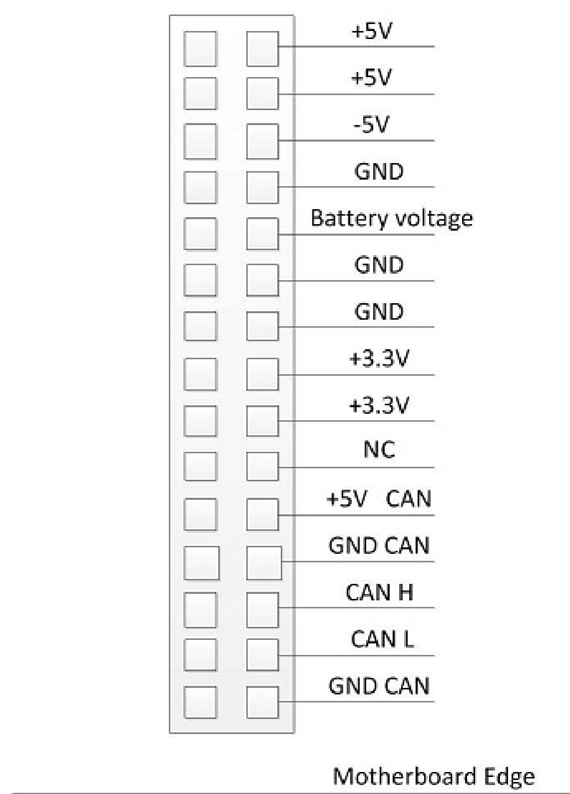

Fig. 11. Top view of backbone header.

5.3 Router card

The router card is designed to reroute the CAN-bus into USB-signals. The card is equipped with an AT90CAN microcontroller from Atmel. The USB serial communication is done by having an FTDI232R chip which transforms the serial signals into UART, which in turn goes into the microcontroller. On the CAN side of the card, there is a TJA 1040 transceiver that serves as a bridge between the microcontroller and the CAN-bus.

5.4 GPIO card

The GPIO card is designed to have a lot of input/output functionality. The card is mainly used for connecting external sensors and to redirect their signals into an AT90CAN. Currently a ”9DOF Razor IMU” is connected to this card which gives Vasa a heading as well as keeping the PD controller functional, as it gives the inclination of the AUV. The card also has an ”Omni Instruments Series 2600 Submersible Depth Sensor” connected to it that gives current depth down to a maximum of 15 meters.

5.5 Solenoid card

The solenoids are controlled by a dedicated card capable of controlling six solenoids. The AT90CAN microcontroller communicates with the rest of the system through the CAN-bus and the solenoid drivers are of model DRV104 from Texas Instruments.

5.6 Power Board

The power board is constructed to stabilize power and to protect the electronics from over-current and transient voltages. It is fitted with an AT90CAN controller which itself is connected to an LCD screen with user information. The board is fitted with relays that are designed to cut the power to the motors or the rest of the system in the event of power failures or if the kill switch is pulled.

5.7 Motor controller board

The thrusters are controllerd by six Pololu VNH5019 H-bridges. Those are connected to an AT90CAN for logical processing and connection to the CAN-bus. In order to maximize heat dissipation, the H-bridges are mounted to an aluminium plate and fitted with cooling heat sinks, see [Fig. 12].

Fig. 12. Motor controller with cooling plate and heat sinks.

5.8 Sonar and hydrophone card

In order to localize the pinger and detect the range to objects, a special active sonar and hydrophone card has been constructed. This card takes input from three passive omnidirectional hydrophones and amplifies and filters their signals in order to distinguish the signal sent from the pinger from other types of sounds and noises. The calculation of the heading to the pinger and the communication with the CAN-bus is done by an AT90CAN microcontroller. The card is also equipped with a port for an active sonar, which feeds an analogue value into the microcontroller that is directly proportional with the distance to the object in front of the sonar.

6 Software

The computational power is distributed by dividing the software into two parts; the high level and low level architecture. The high level architecture runs on the main CPU while the low level architecture runs on the microcontrollers in a the distributed system. The communication between the microcontrollers and the CPU is done via a CAN-bus (Controller Area Network). An architecture overview is shown in [Fig. 13]

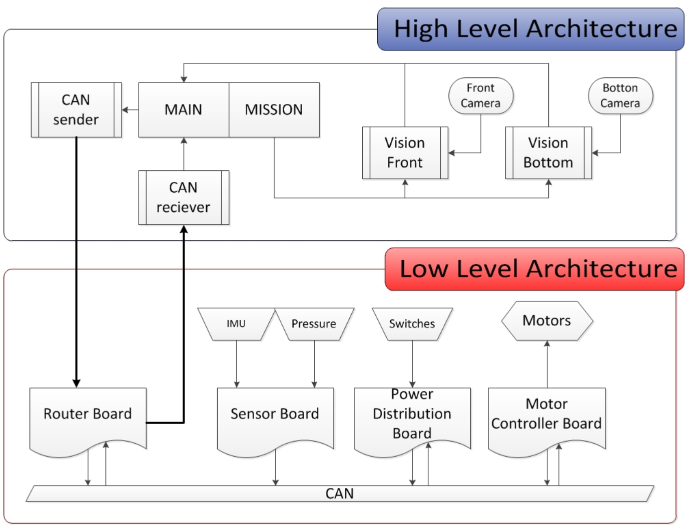

Fig. 13. Illustration of the software architecture.

6.1 High level CPU (mini-ITX)

The high level CPU in Vasa is the brain of the whole system. The CPU processes data from both cameras, the IMU and the pressure sensor. With the help of the gathered data Vasa is able to interpret the surroundings and make decisions. The hardware used for the high level CPU is a mini-ITX from ASUS. The model is P8H67-I and it has been equipped with a core i3 2100T processor from Intel. In addition to this the system has 8GB DDR3 1333MHZ RAM as well as a Corsair 60GB SSD hard drive. Vasa is equipped with a desktop version of Ubuntu because previous implementation have been proven suitable for integrated systems. The design of the high level architecture is divided into five different parts. The different parts consists of separate threads within the system which allow the system fully utilize multi scheduling and use all of the CPU cores.

6.1.1 *State machine*

In order to organize and keep track of missions that will be carried out, a finite state machine has been implemented in the high level architecture. With a state machine the situation awareness is increased and the chances of completing missions are much higher. The implemented state machine will base its transmissions on real time data and past events. The state machine is shown in [Figure 14].

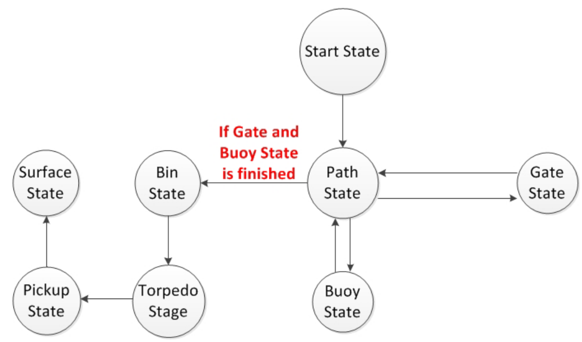

Fig. 14. Illustration of internal state machine.

6.2 Low level CPU's

The low level CPU's are microcontrollers (AT90CAN) from Atmel. These are used because they have support for CAN-bus communication and have enough computational power. All of the microcontrollers are connected to a CAN-bus which enabled communication between the nodes. Below is a short description of each card that the AUV is equipped with:

Router Card
This card is responsible for rerouting CAN-messages to a USB signal. It acts as a link between CAN and the high level CPU.

GPIO Card
The GPIO card is responsible for external modules such as sensors. At the current setup for Vasa, this card is equipped with an IMU and a Pressure sensor. It reads the sensors data and rearrange it into CAN-messages and then transmits them to the CAN-bus.

Solenoid Card
The Solenoid card is responsible for listening to

a set of CAN-messages controlling the solenoids. The card will activate the solenoids based on the type of the message . thus, when a solenoid is activated it can release a marker for example.

Power board
The power distribution board is designed to keep the system running at safe voltages. The corresponding software monitors input voltages and can turn of the power if it goes to high or to low. This is also the board that handles the killswitch of the system. When the attached hall effect sensor is exposed to an invalid magnetic field it will cut of power to the motor controller board. This is how the killswitch on Vasa works. It gives Vasa the ability to turn off the propulsion of Vasa quickly. This board is also equipped with a LCD which gives general information about the current level of the batteries.

Motor controller board
The Motor controller board is in charge of running each motor in a correct way. This card utilizes a PD-controller in order to stabilize the robot. There is also a fail safe system implemented for the CAN-bus. The motor controller periodically sends out an "I am alive" message and waits for a reply from high level CPU. If a reply is not revived, the motor controller board turns of all the motors aromatically.

6.3 Vision

The main goal of the vision system is to be able to detect and differentiate different kinds of objects using cameras. To complete the missions, Vasa has two cameras; one mounted forward and one downwards, [Fig.15].

The OpenCV library is used for image processing, which significantly reduces software development time. As previously mentioned, the main processing unit in Vasa is a mini-ITX board. This choice enabled the team to fully integrate a working platform for OpenCV development. The platform uses Ubuntu, Linux operating system which enables the OpenCV integration to be be easily implemented. A small example of a successful implementation can be seen in [Fig. 16] where it is shown how the detection of circles are done.

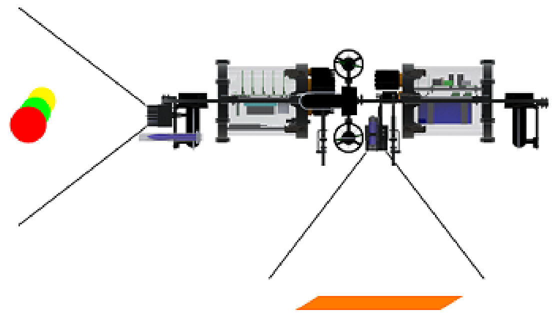

Fig. 15. Camera positioning and field of view.

This choice fully utilizes the possibilities and advantages of an up to date computer with a regular operating system without having restrictions on performance and reliability.

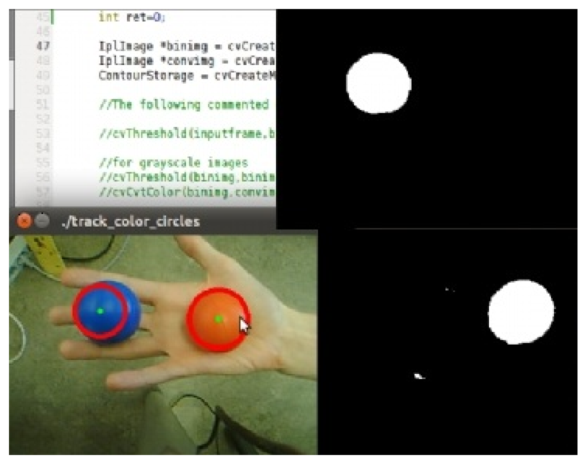

Fig. 16. Illustration of circle detection.

6.3.1 Cameras

As there are several aspects that needs to be considered before choosing a camera for an AUV, there where extensive research done behind the choice of Vasa's two cameras. As result of this Vasa got equipped with two Dragonfly2 cameras from Point Gray Research Inc., USA. It is a Firewire IEEE-1394a board level camera equipped with a FPGA circuit. It is constructed to provide full control and maximum flexibility for digital imaging. It has many functionalities, such as pre-processing, support for DC auto-iris and auto adjustment of image acquisition parameters along with sufficient and good documentation.

To enhance the quality of the images from the cameras and optimize the acquisition there are also a set of optics mounted on Vasa's camera modules. The optics that is mounted on the cameras are ”Computar - TG3Z2910FCS-IR”. It is a vari-focal lens which allows the focal length to vary between 2.9mm and 8.2mm. This is preferable when the suitable focal length is unknown for the application.

When the cameras are installed in the robot, the angle of view and depth of view is easy to adjust. One must remember that the depth of field is influenced by several factors. A smaller iris value closes the aperture which results in a larger depth of field and a camera with high resolution has a larger depth of field. in addition to the vari-focal feature the optics are equipped with a DC auto iris that is compatible with the Dragonfly2 camera. The optics are connected to the camera board through a 4-pin mini connector.

6.4 PD-controller

The robot uses a PD controller for balancing. The PD controller gets input from two nodes; A set point from the high level CPU and current sensor data from the sensor board. By combining the inputs a final adjustment value is achieved and used for controlling the motors.

6.5 CAN-bus system

CAN is implemented in Vasa because of its broadcast characteristics. Each node that is connected to the CAN-bus can at any time read from the bus and use any message that is currently on it. The system can also prioritize messages through the CAN-bus. This is a great advantage and can give a more efficient and reliable system. The CAN-bus system in Vasa is implemented in ADA as a previous robot constructed at Mälardalen University already had created a CAN-bus with working libraries and peripherals written in that language.

7 Conclusions

The members in the mechanical group has successfully constructed and finalized a good starting platform for the robot. This has made it easy to continue to work on and add new features and modifications due to its high level of modularity. The main reason for the success was because of a successful transition from a thoroughly designed SolidWorks CAD model into a real life robotic platform [Fig. 17].

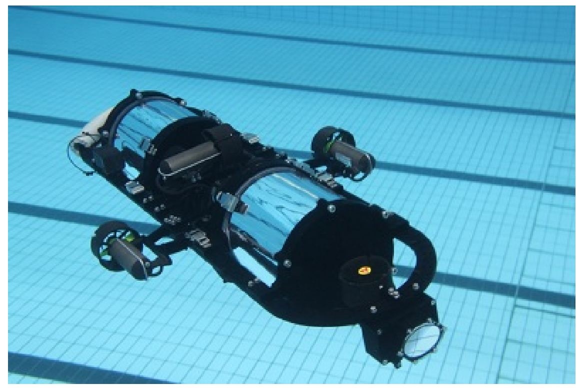

Fig. 17. Vasa during underwater test.

In addition to the mechanical group, there was also a team that was in charge of developing and constructing the onboard electronics in Vasa. This team has managed to reconstruct previously designed electronic boards with some additional features. These boards were given a new customized layout to fully fit within the mechanical design. All of the designed boards have a built in communication interface which have been tested with a successful outcome. In addition to these boards, there has also been a construction of a power distribution board, a backbone, a solenoid card and a hydrophone card for added functionality.

Finally there was the group responsible for the software of Vasa. The group has been doing extensive unit testing on all newly designed components to continuously verify the functionality of the electronics which were designed in parallel. A good achievement of the software team was the integration of the router-, GPIO-, and power distribution board. These boards have a great design to fully work together as a unit which communicates through our CAN bus system that had already been constructed and designed in beforehand the project started. In addition to this, software for the main cpu was developed, which included mission states and image processing.

8 Acknowledgments

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