FEFU/IMTP RoboSub 2019 Autonomous Underwater Vehicle

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Abstract—**The following paper describes the development of the AUV, which our team has prepared for RoboSub 2019. The main goal of developing the vehicle is participation in competitions, research and development of vision-based navigation and control methods, as well as research on group control methods. The paper describes and justifies our solutions in the development of a new vehicle, including its shape and materials, some software solutions and strategy.**

I. COMPETITION STRATEGY

Our team has been participating in RoboSub for last 7 years and each year we consistently reach the final stage of the competition. Each year we get new lessons in robotics development. We started to develop the vehicle from scratch thrice, including this year, given the experience of previous seven years of participation. Electronics, software and even mechanics design has been revised and upgraded.

Because of limited number of team members, we prefer the evolutionary path of development of the vehicle, wherein the only one part of the AUV is significantly changing at a time. This time we have kept the software design of the last year's vehicle. Our main achievement of this year is radically modified mechanics and electronics. This year we have completely migrated to new body and components.

Usually our team relied heavily on acoustic tasks because our acoustics is stable and reliable. However, tasks of this year require strong interaction with the environment through visual system and physical interaction. Both are highly untested, so in any case we have to follow a risky strategy.

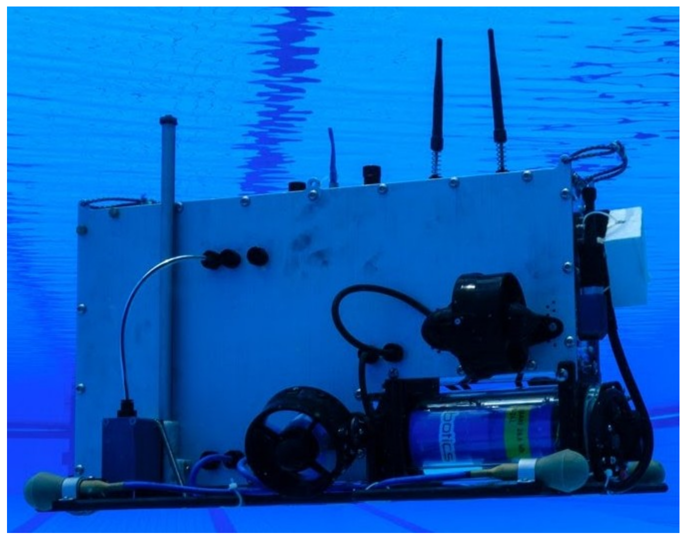

Fig. 1: Pandora. The battery at the bottom-down of the vehicle is easily removable, so when one is decharged, we replace it with another battery, charged during runs

Our vehicle is capable to grab metal items using a magnet located on the bottom side of the rigid retractable actuator (see vertical stick in the left side at fig. 1), and also it will have a grabber, so we will try to not ignore pickups this year.

Usually, on RoboSub we have a baseline and an extended plan. The baseline is titled ”vorotapinger” (literally, gate-pinger), it's well-tested and is simple as possible. We use it during setup runs to test the environment or at the moment of despair.

The extended strategy this year is following. First, we're going to flip a coin, go to gate and path through the 40% section with 180° style (we feel lucky). Next, we're going to slay a vampire. Since our vehicle does not have the precise feedback from the environment (e.g. DVL), from this moment we can not rely on the absolute values of the position of the vehicle. After that, go to drop garlic using path, drop a marker into any open bin and than go to one of the random pingers. On the Stake through Heart Pandora will just shoot the open oval. On Expose to Sunlight it will try to grab the Dracula.

II. VEHICLE DESIGN

A. General construction

Approximate dimensions of the vehicle are: $0.3 \times 0.5 \times 0.3$ meters, weight 15 kilos. We wanted to make the device as light and small as possible, so that one person could carry it, and so that it could fit into one suitcase. At the latest Singapore AUV Challenge we managed to win, never even having disassemble the vehicle.

The body of the vehicle is made of anodized aluminum, acrylic glass and plastic. The contour of the vehicle is made transparent for easy visual inspection. The larger vertical dimension of vehicle and low center of gravity provides it greater stability underwater. The insides of the vehicle are mostly hollow, thus it hardly needs additional buoyancy elements.

The electronics unit is a base made of aluminum. This base is large as possible to freely arrange the electronic components and use the base as a cooler. Electronics unit is easily accessible, we just need to unscrew 24 bolts to remove the side and access it. Special non-magnetic bolts used near the compass.

There are two vertical thrusters at the center-bottom and two horizontal at the center-back of the vehicle. Vertical thrusters are tilted at 45 degrees making possible stabilization along transverse axis. In combination with the effective shape of the vehicle, these thrusters can provide it high speed of movement, which can be useful at long distances, such as RoboSub final run.

On the upper side of the vehicle there are two toggles and kill-switch. One of the toggles is programmable and can be used to start a mission. There are also two antennas for 2.4kHz and 5kHz Wi-Fi access.

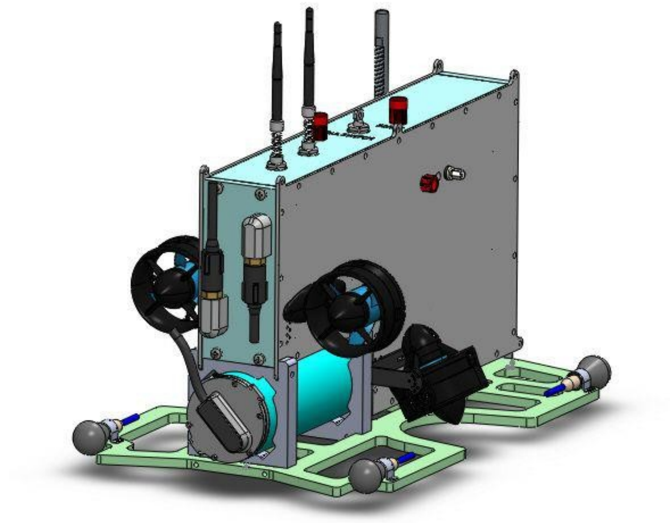

Fig. 2: Render of the vehicle. Even on the picture you can feel its lightness and stability

Actuators and hydrophones are attached to a firm polymeric frame at the bottom. Hydrophones are spaced at four opposite corners of the frame (see fig 2).

B. Acoustics

A new board has been developed for the processing of signals from hydrophones. It contains the FPGA Xilinx Zynq-7010. Compared to the previous board, the new one is smaller and has filtration and amplification functionality on it directly. Also, the advantage of this board is the ability to transmit a signal that will be then used for underwater communication.

To determine the location of the pinger, it is necessary to detect the start of the signal only on three hydrophones. If the signal is detected on all four hydrophones, then we can more accurately determine its position.

C. Actuators

Pandora is equipped with unique electromagnet-based system for torpedo shooting. It consists of 2 plastic tubes with electromagnet trigger. The main feature of the system is a torpedo itself. A torpedo

Fig. 3: A torpedo. A team member on the dock will have to manually spin and charge a torpedo between runs, which takes about 20 seconds for a trained person and a month for others

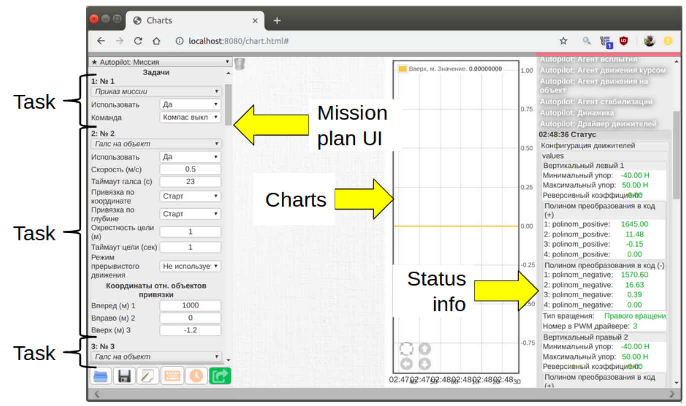

Fig. 4: Ground control

is made of two contacting 3D-printed spirals connected by an elastic band. The shape of a torpedo allows it to effectively move underwater keeping it safe on air. The only problem is it takes a long time to charge a torpedo (see fig. 3).

Also we equipped the vehicle with a system for dropping cargoes based on electromagnets. It can carry three balls at the same time and is designed to be able to dump one load at a time (previous versions dropped everything at once).

All actuators are located next to the corresponding cameras to work effectively with computer vision.

D. Software

1) Mission node: This year we re-implemented the mission node trying to keep backward compatibility with older missions but focusing on the extensibility of new architecture. The node is designed to deal with uncertainty of the underwater environment, buggy hardware and stressful nature of competitions.

As before, a mission consists of separate tasks, each of which can use objects detected during mission execution. Now tasks can be exetuted not only in linear sequence, but as consequence of a specific event or condition, making possible conditional or even asynchronous jumps in a task sequence.

Also, mission writers have ability to combine and bring compound functionality to low-level modules (agents) and easily re-use it in different missions.

2) Web GUI: We are proud of our web interface console used to visualize data and messages in real time. It can plot the numerical values over time and can be used to send commands to the vehicle through a web page which may be accessed through every device with Wi-Fi and browser. We used it on smartphones in RoboSub 2017 when all laptops in the team refused to connect to the vehicle. The web console is one of the most useful tools for us. On the figure 4 you may see a typical example of the web interface usage.

3) Video module: The video system consists of two stereo cameras – front and bottom. We use Stereolabs ZED stereo cameras that can provide a depth map. The depth map allows us to determine the distance to different objects, which allows us to improve the accuracy of the robot's navigation. We use two NVIDIA Jetson TX2 with J120 carrier board. Each stereo camera is connected to one of two computers. These computers have a graphics processor that allows us to use neural networks for recognition and other video camera features, such as depth mapping and simultaneous localization and mapping (SLAM).

The software part of the video system consists of a camera driver and a recognition module. The driver uses the camera's API to capture images and depth maps from cameras. The recognition module uses various computer vision algorithms to recognize objects and recalculate their coordinates for the navigation module.

The main method of object detection is the use of convolutional neural networks. According to the test results, the Single Shot Detector MobileNet V2 demonstrates the best ratio of accuracy and performance. This neural network is based on Inception architecture. SSD MobileNet V2 demonstrates 12-15 FPS on Nvidia Jetson TX2. To improve the performance of the model, we changed the image size to 400x300 pixels. Tensorflow C++ API is used as a backend for evaluating the convolutional neural network model.

Also, traditional recognition algorithms are used for object detection. These algorithms can be used when we need to know the angle of rotation of the object. These are such algorithms as Hough transform, binarization, hsv classification, gradients. Image histogram equalization is used as preprocessing for this class of object detection algorithms.

III. EXPERIMENTAL RESULTS

One of the most essential parts of preparation is testing in the swimming pool. This process is necessary to detect hardware failures, produce some components setup and detect unexpected bugs.

We began testing in the pool in the middle of February in the swimming pool of FEFU campus to prepare for Singapore AUV Challenge (SAUVC). In total, we spent about 60 hours of training in the pool and at the competitions themselves. During these tests we found a lot of mistakes and problems in our new vehicle.

We had problems with acoustics noise when using new thrusters, so we had to add special movement mode to the software. We also ordered another ESC to reduce noise and change its frequency, but we probably will not get them to Robosub.

Another problem detected is the unstable I2C operation for the depth sensor and actuators. And the most unstable work was at the final run of the SAUVC. To solve this problem, the electronic circuit of connection was improved.

And in early June, we started pool tests to prepare for the Robosub.

ACKNOWLEDGMENT

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APPENDIX A: EXPECATIONS

Subjective Measures			
	Maximum Points	Expected Points	Points Scored
Utility of team website	50	20	
Technical Merit (from journal paper)	150	150	
Written Style (from journal paper)	50	50	
Capability for Autonomous Behavior (static judging)	100	100	
Creativity in System Design (static judging)	100	100	
Team Uniform (static judging)	10	10	
Team Video	50	50	
Pre-Qualifying Video	100	100	
Discretionary points (static judging)	40	40	
Total	650	620	
Performance Measures			
	Maximum Points		
Weight	See Table 1 / Vehicle	95.4	
Marker/Torpedo over weight or size by <10%	minus 500 / marker	0	
Gate: Pass through	100	100	
Gate: Maintain fixed heading	150	100	
Gate: Coin Flip	300	300	
Gate: Pass through 60% section	200	0	
Gate: Pass through 40% section	400	400	
Gate: Style	+100 (8x max)	200	
Collect Pickup: Crucifix, Garlic	400 / object	0	
Follow the Path (2 total)	100 / segment	400	
Slay Vampires: Any, Called	300, 600	600	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	1400	
Drop Garlic: Move Arm	400	0	
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	1600	
Stake through Heart: Move lever	400	0	
Stake through Heart: Bonus - Cover Oval, Sm Heart	500	0	
Expose to Sunlight: Surface in Area	1000	1000	
Expose to Sunlight: Surface with object	400 / object	400	
Expose to Sunlight: Open coffin	400	0	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)	0	
Random Pinger first task	500	500	
Random Pinger second task	1500	1500	
Inter-vehicle Communication	1000	0	
Finish the mission with T minutes	Tx100	600	

APPENDIX B: COMPONENT SPECIFICATIONS

Component	Vendor	Model/Type	Specs	Cost (if new)
Frame	In-house	Plastic		
Waterproof Housing	In-house	Acrylic glass and aluminum		
Waterproof Connectors	SubConn	Circular series	Depth rating PEEK: 300 bar, 4,350 psi	
Thrusters	Blue Robotics	T200	Max thrust: 5.1 kg f Max power: 350 Watts	$169
Motor Control	Blue Robotics	Basic ESC	7-26 volts, 30 amps, PWM	$25
Propellers	Blue Robotics	Stock		
Battery	Blue Robotics	BATTERY-LI-4S-18AH-R1	14.8V, 18Ah	
CPU	NVIDIA	Jetson TX2	Dual-Core NVIDIA Denver 2 Quad-Core ARM Cortex-A57	$479
Internal Comm Network		Ethernet	1000 Mbps	
External Comm Interface		Ethernet	100 Mbps tether or Wi-Fi	
Programming Language	C++			
Compass/IMU	VectorNav	VN-100	800 Hz	
Fiber Optic Gyroscope	Fizoptika	VG103	Input range: 190 deg/s Bias stability: 1 deg/h	
Camera(s)	Stereolabs	ZED	Stereo camera 2K, USB3.0 Depth range: 0.5-20m	$449
Hydrophones	Aquarian	AS-1	Linear range: 1Hz-100kHz $\pm$2dB	$395
Algorithms: vision	OpenCV Team, Tensorflow team	OpenCV 3, Tensorflow 1.12	Transparent GPU Support	
Algorithms: acoustics	In-house		Signal delay, FFT, Hilbert transform	
Algorithms: localization and mapping	In-house	Kalman filter	Control system	
Algorithms: autonomy	In-house	IPC	Multiprocessing	
Team size	13			

HW/SW expertise ratio	1:2			
Testing time: simulation	30			
Testing time: in-water	80			