Autonomous Underwater Vehicles for the 2019 RoboSub Competition

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Abstract This year, we are bringing two new robots made by "HEU-AUV" to the game. There two robots share the same name "Zhongkui", a name from a monster-catcher of Chinese legend.

There are two main technology improvements this year. The first one is the end to end underwater simulator, and the second one is the acoustic communication system.

Our team consists of a visual group, a software group, a hardware group, a mechanic group, a navigation group，a sonar group, and this structure makes the team highly efficient.

I. COMPETITION STRATEGY

Firstly, we analyzed the problems we met during the past competition through the final run video， several problems were aroused.

1. Time was not enough for finishing all the competition tasks.
2. When robot worked near to the bottom of the pool or the wall, DR navigation system, which was made by integrated DVL and INS, would have a problem made by invalid DVL value.
3. Spent so much time on finding logistics mistake on software in the pool-testing time.

For the first problem, we decided to make the second robot.

For the second problem,we have to develop a robust navigation method.

For the third problem, we built an end to end underwater simulator, it was a good idea for debugging logistic problems.

We divided the tasks into two categories, one includes the tasks which we had a clear way to achieve so that we don't have to spend much time on the technology. The others are challenging problems like mechanical and acoustic strategy, the algorithm of vision servo, and the robust detection algorithm.

So on the one hand, some of us were concentrating on the basic mechanical frame, PID control algorithm, USBL system and so on, and the rest of us were trying to find an effective method from the paper to solve the challenge problem.

We had spent about three months discussing the method of solving these key technical goals:

1，Acoustic communication system.

2，New navigation algorithm.

3，Underwater simulator.

And with these goals reached, finishing all the tasks will be possible.

"Zhongkui", our new robot can achieve 6 degrees of motions with eight brushless motors. And they were equipped with the navigation system and acoustic communication system, which can help the robots achieve communication with each other, thus two robots can work together.

NVIDIA platform Jetson Xavier is chosen as a core computer, it has a much better performance than Jetson Tx2 we used last year.

Figure 1: Jetson Xavier

The program runs under the ROS software framework. To complete the visual servo task, There are two stereo cameras, one for the front view and the other one for the downward view, helping obtain information like the location of the target.

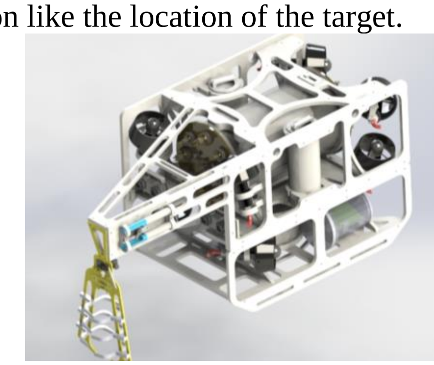

Figure 1: Zhongkui

II. VEHICLE DESIGN

A. End to end simulator

The simulation environment is developed on the "uuvSimulator"[1]. As we know, Ros is based on distributed networks. Therefore, we can do the simulation on multi-platforms. A computer is in charge of simulating and generating sensor information, which includes information from the camera image, DVL, INS, USBL, depth sensor.

First, we analyzed gravity and moment of inertia from SolidWorks. we adopt EKF to estimate the dynamic model of AUV[2], add the unknown dynamic parameters into the state vector, such as mass and current damping parameters. After running the EKF, we can get hydrodynamic parameters. Then bring the parameters to the classic underwater dynamic model raise by TI Fossen[3].

After updating the dynamic model parameters on simulation, the robot will run like real underwater scene. The simulation made by the software is quite similar to the actual pool.

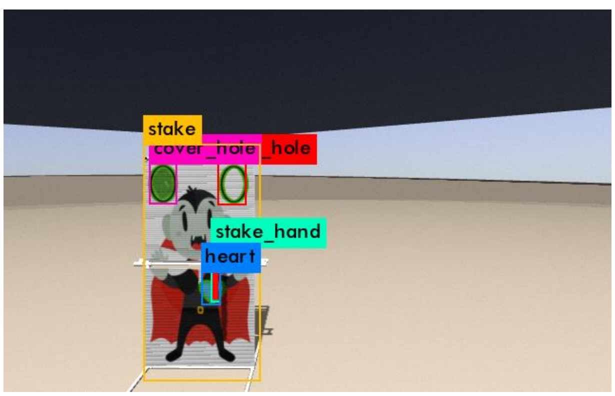

Figure3: Image of front camera

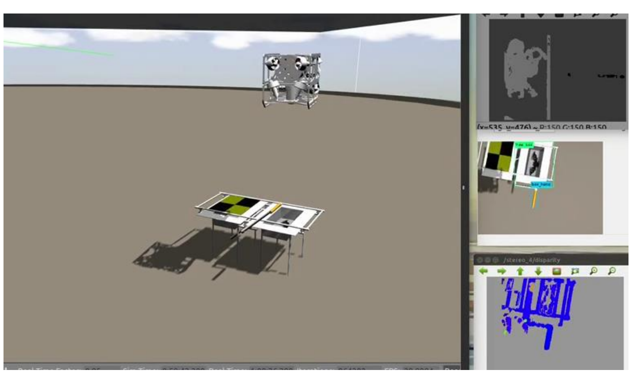

Figure4: open the cover box

B. VIO/DVL/INS/Dynamic model based navigation system

To overcome the navigation problem deliver by DVL (DVL will output some ambitious value sometimes). We attempt to add information from the stereo VIO to our system.

The loose-couple VIO[4] outputs odometry result, and we do subtraction to get velocity.

Besides, Inspired by the other team's navigation algorithm, we also tried to combine the dynamic model with DR navigation. We used the hybrid EKF[5]on X and Y direction of robots.

Using estimated standard deviation through residual, PauTa Criterion is adopted to detect the ambitious value of DVL and Differential of VIO.

C. USBL system

USBL's Software has no big update. We just designed new waterproof warehouse and new electronic system for USBL.

Figure 5 : USBL system electronic board

Figure 6: USBL system

D. acoustics communication system

We try to use two robot for finish more work on limited time. So this year we develop an inertia communication for multi vehicle.

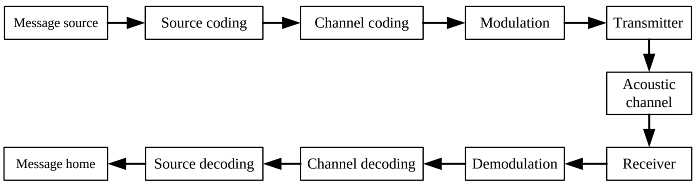

Figure 7: Physical system block diagram of underwater acoustic communication

In the Fig 7, the "Message source" is the data to be sent. "Source coding" is the process that removes the redundancy of the message. "Channel coding" is the process that adds the redundancy of the message and improves the ability to correct errors. We use linear block codes. "Modulation" is the process that adds the coded data to the carrier signal.

We use BFSK and QFSK modulation."Transmitter" realizes the conversion of electric energy to acoustic energy. "Acoustic channel" is the physical space of sound wave propagation; it is a time-varying system. When the acoustic signal passes through the system, the waveform will be distorted, which is mainly caused by multipath effect. So, after the "Receiver" realizes the conversion of acoustic energy to electric energy, we use adaptive filters for channel equalization, that is, to eliminate multipath effects. In the "Demodulation", we use FFT for incoherent demodulation. Than we use linear block codes to decode and get the right message finally.

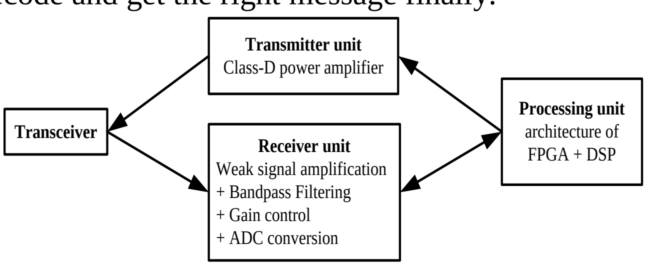

Figure 8: Hardware scheme of underwater acoustic communication system

Fig 8 is the hardware scheme of underwater acoustic communication system.

Fig. 8 and 9 are physical objects. We use transceiver transducer, so it is a half duplex system.

Figure 9: Physical diagram of transceiver transducer

Figure 10: Physical drawing of circuit board

In the horizontal direction, it is non-directional; in the vertical direction, it has an open angle of 30 degrees. The transmitter unit is a class-D power amplifier; it provides about 70 watts of power and 180dB sound source level. The receiver unit is consist of amplifier, band pass filters, gain control and ADC convertor. The processing unit is consist of FPGA and DSP. The functions of signal acquisition, gain control, transmission signal modulation and real-time matched filtering are realized by FPGA. DSP implements data encoding, data receiving from the FPGA, real-time detection of valid data framses, adaptive channel equalization, real-time FFT demodulation, data decoding, automatic gain control, data storage and other functions.

E. PID control system with statistic and dynamic compensation

We didn't pick LQR or SFB for control method, since PID with some compensation seems powerful enough.

Besides the force generated by thruster, robots also suffer current damping force and restoring force. When we use traditional PID, they can be regarded as distribution. These can make the attitude control loop unstable or shake, or even a big constant error. For this reason, we did some feedforward with the model. The dynamic model can be directly applied to compensate to those[6].

After compensation, the robot can keep the balance from any roll and pitch. At the same time, the path track error will be reduced.

III. Experimental Result

We test our acoustic communication system in lake, our transducer can achieve stable communication with the distance more than 300 meters.

Figure 11: acoustic communication system

With same parameters, we find we can adopt the software on simulator directly to real robot. It's really a good way to reduce pool test time.

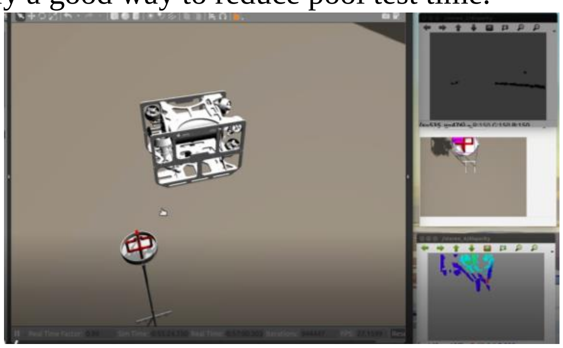

Figure 12: acoustic communication system

As show on figure13 DVL's ambitious value point out by round make no influence to navigation system .

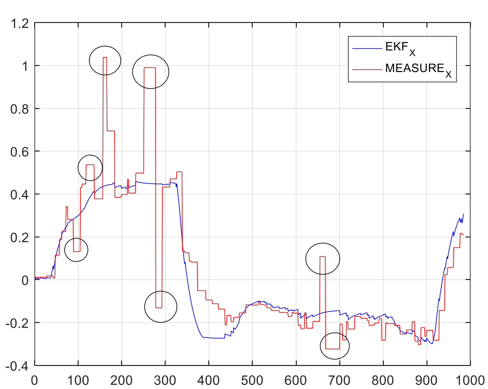

Figure 13: DVL's ambitious value detection

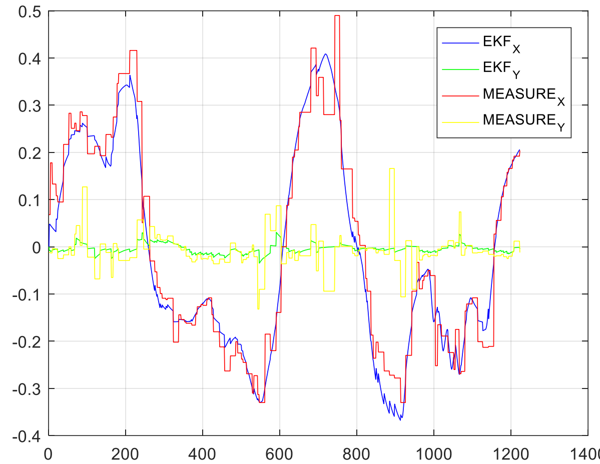

Figure 14: EKF result and origin data

As shown on Figure 14 ,we finish the EKF on STM32 platform. EKF's result is more smooth than origin data, it means our control loop's gain can be higher, this we support an higher control accuracy.

IV. Reference

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[6] Yuh, J. , Ura, T. , & Bekey, G. A. . (1996). Underwater robots. Underwater Robots. Springer US.

AppendixA: Component Specifications

Component	Vendor	Model/type	specs	Cost(dollar)
Buoyancy Control				
Frame		plastic		
Waterproof Housing		5pin 3pin		100
Waterproof Connectors		5pin 3pin		100
Thrusters			Made by my ourselves	100
Motor control		PID		
propellers		Trifolium pulp		
Actuator		brushless motor		
Battery	GESHI	Lipo 5000mah		
Converter				
Regulator	Hobbywing	35A/brushless		
CPU	NVIDIA	Jetson Xavier		
Inernal Comm Network		CAN USART Internet usb		
External Comm Innterface		Internet		
Programming Language 1		C++		
Programming Language 2		python		
Compass		RM3100		1
IMU		Fiber gyro		8000
DVL	Naviquest	NQ 600 Micro DVL		10000
Camera		stereo camera		200
Hydrophones		CS-3B		1500
Manipulator				
Algorithms :vision		Yolov3 dehaze stereomatching semantic segmentation line detection		
Algorithms:acoustics		FFT		
Algorithms:localization and mapping		Viodom EKF		
Algorithms:autonomy		PID		
Open source software		UUVsimulator YOLOv3 Viodom		
Team size		15		
HW/SW expertise ratio		1:2		
Testing time :simulation		100h		
Testing time:in water		1200h		