Design, Development and Control of an Autonomous Underwater Robot "Poo-Pang" for Thai Navy Military

Thip Pasawang[1] and Theerayuth Chatchanayuenyong[2,*]

[1] Roi Et Technical College, Tambon Nai Mueang, Amphoe Mueang Roi Et, Roi Et, Thailand

[2] Faculty of Engineering, Mahasarakham University, Kham Riang, Kantarawichai, Maha Sarakham, Thailand

jds_phe@hotmail.com and theerayuth.c@gmail.com

Abstract. *Autonomous Underwater Robots (AURs), nowadays, play an important role in many applications, in particularly, the military projects. Design and development of most AURs in the military projects of Royal Thai Navy in the past would be based only on unsystematic, self-concept or ideas, which could lead to unsatisfactory results when implemented. This paper presents design, development and control of the "Poo-Pang" AUR to serve three proposes of Thai navy military project; (1) underwater survey under to conserve the environment and underwater resources, (2) military diving training, and (3) inspection of underwater ship structures to find any water leakages. The robot was developed using technical design parameters obtained from the Quality Function Deployment (QFD) design method. A prototype robot was constructed and tested with the conventional PID control. The experimental results showed that the constructed robot could operate and meet the 3 requirements of the project.*

Keywords:

Autonomous Underwater Robots, quality function deployment, QFD, design and development

1. Introduction

An autonomous underwater robots (AURs) have various potential applications including science, environment, ocean mining, oil industry and military tasks [1]. Most designs and developments of AURs published in the literature have been done using the self-concept or idea as found in [2]-[5]. Even if the design concepts are simple but with unsystematic design and development might lead to unsatisfactory robots. In turn, the design technique based on the user's preferences and requirements called Quality Function Deployment (QFD) presented in [6]-[8] would provide better results. Some implemented robots based on the QFD design would be one with the two mechanical robots by Koyarem [9] and a plant nursing robot by Sorensen [10].

This paper proposes the design, development and control of the "Poo-Pang" AUR (Poo-Pang is the name of the crab which could be found only at Maha Sarakham province in the Northeastern region of Thailand). The proposed robot was designed using the QFD technique to serve Thai military tasks. The development of the Poo-Pang AUR utilizes the transformation of information from the users' requirements to the technical design parameters and with the parameters obtained, the robot prototype was constructed using the conventional proportional-integral-derivative (PID) control. The experiment results show its capability to serve the missions.

The explanation of the design, development and control of the Poo-Pang AUR is arranged by in Section 2, the design concepts and principles are explained. Section 3 describes the development procedure for the AUR while Section 4 shows the overall system configuration of the robot prototype. Lastly, the control algorithms, which were used for the robot were tested and summarized.

2. Design Concepts and Principles

The proposed Poo-Pang AUR was developed to meet the 3 missions required by the Royal Thai Navy Military as follows:

(1) to underwater survey under the annual plan in order to conserve the environment and underwater resources

(2) to cooperate with military diving training

(3) to inspect the underwater ships to find any water leakages.

The technical design parameters obtained from the QFD method, which was performed step by step as briefly described in [10] and parameters given in Table 1, were used to develop the Poo-Pang AUR.

3. Robot Development

The Poo-Pang robot was developed based on the expected technical parameters in Table 1; which were grouped into four systems: mechanical, sensor, computing and power supply system, details of each system are as follows:

Table 1: Mapping between design and expected technical parameters from QFD design method

Item	Design Parameters	Expected Technical Parameters
1	AutonomousControlAlgorithm	Conventional PID and intelligent control
2	LowCostController	Micro-controller
3	DepthSensor	Pressure sensor
4	CompassSensor&VerticalGyroscop	Compass sensor, vertical gyroscope
5	UltrasonicSensor	Fish finder sonar sensor
6	PowerSupplyManagement	Three power supply modules; controller power supply, sensor power supply and motor driver power supply modules
7	SmallOverallSize	Not bigger than 120x120x120 cm
8	10-meterRobotStructure	Aluminium alloy
9	RemoteCableOperate	0.9 mm^2 4-cores Cable
10	GraphicUserInterface	Visual basic
11	UseResistanceToCorrosionMaterial	Aluminium alloy
12	UnderwaterLights	Tungsten halogen lamp
13	LowEnergyConsumption	Low energy consumption controller, sensor and motor driver
14	EquippedWithThrusterGuards	Aluminium thruster guards
15	MainPowerSafetySwitch	Safety switch
16	OpenFrameStructureDesign	Aluminium open frame structure
17	AdjustableBuoyancyComponents	Equipped with buoyancy components, e.g. pressurizable plastic tube, foam
18	ConfigurationDesign	3-D Balancing shape designed with SolidWorks
19	UnderwaterCamera	Digital camera installed inside pressurized hull
20	RemoteRadioControl	Not installed, since it is not practical when the robot is underwater.
21	SelfBuoyancySystemDesign	Buoyancy force > gravitational force design
22	EquippedWithEyebolts&Transport Wheel	Eyebolts and transport wheels
23	UseRechargeableBattery	Use rechargeable battery
24	DetailPowerDistributionPlanning	Three power supply modules; controller power supply, sensor power supply and motor driver power supply modules
25	UseStrongButLightWeightMaterial	Aluminium alloy
26	CommunicationSystemDesign	RS232 cable
27	UseCleanEnergy	Use rechargeable battery
28	UseLowNoiseElectricMotor	Electric trolling motor
29	RemoteSurveillanceDesign	Signal sending via RS232 cable
30	PressureHull	Pressurized robot hull
31	BeautifulHullFormDesign	Balancing-shape hull form designed with Solidworks
32	EquipmentModuleDesign	Equipments designed in modules and connected to one another via connectors

3.1 Mechanical System

3.1.1 Faring

The Poo-Pang robot was designed using solid-works to have a balancing hull form, having the physical structure as shown in Fig. 1. The overall size of the robot was relatively small with width, length and height of 85cm, 90cm and 85cm, respectively. The core body of the robot was made from aluminum alloy, which had light weight and could resist to the corrosion when operating underwater. The control unit (microprocessors and its auxiliaries), the sensors and the motor control boards were installed at the upper part of the robot as depicted in Fig. 2 while the battery packs were installed on the lowest part. By making the location of the batteries to be at the lowest position as much as possible, lower the metacentric height and increase the righting moment of the vehicle, the robot became more stable in both pitch and roll directions. The two tungsten halogen lamps were equipped in front of the robot to give the illumination when surveying underwater. The robot was designed to have an open-frame feature, which could facilitate the access and adaptation if additional or some parts would be required to be upgraded or replaced to support various research or applications when operating in the underwater environment. A high resolution digital camera was also installed behind the clear glass of the robot hull to record the underwater photos for the survey.

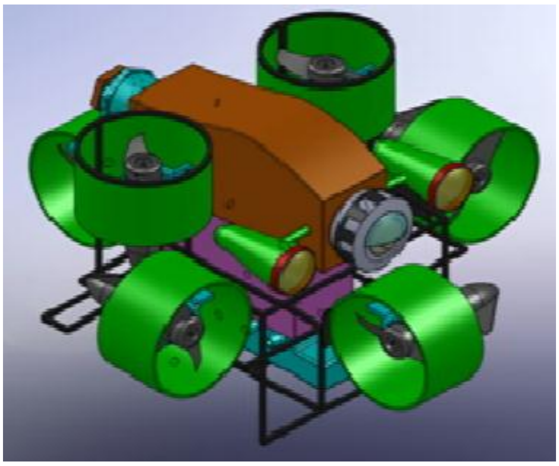

Fig. 1: Physical photograph of the proposed Poo-Pang AUR

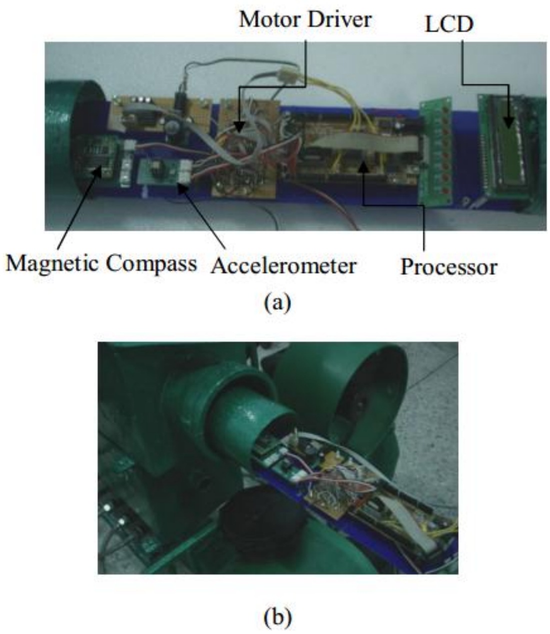

Fig. 2: Control unit, sensors and motor control boards of the Poo-Pang AUR: (a) overall lay-out and (b) installed positions

3.1.2 Thrusters

The proposed Poo-Pang AUR prototype consisted of 6 thrusters as shown in Fig. 1. The thrusters were installed at the positions that allowed the robot to move in the six-degrees of freedom: roll, pitch, yaw, surge, sway and heave. These thrusters were modified from the Minnkota Classic 28, 12V electric trolling motors with the 9-inch diameter propellers; where each of the thrusters has the weight of approximately 28 pounds. The thrusters were fitted with custom O-ring seals for freeing the movement while each of the 6 motors was shrouded with the cylindrical guard for protecting the motor from unexpected components from outside, as well as, for the safety purpose, which had the feature as shown in Fig. 3.

Fig. 3: thruster of the Poo-Pang AUR modified from the trolling motor

3.2 Sensor Systems

3.2.1 Accelerometer

The Accelerometer model aMG-IMU-9A was used to provide the proper roll/pitch/yaw angular setting and three-axis linear accelerations via the I2C interface. The North-East-Down (NED) body-frame Euler angle (roll, pitch and yaw angles) could also be computed using the Direction Cosine Matrix (DCM) method.

3.2.2 Compass Module

A CMPS03 compass module was used to provide the heading angle of the robot via the I2C interface. The compass had an accuracy of 3-4 degrees with resolution of 0.1 degrees.

3.2.3 Depth Sensor

The depth of the robot when in water could be inferred from hydrostatic pressure measurement by using the pressure transducer; having relationship as expressed by the equation (1)

$$P_G = \rho g h \quad (1)$$

Where P_G is the gauge pressure

ρ is the water density in kg/m³. (ρ = 1,000 kg/ m³ for fresh water)

g is the gravitational acceleration (9.806 m/ s²)

h is depth from water surface in meter

An E8EB-01C (Omron) pressure transducer was used to provide the gauge pressure of the water. The transducer had a range of 0 to 100 kPa with ±3% accuracy FS, which was converted to the linear output range of 1-5V. According to this accuracy, the depth of water could be measured with resolution of 30 cm from the maximum 10-meter depth.

3.3 Computing Systems

The proposed Poo-Pang AUR was designed to operate autonomously and dynamically; hence, all the computing systems were embedded.

3.3.1 Main Processor

The main processor used in the project was selected to have relatively but having adequate ability to process the competence for all the computing units: simultaneous filtering, sensor data acquisition and servo control. A Fio-board (Aimagin) was therefore selected. The board had a powerful microcontroller with ARM 32-bits Cortex TM-M3 Processor (STM32F103RET6) with 16 channels of 12-bit, 1μs ADC, 2 channels of 12-bit DAC, 5 USART, 2 I2C, 4 general purpose 16-bits timers with 4 PWM per timer and 1 USB 2.0 full speed interface. The board could be programmed and edited directly via the Matlab/Simulink.

3.3.2 Thruster driver boards

To drive the thrusters, six individual driver boards (San Electronic) were used. The boards generated the PWM outputs to vary speed of the motors continuously in a large variation range; from stop to full forward and from stop to full reverse. The boards required 80 amps rated at 12-48V. The microcontroller generated a command signal via the PWM outputs that were sent to the corresponding driver boards to control the thrusters' speed and direction.

3.4 Power Supply Systems

The robot carried a water-proof battery box with 3 sealed, lead-acid batteries (12V, 12Ah, 432Wh) onboard that provided power for the thrusters and all the electrical devices. All electrical devices had their own protecting fuses. There are 3 sub-power supply systems: controller power supply system, sensor power supply system and motor power supply system. the overall schematic diagram of the robot's power distribution is show in Fig.4.

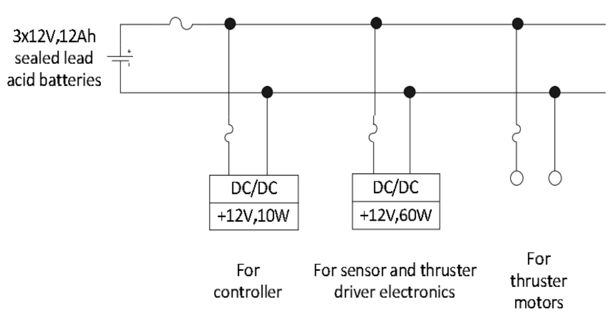

Fig. 4: Overall schematic diagram of the power supply systems of the Poo-Pang AUR

4. Overall Configuration

The overall configuration of the Poo-Pang robot and the completed robot prototype were illustrated in Fig. 5 and 6, respectively.

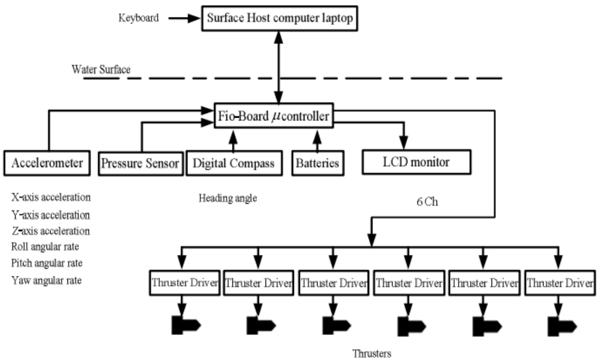

Fig. 5: Overall configuration of the Poo-Pang robot

Fig. 6: Completed prototype of the Poo-Pang robot

5. Robot Servo Motor Control

The conventional PID controller that had the general transfer function described by Equation (2) and the control block diagram shown in Fig. 7 was used to control the heading of the robot prototype.

$$G(s) = \frac{u(s)}{e(s)} = K_P(1 + \frac{1}{T_I s} + T_D s) \qquad (2)$$

; where K_P is the proportional gain

T_I is the integral time

T_D is the derivative time

$u(s)$ is the controller output

$e(s)$ is the error, which calculated from the difference between the actual and desired heading angle

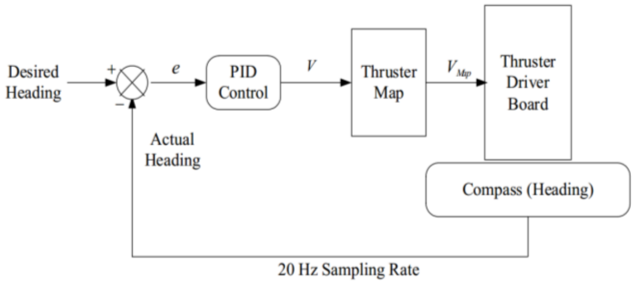

Fig. 7: Heading control block diagram of the Poo-Pang robot

All of the PID parameters were primarily determined by Ziegler and Nichols tuning rule and then were fine-tuned to obtain the satisfactory responses. The final parameters suitable for the control are given in Table 2. Fig. 8 shows the simulated circuit using the Matlab/Simulink program which gave the results shown in Fig. 9.

Table 2: the final values of the PID parameters

K_P	T_I	T_D
3.72	1.125	0.281

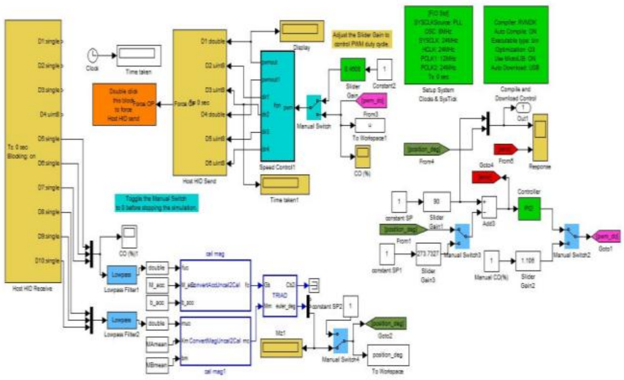

Fig. 8: Simulated circuit using Matlab/Simulink program

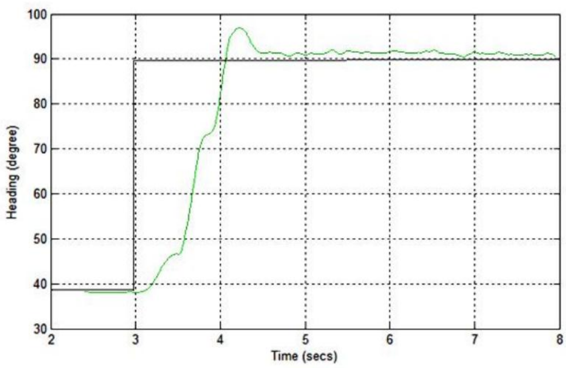

Fig. 9: Some simulated results obtained from the simulated circuit shown in Fig.8

From the above result shown in Fig.9, the designed PID controller could lead the robot's heading to the setting point at 90 degrees with acceptable damping response, settling time less than 1 second with only small errors (less than 2 degrees).

6. Conclusions

The autonomous underwater robot named "Poo-Pang" has been designed and developed according to the design parameters obtained from the QFD method. The robot prototype could be controlled simply using only a conventional PID controller while allowed the robot to be an open-frame robot that could be equipped with various types of devices and sensors. The robot could be used to meet the missions and requirements of the Royal Thai Navy Military.

Acknowledgement

The authors would like to express our sincere gratitude to the Royal Thai Naval Research and Development Office who facilitated the research project and provided all the essential information from the users. The authors would also like to express our sincere appreciation to Energy Policy and Planning Office (EPPO) of Thailand and Mahasarakham University, Thailand, for the financial support of this research.

References

[1] YUH J., Design and Control of Autonomous Underwater Robots: A Survey, *Kluwer Academic Publishers, Autonomous Robots*, Vol.8, 2000, pp. 7-24.

[2] BUESHER B.J., CHANG W., and et. al, *Autonomous Underwater Vehicle, Cornell University*, 2002.

[3] ALTSHULER R.C., ATKINS S.S., and et. al, ORCA-II: An Improved Autonomous University Vehicle, *Massachusetts Institute of Technology (MIT)*, 2002.

[4] LIN X. and GUE S., Development of a Spherical Underwater Robot Equipped with Multiple Vectored Water-Jet-Based Thrusters, *Journal of Intelligent & Robotic Systems*, Vol.67, issue 3-4, 2012, pp.307-321.

[5] TAKEMITSU T., OGURA M., and et. al, System Design and Increment Hardware Development of an Autonomous Underwater Robot "DaryaBird", *AUVSI&ONR's 14th Robosub Competition Journal*, 2011, pp.1-8.

[6] AKAO Y., Quality Function Deployment: Integrating Customer Requirements into Product Design, *Productivity Press*, Cambridge, MA, 1990.

[7] AKAO Y., Quality Function Deployment: Integrating Customer Requirements into Product Design, *Productivity Press*, Cambridge, MA, 1990.

[8] CHAN L.K., A systematic approach to quality function deployment with a full illustrative example, *Omega*, Vol.33, No.2, 2005, pp.119–139.

[9] KORAYEM M.H. and IRAVANI A., Improvement of 3P and 6R mechanical robots reliability and quality applying FMEA and QFD approaches, Robotics and Computer-Integrated Manufacturing, Vol.24, 2008, pp. 472– 487.

[10] SØRENSEN C.G., JØRGENSEN R.N., and et. al, Conceptual and user-centric design guidelines for a plant nursing robot, *bio-systems engineering*, Vol.105, No.1, 2009, pp. 1–11.

Biography

Thip Pasawang received his High Vocational Diploma-Telecommunication from Roi Et Technical College, Thailand in 1992. He received his master degree in Industrial Education Program in Electrical Engineering from King Mongkut's University of Technology Thonburi (KMUTT) in 2002 and his PhD in Mechanical Engineering from Mahasarakham University, Thailand in 2014. He is currently a lecturer at Roiet Technical College, Thailand. His research interests include Telecommunication electronics, Embedded System, Intelligent control and Autonomous underwater robot.

Theerayuth Chatchanayuenyong received his bachelor degree (Honors) in Electrical Engineering from Prince of Songkhla University, Thailand in 1989. He received his master degree in Electrical Engineering from Khon Kaen University, Thailand in 2001 and his PhD in Mechatronics Engineering from Asian Institute of Technology (AIT), Thailand, in 2006. He is currently an Assistant Professor at the Faculty of Engineering and a Vice President for General Management, Mahasarakham University, Thailand. His research interests include Series Active filter, Dynamic voltage restorer, Robust and intelligent control and Autonomous underwater robot.