Development of the 'ThaiXPole' Underwater Robot
for the Antarctica Exploration

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Abstract - **Researchers around the world are increasingly interested in South Pole explorations. However, the extreme weather and geographical conditions, and the difficulty in transportation between other parts of the world and the South Pole territories make many aspects of the South Pole remain unknown and require further investigations. Thailand has a great opportunity to send a marine scientist to explore the South Pole region in collaboration with other world-class scientists. To reduce the risks for a scientist under these extreme conditions and to increase the capability in exploring and acquiring data (such as investigating a site and planning a path for underwater exploration before human exploration), development of the ThaiXPole underwater robotic system for the South Pole exploration project was established. This paper describes the design, construction, experiments and results of a service robot, 'ThaiXPole underwater robot,' prior to being sent to assist the research scientist in exploring the coast of Antarctica.**

I. INTRODUCTION

A. Project Background, Constraints and Goal

Background – Currently, worldwide researchers are increasingly interested in South Pole explorations. However, the extreme weather and geographical conditions, and the difficulty in transportation between other parts of the world and the South Pole territories make many aspects of the South Pole remain unknown and requiring further investigations. Thailand is also a country, among only few countries, that is interested in South Pole exploration. Thailand has a great opportunity to send a marine scientist to explore the South Pole region in collaboration with other world-class scientists. The scientist's mission is to study marine life in shallow-water near the Antarctic coast. Fig. 1 shows a sample image of interesting marine life. To reduce the risks to a scientist under these extreme conditions, and to increase the capability in exploring and acquiring data (such as investigating a site and planning a path for underwater exploration before the human exploration) many institutes in Thailand have realized the importance of the research into and development of an underwater robotic system to assist the Thai scientist in this exploration.

Constraints – The South Pole exploration research is to be conducted near the research facility, "Syowa Station," located on the coast of Antarctica (see the location in Fig. 2) from December 2004 to March 2005. The ThaiXPole underwater robotic system is to be operated by a Thai marine biologist who may not be capable of any engineering maintenance, and may only have a few assistants during robot operation. Moreover, the extreme weather and geographical conditions, and the difficulty in transportation and communication between the research site and the mainland, make a number of constraints for designing the ThaiXPole.

Goal – The robot development goal is, therefore, to develop a truly robust underwater system that is capable of acquiring and sending real-time motion pictures and all sensing data to researchers and operators on the ground surface. The robot should be as lightweight as possible for benefiting the local transferring from the research facility to the diving site. All components on-board must remain functioning at the low-temperatures. The controlling system should not depend on complicate micro-processors which have a great risk of failure under such low-temperature conditions. Our solution is to utilize only basic components, e.g. a mechanical relay circuitry system.

The constraints and our design solutions lead us to a great benefit in the budget of developing the ThaiXPole robot. The total budget is less than 10,000 USD which may make the ThaiXPole the least expensive underwater robot used in the real world.

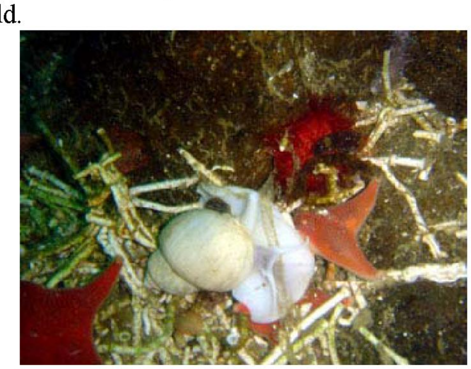

Fig. 1. A sample image of shallow-water marine life from Antarctic.

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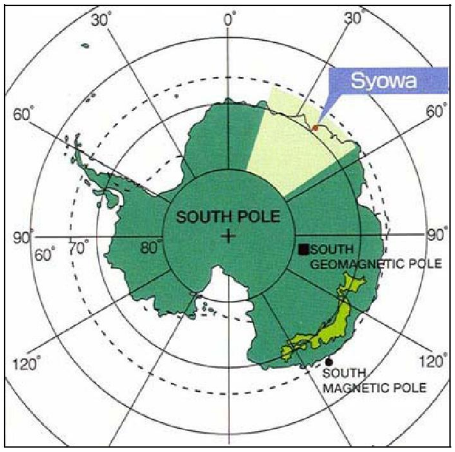

Fig. 2. Map shows the location of Syowa Station on the Antarctica.

B. Literature Review and Overview of the ThaiXPole Underwater Robot

Most undersea operations performed by commercial remotely operated vehicles (ROVs). However, research on developing underwater robot and related technology has increased interest among robotic researchers. Whitcomb discussed a number of underwater research robots being used in the real world (see [1] and reference therein.) Jason and Argo II underwater robots were examples of this kind. Their undersea surveying near by a shipwreck site was reported in [2]. Regarding related technology, an example was a study and development of control architecture done by Ura *et al.* [3]. The control architecture was using distributed behavior technique. The developed system was a multi-agent system which consisted of a pair of autonomous underwater robots, an ultrasonic positing system, and a human diver. The navigation system for an autonomous underwater robot was also an interesting topic for UW robot researcher. Uliana *et al.* [4] discussed a robust navigation system to estimate the robot's heading and position. A measurement of acceleration, rotation rate, and velocity was performed. The optimal integration of inertial and velocity measurement was accomplished by using a Kalman filter for correcting the effect of the biases of the inertial sensors by exploiting a velocity measurement.

Similar research was done by Bono *et al.* [5 – 6]. A number of high-end underwater robots were developed and experimented in the Antarctica region. The robots acquired oceanographic data, which the missions were different to the presented mission here. The ThaiXPole underwater robotic system is a remote-controlled underwater mobile robot. The robot structure/frame is made of Aluminum Alloy 6061 for lightweight and corrosion-resisting reasons. The robot's driving system consists of three thrusters: left, right and level. The robot's controlling system is a mechanical relay circuitry system installed in a water-resistant and temperature-controlled compartment. The robot is also equipped with an underwater video camera and a set of water quality sensors for sensing water temperature, pressure, Dissolved Oxygen, pH and saltiness of water. The robot operators and researchers are able to control and acquire motion pictures and all sensing data in real-time through a connecting cord system, 100 meters in length. The robot is designed to dive to a maximum depth of 50 meters with a radius of 25 meters. The range covers the depth which researchers would be interested in for planning diving exploration.

In subsequent sections of this paper, we report the design, control systems, experiments and results of the ThaiXPole underwater robotic system. Section 2 and 3 discuss the robot design, driving system, control system, and on-board equipped sensor system. Section 4 reports experiments and results which caused many changes in robot design. We then conclude in Section 5.

II. MECHANICAL DESIGN

The ThaiXPole robot's design has been improved and changed from version to version consequent to the experimental results until the final design. We will discuss the design improvements in Section 4. This section is to discuss the final design of the robot, and is separated into two subsections; mechanical structure and driving system.

A. Mechanical Structure

This subsection presents designs and descriptions of the frame structure, component installations, and flotation system.

A.1 Frame Structure

The ThaiXPole robot structure is made of Aluminum Alloy rods welded to be a rectangular frame system. The structure dimensions are 90 cm X 120 cm X 45 cm (Width X Length X Height.) The material, Aluminum Alloy 6061, is selected because of its high strength, light weight and great corrosion resisting properties. All robot components are installed inside the structure to protect against any damage from collisions. The structure is designed as a frame system to reduce the drag force from the water stream.

A.2 Component Installation

The major robot components are: 1) driving system, e.g. left, right and level thrusters, 2) control circuitry and controller compartment, 3) water quality sensor, and 4) underwater video camera and lighting system. The driving system is installed as follows: the left and right thrusters are located near the middle part of the robot, while the level thruster is located at the top-center of the robot. (See Fig. 3 for the thruster installations.) The control circuitry is installed inside a water-resistant and temperature-controlled compartment. The compartment is located near the level thruster for weight balancing reasons. The water quality sensor has a long-cylindrical shape which is tied to the robot frame in the rear section. The underwater video camera and lighting system are installed in the robot's front section. The video camera is contained in a water-resistant housing, set on a ball-head camera support. Two water-resistant lights are installed near the video camera. Fig. 4 illustrates the installations of video camera and lighting system.

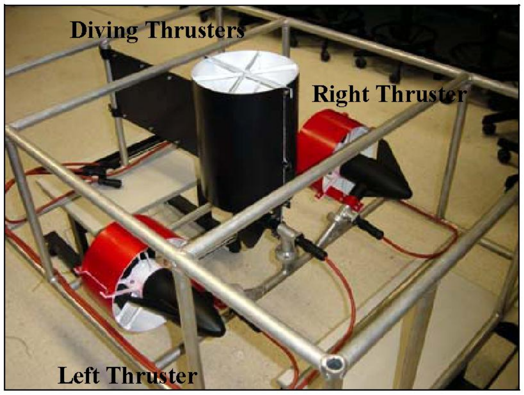

Fig. 3. Thruster installations

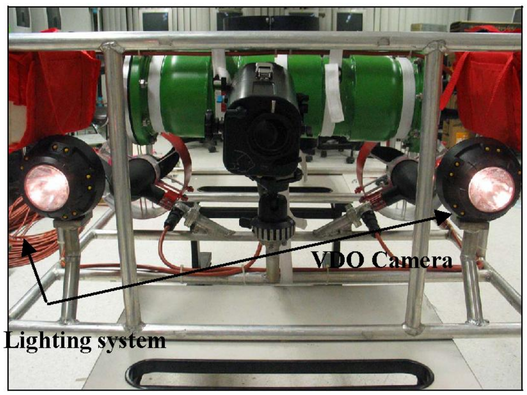

Fig. 4. Installations of VDO camera and lighting system

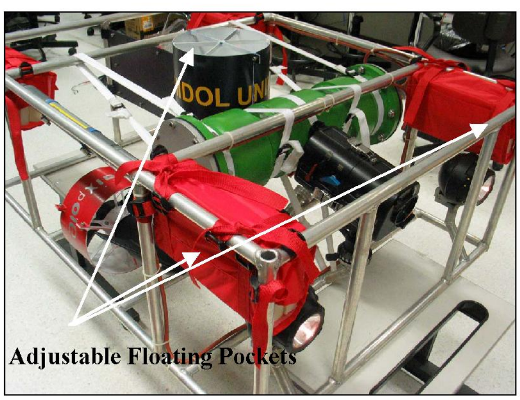

Fig. 5. Image shows robot's frame structure and adjustable floating pockets

A.3 Flotation System

The flotation system of the ThaiXPole robot consists of four adjustable pockets containing poly-urethane (PU) foam sheets. Each pocket is located at a robot's top corner. Adjustable floating pockets are shown in Fig. 5. The buoyancy force of the robot is calibrated to be equal to robot weight. The adjustable floating pockets are designed to allow the robot operator to adjust the robot density to suit any water density. This is because we are concerned that the density of sea water in the Antarctic Ocean may be greatly different from our testing areas. The volume of the controller compartment also affects the robot's buoyancy.

B. Driving System and Robot Operations

The driving system of the robot consists of three thrusters: left, right and level, as shown in Fig. 3. Each thruster is composed of a commercial water-proof electrical motor attached to a propeller and hood. The selected commercial propeller set is Minnkota Endura 30. We have modified the Minnkota set and attached it to our designed aluminum alloy hood. The robot motion in each direction is done by sequence controlling each thruster. To move the robot in forward direction, both left and right thrusters are operated to push the robot in the same direction; vice versa to moving in the rear direction. To turn the robot to the left or right hand, only the left or right thruster is operated. To adjust the altitude of the robot, the level thruster is operated in the upward or downward direction. Fig. 6(a) – (f) show thrusters operating in each direction.

III. CONTROL, SENSOR, NAVIGATION AND POWER SYSTEMS

The ThaiXPole robot has a mission to aid a marine biologist in exploring an Antarctic region which has an extraordinary low-temperature condition. Therefore, our electronic system is specifically designed to handle the situation. This section describes the control, sensor, power and connecting system of the ThaiXPole robot.

A. Robot Control System

The robot has three actuators, which are left, right and level thrusters to manipulate robot motions. The robot's operator can control the robot movement by using a remote controller wired to an on-board controlling system. Our solution to handle the low-temperature condition is not to use any microcontroller and complicated electronic circuit which may have a great risk of failure under such a condition. Therefore, the on-board thruster controller is designed to use a mechanical relay circuitry, should have instead of regular electronic system. The circuitry is installed on a long and narrow platform to be inserted into a cylindrical control compartment. (See Fig. 7 for the circuitry and its compartment.) The diagram of the robot's control architecture and communication system is shown in Fig. 8.

The remote-controller connects to the on-board controlling system via a water-resistant connecting cord system. Water-resistant plugs are used at the connecting port of the controller compartment. (See Fig. 9, 10 for the remote-controller and connecting cord system.)

B. Water Quality Sensor and Navigation System

We use a commercial water quality sensor, YSI 600XL made by YSI Incorporated Company. The YSI 600XL is a sensing and logging system which detects the water temperature, pH, Dissolved Oxygen, salinity and pressure. The sensor has a long-cylindrical shape which is quite easy to be installed on-board. Since the ThaiXPole is a shallow-water exploring robot, and because of many other reasons, such as environmental constraints, budget, mission, etc., the ThaiXPole has no other navigation system installed on-board. The robot navigating depends on real-time monitoring video images from underwater video camera, and water surface observation. Fig. 11 shows monitoring video image from a night experiment.

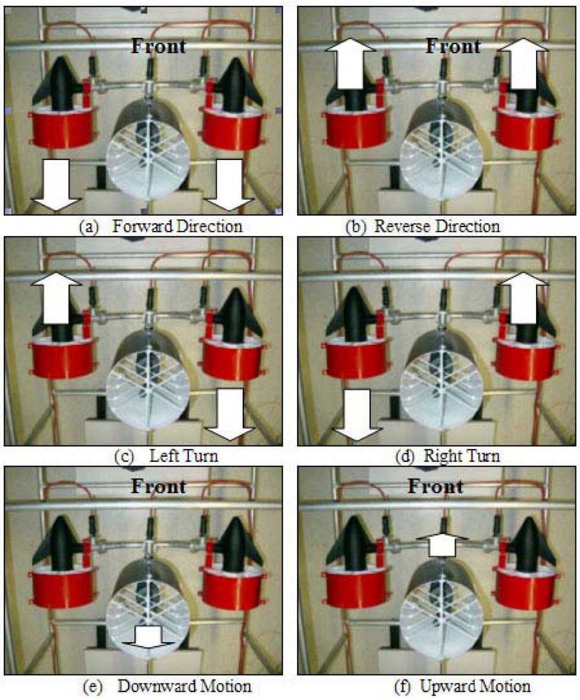

Fig. 6. Left and right thruster operation

C. Power System

The robot power source is a battery which is set on a ground station. The power is relayed via the connecting cord system. The system requires 12 VDC and 24 VDC; where the remote controller and relay circuitry require 12 VDC power, and each thruster requires 24 VDC driving power. The on-site power source is a set of series-connected paired 12 VDC batteries. The battery set is charged and stores the electrical power from a solar-panel system made by a collaborated organization in this project, the National Electronics and Computer Technology Center of Thailand. Fig 12 shows the solar-panel system to be used as an on-site battery charger.

IV. EXPERIMENTS AND RESULTS

The ThaiXPole robot has been developed from version to version by adapting the designs from several experimental results. This section is seprated into 3 subsections ; preliminary, experimetas, experiments in swimming and diving pools. his section is separated into 3 subsections; preliminary experiments, experiments in swimming and diving pools, and experiments in the open sea.

A. Preliminary Experiments

Preliminary experiments include component testing, robot weight/buoyancy balancing, sealing, water-resistant testing and components' low-temp testing. After developed each component and its controller, each individual part was tested. One of the most important experiments is to study, plan and prove the calculation of how to balance the weight and buoyancy force. The experimental results caused us to make a major change in controller compartment dimensions. Fig. 13 illustrates an underwater image of an experiment to test a thruster performance. We have to re-arrange the components' installation on-board. The test was done in a shallow pool in the campus. Each sealing and water-resistant material was tested to guarantee their performances. Since the robot was designed to operate in extraordinary cold weather, low-temp tests were performed in all components with a high risk of failure in low-temperature.

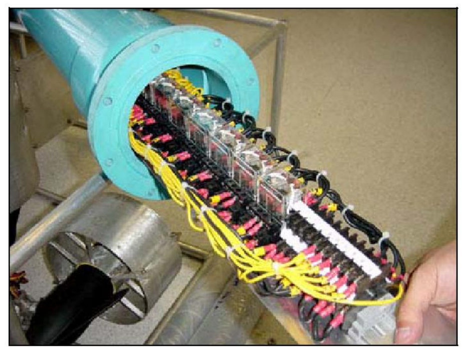

Fig. 7. Mechanical Relay Circuitry and Its Compartment

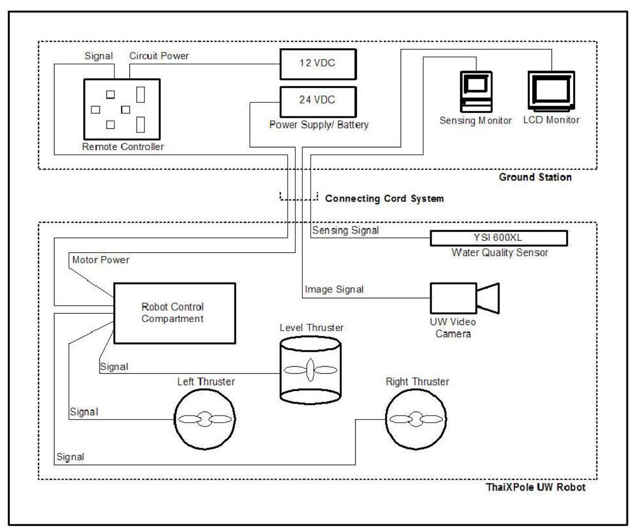

Fig. 8. Diagram of The ThaiXPole Control System and Communications

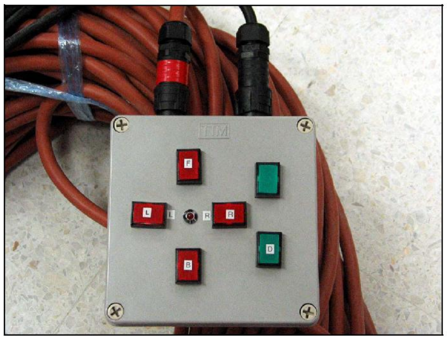

Fig. 9. Home-made Remote Controller

Fig. 10. Water-Resistant Connecting System

Fig. 11. Underwater motion Images from Underwater Video Camera

Fig. 12. Solar-Panel System (On-Site Robot Battery Charger)

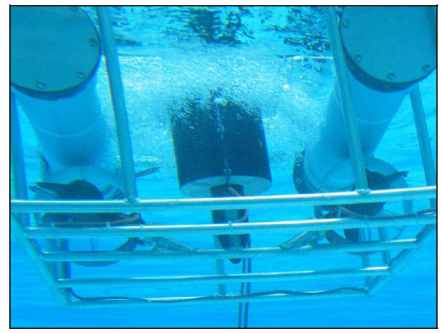

Fig. 13. An underwater image of thruster performance testing

B. Experiments in Swimming and Diving Pools for Motion Observations

This subsection discusses an experiment set in a 1.80m depth swimming pool and 7.00m depth diving pool. The set of experiments was to observe robot motions. In an early design, the robot was covered with a multi-pocket flotation sheet on the robot's upper part. Each pocket was designed to hold a small piece of PU-foam. Therefore, we could be able to adjust the buoyancy force of the robot to suit with *a small change* of water density from each test's site. We found that the upward/downward motions were not properly performing. This was because of the great drag force produced from the shape of flotation sheet. Nonetheless, other motions (forward, backward, left and right turns) were tested, and the results were high satisfactory. The design of flotation system was changed from using a multi-pocket flotation sheet to cornered flotation pocket in the final design.

Other performed experiments were to test the acquiring, sending, receiving and monitoring system of real-time motion pictures and all sensing data. The results shown the systems were working properly under regular operations. Fig. 14 (a) – (d) illustrates underwater images from the experiments.

C. Experiments and Results in the Open Sea

The experiments in an open sea were performed to test the robot operations in real-world conditions. The tests were done near a coast in the Gulf of Thailand. During the test, the sea conditions were medium rough. The wave and water current were quite strong. The experimental result shown the ThaiXPole UW robot was able to operate in such condition with no problem. Fig. 15 illustrates an underwater image from the experiment.

V. CONCLUSION

This paper described a unique project of a true service robot, ThaiXPole underwater robot. The project background, design and development, control system and experimental results were presented. The ThaiXPole UW robot was developed to assist a Thai marine biologist to perform his exploring research in the South Pole region. The robot was a remote-controlled underwater robot capable of working under extra low-temperatures condition, and the robot risk of failure was carefully minimized for the operator's benefits in such extreme conditions. Fig. 16 and 17 illustrate the robot package to be sent to the research site in the Antarctica, and the final version of the ThaiXPole UW robot, respectively.

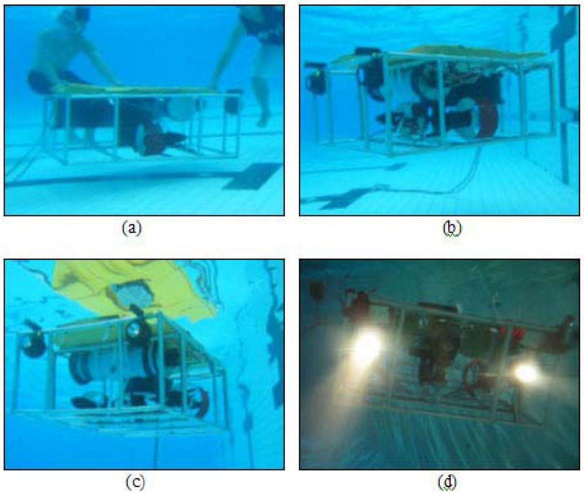

Fig. 14. Underwater images from experiments in 1.80m depth swimming pool and 7m depth diving pool: (a) and (b) show images from horizontal motion tests, (c) shows an image from a vertical motion test, and (d) shows an image from free motion test.

Fig. 15. An underwater image from the open-sea experiment.

Fig. 16. The robot package was sent to Antarctic Research.

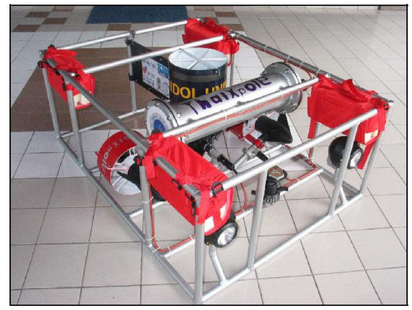

Fig. 17. The final version of the ThaiXPole underwater robot

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