THE THESIS OF DOCTOR OF PHILOSOPHY

Study on a Novel Water-jet-based Father-son Spherical Underwater Robotic System

Chunfeng Yue

Graduate School of Engineering
Kagawa University

Abstract

In order to realize underwater intervention in a narrow and cluttered environment, the conceptual of water-jet based father-son spherical underwater robotic system is proposed. The father robot takes the son robot is actuated by a vectored water-jet propulsion system. The son robot and provide power for the son robot. The son robot takes in charge of underwater manipulation.

In this thesis, several important problems have been dealt with. First, the kinematics and dynamics model are established. Then, we introduce the mechanical design for the father robot, and static analysis is carried out for the propulsion system. We design a launching structure for the son robot which is located on the bottom of the father robot. And, we design and discuss the mechanical structure for the son robot which is actuated by IPMC. The electrical system contains hardware and software of the robotic system is designed. In order to verify the hydrodynamic parameters and investigate the interaction between the robot and fluid, hydrodynamic analysis is carried out for the spherical underwater robot and thruster respectively. Finally, a series underwater experiment is designed to evaluate the performance of the proposed underwater robotic system.

II Study on a Novel Water-jet-based Father-son Spherical Underwater Robotic System

Contents

List of Tables

List of Figures

Acknowledgements

The author would like to express his most sincere appreciation and thanks to his supervisor, Professor Shuxiang Guo, for his invaluable guidance, insight, support, and friendly encouragement throughout the research in his Ph.D. course, and for providing him with first class resources. The author appreciates his supervisor not only for his guidance on the author's research, but also the great encouragement and help on the author's life.

The author would like to extend his special thanks to his thesis committee members, Prof. Hirata and Prof. Suzuki. Thank them for their valuable advice and suggestion on his research, which is vital to the accomplishment of this thesis. The author has improved the thesis greatly with their suggestions and advice.

The author would like to thank Kagawa University for offering this PhD position. And thanks to the Kuraoka Shogakukai Foundation ((公財)倉岡奨学会) and Mitsubishi Corporation (三菱商事株式会社), Japan, for providing scholarship, which make the author has time to focus on his research.

The author would like to record his gratitude to the following people and funs:

Also, the author would like to express his thanks to his friends

Xichuan Lin, Liwei Shi, Zhibin Song, Nan Xiao, Juan Du, Zixin Zhao and Baofeng Gao for their advices on his research. The author wishes to extend his thanks to his group members Yaxin Li, Maoxun Li, Kazuhiro Yamashita for their active ideas and hard work. The author would like to acknowledge the efforts of all his laboratory members.

Last but not least, the author gives special appreciation to his parents and girlfriend for their love, patience and support.

Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Chapter 1

Introduction

1.1 Thesis Scope

Underwater environment and underwater creature is mysterious. With the booming development of ocean scientific exploitation, researchers are eager to realize more and more underwater interventions. Therefore, unmanned underwater vehicles (UUVs) are developed rapidly due to their ability to access deep, dangerous, and confined areas unattainable by divers. Generally, the UUVs can be divided in two categories: Remotely-operated Vehicle (ROVs) and Autonomous Underwater Vehicle (AUVs). ROVs are unoccupied, highly maneuverable, and operated by a human operator. ROVs are linked to the ship by an umbilical cable. The umbilical cable contains a group of electrical conductors and fiber optics that carry electrical power, video, and data signals between the operator and the tether management system. Due to the tether, mother ship and human operator, the cost is really high and the operation range is limited by the length of tether. An autonomous underwater vehicle (AUV) is a robot which travels underwater without requiring input from an operator [2].

Without human operator, tether and mother ship, AUVs finish the given task by itself. They always involve various underwater sensors i.e. compasses, depth sensors, sonars, magnetometers, thermistors, conductivity probes and Inertial Measurement Unit (IMU) to realize underwater navigation, data collection, and strategic decision. Different applications require different shapes, and sizes of AUVs.

Due to the central symmetry, spherical objects always performance high stability and flexibility. Spherical robots can realize rotational motion with a 0 degree turn radius. Therefore, many researchers involved in this research topic and developed many spherical underwater robot. ODIN-III was a typical prototype robot developed at the University of Hawaii [3, 4]. The metal hull with a diameter of 630 mm resisted water pressure. The propulsion system with 8 screw propellers installed outside the body provided propulsive forces. This spherical underwater robot was used to monitor the environment and underwater operations. It used a high accuracy IMU to realize attitude measurement. Besides the large size spherical underwater robot, University of Manchester and Oxford University co-developed a micro-spherical underwater robot to monitor nuclear storage ponds [5-8]. The micro robot installed six propellers around the equator as its propulsion system. The diameter of this robot was only 150mm. Therefore, a MEMS gyroscope was used to measure the angle in yaw direction. These two robots equipped propellers on the outside of their bodies for their propulsion systems. Besides propeller, tunnel thrusters are also favored by the researchers who have high requirements on the propeller. Du et al. developed a spherical underwater robot with water-jet thrusters [9, 10]. But the propulsive force of the thrusters was considerably reduced because the pipeline was curved. All of these spherical underwater robots cannot adjust attitude in pitch and roll direction actively. Lan et al. at the Beijing University of Post and Telecommunications developed a spherical underwater robot that is only actuated by one tunnel propeller [11]. Based on a movable weight-balancing block, the attitude control was realized.

An excellent AUV for a given task always mentioned different technology, from mechanics to electronics, and from material science to hydrodynamics. Especially, the design of the mechanical structure affects the hydrodynamic characteristics largely. AUVs are widely used in military, industrial and scientific research. These applications always mention two functions for the AUVs, monitoring and underwater manipulation. Especially, underwater manipulation is very difficult and favorite. Usually, manipulators are designed according to the given task. The most common underwater manipulator is a multi-DOFs gripper which is actuated by motor, pneumatic or hydraulic system.

Nature is a perfect model for a robot. With the evolution in over billions of years, underwater creatures have succeeded in creating a fantastic variety of structures using an enormous amount of resources.

During the long evolution history, they have evolved lots of locomotion to adapt environments. For example, swimming, flapping, floating, and sinking motions are most common locomotion. Also there are some assistant motions such as sucking, clasping, ejecting, and grasping, which are used to feed and protect themselves. A biomimetic robot has two advantages for underwater monitoring and manipulation. First, it can realize underwater motion by imitating the creature. Second, it is easier to be accepted by the underwater creature rather than a strange shape and high noise robot. So, in this thesis, we will intend to realize underwater manipulation for a spherical underwater robot by a biomimetic robot.

1.2 Literature Review

Based on function, we can divide AUV into two categories. The first kind of AUVs is for high speed. It usually owns streamline shapes and propeller thrusters due to the excellent hydrodynamic characteristics [12]. Torpedo AUVs can be used in high speed survey and mapping. The typical commercial product contains Bluefin-12 by Bluefin Robotics Corporation [13], Hugin 1000 by Kongsberg Maritime [14], ARCS by International Submarine Engineering [15], and so on. The second kind of AUVs are for given task, such as environment monitoring, hull inspection for huge ship [16]. This kind of AUVs does not require high-speed and long-distance movement. But for a high quality on video data, stability and flexibility are essential requirements. Also, the shape of the AUV is designed by the custom requirement. All of these commercial products are big and costly. Of course, employer not satisfied with only underwater observation, but with underwater operation and manipulation.

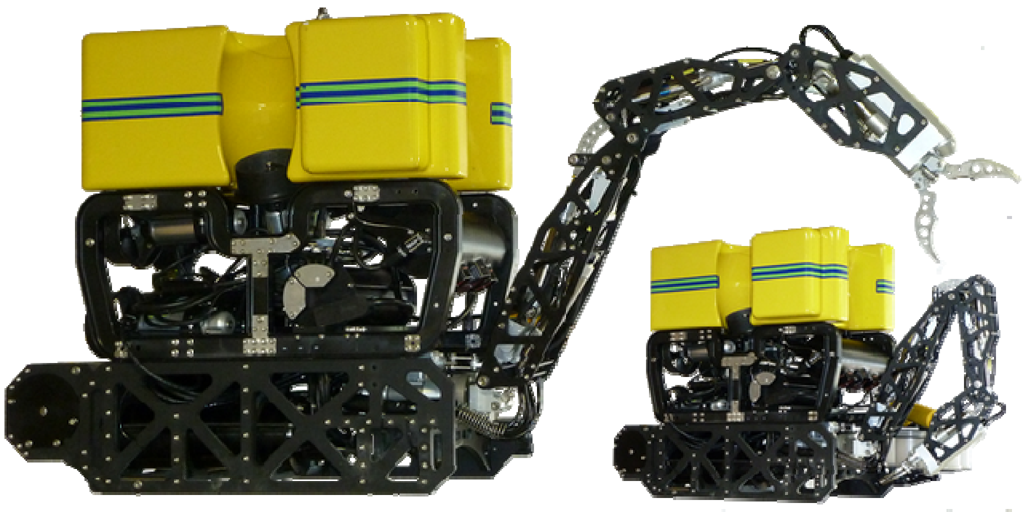

Figure 1-1 SEAMOR ROV (7F-H-ARM) [19]

For a traditional method, we always stall a mechanical arm on a ROV and send the control command by the tether [17-18]. Figure 1-1 shows a traditional underwater manipulation configuration which is developed in SEAMOR Marine Ltd. 2014 [19]. But, due to the advantages of AUVs, more and more researchers are eager to realize underwater interventions by AUVs. One of the first AUV which can realize underwater intervention has been developed in the University of Hawaii and named SAUVIM [20, 21].

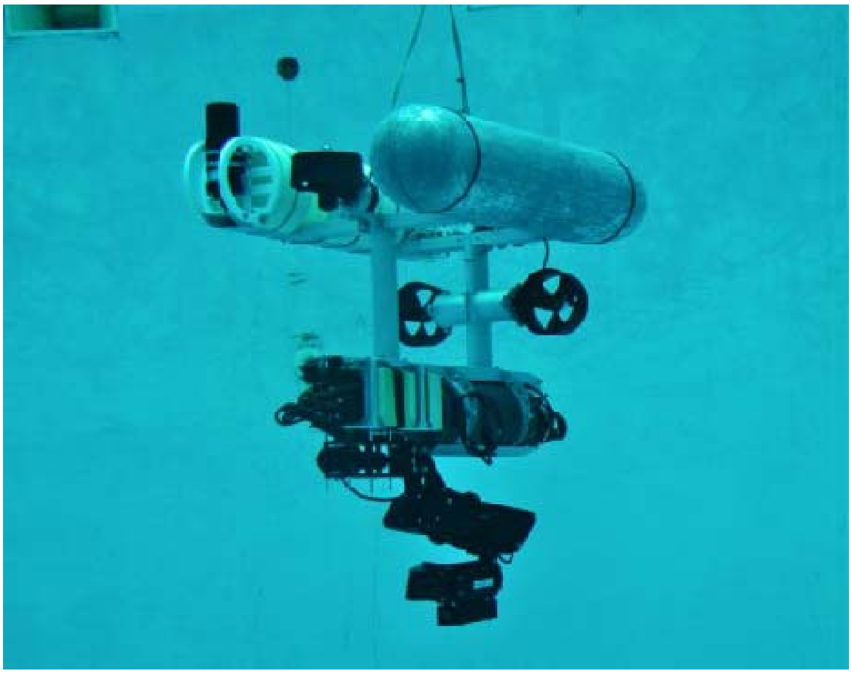

Figure 1-2 Reconfigurable AUV for Intervention mission (RAUVI)

Prof. Pedro J. Sanz (University Jaume I), Pere Ridao (University of Girona) and Gabriel Oliver (Universitat de les Illes Balears) proposed a reconfigurable AUV for Intervention missions (RAUVI) which can realize underwater object searching and manipulation [22, 23]. The prototype is shown in Figure 1-2. In this research, the researchers realized a simulation for intervention mission. It is suspected that the weapon used in a crime has been thrown to the sea. The mission is to find the weapon and recover it. In the Pohang University of Science And Technology (POSTECH), the researchers designed and developed a smart cable to drive an agent vehicle which takes a manipulator. A streamline AUV is adopted as the mother ship for the agent vehicle [24].

Figure 1-3 ALIVE autonomous Light Intervention vehicle by Cybernetix

There also have some commercial products have been developed successfully. As shown in figure 1-3, the engineers in Cybernetix developed an AUV for underwater intervention which is named ALIVE [25]. ALIVE is an Autonomous Underwater Vehicle capable of performing light interventions on deepwater subsea facilities without the requirement for a dedicated DP Support Vessel. The vehicle features a dynamic positioning system, autodocking capability and is equipped with a 7 function manipulator for light interventions.

All of these robots own the same features. They employed a mechanical arm to realize underwater manipulation. Hence, the application fields were industrial area. Usually, the mechanical arm was heave, expensive and high payload. The robots calculated the posture and position to complete the underwater manipulation tasks [26, 27]. These methods almost do not consider the environment effect causing by the robot, e.g. the motor noise, disturbance causing by propulsion system. However, these factors are very important for underwater creature monitoring and underwater manipulation in such environment.

In our laboratory, Dr. Lin proposed the first generation spherical underwater robot (SUR) which is actuated by 3 vectored water-jet thrusters [28-33]. This robot can realize 3 DOF motion. Dr. Lin analyzed the dynamic model for the propulsion system. He has made great achievements on the development of the SUR. But the SUR also has some problems. First, due to the passive attitude stabilization in roll and pitch, the author ignored these two parameters, only considered the yaw attitude. But the pitch and roll attitudes are also very important for adjusting the stability. Second, the stiffness of propulsion system should be improved. Finally, the robot has 3 holes on the hull. These holes are ignored when the author analyzed the hydrodynamic characteristics.

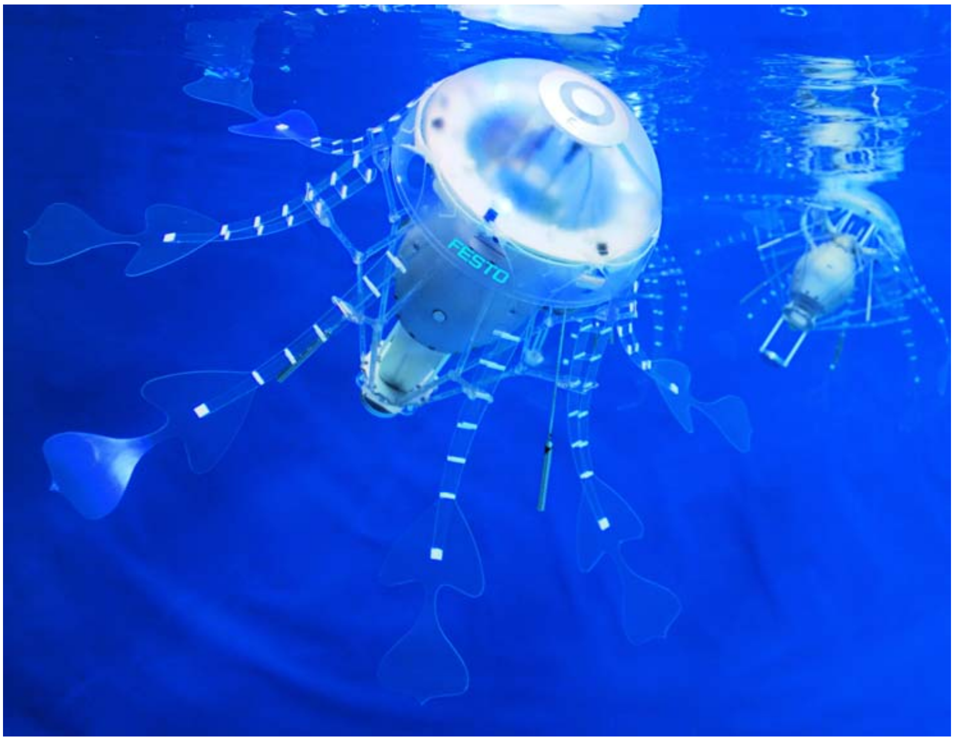

Figure 1-4 Aquajellies 2.0 jelly fish like robot by Festo [34]

Many researchers have studied biomimetic robot. Festo focus on this research field and obtained many impressive research result. Figure 1-4 shows a robot called Aquajellies 2.0 [34]. This robot is an artificial autonomous jellyfish with an electric drive unit and an intelligent adaptive mechanism that emulates swarming behavior. It consists of a translucent hemisphere, a central watertight body and eight tentacles for propulsion. AquaJelly’s translucent hemispherical dome houses an annular control board with integrated, pressure, light and radio sensors.

Besides jellyfish, octopus is also a hot topic. Octopus is a good hunter because it has 8 flexible arms. Based on the arms, octopus can realize swimming motion, grasping motion easily. In Institute of

Computer Science Foundation for Research & Technology Hellas (FORTH), Greece, Dr. Asimina Kazakidi designed an octopus robot which is shown in Figure 1-5 [35, 36]. Rongjie Kang *et al.* in Italy focused on the dynamic simulation for an octopus robot motion [37]. M. Cianchetti et al. developed a robotic arm which is inspired by octopus [38]. This arm can grasp an object by bending motion smoothly.

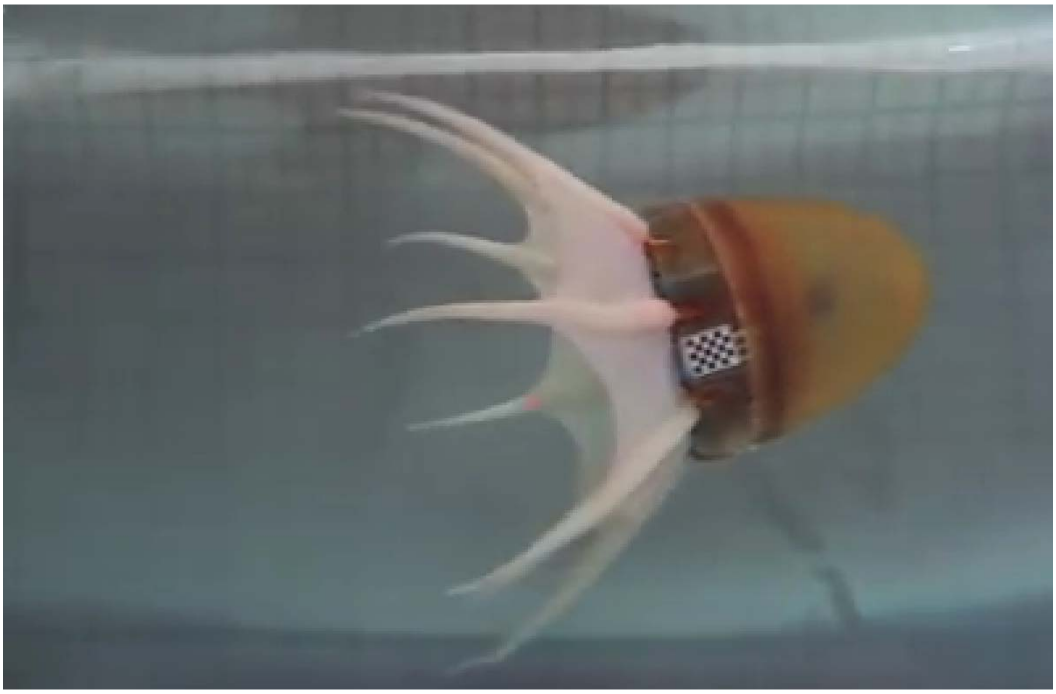

Figure 1-5 Octopus robot by FORTH

Because the development of 3D printing technology, we can realize some structures which cannot be realized by traditional processing. The main part of the robot in Figure 1-5 is fabricated by 3D printer.

For an underwater manipulation task, an octopus like robot is an excellent choice. Because it has 8 flexible arms which can realize grasping and swimming motion easily. Second, it is easier to be accepted by the underwater creature rather than a high noise mechanical arm.

1.3 Thesis Objectives

Generally, small aquatic organisms always live in a cluttered environment. They are vigilant and sensitive to noise. To monitor these creatures and collect valuable sample, a low noise miniature Father-son Underwater Intervention Robotic System (FUIRS) is proposed. Due to the advantages of spherical underwater robot, we will design the second generation spherical underwater robot (SUR-II) for the father robot. And we will design a micro bio-inspired robot as the son robot to execute underwater manipulation task. To achieve the overall objective, this thesis has the following set of sub-objectives:

(1) We design the second generation spherical underwater robot which will remain the propulsion system configuration and spherical hull. In order to improve the performance of the spherical underwater robot, we analyze and the mechanical characteristics for the propulsion system. Based on the analysis result, we improve the propulsion system.

(2) Hydrodynamic feature is one of the most important factors. It rely on the mechanical feature, propulsive system and flow field. In order to investigate the reasonability of the robot design, hydrodynamic analysis is necessary.

(3) To realize underwater manipulation task, a micro octopus like robot is designed. The octopus robot can realize underwater swimming, grasping and object detection and manipulation. The son robot can adjust buoyancy force to overcome the weight of object.

(4) A launching structure is custom designed for the son robot which can deliver and recover the son robot successfully. The launching structure is a capsule for the son robot

(5) The electrical system and control algorithm is designed for the father-son robotic system.

1.4 Thesis Overview

This thesis is organized with the following chapters:

In chapter 2, I study the kinematics and dynamics for the robot, which is very important for the design of a robot.

The mechanical structure of the father robot which is based on the first generation spherical underwater robot is proposed in chapter 3.

The mechanical structure of the son robot which is inspired by octopus is proposed in chapter 4. 3 kinds of arms are designed for the son robot. A novel buoyancy adjustment method is realized for the son robot.

In chapter 5, the electrical system of the proposed father-son robotic system is proposed.

In chapter 6, to estimate the hydrodynamic parameters and investigate the state of flow field, hydrodynamic analysis is carried out.

In chapter 7, the underwater experiments are designed to test the performance of the father robot and son robot.

The final chapter makes the conclusions and presents the future research in this field.

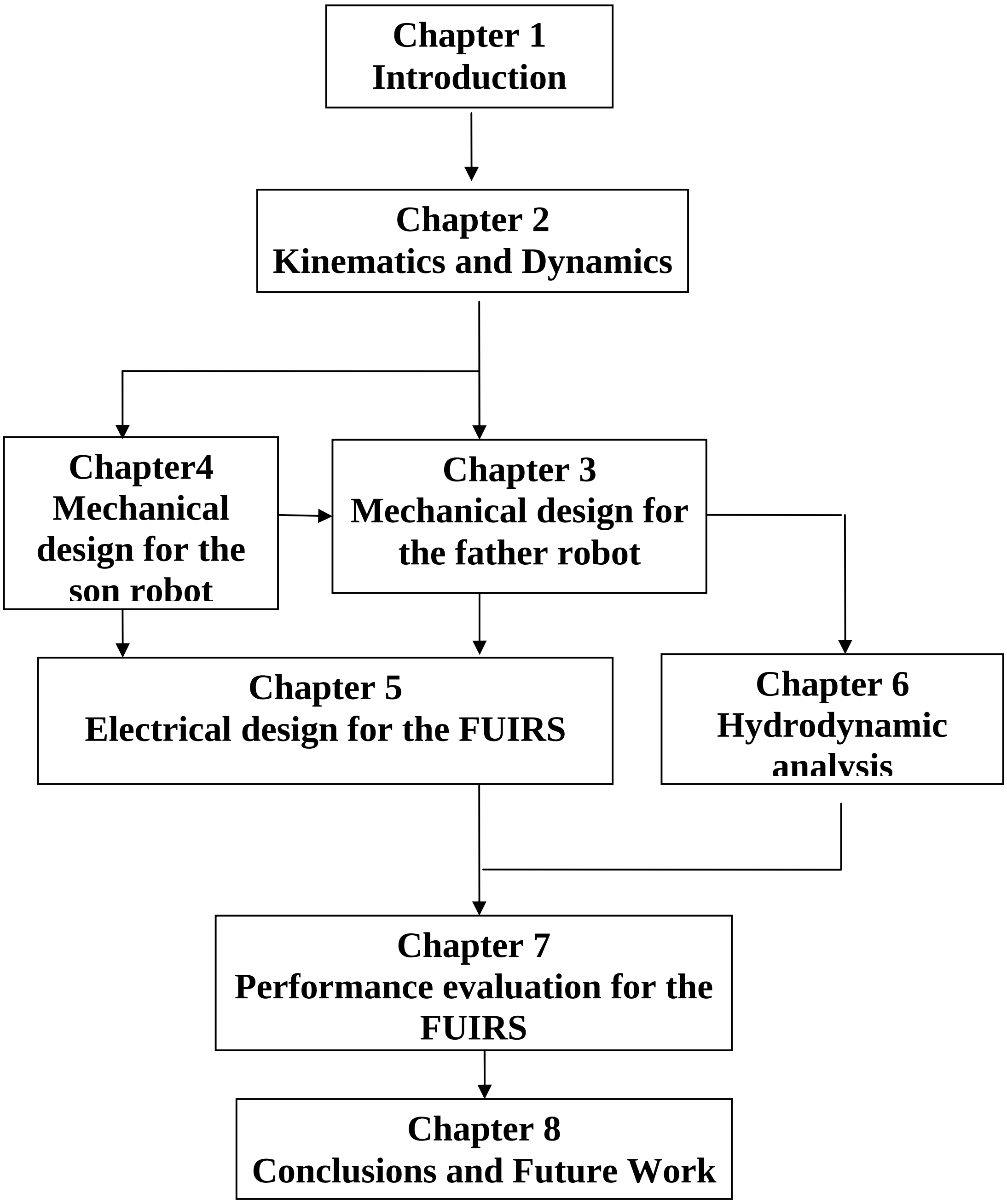

Figure 1-6 Structure of the thesis

Chapter 2

Kinematics and Dynamics

In this chapter, a brief introduction to the fundamental concepts regarding underwater robots has been presented. The kinematic equations are mainly discussed in terms of the Euler angle representation. Due to the Euler angle has singularity, quaternion is also mentioned in attitude calculation. After considering our robot, the dynamic model is established. All the principles and theories in this chapter will be the basis for the design, analysis and modeling of the robot.

Chapter 3

Mechanical Design for the SUR-II

In this chapter, we proposed the design requirements for the father robot first. And then, we analyzed the problem of our previous research. Based on our underwater intervention requirements and the problem of the SUR, we carried out the static analysis for the propulsion system. In the static analysis, CATIA is employed to establish the 3D model. And, the static analysis is executed in ANSYS Workbench. Finally, we obtained the static analysis results. The maximum deformation is about 2mm for the propulsion system. After analyzing the static analysis result, we proposed the improved propulsion system for the SUR-II. For the improved propulsion system, we enhanced the rotation range from -75 degree to -90 degree. In order to verify the performance of improved propulsion system, we also carried out the same static analysis for it. Finally, we obtained the comparison result for the previous propulsion system and improved propulsion system. The comparison result shows that, the maximum deformation of the improved propulsion system is about 50% of the previous propulsion system. Finally, we assembled the improved propulsion system for the SUR-II.

In order to realize son robot launching and recovery, a launching structure is designed for the SUR-II. We proposed the conceptual design of the launching structure and placed it on the bottom of the father robot.

Chapter 4

Mechanical design for the son robot

In this chapter, we discussed the mechanical design for the son robot. After analyzed the advantages of octopus, we decided to design the son robot according to the octopus. And then, we proposed the design requirements for the son robot which are necessary for the underwater manipulation task. To meet these design requirements, IPMC actuators are employed to form the arm of son robot. We proposed three typical arms for the son robot and discussed the deflection and bending force feature. Finally, a kind of human finger shape arm is decided to form the son robot. Due to the harsh requirement on the robot's size and weight, we fabricated the body part for the son robot by 3D printer. We designed a hollow support frame to reduce the weight and enhance the buoyancy force. To enhance the payload for the son robot, we also designed a novel buoyancy force adjustment structure in the support frame. The maximum buoyancy force is about 11.8mN. Finally, we discussed the grasping motion for the son robot

Chapter 5
Electrical system design for the Robotic System

In this chapter, we introduced the electrical system design of the FUIRS. We improved the sensor and actuator system. MEMS IMU ADIS16365 was employed to calculate the position and orientation. To reduce the noise from raw sensor data, we calibrated the sensor output by Kalman and Butterworth filter respectively. And the calibration results showed that the Kalman filter was more suitable for our research. We introduced the hardware of master side and slave side. Finally, we designed the software for the FUIRS. The process of manipulation was divided into two steps: father robot motion and son robot manipulation. Finally, we introduced the communication law for the master side and slave side.

Chapter 6

Hydrodynamic analysis

In this chapter, we mainly focus on the hydrodynamic analysis for the spherical underwater robot and the thruster. We analyzed the main motions which were frequently used in the moment of robot. Based on the motion state analysis results, we carried out the hydrodynamic analysis for 3 basic motions that is surge, heave and yaw motion. The main parameters of hydrodynamic analysis were estimated by theoretical calculation and experiments. Then the 3D model for three basic motions were established and meshed. Hydrodynamic analysis was carried out by using the commercial software, ANASYS FLUENT. According to the results, we obtained the detail information about flow state and verified an assumption i.e. the robot can be seen as a sphere when it only moves in heave direction but not horizontal direction. The analysis results also verified the drag coefficients that were calculated by the theoretical formula. Finally, we carried out the hydrodynamic analysis for the water-jet thruster, and the flow state and propulsive force was obtained. The accuracy of simulation results was verified by an experiment.

Chapter 7

Performance Evaluation for the FUIRS

In this Chapter, we mainly focus on the performance evaluation for the FUIRS. First, we designed 3 experiments for the son robot. 3 different shape objects were prepared for these experiments by 3D printer, i.e. one cylinder, one cuboid and one sphere. The objects owned different volume and weight in water from 0.58g to 1g to test the payload of the son robot. The experimental results indicated the son robot meet all of the design requirements. Hence, the swimming motion of the son robot enhanced the ability of underwater manipulation. Then, a series of underwater experiments were designed to test the father robot. The experimental results indicate the father robot is flexible and it has the ability for underwater manipulation.

Chapter 8

Concluding Remarks

8.1 Contributions

Autonomous underwater robot is a common tool for underwater tasks, e.g. underwater monitoring, underwater manipulation and underwater aquatic investigation. Especially, in underwater aquatic investigation task, monitoring and sample collection functions are used frequently. The small aquatic organisms always live in a narrow and cluttered environment, and they are vigilant and sensitive.

The traditional underwater manipulation always mentions one or more mechanical arm. However, the traditional underwater vehicle is high noise and its screw propellers are easy to be entangled by water plants. In addition, the mechanical arm is high cost, and it needs water proof. Therefore, we propose a high flexibility, low cost, low noise underwater intervention robotic system. Different with the traditional method, a biomimetic son robot is used to realize underwater manipulation task which is small in size, light in weight, low noise and even no need water proof. The father robot can provide power and control commands for the son robot. The son robot can realize object detection and manipulation. The objectives of this thesis include:

(1) Based on the first generation spherical underwater robot which also is developed in our lab propose the second generation spherical underwater robot as the father robot. To enhance the performance of the SUR-II, the vectored water-jet propulsion system needs to be analyzed and improved. The father robot needs a launching structure as the cabin for the son robot.

(2)To realize underwater manipulation task for different shape, size and weight object, the mechanical structure of the son robot needs to be designed particularly. The son robot is actuated by IPMC actuators which is very suitable for small size biomimetic robot. We propose an octopus like son robot which is very convenient for object grasping and swimming. To overcome the weight of object, buoyancy force adjustment is necessary. And the buoyancy force adjustment is also a technical difficulty for such a small robot.

(3)To drive the father-son robotic system, electrical structure and software design is necessary. The electrical system can realize sensor data collection and calculation, control algorithm realization and communication.

(4) Due to the complexity of the hydrodynamic characteristics, hydrodynamic analysis is necessary for the father robot which can represent the robotic system.

The contributions of the research in this thesis consist in the following aspects:

(1) We proposed a novel method for underwater manipulation task which mentioned a son robot. The father-son robotic system is suitable for aquatic organism monitoring and sample collection.

(2) We proposed the SUR-II as the father robot which owned an improved water-jet propulsions system. We carried out the static analysis for the propulsion system and improved it in the SUR-II. We also proposed a custom designed launching structure for the son robot which is installed on the bottom of the father robot.

(3) Based on IPMC, we proposed the octopus like son robot which was driven by 8 human finger shape arms. We designed 3 kinds of arms for the son robot and discussed the main features of the We proposed a novel buoyancy adjustment structure for such small son robot which was fabricated by 3D printer and provided 11.8mN buoyancy force.

(4)We carried out the hydrodynamic analysis for the SUR-II and the thruster, which indicated the hydrodynamic features and flow state. The results of hydrodynamic analysis proved the result of parameter evaluation and enhance the dynamic model for the father robot.

(5)We evaluated the performance of the father son robotic system by series of underwater experiments.

8.2 Future Discussions

In the future, the first task is to reduce the time cost of buoyancy adjustment. Due to the electrolysis process decide the time cost, a more efficient IPMC actuator is considered to overcome this task. If a high accuracy positioning requirement is proposed, a more intelligent control algorithm is necessary. In this research, only one micro robot is employed. We also want to take more son robots which can realize different task. For example, we can take a wireless fish like robot to realize underwater detection. We also want to make an underwater robot team for the father robot which can communicate each other, share information and form into columns to monitor more wide range underwater environment and aquatic organism.

Publication List

International Journal Papers

1. **Chunfeng Yue,** Shuxiang Guo, Liwei Shi, "Hydrodynamic Analysis of a Spherical Underwater Robot: SUR-II," International Journal of Advanced Robotic Systems, Vol.10, DOI: 10.5772/56524, 2013
2. **Chunfeng Yue,** Shuxiang Guo, Maoxun Li, Yaxin Li, Hideyuki Hirata, Hidenori Ishihara, "Mechantronic System and Experiments of a Spherical Underwater Robot: SUR-II", Journal of Intelligent and robotic systems, accepted

International Conference Papers

1. **Chunfeng Yue,** Shuxiang Guo, Yaxin Li, Maoxun Li, "Bio-Inspired Robot Launching System for a Mother-Son Underwater Manipulation Task," Proceedings of 2014 IEEE International Conference on Mechatronics and Automation, pp.174-179, China, 2014
2. **Chunfeng Yue**, Shuxiang Guo, Maoxun Li, Yaxin Li, "Passive and Active Attitude Stabilization Method for the Spherical Underwater Robot (SUR-II)" Proceedings of 2013 IEEE International

Conference on Robotics and Biomimetics, pp.1019-1023, China, 2013.

3. **Chunfeng Yue**, Shuxiang Guo, Maoxun Li, “ANSYS FLUENT-based Modeling and Hydrodynamic Analysis for a Spherical Underwater Robot”, Proceedings of 2013 IEEE International Conference on Mechatronics and Automation, pp.1577-1581, 2013.
4. **Chunfeng Yue**, Shuxiang Guo, Maoxun Li, Liwei Shi, “Electrical System Design of a Spherical Underwater Robot (SUR-II) ”, Proceeding of the IEEE International Conference on Information and Automation, pp.1212-1217, 2013.
5. **Chunfeng Yue**, Shuxiang Guo, Liwei Shi, Juan Du. “Characteristics evaluation of the vertical motion of a spherical underwater robot”, Proceedings of 2012 IEEE International Conference on Robotics and Biomimetics, pp.759-764, Guangzhou, China, 2012.
6. **Chunfeng Yue**, Shuxiang Guo, Xichuan Lin, Juan Du. “Analysis and Improvement of the Water-jet Propulsion System of a Spherical Underwater Robot”, Proceedings of 2012 IEEE International Conference on Mechatronics and Automation, pp.2208-2213, Chengdu, China, 2012.

Others

1. Xichuan Lin, Shuxiang Guo, **Chunfeng Yue** and J. Du, “3D modelling of a vectored water jet-based multi-propeller propulsion system for a spherical underwater robot”, International Journal of Advanced Robotic Systems,vol.10, DOI: 10.5772/51537, 2013
2. Liwei Shi, Shuxiang Guo, Shilian Mao, **Chunfeng Yue**, Maoxun Li, Kinji Asaka, “Development of an Amphibious Turtle-Inspired Spherical Mother Robot”, Journal of Bionic Engineering, vol. 10, pp.446-455, 2013
3. Xuanchun Yin, Shuxiang Guo, **Chunfeng Yue** and Yu Wang, “A Haptic Catheter Operating System Using Magnetorheological Fluids,” *Proceedings of 2014 IEEE International Conference on Mechatronics and Automation*, pp.1631-1636, China, 2014**.**
4. Yaxin Li, Shuxiang Guo and **Chunfeng Yue**, “Preliminary Concept and Kinematics Simulation of a Novel Spherical Underwater Robot” *Proceedings of 2014 IEEE International Conference on Mechatronics and Automation*, pp. 1907 – 1912, 2014
5. Maoxun Li, Shuxiang Guo and **Chunfeng Yue**, “A Roller Skating Mode-based Amphibious Spherical Robot”, *Proceedings of 2014 IEEE International Conference on Mechatronics and Automation*, pp.1957-1961, 2014
6. Shuxiang Guo, Maoxun Li, **Chunfeng Yue,** “Performance

Evaluation on Land of an Amphibious Spherical Mother Robot in Different Terrains", *Proceedings of 2013 IEEE International Conference on Mechatronics and Automation*, pp.1173-1178, 2013.

7. Shuxiang Guo, Qiang Fu, Yasuhiro Yamauchi, **Chunfeng Yue**, "Characteristic Evaluation of a Wireless Capsule Microrobotic System," *Proceedings of 2013 IEEE International Conference on Mechatronics and Automation,* pp.831-836, 2013.

8. Shuxiang Guo, Maoxun Li, **Chunfeng Yue,** "Underwater Performance Evaluation of an Amphibious Spherical Mother Robot", *Proceeding of the IEEE International Conference on Information and Automation*, pp.1038-1043, 2013.

9. Shuxiang Guo, Maoxun Li, Shilian Mao and **Chunfeng Yue,** "Performance Evaluation on Land of an Amphibious Spherical Mother Robot," *Proceeding of 2013 ICME International Conference on Complex Medical Engineering,* pp.602-607, 2013.

10. Shuxiang Guo, Shilian Mao, Liwei Shi, Maoxun Li, **Chunfeng Yue,** "Development of a Spherical Amphibious Mother Robot," *Proceeding of 2013 ICME International Conference on Complex Medical Engineering,* pp.614-619, 2013.

11. Shuxiang Guo, Juan Du, Xichuan Li, **Chunfeng Yue**, "Adaptive Fuzzy Sliding Mode Control for Spherical Underwater Robots," *Proceedings of 2012 IEEE International Conference on*

Mechatronics and Automation, pp.1681-1685, Chengdu, China, 2012.

Biographic Sketch

Chunfeng Yue received the B.S. degree and M.S. degree in mechanical engineering from Changchun University of Science and Technology, China, in 2008 and 2011, respectively. Currently, he is a Ph.D. candidate in Kagawa University, Japan. He researches on spherical underwater robot and microrobot utilizing artificial muscles, such as IPMC (ionic polymer metal composite) actuators for industry and bio-medical applications. His current research interests include legged bio-inspired microrobots, mechanism and control of the spherical underwater robot.

He has published about 21 refereed journal and conference papers in recent three years. He is an IEEE student member.