



Faculty of Mechanical Engineering

**THE DEVELOPMENT OF UNDERWATER MANIPULATOR FOR
MINI-ROV APPLICATION**

Ng Ann Qi

Bachelor of Mechanical Engineering

2018

**THE DEVELOPMENT OF UNDERWATER MANIPULATOR FOR MINI-ROV
APPLICATION**

NG ANN QI

**A thesis submitted
in fulfilment of the requirements for the Degree of
Mechanical Engineering**

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this project report entitled “The Development of Underwater Manipulator for Mini-ROV Application” is the result of my own work except as cited in the references.

Signature :*NgAnnQi*.....
Name :*Ng Ann Qi*.....
Date :*16/01/2019*.....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature :

Name : ..Dr. Ahmad Anas Bin Yusof.....

Date :16/01/2019.....

ABSTRACT

Manipulator is an important tool for remotely operated vehicle (ROV) to perform various tasks such as picking up object from the ocean bed, grasping and transferring equipment underwater and joining parts. This paper presents the designing and development of underwater manipulator for BlueROV2 application. This study also aimed to conduct a testing of manipulator in the water. The details design of manipulator are developed by using CATIA software. The characteristics of new design of manipulator are low cost, low complexity of structure, high portability, ease of handling and ease to manufacture. The position of manipulator on the BlueROV2 is at the center that under the vehicle (inside of Payload Skid). The center position of manipulator can vertically align the center of buoyancy and the center of gravity thus balance the vehicle. This paper also presents the determination of the gripping force of the gripper by using different mass of load. As the mass of load increase, the gripping force is also increase. In addition, the testing results also show low coefficient of friction causes the high force is required to grasp the object by gripper. The maximum gripping force of gripper is obtained in this paper. The testing result based on functionality of manipulator in water is presented. The manipulator is able to grasp and hold the load in water without continuous force generated by motor. The design of finger of gripper enable the manipulator to reach the load at the corner and perform the grasping task underwater successfully.

ABSTRAK

Manipulator merupakan alat yang penting untuk kenderaan beroperasi jarak jauh (ROV) untuk melaksanakan pelbagai tugas seperti mengambil objek dari katil lautan, menggenggam dan memindahkan peralatan di dalam air dan menyambung bahagian. Kertas ini membentangkan reka bentuk dan pembangunan manipulator untuk aplikasi BlueROV2 di dalam air. Kajian ini juga bertujuan untuk melakukan pengujian manipulator di dalam air. Reka bentuk manipulator dikembangkan dengan menggunakan aplikasi CATIA. Ciri-ciri reka bentuk manipulator baru adalah kos rendah, kerumitan struktur yang rendah, mudah untuk dialihkan, mudah untuk mengendalikan dan mudah untuk menghasilkan. Kedudukan manipulator pada BlueROV2 adalah di tengah-tengah di bawah kenderaan (di dalam Payload Skid). Kedudukan manipulator di tengah-tengah adalah untuk menegak pusat keapungan dan pusat graviti secara vertikal supaya mengimbangi kenderaan. Kertas ini juga membentangkan penentuan daya mencengkam penggenggam dengan menggunakan jisim objek yang berlainan. Apabila jisim objek meningkat, daya mencengkam juga meningkat. Di samping itu, keputusan ujian juga menunjukkan pekali geseran yang rendah menyebabkan daya tinggi diperlukan untuk mencengkam objek oleh penggenggam. Kekuatan gripper maksimum telah diperolehi dalam kertas ini. Hasil ujian berdasarkan fungsi manipulator di dalam air dibentangkan. Manipulator dapat mencengkam dan menahan objek dalam air tanpa daya yang berterusan yang dihasilkan oleh motor. Reka bentuk jari penggenggam membolehkan manipulator menyentuh objek di sudut dan berjaya melaksanakan tugas menggenggam objek di dalam air.

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor, Dr. Ahmad Anas Bin Yusof for his invaluable guidance, continuous encouragement and constant support in making this project possible. I really appreciate his guidance from the initial to the final level that enabled me to develop an understanding of this project thoroughly. Without his advice and assistance, it would be a lot tougher to completion. I also sincerely thanks for the time spent proofreading and correcting my mistakes.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I am really thankful for their sacrifice, patience, and understanding that were inevitable to make this work possible. Their sacrifice had inspired me from the day I learned how to read and write until what I have become now. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to achieve my dreams.

Lastly, I would like to thanks any person which contributes to my final year project directly or indirectly. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

TABLE OF CONTENTS

	PAGE
DECLARATION	i
APPROVAL	Error!
Bookmark not defined.	
ABSTRACT	iii
ABSTRAK	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF APPENDICES	xiii
LIST OF ABBEREVATIONS	xv
LIST OF SYMBOLS	xvi
CHAPTER	1
1 INTRODUCTION	1
1.1 Background	1
1.2 Problem statement	4
1.3 Objectives	4
1.4 Scopes	4
2 LITERATURE REVIEW	5
2.1 Introduction to underwater vehicles	5
2.1.2 Remotely Operated Vehicle (ROV)	6
2.1.3 Autonomous Underwater Vehicle (AUV)	7
2.1.4 Difference between ROV and AUV	7
2.2 Type of ROVs	8
2.2.1 World-class ROVs	8
2.2.2 Observation class ROVs	9
2.2.3 Eyeball class ROVs	9
2.3 Power source for the vehicle	10
2.3.1 Surface-powered vehicles	10
2.3.2 Vehicle-powered vehicles	10
2.3.3 Hybrid system	10

2.4	ROVs history	11
2.5	Application of underwater ROVs	13
2.6	Introduction to manipulator arm	15
2.6.1	The components of manipulator	16
2.6.1.1	The base	16
2.6.1.2	The links and joints	17
2.6.1.3	The end effector	17
2.6.2	Design criteria of manipulator underwater	18
2.6.2.1	DOF (Degrees of Freedom)	18
2.6.2.2	Workspace extent	19
2.6.2.3	Load carrying capacity	20
2.6.2.4	End effector maximum speed	20
2.6.2.5	Repeatability and accuracy	20
2.6.2.6	Type of actuator	20
2.6.3	Application of underwater manipulator	21
2.6.4	The current research of underwater manipulator	21
2.6.5	Analysis of Gripping force	31
3	METHODOLOGY	36
3.0	Introduction	36
3.1	Flow chart	36
3.2	Equipment used in this study	38
3.2.1	BlueROV2	38
3.2.2	Robot arm	39
3.2.2.1	Remote controller	39
3.2.2.2	Gripper of robot arm	40
3.3	Structure of gripper	41
3.4	Operation of gripper	44
3.5	Kinematic analysis of gripper	46
3.6	Development of new manipulator	48
3.6.1	The manipulator design considerations	48
3.6.2	Product Design Specification (PDS)	48
3.6.3	Gantt chart	51
3.6.4	Design using CATIA software	51
3.6.5	Conceptual design generation	51
3.6.5.1	Conceptual Design	52
3.6.6	Pugh matrix selection method	54
3.6.6.1	Pugh matrix selection method analysis	56

3.6.7	Modification of design	57
3.6.8	Materials selection	58
3.6.8.1	PVC pipes with end cap	59
3.6.8.2	PVC straight adapter	60
3.6.8.3	PVC reducing adapter	61
3.6.8.4	Small container	61
3.6.8.5	Four core wire	62
3.6.8.6	Battery	63
3.6.8.7	Motor	63
3.6.8.8	Power unit	64
3.6.8.9	Payload Skip	65
3.6.9	Waterproof protection	67
3.7	Implementation of new design of manipulator to BlueROV2	67
3.7.1	Three options for positioning of manipulator on BlueROV2	67
3.8	Determination of gripping force	71
3.3.6	Testing of manipulator	73
3.3.6.1	Testing the gripper in water	73
3.3.6.2	Testing the manipulator in water	73
4	RESULTS AND DISCUSSION	74
4.0	Introduction	74
4.1	Results	74
4.1.1	Drawing of new design of manipulator	74
4.1.2	Electrical circuit of the manipulator	79
4.1.3	Assembly of main parts	80
4.1.4	Modification of the wire connections	82
4.2	Calculations	85
4.2.1	Weight of manipulator in water	85
4.2.2	Gripping force of gripper	90
4.2.2.1	Analysis of results	95
4.3	Testing	96
4.3.1	Testing the gripper in water	96
4.3.2	Testing the manipulator in water	99
5	CONCLUSION	106
5.1	Summary	106
5.2	Recommendations	106
	REFERENCES	108

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Application of Underwater ROVs (Marine, n.d.)	14
3.1	Technical specification (physical) of BLUEROV2 (Bluerobotics, n.d.)	38
3.2	Main parts of gripper	41
3.3	Product design specification	49
3.4	Pugh Matrix selection method	55
3.5	Bill of materials	59
3.6	Technical specification of motor	64
3.7	Physical specification of Payload Skid	66
3.8	Three options for position of robot arm	68
3.9	Advantages and disadvantages of robot arm	69
4.1	The main parts of manipulator	78
4.2	Specification of the manipulator	79
4.3	Gripping force based on different mass of load	93
4.4	Gripping force based on coefficient of friction	94
4.5	The gripper grasping the cylindrical load	101
4.6	The gripper grasping the circular load	102
4.7	The gripper grasping the object at corner	104

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	BlueROV2 (BlueRobotics, n.d.)	2
1.2	Robot arm trainer [MR- 999R] (EK JAPAN, 2008)	3
2.1	Underwater Vehicle Taxonomy (Chris and Wernli, 2007).	5
2.2	Small work-class ROV system- COMANCHE	6
2.3	Autonomous Underwater Vehicle (AUV)	7
2.4	The scientific world class ROVs	8
2.5	Inspection or Observation class ROVs	9
2.6	Eyeball class ROVs	10
2.7	The Navy's CURV II vehicle	11
2.8	Ontoon Implacment Vehicle (PIV)	11
2.9	US Navy's hydraulic SNOOPY	12
2.10	The world's deepest diving ROV-Kaiko	13
2.11	Underwater Vehicle Manipulator System (UVMS)	15
2.12	The base frame of manipulator	16
2.13	Revolute (rotational) joints	17
2.14	End effector at link 6	18
2.15	Manipulator arm with four degree of freedom	19
2.16	Kraft Tele-Robotics Predator-7	19
2.17	2-DOF manipulator	21
2.18	Human-sized manipulator	22
2.19	A Human-Sized ROV with a Dual-Manipulator System	23
2.20	CRABSTER 200 (CR 200)	23
2.21	Leg with arm (folded arm)	24

2.22	Posture change test by using 6 legs and 4 legs	25
2.23	Disturbance observer based control scheme of the ROV	26
2.24	The CSIP Light-Weight ARM 5 E kinematic model	27
2.25	The arm located in the center of the vehicle	27
2.26	The grasping capabilities of the arm	28
2.27	Mechanism design of the manipulator	29
2.28	KORDI ROV with a dual tele-operated manipulator	30
2.29	The lever of servo motor	31
2.30	Friction grip	33
2.31	Encompassing grip	33
2.32	Gripper mechanism	34
3.1	Schematic flow chart diagram of project	37
3.2	Names on the controller	39
3.3	Control PC board	40
3.4	New simplified mechanism of robot arm	40
3.5	Illustration of assembly of the gripper	43
3.6	Structure of assembled gripper	43
3.7	Gear movement	44
3.8	Parallel crank	45
3.9	Structure of finger	45
3.10	Free body diagram of gripper	47
3.11	Design A	52
3.12	Design B	53
3.13	Design C	53
3.14	Design D	54
3.15	Different parts of manipulator	57
3.16	Assembled manipulator	58
3.17	End cap	60
3.18	PVC pipe with end cap	60
3.19	PVC straight adapter	60
3.20	PVC reducing adapter	61
3.21	Small container	61
3.22	Terminal Connector Unit	62
3.23	4 core wire	62

3.24	Batteries in series	63
3.25	Motor	63
3.26	Power Unit	65
3.27	Worm gear and pinion gear	65
3.28	Payload Skid	65
3.29	Payload Skid fit to the bottom of BlueROV2	66
3.30	Weight set	71
3.31	The load grasped by gripper (top view)	72
3.32	The load grasped by gripper (side view)	72
3.33	Small water tank	73
4.1	Gripper	75
4.2	Manipulator	75
4.3	Manipulator on Payload Skid	76
4.4	Payload Skid is attached to BlueROV2	76
4.5	Fully assembled manipulator	77
4.6	The main parts of manipulator	77
4.7	Electric circuit of the manipulator	80
4.8	Assembly of power unit with batteries	81
4.9	Assembly of gripper with batteries	81
4.10	Assembly of manipulator	82
4.11	Wiring throughout the model	82
4.12	Joining of two wires	83
4.13	Multi-pin connectors	83
4.14	The connectors used in project	84
4.15	The connectors used in project	84
4.16	Pressure exerted on object	87
4.17	Basic idea of gripper enclosing object	90
4.18	Free body diagram of the gripper and the load	90
4.19	Gripping force versus mass of load	93
4.20	Gripping force versus coefficient of friction	95
4.21	Testing of gripper in water	97
4.22	The gripper fully immersed in water	97
4.23	Gripper Opening (top view)	98
4.24	Gripper closing (top view)	98

4.25	Gripper opening	99
4.26	Gripper closing	100

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A1	Gantt Chart PSM 1	113
A2	Gantt Chart PSM 2	114
B1	Payload Skid	115
B2	Finger link X	116
B3	Finger link Y	117
B4	Upper finger base A	118
B5	PVC straight adapter	119
B6	Finger	120
B7	PVC reducing adapter	121
B8	PVC pipe	122
B9	End cap	123
B10	Gripper cover (bottom)	124
B11	Gripper cover (upper)	125
B12	Power unit cover (bottom)	126
B13	Power unit cover (upper)	127
B14	Gripper	128
B15	Manipulator	129
B16	Assembled manipulator	130
B17	Full assembly	131

LIST OF ABBREVIATIONS

UVMS	Underwater Vehicle Manipulator System
ROV	Remote Operated Vehicle
DOF	Degree of Freedom
PVC	Polyvinyl Chloride

LIST OF SYMBOLS

ρ = Density

μ = Coefficient of friction

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the underwater vehicles which is considered as useful and efficient equipment are widely utilized in underwater exploring and research. Unmanned underwater vehicles, can be addressed as UUVs, are unoccupied underwater vehicles that are able to submerge underwater without the occupying of a human physically. These underwater vehicles may be divided into two main categories: Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs).

Remotely Operated Vehicle (ROV) is used in this study and the type of ROV used is BlueROV2. The BlueROV2 as shown in Figure 1.1 is the world's most affordable high-performance ROV. It consists of the 6-thruster vectored configuration and strong static stability which ensure the vehicle smooth, stable and highly maneuverable. It is able to navigate to a standard 100m and up to 300m depth. The whole rig weighs about 22 lb (10 kg) in the air, provided a 100-m tether adds around 10 lb (4.5 kg) depending on the intensity of use (BlueRobotics, n.d.).



Figure 1.1: BlueROV2 (BlueRobotics, n.d.)

The underwater vehicle can only perform various survey tasks when equipped with underwater manipulator (UWM). Manipulator is defined as arm-like mechanism on a robotic system. It is composed of revolute and prismatic joints, as well as other mechanism such as slider, that can move and manipulate objects under human control (Ya'akob, 2010). With the manipulator, the underwater vehicle are able to perform various tasks such as picking up object from the ocean bed, grasping and transferring equipment underwater, joining parts and even part assembly.

In this study, the manipulator is designed to be fixed on BlueROV2. This is due to there is no manipulator for BlueROV2 to perform grasping task underwater. The manipulator is designed by modifying the robot arm trainer [model is MR-999CP] as shown in Figure 1.2. The robot arm trainer is comprised of five main components which are gripper, wrist, elbow, shoulder and base arm. It is capable to perform a lot of works with high flexibility of movement (EK JAPAN, 2008).



Figure 1.2: Robot arm trainer [MR- 999R] (EK JAPAN, 2008)

In this project, the gripper of the robot arm trainer is modified and utilised as the manipulator for BlueROV2. The gripper is able to open and close its finger up to 50 mm. The gripper is fixed with the semi-transparent arm and LED lights. During operation, the LED light attached on gripper will light up. This will be useful for users to observe its arm movement clearly when it is used in shallow water.

The underwater manipulator is helpful for human as no direct contact with the items underwater is required if the items is radioactive and hazardous. It also can control and manipulate materials in inaccessible places. The maximum depth it can reach underwater and the pressure it can withstand definitely better than human. It also can perform better than human from the aspect of visibility underwater. Therefore, the development of underwater manipulator (UWM) is important in the marine science and engineering field.

1.2 Problem statement

Nowadays, the improvement of ROV has been carried out to ensure it consists of multiple function. For the BlueROV2 that sold in the market, it is one type of ROV that required an operator to control its navigation underwater. However, it is a type of ROV without any manipulator. It is unable to perform multi tasks underwater without a manipulator. Therefore, this underwater manipulator project is proposed in order to increase the functionality of BlueROV2.

1.3 Objectives

The objectives of this project are as follows:

1. To design and develop underwater manipulator for mini-ROV application.
2. To conduct the testing in the aspect of functionality for manipulator in water.

1.4 Scopes

The scopes are identified based on the objectives of this project. The scopes are:

1. To design and fabricate a small scale of underwater manipulator for BlueROV2 model.
2. To determine the gripping force of the gripper by using different mass of load.
3. To test the functionality of manipulator in water and to investigate whether it can perform tasks underwater successfully.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to underwater vehicles

The underwater vehicles can be categorized into two types as shown in figure below: Manned Underwater Vehicles and Unmanned Underwater Vehicles (UUVs). The constant operator attention is needed for ROV with the use of tether or cable for power, video, and controls (Soffar, 2016). The AUV, is free from a tether and can run either a pre-programmed or logic-driven course. Figure 2.1 shows the taxonomy of underwater vehicle.

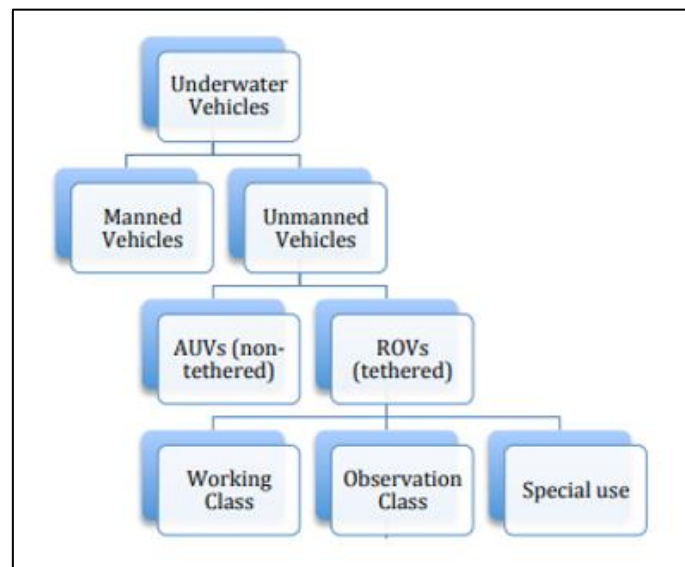


Figure 2.1: Underwater Vehicle Taxonomy (Chris and Wernli, 2007).

2.1.2 Remotely Operated Vehicle (ROV)

A Remotely Operated Vehicle (ROV) is unoccupied and highly maneuverable underwater robot connected with a series of cables to the ship. Generally, there are five types of underwater which are: small electric ROVs, high-capability electric ROVs, general class ROV, work class ROV and heavy class ROV. Different type of ROV has different properties and different application. The remote navigation of ROV is performed by transmitting the command and control signals through cables. The functions of ROV include: search, inspection, equipment repair, scientific analysis, and surveying. If in deep or rough water, the usage of robust umbilical cable of ROV is high. The ROV can be equipped with things such as video camera, lights, sonar systems, an articulating arm and a wide range of sampling options (NOAA, 2018). The limitations of human divers and human-occupied diving vehicles can be overcome by developing the ROV. Figure 2.2 shows one of the small work-class ROV system called COMANCHE.



Figure 2.2: Small work-class ROV system- COMANCHE