DESIGN AND CONSTRUCTION OF A SMALL SCALE UNDERWATER VEHICLE WITH OBSTACLE AVOIDANCE SYSTEM

CHONG ZE MING, BRYAN

BACHELOR OF MECHATRONICS ENGINEERING
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SUPERVISOR ENDORSEMENT

"I hereby declare that I have read through this report entitle "Design and Construction of a Small Scale Underwater Vehicle with Obstacle Avoidance System" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering.

Signature : ……………………………………

Supervisor's Name : Dr. Fariz Bin Ali @ Ibrahim

Date : 23 June 2015

DESIGN AND CONSTRUCTION OF A SMALL SCALE UNDERWATER VEHICLE WITH OBSTACLE AVOIDANCE SYSTEM

CHONG ZE MING, BRYAN

A report submitted in partial fulfilment of the requirements for the degree of Mechatronics Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014 / 2015

STUDENT DECLARATION

I declare that this report entitle "Design and Construction of a Small Scale Underwater Vehicle with Obstacle Avoidance System" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………………………

Name : Chong Ze Ming, Bryan

Date : 23 June 2015

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to my supervisor, Dr. Fariz Bin Ali @ Ibrahim for his guidance and patience in my FYP progress throughout this semester. Dr. Fariz is a wise, pleasant and friendly person. When I have some problems in my progress, he will stay calm and guide me to a correct direction in project based perspective. Besides, he also concern about every detail I try to raise out in problem solving. It would be my pleasure to be supervised by Dr. Fariz.

Besides, I would like to thank my Panel 1, Mdm. Nursabillilah Binti Mohd Ali for sharing her feedback on my progress after my presentation in FYP 1. Mdm. Nursabillilah patiently marked my progress report and gave comments in detail for me to improve before evaluating my FYP 1 report.

In addition, I would like to specially thank Mr. Mohd Shahrieel Bin Mohd Aras for his consultation. Mr. Shahrieel is an expert in the field of underwater robotics. He is willing to share his knowledge with me to enhance my understanding and technical skills for AUV development.

Last but not least, I would like to highlight my appreciation to some of my course mates who willing to lend me helping hand when I was collecting data in experiments.

ABSTRACT

This report is about the Final Year Project for the development and analysis of a small scale Autonomous Underwater Vehicle (AUV) with obstacle avoidance system. AUV need to be in miniature size to ease the mobility of the AUV when it performs missions. Besides, obstacle avoidance system is preferable to be implemented in an AUV because obstacle is unpredicted in deep sea and collision might happen without this system. To develop an AUV, materials and components used have to be well considered. The sensors, motors and the hull of the AUV need to be completely watertight. Meanwhile, algorithm for obstacle avoidance and depth control mechanism need to be designed and improved to yield better outcomes. The purpose of this Final Year Project is to design and develop a low cost AUV in miniature size with obstacle avoidance system. Another objective is to analyse the performance of underwater sensors on obstacle detection and distance measurement. Up to date, the hardware and software development has been completed. Total 6 experiments have been conducted. Experiment 1 and 2 has been conducted to test the functionality of the microcontroller and DC motor. Experiment 5 also has been conducted to test light detection of common blue LED. In addition, Experiment 3, 4 and 6 have been conducted to test the functionality of Ultrasonic, Infrared and Laser sensors on distance measurement in air and underwater environment. Based on the analysis in experiments, DC brushless motor is functional in tap water even though it is not watertight. Besides, results showed blue LED can function as spectrally selective detector, which is sensitive to light wavelength from 380nm to 500nm. Furthermore, analysis demonstrated 405nm Laser sensor is a better sensor among others for short range obstacle detection in underwater environment, which can detect obstacle effectively up to 80cm. Standard deviation and root-mean-squared error has been calculated for all results to examine the accuracy and consistency. As a result, all data collected in the experiments were considered accurate.

ABSTRAK

Laporan ini adalah tentang Projek Saujana Muda yang bertujuan untuk membina dan menganalisis Robot Bawah Air (AUV) yang berskala kecil dan boleh mengelakkan halangan secara automatik. AUV perlu bersaiz kecil untuk memudahkan pergerakannya apabila misi dilaksanakan. Selain itu, sistem mengelakkan halangan secara automatik perlu ditambahkan dalam AUV kerana halangan adalah sukar diramalkan di laut dan kelanggaran mungkin berlaku tanpa sistem ini. Untuk penghasilan AUV, bahan dan komponen perlu dipilih dengan berhati-hati sebelum dimasangkan. Sensor, motor dan badan AUV itu perlu berkalis air. Di samping itu, algoritma untuk pengelakan halangan dan mekanisme kawalan mendalam air perlu direka dan diperbaiki sebaik mungkin. Tujuan Projek Saujana Muda ini adalah untuk mereka bentuk dan menghasilkan AUV dengan kos yang rendah, bersaiz kecil dan mengelakkan halangan. Selain itu, Projek Saujana Muda ini adalah bertujuan untuk menganalisis prestasi sensor dalam pengesanan halangan dan pengukuran jarak. Dalam tahap terkini, perkakasan dan perisian telah dihasilkan. Sejumlah 6 eksperimen telah dijalankan. Exsperimen 1 dan 2 telah dijalankan untuk menguji fungsi mikropengawal dan motor arus terus. Seterusnya, Eksperimen 5 telah dijalankan untuk mengkaji pengesanan cahaya dengan LED biru biasa. Di samping itu, Eksperimen 3, 4 dan 6 telah dijalankan untuk mengkaji fungsi Ultrasonik, Inframerah dan Laser sensor dalam pengukuran jarak dalam persekitaran udara dan air. Berdasarkan analisis dalam eksperimen, tanpa berus motor arus terus tanpa berus boleh berfungsi dalam air paip walaupun ia tidak berkalis air. Seterusnya, keputusan eksperimen menunjukkan LED biru boleh berfungsi sebagai pengesan cahaya terpilih, iaitu sensitif kepada panjang gelombang cahaya daripada 380nm hingga 500nm. Di samping itu, analisis menunjukkan sensor Laser 405nm adalah sensor yang lebih baik bagi pengesanan halangan yang jarak pendak dalam persekitaran air, iaitu boleh mengesan halangan dengan berkesan sehingga 80cm. Sisihan piawai dan ralat punca min kuasa dua telah dikirakan dalam semua keputusan eksperimen untuk memeriksa ketepatan dan ketekalan. Hasilnya, semua data yang dikumpul dalam eksperimen adalah tepat.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	**i**
	ABSTRACT	**ii**
	ABSTRAK	**iii**
	TABLE OF CONTENTS	**iv**
	LIST OF TABLES	**vi**
	LIST OF FIGURES	**vii**
	LIST OF APPENDICES	**ix**
1	**INTRODUCTION**	**1**
	1.1. Motivation	1
	1.2. Problem Statement	3
	1.3. Objectives	4
	1.4. Scopes	4
2	**LITERATURE REVIEWS**	**5**
	2.1. Design and Basic Construction	6
	2.1.1. Guanay II AUV	6
	2.1.2. Dagon AUV	7
	2.1.3. Stingray AUV	8
	2.2. Light Detection of Light Emitting Diode (LED) as Photodiode	13
	2.3. Absorption Spectrum of Light in Water	14
	2.4. Summaries of Literature Reviews	15

3	**METHODOLOGY**	**16**
	3.1. Hardware Development	17
	3.1.1. Mechanical Design	17
	3.1.2. Electrical Design	18
	3.1.3. Prototyping	22
	3.2. Software Development	24
	3.2.1. Obstacle Avoidance and Depth Control Algorithms Design	24
	3.2.2. Programming	24
	3.3. Experiments and Analysis	25
	3.3.1. Experiment 1	30
	3.3.2. Experiment 2	32
	3.3.3. Experiment 3	34
	3.3.4. Experiment 4	39
	3.3.5. Experiment 5	42
	3.3.6. Experiment 6	44
4	**RESULTS AND DISCUSSIONS**	**48**
	4.1. Completed Prototype	48
	4.2. Obstacle Avoidance and Depth Control Algorithms	51
	4.3. Analysis on Experiments	53
	4.3.1. Experiment 1	53
	4.3.2. Experiment 2	54
	4.3.3. Experiment 3	56
	4.3.4. Experiment 4	60
	4.3.5. Experiment 5	63
	4.3.6. Experiment 6	65
5	**CONCLUSION AND RECOMMENDATIONS**	**70**
	REFERENCES	**72**
	APPENDICES	**74**

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Summaries of Specification in Design and Basic Construction of AUVs	9
3.1	Mapping of All Experiments with Related Objectives	25
4.1	Results Obtained in Experiment 2	54
4.2	Description of Abbreviations from Legend in Figure 4.14	66

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Comparison of Small AUV Examples	3
2.1	The Guanay II AUV	6
2.2	The Dagon AUV	7
2.3	The Design of the Stingray AUV	8
2.4	Analysis on Light Absorption Spectrum in Pure Water	14
3.1	Flow Chart of Methodology	16
3.2	Isometric and Three Plane Views of Prototype Design	17
3.3	Block Diagram of the Embedded System Design	18
3.4	The Raspberry Pi and Adafruit Miniature Wi-Fi Module	19
3.5	Mitsumi M31E-1 DC Brushless Motor with 3.9mm Propeller Blade	19
3.6	Laser Sensor	20
3.7	3-Axis Accelerometer	20
3.8	Xiaomi 10400mAh Power Bank	21
3.9	Bottle Cap with Rubber Band	22
3.10	Top View of the Prototype	23
3.11	Rectangular Tap Water Pool	26
3.12	Rounded Tap Water Pool	26
3.13	Measuring Tape	27
3.14	Station (PC)	27
3.15	Ultrasonic Sensor	28
3.16	Infrared Sensor and Multimeter	28
3.17	Laser Sensor	28
3.18	Transparent Perspex and Protractor	29
3.19	Shiny White, White, Grey and Black Papers	29
3.20	Set Up of Experiment 1	31

3.21	Set Up of Experiment 2	33
3.22	Set Up of Experiment 3 in Air Environment	35
3.23	Set Up of Experiment 3 in Underwater Environment	36
3.24	Set Up of Experiment 4 in Air Environment	40
3.25	Set Up of Experiment 4 in Underwater Environment	41
3.26	Set Up of Experiment 5	43
3.27	Set Up of Experiment 6 in Air Environment	45
3.28	Set Up of Experiment 6 in Underwater Environment	46
4.1	Isometric View of the Prototype	49
4.2	Front View of the Prototype	49
4.3	Top View of the Prototype	50
4.4	Side View of the Prototype	50
4.5	The Obstacle Avoidance and Depth Control Algorithms	52
4.6	Analysis on the Direction and Output Voltage of DC Motor	53
4.7	Analysis on Currents of DC Motor in Tap Water and Salt Water in 15 Minutes	54
4.8	Results of Testing DC Motor in Water after 15 Minutes	55
4.9	Analysis on Output Voltages of Ultrasonic Sensor for Distance Measurement in Air Environment	56
4.10	Analysis on Output Voltages of Ultrasonic Sensor for Distance Measurement in Underwater Environment	57
4.11	Comparison on Output Voltages of Ultrasonic Sensor for Distance Measurement in Air and Underwater Environment	58
4.12	Analysis on Output Voltages of Infrared Sensor for Distance Measurement in Air and Underwater Environment	60
4.13	Analysis on the Functionality of Blue LED with Different Wavelengths	63
4.14	Analysis on Output Voltages of Laser Sensor for Distance Measurement of 5 Obstacles with Different Colours in Air and Underwater Environment	65

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Gantt Chart of FYP	74
B	Schematic Diagram of Circuit Design	75
C	Costing of Procurement for Prototype Development	76
D	Coding for Prototype Based on Algorithms	77
E	Results for Experiment 1: Controlling DC Brushless Motor	79
F	Results for Experiment 3: Distance Measurement of Ultrasonic Sensor in Air and Underwater Environment	80
G	Results for Experiment 4: Distance Measurement of Infrared Sensor in Air and Underwater Environment	82
H	Results for Experiment 5: Light Detection of Blue LED with Different Light Wavelengths	83
I	Results for Experiment 6: Distance Measurement of Laser Sensor in Air and Underwater Environment	85

CHAPTER 1

INTRODUCTION

This section covers the motivation, problem statement, objectives as well as scopes of this Final Year Project.

1.1 Motivation

In decades back, marine researchers started to develop Unmanned Underwater Vehicles (UUVs) to fulfill their explorations in ocean underwater. UUVs are vital in marine researches and military purposes because various kinds of missions can be performed in extreme environment without risking the human's life. Indeed, UUVs play an important role in intervention and monitoring in oil and gas industry. Moreover, UUVs also have contributed greatly in wreckage search and rescue mission [1][2][3].

UUVs can be classified into two types: the Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs). In this Final Year Project, AUV is emphasized and will be developed. AUVs are usually untethered which make them capable of long range cruising provided with sufficient power supply. Besides, AUVs is operated autonomously which allow them to perform missions without the need of human inputs [4][5]. One remarkable example of AUV is the utilisation of Bluefin-21 from the Australian Navy to perform missions for searching the black box's signals in the Southern Indian Ocean regarding the incident of missing MH370 on 8 March 2014 [6]. However, AUVs are typically expensive, heavier and larger in size because all components are embedded inside the hull.

In shallow water, the use of large AUVs is not practical since larger object has more inertia when moving around in water and it is difficult to avoid obstacle. Hence, small AUVs which are miniature in size will come useful in shallow water to perform missions because of ease for mobility as well as compact without limiting its functionality and long lasting power [2]. There are number of researchers who do researches on small AUVs. Some of the small AUVs developed are Seabird AUV (2007), Monsun II AUV (2012) and Dagon AUV (2010) [7][8][9]. One researcher named Simon A. Watson developed a spherical AUV (2011) with a dimension of 20cm in length and width, and 15cm in height. AUVs with such miniature size are known as micro-AUV [10]. The prototype developed in this Final Year Project is 35cm in length, which is an intermediate AUV in between SeaBird and Watson's. Figure 1.1 illustrates the comparison of a few small AUV examples includes the prototype of this Final Year Project.

In term of costing, AUVs are typically expensive. This is because various sensors are required to be embedded in AUVs for autonomous operation. In addition, the selection of components in compact size is more favourable in developing AUVs. As a result, higher budgets are needed for AUV's production [4]. For example, a commercialised AUV named Iver 3 Nano manufactured by OceanServer Technology even hits a price quotation of RM 185,000 [11]. Expensive AUVs are not affordable to be generally used in researches. Hence, the development of low cost AUV is a must. One solution is the deployment of cheaper material and components in constructing AUVs. Subsequently, more units of low cost AUVs can be produced at the equivalent cost of an expensive AUV.

AUVs can be in high risk in underwater as obstacles could be in anywhere. Especially for deep sea exploration, AUVs might be cruising far away from the station. These expensive assets can be breakdown and vanish if collision with obstacle happens. Therefore, implementation of obstacle avoidance mechanism can be a good measure to enhance the safety of the AUVs [5][12].

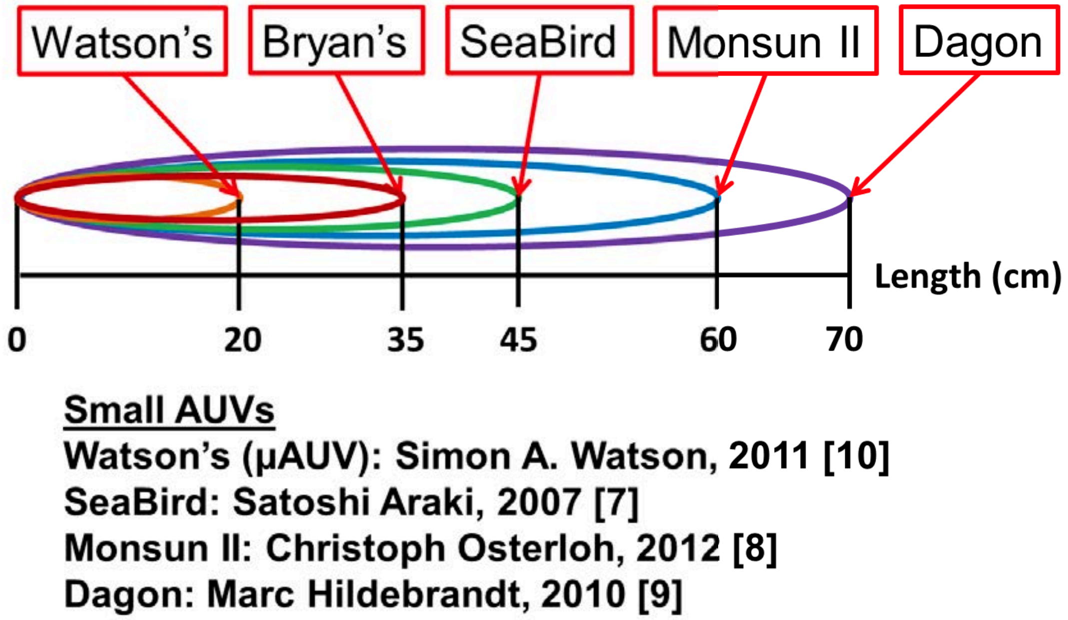

Figure 1.1: Comparison of Small AUV Examples

1.2 Problem Statement

Tremendous mechatronics knowledge is needed to design and develop this AUV. To design AUV in miniature size, the materials and components should be carefully selected in compact but sufficient to be used by studying all the characteristics and specification. The hull design required hydrodynamic to ensure the AUV receive the least friction in water during motion. In addition, the hull should be completely watertight by proper procedure with the aid of technical skills. The kinematic and dynamic of the AUV in underwater will have close relationship with the propulsion system using thrusters. Wireless connectivity between the AUV and the station is necessary because the AUV is untethered. Control algorithm is required to perform obstacle avoidance mechanism and depth control mechanism simultaneously. Selection of suitable sensor is crucial for obstacle detection within 1 meter in underwater. Weight of the AUV has to be specific to achieve stable depth control in underwater with the aid of vertical thrusting by utilizing the fundamental of buoyancy mechanism. Besides, good weight distribution in the AUV is essential to obtain good centre of gravity for stability. Competency in programming is necessary to produce less error in coding, while controlling multi sensors and thrusters in the AUV. Lastly, the AUV need to be powered as long lasting as possible.

1.3 Objectives

The objectives of this Final Year Project are:

1. To design and develop a low cost AUV in miniature size which is less than 0.5 meter in length and 0.55 meter in width.
2. To design and develop an obstacle avoidance system for an AUV in underwater.
3. To analyse the performance of underwater sensors on obstacle detection and distance measurement in underwater.

1.4 Scopes

1. The AUV is required in small scale, which is less than 0.5 meter in length, 0.55 meter in width and 5 kilogram in mass.
2. The depth rating of the AUV is 1 meter from the water surface to prevent extensive water pressure exerts towards the hull.
3. The maximum duration for the AUV activity in underwater is 1 hour per cycle to prevent humidity hazards.
4. The AUV activity is scoped in rectangular tap water pool and rounded tap water pool. The dimension of the rectangular tap water pool is 2.57 meter length × 1.35 meter width × 1.00 meter height, whereas rounded tap water pool is 1.83 meter diameter × 0.38 meter height.
5. Obstacle is needed at least 30 centimetres away from the AUV to prevent collision.
6. The microcontroller used is Raspberry Pi due to it has high processing power and up to 40 General Purpose Input Output pins.
7. Waterproof ultrasonic sensor, Infrared sensor and Laser sensor are tested for sensor performance in underwater. Laser sensor is selected as the input for the obstacle avoidance and depth control mechanisms of the AUV.
8. Performance of Laser sensor is dependent on intensity of reflected light received. Therefore, white obstacle is used to demonstrate obstacle avoidance mechanism.
9. The AUV activity is scoped in indoor under fluorescent lamp. This is because the Laser sensor is UV light dependent sensor. Under sunlight environment, the output voltage of the Laser sensor might be deviated aggressively.
10. 3-Axis accelerometer is used as input for tilt balancing mechanism of the AUV.

CHAPTER 2

LITERATURE REVIEWS

In this section, the design and basic construction of small scale AUVs from three journals has been reviewed. In addition, journals about Light Emitting Diode (LED) as photodiode and absorption spectrum of light in water have been studied to develop a Laser sensor.

2.1 Design and Basic Construction

2.1.1 Guanay II AUV

Guanay II AUV is a torpedo-shaped AUV with the extension of five fins for improvement in hydrodynamic. The AUV is 2.3 meters in length and 90 kg in mass. For hull design, fiberglass has been chosen as the outer hull material and aluminium as the material for watertight module which envelopes the electrical component parts. The AUV is controlled by a PC104 embedded computer. The depth control system has been developed with a stainless steel pneumatic cylinder in ballast tank, with the measurement by a pressure transducer. Navigation system with the combination of GPS and digital compass has been implemented for high accuracy coordination and orientation. A main DC thruster has been used for forward propulsion and two DC side thrusters for directional propulsion. The AUV is connected to base station wirelessly by implementing a radio link modem to transmit data for analysis. 24 V Nickel-Cadmium battery pack with total capacity of 21 Ah has been chosen and a DC to DC converter has been used to step down supply to 5 V and 12 V for supplying power up the AUV [13]. Figure 2.1 shows the hardware of Guanay II AUV in lateral and tail view.

(a) Lateral View (b) Tail View

Figure 2.1: The Guanay II AUV [13]

2.1.2 Dagon AUV

Dagon AUV is a hovering AUV developed in 2010 which is purposed specifically for algorithm evaluation and visual mapping. It weighs around 70 kg in air and has a depth rating of more than 150 meters. To counter high underwater pressure, strong metal alloy material has been used to develop the pressure hull body. The AUV has five DC propellers for propulsion system which two of them are for forward thrusting, two for up-thrusting and one more for side thrusting. It can be operated in tethered mode with fiber-optic link or untethered mode with acoustic modem, depends on types of analysis. The water depth of the AUV can be measured by pressure sensor and Doppler velocity log. The orientation of the AUV is controlled by Altitude Heading Reference System (AHRS) and fiber-optic gyroscope. For visual mapping purpose, scanning sonar as well as the high resolution stereo cameras have been implemented in the AUV. Intel i7 processor based controller has been selected for high processing ability in the basic operation of the AUV as well as analysis activity in several experiments. Two block of Lithium-Ion battery with total capacity of 1.5 kWh has been selected to power up the AUV [9]. Figure 2.2 shows the hardware of the Dagon AUV in different condition.

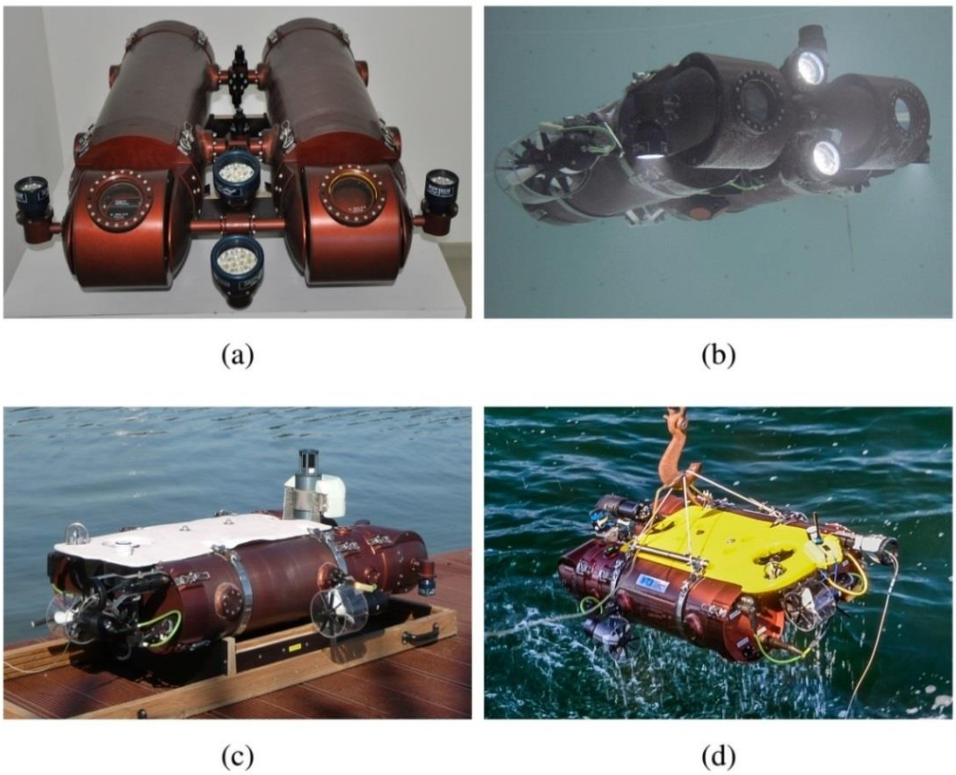

Figure 2.2: The Dagon AUV [9]

2.1.3 Stingray AUV

The Stingray AUV is a lower cost developed AUV. Unlike some common shapes of AUV such as torpedo shape and cube shape, the Stingray AUV is designed in stingray-liked biomimetic shape to achieve improved hydrodynamic. The AUV is stressed on lightweight and compact in size. Hence, lighter material and components has been used for development. In hull design, the carbon fiber material has been selected and the wings and tail are developed by 3D printing. The AUV is propelled by five propellers, two of them for forward thrusting and another three are embedded into the wings and tail for up-thrusting propulsion to stabilize vehicle orientation. To measure the depth of the AUV, a pressure sensor has been implemented. A 3-axis solid state compass which consists of magnetometer and accelerometer has been utilised to determine the orientation of the AUV. The AUV has been built in with two cameras for front and bottom view of surroundings. Besides, hydrophone has been implemented as an alternative for sonar sensor for mapping analysis. The AUV is powered by Lithium Polymer battery with two different rated voltages, one as power supply for controller and another one for propulsion system [14]. Figure 2.3 illustrates the model of the Stingray AUV.

Figure 2.3: The Design of the Stingray AUV [14]

Table 2.1 summarised the specification in design and basic construction of the AUVs in the three journals discussed previously.

Table 2.1: Summaries of Specification in Design and Basic Construction of AUVs

INTENSIVE LITERATURE REVIEW			
CRITERIA	JOURNALS		
	Design and Construction of the GUANAY-II Autonomous Underwater Vehicle [13]	Two Years of Experiments with the AUV Dagon - a Versatile Vehicle for High Precision Visual Mapping and Algorithm Evaluation [9]	The Stingray AUV: A Small and Cost-Effective Solution for Ecological Monitoring [14]
Name	Guanay II	Dagon	Stingray
Length x Width (m)	2.3 x 0.32	0.7 x 0.6	N/A
Mass (kg)	90	70	10
Depth Rating (m)	30	150	N/A
Endurance (hrs)	5	8 to 10	N/A
Hull Material	Outer: fiberglass Inner (Watertight module): Aluminum-6063 - Dimension: 1.1m x 0.25m - Thickness: 5mm	ALMg4,5Mn and AlMg3 - coating is a red coloured hard-coating	Small, lightweight, carbon fiber shell with a biomimetic design

Controller	Aewin PC104+ embedded computer, model PM6100	Two embedded PC system - Intel i7 Duo-Core 2.8GHz	Kontron ETX-CD (PC104-based) - Intel Core 2 Duo with 1.2GHz.
Power Supply	24V Nickel-Cadmium Batteries - Total Capacity: 21Ah - Mornsun DC-DC converter to supply 5V and 12V	Two 14.7 V, 50 Ah Lithium-Ion Battery - Rated Voltage: 29.3 V - Total capacity: 1.5 kWh	4 Ah 14.8 V lithium polymer battery (Controller) 8 Ah 11.1 V lithium polymer battery (Propeller)
Depth Control Sensor (Buoyancy)	GEMS 2200 Series General Purpose Pressure Transducer - Pressure Range: 0 to 6 bar	Desert-Star SSP-1 pressure sensor - Depth Range: 0-344m	SSI Technologies P51-15-S-B-I36-4.5V-R pressure sensor - Output voltage: 0.5 - 4.5 V - Pressure Range: 101 - 203 kPa - Resolution: 2.44 mm in water
Obstacle Avoidance/Visual Mapping Sensor	N/A	Micron DST Scanning Sonar - Range: 2-75m	Aquarian Audio H1a Hydrophones
Communication System	TMOD-C48 Radio Link Modem - Frequency: 403-470 MHz - Transmission Speed: 4800bps - Power: 0.1-0.5W - Max Range: 10km	Seacon Fiber-optic cable link - Diameter: 1.6 mm - Tensile Strength: 1200 N - Support full-duplex Gigabit Ethernet over 20 km length Desert-Star SAM-1 Acoustic Telemetry modem	Nav Module via TCP protocol Labjack Data Acquisition Card

Propulsion System	Main: Seaeye SI-MCT01-B brushless thruster - Voltage Input: 24V DC - Maximum force: 110N - Power: 300W - Speed: 960rpm	Five 150W brushless thrusters - 3.5 kg bollard thrust	Main: Two Graupner 2358 Voith-Schneider - managed by Scorpion Commander 45 A electronic speed controller
	2 Side: Seabotix BTD150 thrusters - Voltage Input: 24V DC - Maximum force: 25N - Power: 80W		
	Upthruster: Festo CRDNG-100-PPV-A Pneumatic Stainless Cylinder - Displacement 1500cm3 - Lineal electric actuator 200mm, 3kN power), controlled by H-bridge	BLDC V1.3 (FPGA-based) motor control electronics - Motor controller - High accuracy at low RPM	Upthruster: Three Scorpion 22mm brushless motor - managed by Castle Sidewinder 25 A electronic speed controller
Camera	N/A	2 Prosilica GE1900C GigE Camera - Stereo - Resolution: Full HD - can be rotated within 270 degree	Remote Ocean Systems CE-X-18 underwater camera
		4 Bowtech LED800/1600 Underwater	Inuktun FireEYE underwater camera