"I hereby declare that I have read through this report entitle "**Integrated Sensor for Unmanned Underwater Vehicle (UUV)**" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering.

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Date : .....

INTEGRATED SENSOR FOR UNMANNED UNDERWATER VEHICLE (UUV)

OOH MAN CHUN

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

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016/2017

I declare that this report entitle "**Integrated Sensor for Unmanned Underwater Vehicle (UUV)**" 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 : OOH MAN CHUN

Date : .....

To my beloved mother and father

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And finally, to God who made everything possible as I believed.

ABSTRACT

Within the past few decades, Unmanned Underwater Vehicles (UUV) are equipped with different types of sensors depending upon the missions and applications of the underwater vehicles. In underwater industries, sensors is the most important issue for the underwater task because of the cost, realibility and accuracy. However, the sensors that are used in the underwater vehicles are not in the form of integrated sensor and even not waterproof. Integrated sensor is very important for the underwater vehicles to carry out the underwater operations in several different areas. Nowadays, a lot of underwater industries are involved in the integrated sensor's design and development to reduce their production cost in order to increase its efficiency, accuracy, sensitivity and productivity. The aim of this project is to design and develop an integrated sensor which consists of IMU sensor, depth sensor, magnetometer and leakage sensor for underwater application. Besides that, the performance of the integrated sensor is evaluated and analysed with MATLAB real-time simulation in terms of accuracy and sensitivity. The hardware is tested by the microcontroller board and integrated with MATLAB real-time simulation. To get the real-time data from the integrated sensor, it will be programmed by a microcontroller (Arduino Mega2560). The data from the sensors are used as input for serial monitor and processed in MATLAB real-time simulation to generate the output graph for the performance analysis. The performance of the integrated sensor will be verified based on its sensitivity and accuracy. The result is the integrated sensor able to collect the data for the analysis movement of UUV with low estimation error and high sensitivity.

ABSTRAK

Dalam beberapa dekad yang lalu, kenderaan bawah air tanpa pemandu (UUV) dilengkapi dengan pelbagai jenis sensor yang bergantung kepada misi dan kegunaan kenderaan bawah air. Dalam industri bawah air, sensor adalah isu yang paling penting untuk tugas bawah air kerana kos, realibiliti dan ketepatan. Walau bagaimanapun, sensor yang digunakan dalam kenderaan bawah air adalah tidak dalam bentuk bersepadu sensor dan kalis air. Sensor yang bersepadu adalah sangat penting bagi kenderaan bawah air untuk menjalankan operasi bawah air dalam beberapa bidang yang berbeza. Pada masa kini, banyak industri bawah air melibatkan dalam reka bentuk dan pembangunan sensor bersepadu untuk mengurangkan kos pengeluaran serta meningkatkan kecekapan, ketepatan, sensitiviti dan produktiviti. Projek ini adalah untuk mencipta dan menghasilkan satu sensor bersepadu yang terdiri daripada sensor IMU, sensor kedalaman, magnetometer dan sensor kebocoran untuk kegunaan bawah air. Selain itu, prestasi sensor bersepadu dinilai dan dianalisis dengan simulasi masa nyata. Perkakasan itu akan diuji oleh mikropengawal dan disepadukan dengan perisian MATLAB simulasi masa nyata. Untuk mendapatkan data masa nyata daripada sensing unit, sensor bersepadu akan diprogramkan oleh mikropengawal Atmel (Arduino Mega2560). Data masa nyata daripada sensing unit berkomunikasi dengan carta bersiri dan perisian MATLAB untuk menjana graf output dan analisis prestasi UUV. Prestasi sensor bersepadu akan disahkan berdasarkan sensitiviti dan ketepatan. Hasil ialah sensor bersepadu mampu untuk mengumpul data bagi analisis pergerakan UUV dengan kesilapan anggaran yang rendah.

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UUV – Unmanned Underwater Vehicle

AUV – Autonomous Underwater Vehicle

ROV – Remotely Operated Vehicle

UG – Unmanned Glider

IMU – Inertial Measurement Unit

IDE – Integrated Development Environment

MATLAB – Matrix Laboratory

ESC – Electronic Speed Controller

MCU – Main Controller Unit

MMCS – Mission Monitoring/Control System

MEMS – Micro Electromechanical System

CHAPTER 1

INTRODUCTION

1.1 Introduction

For the Unmanned Underwater Vehicles (UUVs), sensors have become the most important issue in the underwater application. However, the sensors that are applied in the underwater vehicles are not in the form of integrated sensor. Besides that, most of the sensors that are applied in underwater application are quite expensive, sensitive and even not overall waterproof. Therefore, it is not an easy task to get an accurate measurement by using the UUV [1, 2].

An integrated sensor sometimes known as smart sensor is a sensor in a small size that are designed and developed to gather data for analysis. Basically, it consists of different types of sensors which are combined or integrated into one compact device with signal processing hardware. This means that it can be sends the signal without any additional processing hardware or amplifier. Not only this, the space and weight can be reduced to put other components. Furthermore, it can also save the time taken to design a new sensor. It is very important for the UUV to carry out the submerged operations in several different areas such as communications, localization, motion planning and hydrodynamics. For example, the tragedy MH370 which a MH370 plane crashed and sank into the Indian Ocean. The integrated sensor can provide the facilities for UUV to find objects which are submerged beneath the sea and navigation or localization of UUV.

In this project, an integrated sensor system is designed to apply in the underwater application which consist of four major sensors: 5 degree of freedom (DOF) Inertial Measurement Unit (IMU) sensor, depth sensor, magnetometer and leakage sensor. To get

the real-time data from the integrated sensor, it will be programmed by a microcontroller (Arduino Mega2560). The data from the sensors are used as input for serial monitor and processed in MATLAB real-time simulation to generate the output graph for the performance analysis. The performance of the integrated sensor will be verified based on its sensitivity and accuracy.

The aim of this project is to design and develop the ability of each sensor into an integrated sensor and analyse its performance by using MATLAB real-time simulation. The goal performance of this integrated sensor is improved based on low cost, small space, low estimation error, waterproof and multifunctional. However, the performance of the different types of sensors in underwater are more emphasized in this project. The experimental on each sensor are performed to test their functionality and performance.

1.2 Motivation

In Malaysia, the sensor and vehicle in underwater industries are not widely studied and researched. The underwater technology in Malaysia is not much advanced if compared to other foreign countries, such as United States of America (USA), Russia, Australia and etc. They have advanced underwater technology to perform the more challenging underwater mission. It can be proven by missing incidence of MH370 plane on 8th March 2014, Bluefin-21 from Australia Navy performed black box's signal searching mission in the Southern Indian Ocean as shown in Figure 1.1. Malaysia need to seek underwater technology assistance from Australia to carry out the searching mission. In this searching mission, Malaysia need to sponsor in term of financial for some foreign countries. However, they took this chance to research and develop their underwater industries. So, Malaysia need to expand the underwater technology in order to compete with the foreign countries.

Therefore, a greater performance of integrated sensor for UUV is needed to be developed in order to apply in underwater tasks. The integrated sensor consists of four sensors: 5 DOF IMU sensor, depth sensor, magnetometer and leakage sensor. The 5 DOF IMU sensor integrates accelerometer and gyroscope which provides 5 DOF. The depth sensor is used to measure the underwater pressure and control the water depth of UUV. Magnetometer is used to measure the heading degree of UUV and leakage sensor is used to detect water leakage inside the integrated sensor casing.

In the development of integrated sensor, the space and weight of the UUV are reduced. The integrated sensor can help the UUV to collect different types of data information in underwater.

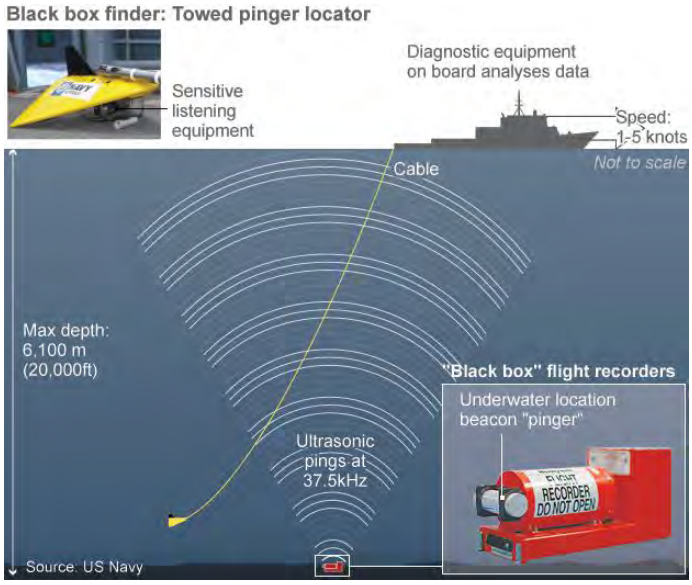

Figure 1.1: The searching of MH370 plane in underwater

1.3 Problem Statements

In underwater industries, UUV is divided into Remotely Operated Underwater Vehicle (ROV), Autonomous Underwater Vehicle (AUV) and Underwater Glider (UG) [3, 4, 5]. These vehicles are the good platform in the underwater industries which cover different kinds of application such as monitoring, inspection, maintenance, communication, and construction [1, 2, 6].

Within the past few years, different types of sensors are installed into UUV to determine the depths of the ocean, monitor, maintain, search and rescue operation. Within the growing of underwater technology, an integrated sensor is designed and developed to perform more challenging underwater operations and even used in military mission.

However, the number of integrated sensor for UUV is limited because most of the sensors utilized in this field are not in the integrated sensor form. Every task performed by UUV is quite expensive because the sensors used in underwater industries are different with the others in terms of waterproof, long-lasting, high durability and other requirement factors

[1, 2]. Furthermore, underwater industries of Malaysia are still much left behind if compared with the other foreign countries. For example, crashing and missing of MH370 plane on 8th March 2014, Australia Navy supplied the advanced underwater technology to perform the searching operation in the Southern Indian Ocean. Therefore, it is necessary to improve the performance of integrated sensor for UUV in terms of the factors requirements.

Furthermore, the underwater sensor for the vehicle is quite expensive if compare to the ground sensor due to the many factors requirements of underwater application. Not only this, most of the sensors available in the market are not suitable to be applied in the underwater industries. For example, altimeter is an instrument used to determine the altitude of an object above the fixed level. However, it is quite expensive and even not suitable applied in underwater vehicles. The performance of the sensor is also one of the problem statement of the integrated sensor. For example, the sensitivity of accelerometer ADXL345 is between +/-2g to +/-16g. Therefore, it is very important to analyse the performance of the sensor based on its sensitivity and accuracy.

In this project, the UUVs must be able to interpret its environment by gathering data information from its sensors. Four suitable sensors are chosen to design and develop an integrated sensor for UUVs to collect the underwater data information. Besides that, a suitable microcontroller platform is required in order to interface with all of the sensors chosen. Therefore, the mechatronics knowledge is required to develop an integrated sensor circuit from all of the sensors and microcontroller. Competency in programming is necessary to program the sensing unit in order to communicate with the processing software. All these are important parameters that need to be considered in order to make the integrated sensor able to collect the accurate measurement for underwater application.

1.4 Objectives

In this project, there are two objectives going to achieve:

1) To design and develop an integrated sensor which consists of IMU sensor, depth sensor, magnetometer and leakage sensor for underwater application.
2) To analyse the performance of integrated sensor with MATLAB real-time simulation in terms of sensitivity and accuracy.

1.5 Scope

The main scope in this project is to design and develop an integrated sensor with the combination of four sensors: 5 DOF IMU sensor, depth sensor, magnetometer and leakage sensor to get data in rotational speed, acceleration, underwater pressure, heading degree and also detects water leakage inside the integrated sensor casing. The overall integrated sensing system should be in a waterproof casing that is purposely used to gather underwater data.

The program is wrote and load into a microcontroller board (Arduino Mega2560). The integrated sensor is interfaced with a microcontroller board and then installed into an UUV. To reduce the delay time and get the more accurate output signal values, all the outputs of the sensors are connected to USB cable with length of 10m. All hardware design works are held in laboratory, the experiments are carried out at swimming pool or underwater laboratory.

The hardware is tested by the microcontroller board and integrated with MATLAB real-time simulation. To get the real-time data from the sensing unit, the measurement unit will be programmed by an Atmel microcontroller. The data from the sensors are used as input for serial monitor and processed in MATLAB real-time simulation to generate the output graph for the performance analysis. The performance of the integrated sensor will be verified based on its sensitivity and accuracy.

1.6 Summary

As the conclusion of this chapter, it explains the importance of integrated sensor utilized in underwater industries. Integrated sensor is limited used in underwater industries because it is designed and developed in terms of many criteria, such as waterproof, long lasting, high durability, accuracy and sensitivity. The aim of this project is to design and develop the ability of each sensor into an integrated sensor and install it into an UUV for data analysis. This project also need to interface the integrated sensor with MATLAB real-time simulation in order to get the accurate real-time data from the sensing unit.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, literature review is discussed from journals or conference papers that are related to this project title in order to achieve the objectives of this project. There are many papers have been studied in order to develop an integrated sensor for UUV. The important hardware and software methodology are extracted from these papers. In hardware development, the microcontrollers and sensors are studied, compared and selected. The suitable microcontroller and sensors are discussed to develop an integrated sensor and interface between them. Therefore, it is very important to study the basic working operation of each type of the sensor before the sensor is selected for the integrated sensor development. In software development, the integrated sensor is communicated with the MATLAB real-time simulation and analysed to get the real-time output graph.

2.2 Microcontroller

Microcontroller is a small integrated circuit that consists of a microprocessor core as a brain of the controller, program memory such as random-access memory (RAM) and programmable input/output peripherals. Microcontrollers have been widely used in the devices and system such as robot system, security system and automatically controlled devices. In this part, there are four types of microcontrollers discussed which are Arduino Uno, Arduino Mega2560, Arduino Nano and Microbox 2000/2000C.

2.2.1 Arduino Uno

According to the journal of M.S.M Aras, M.F. Basar, S.S. Abdullah, F.A. Azis and F. A. Ali [6], it presented the Arduino Uno as shown in Figure 2.1 which is used as a microcontroller of the system. The Arduino Uno is a microcontroller board based on the ATmega 328 by Atmel. It has 14 digital input/output pins and 6 analog inputs. It features 32Kb flash memory, 2Kb SRAM and 16 MHz of clock frequency. It also consists of a USB interface and a power jack for 9V to 12V AC to DC adapter connection. Its operating voltage is 5V. An ICSP header of the Arduino is used to upload programming language from an Integrated Development Environment (IDE). In this journal, the Arduino Uno is used as a microcontroller of the system and interfaced with sensing unit (IMU sensor). The sensing unit is programmed via serial communication of Arduino Uno to obtain UUV's navigation data.

Figure 2.1: Arduino Uno

2.2.2 Arduino Mega2560

According to J. Busquets, J. V. Busquets, A. Perles, R. Mercado, R. Saez, J. J. Serrano, F. Albentosa and J. Gilabert [7], the Arduino Mega2560 is chosen as a main controller unit (MCU) of the sensors as shown in Figure 2.2. Arduino Mega is an 8 bits 100 pins microcontroller board based on the ATmega 2560 by Atmel. It has 8Kb SRAM, 4Kb EEPROM, 256Kb flash memory and 16 MHz clock frequency. It has 54 digital input/output pins and 15 of them can be used as PWM outputs, 16 analogue inputs of 10 bits resolution, 4 UARTs (hardware serial port), I2C and SPI. This platform is the most reliable and high performance 8 bits microcontroller board available today by Arduino. All the components, devices or programming can easily interface with Arduino microcontroller boards because most of the header and connector are compatible. It can be used to connect to a computer with a USB cable or powered with an adapter or battery.

Figure 2.2: Arduino Mega2560

2.2.3 Arduino Nano

According to C. R. Rocha, R. M. Brancoy, L. A. D. Cruzz, M. V. Schollx, M. M. Cezarx and Felipe D [16], the Arduino Uno as shown in Figure 2.3 is chosen as a microcontroller for the Mission Monitoring/Control System (MMCS) to supervise te underwater vehicle. Arduino Nano board is a small and complete board based on the ATmega328. It has 14 digital input/output pins (6 provide PWM output) and 8 analog inputs. It features 32KB flash memory, 2KB SRAM and 16 MHz of clock frequency. It consists of a mini USB interface but no DC power jack. Its operating voltage is 5V. The mini USB header of the board is used to upload programming language from an IDE and supply power.

In this journal, there are three Arduino Nano are used to interface H-bridge, sensors and joystick. One of the Arduino Nano board is used to connect with the IMU and pressure sensor to process the sensor information from IMU and pressure sensor in order to determine UUV's attitude, heading and depth.

Figure 2.3: Arduino Nano