Microcontroller- and Microprocessor-based Embedded System Design and Comparison for Aquaponic Implementation

By

Megat Muhammad Firdaus Bin Othman
1432321164

A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science (Embedded System Design Engineering)

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2016

ACKNOWLEDGEMENT

Primarily, a very sincere appreciation I would like to express to my advisor Mr. Mohammad Asmi Romli through the non-stop provision of my postgraduate study Master of Science (MSc) and related research, for his motivation, patience, and massive knowledge. His guidance always helped me in developing project research and also of thesis writing. I might not have imagined having a well advisor and mentor for my MSc study.

Other than my advisor, a very special thanks I would like to express the rest of my thesis main supervisor Dr. Phaklen Ehkan, and co-supervisor Dr. Shahrul Nizam Yaakob, for their perceptive comments and encouragement, but also for the hard question which incented me to expand my research from different perspectives.

Last but not the least, uncountable thank I would like to appreciate my family; my parents and to my brothers and sister for always be with me through the spiritual support during writing this thesis and generally, my life.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

FAO	Food and Agriculture Organization (FAO)
pH	Potential Hydrogen
DO	Dissolve Oxygen
I^2C	Inter-integrated Circuit
PC	Personal Computer
NFT	Nutrient Film Technique
LAN	Local Area Network
EC	Electro – Conductivity
Temp	Temperature
ORP	Oxidation - Reduction Potential
OS	Operating System
SBC	Single - Board Computer
DC	Direct Current
AC	Alternating Current
NC	Normally Close
RX	Receiver
TX	Transmitter
UART	Universal Asynchronous Receiver/Transmitter

LIST OF SYMBOLS

°C	Temperature
NH_3	Ammonia
%	Percentages
V	Voltage
L/h	Liter per Hour
L/min	Liter per Minute
mA	mili-Ampere
V	Voltage
kWh	kilowatt hour
RM	Malaysia Ringgit

Rekabentuk Sistem Terbenam berasaskan Mikropengawal dan Mikropemproses dan Perbandingan bagi Pelaksanaan Akuaponik

ABSTRAK

Tesis ini membentangkan satu pendekatan yang lebih baik bagi kaedah pengeluaran makanan. Ikan dan tanaman adalah fokus utama pengeluaran makanan. Kedua-dua pengeluaran makanan ikan dan tanaman telah dibangunkan menggunakan gabungan akuakultur dan pertanian. Terma atau kaedah yang berkaitan dengan gabungan ini dipanggil *aquaponics*. Penggunaan sistem *aquaponics* mengandungi air yang sama mengelilingi di dalam tangki ikan dan tanaman. Tujuan utama sistem ini adalah untuk memudahkan peredaran air. Air dari kolam ikan perlu dipam ke dalam tangki *growbed*. Tangki *growbed* pada dasarnya bertindak sebagai tempat di mana najis ikan akan ditapis keluar. Saki-baki daripada ikan boleh wujud dalam bentuk cecair atau zarah-zarah. Pemproses adalah otak dalam mana-mana sistem terbenam. CT-UNO daripada produk Adruino telah digunakan sebagai sistem berasaskan mikropengawal manakala Raspberi-pi adalah sistem berasaskan mikropemproses. Setiap *board* masing-masing telah mempunyai sistem terminal *powering* dan sambungan litar tersendiri. Kedua-dua *boards* ini disambungkan ke input daripada sensor dan output bagi injap dan komunikasi Wi-Fi. Penderia yang digunakan terdiri daripada penderia-penderia paras air, pH, DO, Temp, EC dan ORP. Semua elemen ini adalah kandungan yang boleh mengoptimumkan proses pengeluaran. Penderia paras air telah digunakan untuk mengesan air maksimum dalam *growbed* itu manakala yang lain digunakan untuk merekod dan pengukuran data dari elemen-elemen tangki air ikan seperti pH, NH_3, DO dan suhu. Data yang dibaca oleh penderia larutan telah dihantar kepada pemproses *board* melalui sambungan I^2C. Data tahap penderia yang dikendalikan oleh rintangan yang berdasarkan paras air yang berubah-ubah. Semua data ini adalah pemantauan melalui sambungan tanpa wayar. Data boleh dianalisis daripada penderia yang merekod data dimana ianya boleh dibaca beberapa kali sekiranya diperlukan. Pengesan tahap penderia juga boleh dikategorikan sebagai suis untuk injap yang dipasang di bahagian bawah tangki *growbed*. Apabila air sampai ke tahap maksimum, injap air akan dibuka untuk mengeluarkan air dari growbed itu ke dalam tangki ikan. Air yang keluar ini telah ditapis oleh tanaman dan medium *growbed* itu. Injap air mempunyai sumber kuasa luar yang terdiri daripada *relay* kuasa untuk membuka dan menutup aliran air. Dengan melaksanakan kaedah ini, tanaman mendapat semua keperluan yang diperlukan untuk tumbesaran dengan berkesan. Secara keseluruhannya, sistem yang dibangunkan berfungsi dengan jayanya serta memenuhi objektif projek.

Microcontroller- and Microprocessor-based Embedded System Design and Comparison for Aquaponic Implementation

ABSTRACT

This thesis presents an improved approach of food production methods. Fish and crops are the main focus of food production. Both fish and crops food productions were developed using the combination of aquaculture and agriculture. The term or method related to this combination called aquaponics. Aquaponics system uses the same circulating water contain in the tank for fish and crops. The main purpose of this system is to facilitate water circulation. The water from the fish pond required to be pumped into the growbed tanks. The growbed tanks are essentially acted as a place where the waste of the fish will be filtered out. The residue of the fish can exist in the form of liquid or particles. The processor is the brain of any embedded system. CT-UNO from Adruino product was used as the microcontroller-based while Raspberry-pi board used as microprocessor-based system. Each board has its own powering system terminal and circuit connection. These two boards were connected to an input from sensor and output for the valve and Wi-Fi communication. The sensors composed of water level, pH, DO, EC, Temp and ORP sensor. All these elements were the content that can optimizing production process. A water level sensor was used to check the maximum water in the growbed while the rest were used to record and data measurement from the fish tank water elements such as pH, NH3, DO, and temperature. The data read by the solution sensor was sent to the processor board through I^2C connection. Data of level sensor operated by varying the resistance based on the water level. All these data were monitored through wireless connection. Data can be analyzed from the recorded sensor which can be read several times if needed. Level sensor also can be categorize acted as switch for the valve that mount on the bottom of growbed tank. When the water reach the maximum level, water valve will open to flush the water from the growbed to the fish tank. This output water has been filtered by the crop and medium in the growbed. A water valve has an external power source that consist of power relay to open and close the water flow. By implementing this method, crops get all based requirement to grow up effectively and all in all, the entire system worked successfully and served the project objectives.

CHAPTER 1

INTRODUCTION

1.1 Background

In modern human history, populations around the worldd have many inquiries of food security on a level that has not been seen. The evolution of food feeding for our populations and the technologies used to overcome this issue have generated a unique set of conditions that bring with them unique challenges, and even though important developments in food production and our understanding of food nutrition and food safety, hunger remains to plague millions of people around the world. It is thought that over a billion people in the world are currently undernourished (World Food Programme, 2010). Many factors relate to hunger and decreasing food security in the world today including conflict, poverty, poor agricultural infrastructure, and over deployment of the environment.

The idea of food security is defined by the Food and Agriculture Organization of the United Nations (FAO) in the following way:

> *"Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. Household*

food security is the application of this concept to the family level, with individuals within households as the focus of concern."

The main issues that threaten food security are the intensive resources needed for agricultural activities. Agriculture is by far the largest strain on the world's precious freshwater resources, currently accounting for 70% of the world's freshwater consumption (Pimentel, Berger, Filberto, & Newton, 2004). Some predictions have human consumption of the world's freshwater resources at over 90% by 2025 (2003 International Year of Freshwater, 2003). Increasing water shortage has given rise to an extraordinary water conservation movement, although consumption levels remain high at all time.

Agriculture's requirement of healthy soil presents additional problem in food production, as present estimations are that 38% of global agricultural land is degraded. Soil degradation is the change made by the natural reduction in the soils' potential for productive use, and generally results in reduced yields due to lack of or insufficient nutrients or water availability. Improper land use and poor land management have been singled out as the most important factors leading to soil degradation (The World Bank, 2010). In order to increase value to the soils' nutrient stock, agricultural tendencies have been to adding amounts of fertilizer, which along with herbicides and pesticides has contributed to significant and overcome environmental problems.

When considering food security, access to food is another problem that families and countries face in their daily routine. Frequently, it is difficult or impossible to produce food locally and a worldwide trend for many has been to get food that has been grown far from the place of purchase. However, several developing countries lack the infrastructure such as roads or transportation and storage facilities to make this situation sustainable and effectively. In addition, millions of people become vulnerable to market related supply problems associated with distant producers due this situation.

As focusing on our country, the main requirements of food are vegetables in daily meals. Recently, pesticide usage in growing vegetables are always used in order to increasing the product. Pesticides is dangerous poison that can affect human health and the environment. Due to the lots of pesticides use in the agricultural sector and at home, these toxic chemicals are found in all living things from as small as the life of men. The use of pesticides on vegetables excessively cause the rate of poison and chemical absorb very high at vegetables. This will have an impact of food poisoning to the human if eating these vegetables. Chemical substances used for the purpose of growing of plants if not detoxifies before the sale will result in an absorbed chemicals are high potentially to activate cancer germs in the human body. Similarly, the chemicals agent-based to boost the growth of the fruit if its content usage is not controlled can cause any complications to the nerves and the human body system.

Food security also relating with the environment among different region. Our country does not miss from experiencing natural disasters. The natural disaster cannot be expected. It might be happen any time any place due the current climate changing. Food chains as part of the mesh ecosystem at a food will not be disconnected for all parts of the chain on a regular role. Unexpectedly changes, even giving substantial damage effects will interfere with the mesh food. Natural disasters, environmental pollution, fires, or global warming, will usually cause the interference of mesh food. Needs of food, shelter, and basic health checkup during a disaster is usually not comprehensive. The example to our daily life for this situation is from what happen to our country due to the trans-boundary issues of haze where people need to limit their outside movement and activities.

Another big issue that relate with the food security is about how the food produce. That means what ingredient used, how the ingredient prepared, and where the ingredient from and the preparing location from early process till end of manufacturing food. The issue is contamination of the food that unknown and unseen by the user. This contamination also may cause adverse effect to human health that can happen immediately or in the long time as known as food poisoning.

1.2 Problem Statement

Food is the main source as the basic requirement for human daily life. There are many categories of food in the modern life, but this project focusing on meals of fish and vegetables. Fish aquaculture routine and vegetables growth can be synchronize in the same system. Fish waste produces nutrients that are important as a source of fertilizer to the vegetables. The aquaculture fish water contains of natural chemicals content that are needed for the growth of fish and vegetables. This means fish and vegetables can grow at the same time with a good water quality. The content of water in this system are potential hydrogen (pH), ammonia (NH_3), temperature (ºC), and dissolve oxygen (DO). Most of the farmers who apply this concept does not create or use any system to measure the content of the fish water in the tank. This element must be measuring automatically to reduce hand workers requirement and save maintaining cost. Else, it will be save maintaining time and fast data generating will produce.

1.3 Main Hypothesis

Water quality in the fish tank can be optimized by measuring all element of the fish water tank. A good water quality make the fish and vegetables production high and great quality. The element of the water in the fish tank can be controlled by increase or reduce when there are the recording data and analysis. There is no any chemical solution product is used for growing vegetables as fertilizer that have bad effect for human body which mentioned earlier. Otherwise, good water quality is able to accelerate the process of growth of fish and vegetables. Fish and vegetables health rate become much longer by using this system.

1.4 Project Objectives

This project is focusing on data analysis and developing or upgrading any project that useful for ecosystem in real life. The main objective for this project is to developing a sensing system for recording and measuring data of fish tank water elements such as pH, NH_3, DO, and temperature. All these elements are the content that can optimizing the production process. This project use embedded board communicate with combination of electronic sensors. An improved aquaponics system and management commendations with the goal of improving fish and plant biomass outputs is already designed. Thus was essential an objective of this project to monitoring the system by collecting data several times for analyzing with the actual theory for fish and vegetables. Wireless communication is used for the monitoring phase. Other than that, this project is developing to reducing food security problem where this project producing food of fish and vegetables which may overcome daily food requirement.

1.5 Project Outline

As a medium for collecting data for the fish tank, a separated sensor of each element of fish water is connected with embedded board of raspberry pi board that uses an open source based of Linux operating system (OS). Data type from the sensor will communicating with the board using Inter-integrated Circuit (I^2C) protocol. Then, a user equipped with PC can monitoring the system via wireless internet connection that allow user to manage data for fix sequencing time or on the requesting time. The user can also raise livestock and crops when the results already attained the age of maturity by self-pickup without make purchasing process. It looks like a backup plan of food requirement during natural disaster and pollutions. The food security quality also guaranteed in terms of hygiene and health.

1.6 Thesis Organization

This thesis consists of 5 chapters as following:

Chapter 1 briefly introduces about the issues that threaten food security in agriculture activities and how can it affecting in human's daily life. The explanation of food produced is also briefly presented. Problem statement, hypothesis, objectives, and scope of work are stated clearly.

Chapter 2 conducts a review of previous works. It covers several types of food production methods such as aquaculture, hydroponics and aquaponics. Besides, the comparison of various forms of food production also presented.

Chapter 3 describes the methodology of the entire system set up and explanation of the system functionality. The integration and communication system between main processor and input-output ports are also mentioned in this chapter.

Chapter 4 presents the results and discussions based on the system development in previous chapter. The testing set up and program for each component such as pump, flow sensor, valve, liquid level sensor and pH sensor also discussed in here. Discussion ends up with the analysis of entire system operation.

Chapter 5 summarizes about the findings, conclusions and work recommendations for the future system development. Following these are the lists of references, and appendices.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the theories and principles of food production method. It also reviews some of the related work in related field and includes the conceptual design, implementation platform, and comparison of several of food production.

2.2 Food Production Method

There are several type of food production method throughout the globe. But only some of them will be elaborated in this chapter. The food production methods related in this project include aquaculture, hydroponics, and aquaponics.

2.2.1 Aquaculture

Aquaculture is the farming and rearing of aquatic plants and animals in a fully or semi-controlled environment. There are many species around the world by means of aquaculture including both saltwater and freshwater fish, crustaceans, and molluscs, along with plants such as seaweed. The heritages of aquaculture age back thousands of years. There are different theories as to how the practice came about but it is generally thought to have developed independently in several parts of the world, usually by a lowlying area of land being flooded and stocked with fish during high tide or rainy season and the surrounding human population implementing preliminary aquacultural practices to maintain the fish in order to have a reliable food source (Herminio, 1988).

Freshwater finfish, for the most part of Chinese and Indian carp species, interpretation for the ultimate part of total aquaculture production, and followed by molluscs. Even though it is low in production quantity, several of the minor product groups, such as shrimp and marine fish, have an inconsistent economic significance because of their high unit values. Pacific cupped oyster and the silver carp have been the most harvested species in recent years. By 2006, an aquaculture was provided nearly 50 percent (or 51.7 million tonnes) of all world fisheries production (Aquaculture resources, 2010).

The latter half of the 19th century saw the capacity of commercial fishing increase at unprecedented rates. The result was the plummeting of fish stocks around the world forcing some fisheries, such as the North Atlantic cod fishery, to be completely shut down in order to recover. The state of the world's oceans is in dire circumstances, whereas demand and consumption for seafood is at an all-time high. Aquaculture will be a powerful tool to reconcile this paradox. Current predictions are that aquaculture production will need to reach 80 million tonnes by 2050 to keep pace with seafood consumption (Aquaculture resources, 2010).

There are any different forms of aquaculture take place at variable levels of intensity and scale. In marine culture for instance, organisms are generally cultured in sheltered marine environments, whereas included multi-trophic aquaculture combines many organisms in a tank trying to use the waste from one (such as fish), for the input of another, such as seaweed.

There are lots of important issues are surviving within the world of aquaculture such as decreasing genetic variation associated through fish farming, struggle between wild and farmed animals, propagation of diseases associated with aquaculture's high stocking densities, and waste management. Seashore aquaculture requires massive amounts of water exchange to retain water quality at non-toxic levels. Discovery routines for the wastewater produced in aquaculture has shown to be a difficult and awkward effort.

2.2.2 Hydroponics

The term hydroponics is taken from the Greek words 'hydro' which means water, and 'ponos' is described as labour. It is a technique of growing plants using a mineral nutrient solution in water, but without soil. In traditional agricultural techniques, soil is used as the medium whereby nutrients are dissolved in water. It can then be taken up by the plant roots, even though the soil itself is unnecessary. If nutrients are mixed with the water in which the plants are grown, then the soil medium is not required. Even though the technique is supposed to be a technologically advanced method to grow plants which referred to hydroponic methods, or at least ones with their roots in hydroponics are quite simple to employ and have been used for centuries.

The hydroponics used in this project or applied to a system by using growing media. A system uses certain method of growing media that is not soil are nominated as simply 'soilless culture'. Both soilless culture techniques and hydroponics techniques use a nutrient solution but hydroponics is usually thought of as a subset of soilless culture as it does not employ media to support the root structure of the plants. The capability to grow plants in spaces where soil is not conducive for in-ground agriculture is the great benefit of hydroponics. Otherwise, it is also much more efficient in its water used as water is maintained in a system and can be reused, as different to it saturating through the soil and ultimately refilling the groundwater reserves. By having better control over nutrient levels effects in healthier produces, fertilizers which regularly contribute to pollution are not used, pesticides are not required to deal with pests, and eventually, much complex and more stable crop yields are attained.

Hydroponic techniques have been the issue of many researches during the last century as more of them focus has been put up on the agricultural techniques. At the end, many developments have been prepared in the field and existing hydroponic techniques take many arrangements. Aquaponics systems the other types of systems possible will be further discussed while outlining the hydroponic element, however as noted before, whether the system uses a media or not is a primary difference. If there is no media used in an aquaponic method, the plant roots are exposed to the nutrient solution directly. All of these types of methods are the nutrient film technique (NFT), drain and flood technique, raft technique and deep water culture technique.

2.2.3 Aquaponics

A system of aquaponic which combine the two methods of agricultural production that already stated, recirculating aquaculture and hydroponics. Aquaponics provides a solution to the main issues of these two systems encountered; the need for sustainable ways of filtering or disposing of nutrient-rich fish waste in aquaculture and the need for nutrient-rich water to act as a fertilizer with all of the nutrients and minerals needed for plants grown through hydroponics (Nelson, 2008). Generally, the advantage of combining these two systems produce all-natural nutrient solution for plant growth with an additional of eliminating a waste product which is regularly disposed of as wastewater.

Due to these systems, the fish grown in a freshwater tank secrete wastes through urine and through their gills into their surrounding tank water. Over time, these waste compounds, which are toxic to the fish accumulate and compromise fish health, but can be used as an organic fertilizer for plants (Nelson, 2008). This nutrient-rich waste is used to irrigate a connected hydroponic bed while fertilizing its plant picks at the same time. Mostly, in the form of ammonia via the nutrient are changed by denitrifying bacteria in the hydroponic grow bed into forms easily pick up by plants for its growth and energy. Basically, the hydroponic bed and its harvests served as a bio-filter for the fish waste water before it is returned and re-cleaned into the fish tank. Thus, the waste of one biological system becomes nutrients for another biological system (Diver, 2006). Figure 2.1 shows the conceptual diagram of the nutrient/water flows in a general aquaponic system.