CONTROL AND MONITORING OF SWIMMING POOL MAINTENANCE VIA IOT

HAZIQ NAJMUDDIN BIN ROSDI
B071710697

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This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electronic Engineering Technology (Industrial Electronics) with Honours.

by

HAZIQ NAJMUDDIN BIN ROSDI

B071710697

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....

HAZIQ NAJMUDDIN BIN ROSDI

Alamat Tetap:

No. 28 Jalan Amanputra 1/6,

Taman Amanputra,

47130 Puchong, Selangor

Tarikh: 14/2/2021

Disahkan oleh penyelia:

....

MOHAMAD NA'IM BIN MOHD NASIR

Cop Rasmi Penyelia

MOHAMAD NA'IM BIN MOHD NASIR
PENSYARAH KANAN
JABATAN TEKNOLOGI KEJURUTERAAN
ELEKTRONIK DAN KOMPUTER
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APPROVAL

This report is submitted to the Faculty of Electric and Electronic Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of the Bachelor of Electronic Engineering Technology (Industrial Electronics) with Honours. The member of the supervisory is as follow:

Signature: ……………………………………………………

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ABSTRAK

Kolam renang adalah lembangan besar yang dipenuhi dengan air untuk aktiviti mandi dan juga untuk tujuan rekreasi. Air kolam bukannya 100% air tulen dan dipenuhi dengan bahan pencemaran yang tidak dapat dilihat dengan mata kasar. Bahan pencemaran ini akan menyebabkan perubahan pH yang tidak sesuai untuk pengguna kolam kerana ia akan menyebabkan masalah kesihatan yang tidak diingini. Pembasmi kuman diperlukan untuk membersihkan air kolam. Walau bagaimanapun, beberapa bentuk biproduk akan terbentuk apabila pembasmi kuman ini larut di dalam air. Oleh itu, jenis pembasmi kuman yang akan digunakan mestilah berdasarkan biproduknya. Biproduk ini juga akan mengubah pH air kolam. Air kolam perlu dipantau dan dikendalikan untuk menjaga kualiti air kolam. Walau bagaimanapun, penyelenggaraan kolam kebanyakannya dilakukan secara fizikal dan memerlukan tenaga kerja manusia. Penyelenggaraan ini dapat dilakukan secara automatik dengan menentukan jenis penyelenggaraan, jenis data yang akan diukur dan alat yang ada pada masa kini untuk digunakan untuk memperoleh data dan untuk membentuk sebuah sistem automasi.

ABSTRACT

Swimming pool is a large basin that is filled with water for bathing activities as well as for recreational purposes. The pool water is not 100% pure water and filled with contaminants that cannot be seen with naked eyes. These contaminants will cause the change of pH that is not suitable for the pool users as they will cause unwanted health problems. Disinfectants are needed to sanitize the pool water. However, some form of biproducts will be formed when these disinfectants dissolves in the water. Hence, the type of disinfectant that will be used must be based on their biproducts. These biproducts also will change the pH of the pool water. The pool water needs to be monitored and controlled to maintain a healthy pool water. However, the maintenance of the pool is mostly physically and requires human labour. This maintenance is possible to be automated by determining the type of maintenance, the data type to be measured and the devices available today to be used to acquire the data and to build an automation system.

DEDICATION

I dedicate this thesis to my beloved parents, Hazlina Binti Abu Samah and Rosdi Bin Ahmad, that keeps me well, living like rollercoaster and pushing me to the limit over the years as a proof that something useful and somewhat interesting can come out from me.

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CHAPTER 1

INTRODUCTION

1.1 Background

The earliest swimming pool or public water tank was built by the ancient civilization called “the great bath” over 5000 years ago located at Mohenjo-daro, today’s Pakistani city settlement. The tank is approximately 12 meters by 7 meters wide with 2.4 meters of maximum depth. Later in 305 A.D, a mesmerizing 900 000 square feet pool was built by the Romans equipped with giant fires in the basement beneath the pool’s floor to heat up the pool and uses the columns and walls to transfer the heat to the pool above it (PoolCorp, 2016). During this era, pools were cleaned through filtration and frequent backwashing. This method is not good enough to sanitate the water as it still contains a small portion of bad bacteria, germs, and chemical compounds that might cause unwanted infections to the public (ClearComfort, no date). In the early 1900, engineers found a solution to disinfect water by using chlorine. Bleaching powder was mass produced in 1890 as the Chlorine. Bleaching powder is generally a Calcium Oxychloride ($CaOCl_2$) or commonly called Calcium Hypochlorite $[Ca(OCL)_2*4H_20]$. Chlorine provides unsuitable living conditions for bacteria, algae and other pathogens yet harmless for swimmers. The first attempt of using Chlorine as a pool sterilizer was at the 70 000-gallon Colgate Hoyt Pool located at Brown University, United States in 1910 by graduate student John Wymond Miller Bunker (Olsen, no date). In the 1960s, Ozone was adapted as a method to clean swimming pool water by Europe. This method was discovered in Nice, France to purify drinking water (ClearComfort, no date). Ozone makes the natural organic matter partially oxidized and easily biodegradable. The natural organic matter then can be removed by a subsequent filter. In other word, Ozone enhances the coagulation process of the natural organic matter (Lenntech B.V., 2015). During the period, another method of sanitizing water was discovered is Australia by using saltwater. This method was considered as a simple and cheap way to produce chlorine as the saltwater contains a small amount of Chlorine. Over 80 percent of pools in Australia applied this method as water treatment (ClearComfort, no date). A saltwater contains 10 times less salt compared to ocean (Chertoff, 2017). Later in the 1970s, Ultraviolet was commonly used to sanitize drinking water and wastewater. This method was known by scientists about for over a century yet there's no practical application during this period. Ultraviolet has slowly become a popular method to disinfectant pool water (ClearComfort, no date). Ultraviolet pool sanitizer able to disrupts or alter the DNA or RNA of targeted organic material by emitting a high density germicidal light ray to them. Hence, there's no formation of dangerous chlorine by-products. The optimal wavelength to destroy microorganisms as between 250 nm and 270 nm. Ultraviolet is a form of light waves in the light spectrum and considered as environmentally friendly because it is a physical process rather than chemical process which doesn't produce unwanted chemical compounds in the water (Spectralight Technologies, 2015). In recent years, Direct Hydroxyl Injection was adapted for pool treatment in 2014. This technology was first implemented for industrial water treatment in the early 2000s (ClearComfort, no date). Hydroxyls are unstable and highly oxidative as they are negatively charged radicals. Radicals seek other organisms, minerals or chemicals to be reacted to become stable. When hydroxyls attached to the substances or organisms, their cells will be disrupted, breakdown and destroyed which kill the organisms. Hydroxyl radicals are commonly used in pools and spas to destroy oils, sweat and bacteria without producing toxic by-products. They are also strong enough to kill chlorine-resistant Cryptosporidium Parvum which becoming a huge concern in commercial pools. Direct Hydroxyl Injected Advanced Oxidation Process (AOP) system works by treating the oxygen in surrounding air around the system to generate monoatomic Oxygen, O. The monoatomic Oxygen then injected into the water through tubes to produce a large amount of hydroxyl radicals in the pool pipes. Measurable residual Hydrogen Peroxide (H_2O_2) is left in the water body when these hydroxyls are made (Berens, 2017).

1.2 Problem Statement

Swimming pools are needed to be maintained to keep the water quality and to avoid further damage of the pool. Measurements are needed to be taken corelates to the set variables to determine the suitable action that needed to be taken to combat the variable readings that is out of range from the set values. These measuring and applying appropriate actions are done physically which uses human labour and sometimes not efficient due to human error. There are many types of disinfectants that are available in the market but the produces different amount and toxicity level of by-products with different prices. These actions can be automated but there are already pool automation products available with a quite high price tag.

1.3 Objectives

The objectives of this project are listed as follow:

i. To control swimming pool water quality remotely
ii. To study the data required for pool water disinfection
iii. To develop Android application for water quality monitoring

1.4 Scope of Project

To achieve the stated objectives, there are topics that will be discussed within the scope of this project. There are multiple of disinfection methods that are available involving different chemicals. These disinfectant chemicals will produce by-products when reacted with the pool water. The suitable disinfection method is needed to be determined by the amount and the level of toxicity of their by-products.

Next, pH and disinfectants level of the pool water are vital to be monitored regularly to ensure the cleanliness of the pool water. They are traditionally measured physically by taking sample of the water and doing analysis such as determining the colour of the universal indicator for pH and calculation to determine the PPM of the chlorine. ORP is used to substitute PPM for digital usage. Hence, the optimum pH, ppm and ORP values are needed to be studied.

Finally, a system needed to be designed by determining the suitable devices to be used in this project depends on their price per performance. The working principle of these devices are needed to be discussed for better understandings and a better design. This system requires a microcontroller that receives signals from sensors that will monitor the pool, deploy actions to maintain the pool and able to be controlled remotely via Internet of Things.

CHAPTER 2

LITERATURE REVIEW

2.1 Chemical Contaminants in Swimming Pool

Swimming pools are needed to be sanitized because the pool water contains unwanted or toxic chemical compounds such as organic matter that is not suitable for human usage because of known health concern. One of the main sources of chemical contaminants in the swimming pool is the pool users because humans consist of organic matter such as body fluids, skin and hair. UV protection chemical products are also a factor that contaminates the pool water such as lotions and sunscreens (Teo, Coleman and Khan, 2015). According to a report, swimming pool water is more genotoxic contrasted with tap water and 4 times more genotoxic compared to a pool that was treated with chlorine and UV disinfectants (Plewa, Wagner and Mitch, 2011). Swimming pool that was treated with Bromine shows the highest level of toxicity. This is because of the presence of Bromochlorodimethylhydantoin which is relatively safe to use as it does not need pH correction and is easy to dose. However, a certified laboratory should regulate Dimethylhydantoin because there is no suitable test kit for it (WHO, 2006; Teo, Coleman and Khan, 2015). Pools displayed at daylight (open air pools) have really been determined to be five times less poisonous than indoor pools. Natural condition might damage the chemical compounds in the pool (Liviac *et al.*, 2010; Teo, Coleman and Khan, 2015). Two main organic possible factors to the accumulation of disinfection by-products in pools are organic matter from spring water and body substances from swimmers, such as urea, sweat and skin lipids (Teo, Coleman and Khan, 2015). Expanded time of contact for both disinfectants and organic sources in pools prompts larger amounts of disinfection by-products formation (Kanan and Karanfil, 2011; Teo, Coleman and Khan, 2015). There are reportedly more than 700 distinguishable disinfection by-products in fresh waters, primarily chlorinated drinking waters (Malliarou *et al.*, 2005; Richardson *et al.*, 2007; Teo, Coleman and Khan, 2015). Trihalomethanes are among the most usually observed disinfection by-products in both sterile drinking waters and pool waters with the most recorded Trihalomethanes being chloroform (Teo, Coleman and Khan, 2015). Chloroform had the largest concentration of Trihalomethanes in 10 of the 11 pools tested over a period of 6 months (Weaver *et al.*, 2009; Teo, Coleman and Khan, 2015). Chlorate was imperceptible in 20 pools while chlorate levels exceeds 40 mg / L in another 12 pools. It was theorized that low chlorate concentrations could end in the pools being normally retained at pH 7.2–7.8 as the formation of chlorate lessens under alkaline conditions (Beech *et al.*, 1980; Teo, Coleman and Khan, 2015). In addition, chlorite was recognized distinctly at levels between 0.3–2.5 mg / L in the chlorinated pools (Teo, Coleman and Khan, 2015). The biggest issue is the oxidative chlorite and chlorate vulnerability that could really damage red blood cells (Couri, Abdel-Rahman and Bull, 1982; WHO, 2006; Teo, Coleman and Khan, 2015). Chloroform has also been identified among the Trihalomethane compounds at a higher concentration in chlorinated pools. Studies found that bromoform concentrations significantly increased in pools which used bromine as a disinfectant, whereas chloroform concentrations diminished (Chambon *et al.*, 1983; Benoit and Jackson, 1987; Richardson *et al.*, 2010; Lourencetti *et al.*, 2012; Teo, Coleman and Khan, 2015). Five chlorinated pools had nitrate concentrations of 4–9 mg / L, while two chlorinated / ozonated pools had nitrate concentrations of 16–26 mg / L (Michalski and Mathews, 2007). Ozonated pools generally should have a higher concentration of nitrate. This could be due to oxidation of salts by ozone into nitrate (Singer and Zilli, 1975; Teo, Coleman and Khan, 2015). Furthermore, organic substances contained in source water, when chlorinated, could provide more substantial levels of disinfection by-products (Singer, 1999; Teo, Coleman and Khan, 2015). Compared with different disinfection by-products, the concentration of Trihalomethanes in outdoor pools was seen to be lower than indoor pools (Zwiener *et al.*, 2007; Teo, Coleman and Khan, 2015). Bromoform overloaded in the outdoor pool which was interpreted as becoming prone to composing before the examination due to the lingering bromide particles from past bromine sterilization. Comparable results were obtained where bromoform levels in pools increased due to the higher bromide levels from bromine sterilization (Lourencetti *et al.*, 2012; Teo, Coleman and Khan, 2015). The formation of brominated disinfection by-products strongly influenced in pools treated with chlorine-based disinfectants since the seawater contains high bromide levels (Parinet *et al.*, 2012; Teo, Coleman and Khan, 2015). Bromoform had the highest concentration of chlorinated four chlorine / bromine Trihalomethanes in Miami's open-air saline pools (Beech *et al.*, 1980; Teo, Coleman and Khan, 2015). Bromate is an inert compound normally found in ozone-treated waters containing bromide (von Gunten and Hoigné, 1994; Teo, Coleman and Khan, 2015). In three of the 24 chlorinated indoor pools tested, bromate levels extending from 10–48 μg / L were distinguished. They were however absent in the source water, which generally used chlorine dioxide as the main method of disinfectant (Righi *et al.*, 2014; Teo, Coleman and Khan, 2015). Due to the existence of bromide particles from clouded sodium chloride salt used during the electrochemically generated mixed oxidants purification process, higher concentration levels of brominated disinfection by-products (CHCl2Br2, bromoform, Bromochloroacetonitrile, and Dibromoacetonitrile) were documented in electrochemically generated mixed oxidants-cleaned pools. High pure sodium chloride salts are commercially accessible and could be used to limit the formation of brominated disinfection by-products in electrochemically generated mixed oxidants sanitized pools (Teo, Coleman and Khan, 2015). Bromate has been categorized as a potential carcinogenic substance to humans (Group 2B) ('IARC monographs on the evaluation of carcinogenic risks to humans', 2010; Teo, Coleman and Khan, 2015). The most well-known Haloacetic Acids documented in pools are Monochloroacetic, Dichloroacetic, Trichloroacetic, Monobromoacetic and Dibromoacetic Acids (Legay *et al.*, 2010). Trihalomethanes are more volatile than Haloacetic Acids (Lee *et al.*, 2010; Teo, Coleman and Khan, 2015). Halobenzoquinones were known as disinfection by-products in drinking water over the last year (Zhao *et al.*, 2010; Teo, Coleman and Khan, 2015). Four lotions and four sunscreens were broken down into the water and exposed to a solution of sodium hypochlorite to compare the formulation potential of Halobenzoquinones from different personal care products (Wang *et al.*, 2013; Teo, Coleman and Khan, 2015). 10 Concentrated Halobenzoquinones were reported indoor pools treated with either chlorine or chlorine / UV disinfectants. It was also stated that moisturizers and sunscreens brought by swimmers into the pools are a possible cause of

Halobenzoquinone precursors and may promote the formation of Halobenzoquinones in pool waters (Teo, Coleman and Khan, 2015). The number of Trihalomethanes and Haloacetic Acids detected in outdoor pools compared doubly with indoor pools. This is because the open air pools provide additional external exposure, such as air particles, grass, soil, leaves, rain and creepy crawls, which could also prompt more disinfection by-products precursors in the pool (Simard, Tardif and Rodriguez, 2013; Teo, Coleman and Khan, 2015). The concentration of nitrates in "101 chlorinated pools" recorded average at 8.6 mg / L, while the drinking water used as filling water had a typical concentration of nitrates below 0.1 mg / L (Beech *et al.*, 1980; Teo, Coleman and Khan, 2015). Nitrate concentrations in pool waters seem to be much higher than in tap water with a mean of 1.5 mg / L at concentrations of nitrate between 6.6–24 mg / L for chlorinated pools, 1.2–22 mg / L for ozone / chlorine treated pools, and 11–49 mg / L for electrochemically created blended oxidants treated pools (Lee *et al.*, 2010; Teo, Coleman and Khan, 2015). Urea is likely a significant nitrate origin since chlorine oxidizes the two nitrogen particles in the urea molecule to produce nitrate (Samples, 1959; Beech *et al.*, 1980). Biofilms are found in pools that give an environment for biological activity other than chlorination (Goeres *et al.*, 2004; Teo, Coleman and Khan, 2015). The formation of nitrate may be caused by biological filtration used in certain pools to minimize urea (Teo, Coleman and Khan, 2015). Frequent dilution with fresh water to limit its own accumulation is an effective method of controlling nitrate concentrations (Judd and Bullock, 2003; Teo, Coleman and Khan, 2015). Increasing Trihalomethane formation has also documented under the influence of UV radiation (Liu *et al.*, 2006; Teo, Coleman and Khan, 2015). Indoor pools have shown greater concentrations of N-nitrosodimethylamine (44 ng / L) as opposed to open air pools (7 ng / L) at a similar temperature suggesting that levels of N-nitrosodimethylamine may be reduced from UV photolysis (Walse and Mitch, 2008; Teo, Coleman and Khan, 2015). Concentrations of total disinfection by-products (Trihalomethanes, Haloacetic Acids, haloacetonitriles and chloral hydrate) were 180 µg/L, 33 µg/L and 140 µg/L for pools treated with chlorine, ozone/chlorine and electrochemically generated mixed oxidant respectively (Lee *et al.*, 2010; Teo, Coleman and Khan, 2015). The combination of UV and chlorine used in pools lessened N-nitrosodimethylamine concentration levels, as the pools implementing UV treatment showed lower N-nitrosodimethylamine concentration levels (Walse and Mitch, 2008; Teo, Coleman and Khan, 2015). UV treatment can be effective for N-nitrosamine disruption when pool water produces relatively high concentrations of N-nitrosamine in comparison to chloramines and secondary chlorinated amines, but it is not hazardous to have a net formation of N-nitrosamine (Teo, Coleman and Khan, 2015). UV light from pool waters of 222 nm and 254 nm led to the formation of some other N-disinfection by-products consisting of DCAN and Cyanogens chloride and to the elimination of others such as chloramines (Weng, Li and Blatchley, 2012; Teo, Coleman and Khan, 2015). Concentrations of chloroform and CHCl2Br increased significantly, yet bromoform, and concentrations of CHClBr2 decreased at a wavelength of 254 nm in pools treated with medium pressure UV lights (Cassan *et al.*, 2006; Teo, Coleman and Khan, 2015). UV radiation could also increase the reactivity of organic matter from anthropogenic sources to chlorination which induces extra Trihalomethane formation (Teo, Coleman and Khan, 2015). The combination of ozone / UV with lower doses of chlorine used in the pools resulted in lower N-nitrosodimethylamine levels (Walse and Mitch, 2008; Teo, Coleman and Khan, 2015). The most Haloacetic Acids found in chlorinated pools compared with ozone / chlorine and electrochemically generated mixed oxidant treated pools ((Lee *et al.*, 2010; Teo, Coleman and Khan, 2015). The cumulative mass of disinfectants applied to the pools will affect disinfection by-products formation. Even so, before direct interactions can be made, the amount of pollutants created in a pool and the mass of disinfectants used for each situation should be measured. The perfect purification procedure would be one that achieves efficient cleaning with insignificant disinfection by-products formation with known health hazards. Based on the information gathered in (Table 2), there is evidence that the use of chlorine at reduced concentrations with the addition of other treatment methods, such as UV or ozone, leads to lower concentrations of disinfection by-products in pools. For the selection of disinfection processes an appropriate focus on efficient pathogen control must always be maintained. Another efficient treatment, such as periodic backwashing and shock chlorination of pool water, can reduce the measurement of toxins in pools, thus reducing the measurement of disinfectants necessary to maintain the quality of pool water. Effective treatment would