UNIVERSITI SAINS MALAYSIA

Laporan Akhir Projek Penyelidikan Jangka Pendek

Development of Prototype of Water Quality Monitoring System for Fresh Water Fish Culture

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TECHNICAL REPORT

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1. Introduction

Aquaculture is one of the important sectors in agriculture. Aquaculture is the activity of farming aquatic organism such as fish, crustaceans, shellfish and even aquatic plants. Recent statistics provided by the Department of Fisheries Malaysia (DOF) has expected that aquaculture industry will generate almost RM 1.39 billion of income per year. This huge amount has depicted the potential of this industry to be developed.

Aquaculture sector is very profitable since the demand is quite high, either from local demand or international demand. However, this sector has high risk where livestock is susceptible to diseases, which bring to death. Indeed, the deaths of many livestock have caused massive losses to fish farmer. The main cause of diseases is caused by polluted water as shown in Figure 1.

Figure 1: Dead Fishes

Water quality is a field to investigate the level of water quality whether the water is polluted or clean and suitable for various type of applications such as farming, aquaculture, industry and domestic. There are several parameters of water quality, which can determine the level of quality for the water sample such as dissolved ammonia, pH, temperature and dissolved oxygen.

Among all of the water quality parameters, dissolved ammonia is the most important after dissolved oxygen. In small amounts of dissolved ammonia, it can cause gill damage and stress. Any aquatic life which is exposed to low levels of dissolved ammonia over time will have poor growth and susceptible to bacterial infections. At higher concentration, dissolved ammonia can kill most of aquatic life and many inexplicable production fatalities have been caused by dissolved ammonia. However, the dissolved ammonia lethal limit to the fish is depending on fish species because each species have different resistance ability toward the dissolved ammonia.

Real time monitoring system is a system, which is able to monitor continuously in situ. The real time monitoring of dissolved ammonia is needed because the concentration of dissolved ammonia is no longer accurate if the water sample has to be transferred to lab for testing.

2. The effect of dissolved ammonia to the aquatic life

Dissolved ammonia is one of the water quality parameter, which is very crucial to be monitored continuously. This is because dissolved ammonia can cause stress and gill damage even in a small amount. Any aquatic life exposed to low levels of ammonia over time will have poor growth and more susceptible to bacterial infections. Some aqua culturist call dissolved ammonia is a silent killer because most of the production losses are caused by the toxicity of dissolved ammonia.

The only way for an aqua culturist to know whether there is dissolve ammonia exist in water or not is to test the water because the dissolved ammonia is colorless and odorless. The concentration of dissolved ammonia in water samples which are transferred to the laboratory are not reliable, as the level of concentration often will increase during the transfer due to bacterial decomposition of organic matter. Therefore, the monitoring of dissolved ammonia should be done in real time.

2.1 Ammonia Test Kit

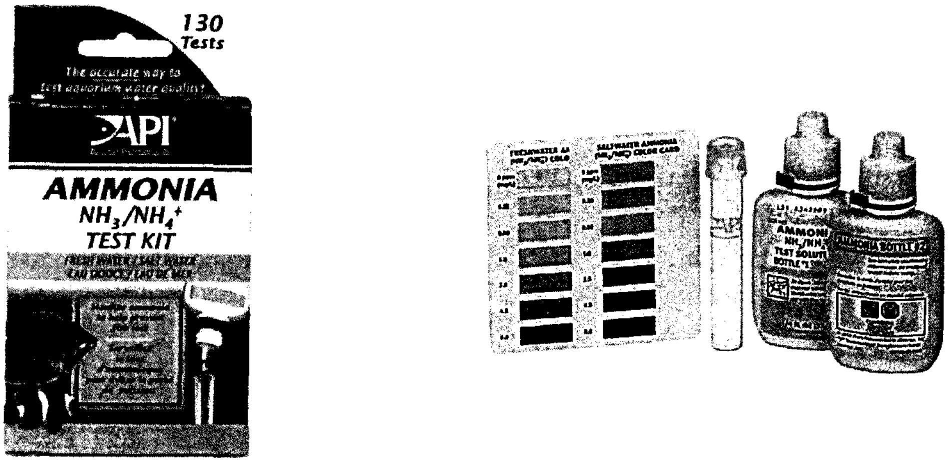


Figure 2: Ammonia test kit

Traditional method to measure the concentration of dissolved ammonia is by using ammonia test kit as shown in Figure 2. The price of ammonia test kit is cheap and available at most of aquarium shop. However, the ammonia test kit does not give the reading of dissolved ammonia directly. The ammonia test kit actually measure the Total Ammonia Nitrogen (TAN) in parts per million (ppm) which is similar to miligrams per liter (mg/L) unit. The ammonia test kit can measure TAN value from 0 ppm to 8 ppm (Aquarium Pharmaceuticals, 2004). TAN is a total or the sum of Ammonia (NH_3) and Ammonium (NH_4^+) in water.

NH_3 is called as dissolved ammonia or unionized ammonia which is very toxic to the aquatic life while NH_4^+ is called as ammonium ion or ionized ammonia which is safe and not harm to aquatic life at all. By using ammonia test kit, there are 2 methods for measuring the concentration of dissolved ammonia. The first method is by using formulas as in Equation 2.1, 2.2 and 2.3 and another method is by referring to the percentage of un-ionized ammonia table as in Table 1. Both methods require user to know the value of pH, temperature and TAN of the sample at first.

The formulae to calculate the dissolved ammonia is as below:

$$pKa = 0.0901821 + \frac{2729.92}{T + 273.15} \tag{2.1}$$

Where,
pKa = Dissociation constant
T = Temperature of the sample in degree Celcius unit (°C)

$$f = {}^{1}\!/_{[10^{(pKa-pH)} + 1]} \tag{2.2}$$

Where,
f = fraction of total ammonia that is unionized
pKa = Dissociation constant from equation 2.1
pH = pH of the sample

$$NH_3 = f * TAN \tag{2.3}$$

Where,
NH_3 = Unionized ammonia
f = Fraction of total ammonia that is unionized from equation 2.2
TAN = The value of Total Ammonia Nitrogen obtained from ammonia test kit

Table 1: Percentage of un-ionized ammonia at different pH values and temperatures

	Temperature °C								
pH	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**
7.0	0.30	0.34	0.40	0.46	0.52	0.60	0.70	0.81	0.95
7.2	0.47	0.54	0.63	0.72	0.82	0.95	1.10	1.27	1.50
7.4	0.74	0.86	0.99	1.14	1.30	1.50	1.73	2.00	2.36
7.6	1.17	1.35	1.56	1.79	2.05	2.35	2.72	3.13	3.69
7.8	1.84	2.12	2.45	2.80	3.21	3.68	4.24	4.88	5.72
8.0	2.88	3.32	3.83	4.37	4.99	5.71	6.55	7.52	8.77
8.2	4.49	5.16	5.94	6.76	7.68	8.75	10.00	11.41	13.22
8.4	6.93	7.94	9.09	10.30	11.65	13.20	14.98	16.96	19.46
8.6	10.56	12.03	13.68	15.40	17.28	19.42	21.83	24.45	27.68
8.8	15.76	17.82	20.08	22.38	24.88	27.64	30.68	33.90	37.76
9.0	22.87	25.57	28.47	31.37	34.42	37.71	41.23	44.84	49.02
9.2	31.97	35.25	38.69	42.01	45.41	48.96	52.65	56.30	60.38
9.4	42.68	46.32	50.00	53.45	56.86	60.33	63.79	67.12	70.72
9.6	54.14	57.77	61.31	64.54	67.63	70.67	73.63	76.39	79.29
9.8	65.17	68.43	71.53	74.25	76.81	79.25	81.57	83.68	85.85
10.0	74.78	77.46	79.92	82.05	84.00	85.82	87.52	89.05	90.58
10.2	82.45	84.48	86.32	87.87	89.27	90.56	91.75	92.80	93.84

Table 1 is an example of Ammonia, commonly used as a reference by user who uses ammonia test kit. The table is not detailed, for example this table is not display the percentage of unionized ammonia at temperature of 27°C and pH 7.5. The Table 1 only shows the percentage of unionized ammonia, thus to get the concentration of unionized ammonia in the sample, the user must multiply the percentage of unionized ammonia according to the pH and temperature of the sample from Table 1 with the value of TAN which is obtained from ammonia test kit. From Table 1, it is clearly indicates that the percentage of unionized ammonia become larger as the pH and temperature is increasing. In short, as pH and temperature is increasing, there is an increasing in un-ionized ammonia, which is very toxic to aquatic life.

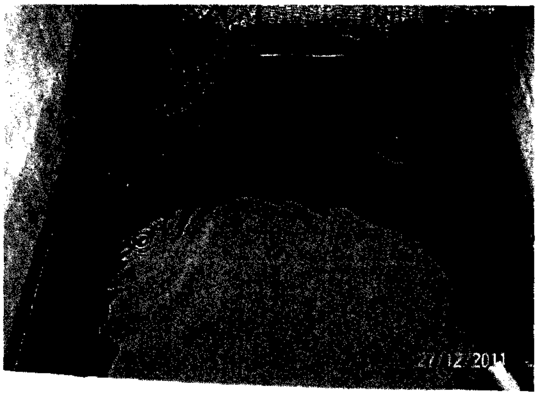


Figure 3: Fish pond water

Figure 4: Top view of sample water from fish pond

Normally, the water sample from fishpond is very cloudy or high in turbidity such in Figure 3 and Figure 4. Ammonia test kit cannot measure the cloudy water. Thus, the water sample must be filtered first by using filter paper until become clear as illustrated in Figure 5. Sometimes, the filtering process must be done for several times until the sample become clear. The filtering process may take long time from 15 minute up to 60 minute depend on the level of the water cloudy. Figure 5 shows the labeled picture of filtering process.

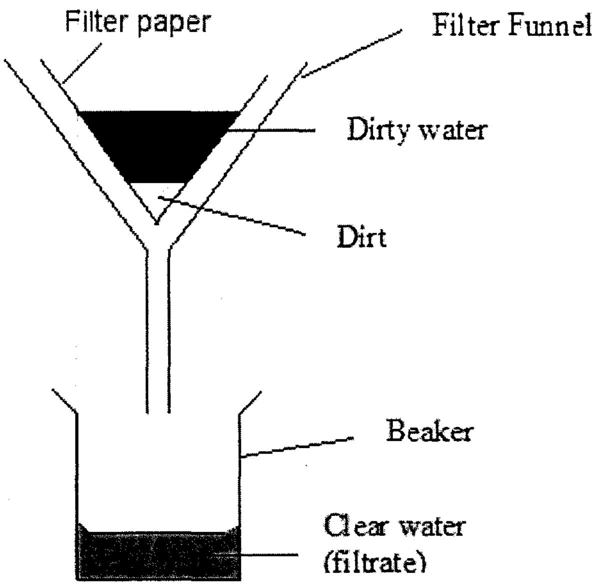


Figure 5: Labeled picture of filtering process

The test solution to measure TAN is toxic to aquatic life. Thus, user must be careful to avoid the test solutions from getting into fish tank or aquarium.
Below is the procedure on how to measure TAN by using ammonia test kit and Figure 6 is a graphical instruction for measuring TAN.

1) Fill a clean test tube with 5 ml of water to be tested (to the line on the tube).
2) Add 8 drops from Ammonia Test Solution Bottle #1, holding the dropper bottle upside down in a completely vertical position to assure uniformity of drops added to the water sample.
3) Add 8 drops from Ammonia Test Solution Bottle #2, holding the dropper bottle upside down in a completely vertical position to assure uniformity of drops added to the water sample.
4) Cap the test tube and shake vigorously for 5 seconds. Do not hold finger over the open end of the tube, as this may affect the test results.
5) Wait 5 minutes for the colour to develop.
6) Read the test results by matching the test solution against the Ammonia Color Chart. The tube should be viewed against the white area beside the colour chart. Colour comparisons are best made in a well-lit area. The closest match indicates the ppm (mg/L) of ammonia in the water sample. Rinse the test tube with clean water after each use.

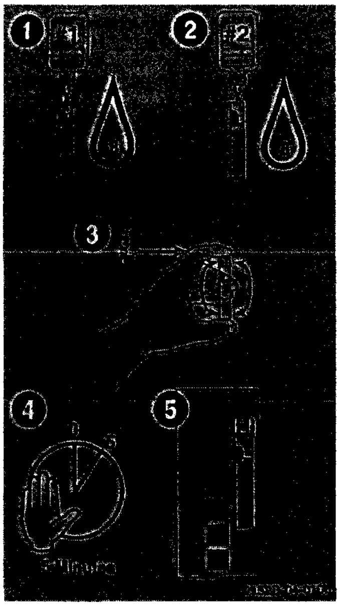


Figure 6: Graphical instruction for measuring TAN by using ammonia test kit

From the above, it can be concluded that the ammonia test kit has many drawbacks. At first, the ammonia test kit deploys test solution to measure the concentration of TAN in water sample. This test solution is toxic to aquatic life.Thus, the user must be careful when deal with the test solution and avoid from getting test solution into the fish tank. In short, the ammonia test kit is not safe to be used because of using test solution to measure the concentration of TAN.

Second, the job of measuring the concentration of TAN by using ammonia test kit will take a long time and will be a tedious job to be done if we have many water samples to be tested. This is because the ammonia test kit only can be used to test the clear water sample. If the water sample is not clear, the water sample needs to be filtered first. The filtering process could be a long time process. When the water sample is clear, then the water sample need to be well mixed up with 2 test solutions and then, the user has to wait for 5 minute for the colour of the sample to be developed. After that, the colour of the sample has to be compared with the TAN colour card (Aquarium Pharmaceuticals, 2004). However, the value obtained from this is not already dissolved ammonia. Thus, the user needs to measure the temperature and pH of the water sample. With these three parameters which are TAN, temperature and pH, the user can measure the concentration of dissolve ammonia by using the formulae as in Equation 2.1, 2.2 and 2.3 or by referring to the table as in Table 1.

Third, the reading of TAN obtained from ammonia test kit is not accurate. This is because the colour scale is coarse and not detail as in Figure 7. For example, ammonia test kit cannot measure the concentration of TAN at 3 ppm, 5 ppm, 6 ppm and 7 ppm.

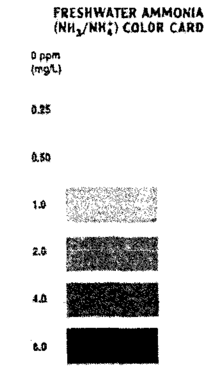


Figure 7: Ammonia colour card for freshwater application

Fourth, there are several factors which possible to make the user make a mistake or error when measuring the concentration of TAN by using ammonia test kit. One of the common mistake done by user is the user is mismatch the colour of the sample with the colour on the ammonia colour card. Thus, result in wrong measurement of the concentration of dissolved ammonia. This is because, sometimes the developed colour of the water sample is almost resembling two colours on the ammonia colour card which make the user hard to determine which reading is the best representing the developed colour of the water sample. Others, the user also possible to do wrong calculation of dissolved ammonia. The user also tends to do parallax error when taking 5ml of water sample as in step number 1 in the procedures on how to use ammonia test kit. Sometimes, the user may put much or little drop of test solution into water sample which can effect to the colour to be developed.

2.2 Spectrophotometer

Figure 8: Spectrophotometer model DR2800

Nowadays, researchers from various disciplines such as biology, chemical and environment use a sophisticated instrument to measure the concentration of dissolved ammonia so called spectrophotometer as in Figure 8. The spectrophotometer is a popular instrument for measuring variety of chemical nutrient by sampling method

and has been used in most research centre such as National Fish Health Research Centre (Nafish) in Batu Maung, Penang and also at laboratory in University Sains Malaysia such as Environment Laboratory in Civil Engineering School and also in Chemical Analysis Laboratory in Chemical Engineering School for measuring variety of chemical nutrient in a sample such as dissolved ammonia, nitrate and calcium.
Based on Beer's law, the amount of light absorbed by a material is proportional to the concentration of the absorbing material. Thus, the spectrophotometer is designed by applying the Beer's law to measure the amount of light which is absorbed after it passes through a sample solution whereby the amount of light which is absorbed is proportional to the concentration of the sample solution.

There are many methods, which can be used to measure the concentration of dissolved ammonia by using spectrophotometer. Each method will be difference in term of the reagent, which is used, the procedure to measure, the time it take and also the range of available measurement. For example is the Salicylate method. The available range of measurement for this method is from 0.01 to 0.5 mg/L NH_3-N. This method use Ammonia Cyanurate Reagent Pillows and Ammonia Salicylate Reagent pillows as reagents. The second example is Nessler method. The range of available measurement for this method is from 0.02 to 2.50 mg/L NH_3-N. This method use Ammonia Nitrogen Reagent set which comprised of Nessler Reagent, mineral stabilizer and Polyvinyl Alcohol Dispersing Agent.

Both methods may be used to measure the concentration of dissolved ammonia in water, wastewater and seawater. Thus, Nessler method is chosen for measuring the concentration of dissolved ammonia in a water sample because the available range of measurement is wider compared to Salicylate method even though the Salicylate method is easier in term of procedure to measure. The procedure to use spectrophotometer for measuring the concentration of dissolved ammonia by using Nessler method is as in Table 2.2. By using Nessler method, Spectrophotometer only can measure the concentration of dissolved ammonia in the range of 0.02 to 2.50 mg/L NH_3–N. If the concentration of the water sample if greater than 2.50 mg/L, the spectrophotometer will display the concentration is over the limit. Thus, the water sample needs to be diluted first. The dilution process could be a challenging process to be done because we do not know how much we have to dilute the water sample since we do not know the original concentration of the sample. Sometimes, the dilution process has to be done for several times until the spectrophotometer can read the concentration of the sample. Then, the value of concentration obtained from the spectrophotometer must be multiplied with the dilution factor to get the original concentration of the water sample. The formulae to calculate the dilution factor is as in equation 2.4:

$$DILUTION\ FACTOR = \frac{V_1}{V_2} \tag{2.4}$$

V_1 = Final Volume
V_2 = Aliquot volume

Where,
Final Volume (V_1) = Aliquot volume (V_2) + Diluent volume
Aliquot is the original concentration of the sample (Fankhauser, 2012). The diluents is used in this dilution process is deionized water. The final volume is a volume of aliquot, which is added with or mixed up with a volume of diluents.

Even though the spectrophotometer is a very sophisticated instrument in this age, the spectrophotometer still has several drawbacks. The drawbacks are as below.
The spectrophotometer is able to measure variety of chemical nutrients in a water sample but the spectrophotometer depends on the type of reagent, which is used. Without recommended chemical reagents, the spectrophotometer will be useless. For each chemical nutrient, it will have the recommended reagents to be used and it depends on the method chosen by user. Since the spectrophotometer use chemical reagent, the spectrophotometer is not suitable to be utilized as a continuous monitoring system, which is very important for measuring the concentration of dissolved ammonia in situ. Furthermore, some of the reagent like Nessler reagent is toxic and corrosive which is very dangerous to operator and aquatic life if the reagent is felt down into the fish tank.

Second, the range of available measurement for concentration of dissolved ammonia is too small and the available range is depending on the method that is used. For example, the range of available measurement for concentration of dissolved ammonia by using Nessler method is from 0.02 to 2.50 mg/L NH_3–N while Salicylate method is from 0.01 to 0.5 mg/L NH_3-N (Hach, 2007).

Third, measuring the concentration of dissolved ammonia by using spectrophotometer take a long time. This is because, the spectrophotometer need to be calibrated for each time of measurement to be made as stated in step number ten in Table 2.2. Others, if the concentration of the sample is over the limit, the sample must be diluted first. As mentioned before, the dilution process is not an easy process and sometime may take a long time.

Fourth, the user is vulnerable to do mistake when using spectrophotometer for measuring the concentration of dissolved ammonia. This is because there are many steps must be followed one by one carefully by the user as stated in Table 2.2. For example, the user is possible to do parallax error when taking the sample to the certain amount of volume and also during dilution process. The user also possible to do mistake while mixing reagent with the sample whereby the user might put much reagent or less into the sample. The user also might do wrong calculation of dilution factor during dilution process. Thus, the person who operates the spectrophotometer must be a person who has ample knowledge to operate it, a person who have basic chemical knowledge especially for dilution process and a person who is really careful and patient.

2.3 Dissolved ammonia sensor

Therefore, a system or an instrument to measure the concentration of dissolved ammonia continuously, fast, safe, reliable and easy to be used for aquaculture application is needed to be designed. Thus, any suitable dissolved ammonia sensor is required to be reviewed for being utilized in the proposed system. In 2008, Kerstin Waich et al from Institute of Analytical Chemistry and Radiochemistry, Graz University of Technology in Graz, Austria present new ammonia sensitive materials consisting of fluorescent pH indicators embedded into different cellulose esters for detection of dissolved ammonia. The materials are used to detect dissolved ammonia are Cellulose acetate propionate combined with Eosin ethylester. The range of detection is between 5 and 1000 μg/L and the response time is between 20-30 minutes.

In 2007, Waich et al from Institute of Analytical Chemistry, Graz, Austria have developed a fibre optic sensor for the detection of dissolved ammonia in concentration from 0.5μg L^{-1} to 100 μg L^{-1}. The sensing principle of the sensor is based on an immobilized fluorescent pH indicator, which is deprotonated by ammonia. The sensor response time is 15 minutes. In 2005, Shiquan Tao et al from Diagnostic Instrumentation and Analysis Laboratory, Mississippi State University, United State of America have developed an optical fiber probes for sensing ammonia vapor in gas samples and trace ammonia dissolved in water. The concept used to measure the concentration of dissolved ammonia is similar to the concept for measuring ammonia in vapor form. Henry's law indicates that it is possible to detect ammonia in water through detecting ammonia vapor in a gas phase in equilibrium with the aqueous solution.

The fiber optic probe for measuring the concentration of dissolved ammonia in water is coated with PDMS (poly dimethyl silloxane) protection and use Bromocresol purple as a chemical reagent to convert the dissolved ammonia into vapor form. The PDMS protection is a hydrophobic polymer is used to block liquid water from entering the porous silica coating layer. Without PDMS protection, the liquid water may de-activate the functionality of the sensor. The fiber optic probe coated with PDMS protection able to detect the concentration of dissolved ammonia from 0.5ppm to 5 ppm however the probe response time is about 5 to 10 minutes.

In 2004, Zenghong Xie et al from Fuzhou University in Fujian China have developed a porous plastic fiber probe for detection of dissolved ammonia. The porous plastic fiber probe has been developed based on the cross-linking polymerization technique. The probe responds to dissolved ammonia over the linear concentration range of 3.4 to 155 ppm and it is not influenced by pH in solution. The response time is about 22 minutes under the optimum condition.

In 2003, King Tong Lau et al from National Centre for Sensor Research, Dublin, Ireland have developed a non-reversible solid-state ammonia sensor based on Berthelot's reaction. The sensor measures the concentration of dissolved ammonia by using the concept of image processing technique as being used in spectrophotometer.

This method requires Cellulose, sodium nitroprusside, sodium dichloroisocyanourate, Lithium hydroxide, ammonium chloride and sodium salicylate as chemicals and reagents. By using of a semi-automatic imaging system, the detection range available for this sensor is between 0.5 and 10ppm of dissolved ammonia. The response time of the sensor is about 3 minutes.

Based on the revision above, there is no dissolved ammonia sensor for monitoring the concentration of dissolved ammonia continuously for aquaculture application. This is because the response time of the sensor is too long which make the real time monitoring becomes impossible to be done. Some of the sensor use chemical reagent to convert the dissolved ammonia into vapor form since the sensor actually able to read ammonia in vapor form only. Furthermore, some of the sensor range of detection is too small in range of µg/L which is out of range for aquaculture application. The suitable range of detection for dissolved ammonia for aquaculture application is from 0 ppm to 15 ppm which covers up for all of fresh water fish species.

2.4 The source of dissolved ammonia in water

Therefore, a new alternative should be found for monitoring the concentration of dissolved ammonia in real time without using dissolved ammonia sensor. Thus, the theory of existing of dissolved ammonia in water should be studied to find the new solution for this problem. The main source of ammonia in aquaculture systems is fish food. When the fish food is eaten by fish, it is metabolized into the nutrients and energy used for growth and survival. As with all animals, there is a waste produced by these normal metabolic processes. The major metabolic waste product excreted by fish is Ammonia. It is excreted through the urine and also across the gill membranes. Others, the source of ammonia in water is due to uneaten fish food and also results from the decomposition of organic matter as illustrated in Figure 9 .

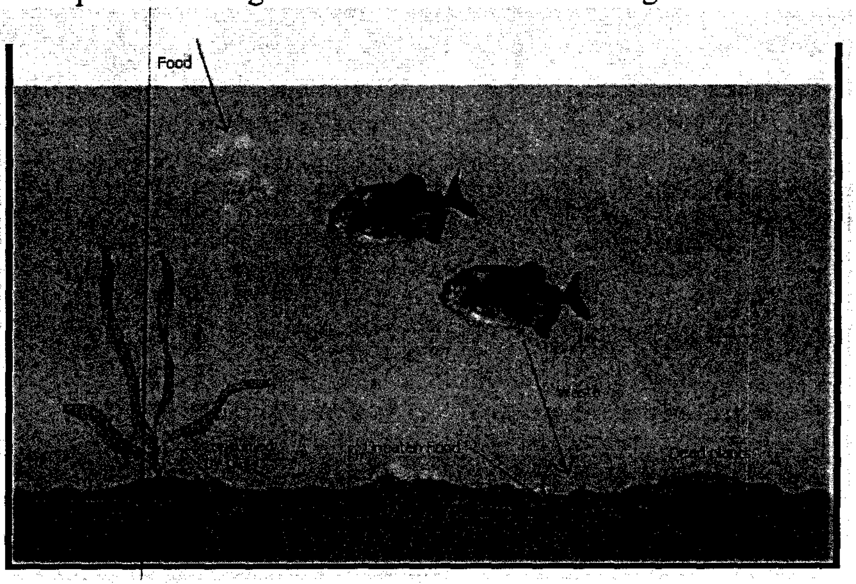


Figure 9: The Nitrogen cycle in Aquaculture system

From Figure 9, it can be noticed that the existence of dissolved ammonia in water is occurred naturally from the waste excreted by aquatic life, uneaten food caused by overfeeding and also the decomposition of organic matter such as dead plants. Some of the causes cannot be controlled such as the waste excreted by aquatic life and also the decomposition of organic matter. Thus, it is impossible to avoid the dissolved ammonia from existing in water because this is a natural process of Nitrogen cycle in Aquaculture system.

2.5 The range of dissolved ammonia in aquaculture system

Dissolved ammonia is a chemical nutrient that is undesirable to exist in aquaculture system. This is because as mentioned before, dissolved ammonia is very toxic to aquatic life and can cause stress to the aquatic life even though the aquatic life is exposed to the small amount of concentration of dissolved ammonia. Therefore, the best water for aquaculture is the water, which has no dissolved ammonia. In another words, the reading of concentration of dissolved ammonia in the water must be at 0 ppm at any time.

However, this is impossible because the existence of dissolved ammonia come from the natural in the process of nitrogen cycle as mentioned earlier. Each species of fish may have different resistance ability to concentration of dissolved ammonia. There are some species of fish which have high resistance to dissolved ammonia and there is also a very sensitive fish species which can die easily even though the species is exposed to a low concentration of dissolved ammonia. Thus, the allowable range of dissolved ammonia in aquaculture system will be depending on the fish species.

Dissolved ammonia concentration in catfish ponds varies from 0.6 to 12.0 ppm. When concentration is higher than 7 ppm, the health of catfish is impaired and at above than 10 ppm, the catfish will die. However, a low dissolved ammonia level which is from 0.2 to 2.0 ppm is beneficial for the health of catfish.

Catfish is chosen as a benchmark to determine the range of dissolved ammonia in aquaculture system because catfish can sustain in high level of dissolved ammonia.This meant that, if we are able to design a system which can measure the high level of dissolved ammonia as in catfish pond, the designed system also possible to measure the low level of dissolved ammonia in a more sensitive fish pond such as in salmonids fish pond. In another words, if the designed system is able to measure the concentration of dissolved ammonia for catfish culture application, the designed system also be able to measure the concentration of dissolved ammonia for all species of fresh water fish. As a conclusion, the proposed system must be able to measure the concentration of dissolved ammonia from 0 to 15 ppm which this range will cover up all of fresh water fish species.

2.6 The relationship of dissolved ammonia with other parameters

In water, there are two forms of ammonia which are ionized Ammonia (NH_4^+) and unionized ammonia (NH_3). Ionized ammonia which has positive electrical charge is also being called as ammonium ion while unionized ammonia, (abbreviated as UIA), which has no charge is being called as dissolved ammonia which is very toxic to aquatic life.

The combination of these two forms together is called as Total Ammonia Nitrogen, or TAN as shown in Equation 2.5.

$$TAN = NH_3 + NH_4^+ \quad (2.5)$$

The Equation 2.6 shows that the chemical reaction happen when the ammonia dissolve in water.

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^- \quad (2.6)$$

The chemical equation in Equation 2.6 has the doubled headed arrow which shows that the chemical reaction can go either way to the left or to the right of the equation depending on the pH. An increase in hydroxyl ions (OH^-) will pushed the equilibrium to the left and more dissolved ammonia is formed. In brief, the ammonium ions and hydroxyl ion could combine to form the dissolved ammonia and water when pH is higher and the chemical reaction will reverse back when the pH is lower).

The pH and water temperature will affect which form of ammonia whether dissolved ammonia or ammonium ion is predominant at any given time in an aquatic system as in Figure 10 and Figure 11.

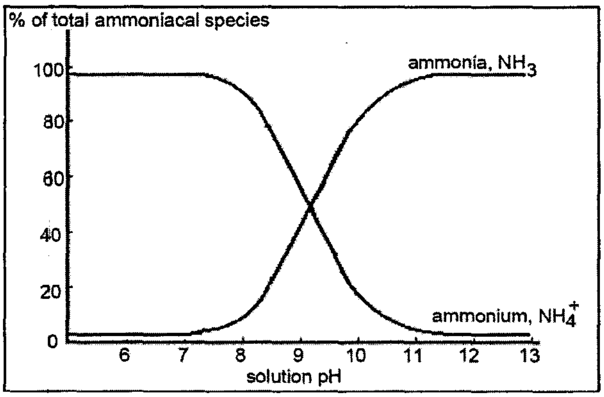


Figure 10: Percentage of Ammonia and Ammonium based on pH

Figure 10 indicates that the dissolved ammonia become higher at higher pH while ammonium ion becomes lower at higher pH and vice versa.

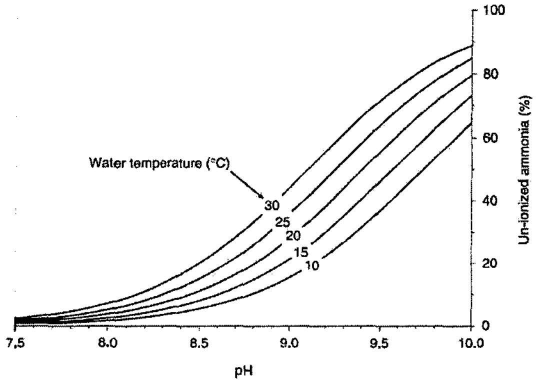


Figure 11: Percentage of Unionized ammonia based on pH and water temperature

Figure 11 shows that the percentage of unionized ammonia becomes larger when the pH and water temperature is increasing. Based on Equation 2.6, Figure 10 and Figure 11, it clearly can be concluded that the pH and temperature can affect the concentration of dissolved ammonia in water.

The main factors that influence the equilibrium between dissolved ammonia and ammonium ions are pH and temperature. Raising pH by one unit can cause the dissolved ammonia concentration to increase nearly tenfold, while a 5°C temperature increase can cause an increase of 40-50%.

Therefore, there must be a relationship to relate the dissolved ammonia to the pH and temperature.

Since we know that:

$TAN = NH_3 + NH_4^+$ from Equation 2.5 and

$NH_3 = TAN * f$ from Equation 2.3

Then we can solve by substituting Equation 2.5 into Equation 2.3:

$NH_3 = [NH_3 + NH_4^+]*f$

Next, multiply f into the components in the bracket:

$NH_3 = fNH_3 + fNH_4^+$

Then, move fNH_3 to the left hand side of the equation:

$NH_3 - fNH_3 = fNH_4^+$

Factorize NH_3:

$NH_3 (1-f) = fNH_4^+$

Move (1-f) to the right hand side of the equation:

$$NH_3 = \frac{fNH_4^+}{(1-f)}$$

Rearrange the equation:

$$NH_3 = \frac{f}{(1-f)} * NH_4^+ \qquad (2.7)$$

Where f is from Equation 2.2:

$$f = {}^{1}/_{[10^{(pKa-pH)} + 1]}$$

And pKa is from Equation 2.1:

$$pKa = 0.0901821 + \frac{2729.92}{T + 273.15}$$

Equation 2.7 shows that this is another way to get the concentration of dissolved ammonia by knowing the concentration of ammonium, pH and temperature of the water sample. The concentration of ammonium, pH and temperature are possible to be measured continuously because there are many sensors in the market which are reliable, safe and non-destructive typed. These three sensors can be integrated in a system to calculate and display the concentration of dissolved ammonia at Liquid Crystal Display (LCD) as in Figure 12. This alternative way is believed to be able to solve the drawbacks of using dissolved ammonia sensor, spectrophotometer or ammonia test kit for monitoring the concentration of dissolved ammonia continuously for aquaculture application.

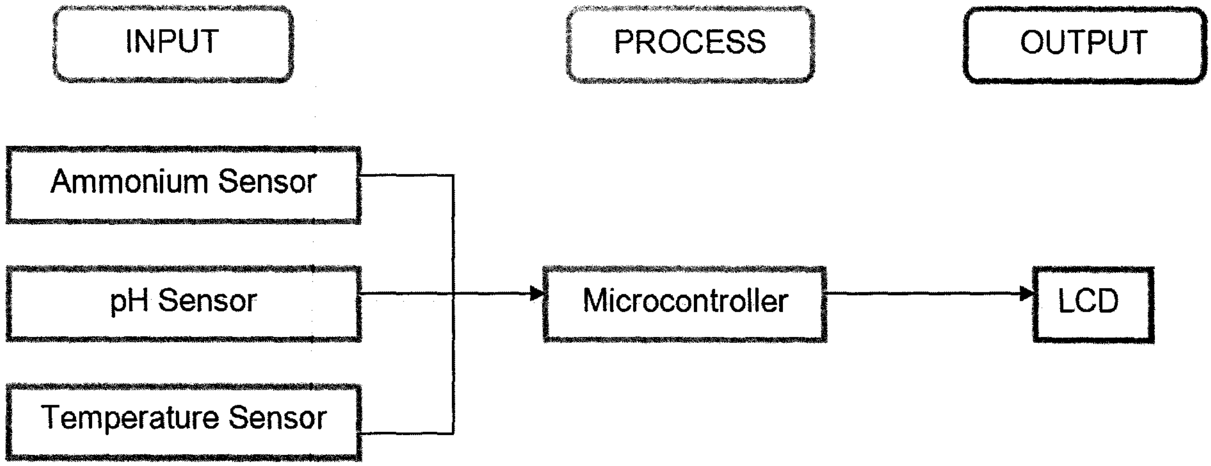


Figure 12: Block diagram of a proposed system to calculate and display the concentration of dissolved ammonia at LCD

2.7 The effect of pH to the aquatic life

The reading of pH can determine the characteristic of the water in term of how acid or basic it is. The scale of pH is from 0 to 14 with 7 is being neutral. The pH of water which is less than 7 is categorized as acidic water while the pH of water which is greater than 7 is categorized as basic water. The most acidic water is 0 pH while the most basic water is 14 pH.

In fish ponds, the time of day that a sample is taken often will influence the pH because of variations in the carbon dioxide (CO_2) concentration. As plants in the water remove carbon dioxide for photosynthesis, the pH will increase. At night, the pH will decrease as carbon dioxide accumulates.

A pH reading below 6.5 may reduce fish reproduction and below 4.5 indicates that there is strong mineral acidity which is very harmful to aqua life and difficult to be neutralized. Newly hatched fish so called fry are often sensitive to pH levels above 9.0 t o 9.5.
Most fish species do well within the pH range of 6.5 to 9.5.

The measurement of pH is not only being used as one of the parameter to calculate the concentration of dissolved ammonia but the reading of pH also can be a great indicator to determine the level of water quality for aquaculture application after dissolved ammonia as in Table 2 as being proposed by Malaysian Fisheries Research Institute.

Table 2: The proposed water quality standards for aquaculture based on pH values by Malaysian Fisheries Research Institute

Type of water	pH
Very clean	6.5 – 8.5
Clean	6.0 – 9.0
Slightly polluted	5.5 – 9.5
Moderately polluted	4.5 – 10.0

Grossly polluted	< 4.5

The measurement of pH also should be measured continuously because the pH of water sent to the testing laboratory will change during shipment, especially for water which has significant amounts of organic matter such as algae and bacteria or elevated carbon dioxide concentrations.

2.8 The effect of temperature to the aquatic life

Water temperature is a measurement of heat in a water sample. The value of temperature can be expressed in Kelvin (K) unit, degree Celsius (°C) unit or Fahrenheit (F) unit. The larger temperature value indicates that the water sample contains more heat while the little temperature value indicates that the water sample contains less heat.
Each species of aquatic life has a temperature range that it can tolerate; within that range, there is an optimum temperature for growth and reproduction, which may change as the aquatic life grows.

Temperature has a direct impact on fish metabolism, feeding rate, and survival ability. Metabolic rates of fish increase rapidly as the temperature rises. Conversely, as temperature decreases, the aquatic life demand for food and oxygen also decreases. No other physical factor affects the growth and development of aquatic life as much as water temperature.

Many biological processes, such as spawning and egg hatching, are geared to annual changes in environmental temperature. Large, rapid changes in temperatures are stressful to aquatic life and may result in death. Aquatic lives that initially survive a temperature shock may be sufficiently stressed to later succumb to infection. The optimum temperature range for cold water fish species is from 14 °C to 18°C and the optimum temperature range for warm water fish species is from 24 °C to 30°C.

3.0 Proposed System

The system can be divided into three main sub-systems, namely, sensor platform, wireless communication, and GUI software. In the present project, three sensors are used, namely, temperature sensor, pH sensor, and dissolved oxygen sensor. All are electrode-type sensors, which are waterproof and suitable for submersion in a pond for a long period.

Several important criteria, such as range of sensor output, wiring of the sensor, and detection range, need to be considered in choosing a sensor for water-based applications. The sensor responds to the parameter and detects voltage, current, or frequency. These analog signals are converted to digital signals and are processed by a microcontroller. The wiring diagram of the sensor should also be considered to know which of the wires is the output signal, the power, or the ground. If the wire from the sensor is connected wrongly to the system, then it damages the sensor itself.

The range of detection of the sensor in measuring the parameter should satisfy the project requirements. This is to ensure that the sensor is capable of detecting the minimum or the maximum value of the parameter in a real case. The accuracy and the sensitivity of the sensor should also be considered to determine which resolution of the ADC (analog digital converter) is suitable for this project.

The signal conditioning stage changes or alters the output from the sensor so that the output can be read by the ADC and can be processed well by the microcontroller. Some sensor outputs are in current form, e.g., all Global Water sensors, especially water quality sensors, which produce 4–19 mA output signals. Sensor output must be converted to a voltage signal by reading the voltage across a precision resistor in series with the signal wire . The output is 1.04–4.94 volts DC because Ohm's Law states that V=IR, particularly if the 4–19 mA signal is dropped across a 260 ohm resistor.

Mostly, ion selective electrodes, such as ammonium sensor and nitrate sensor, produce output in a negative millivolt range. This millivolt output is too small and cannot be accepted by the DC. Thus, the output needs to be conditioned from 0 to 5V DC. In this case, op-amp is the best solution because it is more versatile, flexible, and can be configured to do certain operations, such as attenuating or amplifying the signal, converting the polarity of the signal from negative to positive or vice versa, or obtain the sum or the difference of the signal. The op-amp can even be configured as a converter, which can be used to either convert the current into voltage or vice versa. The op-amp as an inverting amplifier, which is shown in Figure 13, is used to invert the polarity of the negative signal that is produced by the sensor and amplify the millivolt signal to a suitable range for the ADC.

Any negative input signal is inverted into a positive output signal because the inverting op-amp formula is Vout = (-Rf/Rin)*Vin. The gain of the amplifier can be controlled by changing the value of the feedback resistor, and the value of the Rin must be fixed. Figure 13 shows the diagram for simulation using the Multisim software, and Table 3 shows the results obtained from the simulation and the experiments.

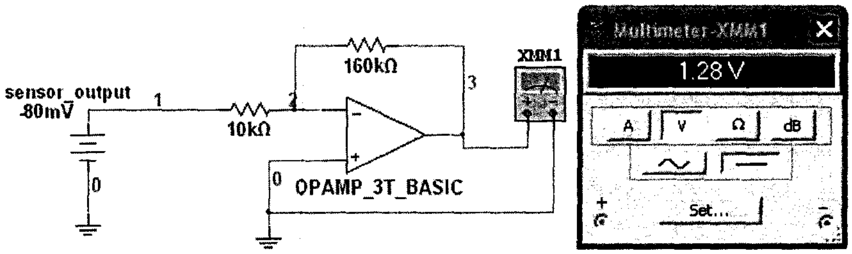


Figure 13: Simulation of the inverting amplifier circuit

Table 3. Output voltage obtained from the experiments and the simulations

INPUT VOLTAGE (V)	SIMULATION VOLTAGE (V)	EXPERIMENT VOLTAGE	DIFFERENCES
-0.080	1.28	1.32	0.041
-0.120	1.92	1.96	0.04
-0.140	2.24	2.28	0.04
-0.180	2.88	2.92	0.04
-0.220	3.52	3.55	0.03
-0.260	4.16	4.20	0.04
-0.290	4.64	4.70	0.06

The data acquisition circuit is a stage where the microcontroller is placed. The project microcontroller of CY8C29466-24PXI is used. This PSOC microcontroller is versatile, flexible, and programmable, where all ports can be configured to become an ADC module, a UART module, or even an analogue module, such as PGA (Programmable Gain Amplifier). Thus, PSOC allows the designer to reduce board size, the time taken to finish a project, and project cost. The microcontroller is responsible for getting data from the ADC and for sending the data to the transmitter through UART.

The Xbee module is used to send data from the microcontroller to a PC. Radio frequency (RF) with a 2.45 GHz frequency is used as transmission medium. The Xbee module with a 10 mA transmission current, a 1 mWatt output power, and a 150 m transmission range is applicable for the present project. The module is then interfaced to the board of the sensor. The module that is connected to the sensors is programmed as a transmitter, whereas the module connected to the PC is programmed as a receiver. Data are transmitted every 5 min in one data frame, which consists of one start byte data, sensors's data, and one stop byte data. The receiver is interfaced to the PC via a USB cable. The receiver is programmed under point-to-multipoint network topology, which enables the receiver to read data from all ponds in the system.

Using Visual Basic software, a GUI can be developed to show data in table form and also to display the graph over time. Data are retrieved through a USB port and saved in a database system. Data are received every 5 min. For a web-based application, the software is developed in Adobe Dreamweaver using PHP programming and MySQL Database. The software is developed to access up to 10 ponds.

3.1 Development Process of PSoC CY8C29466

The development process can be divided into three major steps which are configuration on device, write code and load program into device. The development process is shown in the figure 14 below. The detail of each step is explained in next subsections.

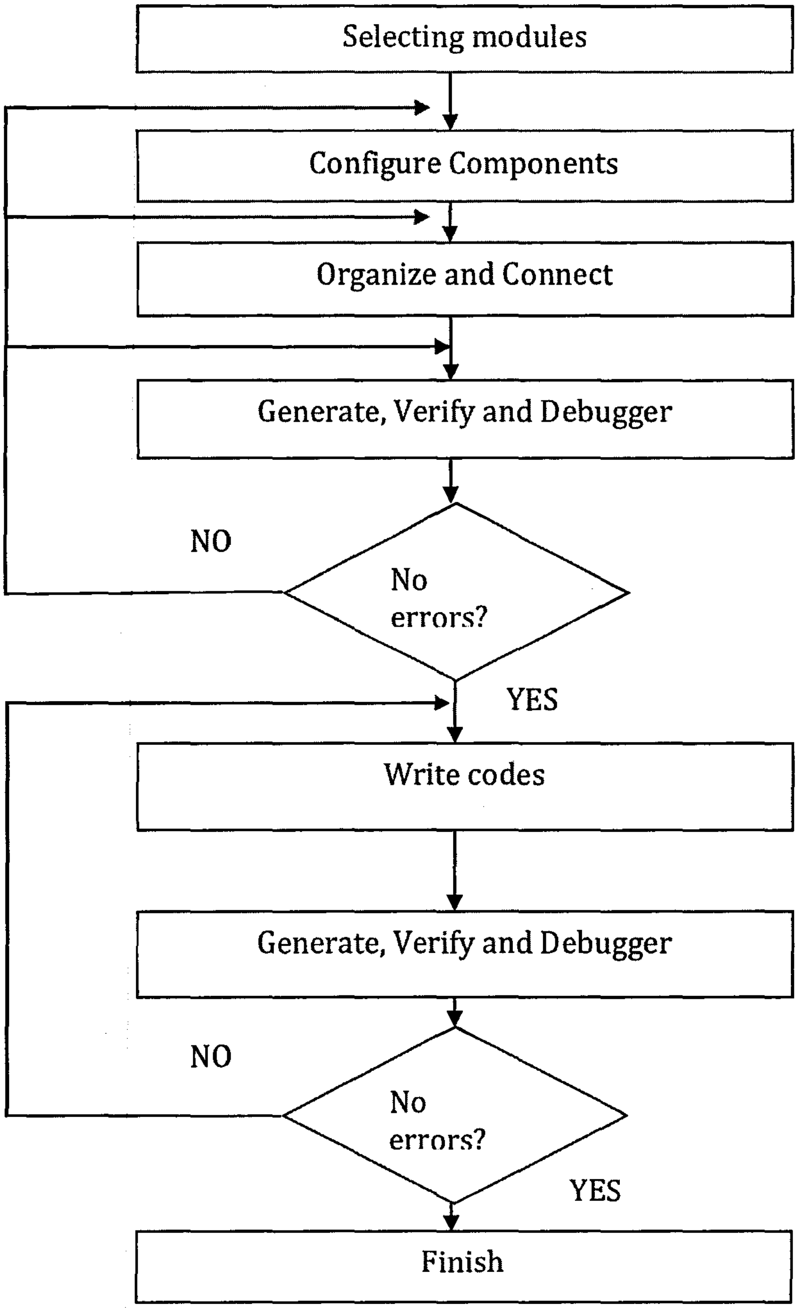


Figure 14: Flow chart for PSoC software development

3.1.1 Selecting Modules

There are three categories of module that are used to build the system for this project which are amplifier, analog-to-digital converter, and digital communication. Each category contains many modules. For amplifier, programmable gain amplifier is used. While analog-to-digital converter category, two types of ADCs are used which are triple input 7-to-13 incremental ADC and Delta Sigma ADC. Universal Asynchronous Receiver Transmitter (UART) is chosen from digital communication category for serial communication. These modules can be selected by double click on the desired modules in the User Modules window. The modules will be shown at the default main view of PSoC designer window.

3.1.1(a) Selecting programmable gain amplifier

Programmable gain amplifier (PGA) is a non-inverting operational amplifier which user can set gain. The figure 15 is the analog block of PGA which is shown in PSoC designer default view. The operational amplifier has high input impedance, selectable voltage reference, and wide bandwidth. The gain of the amplifier can set as low as 0.062 and as high as 48. This amplifier is not rail-to-rail amplifier because its input and output voltage range does not extend to the power supplies. The allowed input range is a combination of factors, which are input limit, output limit, power supply voltage, analog ground value, and selected gain.

In this project, four PGAs are use as amplifier for the four sensors. The output signals from the sensors are the input signals for the PGAs. The amplifiers are use as unity gain amplifier to buffer the input signals from the Global water's sensors. The signal from ammonium sensor is amplifier sixteen times before the output signal of the amplifier is process by ADC.

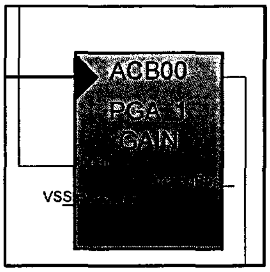


Figure 15: Analog block for PGA

3.1.1(b) Selecting triple input 7-to-13 incremental ADC

Triple input 7-to-13 incremental ADC (TRIADC) is a triple input integrating ADC with ADC resolution between 7 to 13 bits. A variety of input voltage ranges can be measured by configuring the proper reference voltage and analog ground. The output can be configure either to two's complement or unsigned integers based on an input voltage between $-V_{ref}$ and $+V_{ref}$ centered at AGND. The three input channels are sampled at the same time and duration since they are controlled by a common signal. Power settings, resolution, and speed are common to all three input channels. The figure 16 shows two out of five digital blocks and analog block required when using TRIADC.

This project used only one triple input incremental ADC to convert the input signals from pH, temperature and DO sensor into digital signals. The input signals from sensor are multiplexed when using this ADC. The sampling is fully synchronized because this ADC used the same timer. This type of ADC is used because the limited analog blocks available in the microcontroller's resources and the microcontroller can only support one variable resolution incremental ADC.

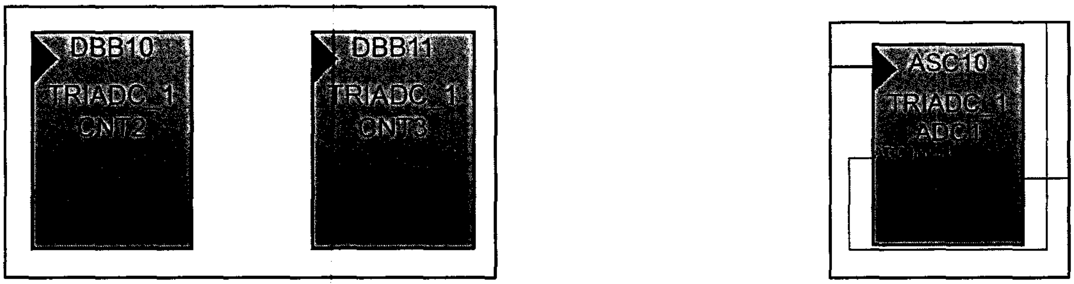


Figure 16: Digital blocks for TRIADC (left) and analog block for TRIADC (right)

3.1.1(c) Delta sigma ADC

Delta sigma ADC (DelSig) is a 6-bit resolution ADC with 32X oversampling which gives maximum of 14-bit resolution. The output of this ADC can be either signed 2' complement or unsigned data format. The maximum sampling rate is 65,500 samples per second at 6 bit resolution and minimum sampling rate is 7812 samples per second at 14-bit resolution.

The resolution and sample rate of the DelSig are determined by the modulator type, decimation rate, and column clock frequency. The linearity and offset voltage of the converter is also determine by the selection of these parameters and the power setting. In this project, only one DelSig is used for converting voltage signal from ammonium sensor to digital signal. Since DelSig only uses two analog blocks, there is enough place to acommodate the blocks in analog column. The figure 17 shows analog and digital blocks which can be view in PSoC Designer default view.

Figure 17: Digital block of DelSig (left) and analog blocks of DelSig (right)

3.1.1(d) Universal asynchronous receiver transmitter

Universal asynchronous receiver transmitter (UART) is an 8-bit transceiver and can support duplex RS232 communication over the two wires. This digital communication module can support up to 6 Mbits/s of data rate. Its data frame consists of start bit, optional parity bit, and stop bit. The data received and transmitted is a bit stream that consists of a start bit, eight data bits, an optional parity bit, and a stop bit.

RX and TX blocks operate independently. Each has its own control and status register, programmable interrupts, I/O, buffer register, and shift register. However, they share the same enable, clock, and data format. In this project, one UART module is sufficient for accomplish serial communication. As shown in figure 18, one UART module consists of one digital block for receiving and one digital block for transmit.

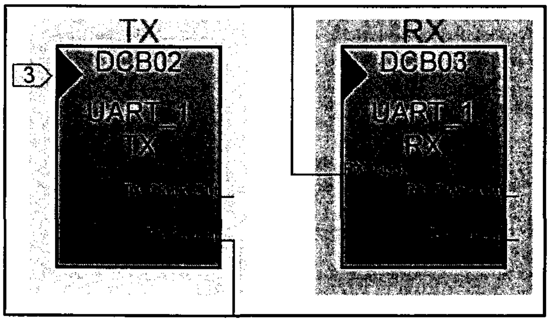


Figure 18: Digital blocks for UART where transmitter block at left and receiver block at right

3.1.2 Configure Components

The configuration of components is divided into two parts which are global resources and user modules parameter. Global resources contains configuration on clock frequencies which are shared by various user modules. The global resources and user modules parameter are configured based on the figures shown.

3.1.2(a) Setting Global Resources

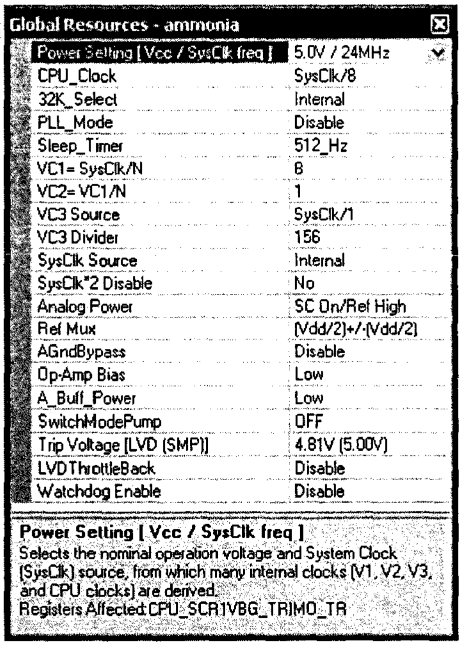


Figure 19: The setting of global resources

As shown in the figure 19, the power setting is 5.0 V and the system clock frequency is 24 MHz. The VC1 is set to 8 which give a 3 MHz as clock frequency. The clock frequency for VC2 and VC1 are the same. While, the VC3 source is set as SysClk/1 and the VC3 divider is set to 156. The Ref Mux is set to Vdd/2 +/- Vdd/2 which set the ADCs input to take input voltage range of 0 to 5 V. The Analog power is set to SC On/Ref High is to bias the analog blocks of ADCs. The other properties in global resources window are leave as default.

3.1.2(b)Setting User modules parameter

The first module to configure is programmable gain amplifier (PGA). Since the amplifiers for Global water's sensors acts as a buffer, the gain of the all the four amplifiers are set as 1. The table 4 shows all the configuration of the PGAs parameters.

Table 4: PGAs parameters

Parameter	Values	
Name	PGA_1	PGA_15
User Module	PGA	PGA
Version	3.2	3.2

Gain	1	1
Input	AnalogColumn_InputMUX_0	AnalogColumn_InputMUX_1
Reference	VSS	VSS
AnalogBus	Disable	Disable
(continue)		
Parameter	Values	
Name	PGA_2	PGA_3
User Module	PGA	PGA
Version	3.2	3.2
Gain	1	1
Input	AnalogColumn_InputMUX_2	AnalogColumn_InputMUX_3
Reference	VSS	VSS
AnalogBus	Disable	Disable

The PGA name such as PGA_1, PGA_2 and so on is used to instantiate the module for C programming part. The inputs are connected to AnalogColumn_InputMUX respectively. The gain of the amplifier is referred to the reference voltage which is set to VSS.

The triple input 7-to-13 bit incremental ADC parameter windows have three clock phases for the three inputs. The selection of the Clock Phase is used to synchronize the output of one switched capacitor analog PSoC block to the input of another. The switched cap analog PSoC blocks use a two-phase clock (φ_1, φ_2) to acquire and transfer signal. Typically, the input to the TriADC is sampled on φ_1, the Normal setting. So, these clock phases are set to Norm. The other parameters are set as shown in the figure 3.10. Notice that in the figure 3.10, the clock source is VC1 which is 3 MHz. The CalcTime is the amount of time it takes the CPU to calculate intermediate integration results before the next integrate cycle can start. The time it takes to calculate the result "CalcTime" varies inversely proportionally with the CPU clock. The CalcTime is calculated based on Eq. (3.5).

$$CalcTime \geq \frac{DataClock \times 371}{CPU\ Clock} \quad (3.5)$$

$$CalcTime \geq \frac{3\times10^6\times371}{3\times10^6}$$

$$CalcTime \geq 371$$

Therefore, the CalcTime is set to be 1000 with some margin. This value must be in terms of the Data Clock. Minimum CPU calculation time is 371 CPU clocks.

CalcTime may also be increased to optimize the sample rate. The name TRIADC_1 is used to instantiate the module for C programming. The ADC Input1, Input2 and Input3 are connected to output of PGA_0, PGA_1, PGA_2 respectively. ACB00, ACB01 and ACB02 are analog blocks name of PGA. Note that the interconnecton between modules, and input or output pins can be done using parameter window. The ADC resolution is 13 bit and data format is unsigned. This means that for every increased of 0.0006104260774 V of input voltage, the ADC output increased by one bit. This value is obatained from Eq. (3.6); n is 1 when data format is unsigned and n is 2 when data format is signed. The 0.0006104260774 voltage per bit is used in programming the PSoC. This value is used to get back the input voltage received from the sensors.

$$Voltage\ per\ bit = \frac{Highest\ input\ that\ ADC\ can\ process}{(2^{ADC\ Resolution} - 1)/n} \qquad (3.6)$$

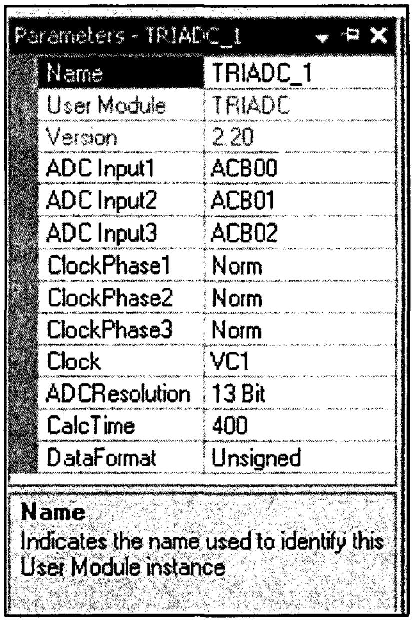
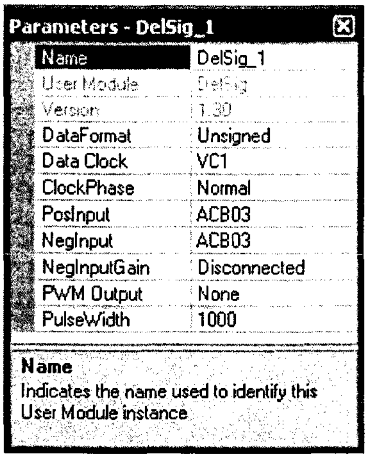


Figure 20: The configuration parameters of TRIADC

The Delta Sigma ADC (DelSig) is configured based on the figure 21. The output data is unsigned and the clock source is VC1. Since single ended input is used, the NegInputGain is disconnected from the converter. The PosInput which is the input of DelSig is connected from ACB03 which is the output of analog block of the PGA_3. DelSig_1 is the instance name of the module. The ADC resolution is 14 bit which gives 0.0003051944088 voltage/bit based on Eq. (3.6).



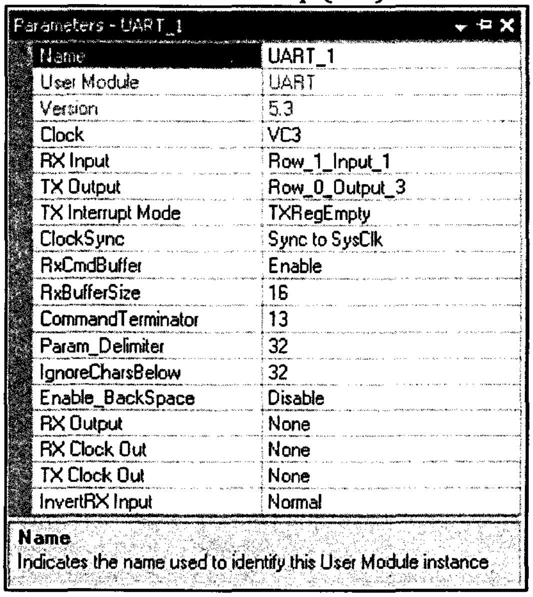
Parameters - DelSig_1

Name	DelSig_1
User Module	DelSig
Version	1.30
DataFormat	Unsigned
Data Clock	VC1
ClockPhase	Normal
PosInput	ACB03
NegInput	ACB03
NegInputGain	Disconnected
PWM Output	None
PulseWidth	1000

Name
Indicates the name used to identify this User Module instance

Figure 21: The configuration parameters of DelSig

The UART parameters are set based on the figure 22. The clock source used is VC3. The transmitter output is connected to Row_1_Output_3 bus and the receiver input is connected Row_1_Input_1 bus. The instance name of the module is UART_1. The UART clock is calculated based on the Eq. (3.7).



Parameters - UART_1

Name	UART_1
User Module	UART
Version	5.3
Clock	VC3
RX Input	Row_1_Input_1
TX Output	Row_0_Output_3
TX Interrupt Mode	TXRegEmpty
ClockSync	Sync to SysClk
RxCmdBuffer	Enable
RxBufferSize	16
CommandTerminator	13
Param_Delimiter	32
IgnoreCharsBelow	32
Enable_BackSpace	Disable
RX Output	None
RX Clock Out	None
TX Clock Out	None
InvertRX Input	Normal

Name
Indicates the name used to identify this User Module instance

Figure 22: The configuration parameters of UART

$$UART\ clock = \frac{SysClk}{VC3\ divider} \times \frac{1}{8} \tag{3.7}$$

$$UART\ clock = \frac{24 \times 10^6}{156} \times \frac{1}{8} \approx 19200$$

The UART clock is 19200 bps which is the baud rate used for RS232 serial communication in this project. The VC3 divider is used to generate baud rate for UART by dividing 24 MHz by 156. The UART internally divides UART clock by 8, resulting in a baud rate of 19200 bits per second.

3.1.3 Organization and Connection

The connection of modules can also be done on the chip-level view editor. The interconnection for digital blocks and analog blocks are similar. The placement of user module can be change by clicking Next Allowable Placement icon as shown in figure 23. This highlights the next possible module for placement. The Place User Module icon is use to place the module on new placement.

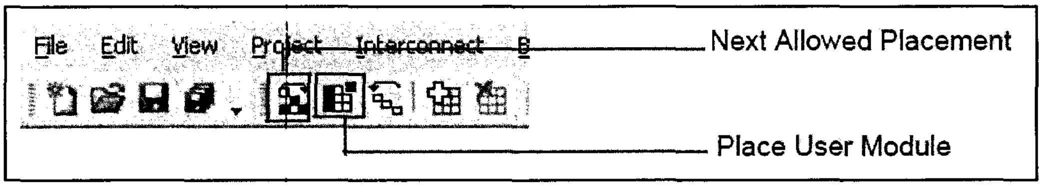


Figure 23: The toolbar for user module placement

In the analog block, the clock signal can be selected by clicking on the AnalogColumn_Clock multiplexer and a drop down list of possible clock sources is shown in the figure 24. The connection of input signal to the CPU is done by connecting the input pin to analog column input multiplexer, then to PGA, and finally to ADC. The input pin to PGA can be connected by clicking the AnalogColumn_InputMUX and a drop down list of possible input pins is shown in the figure 3.14. The input of ADC can be set by clicking on the ADC Input or PosInput and a drop down list of possible input pins are shown in the figure 24.

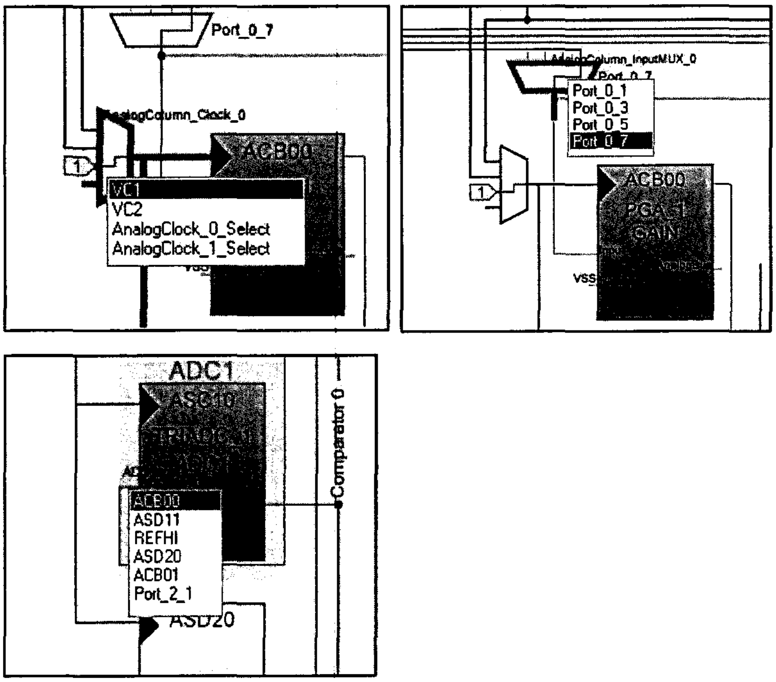


Figure 24: Select clock source (left), select input to PGA (middle) and select ADC input (right)

In the digital block at chip-level view editor, the clock signal of digital module can be selected by clicking on the clock of the module block and a list of clock sources is shown in the figure 25. Data can be send from digital block to output pin of the device by connecting the digital block to row bus, then to column bus and finally, to output pin. The row output bus can be selected by clicking on the output of the digital module block and then a drop down list of Row output bus is shown as in figure 25. While to connect the Row output bus to global column output bus, click on the digital interconnect row output to select the column output bus as shown in the figure 26. The column output bus can be connected to any of the listed output pins by clicking on the connected column output bus as shown in the figure 26. Similar steps are used for digital input interconnection.

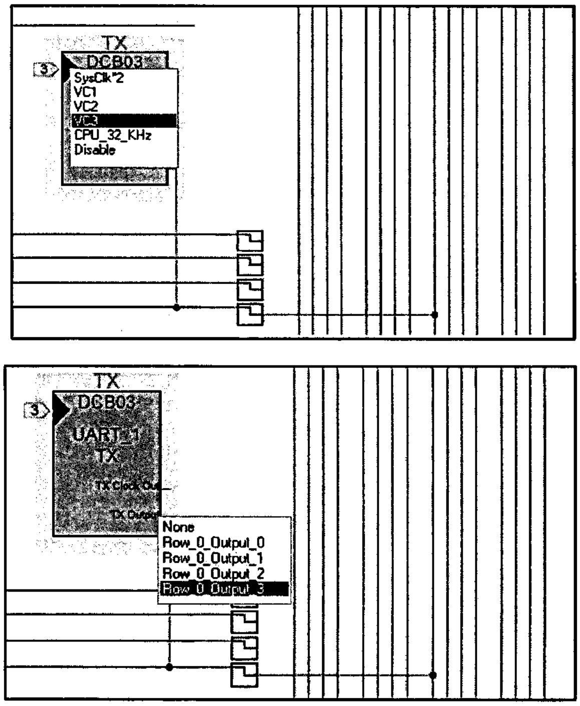


Figure 25: Setting the clock source (left) and choosing the row bus (right)

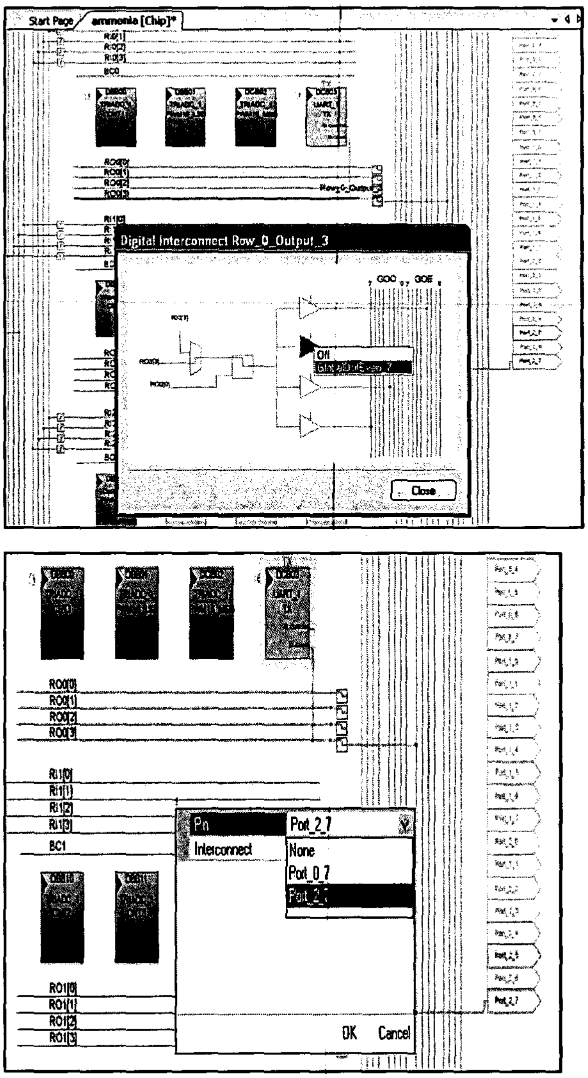


Figure 26: Choosing the column bus (left) and selecting the output pin (right)

3.1.4 Generate, Verify and Debug

It is good precaution step to generate application or project to verify whether all previous steps have any errors or warnings. The debugger output window show any warnings and errors. Warnings maybe missing interconnection, parameters are not set in the parameter user module window, and etc. This step can ease the troubleshooting when there are errors or warnings after compiling the C code. Generate and Build application is done by clicking Build > Generate/Build as shown in the figure 27.

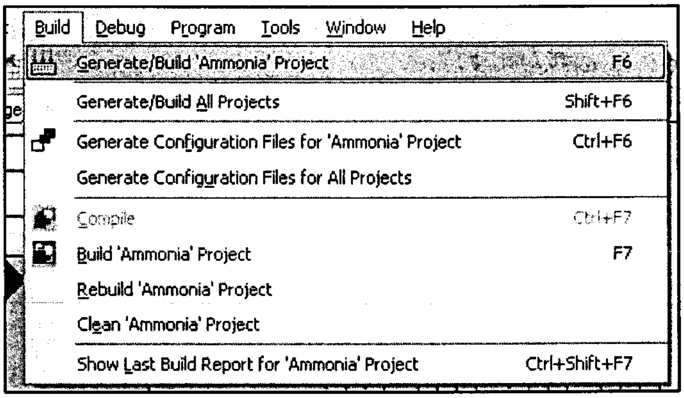


Figure 27: Generate/Build project menu

3.1.5 Coding

The program for the water quality monitoring system can be explained using flow chart as shown below.

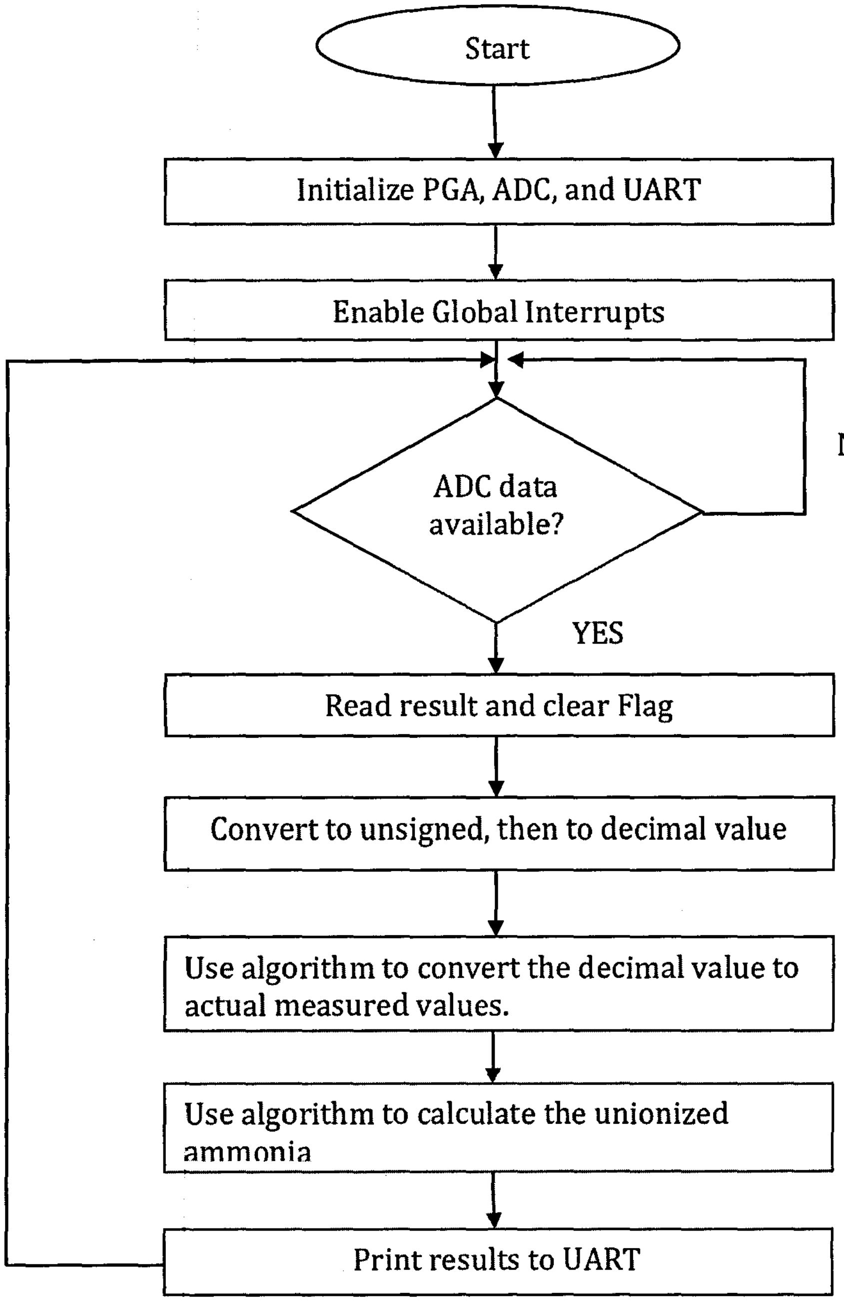


Figure 28: Flow chart for C programming of PSoC

The first few statements of the main program are initializing the user modules. These statements are to turn on the PGAs, ADCs, and UART. Some of statements are shown below and a complete statement is shown in appendix A. As shown below, the UART_1, PGA_1, TRIADC_1 and DelSig_1 are the instance name of the modules.

```
UART_1_Start(UART_PARITY_NONE);

PGA_1_Start(PGA_1_HIGHPOWER);

TRIADC_1_Start(TRIADC_1_HIGHPOWER);

DelSig_1_Start(DelSig_1_HIGHPOWER);
```

The UART module is turn on with high power source and set to no parity bit in the data frame. PGAs, TRIADC and DelSig modules are also turn on with high power source. The global interrupt is enables to allow the modules to interrupt CPU. The statement in the C program to enable global interrupt is shown below.

```
M8C_EnableGInt ;
```

Before enter to an infinite loop for continuous reading, the TRIADC and DelSig modules are set to read data continuously by using the following statements. Continuously readings by ADCs are important because the system is real-time application.

```
TRIADC_1_GetSamples(0);
DelSig_1_StartAD();
```

ADCs required time to convert the analog signal to digital signal. Therefore, the program must wait for the hardware to finish converting signal. In order to accomplish that, Boolean equation is used. If the Boolean equation is true, then the program enters a loop for processing the data. The statements to accomplish this are shown below.

```
for(;;)                                    //Wait for data to be ready
{
while(TRIADC_1_fIsDataAvailable()==&&DelSig_1_fIsDataAvailable()==0);
//read data
                    DO_adc = TRIADC_1_iGetData1();
                    temp_adc = TRIADC_1_iGetData2();
                    pH_adc = TRIADC_1_iGetData3ClearFlag();
                    nh4_adc = DelSig_1_iGetDataClearFlag();
                    process_data( temp_adc, nh4_adc, pH_adc, DO_adc);
}
```

As shown above, the statements such as "TRIADC_1_fIsDataAvailable() == 0 " and "DelSig_1_fIsDataAvailable() == 0 " are statements that check the flag register of converter whether the data is available or not. If it is equal to 0, then data is available. The for loop is to make the system run continuously as long there is power supply to the system. When data is available, the program instructs the device to get the samples data from ADC. The statement to do that is "nh4_adc = DelSig_1_iGetDataClearFlag();". There are other statements for reading data which is similar to the DelSig statement are shown in appendix A. Notice the ClearFlag which is part of the statement. This ClearFlag is to ensure the next data to be read is when data is available or else data will be read while the ADCs are not finish converter the signals. DO_adc, temp_adc, pH_adc, and nh4_adc are stored as integer values from ADCs. The process_data void is a series of statements to convert signals to measured values and send them to UART.

The integer values are converted to unsigned values and then to decimal values. This can be accomplished by using a single statement for each sensor as shown below. temp_dec=(temp_adc)*DECIMAL1;

The temp_adc value is multiple by DECIMAL1. The DECIMAL1 is a constant which is declare early in the program and is used to multiple the unsigned value to get the input voltage of the sensor. Its value is 0.0006104260774 voltage per bit.

The next step is to convert the decimal values to actual measured values. Each sensor has its own algorithm to convert the decimal value to actual measured value. This algorithm is obtained from calibration of the sensor. The algorithm may be different for different sensor of the same type. One of the algorithm statements is shown below.

```
temp = (25.86 * temp_dec) - 76.81;                //temperature
```

After obtained all the measured values from sensors, the next step is to calculate the unionized ammonia. The equations at the ammonia literature review chapter are used and the corresponding statements are shown below.

```
    temp_kelvin = temp + 273.15;
    pka= (2729.92/temp_kelvin) + 0.0901821;
    f=1/(pow(10,(pka-pH))+1);

    nh4 = pow(10,log_nh4);                        //NH4
    nh3 = (f/(1-f))*(nh4);                                  //NH3
```

The final step is to send all the measured values to UART. Each data is separate by | symbol to distinguish different measured value for each other. The statements are shown below.

```
strncpy(value, ftoa(pH,0), 14);          //convert float to string variable
UART_1_PutString(value);                 //send string via serial communication
UART_1_PutChar('|');
```

The measured values are in floating data type. These values are converted to string data type by using the statement "strncpy(value, ftoa(pH,0), 14);". The number 0 indicates the first position of character to take and number 14 indicates the maximum number of characters to convert. The `value` variable is the return string after converting from float to string. Data are send out via UART by using the command "UART_1_PutString(value);".

The whole data format that will be sending via UART is #01|pH|temp|DO|nh3$. The # symbol represents the start of transmission and $ symbol represent the end of transmission of one set of data. These symbols along with | symbol are used in data logger to identify and separate the received measured values. Notice that 01 is the identity number of the device. Besides, the statement "UART_1_PutCRLF();" is used to start a new line. Lastly, the program runs all over again from checking data availability to send data via UART.

3.2 Programming the PSoC

Before start to program the device, connect the MiniProg to any USB on computer or laptop. Run the PSoC programmer from the Start > All Programs > Cypress > PSoC Programmer. The first step is to load HEX file from project folder by click on File Load icon as shown in figure 29. All the settings are leave as default. Next step is to switch on the power to the device by clicking on the Toggle Power icon. After that, click on Program icon to start programming the device. The MiniProg can be removed anytime as long as the power is not on and the MiniProg is not programming the device.

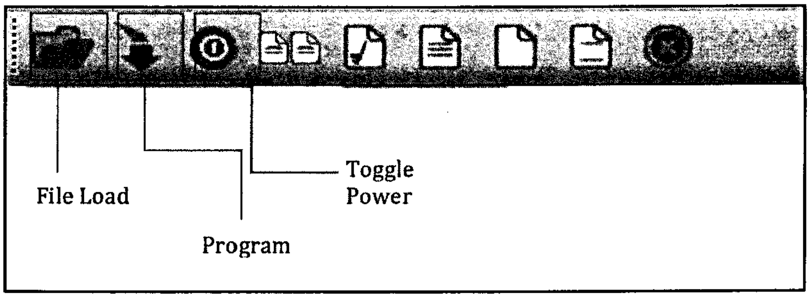


Figure 29: The main toolbar for PSoC programmer

3.3 Printed Circuit Board Development

There are three modules of EAGLE software used for creating a printed circuit board layout. These modules are schematic capture editor, board layout editor and auto router. The schematic capture editor can draw electrical wiring diagram with or without board layout. While, the board layout editor is design printed circuit boards. The auto router automatically routes the airwires of the board layout. In this project, the first step of printed circuit board development is draw schematic, follow by board layout generations, then auto route and finally, generates the output data for the production of the PCB.

3.3.1 Schematic

The first step of designing the PCB is drawing schematic as shown in the figure 30. In this schematic, there few important components which are 28 pins zero insertion force socked, MAX232, RS232 interface, voltage regulator, trimming resistors, ISSP header, power jack, capacitors, LED, normal resistors, push button switch, diode, and 5-pin header. All these components can be added to the board from library. The 28 pins zero insertion force socked is to allow easy remove and insert the PSoC CY8C29466 microcontroller on the board. The trimming resistors are to allow fine tune of the output signals of the Global water's and Elit's water quality sensors. The ISSP header is an interface to allow on-board programming. The push button is to enable reset on the system. The MAX232 and RS232 interface is to enable serial communication with computer. The 5-pin header is to allow the output wires from sensors connected to the system.

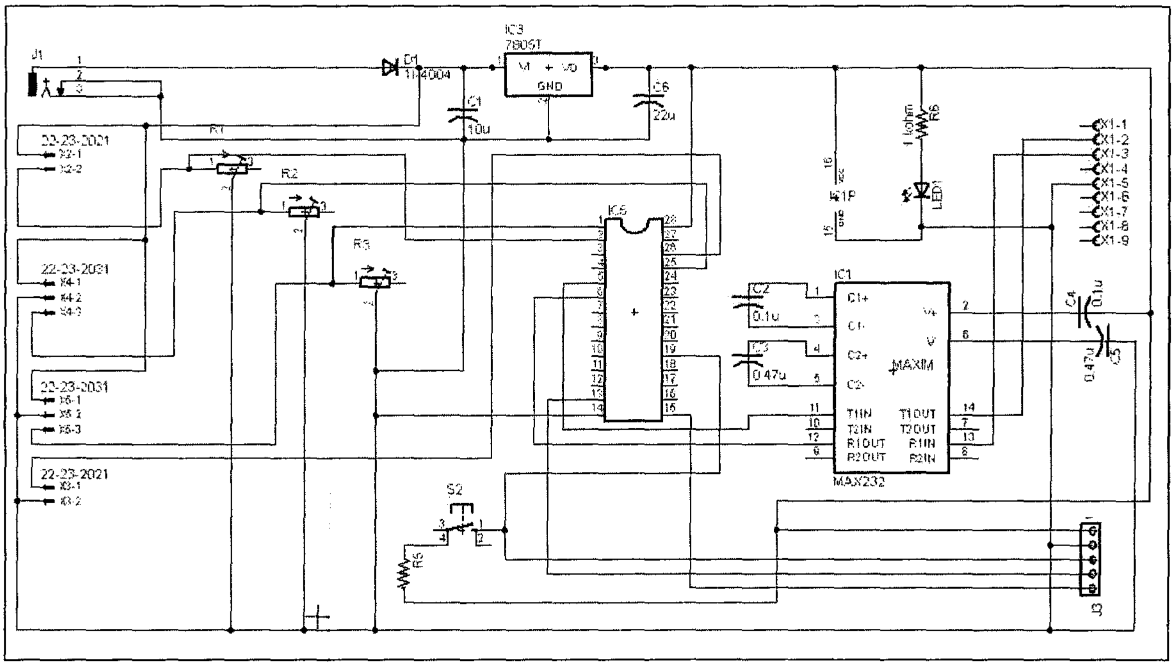


Figure 30: The monitoring system schematic block diagram for water quality

On the schematic editor window, net are drop to perform electrical connections between the block diagram components of the system. A junction is created manually by dropping a junction on the net and another net line to generate a connection between these two nets. Next, the electrical rule check (ERC) is performed. The ERC is used to check schematic for electrical errors. The results are warnings and error messages listed in the ERC window. The schematic editor will show where the reason for the problem is located in the schematic by clicking on the error message.

3.3.2 PCB Layout

Once the schematic already drawn using schematic editor, the board file can be generated by clicking on the Board icon. A board containing parts that have already names, values and whose pads are connected through airwires. After generating a board file, arrange all packages within the board outline. Before using auto router, all the packages must removed into the board outline and already arranged. Auto routing process starts once click on AUTO icon and the generate layout is shown in the figure 31. Different arrangement of the packages on the board will give different tracks pattern layout. If a certain tracks are not suitable, it can be reroute by using RIPUP command.

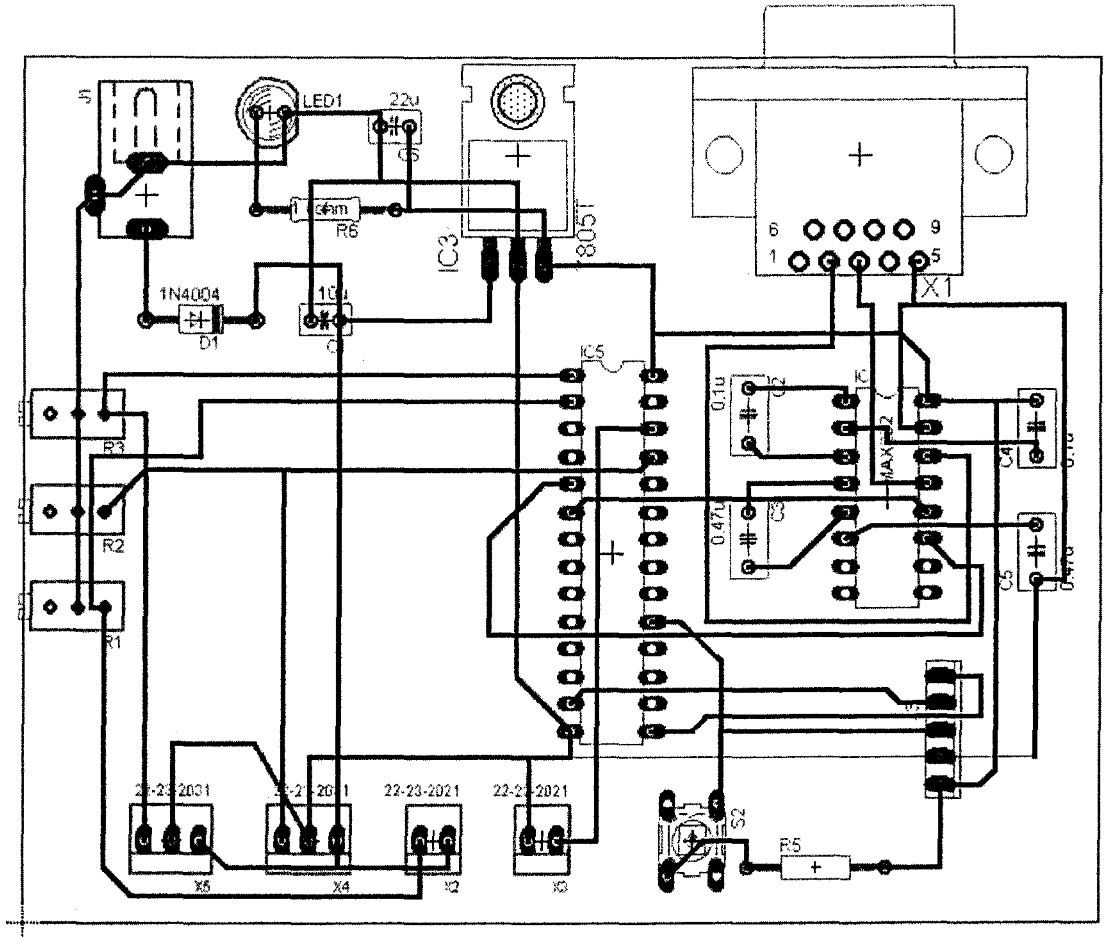


Figure 31: Layout for PCB fabrication

Design rule check (DRC) is done to check whether the board layout comply with the design rules from manufactures. The results are warnings and error messages listed in the DRC window. The board layout editor will show where the reason for the problem is located in the layout by clicking on the error message. The last step is to generate Gerber data by using CAM processor of EAGLE. The CAM processor generates film and manufacturing data necessary from fabrication process. Another important file that needs to be generated for fabrication process is drill data. Drilling data can be generated in single step by using the job *excellon.cam* which the output file has the file extension *.drd.* The EXCELLON device generates a file that contains both drill data and drill table.

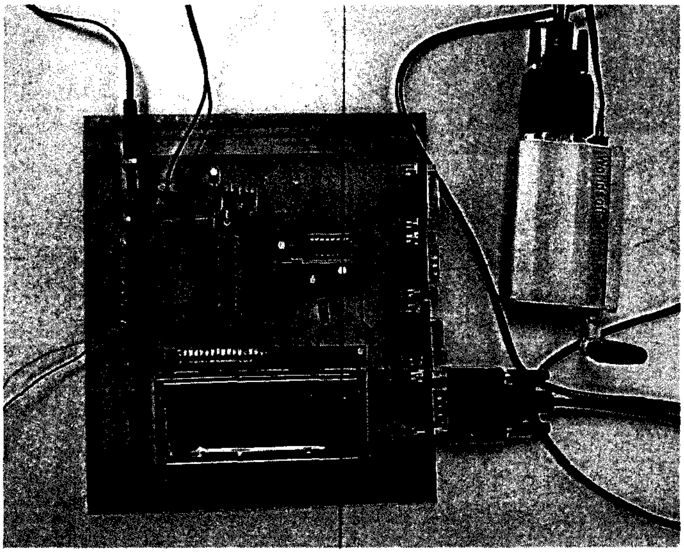


Figure 32: Printed circuit Board for the system

4.0 System Calibration

Calibration is a procedure to ensure the sensor works properly. The output of the sensor changes according to parameter changes, such as pH, temperature, and dissolved oxygen. The pH meter and thermometer are used as reference tools. The data of reference solution are taken using a data acquisition board, and are compared with the data obtained using reference tools. The graph of the data from data acquisition board versus the data from the reference tools is plotted. The trend line of the graph is generated to get an equation that represents the relationship between data from the data acquisition board and data from the reference tools.

4.1 Calibration Results

This section shown the result of the pH, temperature, dissolved oxygen and ammonium sensor obtained from calibration process. The tables shown the tabulated data obtained from calibration. Graphs are shown the relationship between the environment parameter and output voltage of the sensors.

4.1.1 pH sensor calibration results

Based on table 5, only three pH buffer solutions are used for calibration. This is because the Global's water pH sensor is a linear output device. Hence, a minimum of two readings of different pH buffer solutions are needed to obtain the calibration equation.

Table 5: The tabulate result of pH and its corresponding output voltage of the sensor

pH	Voltage (V)
3.97	2.266
6.98	3.105
9.99	3.900

As shown in figure 33, the linear polynomial is suitable to represent the linear relationship between measured pH and the sensor output signal. The graph is plotted from the data in table 4.1. The figure 34 shows the equation generated from MATLAB fit editor. The result shown in figure 34 is the equation for converting the measured voltage to actual measured pH value which is pH=3.683*voltage – 4.403. This equation is written in C language to program the PSoC microcontroller.

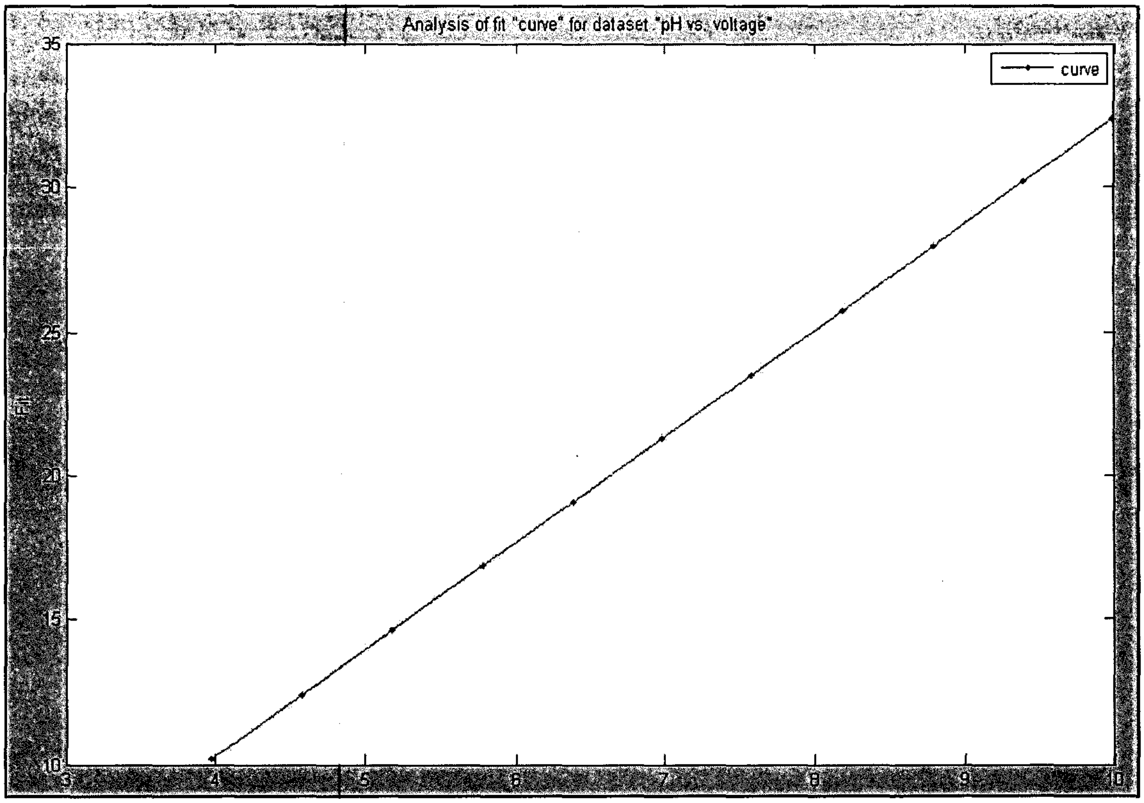


Figure 33: The pH versus output voltage graph

Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 3.683 (2.956, 4.411)
p2 = -4.403 (-6.703, -2.102)

Goodness of fit:
SSE: 0.004379
R-square: 0.9998
Adjusted R-square: 0.9995
RMSE: 0.06617

Figure 34: The result obtained from the MATLAB Fit editor for pH versus output voltage graph.

4.1.2 Temperature sensor calibration results

Based on table 6, only two different temperatures are used for calibration. This is because the Global's water temperature sensor is a linear output device. Hence, a minimum of two readings of different temperature solutions are needed to obtain the calibration equation.

Table 6: The tabulate result of temperature and the voltage output of the temperature sensor

Temperature (°C)	Voltage (V)
0	2.97
45	4.71

A linear relationship between the measured temperature and the sensor output voltage is shown in the figure 35 which is obtained from table 6. As shown in the figure 35, linear curve is suitable for curve fitting the data obtained from temperature sensor calibration. The result shown in figure 36 is the equation for converting the measured voltage to actual measured temperature value which is temperature=25.86*voltage – 76.81. This equation is written in C language to program the PSoC microcontroller.

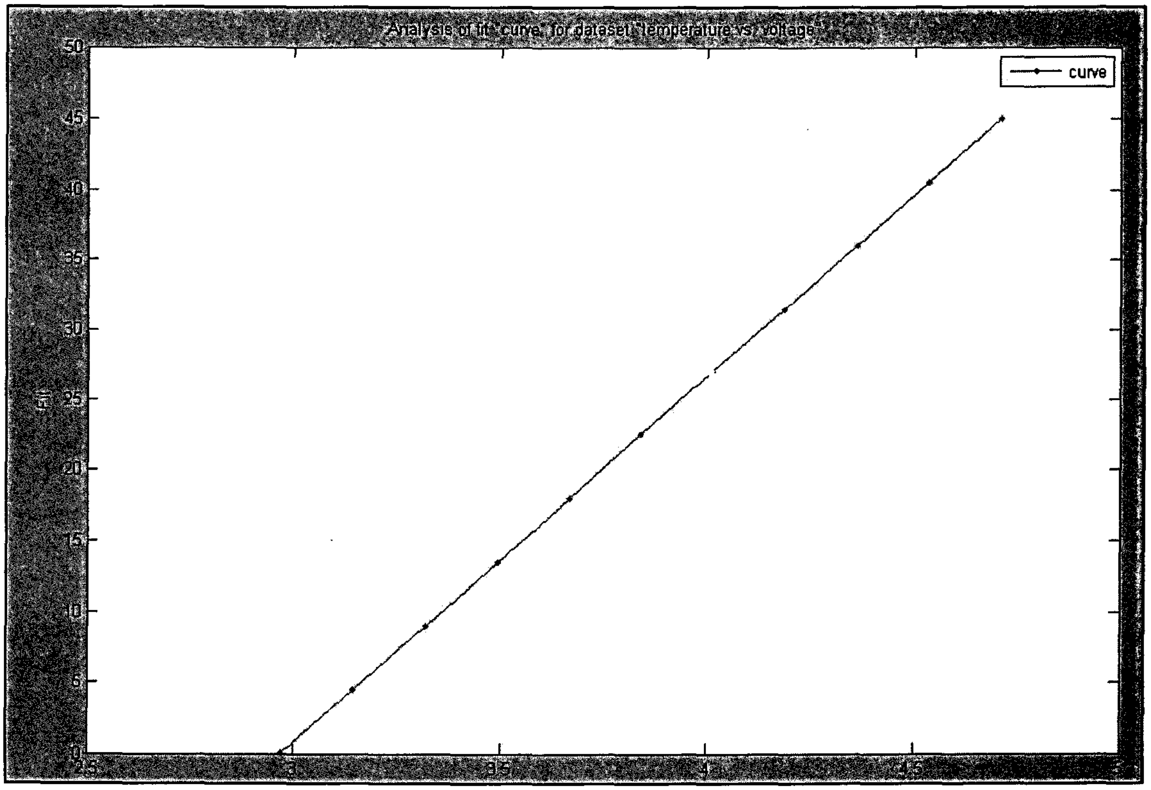


Figure 35: The temperature versus voltage graph for temperature sensor calibration.

```
Linear model Poly1:
    f(x) = p1*x + p2
Coefficients:
    p1 =     25.86
    p2 =    -76.81

Goodness of fit:
  SSE: 1.01e-027
  R-square: 1
  Adjusted R-square: NaN
  RMSE: NaN
```

Figure 36: The result obtained from the MATLAB Fit editor for temperature versus output voltage graph.

4.1.3 Dissolved oxygen sensor calibration results

Based on table 7, only two different dissolved oxygen level solutions are used for calibration. This is because the Global's water dissolved sensor is a linear output device. Hence, a minimum of two readings of different dissolved oxygen level solutions are needed to obtain the calibration equation.

Table 7: The tabulate result for dissolved oxygen sensor output voltage and its corresponding dissolved oxygen level in percentage.

Dissolved oxygen (%)	Output voltage (v)
0	1.18
100	4.59

As shown in figure 37, the data in table 4.3 give a linear graph. Hence, the relationship between the dissolved oxygen in percentage and output voltage sensor is directly proportional. As shown in the figure 37, linear curve is suitable for curve fitting the data obtained from dissolved oxygen sensor calibration. The result shown in figure 38 is the equation for converting the measured voltage to actual measured dissolved oxygen in percentage which is dissolved oxygen in percentage = 29.33*voltage – 34.6. This equation is written in C language to program the PSoC microcontroller.

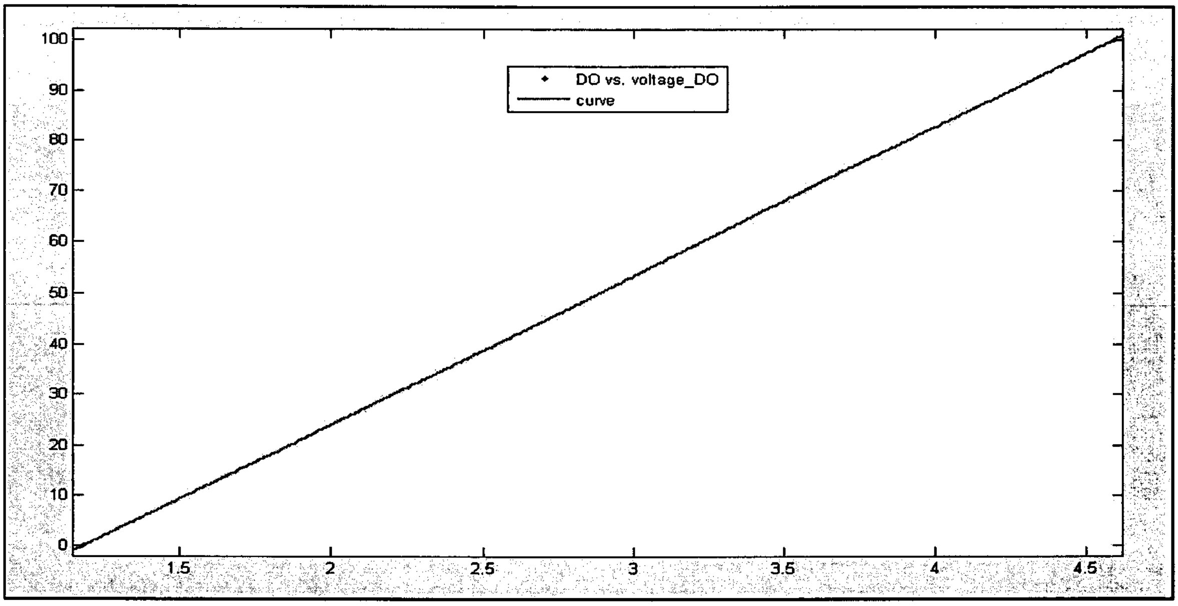


Figure 37: The graph of dissolved oxygen in percentage versus output voltage sensor.

```
Linear model Poly1:
    f(x) = p1*x + p2
Coefficients:
    p1 =      29.33
    p2 =     -34.6

Goodness of fit:
  SSE: 5.049e-029
  R-square: 1
  Adjusted R-square: NaN
  RMSE: NaN
```

Figure 38: The result obtained from the MATLAB Fit editor for dissolved oxygen in percentage versus output voltage graph.

4.1.4 Ammonium sensor calibration results

The ammonium sensor has been calibrated three times to obtained the accurate calibration equation. Ammonium sensor is firstly calibrated by measuring the output voltage of the sensor directly. On second time, the data collection for ammonium sensor calibration is collected via HyperTerminal with the sensor itself connected to the system. Lastly, calibration is done using data from DR2800 and system.

Table 8: The tabulate result for ammonium sensor output voltage and its corresponding ammonium concentration by direct measurement from the sensor.

Ammonium concentration in ppm	Logarithm of ammonium concentration	Output Voltage (V)
0.1	-1	0.104
1	0	0.130
10	1	0.161
100	2	0.190
1000	3	0.216

As shown in the figure 39, the graph is exponential when plotting ammonium concentration versus output voltage using the data in table 8. Figure 40 shows the equation that represents the graph in figure 36. Since the gradient of each point in the graph is different, it is difficult to represent the graph with a single linear equation. The purpose of using linear equation is for easy analysis and interpretation of graph. Therefore, a logarithm of ammonium concentration versus output voltage is plotted as shown in figure 40.

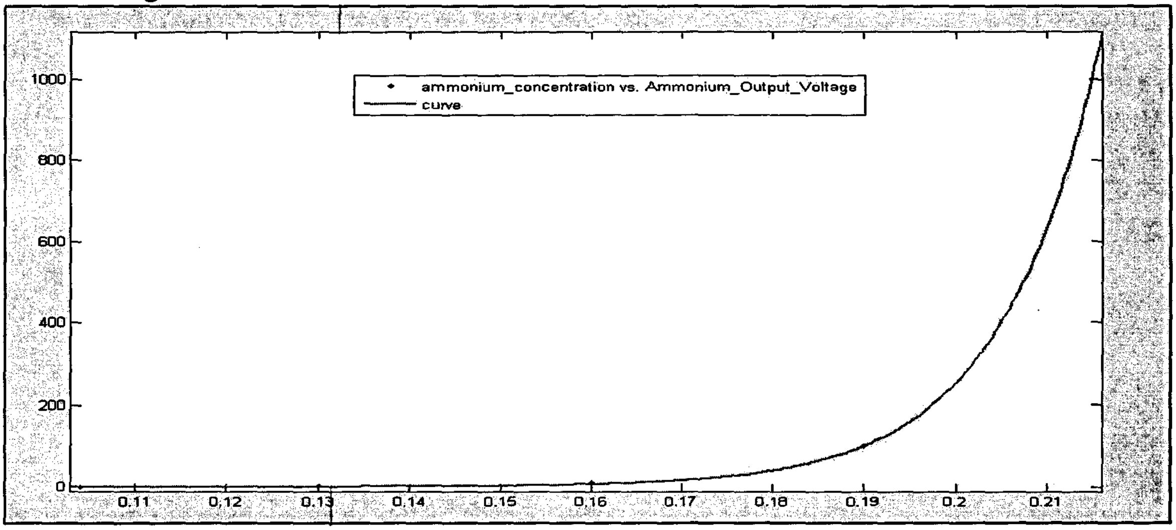


Figure 39: The ammonium concentration versus ammonium sensor output voltage graph by direct measurement from the sensor.

```
General model Exp1:
    f(x) = a*exp(b*x)
Coefficients (with 95% confidence bounds):
    a =  2.626e-006  (1.106e-006, 4.145e-006)
    b =       91.9  (89.2, 94.59)

Goodness of fit:
  SSE: 13.72
  R-square: 1
  Adjusted R-square: 1
  RMSE: 2.138
```

Figure 40: The equation generated from MATLAB fit editor for ammonium concentration versus output voltage graph by direct measurement from the sensor.

As shown in the figure 41, the graph is linear. The linear curve is suitable for curve fitting the data obtained from ammonium sensor calibration. The result shown in figure 42 is the equation for converting the measured voltage to logarithm ammonium value which is logarithm ammonium concentration=35.42*voltage – 4.661.

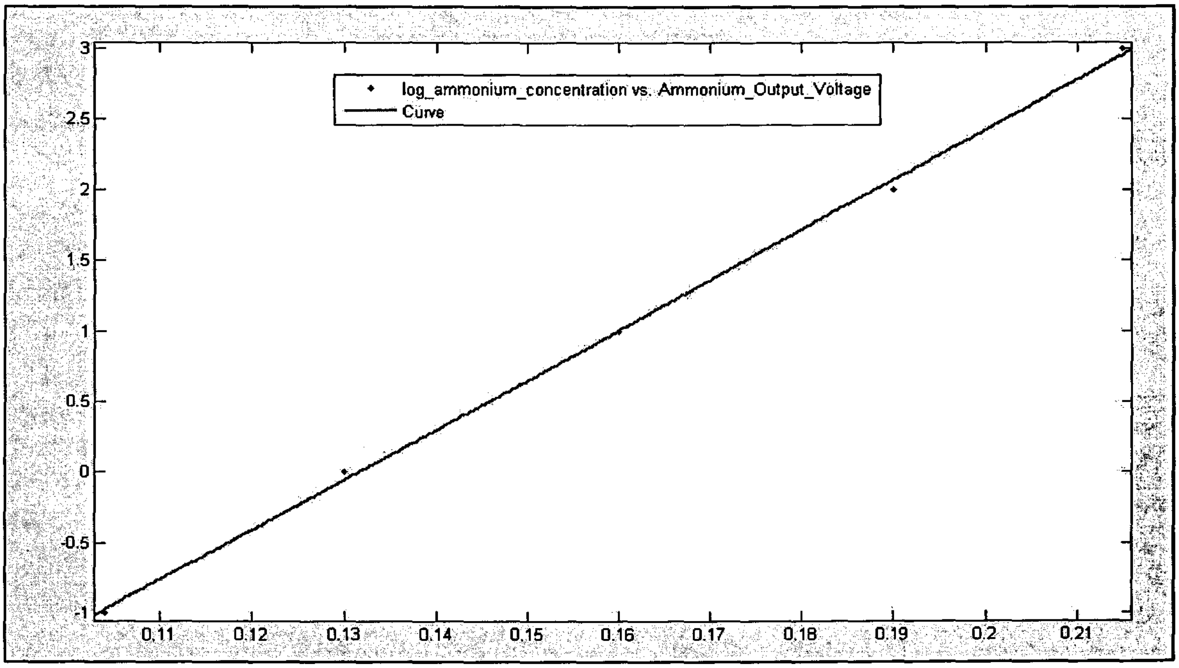


Figure 41: The logarithm ammonium concentration versus ammonium sensor output voltage graph by direct measurement from the sensor.

Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 35.42 (33.31, 37.54)
p2 = -4.661 (-5.009, -4.312)

Goodness of fit:
SSE: 0.01055
R-square: 0.9989
Adjusted R-square: 0.9986
RMSE: 0.05931

Figure 42: The result obtained from the MATLAB Fit editor for logarithm ammonium concentration versus output voltage graph by direct measurement from the sensor.

The results from table 8 are obtained by measuring the output voltage of the sensor directly from its BNC connector and recorded from digital multimeter. Based on the observation in HyperTerminal, there are no errors in the calculation except the DelSig output values are always higher than expected. During troubleshooting, the microcontroller has been countless configured to obtain the same input voltage as with the output voltage of the sensor but failed to do so. In addition, the output values from DelSig changes when the sensor is immersed in different concentration solutions. Therefore, a new method is used to collect the data which is collecting data from the HyperTerminal. This method is further discussed at section 3.1.4 in chapter 3.

Table 9: The tabulate result for ammonium sensor output voltage and its corresponding ammonium concentration using HyperTerminal to collect data.

Concentration of ammonium (ppm)	Output voltage of each data set (V)					Average output (V)
	1	2	3	4	5	
5	0.285307	0.284787862	0.289565	0.286849	0.278455	0.284992635
4	0.281107	0.275797647	0.280921	0.281826	0.280156	0.279961633
3	0.265075	0.269927451	0.272235	0.278066	0.275579	0.272176559
2	0.256604	0.259591388	0.261396	0.259894	0.258767	0.259250442
1	0.259931	0.257360417	0.253716	0.248801	0.247344	0.253430298

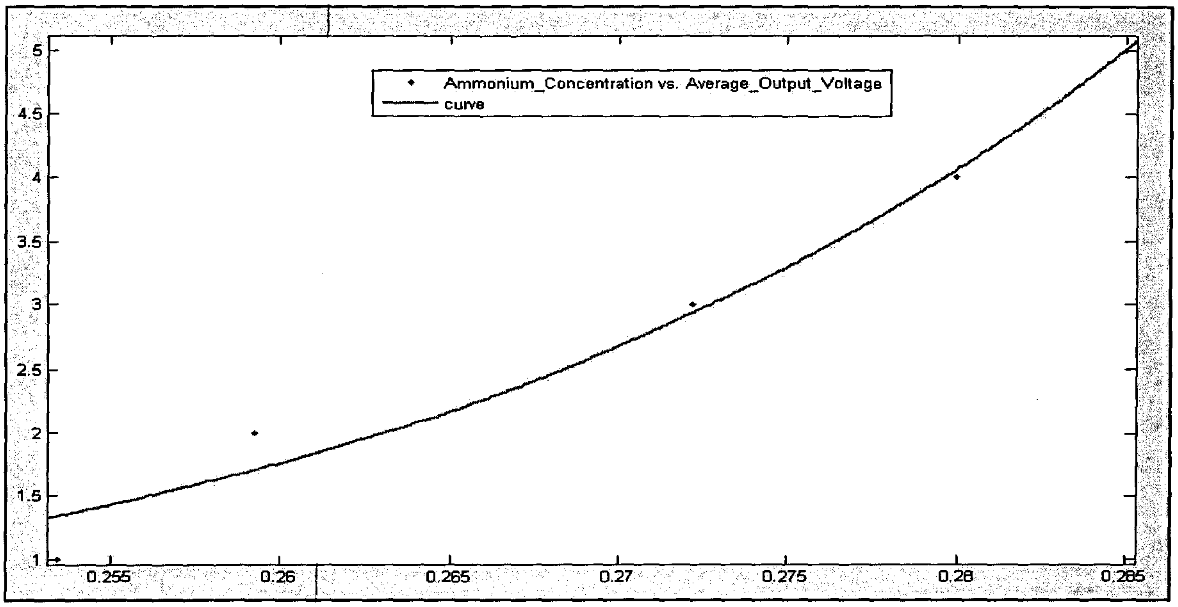


Figure 43: The ammonium concentration versus average output voltage graph using new method of collecting data.

Based on table 9, five set of data are taken and an average is calculated from these five sets of data. This way can provide the best approximation of output voltage of a different ammonium concentration. As shown in graph 43, the graph is has an exponential curve. The curve is just representing the small portion of a larger scale graph such as in figure 36. MATLAB fit editor also generated the equation as shown in figure 44 that represent the graph in figure 43.

```
General model Exp1:
   f(x) = a*exp(b*x)
Coefficients (with 95% confidence bounds):
   a =  3.385e-005  (-9.787e-005,
0.0001656)
   b =     41.77  (27.83, 55.71)

Goodness of fit:
 SSE: 0.2085
 R-square: 0.9791
 Adjusted R-square: 0.9722
 RMSE: 0.2636
```

Figure 44: The equation generated from MATLAB fit editor for the ammonium concentration versus output voltage graph.

As shown in figure 45, the graph is a linear curve. The result obtained from MATLAB fit editor as shown in figure 46 is the equation of converting the output voltage to logarithm ammonium concentration. This equation is logarithm ammonium concentration=19.97*voltage – 4.976. This equation is written in C language to program the PSoC microcontroller.

This new equation using the new method of collecting data along with other calibration equations of other sensors are program on PSoC. Test of reliability is conducted on the system and DR2800 with ten different amount of fish food dissolved in water.

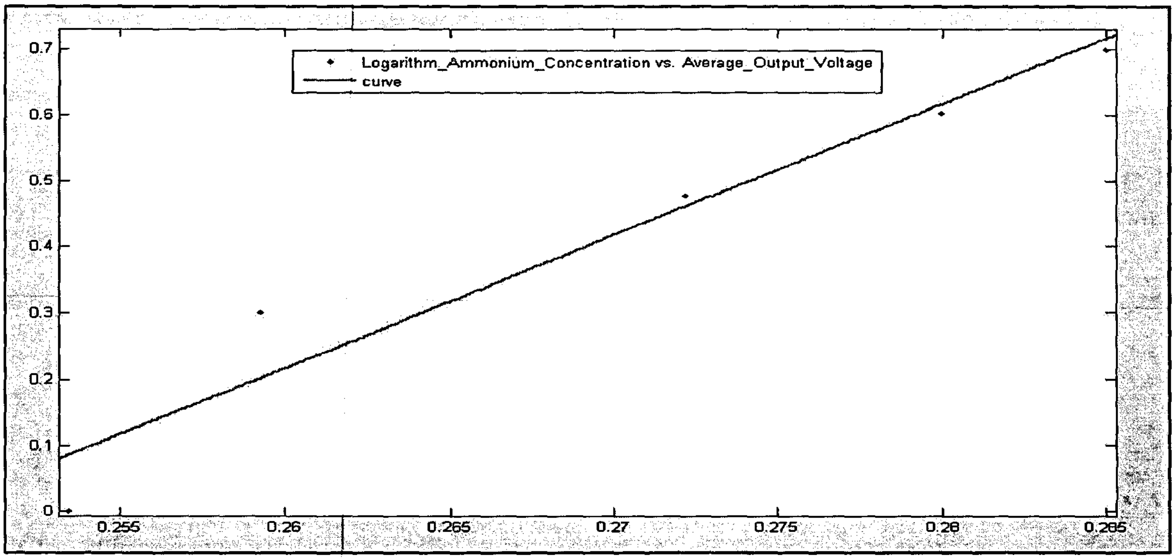


Figure 45: The ammonium concentration versus ammonium sensor output voltage graph using new method of collecting data.

```
Linear model Poly1:
    f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
    p1 =      19.97  (10.8, 29.15)
    p2 =     -4.976  (-7.456, -2.497)

Goodness of fit:
  SSE: 0.01793
  R-square: 0.9412
  Adjusted R-square: 0.9215
  RMSE: 0.0773
```

Figure 46: The equation generated from MATLAB fit editor for logarithm ammonium concentration versus output voltage graph using HyperTerminal data collection.

However, the results obtained from the system using the new logarithm ammonium concentration versus output voltage equation do not give an accurate result compare to the result obtained from DR2800. This is shown in figure 47 which the data distribution of DR2800 does not overlap with data from system. This means that the system readings are not as accurate as DR2800. Therefore, another new method of calibration is done to improve the accuracy of the system by doing calibration based on the measured ammonia nitrogen from DR2800 and the DelSig ADC output voltage from the system.

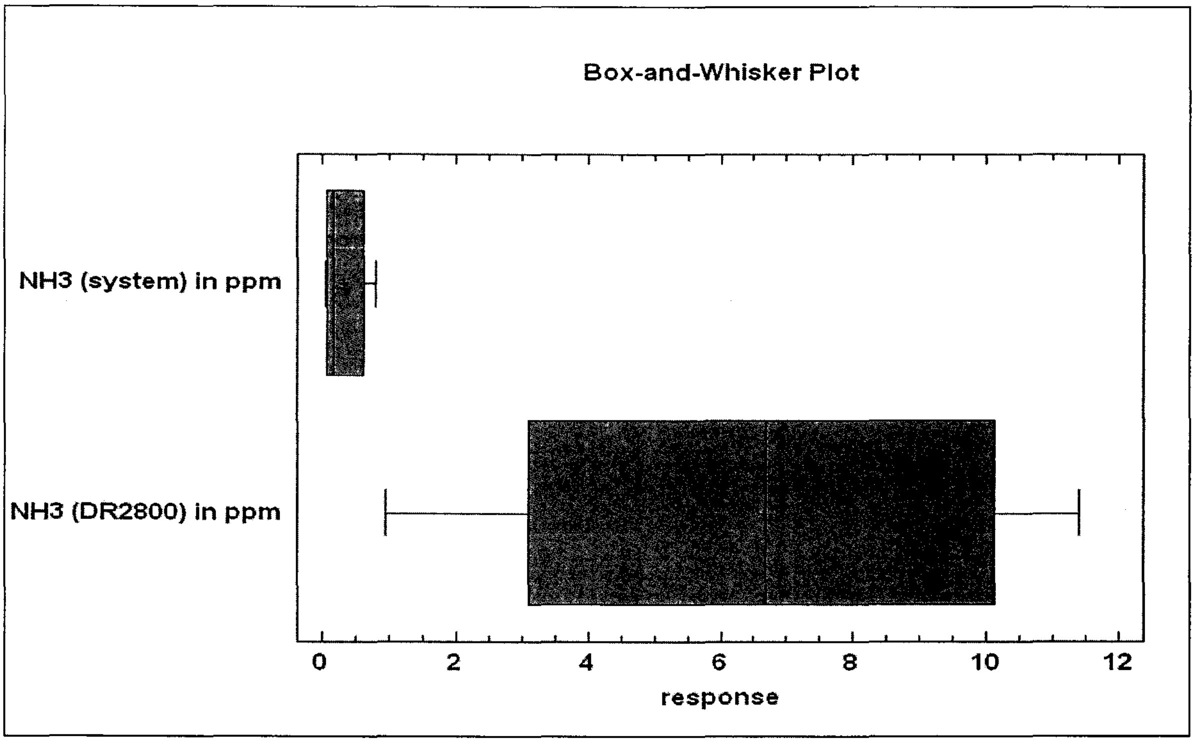


Figure 47: Box-and-Whisker plot for data distribution of NH_3 for system and DR2800.

The data collected from DR2800 and system for new calibration is shown in table 10. As shown in the table 10, the amount of output voltage increase is very small for every increased of one grams of fish food. The amount of output voltage increased is between 0.004 and 0.002 V.

As shown in figure 48, the relationship between logarithm ammonium concentration and output voltage is linear. The result obtained from MATLAB fit editor as shown in figure 49 is the equation of converting the output voltage to logarithm ammonium concentration. This equation is logarithm ammonium concentration = 49.47*voltage – 13.62. This new equation is written in C language to program the PSoC microcontroller. In order to obtain ammonium concentration in ppm, the logarithm ammonium concentration value is power to base of ten. Using Eqs. (2.2) – (2.5), the un-ionized ammonia is calculated using data from ammonium concentration, pH and temperature.

Table 10: Tabulate result of new calibration based on data from DR2800 and system

Fish food mass (g)	Logarithm Ammonium concentration	Output Voltage (V)
1.0569	2.882912749	0.333737259
2.0208	3.140592499	0.33776103
3.0102	3.089909599	0.340215849
4.0114	3.360724661	0.342042159

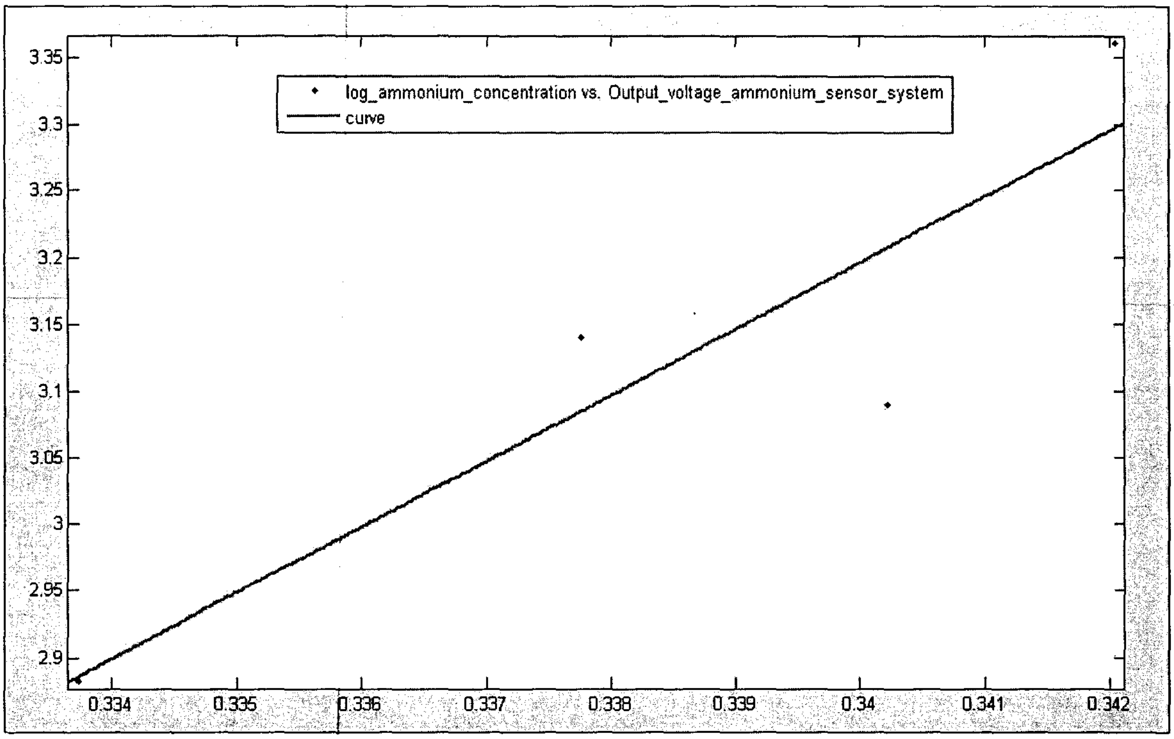


Figure 48: Logarithm ammonium concentration versus output voltage of ammonium sensor using data from DR2800 and system.

Linear model Poly1:
f(x) = p1*x + p2
Coefficients (with 95% confidence bounds):
p1 = 49.47 (-21.01, 119.9)
p2 = -13.62 (-37.47, 10.23)

Goodness of fit:
SSE: 0.02077
R-square: 0.8202
Adjusted R-square: 0.7303
RMSE: 0.1019

Figure 49: The equation generated from MATLAB fit editor for logarithm ammonium concentration versus output voltage graph using data from DR2800 and system.

4.2 Result and Discussion of Reliability Test

As shown in table 11, the concentration of ammonia nitrogen varies for different amount of fish food. The un-ionized ammonia, NH_3 concentration is obtained by multiple the ammonia nitrogen concentration by 1.2. Fish food is used as the source of ammonia in water. The table 11 shows that the ammonia nitrogen increased as the mass of fish food increased. However, the ammonia nitrogen concentration is lower than expected for 5.0169 g sample. The cause of lower ammonia nitrogen concentration than expected is the fish food is not fully dissolved in water. This happens because the fish food is not crush properly into fine small particle and the samples do not stirred long enough.

As shown in table 4.8, the concentrations of un-ionized ammonia in the samples are very near to the results obtained from DR2800. The table 12 also shows that the concentration of un-ionized ammonia is lower than expected for 5.0169 g sample.

Table 11: The tabulate result obtained from ammonia nitrogen testing using DR2800

Mass of fish food (g)	Actual measured mass (g)	Added distilled water (ml)	NH_3-N (mg/l)	NH_3 (ppm)
0.5	0.576	800	0.82	0.984
1.0	1.0564	800	1.54	1.848
1.5	1.5688	800	1.76	2.112
2.0	2.0208	800	2.6	3.12
2.5	2.504	800	3.08	3.696
3.0	3.0102	800	3.69	4.428
3.5	3.5134	800	4.27	5.124
4.0	4.0114	800	4.95	5.94
4.5	4.5068	800	5.02	6.024
5.0	5.0169	800	4.78	5.736

Table 12: The tabulate result of un-ionized ammonia concentration obtained from system.

Actual measured mass (g)	NH_3 (ppm)
0.576	1.068526691
1.0564	1.631225025
1.5688	2.188083173
2.0208	2.93624152
2.504	3.318799496
3.0102	3.986288502
3.5134	4.671029494
4.0114	5.491873371
4.5068	5.629821355
5.0169	4.815279175

4.2.1 Normality Testing

In order to determine whether the water quality monitoring system can measured un-ionized ammonia, the readings from the system and DR2800 must be compared to determine whether the readings are similar or not. Therefore, hypothesis testing is needed to conduct to determine the similarity of readings between the system and DR2800. The first step is normality test which determine whether both data are normally distributed or not. If the data are normally distributed, Bartlett's test is conducted for hypothesis testing on variance. On the other hand, Levene's test is conducted for hypothesis testing to check variance homogeneity when the data is not normally distributed. This test is less sensitive than the Bartlett's test (Retrieved from http://www.texasoft.com/winkmann.html).

Since the points in figure 50 are distributed near the straight line and the P-values obtained from Shapiro-Wilk W test is more than 0.05 as shown in table 13, the data collected from the system is proven to be normally distributed at 95% confidence level. On the other hand, the data obtained from DR2800 is also normally distributed at 95% confidence level. This is because the points in figure 51 are distributed near the straight line and the P-value is more than 0.05 as shown in table 14. The P-value is obtained from Shapiro-Wilk W test. This test is conducted by comparing the quantiles of the fitted normal distribution to the quantiles of the data (Retrieved from http://www.itl.nist.gov/div898/ handbook/). Based on the normality test, Bartlett's test is chosen because the data collected from the system and DR2800 are normally distributed.

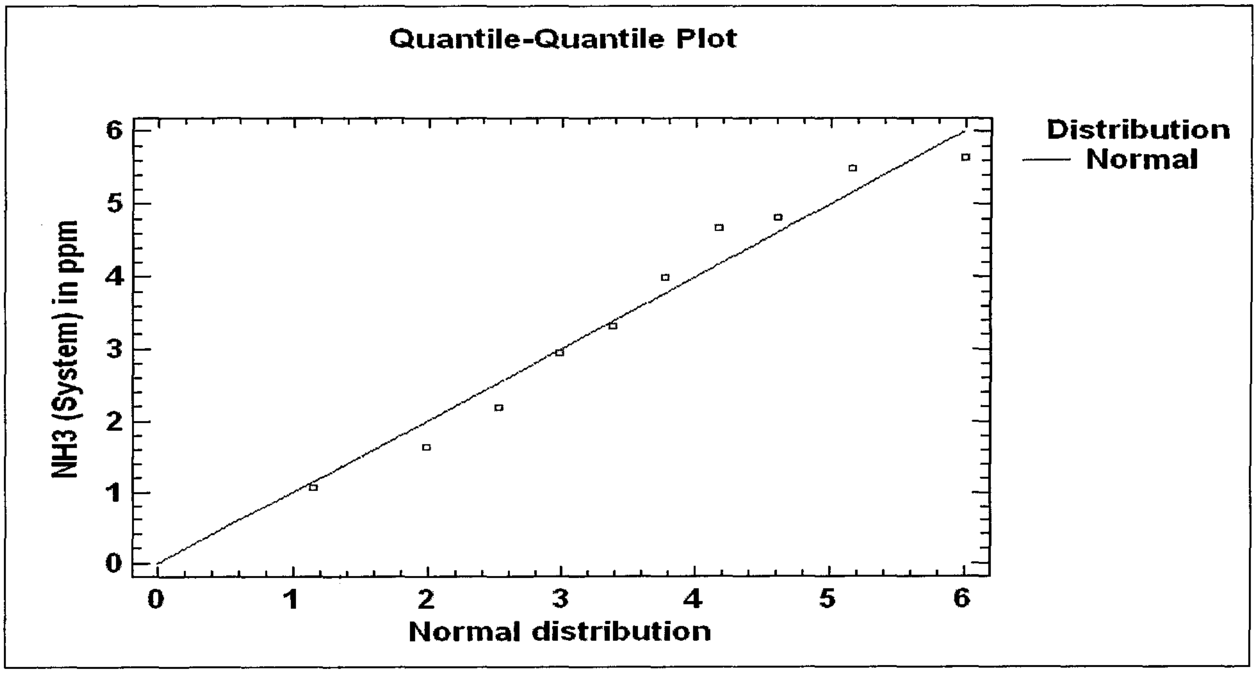


Figure 50: The quantile-quantile plot for normal distribution of NH_3(System) in table 4.7.

Table 13: Tests for Normality for NH_3(system)

Test	*Statistic*	*P-Value*
Shapiro-Wilk W	0.9496	0.648139

Table 14: Tests for Normality for NH3 (DR2800)

Test	*Statistic*	*P-Value*
Shapiro-Wilk W	0.925784	0.39231

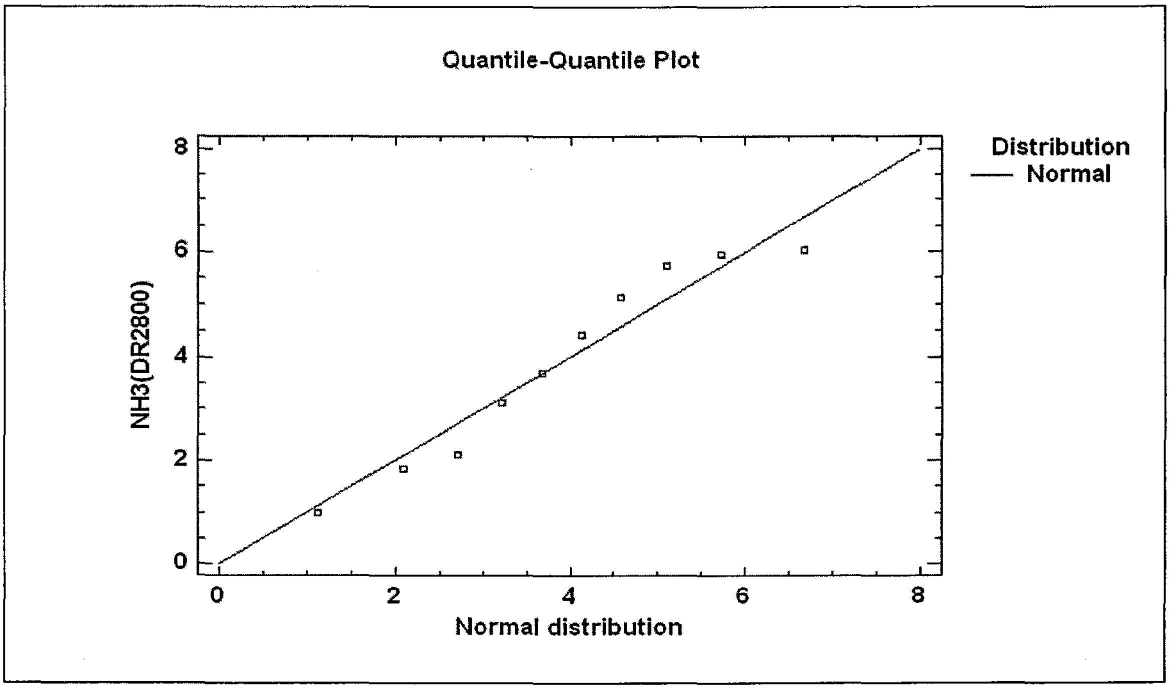


Figure 51: The quantile-quantile plot for normal distribution of NH_3 in table 4.6.

4.2.2 Hypothesis Testing

Bartlett's test for hypothesis testing was chosen based on the analysis from section 4.2.1. In hypothesis testing, there are two statistical parameters that are needed to be tested which are standard deviation and mean. Mean for both data are needed to be considered because the data are more distributed around mean compared to median. Variance check is used to determine the standard deviation for both data whether it is same or not. If either standard deviation or mean or both are not same for both data, the system reading is not similar with DR2800.

Null hypothesis, H_o: $\sigma_{NH_3 from\ system} = \sigma_{NH_3 from\ DR2800}$

Alternative hypothesis, H_a: $\sigma_{NH_3 from\ system} \neq \sigma_{NH_3 from\ DR2800}$

As shown in figure 52, the box-and-whisker plot shows the data distribution for system overlaps with data from DR2800. The vertical line is the median and the plus sign is the center line of the box. Based on Bartlett's test on standard deviation shown in table 15, the standard deviation for both data are similar because the P-value is more than 0.05. Therefore, the null hypothesis is accepted and alternative hypothesis is rejected.

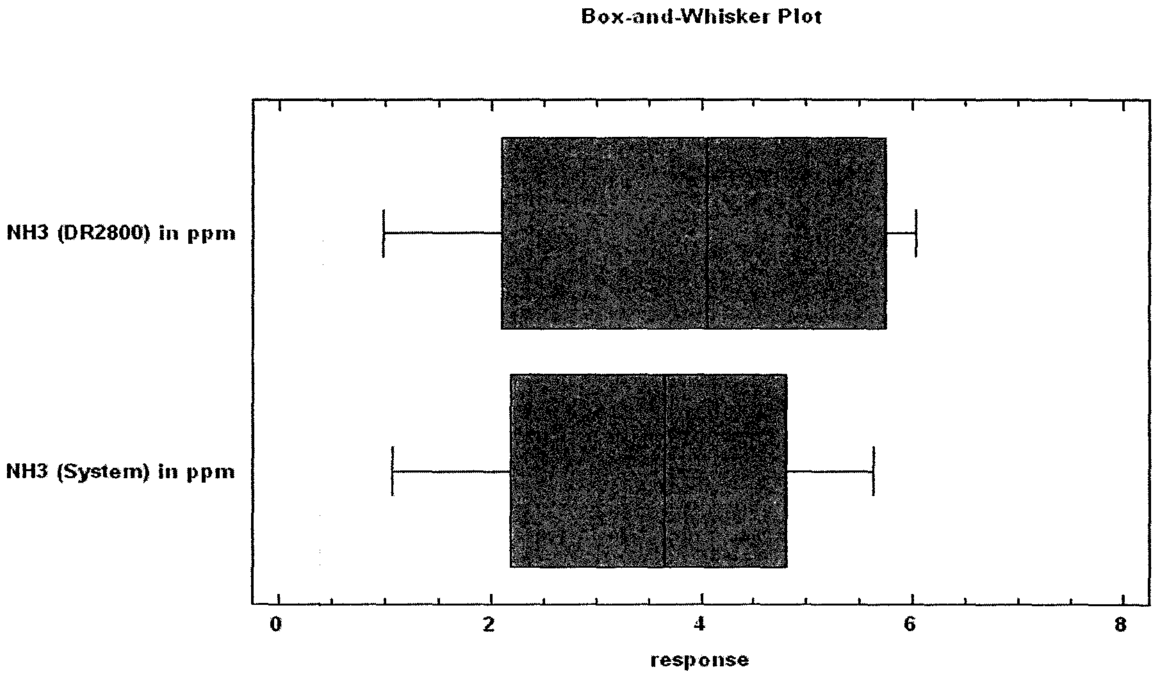


Figure 4.20: Box-and-Whisker plot for average of NH_3 from system and NH_3 from DR2800.

Table 15: Variance Check for Bartlett's test

	Test	*P-Value*
Bartlett's	1.00892	0.697141

The next test is comparing mean of data from system and DR2800. The t-test compare both data whether the means are equal or not at 95% confidence level. This test is an independent group t-test with the assumption of normality or equality of variance is met. As shown in figure 53, sample 1 is the data from DR2800 and sample 2 is the data from system. Since the P-value is more than 0.05, the null hypothesis is accepted and alternative hypothesis rejected. This means that the mean for both data are the similar at 95% confidence level.

Comparison of Means
95.0% confidence interval for mean of NH3 (DR2800) in ppm: 3.9012 +/- 1.31434 [2.58686, 5.21554]
95.0% confidence interval for mean of NH3 (System) in ppm: 3.57372 +/- 1.15011 [2.42361, 4.72382]
95.0% confidence interval for the difference between the means
assuming equal variances: 0.327483 +/- 1.62201 [-1.29453, 1.94949]

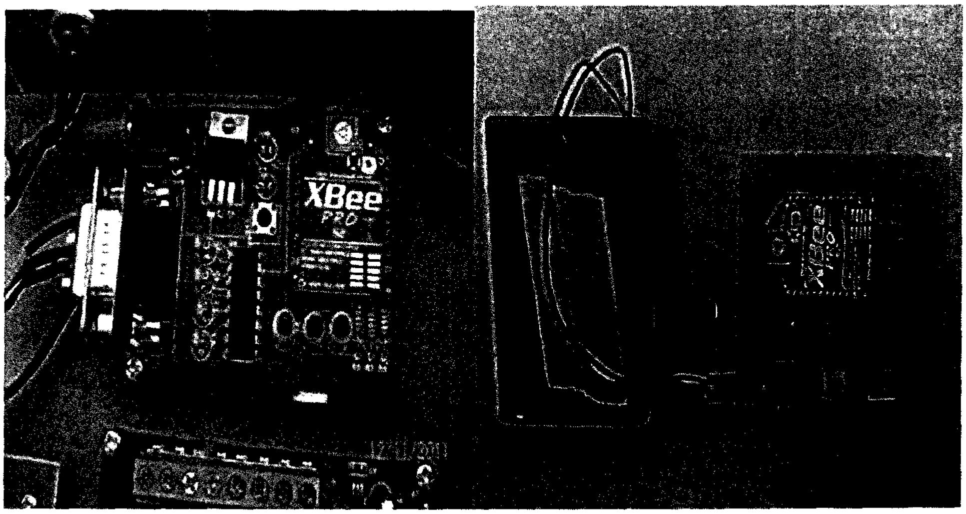
<u>t test to compare means</u>
Null hypothesis: mean1 = mean2
Alt. hypothesis: mean1 NE mean2
assuming equal variances: t = 0.424176 P-value = 0.676463
Do not reject the null hypothesis for alpha = 0.05.

Figure 53: The comparison of medians for average NH_3 from system and NH_3 from DR2800.

Based on the hypothesis testing for standard deviation and mean, the standard deviations and means for the system and DR2800 are similar. Hence, it is clear that the system is able to measure un-ionized ammonia. Therefore, the readings for the system and DR2800 are similar but not same for the same samples concentration.

5.0 System Implementation

Sensors are immersed in the pond to monitor the 100 of catfishes. Sensors also immersed in the pond without fish as a control in this experiment. Data are collected every 5 second. Data are sent to PC through Xbee module and data are collected in PC through USB port.



a. Hardware for end device and coordinator. b. Hardware for router

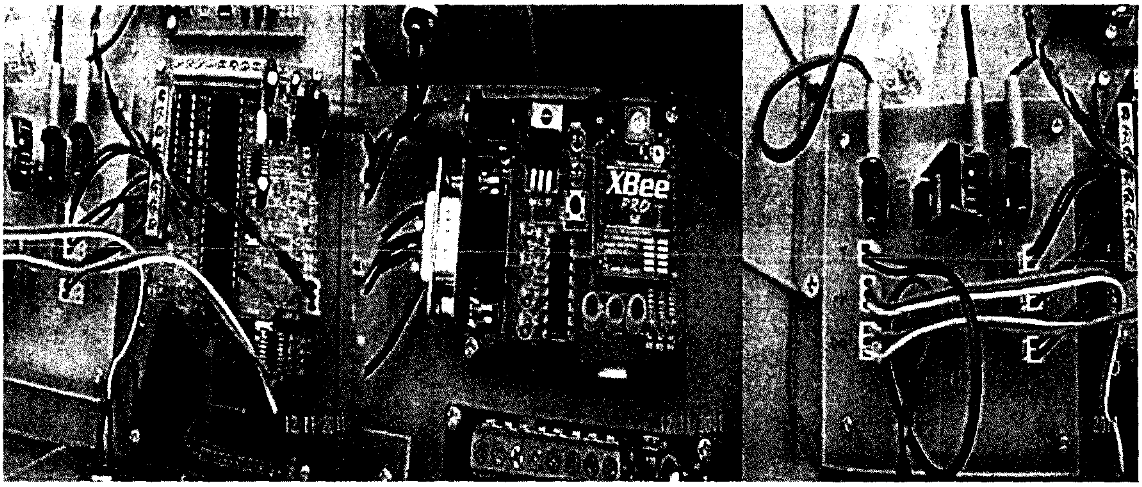


Figure 54: Board used for testing

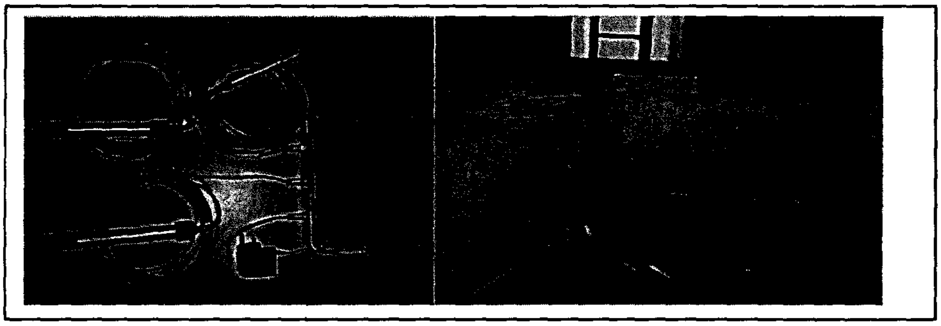


Figure 55: System implementation at Pusat Akuatik USM

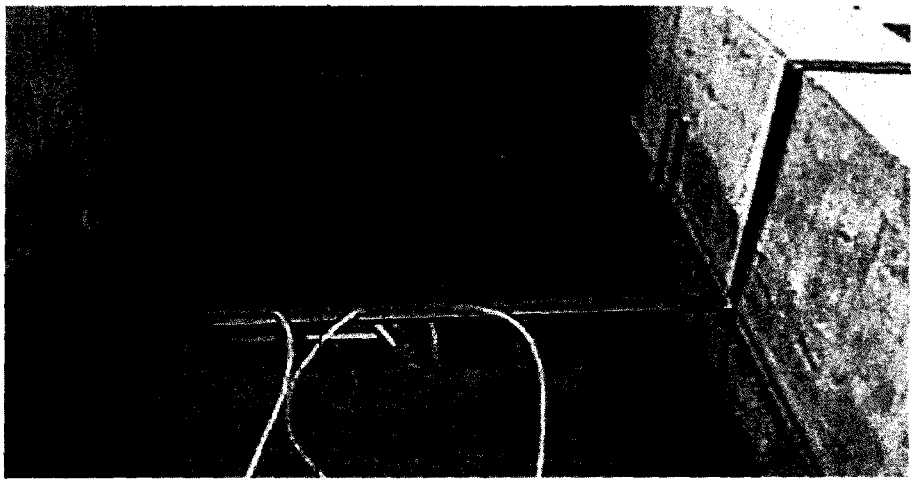


Figure 56: Pond without Fish

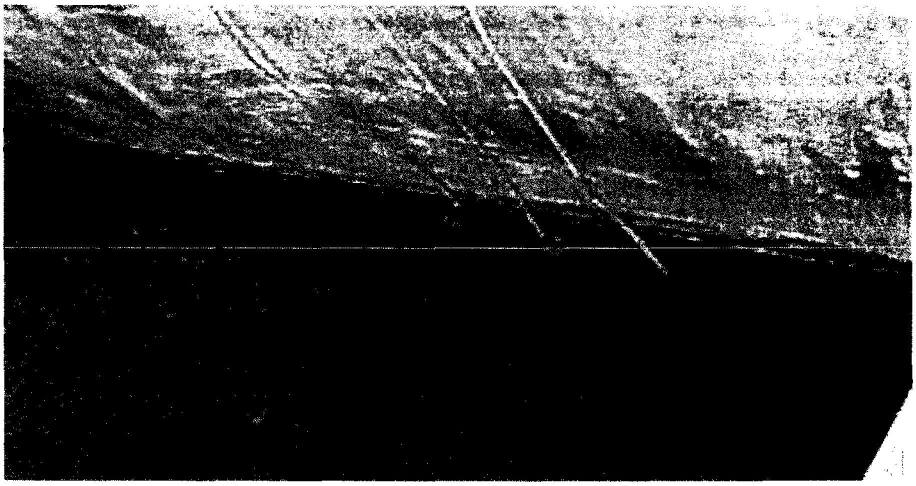


Figure 57: Pond with catfishes

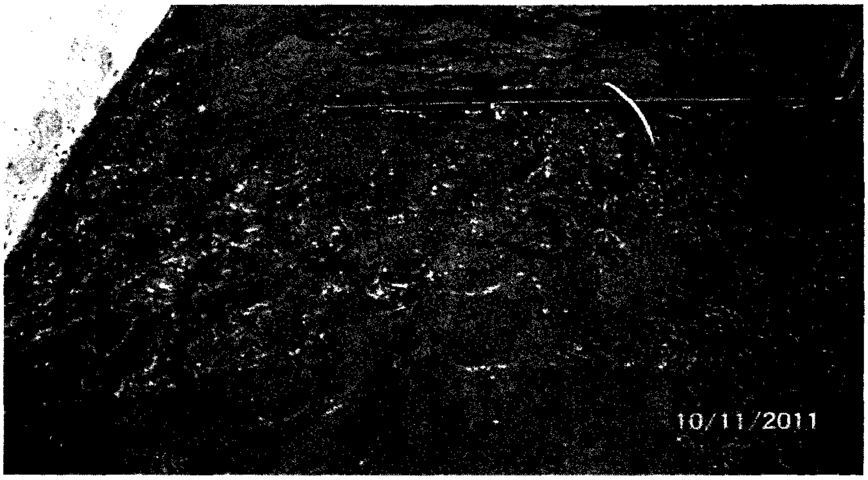


Figure 58: Pond with catfishes after 5 months

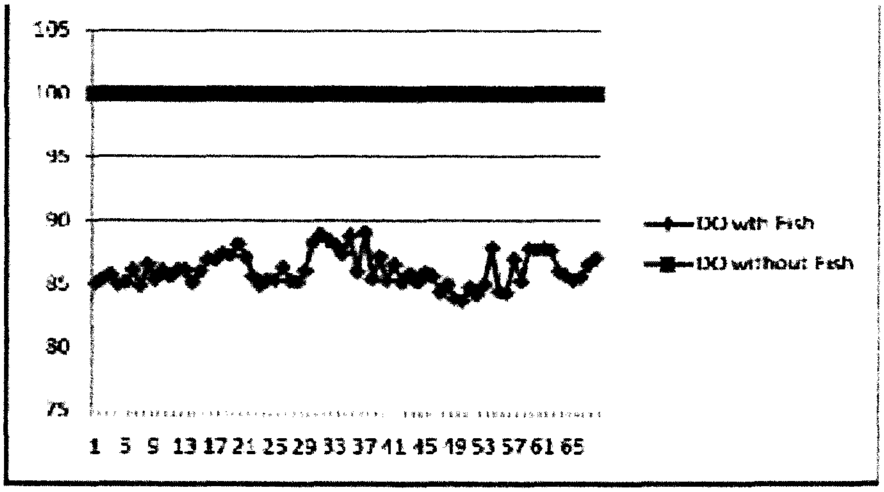


Figure 59: Results from DO sensor

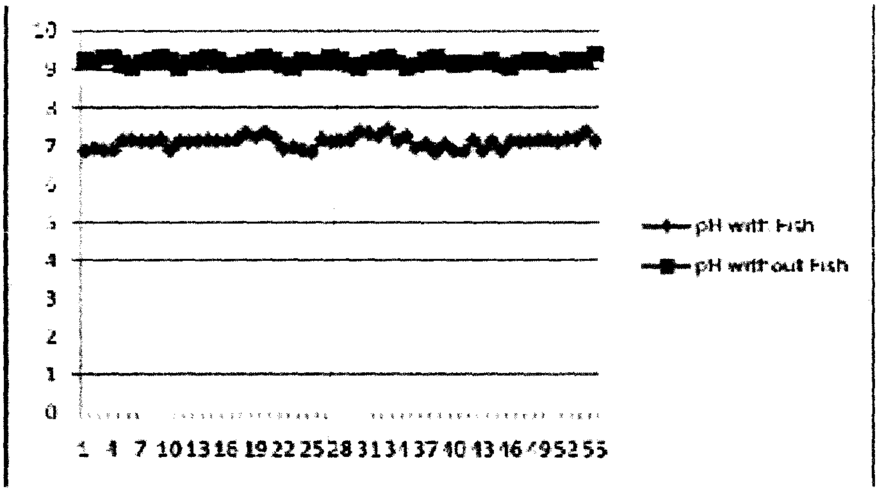


Figure 60: Results from pH sensor

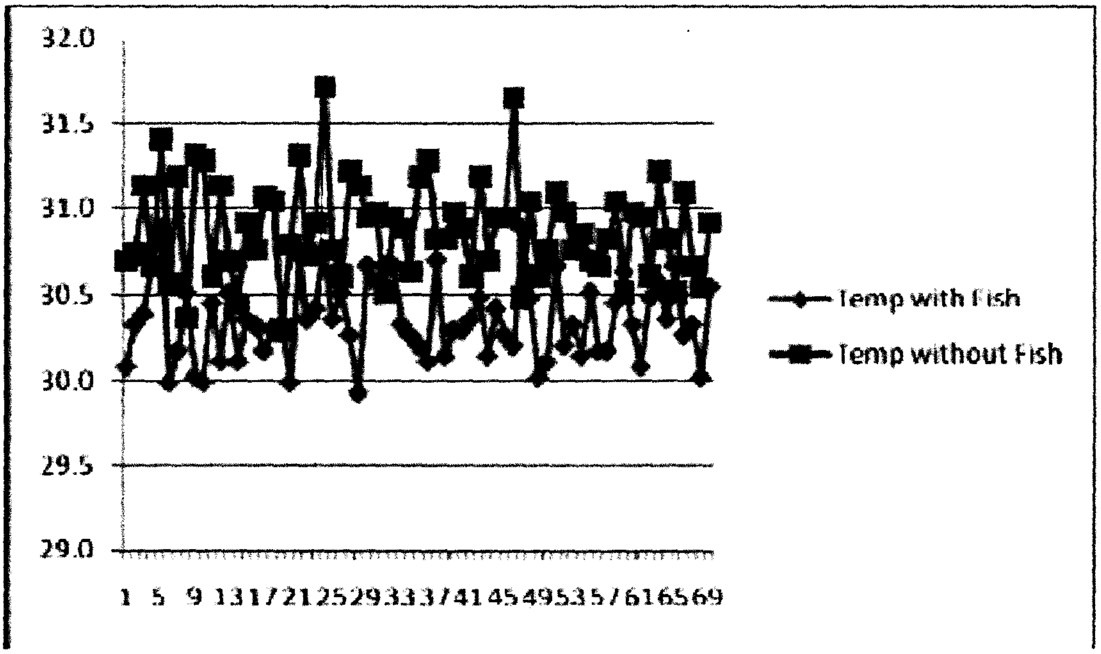


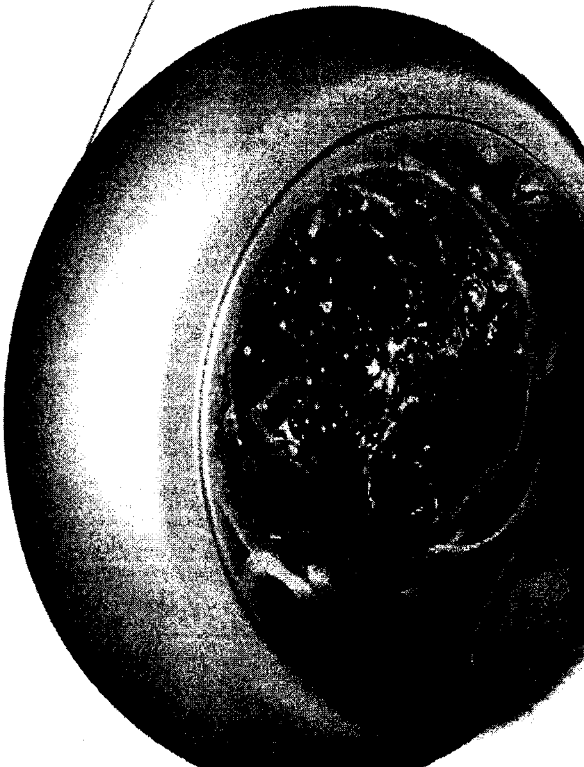
Figure 6 1`   1: Results from temperature sensor

6.0 Database System Development

Graphical user Interface and database system for Water Quality Monitoring System is shown in Appendix 1.

Appendix 1

User Guide for Water Quality Monitoring System



30/Aug/2012

Contents

1. DESKTOP APPLICATION

Introducing Water Quality Monitoring System (WQMS) software which is a software that had been developed to integrate with devices which are going to be use in monitoring water quality level. This software is able to receive data send by sensors and display meaningful data to the user that can be use to analyze any environmental changes that happen in any specific locations involve.

1.1 Hardware and Software Requirement

Hardware Platform		PowerPC-based Computer x32
Min. RAM		1.99 GB
Min Free Hard Disk Space		2 GB
Min Operating System		Window XP
Additional Requirements		Internet (Min Speed: 5.0 Mbps), Navicat for MySQL Premium
Hardware Devices		Radio Frequency (RF) receiver unit, Global System for Mobile Communication (GSM) modem.

1.2 Hardware and Software Installation Setup

1.2.1 Software Installation Setup

This software is distributed with four items in a package as shown below:

Name	Date modified	Type	Size
setup	05/Sep/2012 6:57 ...	Application	418 KB
Setup	05/Sep/2012 6:58 ...	Windows Installer ...	8,434 KB
Username n Password	05/Sep/2012 7:05 ...	Text Document	1 KB
wqms	05/Sep/2012 7:03 ...	Microsoft SQL Ser...	10 KB

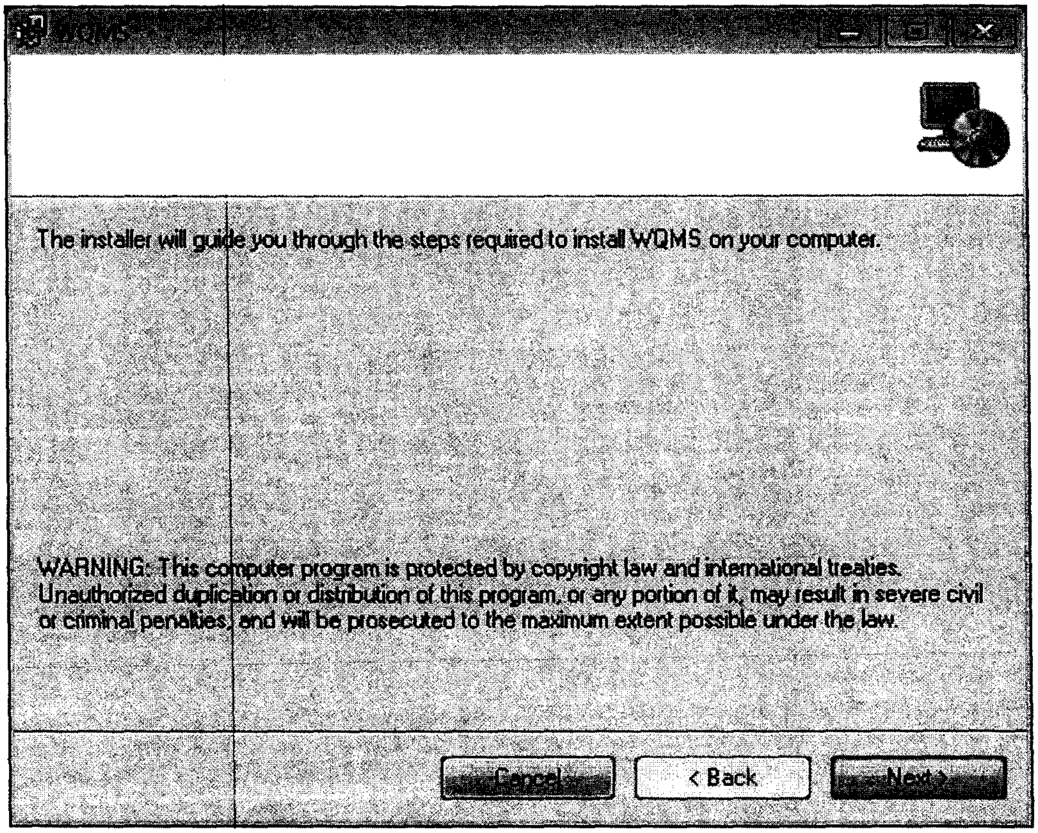
Setup.exe – Installer for desktop application

Username n Password.txt – Contain default username and password for administrator.

Wqms.sql – Contained sql file for database.

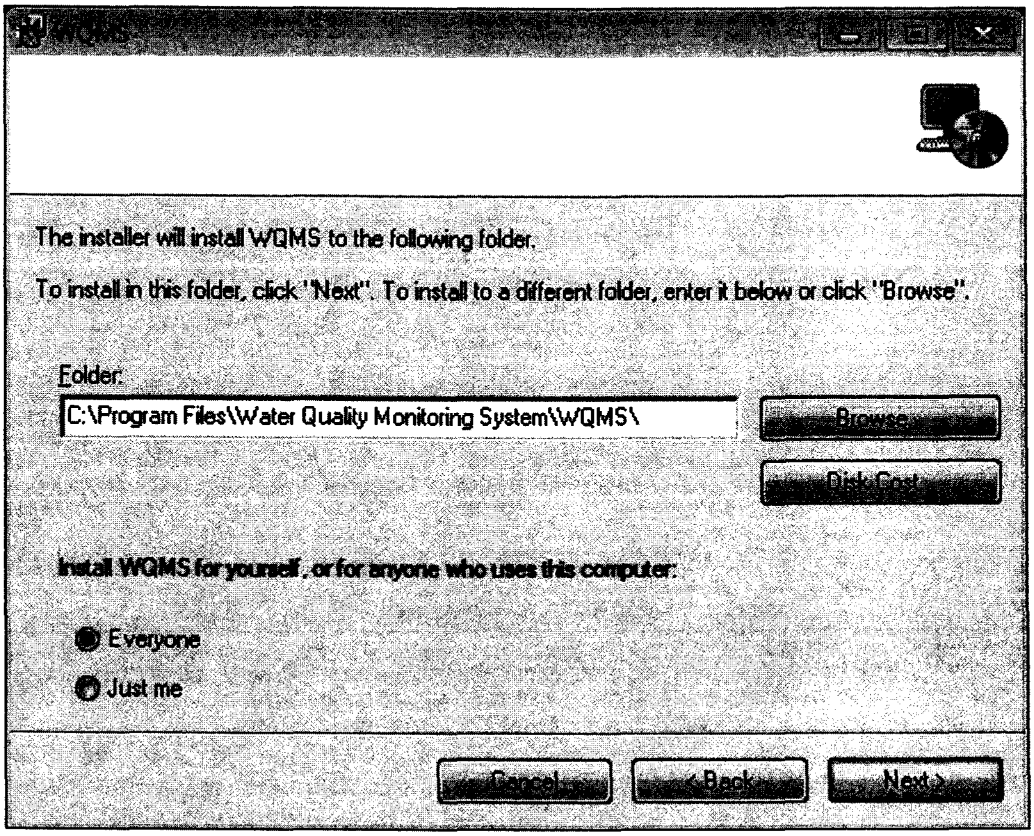
1.2.2 Application Installation Guide

1. Double-click or run setup.exe file.
2. Users will be prompt a window shown below :

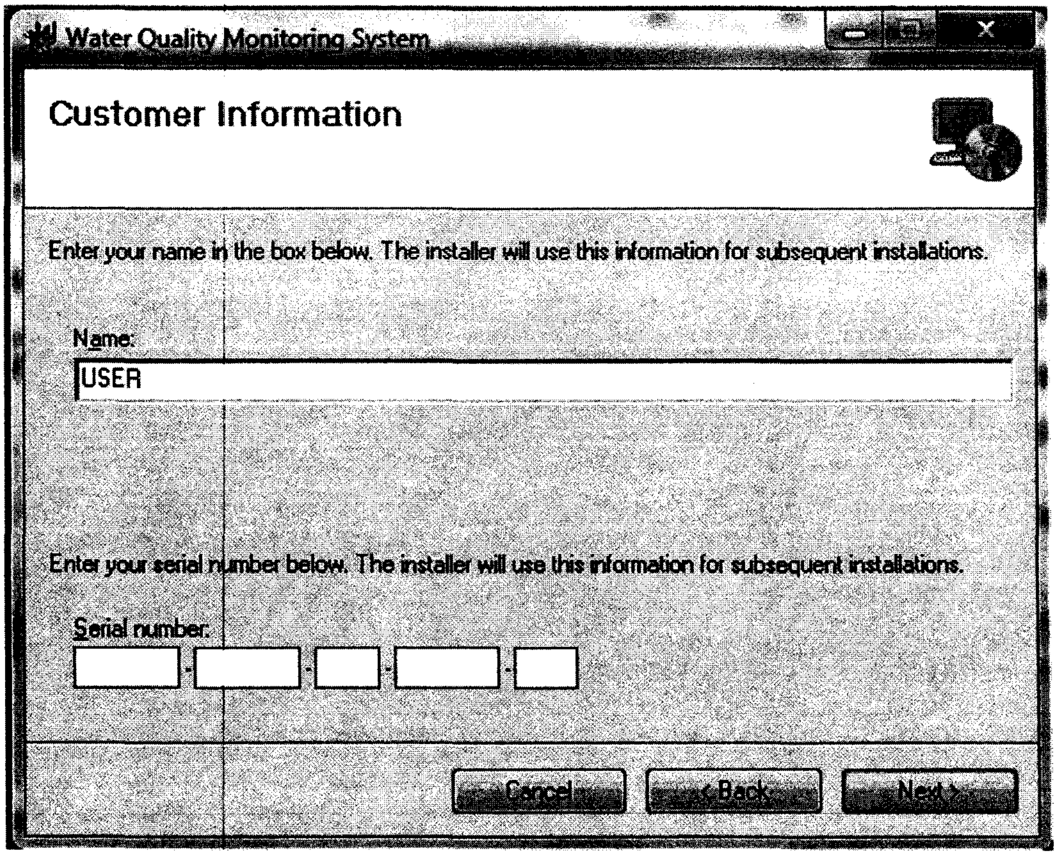


3. Click Next to go to the next instruction.

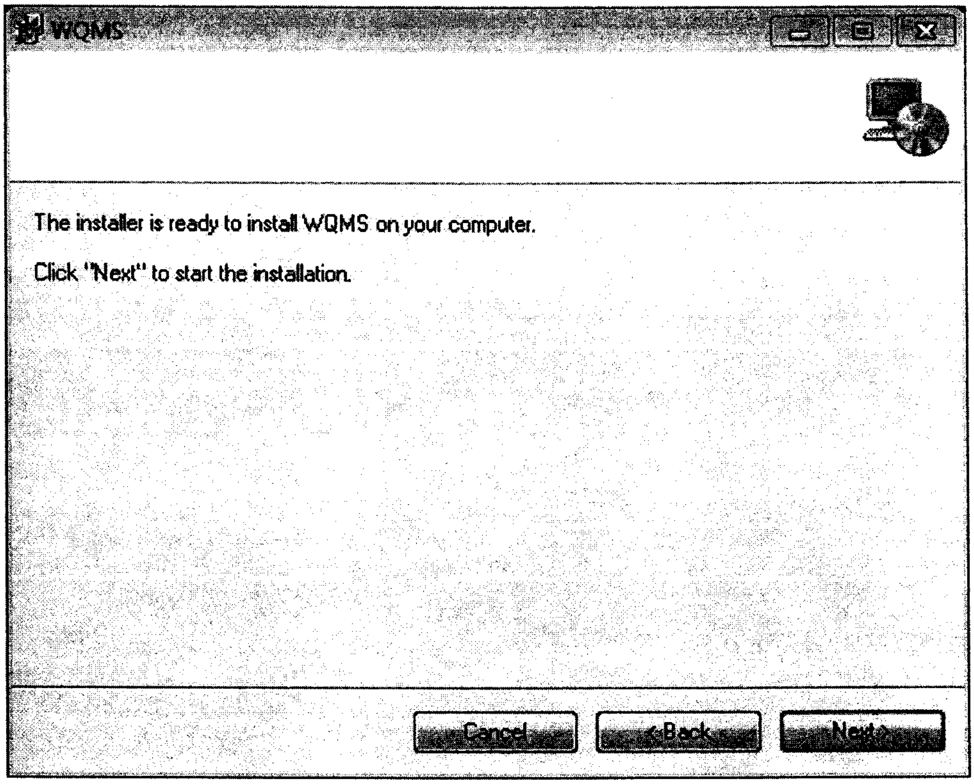
4. Specify the destination folder to install this application by clicking button browse.
   The default destination folder is C:\Program Files\Water Quality Monitoring System\WQMS\.
   Click Next button when you are ready to go to the next step.

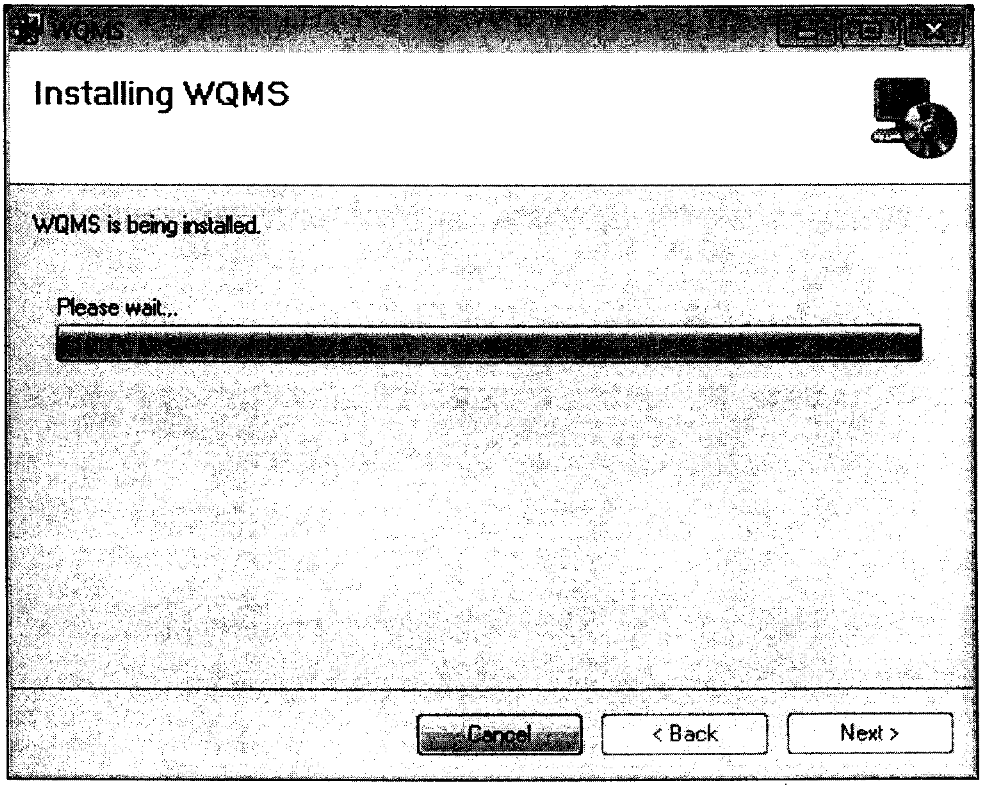


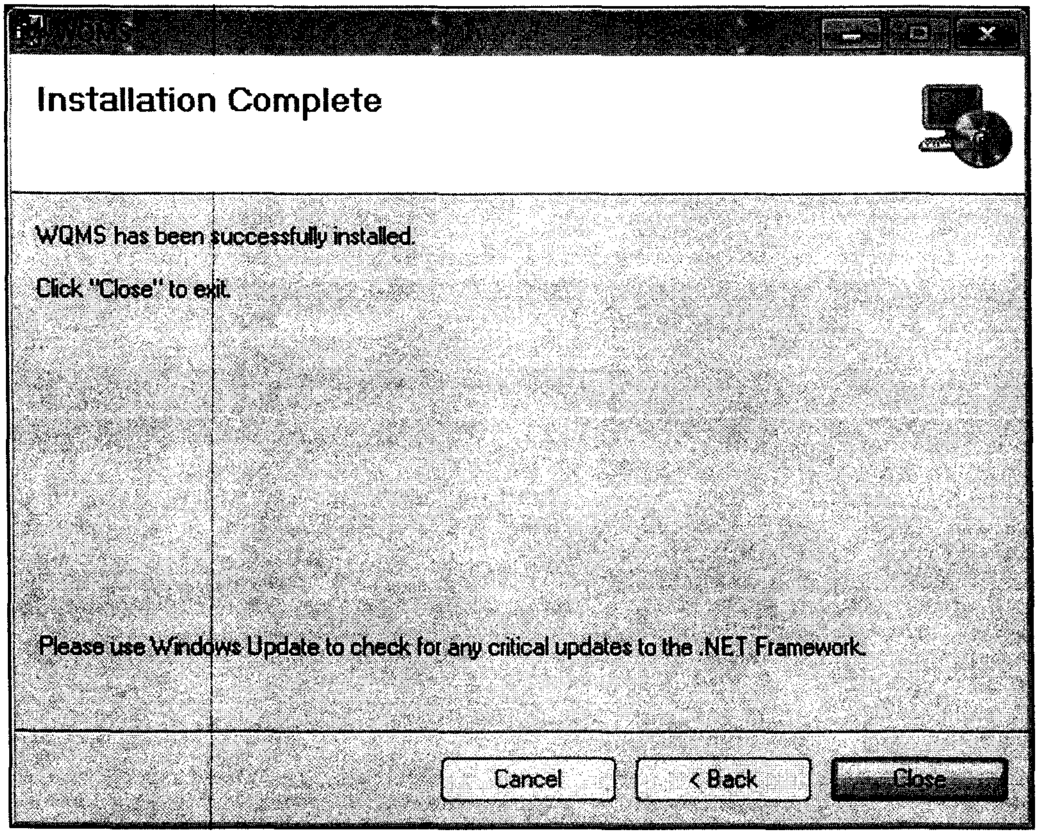
5. Please enter serial number provided with this installation package and click “Next” button.



6. Click Next button to proceed with the installation.



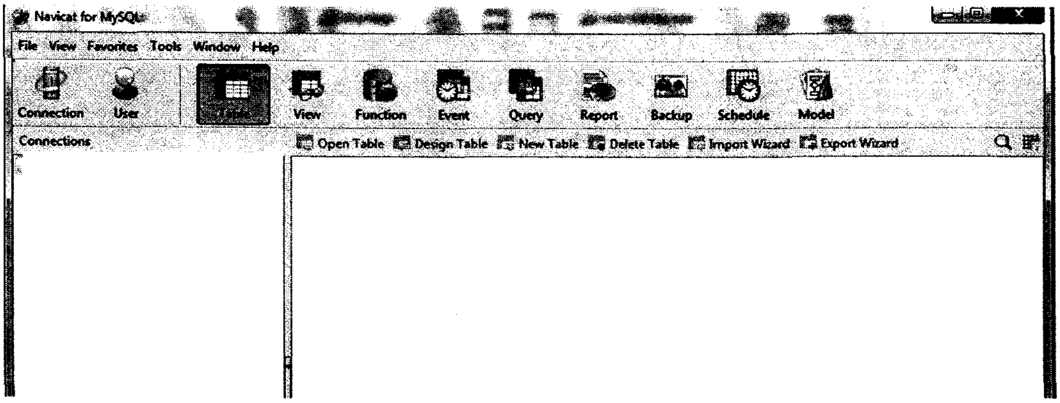




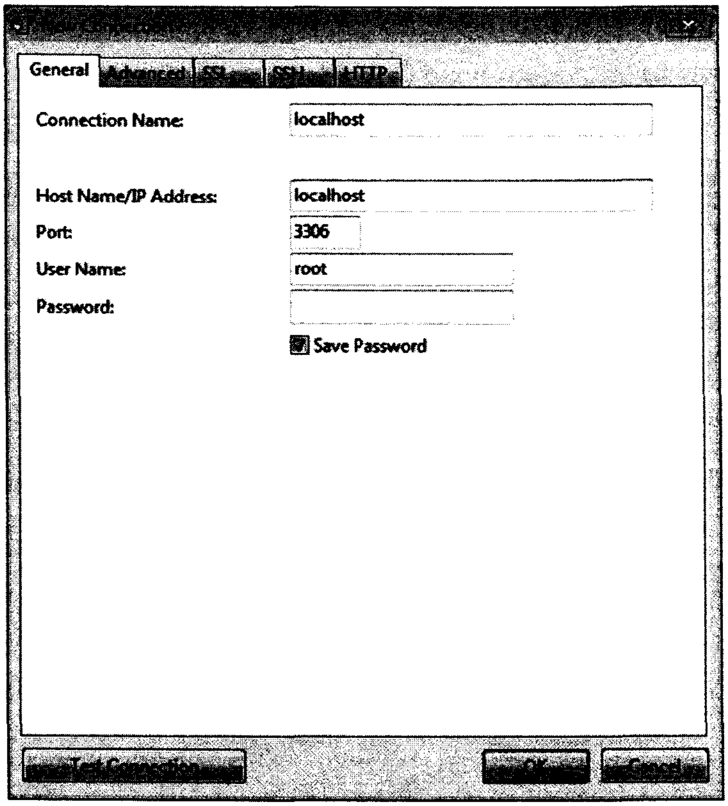
7. Your Water Quality Monitoring System Application is now installed. A shortcut of this application will be created at your desktop and program's menu.

1.2.3 Database Installation Guide

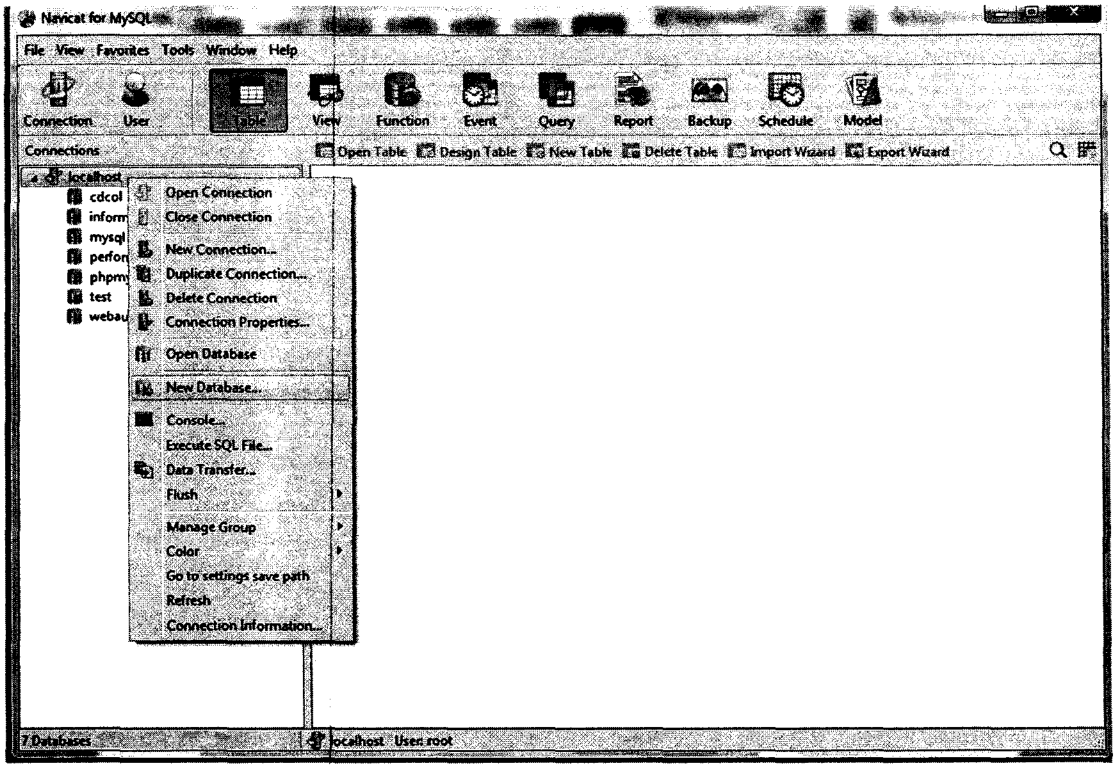
1. Open Navicat for MySQL.
2. Click button Connection at the left top of the window.



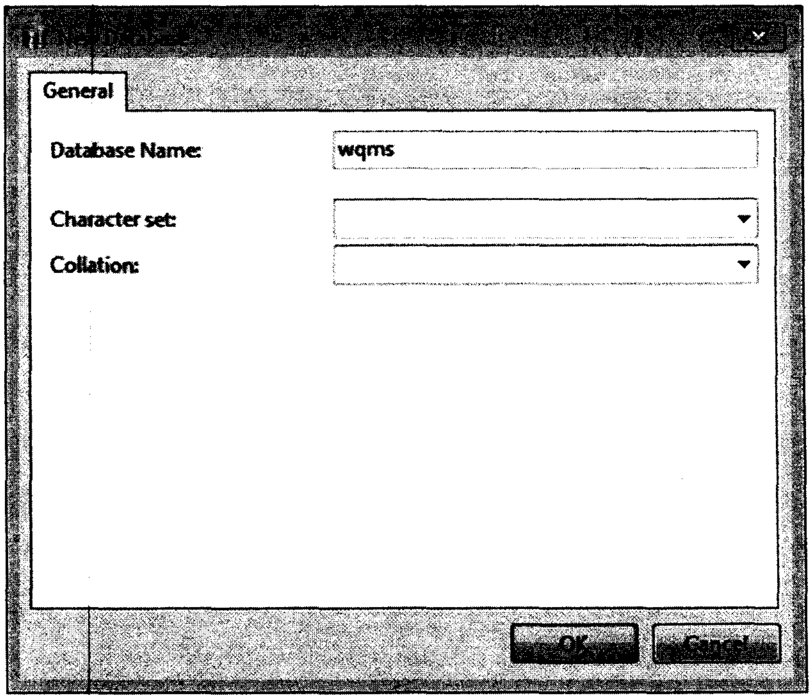
3. You will be asked to insert new connection.
   Insert *localhost* as the Connection Name.



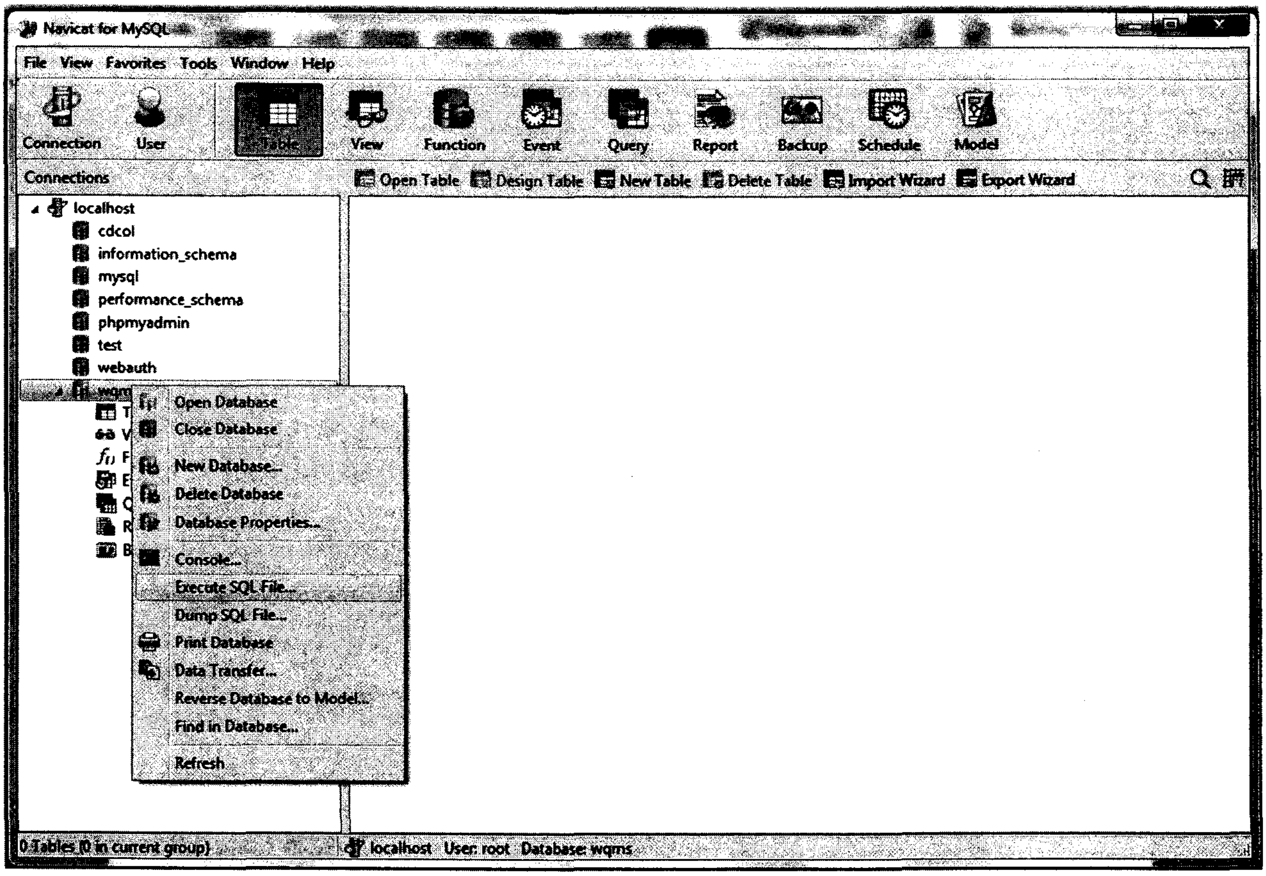
4. Right-click at localhost and select New Database.



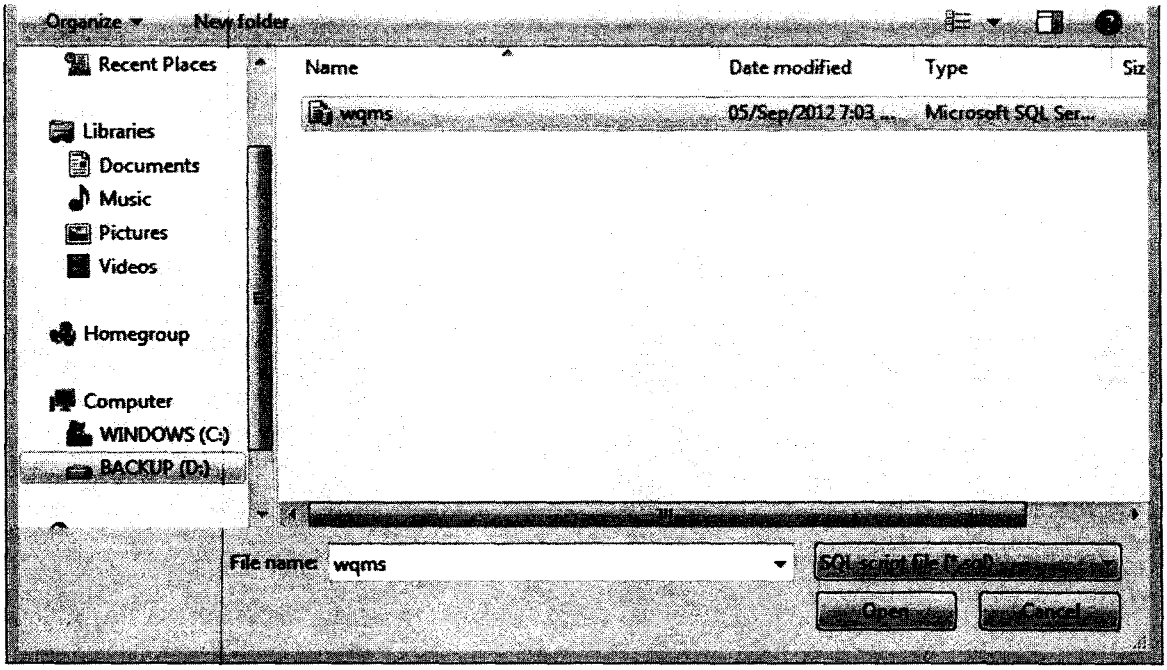
5. At Database Name section, please type wqms. Then, click OK.



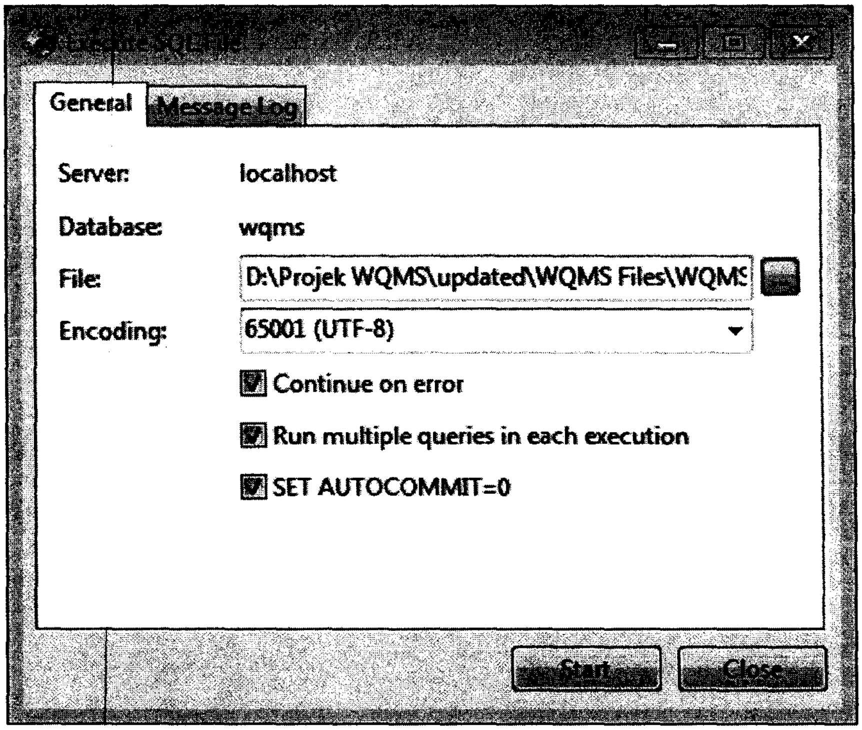
6. Double-click wqms database so that icon beside it will change to green.
7. Right-click on wqms and choose Execute SQL File.

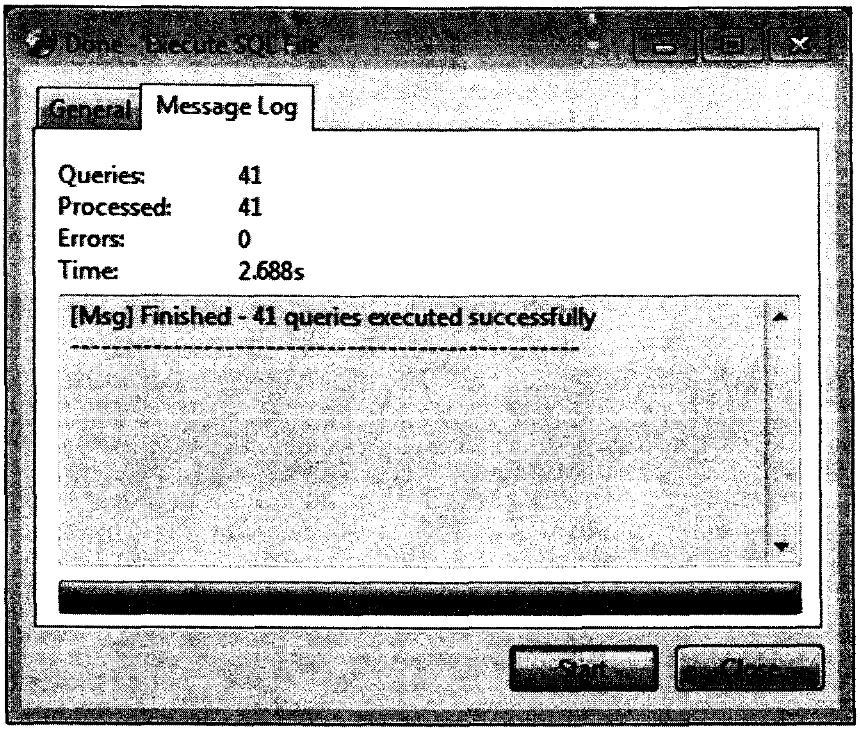


8. In File section, click and select .sql file that given in the package.

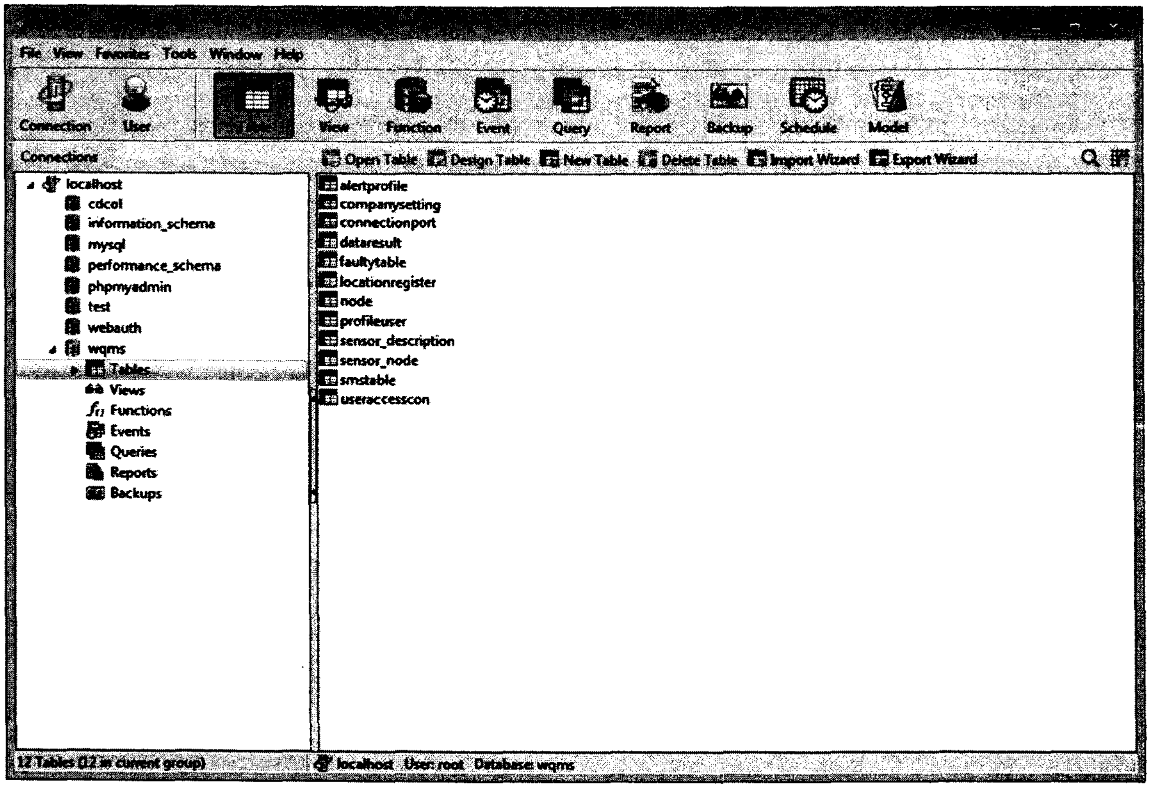


9. Click Start button.





10. Water Quality Monitoring System's Database is now created and this application is now ready to use.



1.3 Application's Setup Summary

REMINDER :

✓ Please make sure you have plug in all the devices required on your PC or computer

<u>1st step</u>

Please fill in all the company's information and location details required in the software system.

- Administrator need to **login** into the system using the username and password **that will be** provided **in the package.**

Name	Date modified	Type	Size
setup	05/Sep/2012 6:57 ...	Application	418 KB
Setup	05/Sep/2012 6:58 ...	Windows Installer ...	8,434 KB
Username n Password	05/Sep/2012 7:05 ...	Text Document	1 KB
wqms	05/Sep/2012 7:03 ...	Microsoft SQL Ser...	10 KB

- Go to system section by **clicking system button** on the left menu side bar.
- Fill in the organization name, address and contact number of your company.
- Click button choose to select your company logo.
- Click save setting to save your company information and apply changes.
- **Register** the **new location** by clicking **add button.**
- Added location will be display on the left bar. **Double click** the location name to view the details.
- Click **Edit** button to **change any location details**

All of your company information will be display on your software system.

<u>2nd step</u>

Now, we need to do the **connection setting**.

- Go to the **communication button** on the left menu side bar.
- There are a few connection listed in the data gateway setting bar on the left side . Please **click the chosen connection** to edit the connection setting.

✓ Please remember to **double click** on the connection's name on the left side bar before proceed with editing.

- You need to **test the connection** setting before save the setting.
- **Click save button** to save the connection setting .

<u>3rd step</u>

Next, we need to **add** all the **nodes exist** in each location.

- Click the **Node button** on the left menu bar.
- Add new node by clicking add button.
- Fill in all the required fields.
- Save the setting by clicking save button.
- Click **refresh button** on the left menu bar to **view the added node** in each existing location.
- If there are any unwanted nodes, just select the nodes on the list and click delete button (minus button image).
- To **view** the nodes details, please **double click the nodes name.**

4th step

Next step is to **configure alert setting.**

- The method use to add this alert setting is exactly same like method to add the existing nodes above.
- Click add button to add, save the setting and click the delete button to delete.

> ✓ Always remember to **double click** on the location's name or selected alert name list on the left side bar to view their details.

5th step

Any supervisor is allows to **change** their own **profile details** and manage their own **password.**

- Go to main **profile button** and choose profile button to edit their own details.
- Choose manage password button to change their own password and save it.

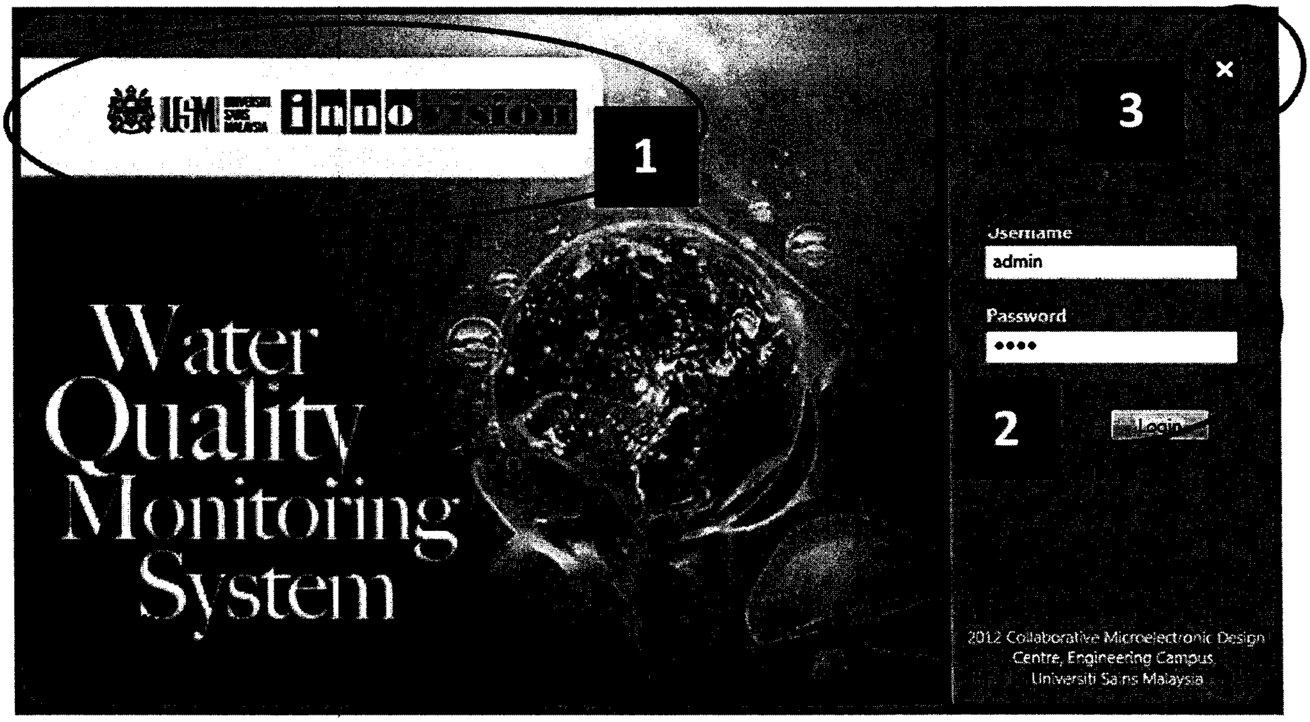
6th step

The authorized manager whom acts as administrator is the only people who allowed to **register new user or supervisor.**

- Go to the **user button** to register new user or new supervisor.
- Same method use to add, delete , save and view registered user.

1.4 Getting Started (How to use)

1.4.1 Login



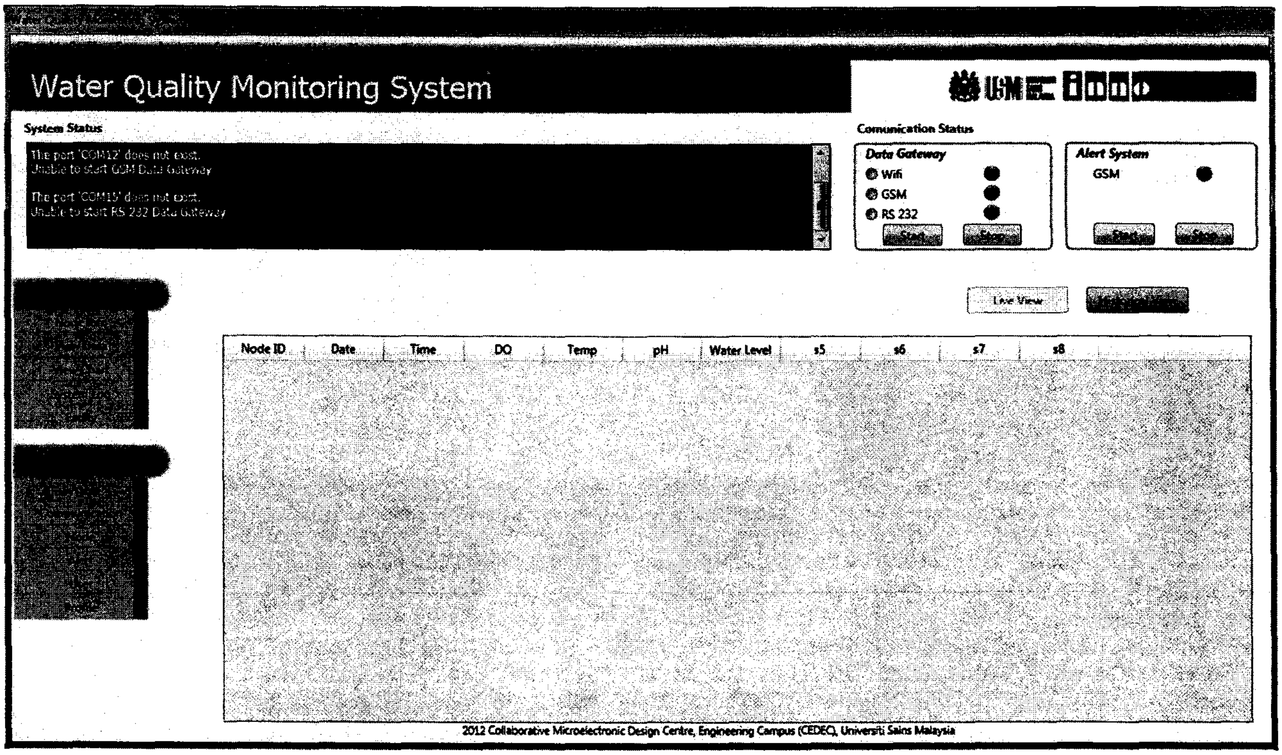
GUI for user LOGIN

1. Company Logo
   Administrator can upload their own logo at system setting later. For example USM and Innovision as shown in all figures.
2. Login section
3. Button for exit application

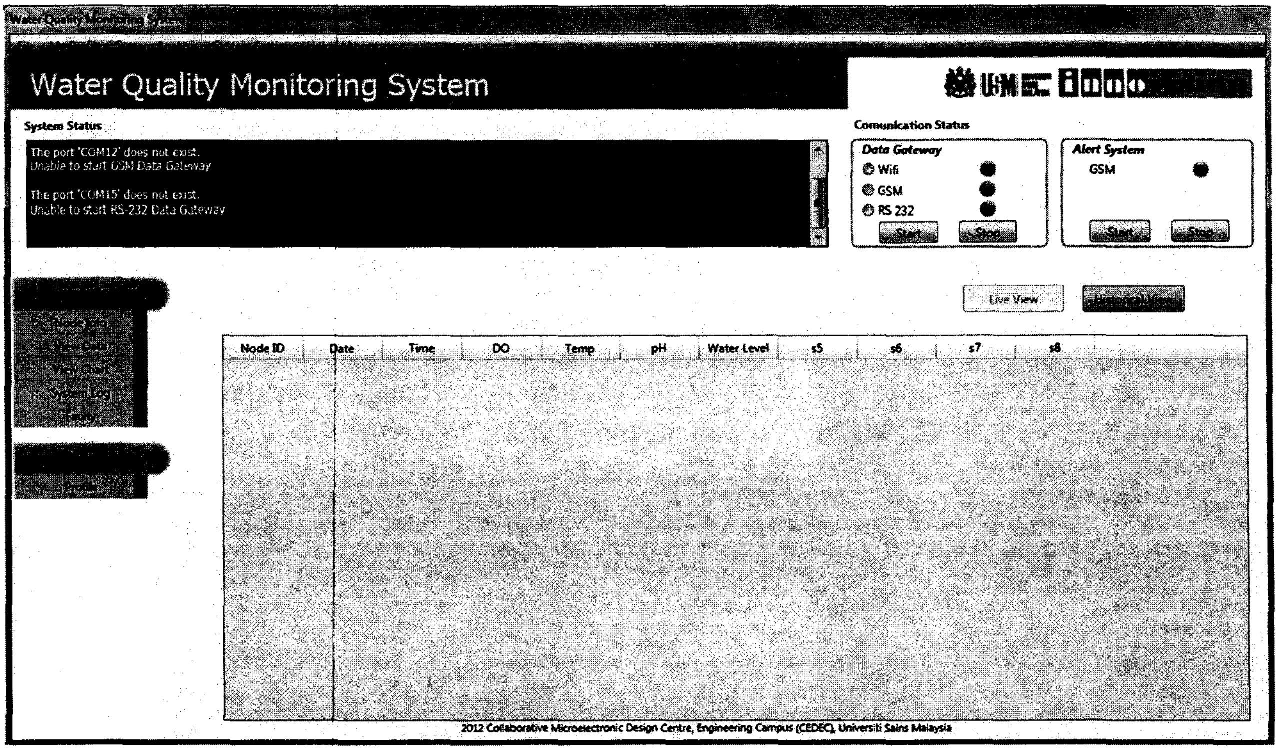
- To login into the system, user need to register into an account .Only administrator as the main and authorize user of the organization is allow to make any setting changes of the system and register another users(supervisors) who are only have the right to view data and change their profile account. All the system setting must be done by administrator.

1.4.2 Administrator's / Supervisor's View

1.4.2.1 Administrator's View GUI



1.4.2.2 Supervisor's View GUI

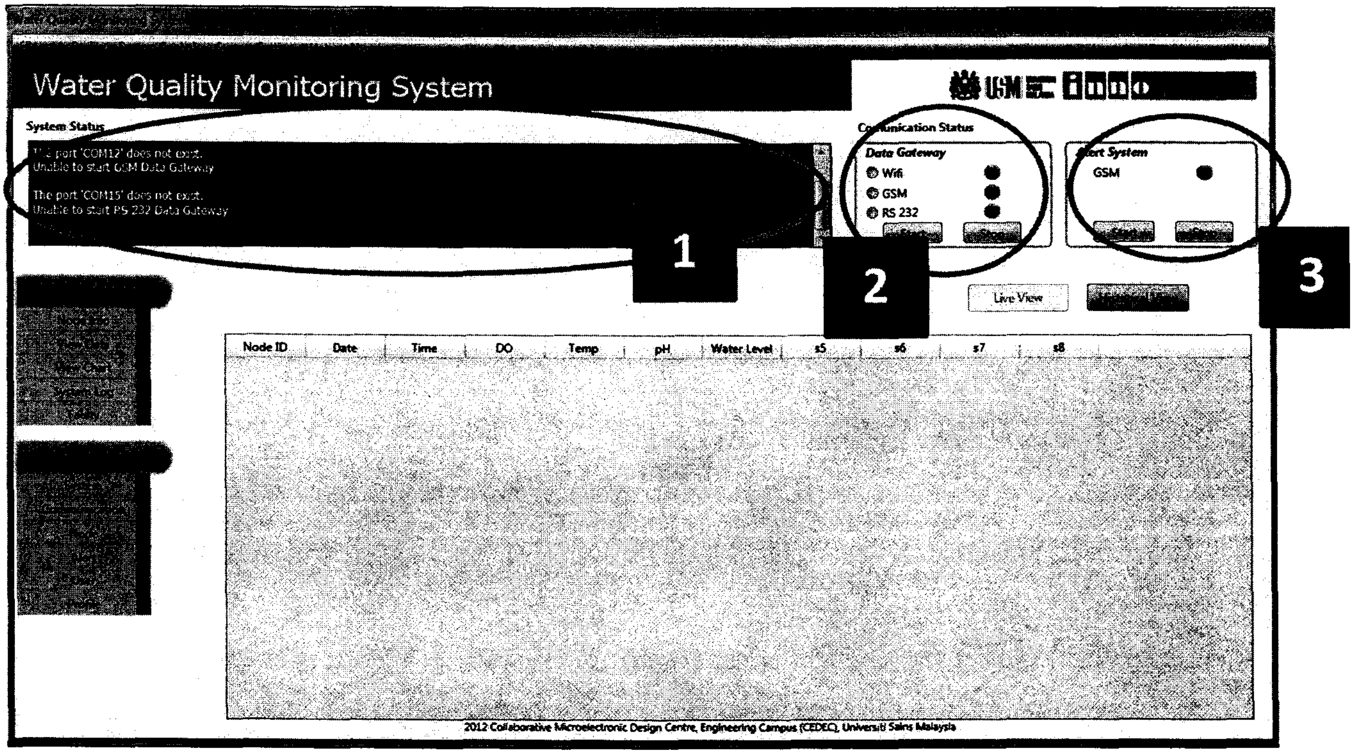


There are different views for administrator and supervisors.
Administrator can use all of the functions inside in the system especially in system setting.

Supervisors are basically having the right to view the data collected or stored by the software system.

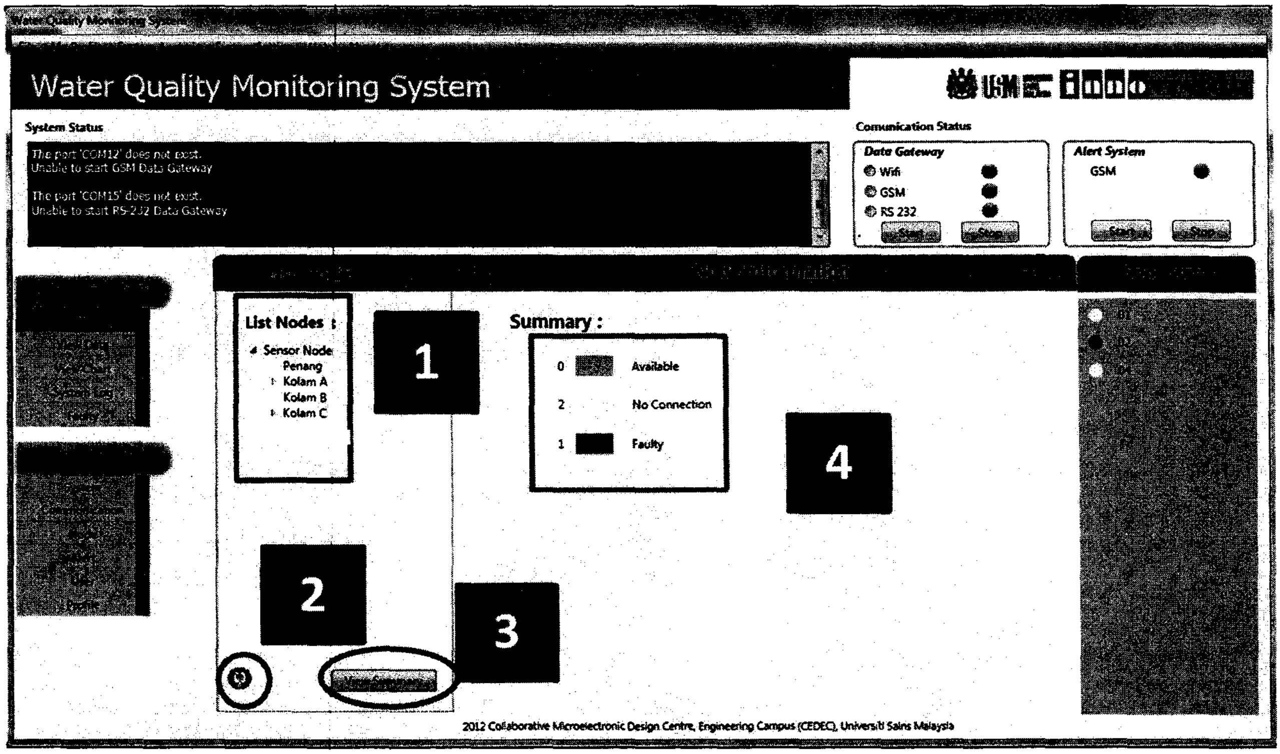
However, supervisors are permitted to edit their own profile.

1.4.3 Main Interface



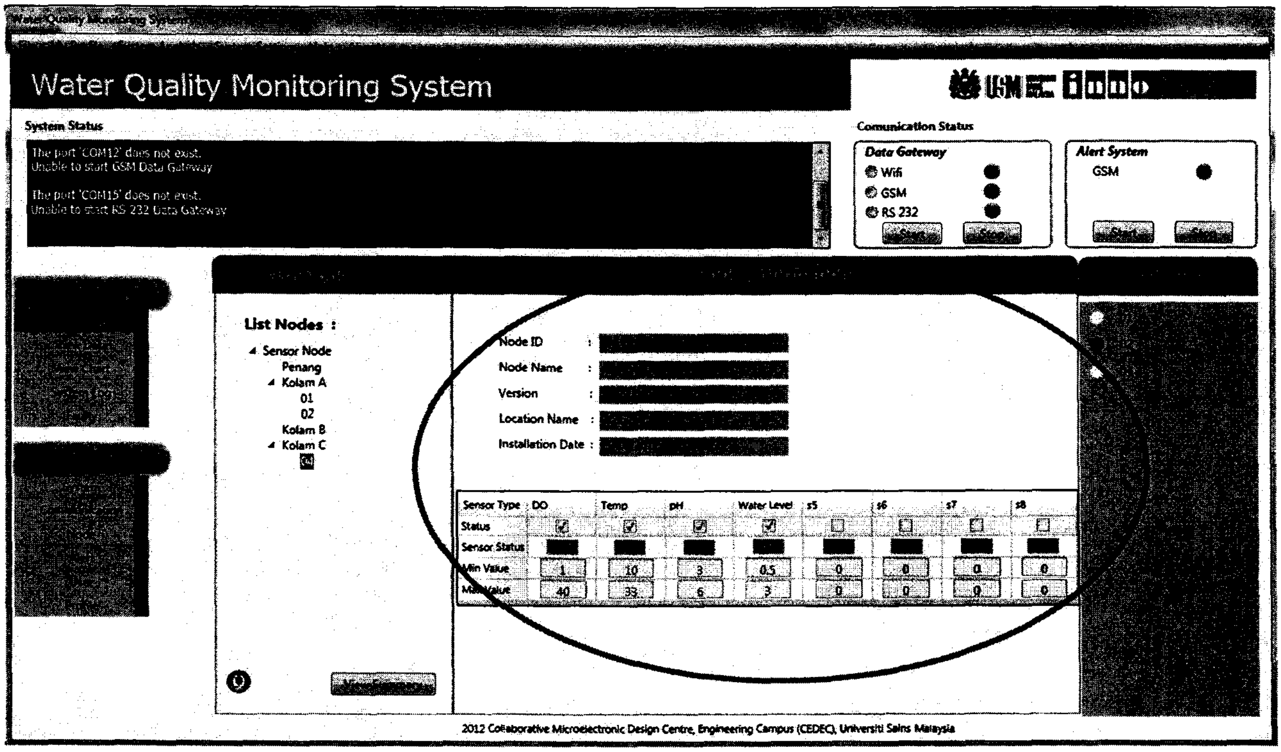
1. System Status
    a. Display system message or activities triggered by user.
    b. These status messages will be write into log files and can be open and view by user in System Log menu.
2. Display COM port status for Data Gateway.
    a. There are 3 type of data gateway
        i. Wifi
        ii. GSM
        iii. RS232
    b. These 3 types of gateway is used to receive data received from receiver
    c. Red light will appear if the COM port is not connected/start while green light will appear if the gateway is connected.
3. Display COM port status for alert system. This port has to connect with GSM module so that this software can send SMS for alert purpose.
    a. Red light will appear if the COM port is not connected/start while green light will appear if the gateway is connected.

1.4.4 Node Info



Node Status summary GUI

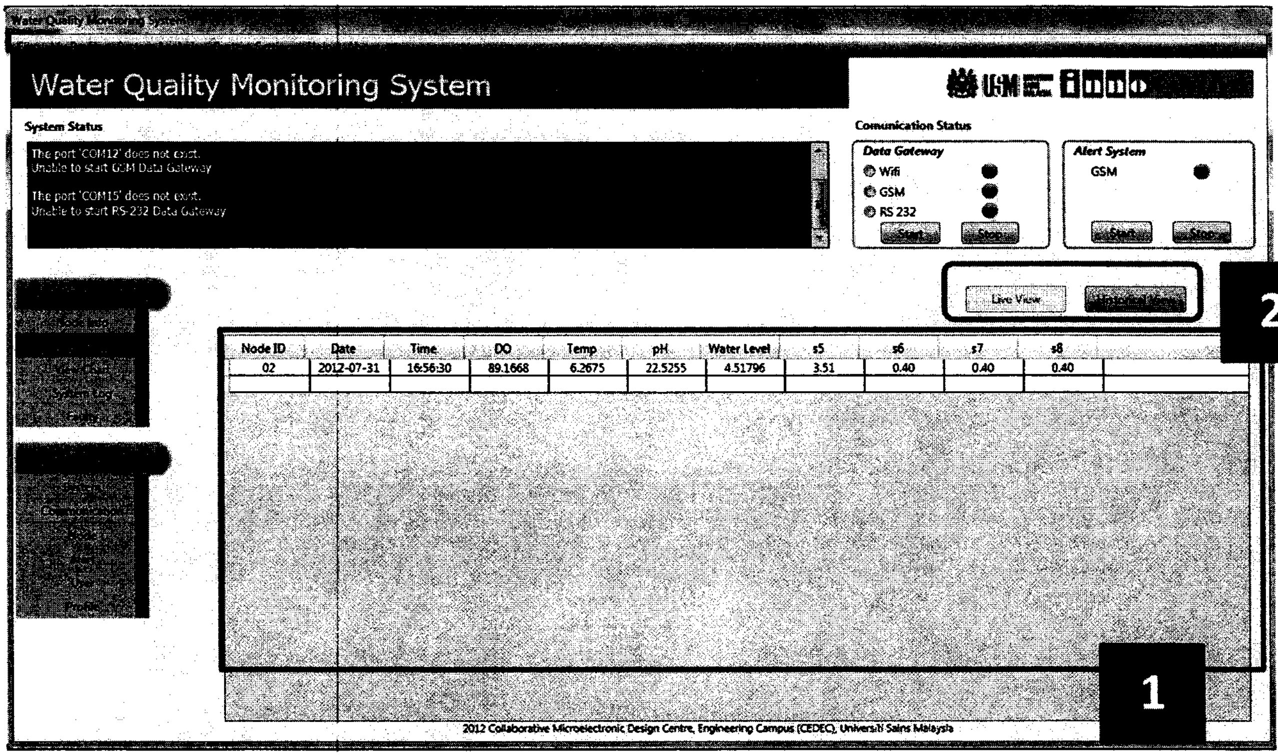
1. Display list of nodes registered in the software according to its location
2. Button Refresh
    a. Used to refresh the list of nodes registered if the node that user has registered is not listed in the list
3. Button view summary – used to view node status (summary)
4. View Node Status (summary)
    a. Used so that users can see summary of node information such as
        i. the number of nodes that currently active and available
        ii. the number of nodes that has no connection/not active/not sending any data
        iii. the number of nodes that is faulty (sending faulty data)



Node Information GUI

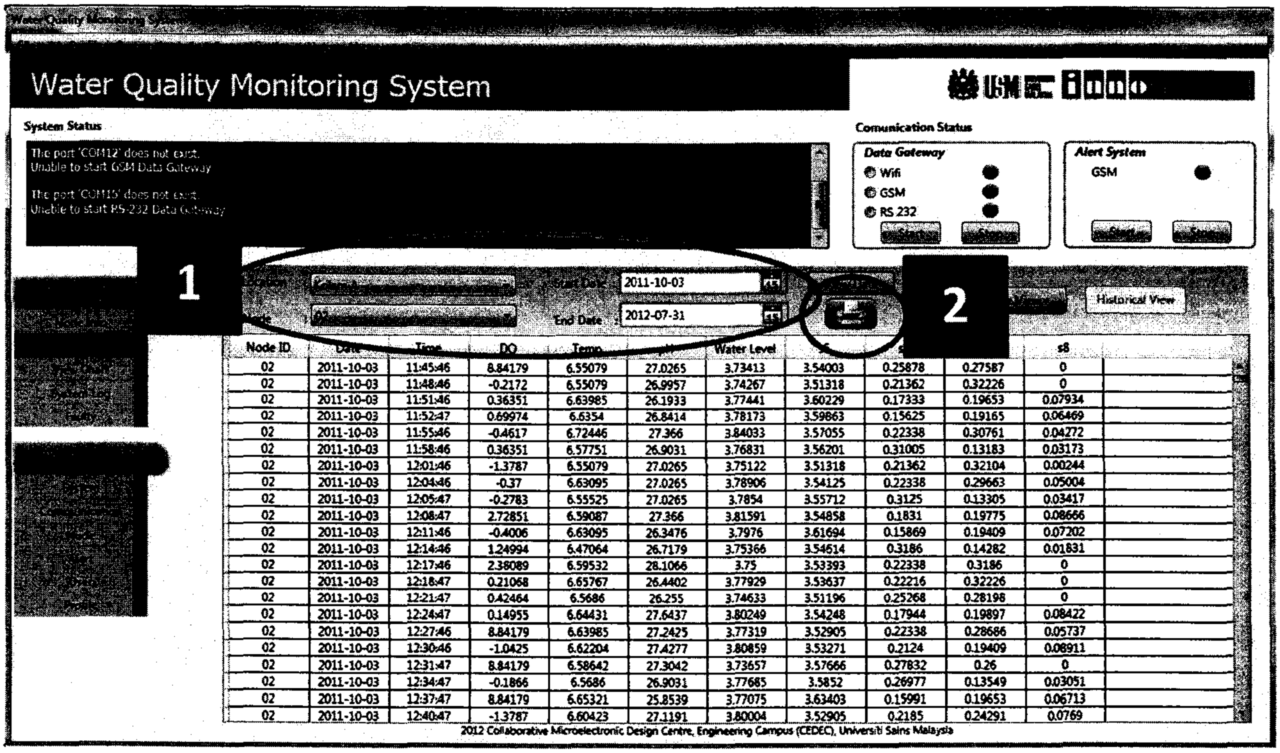
1. When users double click node ID in the list node, users can view node details of each node.
    a. Node ID
    b. Node Name
    c. Node Version
    d. Location
    e. Installation date
    f. Sensor Type used by node
    g. Maximum and minimum value for alert purpose

1.4.5 View Data



View Data Live GUI

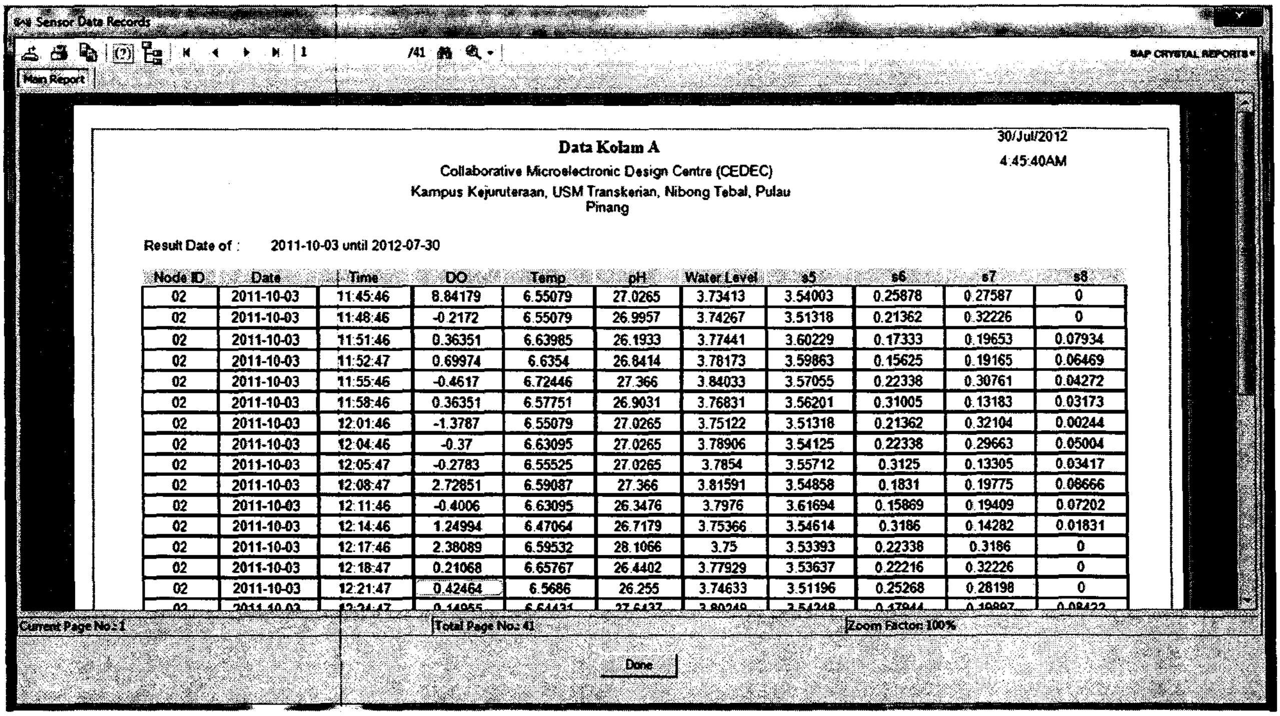
1. Data grid (data table) used to display current data (live view) received by receiver.
2. Button Live View / View History used to change data grid display mode.



Data Grid View History Mode GUI

1. When users select history mode, users can search or filter data history by selecting location, node id and the range of date required.
2. Button Print
    a. To print search results.

1.4.5.1 Sample Report to print:



Data Kolam A

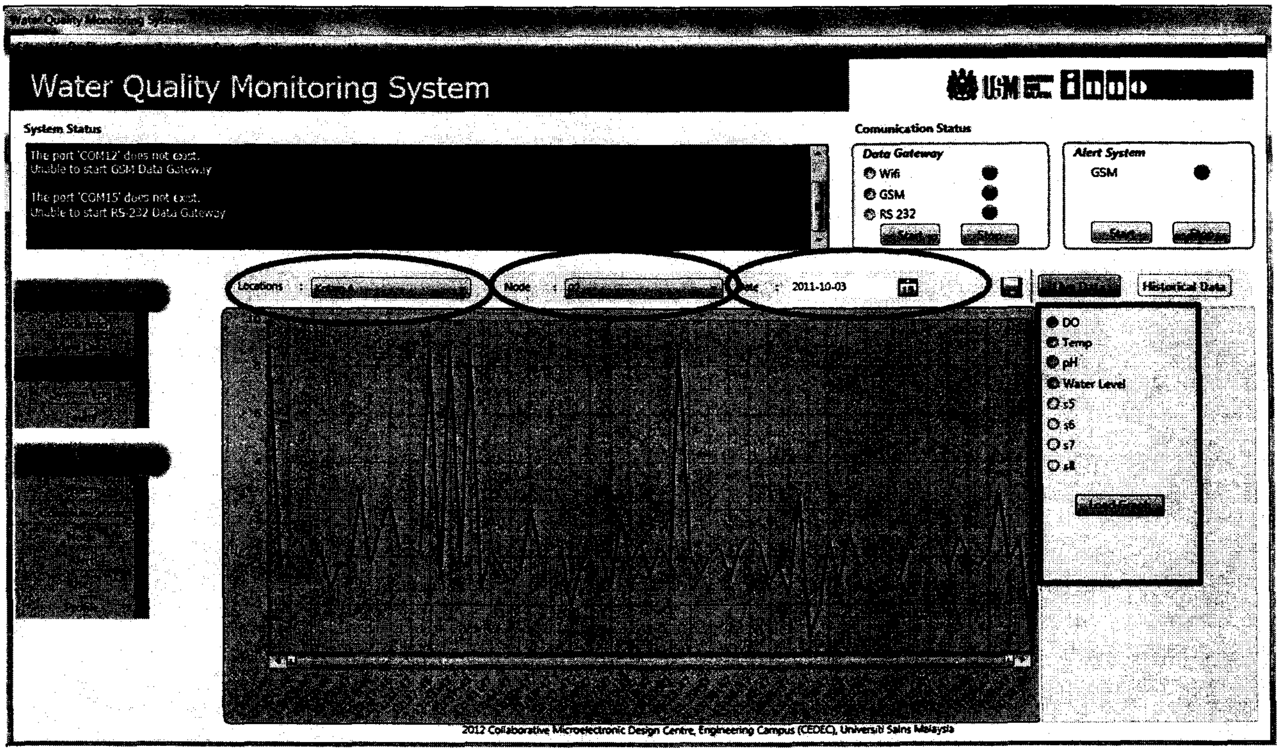
Collaborative Microelectronic Design Centre (CEDEC)
Kampus Kejuruteraan, USM Transkerian, Nibong Tebal, Pulau Pinang

30/Jul/2012
4:45:40AM

Result Date of : 2011-10-03 until 2012-07-30

Node ID	Date	Time	DO	Temp	pH	Water Level	s5	s6	s7	s8
02	2011-10-03	11:45:46	8.84179	6.55079	27.0265	3.73413	3.54003	0.25878	0.27587	0
02	2011-10-03	11:48:46	-0.2172	6.55079	26.9957	3.74267	3.51318	0.21362	0.32226	0
02	2011-10-03	11:51:46	0.36351	6.63985	26.1933	3.77441	3.60229	0.17333	0.19653	0.07934
02	2011-10-03	11:52:47	0.69974	6.6354	26.8414	3.78173	3.59863	0.15625	0.19165	0.06469
02	2011-10-03	11:55:46	-0.4617	6.72446	27.366	3.84033	3.57055	0.22338	0.30761	0.04272
02	2011-10-03	11:58:46	0.36351	6.57751	26.9031	3.76831	3.56201	0.31005	0.13183	0.03173
02	2011-10-03	12:01:46	-1.3787	6.55079	27.0265	3.75122	3.51318	0.21362	0.32104	0.00244
02	2011-10-03	12:04:46	-0.37	6.63095	27.0265	3.78906	3.54125	0.22338	0.29663	0.05004
02	2011-10-03	12:05:47	-0.2783	6.55525	27.0265	3.7854	3.55712	0.3125	0.13305	0.03417
02	2011-10-03	12:08:47	2.72851	6.59087	27.366	3.81591	3.54858	0.1831	0.19775	0.08666
02	2011-10-03	12:11:46	-0.4006	6.63095	26.3476	3.7976	3.61694	0.15869	0.19409	0.07202
02	2011-10-03	12:14:46	1.24994	6.47064	26.7179	3.75366	3.54614	0.3186	0.14282	0.01831
02	2011-10-03	12:17:46	2.38089	6.59532	28.1066	3.75	3.53393	0.22338	0.3186	0
02	2011-10-03	12:18:47	0.21068	6.65767	26.4402	3.77929	3.53637	0.22216	0.32226	0
02	2011-10-03	12:21:47	0.42464	6.5686	26.255	3.74633	3.51196	0.25268	0.28198	0

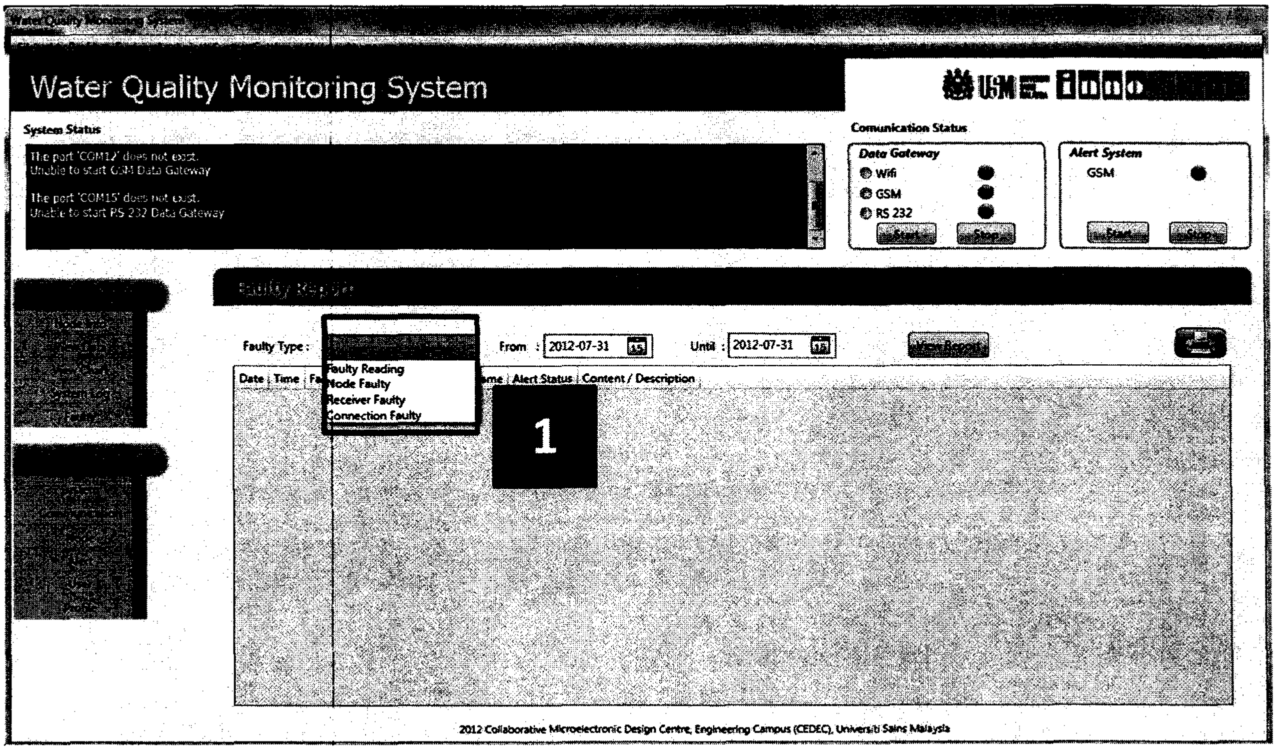
1.4.6 View Chart

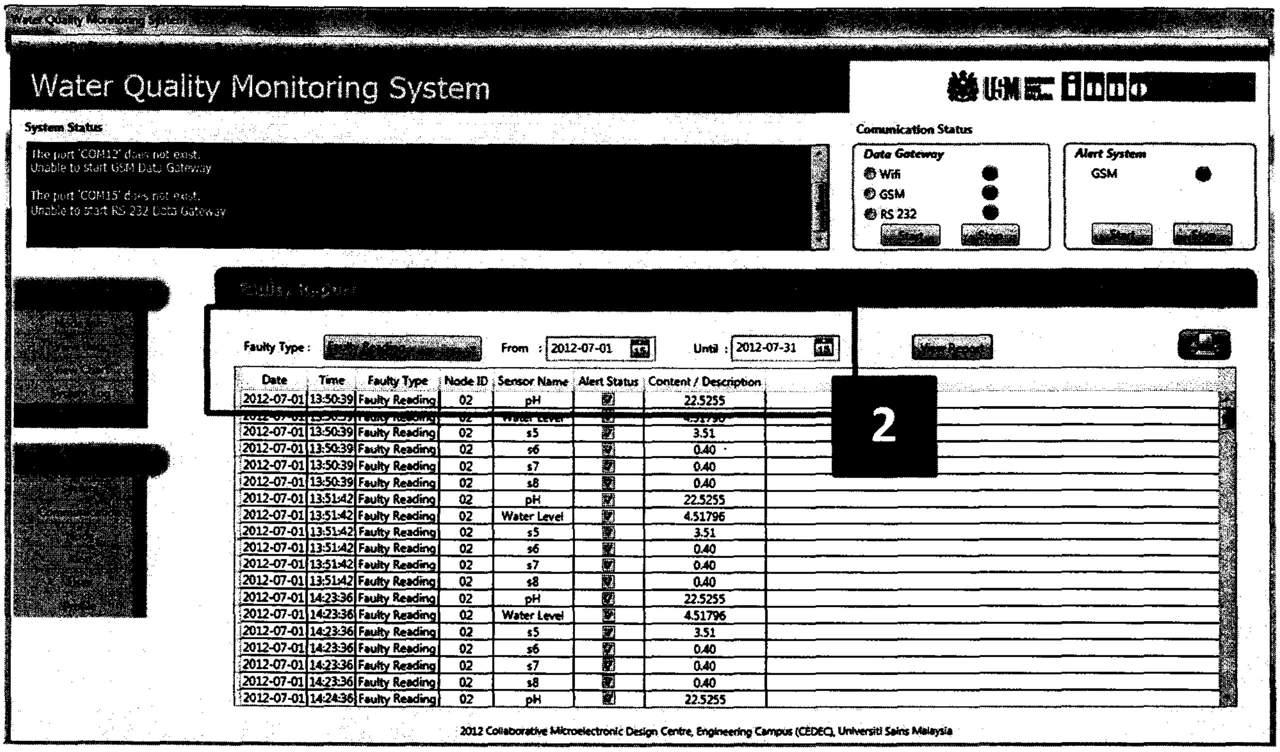


Graph View (Historical data) GUI

1. To view historical data in graph mode, users need to select location, node is, date and the sensor data type that need to display.
   a. GUI above is showing the temperature sample data collected by node 2 on 3rd Oct 2011.

1.4.7 Faulty


Water Quality Monitoring System
System Status
The port 'COM12' does not exist.
Unable to start GSM Data Gateway
The port 'COM15' does not exist.
Unable to start RS 232 Data Gateway
Comunication Status
Data Gateway
Wifi
GSM
RS 232
Alert System
GSM
Faulty Type :
Faulty Reading
Node Faulty
Receiver Faulty
Connection Faulty
From : 2012-07-31
Until : 2012-07-31
Date
Time
Alert Status
Content / Description
1
2012 Collaborative Microelectronic Design Centre, Engineering Campus (CEDEC), Universiti Sains Malaysia

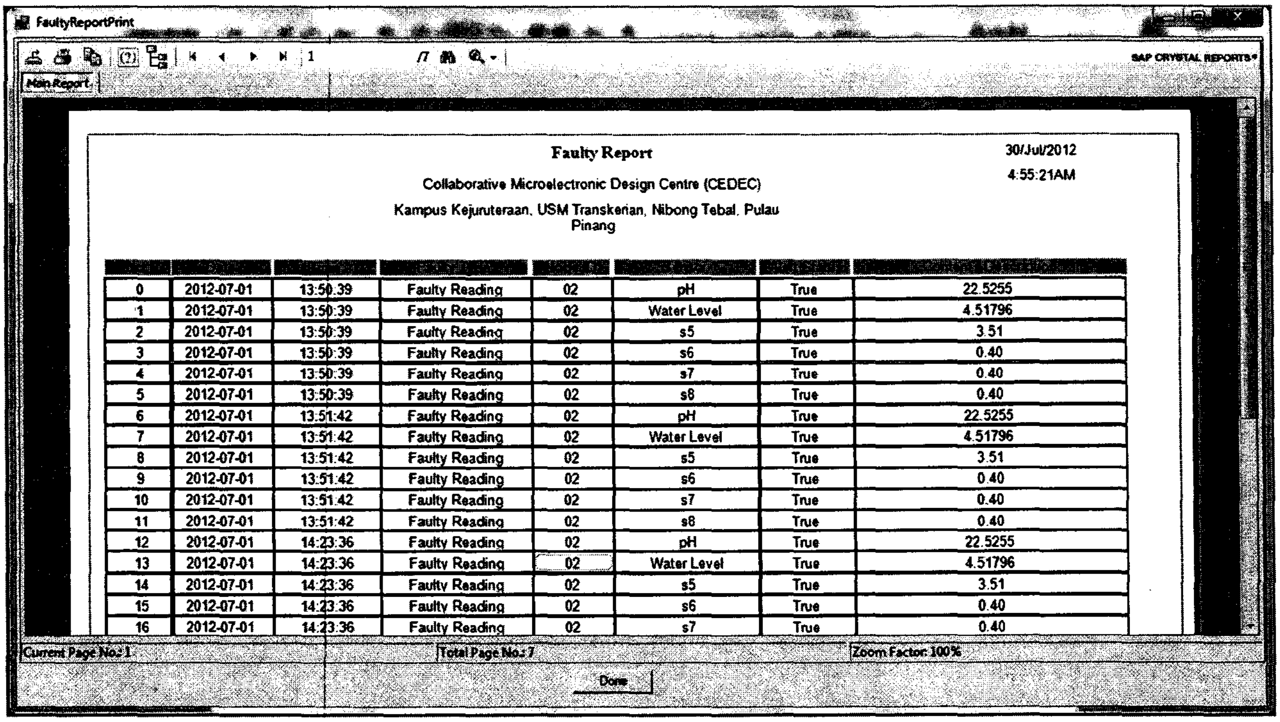


Faulty GUI

1. Display faulty report.
    a. Users can choose type of faulty report that they want to view.
        i. Faulty Reading
        ii. Node Faulty
        iii. Receiver Faulty
        iv. Connection/ System Faulty

2. View Faulty Report by choose Faulty Type and date range required.

1.4.7.1 Example of Faulty report to print :


FaultyReportPrint

Main Report

SAP CRYSTAL REPORTS

Faulty Report

30/Jul/2012
4:55:21AM

Collaborative Microelectronic Design Centre (CEDEC)

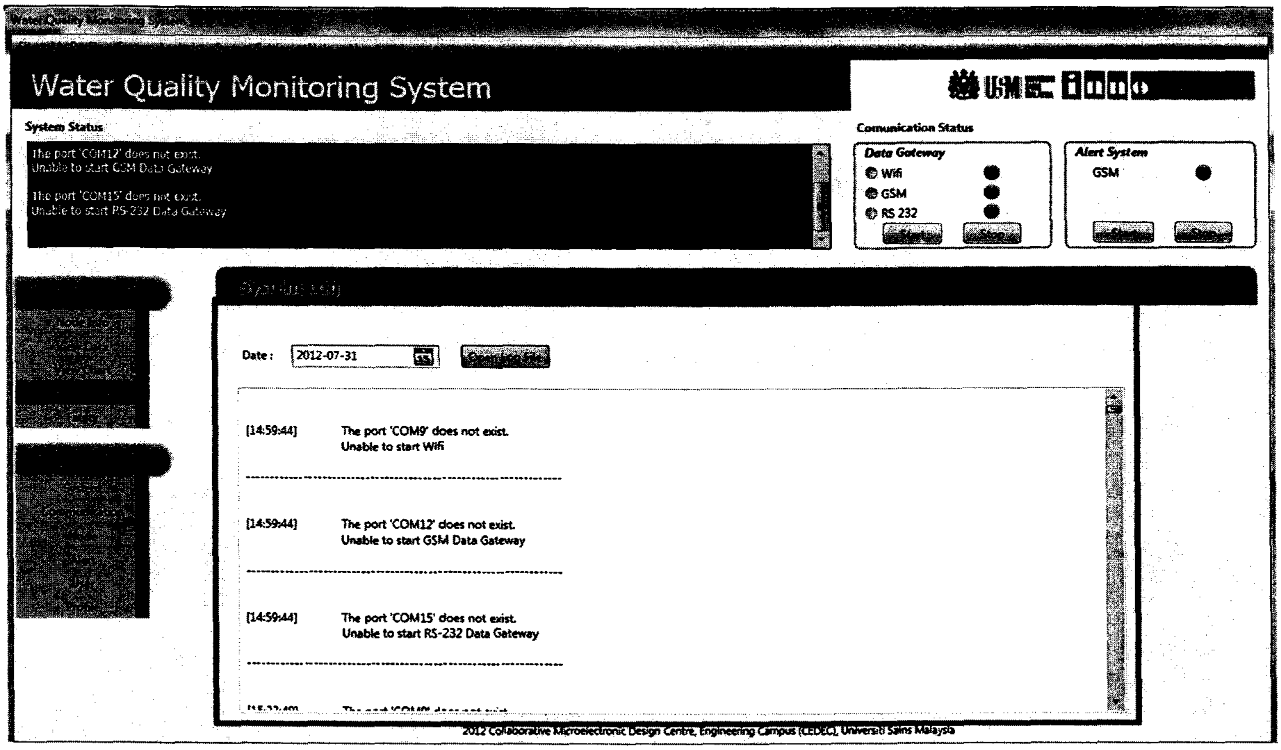
Kampus Kejuruteraan, USM Transkerian, Nibong Tebal, Pulau Pinang

0	2012-07-01	13:50:39	Faulty Reading	02	pH	True	22.5255
1	2012-07-01	13:50:39	Faulty Reading	02	Water Level	True	4.51796
2	2012-07-01	13:50:39	Faulty Reading	02	s5	True	3.51
3	2012-07-01	13:50:39	Faulty Reading	02	s6	True	0.40
4	2012-07-01	13:50:39	Faulty Reading	02	s7	True	0.40
5	2012-07-01	13:50:39	Faulty Reading	02	s8	True	0.40
6	2012-07-01	13:51:42	Faulty Reading	02	pH	True	22.5255
7	2012-07-01	13:51:42	Faulty Reading	02	Water Level	True	4.51796
8	2012-07-01	13:51:42	Faulty Reading	02	s5	True	3.51
9	2012-07-01	13:51:42	Faulty Reading	02	s6	True	0.40
10	2012-07-01	13:51:42	Faulty Reading	02	s7	True	0.40
11	2012-07-01	13:51:42	Faulty Reading	02	s8	True	0.40
12	2012-07-01	14:23:36	Faulty Reading	02	pH	True	22.5255
13	2012-07-01	14:23:36	Faulty Reading	02	Water Level	True	4.51796
14	2012-07-01	14:23:36	Faulty Reading	02	s5	True	3.51
15	2012-07-01	14:23:36	Faulty Reading	02	s6	True	0.40
16	2012-07-01	14:23:36	Faulty Reading	02	s7	True	0.40

Current Page No.: 1 Total Page No.: 7 Zoom Factor: 100%

Done

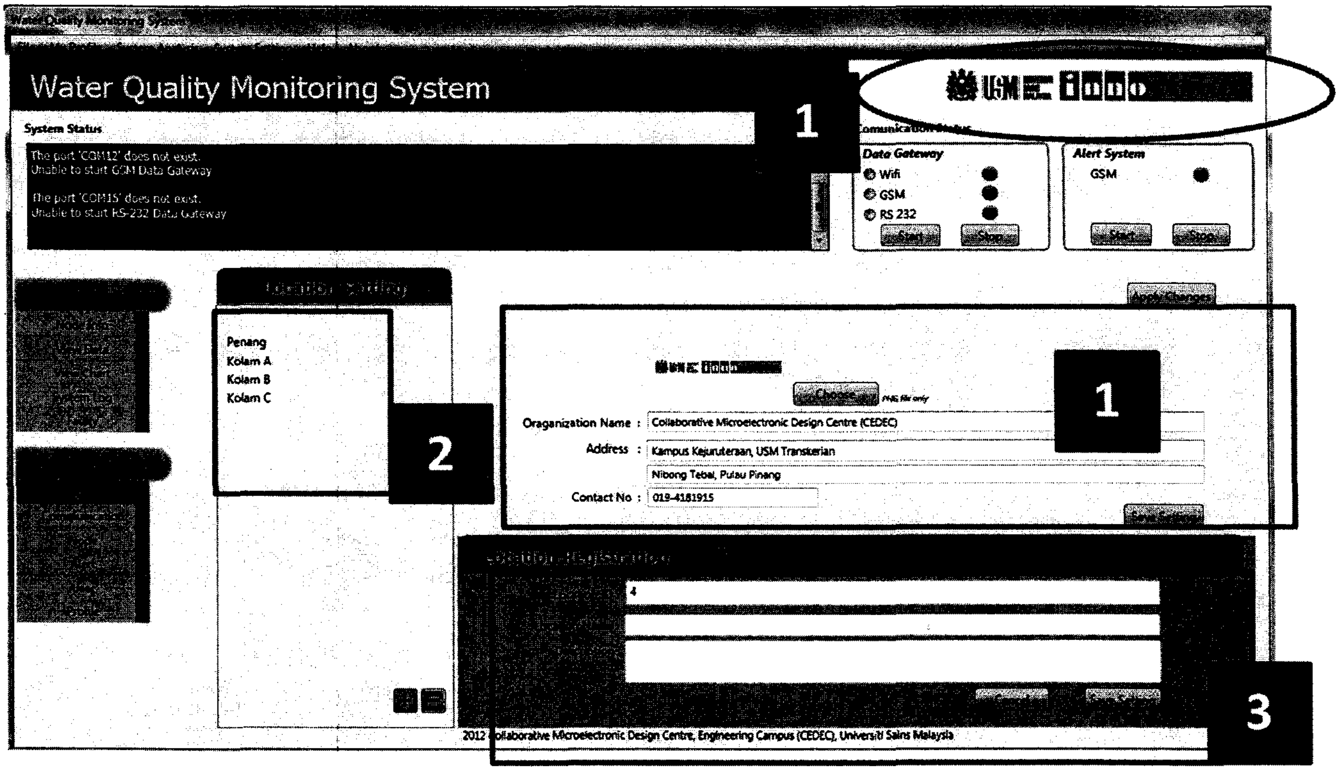
1.4.8 System Log



System Log GUI

1. Allowing users to view/open system logger files.
   This software will log all software's activities daily.

1.4.9 Company and Location Setting

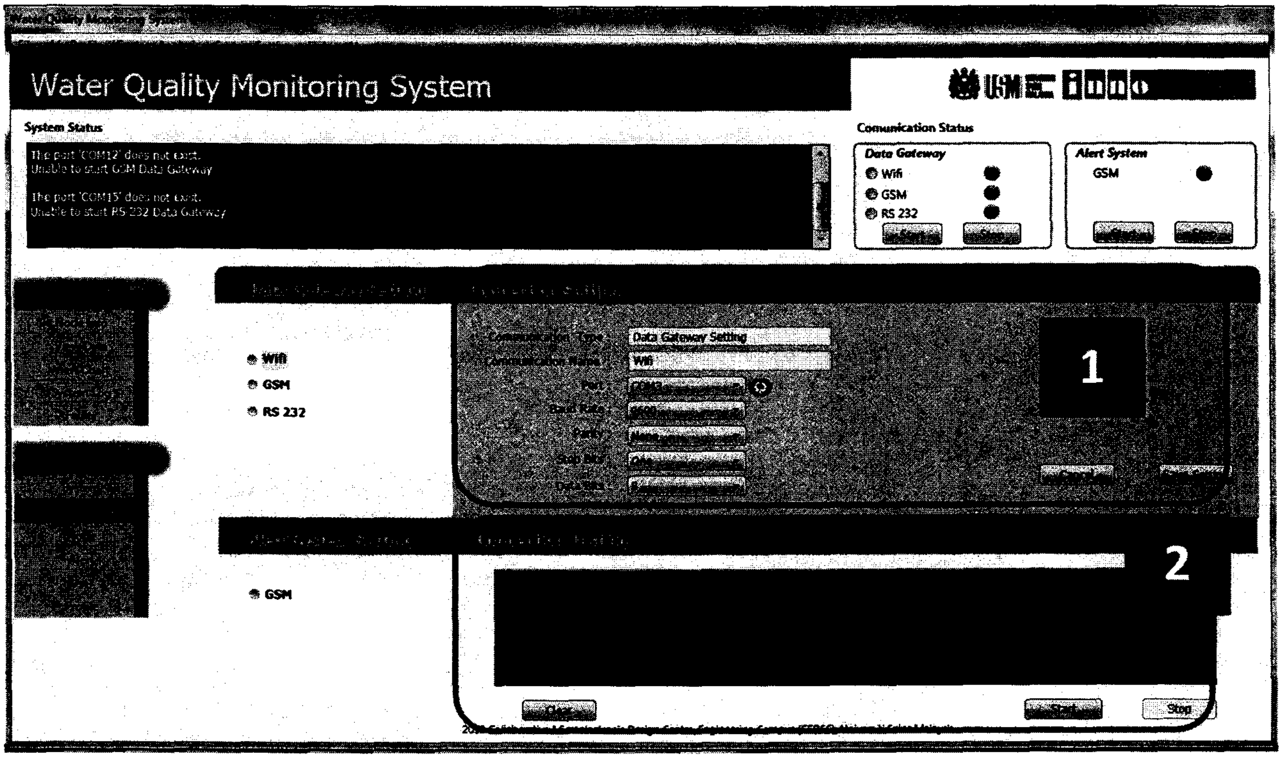


System Setting and Location Registration GUI

1. Users can change/customize their own organization name and details. Once the details are saved, the changes will apply on the top of interface.

2. Listing all the locations had been registered.
3. Add new location.

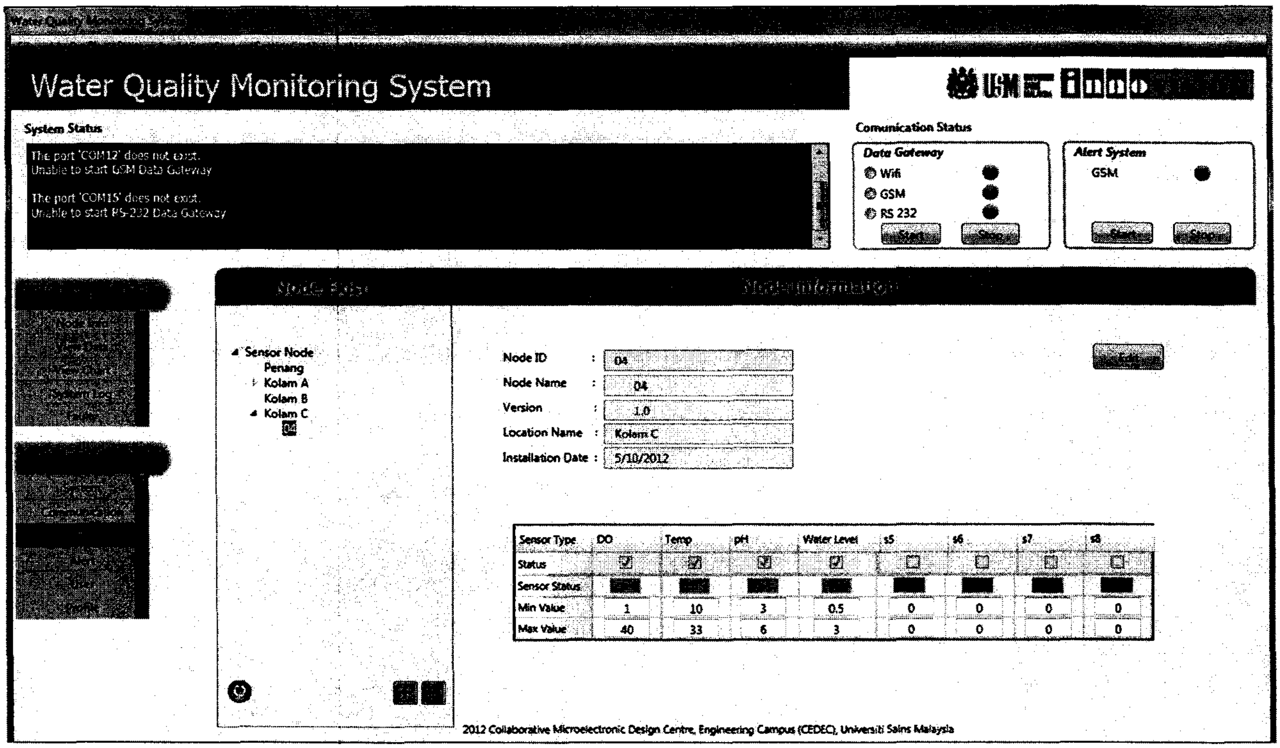
1.4.10 Communication Setting



Communication GUI

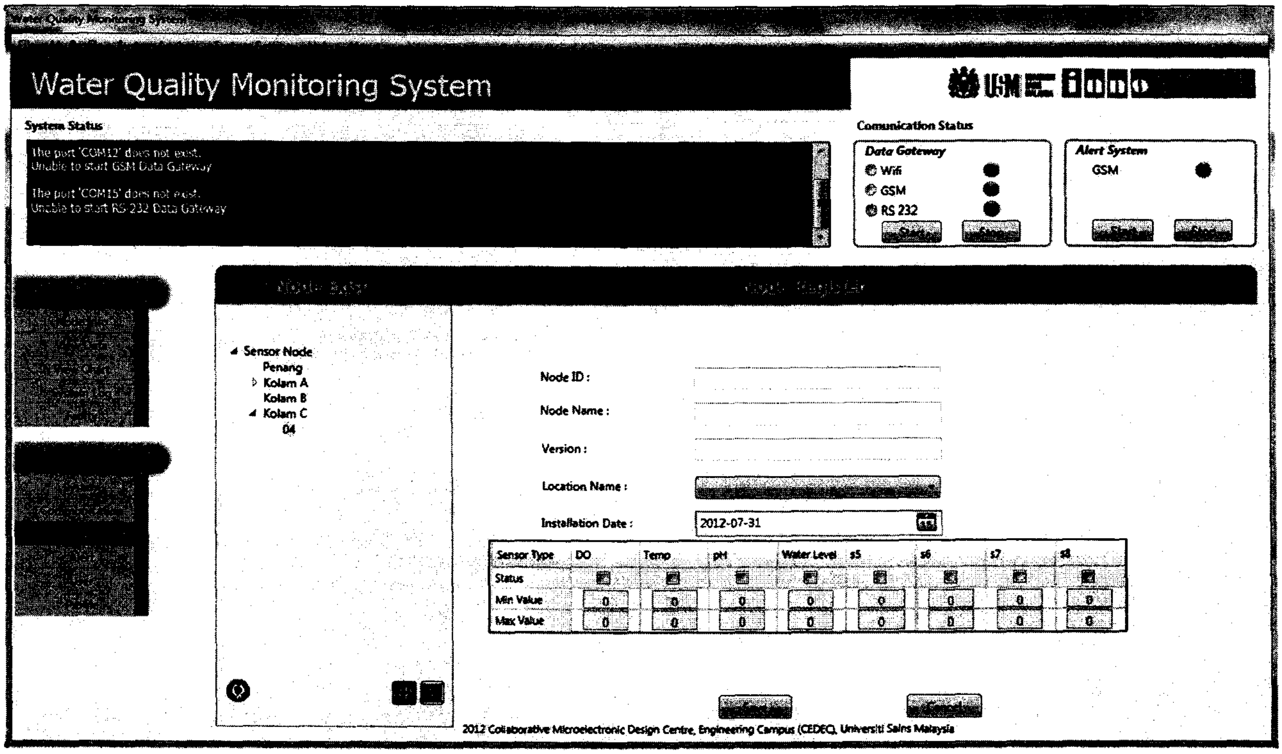
1. Setting communication port for each data gateway
2. Testing communication port set for each gateway. Act like hyperterminal.

1.4.11 Node Setting



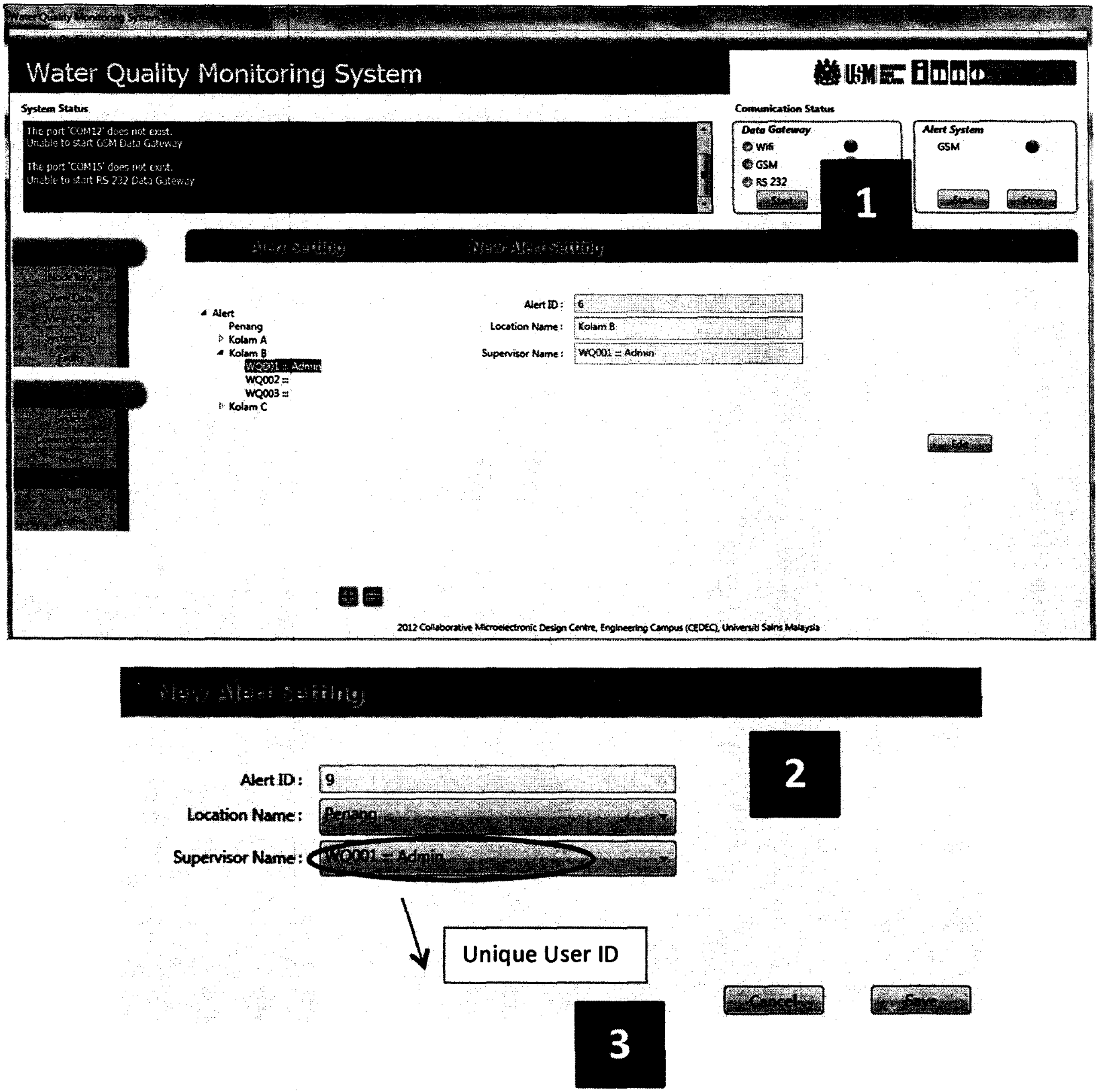
Node Setting GUI

1. Used for admin to View, Add and delete nodes.



1. .Add New Node

1.4.12 Alert Setting

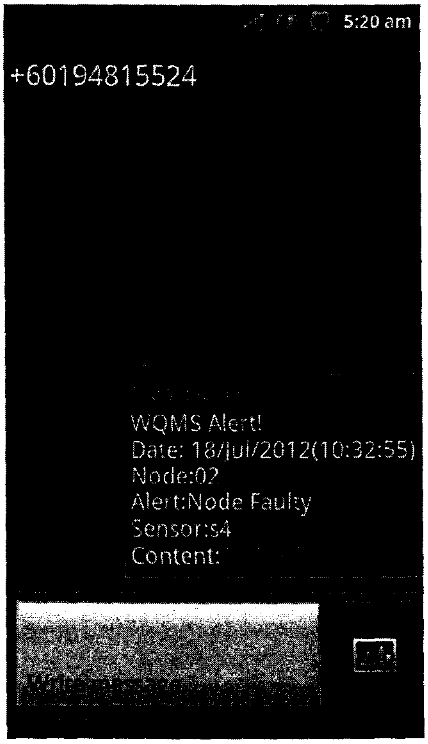


Alert GUI

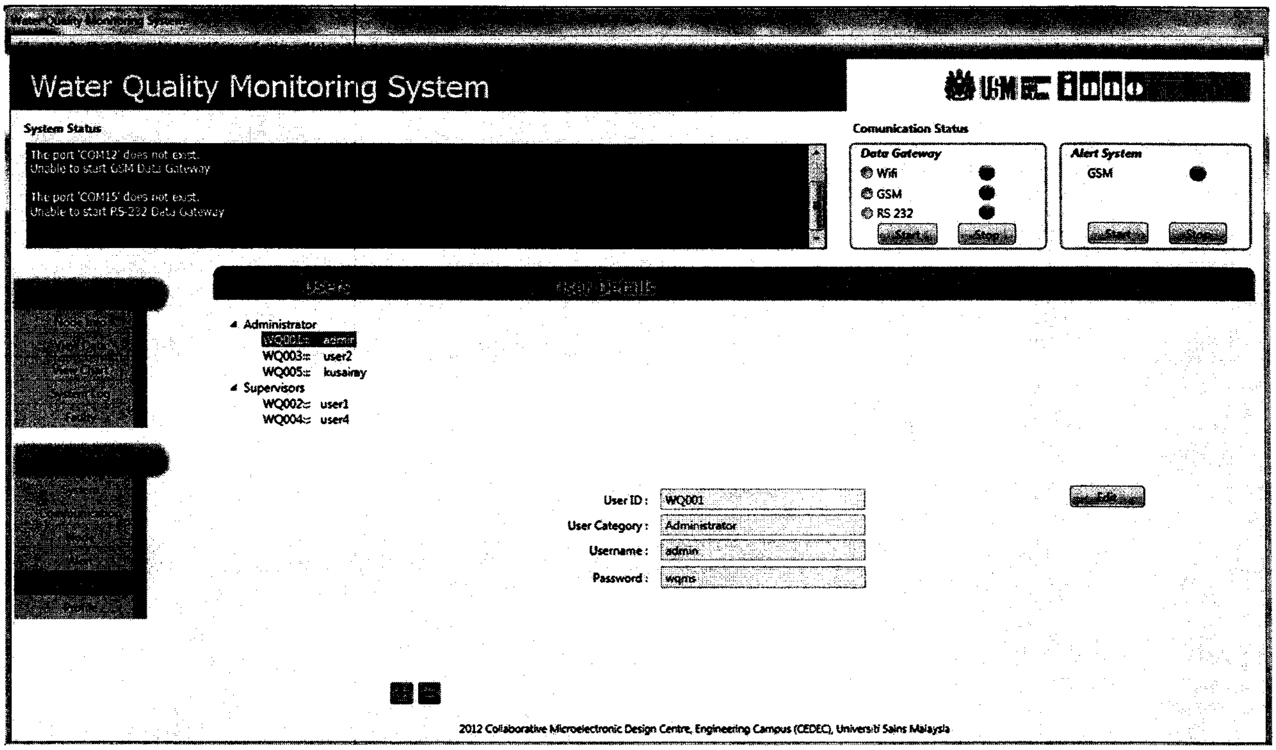
1. Admin can view alert details that had been registered before. Every one location registered in the software can has many supervisors/users registered to it.
   - Alert setting is used and has to be registered so that this software can send SMS alert to particular user when needed. It is important for every user to update valid phone number in their profile.

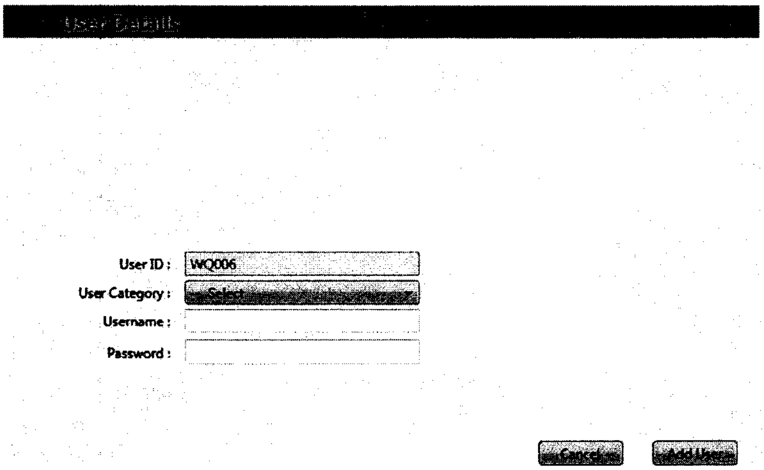
2. To add new alert, administrator has to choose the location name and supervisor that supposed to manage that location.
3. Every supervisor name will have their unique user ID.

1.4.12.1 SMS Alert Sample :



1.4.13 Users Setting

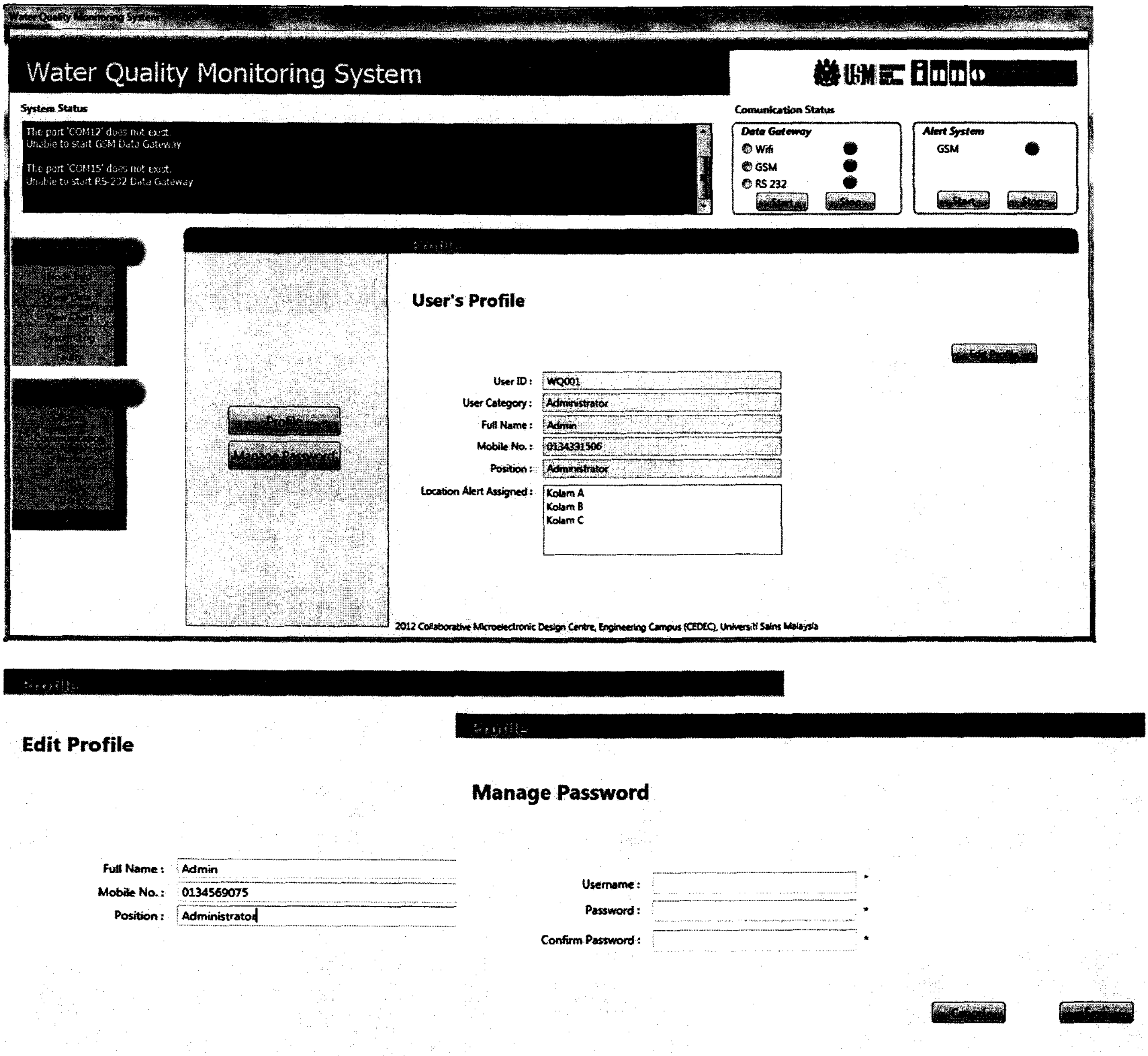




User GUI

1. Allowing administrator to add new users to the software.
2. Users/Supervisors have to be registered first before he/she is allowed to login to the software.
3. Temporary username and password will be given by the administrator to register a new user.
4. Administrator also can reset/edit username or user's password in case if the user forgot their login details.

1.4.14 User's Profile Setting



Profile GUI

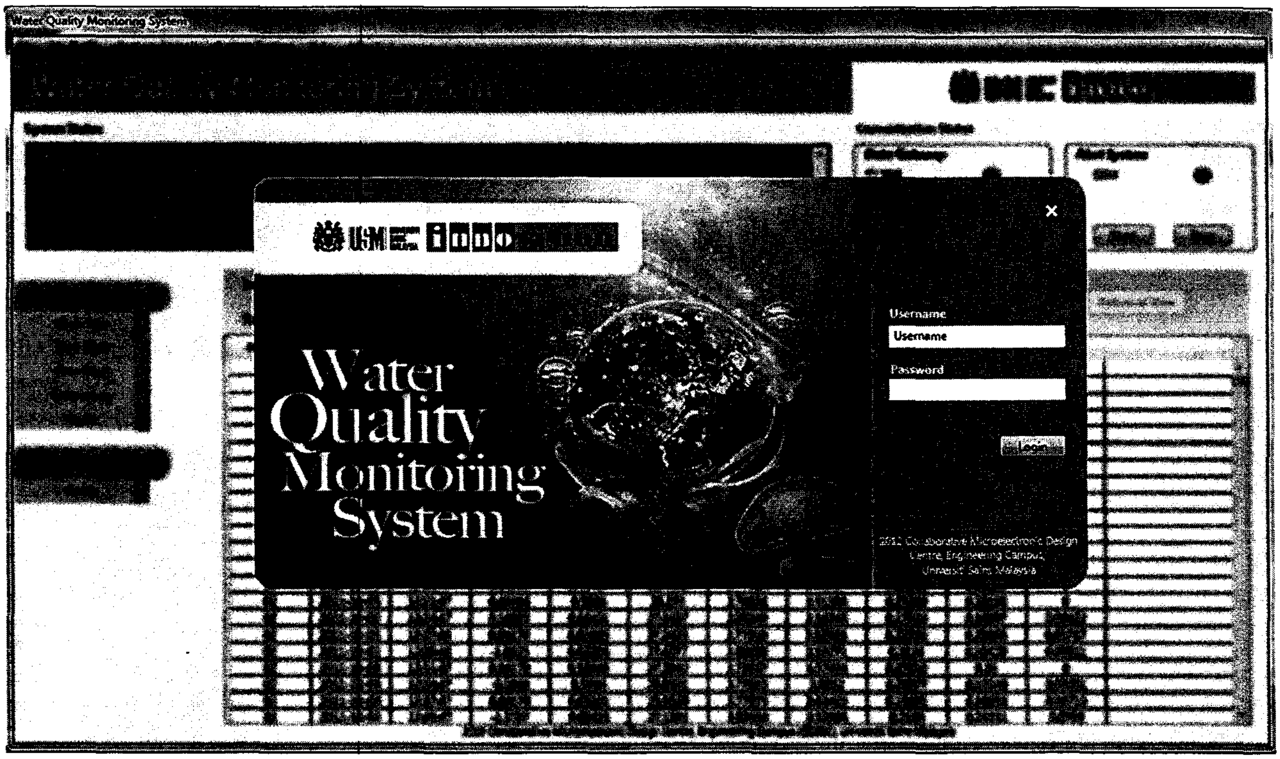
1. Once users (administrator and supervisors) successfully login to the system, they can view and edit their profile.
2. However, users are only allowed to edit their full name, mobile number and their position/occupation.
3. Users also are advised to change their temporary username and password given by administrator.

1.4.15 Log Out

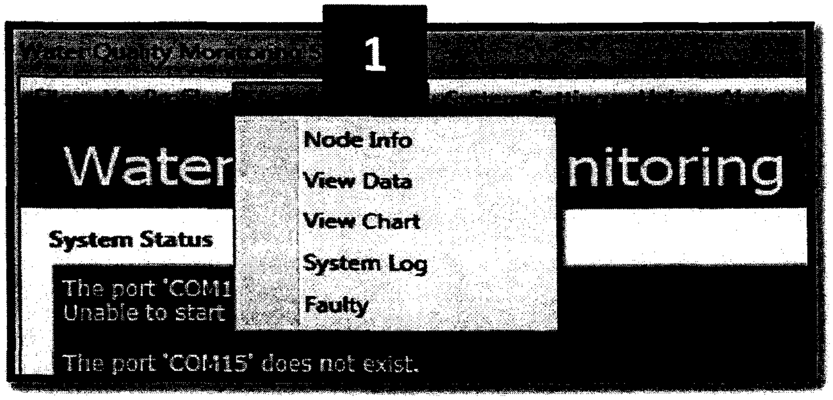
1.4.15.1 Logout menu

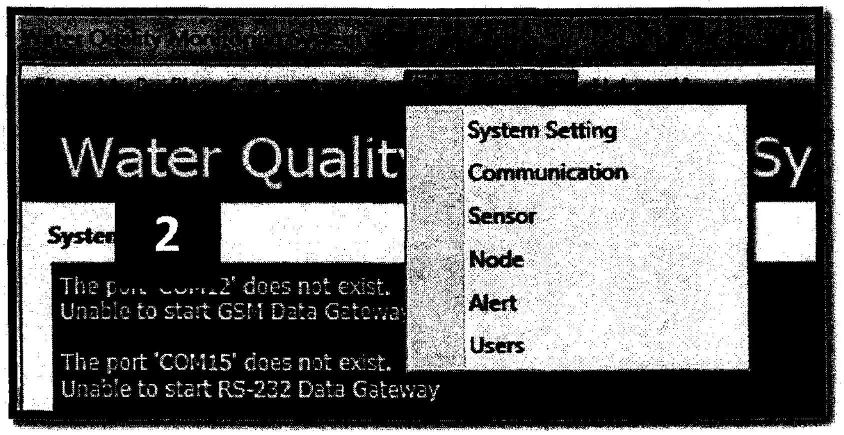
1. To exit the system, click on **File >> Log Out**

1.4.15.2 GUI After Users Log Out



1.4.16 Shortcut TopMenu





1. For a quick view and shortcut, you can just choose the section from the top menu by clicking **system analysis >> (choose section)**
2. For system analysis click **system setting >> (choose section).**

2. WEBSITE APPLICATION

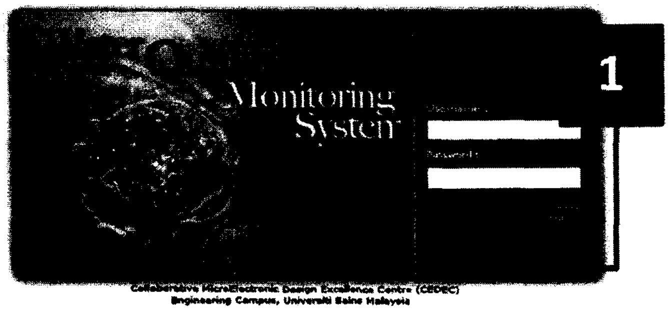
Website application enable user to monitor all the data and report from the web application ubiquitously. All users just can view the data and report from the website application and manage their own password. There is an extra feature which is the company setting, that enable manager or administrator to change the logo of their website interface.

2.1 Hardware and Software Requirement

Hardware Platform	PowerPC-based Computer Server
Min. RAM	1.99 GB
Min Free Hard Disk Space	5 GB
Min. Operating System	Microsoft Windows Server 2008
Additional Requirements	Web Server (Apache), MySQL 5.2.6, IIS, PhpMyAdmin 2.11.4, Silverlight 3, Internet, Web Browser, Navicat for MySQL Premium

2.2 Getting Started (How to use)

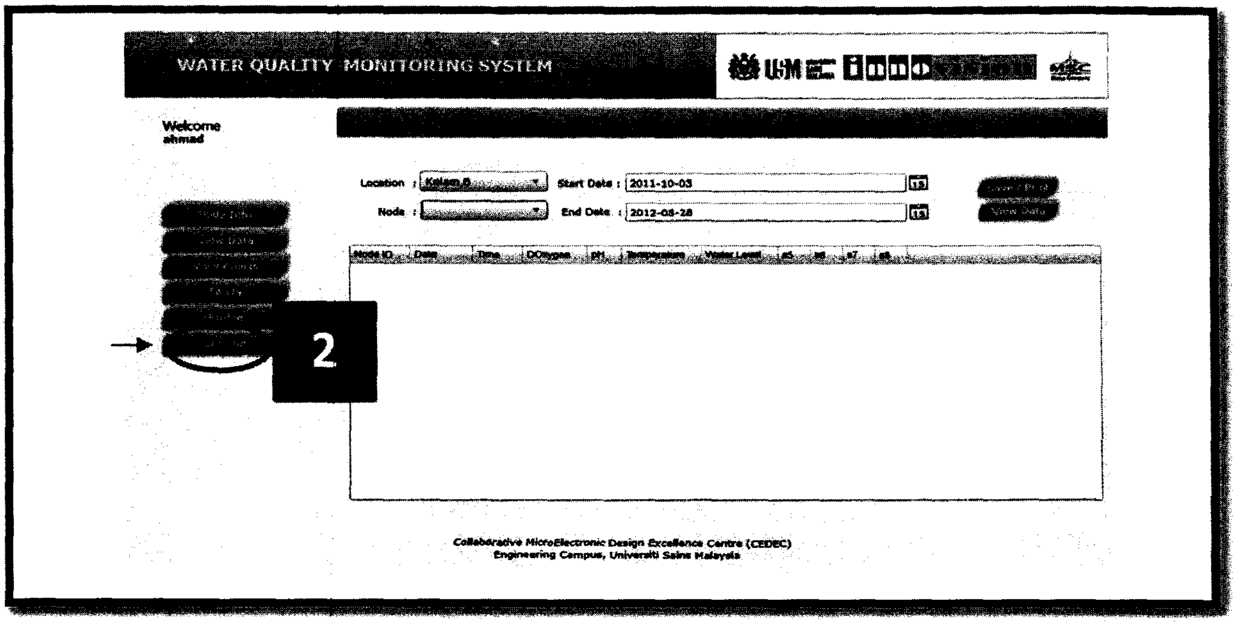
2.2.1 Login and Logout



GUI for user LOGIN on website

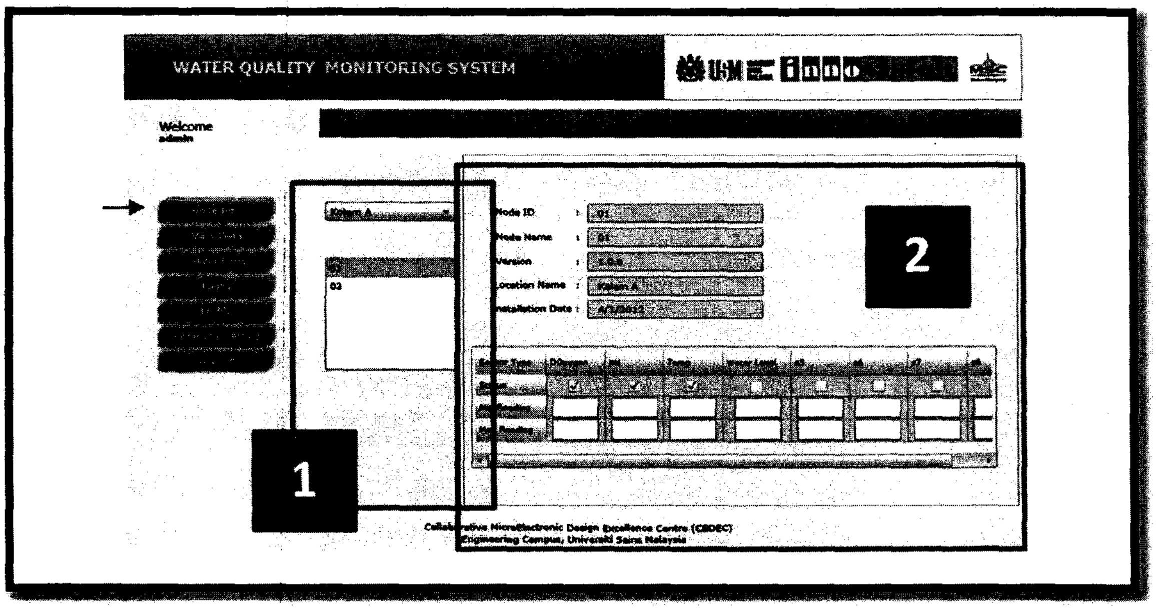
1. Login section

- Different type of user can access different type of features.
- Extra feature for manager or administrator to change company logo is available.
- Normal user or supervisor can only change their own password and view all the data and report stored in the website.



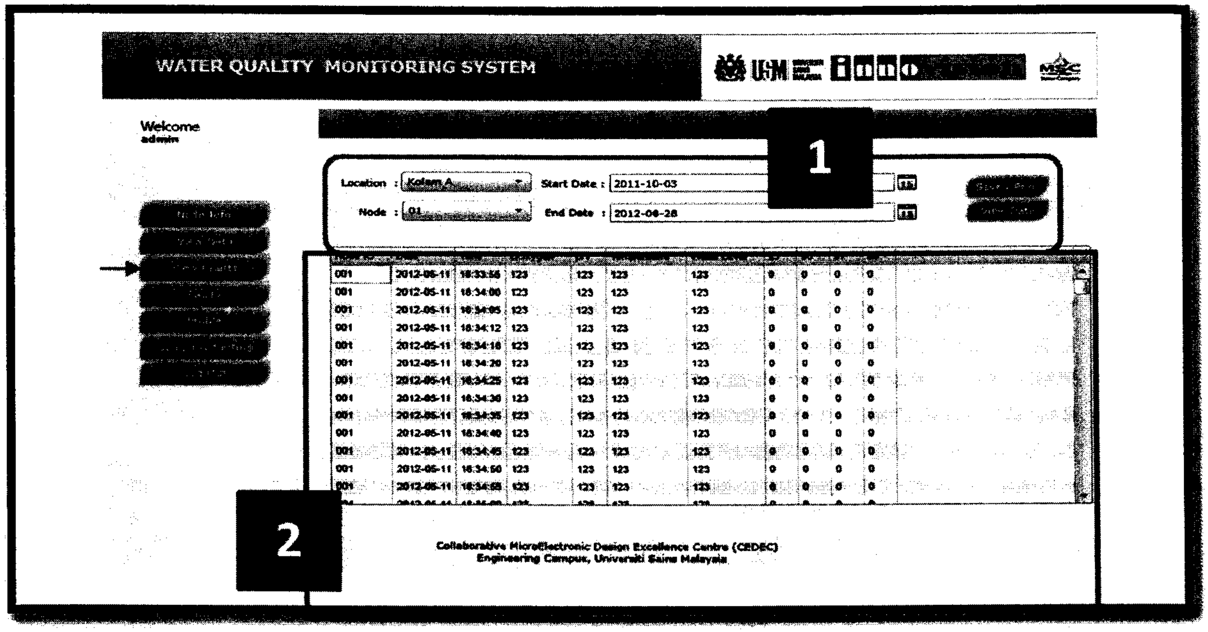
2. Click button logout to log out from the account.

2.2.2 Node info



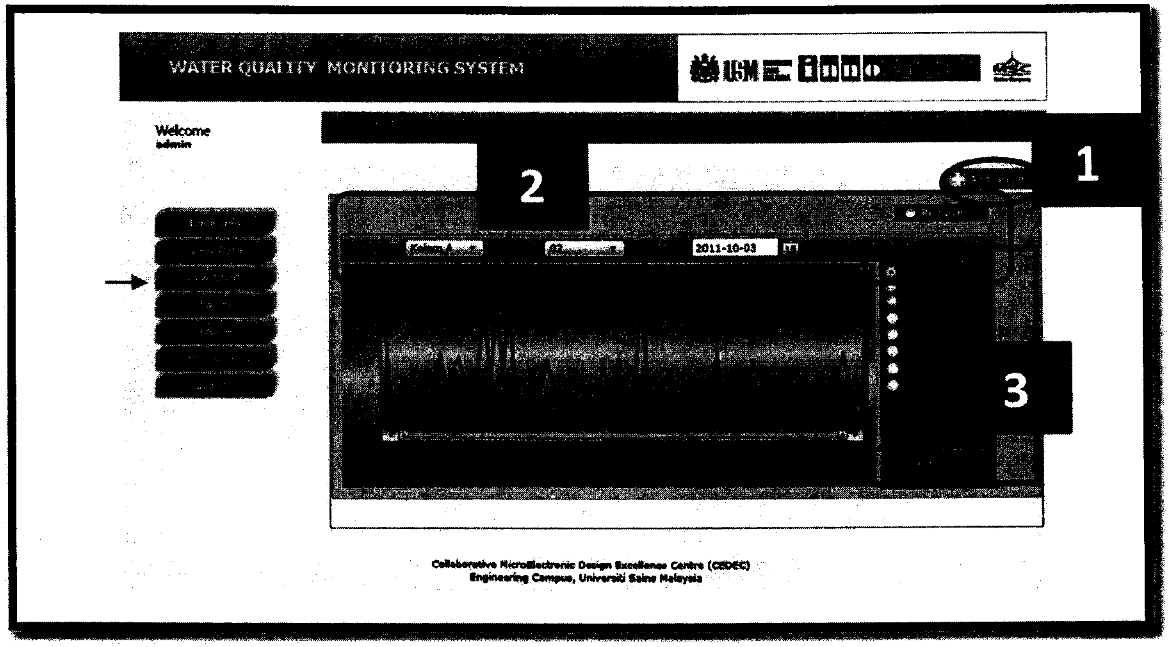
1. Select chosen location from the combo box and the existing node will be display on the list box below.
2. Node details will be display after clicking the selected node ID on the list box.

2.2.3 View Data



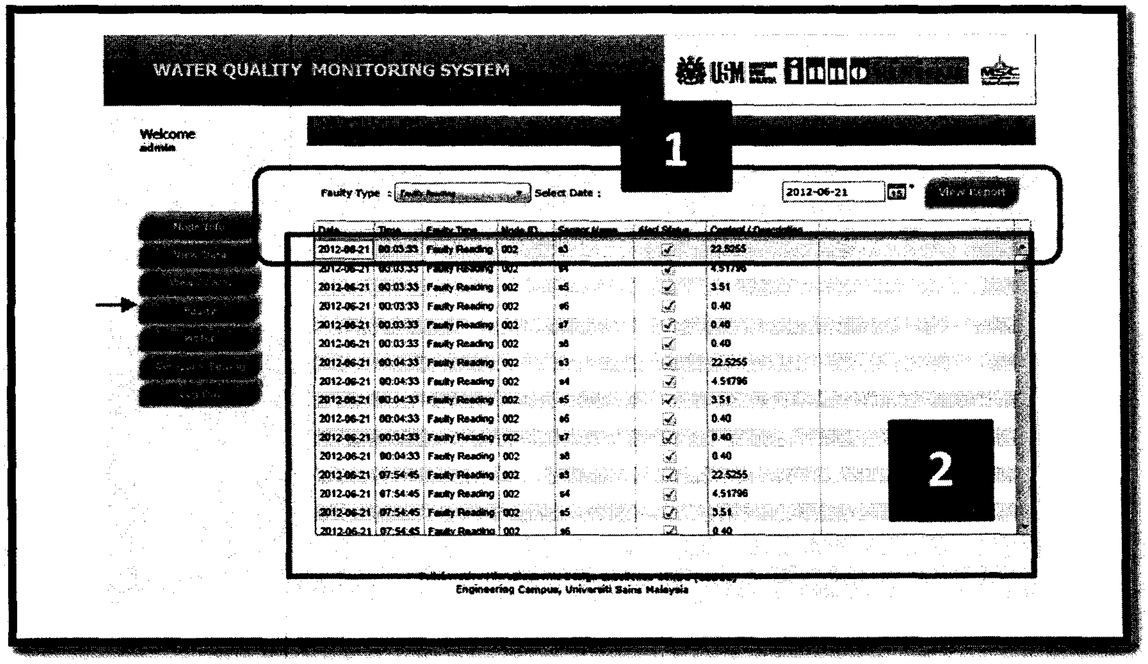
1. Search engine use to search data by selecting chosen location, node and date.
2. Data grid (data table) used to display stored data (historical view) .

2.2.4 View Charts



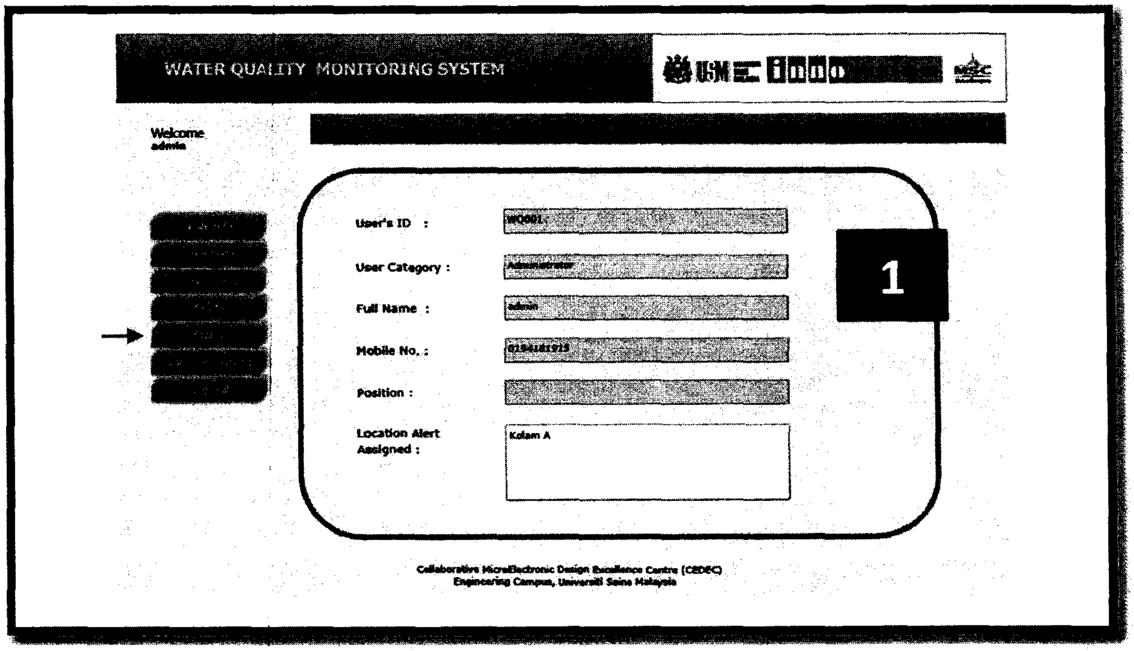
1. **Click button add graph** to generate a chart/graph features.
2. It is necessary to select location, node and date to start the data searching process.
3. Make sure to click the radio button to select any data type and **click load graph** to view data on the graph.

2.2.5 Faulty



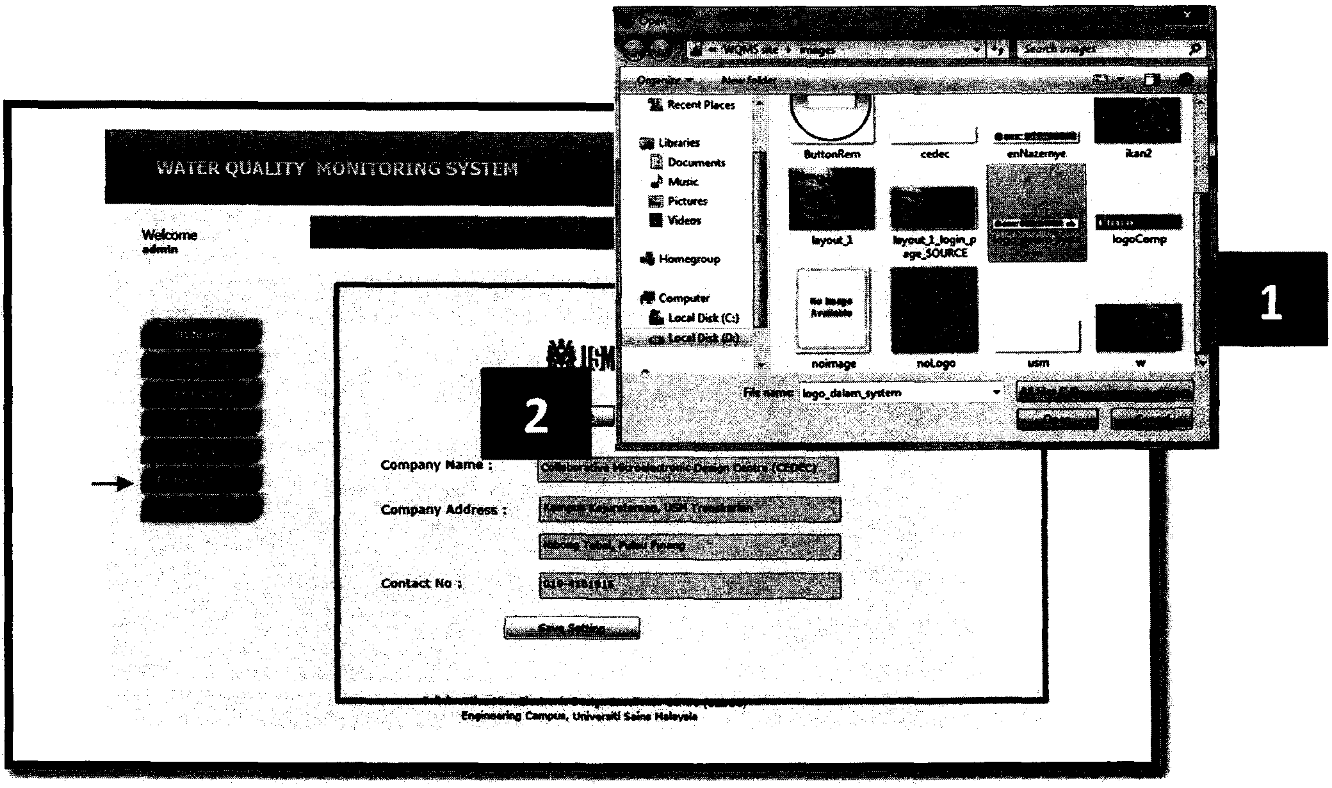
1. Choose faulty type on the combo box and select the date. Click view report to view the report.
2. The faulty reading will be display on the list box.

2.2.6 Profile



1. Click profile button to view the user profile details.

2.2.7 Company Setting



1. The company details will be displayed according to the user's account. This features enable a manager or administrator to change the company logo.
2. Manager or administrator need to choose the logo after clicking the browse button.

APPENDIX II – Data Collection for the System

Date: 18/5/2012					
For sample of 0.5 g of fish food.					
Time	pH	Temperature(°C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)
9:27:58	6.754813	25.086166	35.477489	275.589793	0.894011
9:27:59	6.680623	24.944099	35.263020	1.304121	0.003531
9:28:00	6.613176	24.817817	35.084285	1567.164282	3.600095
9:28:01	6.545731	24.644172	35.048534	1.846236	0.003587
9:28:02	6.592942	24.707313	35.388126	0.801600	0.001744
9:28:03	6.736827	25.101959	35.995815	1317.135427	4.104013
9:28:04	6.718842	25.101959	35.495372	26.838647	0.080233
9:28:05	6.642403	24.912528	35.227268	1.911546	0.004728
9:28:06	6.577205	24.770454	35.084285	42.171746	0.088878
9:28:07	6.496270	24.549461	35.120029	194.667140	0.335218
9:28:08	6.680623	25.023026	35.763462	552.337623	1.503682
9:28:09	6.757061	25.196671	35.834965	351.512901	1.155206
9:28:10	6.673878	24.975669	35.584735	26.838647	0.071699
9:28:11	6.577205	24.802032	35.513240	295.431604	0.624021
9:28:12	6.496270	24.675743	35.691974	1411.966975	2.453281
9:28:13	6.485029	24.612602	36.138805	142.370277	0.239970
9:28:14	6.696360	25.086166	37.086086	809.600273	2.295604
9:28:15	6.685119	25.086166	36.442653	448.354872	1.238817
9:28:16	6.583950	24.880959	36.120937	704.504676	1.519840
9:28:17	6.512008	24.754676	35.977947	59.702614	0.108164
9:28:18	6.442314	24.549461	35.906452	898.590756	1.366597
9:28:19	6.579453	24.912528	36.424777	257.080470	0.550119
9:28:20	6.712097	25.228240	36.603511	2.049173	0.006086
9:28:21	6.673878	25.086166	36.192424	50.177253	0.135099
9:28:22	6.606432	24.944099	35.799213	1680.007004	3.833958
9:28:23	6.521000	24.754676	35.709842	1.979161	0.003661
9:28:24	6.460299	24.628387	35.638355	898.590756	1.432370
9:28:25	6.563716	24.896736	35.977947	1567.164282	3.230572
9:28:26	6.658141	25.133529	36.138805	39.339383	0.102492
Average	6.611161	24.891843	35.783805	469.897560	1.068527
For sample of 1.0 g of fish food.					
Time	pH	Temperature(°C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)
9:37:18	6.458051	25.1651	33.351482	87.51036739	0.144144801
9:37:19	6.514256	25.307174	33.439945	10.14012378	0.019201919

9:37:20	6.462547	25.1651	33.243336	295.4316195	0.491691896
9:37:21	6.518752	25.259811	33.904644	1186.693835	2.26299665
9:37:22	6.514256	25.22824	33.886775	266.1739998	0.501241801
9:37:23	6.595191	25.417671	33.779537	2639.806388	6.070062787
9:37:24	6.586199	25.386093	33.600803	729.4227199	1.639234311
9:37:25	6.624417	25.480812	33.958271	1392.770626	3.44080636
9:37:26	6.604184	25.401878	33.386325	2733.180566	6.409126633
9:37:27	6.586199	25.354522	33.654415	1739.427009	3.900325173
9:37:28	6.543483	25.275596	33.36845	552.3376131	1.116257577
9:37:29	6.538986	25.259811	33.529308	1800.957539	3.598180007
9:37:30	6.47154	25.117744	33.422061	132.8084	0.22490639
9:37:31	6.395102	24.912528	32.742885	285.3387141	0.399389367
9:37:32	6.678374	25.543952	33.31483	104.1229078	0.292560848
9:37:33	6.642403	25.433456	33.439945	2297.116542	5.895207662
9:37:34	6.55922	25.19667	33.743785	295.431604	0.615650686
9:37:35	6.476036	25.00724	33.851025	552.3376227	0.937744061
9:37:36	6.541234	25.180885	33.994007	100.5653562	0.200842388
9:37:37	6.442314	24.959884	33.851024	327.9045931	0.513394043
9:37:38	6.428824	24.944099	33.22546	3737.158006	5.665916517
9:37:39	6.428824	24.928314	33.886775	497.6376815	0.753627962
9:37:40	6.410838	24.896736	33.654415	376.8221808	0.546290406
9:37:41	6.381612	24.802032	33.153972	64.00113094	0.086166243
9:37:42	6.410838	24.865173	33.922519	73.54857845	0.106387676
9:37:43	6.397349	24.865173	33.547183	930.3785221	1.304631667
9:37:44	6.460299	25.023025	34.208492	119.6558157	0.196137534
9:37:45	6.455802	24.991455	33.350574	128.2708297	0.207629345
9:37:46	6.453554	25.00724	33.976139	208.6826694	0.336421833
9:37:47	6.38386	24.833595	33.332706	781.9411664	1.060576196
Average	6.498818	25.140367	33.590703	814.9191576	1.631225025

For sample of 1.5 g of fish food.

Time	pH	Temperature(°C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)
9:51:26	6.58395	25.417671	34.530216	2378.376318	5.329183562
9:51:27	6.498518	25.180885	34.565952	90.60603217	0.164001562
9:51:28	6.437817	25.070388	34.583835	2142.836019	3.346478199
9:51:29	6.449058	25.101959	33.725917	403.952415	0.648842304
9:51:30	6.395102	24.991455	34.530216	128.2708297	0.180546192
9:51:31	6.451306	25.133529	34.047626	137.505984	0.222509264
9:51:32	6.467044	25.149307	34.119129	1864.660858	3.132188835
9:51:33	6.545731	25.307174	34.476589	1032.644748	2.102453553
9:51:34	6.579453	25.386093	34.065509	1622.602501	3.590281408
9:51:35	6.552475	25.338737	34.36935	571.8750731	1.185190716

9:51:36	6.485029	25.149307	34.548084	339.5049354	0.594401059
9:51:37	6.516504	25.22824	33.833156	809.6002731	1.532498638
9:51:38	6.462547	25.133529	33.81528	4294.6642	7.131759856
9:51:39	6.453554	25.101959	34.494464	275.5897931	0.447268875
9:51:40	6.419831	25.00724	34.458721	30.84250939	0.046007072
9:51:41	6.419831	25.023025	34.422969	142.370277	0.21260767
9:51:42	6.379364	24.928314	34.476589	169.396108	0.228921604
9:51:43	6.368123	24.944099	33.636547	1998.919185	2.635254475
9:51:44	6.332151	24.84938	34.101253	51.95227451	0.062625245
9:51:45	6.437817	25.133529	34.279979	90.60603217	0.142132669
9:51:46	6.440065	25.133529	34.065509	2462.502382	3.882953219
9:51:47	6.49627	25.22824	34.244243	571.8750731	1.033228836
9:51:48	6.572709	25.401878	34.208492	2462.502437	5.370714996
9:51:49	6.554723	25.354522	34.315731	285.3387335	0.595085319
9:51:50	6.525496	25.259811	34.476589	3367.054501	6.521383774
9:51:51	6.467044	25.117744	34.619571	2142.836019	3.591439768
9:51:52	6.485029	25.1651	34.512341	2378.376318	4.168679887
9:51:53	6.417583	25.00724	33.672298	781.9411664	1.160382493
9:51:54	6.354633	24.896736	33.779537	4603.880266	5.864167076
9:51:55	6.35913	24.880958	34.601703	403.952415	0.519307051
Average	6.463596	25.134053	34.25258	1267.901189	2.188083173
For sample of 2.0 g of fish food.					
Time	pH	Temperature(°C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)
10:11:04	6.48278	24.628387	34.101253	64.00113094	0.107439236
10:11:05	6.586199	24.865173	34.029758	71.03606045	0.15387094
10:11:06	6.516504	24.754676	33.8689	51.95227451	0.095102078
10:11:07	6.50976	24.738883	33.618671	2297.116542	4.135598251
10:11:08	6.536738	24.786239	33.940395	898.5907563	1.727238397
10:11:09	6.485029	24.644172	33.618671	592.1049524	1.000250325
10:11:10	6.491774	24.691528	34.101253	634.7351758	1.092709011
10:11:11	6.485029	24.659957	34.101253	78.84388987	0.133341072
10:11:12	6.467044	24.628387	33.654415	4147.947573	6.715400576
10:11:13	6.523249	24.770454	34.065509	1032.644748	1.922056272
10:11:14	6.518752	24.738884	34.083378	37.99532321	0.069835715
10:11:15	6.476036	24.659958	33.92252	2549.614928	4.223546859
10:11:16	6.49627	24.707313	33.708034	448.3548723	0.780757362
10:11:17	6.473788	24.644172	33.8689	363.947702	0.59911196
10:11:18	6.69636	25.086166	34.476589	36.69727148	0.104054322
10:11:19	6.682871	25.054603	34.691074	680.4332871	1.866183129
10:11:20	6.664885	24.991455	34.941296	4446.588321	11.64850936
10:11:21	6.640155	24.944099	34.887676	1069.17277	2.636981

10:11:22	6.658141	24.991455	34.744694	1411.967008	3.641871173
10:11:23	6.615425	24.880958	34.905544	2639.806356	6.122958004
10:11:24	6.678374	25.03881	34.834056	5109.939565	13.85488801
10:11:25	6.671629	25.023025	34.315731	33.06310193	0.088165951
10:11:26	6.653645	24.991455	34.816189	107.8058901	0.27519841
10:11:27	6.617673	24.896736	34.816188	2069.623198	4.830734829
10:11:28	6.604184	24.880958	33.994007	497.6376815	1.124764158
10:11:29	6.676126	25.054603	34.190616	14.86310273	0.040135972
10:11:30	6.660389	25.00724	34.583835	2733.180566	7.094158934
10:11:31	6.597439	24.84938	34.601703	3737.157986	8.298005708
10:11:32	6.680623	25.070389	33.958271	1317.13547	3.597790985
10:11:33	6.705353	25.133529	34.101253	36.69727148	0.106587598
Average	6.585074	24.860435	34.251388	1307.021826	2.93624152

For sample of 2.5 g of fish food.

Time	pH	Temperature(°C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)
10:24:58	6.748069	25.244026	32.02795	39.33938331	0.127059055
10:24:59	6.624417	24.944099	31.777729	257.0804827	0.611491913
10:25:00	6.63341	24.959884	32.760761	480.6355023	1.168464365
10:25:01	6.592942	24.865173	32.707134	76.15028975	0.167530043
10:25:02	6.536738	24.770454	32.546276	35.44346513	0.068052022
10:25:03	6.736827	25.244026	32.653514	1186.69382	3.734863667
10:25:04	6.732331	25.180885	32.796504	2142.836019	6.644971289
10:25:05	6.669381	25.03881	32.206684	42.17174574	0.11199941
10:25:06	6.637907	24.97567	32.903744	1567.16433	3.853857486
10:25:07	6.590694	24.880958	32.796504	68.6090427	0.150327997
10:25:08	6.568213	24.896736	32.653514	10978.67661	22.86712194
10:25:09	6.586199	24.975669	32.224559	704.5046573	1.53800149
10:25:10	6.631163	25.03881	32.456912	104.1229078	0.253233959
10:25:11	6.757061	25.307175	32.617771	132.8084027	0.439877291
10:25:12	6.694111	25.086166	32.760761	6517.714218	18.38539077
10:25:13	6.745821	25.22824	32.117321	2218.631037	7.120840127
10:25:14	6.644651	25.00724	32.689266	1272.134119	3.184402751
10:25:15	6.653645	25.03881	31.849224	181.5927399	0.465110386
10:25:16	6.586199	24.880958	32.385417	351.5128983	0.762261835
10:25:17	6.626666	24.97567	32.492657	35.44346513	0.084932965
10:25:18	6.541234	24.833595	31.741978	809.6002973	1.577657996
10:25:19	6.779543	25.338737	32.313922	1272.134119	4.447213451
10:25:20	6.793033	25.338737	32.492656	729.4227199	2.630413716
10:25:21	6.637907	24.991455	31.563251	194.6671525	0.479246121
10:25:22	6.581702	24.84938	32.385417	480.6355023	1.029227824
10:25:23	6.691863	25.149307	32.296055	275.5898121	0.776837975

10:25:24	6.768302	25.259811	32.17094	4147.947573	14.05168388
10:25:25	6.682871	25.086166	31.902843	515.2403449	1.416274426
10:25:26	6.610929	24.928314	32.653514	257.0804705	0.592129818
10:25:27	6.574957	24.865173	31.777729	390.1508517	0.823508904
Average	6.655293	25.039338	32.357417	1248.857799	3.318799496
For sample of 3.0 g of fish food.					
Time	pH	Temperature(°C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)
10:37:26	6.653645	24.880958	31.366634	339.5049354	0.859913372
10:37:27	6.85823	25.307174	31.741977	163.6093573	0.684041906
10:37:28	6.826756	25.212455	31.170032	123.8886355	0.478550945
10:37:29	6.723339	25.070389	31.062794	339.5049474	1.023216633
10:37:30	6.691863	24.912529	31.884968	657.1887149	1.821744316
10:37:31	6.885208	25.370315	32.296054	137.505984	0.614482235
10:37:32	6.691863	24.97567	31.02705	997.3638996	2.77709513
10:37:33	6.687367	24.975669	31.456005	123.8886355	0.341407421
10:37:34	6.69636	25.023025	30.812572	963.2907317	2.719226477
10:37:35	6.768302	25.1651	30.134289	231.6208338	0.779414167
10:37:36	6.826756	25.275596	31.134288	248.297172	0.963394969
10:37:37	6.92118	25.449234	31.134289	57.66280532	0.281495889
10:37:38	6.844741	25.259811	30.741077	2142.836019	8.656113659
10:37:39	6.806521	25.180885	31.563251	8313.292473	30.58210893
10:37:40	6.781792	25.133529	30.562343	515.2403449	1.784520993
10:37:41	6.716594	25.101959	30.544467	248.297172	0.738442904
10:37:42	6.806521	25.212455	30.741077	1461.913863	5.389945744
10:37:43	6.75931	25.117744	30.651714	3367.054501	11.06103319
10:37:44	6.718842	25.03881	31.313022	729.4227199	2.170870127
10:37:45	6.694111	25.023025	30.812572	403.952415	1.134408332
10:37:46	6.766053	25.1651	30.080669	809.6002973	2.710269851
10:37:47	6.869472	25.338737	31.205783	1622.602501	6.977435249
10:37:48	6.900946	25.433456	31.420261	46.8072375	0.217857286
10:37:49	6.864975	25.338737	31.223651	1069.17277	4.550246911
10:37:50	6.8335	25.338737	31.313022	5477.84663	21.68312845
10:37:51	6.84699	25.291381	31.277278	46.8072375	0.190486213
10:37:52	6.799777	25.196671	31.062794	71.03606516	0.257580527
10:37:53	6.844741	25.307174	31.884967	1186.69382	4.809771564
10:37:54	6.768302	25.133529	30.991306	81.63298946	0.274086598
10:37:55	6.75931	25.117744	31.741977	930.3785221	3.056365055
Average	6.787112	25.178253	31.145073	1096.930474	3.986288502
For sample of 3.5 g of fish food.					
Time	pH	Temperature(°C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)

10:51:16	6.579453	24.817817	31.634738	6517.714218	13.85389213
10:51:17	6.619921	24.928314	32.153064	123.8886355	0.291320814
10:51:18	6.613176	24.912528	31.724109	403.952415	0.934202031
10:51:19	6.678374	25.054603	32.063701	78.84388987	0.214012998
10:51:20	6.673878	25.00724	31.992206	316.702943	0.847956335
10:51:21	6.768302	25.212455	32.331798	115.5676232	0.390192835
10:51:22	6.770551	25.1651	32.206684	11769.12367	39.80921386
10:51:23	6.741323	25.117744	32.135189	552.3376227	1.740860117
10:51:24	6.628914	24.833595	33.22546	3609.475622	8.607283559
10:51:25	6.63341	24.865173	32.742885	100.5653469	0.24284977
10:51:26	6.554723	24.691528	32.707134	248.297172	0.494120453
10:51:27	6.538986	24.659957	33.010982	128.2708216	0.245629642
10:51:28	6.494022	24.565246	33.636547	5872.237441	10.0710895
10:51:29	6.527744	24.659957	33.797405	93.81117972	0.175051363
10:51:30	6.462547	24.45475	33.314831	1069.172775	1.692159209
10:51:31	6.541234	24.691528	33.958271	257.0804827	0.495954087
10:51:32	6.514256	24.644172	33.36845	2733.180566	4.938619101
10:51:33	6.525496	24.659957	33.81528	351.5128983	0.652535832
10:51:34	6.532241	24.675743	33.672298	533.4664324	1.006932751
10:51:35	6.53449	24.659957	33.565052	295.4316195	0.559903618
10:51:36	6.518752	24.707314	33.010983	115.567632	0.211939705
10:51:37	6.574957	24.738883	33.028858	6748.240182	14.11701074
10:51:38	6.597439	24.770454	33.886775	285.3387141	0.630037004
10:51:39	6.581702	24.754676	32.993106	13524.85418	28.76842153
10:51:40	6.592942	24.770454	33.851024	2929.971539	6.402832777
10:51:41	6.516504	24.612602	32.975238	128.2708216	0.2324561
10:51:42	6.586199	24.770454	33.636547	100.5653562	0.216378325
10:51:43	6.561468	24.738883	32.742885	275.5897931	0.55889039
10:51:44	6.561468	24.723098	33.332706	216.064756	0.437685149
10:51:45	6.521	24.628387	32.725009	704.5046573	1.291453083
Average	6.584849	24.783086	32.97464	2006.653367	4.671029494

For sample of 4.0 g of fish food.

Time	pH	Temperature(°C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)
11:15:51	6.698608	24.470527	33.189716	376.8221808	1.028198705
11:15:52	6.651397	24.423171	32.385417	8029.286249	19.58602115
11:15:53	6.626666	24.328461	33.010983	480.6355023	1.100103759
11:15:54	6.770551	24.707313	33.064601	1363.729037	4.465837151
11:15:55	6.644651	24.391601	32.474788	1411.966975	3.383569766
11:15:56	6.750317	24.691528	32.796504	634.7351758	1.981743875
11:15:57	6.824508	24.817817	32.796504	838.2396515	3.132557044
11:15:58	6.811018	24.802032	32.725009	1317.135427	4.766351234

11:15:59	6.871719	24.928314	32.617771	2142.836019	8.997618676
11:16:00	6.795281	24.738883	32.242435	2142.836019	7.445017991
11:16:01	6.700856	24.51789	32.760761	1228.674028	3.381307276
11:16:02	6.694111	24.502105	32.742885	305.8826751	0.827887042
11:16:03	6.655892	24.45475	32.08157	1363.729086	3.368731782
11:16:04	6.595191	24.281105	2.4032936	1864.660918	3.956230368
11:16:05	6.606432	24.281105	33.171841	1032.644762	2.248399864
11:16:06	6.599687	24.281105	32.885868	3140.923427	6.733403689
11:16:07	6.640155	24.391601	33.582927	898.5907563	2.131159447
11:16:08	6.637907	24.360031	32.760761	201.552848	0.474483977
11:16:09	6.691863	24.486313	32.814381	6079.966135	16.35245404
11:16:10	6.723339	24.502106	33.582928	755.2260181	2.186358476
11:16:11	6.75931	24.581031	33.547183	257.0804705	0.813046684
11:16:12	6.867224	24.644172	33.100353	3033.60986	12.35561124
11:16:13	6.813266	24.691528	33.457813	4147.947573	14.97053829
11:16:14	6.85823	24.817817	32.81438	3869.348744	15.62753795
11:16:15	6.837996	24.817817	32.885868	963.290763	3.713436344
11:16:16	6.75931	24.628387	32.689266	1800.957539	5.714892145
11:16:17	6.745821	24.628387	32.796504	2462.502382	7.575170708
11:16:18	6.640155	24.281105	32.778629	119.655817	0.281565422
11:16:19	6.651397	24.360031	32.367542	1739.427009	4.224044824
11:16:20	6.658141	24.391601	32.439037	781.9411664	1.932922202
Average	6.719367	24.539988	31.832251	1826.194474	5.491873371

For sample of 4.5 g of fish food.

Time	pH	Temperature(°C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)
11:31:20	6.42208	23.981178	34.22636	26180.43306	36.49915805
11:31:22	6.617673	24.344245	34.780437	1739.427009	3.904071976
11:31:23	6.491774	24.012748	35.2094	4766.734217	7.81981761
11:31:24	6.43332	23.949608	34.27998	295.4316195	0.421722433
11:31:25	6.379364	23.728607	34.816189	9553.491518	11.85593334
11:31:20	6.395102	23.870674	34.458721	3252.014902	4.227288385
11:31:22	6.595191	24.29689	35.048534	305.8826864	0.649716182
11:31:23	6.529993	24.07589	35.2094	781.9412019	1.407086358
11:31:24	6.440065	23.933815	35.030666	634.7351897	0.919219325
11:31:25	6.444562	23.949607	35.06641	188.0161003	0.275427084
11:31:20	6.386108	23.775962	34.619571	2462.502382	3.114304726
11:31:22	6.494022	24.075889	34.780437	15542.55397	25.74532173
11:31:23	6.599687	24.265319	34.691074	305.8826751	0.655005615
11:31:24	6.521	24.075889	35.173648	1106.993451	1.951185639
11:31:25	6.47154	23.996963	34.440845	464.2139353	0.726060231
11:31:20	6.42208	23.854897	35.102154	552.3376227	0.763140023

11:31:22	6.397349	23.854896	34.887676	5290.683815	6.905270511
11:31:23	6.556972	24.1706	35.245143	5290.683815	10.19912013
11:31:24	6.449058	23.918037	35.2094	285.3387141	0.421396978
11:31:25	6.392854	23.854896	34.297863	930.3785264	1.201802123
11:31:20	6.368123	23.618103	34.905544	158.0190645	0.189591178
11:31:22	6.392854	23.854896	34.601703	418.2411242	0.540256527
11:31:23	6.547978	24.10746	35.280888	316.7029522	0.595332555
11:31:24	6.473788	23.949607	35.352382	1069.17277	1.675273787
11:31:25	6.42208	23.902252	34.42297	55.69274287	0.077208214
11:31:20	6.406342	23.870674	35.137897	2733.180566	3.646008471
11:31:22	6.352386	23.570747	34.279979	4603.880266	5.309175052
11:31:23	6.43332	23.949608	34.887676	339.5049474	0.484636183
11:31:24	6.53449	24.075889	35.37025	9227.089634	16.77675564
11:31:25	6.476036	23.996964	34.476589	12616.50962	19.93835457
Average	6.461573	23.96276	34.842993	3715.589003	5.629821355

For sample of 5.0 g of fish food.

Time	pH	Temperature(^{0}C)	DO (%)	Ammonium (ppm)	Un-ionized Ammonia (ppm)
11:50:02	6.354633	23.712821	33.708034	266.1739998	0.311687638
11:50:03	6.505262	23.965393	34.154873	128.2708297	0.216335656
11:50:04	6.365874	23.681243	34.029758	142.370277	0.170700929
11:50:05	6.507511	23.996963	34.01189	634.7351758	1.078494024
11:50:06	6.437817	23.807533	34.244243	248.297172	0.354521005
11:50:07	6.291684	23.381317	33.940395	1680.007004	1.662016708
11:50:08	6.53449	24.028533	34.297863	1998.919185	3.622220472
11:50:09	6.40859	23.760177	33.565052	4006.22421	5.329824488
11:50:10	6.374867	23.681243	34.083377	68.6090427	0.083982948
11:50:11	6.397349	23.760177	32.903743	132.8084	0.172171872
11:50:12	6.547978	24.13903	32.725009	5290.683815	9.967691115
11:50:13	6.547978	24.10746	32.403294	1186.693835	2.230725885
11:50:14	6.460299	23.949607	32.885868	1363.729086	2.071458835
11:50:15	6.523249	24.123245	32.635646	997.3638905	1.77304194
11:50:16	6.543483	24.13903	33.100353	4766.734217	8.88808094
11:50:17	6.370372	23.649681	32.671391	1461.913863	1.767087004
11:50:18	6.556972	24.10746	33.100353	339.5049474	0.651548468
11:50:19	6.410838	23.791748	33.386326	963.290763	1.29110157
11:50:20	6.327656	23.539184	32.742885	2829.865347	3.075815141
11:50:21	6.556972	24.123245	33.457813	137.505984	0.264186041
11:50:22	6.460299	23.918037	33.082469	275.5897931	0.417671503
11:50:23	6.514256	23.981178	33.797405	50678.14325	87.35808577
11:50:24	6.473788	23.918037	33.279079	327.9045931	0.512635782
11:50:25	6.419831	23.807533	33.81528	152.6201808	0.209072428

11:50:26	6.332151	23.539184	32.921619	142.370277	0.156354177
11:50:27	6.538986	24.060104	33.725917	123.8886355	0.227344005
11:50:28	6.426576	23.823318	33.654415	119.6558157	0.166667777
11:50:29	6.341144	23.697036	32.778629	464.2139353	0.526372782
11:50:30	6.554723	24.13903	33.600803	5109.939565	9.777837772
11:50:31	6.516504	24.044319	32.885868	71.03606516	0.123640593
Average	6.453404	23.879096	33.386322	2870.302105	4.815279175

PUBLICATIONS

Development of Water Quality Monitoring System Prototype for Fresh Water Fish Culture

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Abstract. The common way to monitor water quality in fresh water fish culture is to use intermittent monitoring that requires users to collect data manually. It is a tedious work for them and there is a possibility that the data are not taken in a day. Not taking the reading in a day can create a problem in fresh water farming especially if water source comes from river. Fish will die in a few hours if the water is heavily polluted and this will cause thousands of dollars in losses to fish farmer. The present project proposes continuous monitoring of water quality for fresh water fish. Temperature sensor, pH sensor, and dissolved oxygen sensor are the sensors that are critically important in a fresh water fish monitoring system. Wireless technology and Internet facilities that are adopted in the system have made the system more robust and more reliable. The system is much better than intermittent monitoring because users can access data regardless of where they are.

Keywords: water quality monitoring system, pH sensor, temperature sensor, dissolved oxygen sensor.

1 Introduction

Fish need a balanced ecosystem to survive and breed. However, factors outside their required environment or behavioral needs subject them to stress, thereby resulting in negative effects. These stress factors affect their health, reduce their life span, and increase their vulnerability to diseases.

One stress factor is the pH value of water[1] . Changes in pH have a marked effect on fish health. The pH value of water is greatly influenced by numerous compounds that are added or dissolved in the water system. The greatest factors affecting pH balance in pond water, such as plant and animal respiration and plant photosynthesis, come from the ecosystem itself. All submerged plants and animals are constantly removing dissolved oxygen from water and excreting carbon dioxide during normal respiration. The release of carbon dioxide increases water acidity. During photosynthesis, plants absorb carbon dioxide from the water and use the energy of the sun to convert it to

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simple organic compounds. In other words, acidity is caused by respiration, whereas alkalinity is caused by photosynthesis. Alkalinity is important for fish life because it protects or buffers against pH changes and makes water vulnerable to acid rain.

Another stress factor affecting the sustenance of fish in their habitat is ammonia. Ammonia is toxic to fish even in very low concentrations because it causes red or inflamed gills. When levels reach 0.06 mg/L, fish may suffer from gill damage. When levels reach 0.2 mg/L, sensitive fish begin to die. As levels near 2.9 mg/L, even ammonia-tolerant fish, such as carp, begin to die. Ammonia levels greater than approximately 0.1 mg/L usually indicate polluted waters. The temperature of water is also important to fish. For example, the optimum temperature range for tilapia is 25–32 °C[2]. The higher the pH and the warmer the temperature, the more toxic ammonia is. Ammonia is much more toxic when water contains very little dissolved oxygen.

The information above shows that pH, temperature, and dissolved oxygen are important for sustaining fish in their habitat and keeping fish healthy. Water monitoring is important, especially if the water source comes from the river. We will never know the quality of water until we measure the mentioned parameters in the water. The water could be polluted with chemical toxins, and without a proper monitoring system, fish die and causes thousands of dollars in losses to fish farmers.

Intermittent monitoring is a common practice among fish farmers, in which they gather data manually. They normally take a reading once a day, which they record on a piece of paper or in a book. Today, this is done using a computer, in which data are recorded automatically and visualized regardless of where they are. Continuous monitoring enables a fish farmer to know the quality of water immediately. Wireless technology and Internet facilities are the key factors in continuous monitoring, as shown in Figure 1.

2 Wireless Technology

Zigbee is a wireless technology that operates on long battery life, ultra low power consumption, and at a low cost, and is used for wireless monitoring and control[3][4]. These Zigbee characteristics are best and most suitable for a water quality monitoring system that is operated 24 h nonstop. For the Zigbee devices, the specified maximum operation range is 250 ft, which is suitable for this application . Zigbee builds upon the IEEE 802.15.4 standard that defines the physical layer and the MAC layer for low cost and low data rate for a personal area network. Point-to-multipoint network topology is the best network to read data from all ponds. In this topology, the working concept is more like a master-slave network concept. An FFD (full function device) assumes the role of PAN (Personnel Area Network) coordinator, and the other nodes can be RFDs (Reduced Function Devices) or FFDs, which only communicate with the PAN coordinator.

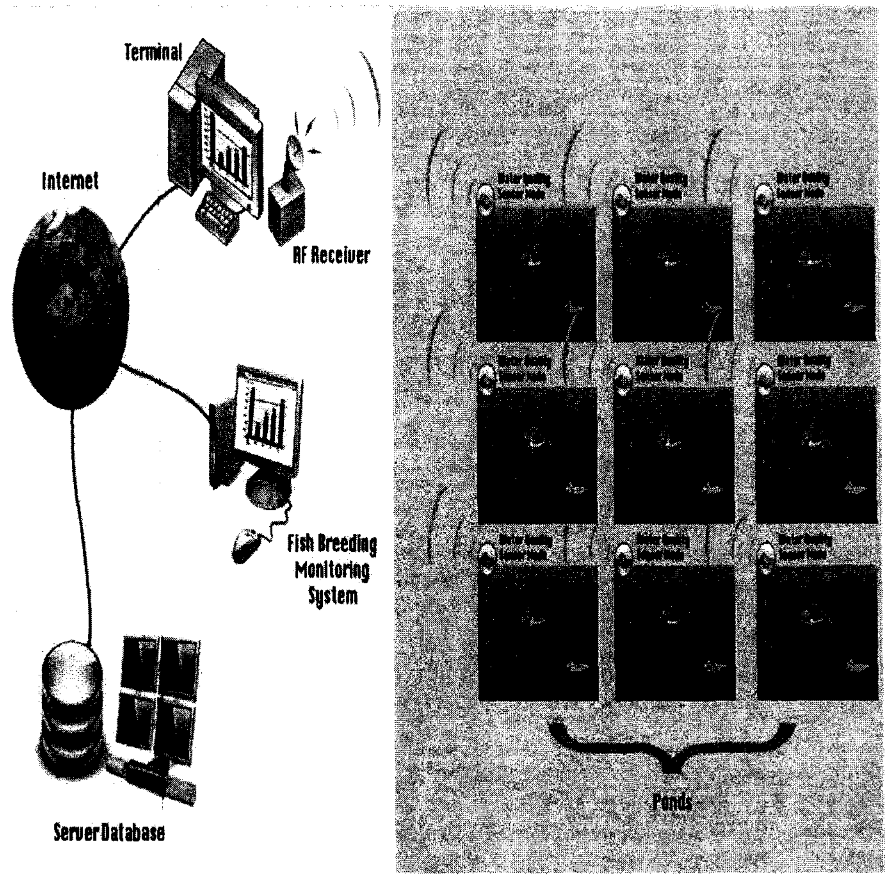


Fig. 1. Wireless technology and Internet facilities in continuous monitoring implementation

3 Proposed System

The system can be divided into three main sub-systems, namely, sensor platform, wireless communication, and GUI software. In the present project, three sensors are used, namely, temperature sensor, pH sensor, and dissolved oxygen sensor. All are electrode-type sensors, which are waterproof and suitable for submersion in a pond for a long period [5].

Several important criteria, such as range of sensor output, wiring of the sensor, and detection range, need to be considered in choosing a sensor for water-based applications. The sensor responds to the parameter and detects voltage, current, or frequency. These analog signals are converted to digital signals and are processed by a microcontroller. The wiring diagram of the sensor should also be considered to know which of the wires is the output signal, the power, or the ground . If the wire from the sensor is connected wrongly to the system, then it damages the sensor itself.

The range of detection of the sensor in measuring the parameter should satisfy the project requirements . This is to ensure that the sensor is capable of detecting the minimum or the maximum value of the parameter in a real case. The accuracy and the sensitivity of the sensor should also be considered to determine which resolution of the ADC (analog digital converter) is suitable for this project[6] .

The signal conditioning stage changes or alters the output from the sensor so that the output can be read by the ADC and can be processed well by the microcontroller. Some sensor outputs are in current form, e.g., all Global Water sensors, especially water quality sensors, which produce 4–19 mA output signals. Sensor output must be converted to a voltage signal by reading the voltage across a precision resistor in series with the signal wire . The output is 1.04–4.94 volts DC because Ohm's Law states that V=IR, particularly if the 4–19 mA signal is dropped across a 260 ohm resistor.

Mostly, ion selective electrodes, such as ammonium sensor and nitrate sensor, produce output in a negative millivolt range. This millivolt output is too small and cannot be accepted by the DC. Thus, the output needs to be conditioned from 0 to 5V DC. In this case, op-amp is the best solution because it is more versatile, flexible, and can be configured to do certain operations, such as attenuating or amplifying the signal, converting the polarity of the signal from negative to positive or vice versa, or obtain the sum or the difference of the signal. The op-amp can even be configured as a converter, which can be used to either convert the current into voltage or vice versa[7][8] . The op-amp as an inverting amplifier, which is shown in Figure 3, is used to invert the polarity of the negative signal that is produced by the sensor and amplify the millivolt signal to a suitable range for the ADC.

Any negative input signal is inverted into a positive output signal because the inverting op-amp formula is Vout = (-Rf/Rin)*Vin. The gain of the amplifier can be controlled by changing the value of the feedback resistor, and the value of the Rin must be fixed. Figure 2 shows the diagram for simulation using the Multisim software, and Table 1 shows the results obtained from the simulation and the experiments.

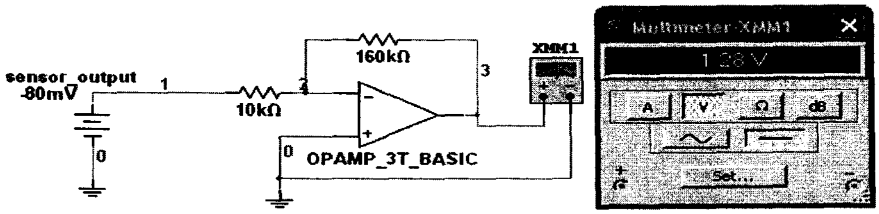


Fig. 2. Simulation of the inverting amplifier circuit

The data acquisition circuit is a stage where the microcontroller is placed. The project microcontroller of CY8C29466-24PXI is used. This PSOC microcontroller is versatile, flexible, and programmable, where all ports can be configured to become an ADC module, a UART module, or even an analogue module, such as PGA (Programmable Gain Amplifier). Thus, PSOC allows the designer to reduce board size, the time taken to finish a project, and project cost. The microcontroller is responsible for getting data from the ADC and for sending the data to the transmitter through UART.

Table 1. Output voltage obtained from the experiments and the simulations

INPUT VOLTAGE (V)	SIMULATION VOLTAGE (V)	EXPERIMENT VOLTAGE	DIFFERENCES
-0.080	1.28	1.32	0.041
-0.120	1.92	1.96	0.04
-0.140	2.24	2.28	0.04
-0.180	2.88	2.92	0.04
-0.220	3.52	3.55	0.03
-0.260	4.16	4.20	0.04
-0.290	4.64	4.70	0.06

The Xbee module is used to send data from the microcontroller to a PC. Radio frequency (RF) with a 2.45 GHz frequency is used as transmission medium. The Xbee module with a 10 mA transmission current, a 1 mWatt output power, and a 150 m transmission range is applicable for the present project. The module is then interfaced to the board of the sensor. The module that is connected to the sensors is programmed as a transmitter, whereas the module connected to the PC is programmed as a receiver. Data are transmitted every 5 sec in one data frame, which consists of one start byte data, sensors's data, and one stop byte data. The receiver is interfaced to the PC via a USB cable. The receiver is programmed under point-to-multipoint network topology, which enables the receiver to read data from all ponds in the system.

Using Visual Basic software, a GUI can be developed to show data in table form and also to display the graph over time. Data are retrieved through a USB port and saved in a database system. Data are received every 5 min. For a web-based application, the software is developed in Adobe Dreamweaver using PHP programming and MySQL Database. The software is developed to access up to 10 ponds.

4 System Calibration

Calibration is a procedure that ensures that the sensor works properly. The output of the sensor changes according to parameter changes, such as pH, temperature, and dissolved oxygen. The pH meter and thermometer are used as reference tools. The data of reference solution are taken using a data acquisition board, and are compared with the data obtained using reference tools. The graph of the data from the data acquisition board versus the data from the reference tools is plotted. The trend line of the graph is generated to get an equation that represents the relationship between data from the data acquisition board and data from the reference tools.

4.1 Temperature Calibration

Temperature calibration requires at least two points, namely, cold temperature and warm temperature. Ice bath and warm water are used as reference solutions, whereas thermometer is used as a reference tool to measure temperature. Experimental setup is shown in Figure 3. In the experiments, eight data are collected to represent cold water and warm water. Table 2 shows the collected data, and the graph in Figure 4 illustrates the relationship between collected data from the data acquisition board and the thermometer. Data from the data acquisition board change linearly with temperature change from the thermometer, with R^2 being 0.987.

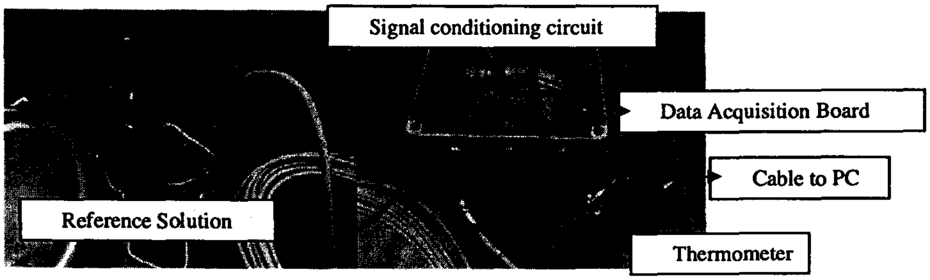


Fig. 3. Experimental setup for temperature calibration

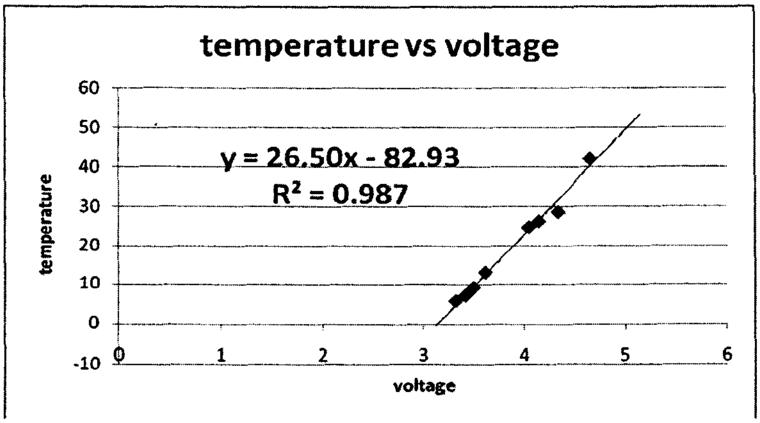


Fig. 4. Graph shows the relationship between voltage level from the data acquisition board and temperature

4.2 pH Calibration

The pH calibration process requires pure buffer solution. At least three buffer solutions are required, namely, acidic, neutral, and alkaline. In the present project, seven buffer solutions are used, ranging from 4.01 to 10.01. Readings from the data acquisition board are plotted, as shown in Figure 5. The graph shows that data from

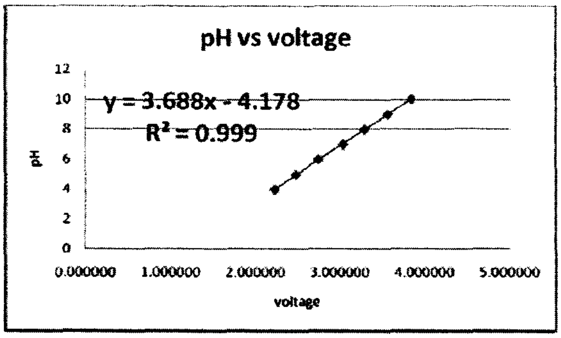


Fig. 5. Graph shows the linear relationship between pH and voltage

the data acquisition board change linearly with change in buffer solution, with R^2 being 0.999.

4.3 Dissolved Oxygen Calibration

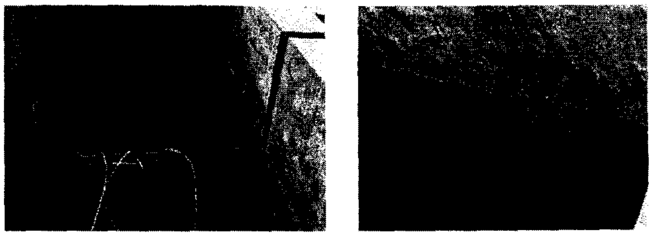
The Dissolved Oxygen Calibration process requires at least two solutions, with one solution containing 0% oxygen, and another containing 100% oxygen. For this calibration process, we used the 0%-oxygen solution and tap water. To increase the quantity of oxygen in tap water, a speed-controllable aquarium air pump is used. The motor speed of the air pump can be set to low, medium, and high. By increasing the speed of the air pump, the quantity of dissolved oxygen in the tap water is also increased. Data collected from the data acquisition board is tabulated in Table 3, and a graph is plotted, as shown in Figure 6.

Table 3. Data from the data acquisition board with different levels of oxygen

DISSOLVED OXYGEN	EXPERIMENT VOLTAGE (V)
0% O2	0.15380
TAP WATER	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
99.8% O2	4.99755

5 System Implementation

Sensors are immersed in the pond to monitor the 100 of catfishes. Sensors also immersed in the pond without fish as a control in this experiment. Data are collected every 5 second. Data are sent to PC through Xbee module and data are collected in PC through USB port. Figure 7 shows the sensors immersed in the pond. Figure 8 until figure 9 show data that are collected from the sensors. Water with fish will have less oxygen than the water without fish. pH of water that has fish is less than the water without fish and temperature in water that has fish is slightly higher than the water without fish.



(a) Pond without fish (b) Pond with fish

Fig. 7. Sensors immersed in the pond

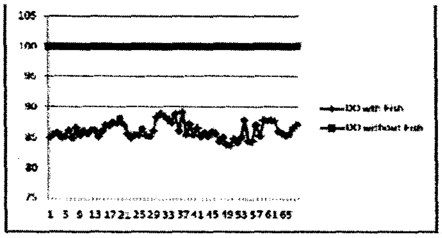


Fig. 8. Data from DO sensor

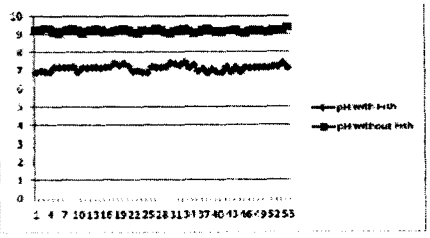


Fig. 9. Data from pH sensor

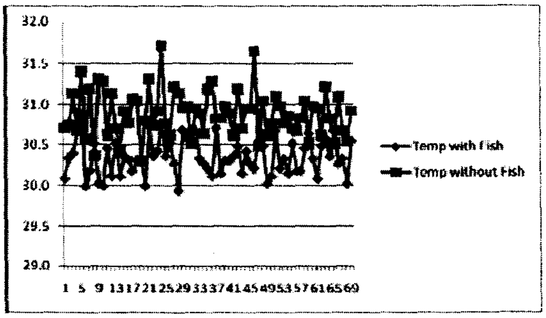


Fig. 10. Results from temperature sensor

6 Conclusion

Three waterproof sensors were integrated in a sensor platform to monitor three parameters in a pond, namely, temperature, pH, and dissolved oxygen. These parameters are critically important to fish farmers to ensure that their fish live in a good habitat. Preliminary test proves that the developed prototype is capable of monitoring temperature, pH, and dissolved oxygen. The Xbee module that was used for wireless communication through RF and Internet facilities enabled the system to monitor water quality in fresh water fish culture. The system can be applied in the field to help fish farmers collect data continuously and remotely.

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UN-IONIZED AMMONIA DETECTION SYSTEM FOR WATER QUALITY MONITORING

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***Abstract*—Un-ionized ammonia (UIA) in freshwater is a primary source of toxins that kill freshwater fish. Concentrations as low as 0.03 mg/L can harm fish and concentrations of more than 2.00 mg/L can kill them. The availability of water quality monitoring systems that can directly measure UIA without any chemical treatment on samples is limited. This paper designs a new system by using a programmable system on chip and nondestructive types of measurement instruments. Four water environment parameters are measured, namely, pH, temperature, dissolved oxygen, and ammonium. Algorithms are applied on the system to calculate the UIA using data from the measurement instruments. The designed system can measure UIA in freshwater at 95% confidence level. Data from the system are monitored and recorded using a data acquisition system.**

I. INTRODUCTION

Ammonia is an important compound that can be used in various domestic, industrial, and agricultural applications. The main application of ammonia is the production of nitrogenous fertilizers such as urea, ammonium phosphate, ammonium sulphate, and ammonium nitrate. Anhydrous ammonia is used in agriculture. Ammonia is also used in refrigeration, refining, mining (as explosive), food processing, pulp and paper, and animal husbandry sectors.

However, despite its varied uses, ammonia is extremely toxic to fish. The main source of ammonia in fish pond is come from the uneaten feed. Thus, over feeding the fish can raise the quantity of ammonia. Others, the fish also excrete ammonia through their gills and their feces. Ammonia also can enter the pond from bacterial decomposition of organic material such as uneaten feed or dead algae and aquatic plants [1].

In water, ammonia is decomposed into un-ionized and ionized ammonia. An un-ionized ammonia (UIA) concentration of 2.00 mg/L or above in water can kill fish. Ionized ammonia, on the other hand, is not toxic to fish [2]. In the freshwater fish farming industry, monitoring and controlling the UIA level is crucial. Failure to do so can cause immense losses in the freshwater fish industry.

Ammonia is odorless and colorless, so the only way for an aqua culturist to know if it is there is to test the water. Normally, people who involved in aquaculture will invest in water quality test kit because it is cheap and available in most aquarium shop. The result from the test kit is not accurate because it is gotten by comparing the color of the sample after treated with reagent with the chart color. Furthermore, the result is not UIA but in TAN (Total Ammonia Nitrogen). Thus, the aqua culturist need to calculate the fraction of UIA or by referring to the table after the readings of temperature and pH are obtained [3]. Usually, the sample of water will be cloudy, thus, the aqua culturist have to filter the sample first before testing with water quality test kit. Thus, it will take long time and not efficient for large scale fish farming application.

The most common instruments used to measure UIA are gas spectrometers and spectrophotometers. These types of instruments require samples to be treated with a chemical first before they are placed into the instruments for measurement [4]. Most of these instruments are bulky and built for indoor use.

The availability of instruments that can directly measure the UIA concentration in freshwater is currently limited. Most of these instruments use an ammonia gas-sensing electrode to measure the gas-liberated NH_3 after the sample is treated with a strong alkali [5]. This measurement method is destructive because samples cannot be used again for measurement.

Conventional online ammonia monitoring systems are generally expensive, complex, and labor-intensive. Most

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systems are automated versions of ammonia selective ion electrode methods, which are suitable for laboratory measurements [6]. These reasons prevent the implementation of a real-time monitoring system for outdoor use.

Our approach uses the ELIT's ammonium electrode to directly measure ammonium ion in water. Global Water's pH, temperature, and dissolved oxygen (DO) sensors are also used. ELIT's and Global Water's sensors are nondestructive, and do not require pretreatment with caustic chemicals to measure environment parameters in water. These sensors do not release noxious gases because chemicals are not used during measurement [7].

Cypress's Programmable System on Chip (PSoC) is used to develop real-time application systems that process the output sensors voltage values and send the measured values to the data acquisition system running on a computer via serial communication port.

II. LITERATURE REVIEW

A. Ammonia

Ammonia (NH_3) is made up of one nitrogen atom and three hydrogen atoms. This compound is usually in a gaseous state at ambient temperature and pressure. Ammonia is colorless, odorless, and alkaline.

Ammonia is soluble in water. Its decomposition in water is mainly affected by two environmental parameters: pH and temperature. In aqueous solutions, equilibrium exists between UIA, NH_3, and ionized ammonia NH_4^+. UIA refers to all forms of ammonia in water except ammonium ion [8, 9] while ionized ammonia refers to the ammonium ion in water. The term total ammonia (TAN) is used to describe the sum of UIA and ammonium concentrations. This term can be expressed as "total ammonia-nitrogen" due to the slightly different relative molecular masses [8]. The equilibrium equation (1) is shown below [10, 11]:

$$NH_4^+ + H_2O \Leftrightarrow NH_3 + H_3O^+ \quad (1)$$

Ammonia is one of the main waste products excreted by fish during their normal metabolic processes. Ammonia in small amounts causes stress and gill damage. If fish are exposed to low levels of ammonia over time, they become susceptible to bacterial infections, poor growth, and low tolerance to routine handling [8-10]. Normally, the ammonia level in a pond or tanks should be zero. The presence of ammonia in these bodies of water may cause ecosystem imbalance [12].

However, only UIA is toxic to fish. The toxicity level of ammonia is critically dependent on pH and temperature [12]. The un-ionized form (NH_3) is more toxic than the ionized form (NH_4^+). Toxicity increases when pH increases because the concentration of H^+ is decreased. Based on (1), equilibrium must be maintained between the concentrations on the left and right sides of the equation, which must be the same. Therefore, more NH_4^+ is converted to NH_3 to compensate for the loss of H^+ concentration and to maintain equilibrium. Higher temperatures also favor the more toxic form because more energy is available for ammonia decomposition in water. A pH increase of one unit can cause UIA concentration to increase by nearly tenfold. On the other hand, a temperature increase of 5°C can result in a UIA increase of 40% to 50% [8].

UIA concentration in water can be measured by obtaining the temperature as well as the pH and ammonium concentrations of the water. UIA fraction f can be obtained using the equation (2) below:

$$f = \frac{1}{10^{(pKa-pH)}+1} \quad (2)$$

where pKa is the dissociation constant given by

$$pKa = 0.0901821 + \frac{2729.92}{T(in\ K)} \quad (3)$$

$$T(in\ K) = T(in\ °C) + 273.15 \quad (4)$$

The UIA fraction f is the ratio of UIA to the total ammonia in water. Only the ionized ammonia (NH_4^+) is detected in water because an ammonium sensor is used. Thus, a formula is used to calculate the UIA in mg/L, as shown below:

$$[NH_3] = \frac{f}{1-f}[NH_4^+] \quad (5)$$

where $[NH_4^+]$ = concentration of ammonium in mg/L, and
$[NH_3]$ = concentration of UIA in mg/L.

The equations (2-5) are used to calculate the concentration of UIA using data obtained from ammonium, pH and temperature sensor. These equations are programmed onto PSoC.

B. Related Research

There has been lot of work reported by various researchers in ammonia detection system for water quality monitoring. However, most systems are still required pre-chemical treatment before measurement. Some systems are:

The on-line nitrogen monitoring system developed by Davey et.al [6] used a procedure called Microdistillation Flow Analysis (MDFA). This procedure converts the dissolved compounds into volatile compounds which can be transferred and isolated into another solution for determination by conductivity. This procedure required reagent treatment prior to conduction detection. MDFA provided ammonia nitrogen data at a rate of 12 samples per hour with 2 % precision for samples containing ammonia.

Deep-Sea Probe Analyzer (DPA) is designed by SYSTEA [13] to perform measurement of four common nutrient parameters namely, dissolved orthophosphate, ammonia, nitrite and nitrate. This probe consists of two identical PVC cylinders (diameter 140 mm, height 785 mm), of which one is the analytical and the other the reagent container. Ammonia is flourometricaly detected at 370/420 nm (excitation/detection) by using spectrophotometric optoelectronics.

The fiber optic sensing system designed and developed by Pisco et.al [14] for detection of ammonia in aqueous ambient at room temperature. The optical fiber has dual role of sensor and data transportation system. It is small in diameter, light, able to measure simultaneously several parameters, resistant to corrosion and fatigue, and capable of high-bandwidth operation.

The new Multi-spectral Water Quality Analyzer based on MSP430 designed and developed by Liqing et.al [15] for detection of ammonia nitrogen in water. This water quality analyzer is designed based on spectral analysis of the water body compounds. Nessler's reagent is required to pre-treat the sample before measurement.

The water quality system/analyzer developed by Davey et.al [6] and Liqing et.al [15] required pre-chemical treatment prior to measurement. However, we developed a water quality system that does not require any pre-chemical treatment. This system has fewer hazards and no toxic chemical handling required. Despite the DPA designed by SYSTEA [13] can perform measurement of four parameters, the analyzer is bulky. Our system is less bulky in comparison with DPA. The fiber optic sensing system designed and developed by Pisco et.al [14] is small in diameter and light but it can only detect ammonia at room temperature. Our system can work at temperature between -50°C and 50°C which give a higher flexibility when measuring ammonia in different aqueous environment temperature. Furthermore, our system does not required user knowledge and skill of handling chemical. The used of PSoC as microcontroller greatly simplify the circuit. Thus, the system takes up little space.

III. METHODOLOGY

A. *Calibration on Elit's and Global Water's sensors*

Each sensor is calibrated with its own standard buffer solutions based on its own manual calibration procedures. The sensors are immersed in its own standard buffer solution for a few minutes before the output voltage of the sensors are measured. The mathematical relationship between the measured parameter and the output voltage of the sensors are obtained by plotting the graph.

As shown in Figure 1, the relationship between the pH and output voltage of the sensor is linear. The equation obtained from the graph shown in Figure 1 is pH=3.683*voltage – 4.403. The relationship between temperature and output voltage of the sensor is also linear as shown in Figure 2. This relationship is described as temperature=25.86*voltage – 76.81. The relationship of dissolved oxygen in percentage and its sensor output voltage is linear. Figure 3 shows the linear relationship and the equation is dissolved oxygen in percentage = 29.33*voltage – 34.6. As shown in Figure 4, the relationship of logarithm ammonium concentration and output voltage sensor is a linear. The equation that represents the linear relationship is logarithm ammonium concentration = 57.64*voltage – 16.29. All these equations are written in C language and implemented on PSoC.

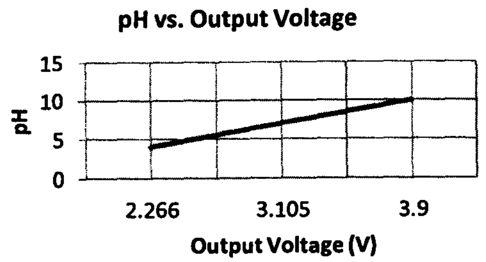

Figure 1: pH versus output voltage graph.

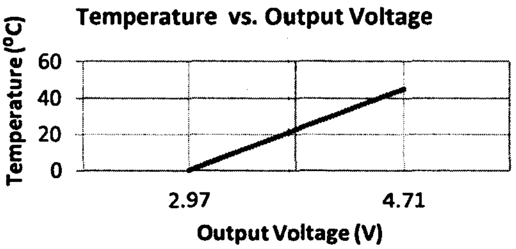

Figure 2: Temperature versus output voltage graph.

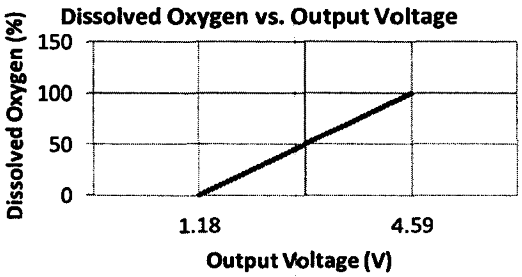

Figure 3: Dissolved oxygen in percentage versus output voltage graph.

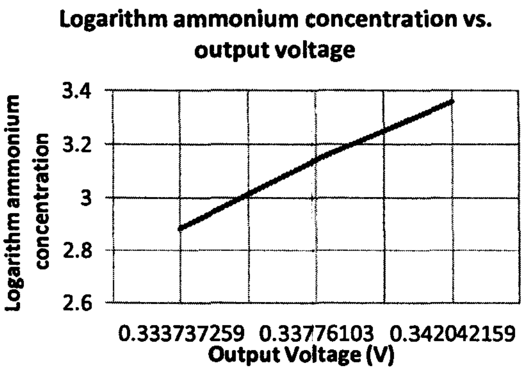

Figure 4: Logarithm ammonium concentration versus output voltage graph.

B. Development of the embedded system

The water quality monitoring system as shown in Figure 5 is a system that collects and processes data, and then sends the data to other systems such as a computer via serial communication. This system collects data from water quality sensors by continuously reading data from its inputs. The data are processed by converting the analog signal to digital signal. The microcontroller further processes the digital signal by executing the program. The processed data are then sent via its output port to other systems [16-18].

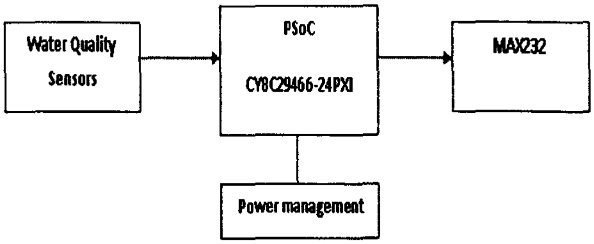

Figure 5. Block diagram of the UIA detection system

C. Test of ability

To determine whether the system can measure UIA or not, the system is put to an experiment with another instruments. This instrument is HACH's DR2800, which is used as a benchmark. It is a spectrophotometer instrument that can measure UIA. Fish food is used as the source of UIA. This instrument requires a chemical treatment first before the sample can be placed into the DR2800 for measurement. The Nessler Method is used to measure UIA.

The fish food is crushed and dissolved in 800 ml of distilled water. Ten samples are made with different amounts of fish food and a fixed amount of distilled water. The amounts of fish food used are 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0 g. Once a sample is made, 25 ml is taken from the sample to measure UIA using DR2800. Almost immediately, the rest of the sample is used by the system to measure UIA. When the results are obtained from the system and DR2800, the next sample is made and a measurement is taken again. The experiment starts from the lowest weight of fish food sample to the highest. Thirty readings are taken from the system and the average value is calculated. This average value is the UIA concentration.

After collecting the data from the system and from DR2800, hypothesis testing is conducted to determine whether the readings of the system and DR2800 are similar. Three series of tests are conducted, namely, normality test, variance check, and comparison of mean or median.

Data in the normality test are normally distributed with a 95% confidence level when the P-value is greater than 0.05. When data are normally distributed, Bartlett's test is conducted to compare whether the standard deviations of both data are similar or not. Levene's test is conducted when the data are not normally distributed. Again, the P-value must be greater than 0.05 for the standard deviations to be similar. If Bartlett's test is chosen, t-test is conducted to compare the means between the data from the system and DR2800. Otherwise, Mann-Whitney test is conducted to compare the median when the data are not normally distributed. The P-value of t-test and Mann-Whitney test must be more than 0.05 to conclude that the means or medians are similar between the data from the system and DR2800. The data obtained from the system and DR2800 are only regarded as similar when the standard deviations and means or medians are similar.

IV. Experiment Results

A. Results

Table 1. Data collected from measuring 10 samples of UIA using the system and DR2800

Fish food (g)	UIA concentration (ppm)	
	System	*DR2800*
0.5	1.068536691	0.984
1.0	1.631225025	1.848
1.5	2.188083173	2.112
2.0	2.93624152	3.12
2.5	3.318799496	3.696
3.0	3.986288502	4.428
3.5	4.671029494	5.124
4.0	5.491873371	5.94
4.5	5.629821355	6.024
5.0	4.815279175	5.736

Table 1 shows that the UIA increased as the mass of fish food increased. However, the UIA concentration is lower than expected for the 5.0 g sample. The ammonia nitrogen concentration is lower than expected because fish food is not fully dissolved in water. This happens because fish food is not crushed properly into fine small particles and the sample is not stirred long enough.

B. Hypothesis testing

Null hypothesis H_0: The data obtained from the system and DR2800 are similar.

Alternative hypothesis H_A: The data obtained from the system and DR2800 are different.

Normality tests are conducted using the Shapiro-Wilk W test to determine whether both data are normally distributed or not. Tables 2 and 3 show that both data are normally distributed with a 95% confidence level because the P-values are greater than 0.05. Since the data are normally distributed, Bartlett's test is conducted to determine whether the standard deviations are similar.

Table 2. Normality tests for UIA (system)

Test	Statistic	P-Value
Shapiro-Wilk W	0.9496	0.648139

Table 3. Normality tests for UIA (DR2800)

Test	Statistic	P-Value
Shapiro-Wilk W	0.925784	0.39231

In Table 4, the Bartlett's test shows that the P-value is greater than 0.05. Hence, the standard deviations of both data are similar at a 95% confidence level. The next test compares the means of both data. Equal variance t-test is conducted because the data have equal standard deviations or variances.

Table 4. Variance check for Bartlett's test

	Test	P-Value
Bartlett's	1.00892	0.697141

As shown in Figure 6, the means of both data are similar with a 95% confidence level because the P-value is more than 0.05. In this t-test, mean1 is the mean of data obtained from DR2800 and mean2 is the mean of data obtained from the system. Based on the analysis, the data obtained from the system and DR2800 are normally distributed with similar means and standard deviations. Hence, the null hypothesis is accepted.

```
Comparison of Means
95.0% confidence interval for mean of NH3
(DR2800) in ppm: 3.9012 +/- 1.31434   [2.58686,
5.21554]
95.0% confidence interval for mean of NH3 (System)
in ppm: 3.57372 +/- 1.15011   [2.42361, 4.72382]
95.0% confidence interval for the difference between
the means
  assuming equal variances: 0.327483 +/- 1.62201   [-
1.29453, 1.94949]

t test to compare means
  Null hypothesis: mean1 = mean2
  Alt. hypothesis: mean1 NE mean2
    assuming equal variances: t = 0.424176   P-value
= 0.676463
  Do not reject the null hypothesis for alpha = 0.05.
```

Figure 6. Comparison results of means using t-test for data from the system and DR2800.

V. Conclusion and Further Work

The UIA detection system for water quality monitoring application can measure UIA with a 95% confidence level.

One limitation of the system is the amount of used power. For example, the sensors of Global Water use a minimum of 10 V for normal operation, which limits the system for outdoor use because power outlets are not available in remote locations unless powered by battery. However, batteries have a limited amount of power, which soon run out soon if not replaced. If the system is equipped with solar panels, the battery can be recharged during daytime while this new system switches to another battery source. This allows the new system to be used for months at a remote location. The new system can detect low battery power, safely switch to a new power source, and recharge the low battery power using solar panels.

The new improvement of the system is the wireless communication system using Zigbee which can cover a wide area [19]. This improvement makes the system practical in large area of fish farming facilities. Besides, the used of Zigbee can avoid connecting hundred meters of cable to a master data acquisition system which is not cheap and practical. Signal loss is a big problem in RS232 for long-distance wired communication.

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029

HARDWARE DEVELOPMENT OF WATER QUALITY MONITORING SYSTEM FOR AQUACULTURE APPLICATION

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ABSTRACT

This paper discuss about the hardware development of water quality monitoring system for aquaculture application. The system consists of 4 waterproof sensors, which are dissolved oxygen sensor, pH sensor, temperature sensor and water level sensor. Microcontroller with 12 bit ADC is used to collect data from the sensors. Data are transferred to the computer by using RS232 communication standard and visualized in Microsoft Excel for further analysis. The readings from the developed system are compared with the readings from commercialized water quality portable meter. Results show that the reading from the developed system is comparable to the existing water quality portable meter were discussed.

Keywords: *Monitoring system, Programmable system on chip, water quality parameter.*

INTRODUCTION

The Development of water quality monitoring system was discussed. The monitoring system consists of 4 water quality sensors such as temperature sensor, pH sensor, Dissolved oxygen sensor and water level sensor. These parameters are very imperative to determine the level of water quality for fish farming especially. The level of water quality for breeding the baby fish is very strict. Thus, an efficient monitoring system should be developed to help fish farmers. Monitoring the water quality by using fresh water test kit is not an efficient way because the result is not accurate. Others, it takes a long time about 5 to 15 minute to get the result because the water sample needs to be treated with reagent first. Normally, the fish tank water sample is cloudy. Thus, the water sample need to be filtered first and this process will take about 30 minutes [1]. Another way to monitor the water quality is by using water quality portable meter. This way is better than fresh water test kit. However, this way is not practical for large scale fish farming since it required workers to operate the portable meter. Thus, an efficient continuous monitoring system should be developed to settle the problem. The continuous monitoring system does not need any worker to do water quality monitoring. The data in each fish tank such as temperature, pH, quantity of dissolved oxygen and water level will be sent to the database in the computer automatically. The water temperature is considered to be one of the most important factors in aquatic environment because it affects all metabolic, physiological activities and life processes of different tropic levels of pond ecosystem. In addition, it also affects the speed of chemical changes in soil and water [2]. Water temperature plays an important role in influencing the periodicity, occurrence and abundance of phytoplankton as it had a direct relationship with total plankton [3]. Fishes are cold-blooded animal and dependent upon the water temperature in which they live. Every fish species has an ideal temperature range within which it grows quickly. The optimum temperature range for 'cold water' and 'warm water' fishes are 14-18°C and 24-30°C respectively. Dissolved oxygen is one of the most important chemical parameters in aquaculture. Low dissolved oxygen levels are responsible for fish kills, either directly or indirectly. The concentration of dissolved oxygen in natural water is influenced by the relative rates of diffusion to and from the atmosphere, photosynthesis by aquatic plants and respiration by aquatic biological community [4]. pH is a measure of hydrogen ion concentration in water is acidic or basic. It has direct effects on fish growth and survival of food organisms. Hence, to achieve good fish production pH of the water should be monitored regularly to ensure its optimum range of 6.5-8.5 [5]. The depth of water in the fish tank also been considered as an important factor in breeding the fish especially in equatorial climate country. The depth of water depends on the age of fish. In hot season, the water in the fish tank can be decreased quickly by evaporating process. The lack of water can make the fish become stress. The stress can retard the growth of fish [6]. This paper will discuss on the hardware development of water quality monitoring system that

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consists of ph sensor, temperature sensor, dissolve oxygen sensor and water level sensor. This system is useful for continuous monitoring to ensure that fish can grow in a good habitat and fish farmer can get optimum yield from fish farming. The reliability of the system also will be discussed to ensure that the system is comparable to the existing commercialized water quality monitoring test kit.

MATERIALS AND METHODS

PROPOSED SYSTEM

Four water proof electrode shaped sensors which are Dissolved Oxygen sensor (WQ401), pH sensor (WQ201), temperature sensor (WQ101) and water level sensor (WL400) from Global Water Instrumentation are used. Below is the block diagram to show that how the sensors are connected to the proposed system.

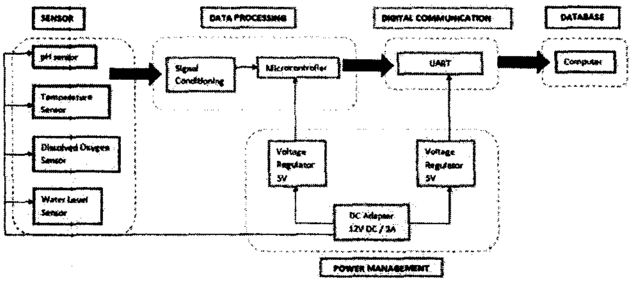

Figure 1: Block diagram of the proposed system.

TEMPERATURE SENSOR

The output of the temperature sensor is from 4mA to 19mA. The sensor is capable to detect the temperature from -50 °C to 50 °C. The accuracy of the sensor is ± 0.1 °C. The sensor must be operated by DC voltage in the range of 10V to 36V. The current drawn by the sensor is same as the sensor output. The warm up time for the sensor is 5 seconds minimum before the sensor can give out steady output. The sensor can be operated in the temperature from -50 °C to +100°C. The size of the probe is ¾" diameter and 4 ½" long. The weight is ½ lb. The sensor is a two-wire sensor using the red wire for power and the black for the output signal [7]. Temperature calibration requires at least two points, namely, cold temperature and warm temperature. More point will give better calibration result. Ice bath and warm water are used as calibration solutions, whereas digital thermometer is used as a calibration tool to measure temperature. The relationship between the voltage and the temperature is obtained by plotting the graph [8]. The relationship between the temperature and voltage is as below:

$$\text{Temperature } (^\circ C) = (42.69 * \text{voltage}) - 146.1 \quad (1)$$

PH SENSOR

The output of the pH sensor is in the current form which range from 4mA to 19mA. The sensor can detect the pH of the solution whether it is acidic, neutral or basic in the range between 0 pH and 14 pH. The accuracy of the sensor is 2% of full scale. The sensor can be operated by DC voltage from 10V to 36V. The current drawn by the sensor is 16.6mA plus the sensor output. The required warm up time is 3 seconds minimum. The allowable operating temperature for the sensor is between -5 °C and +55 °C. The size of the probe is 1 ¼" diameter and 10" long. The weight is 1 lb. The sensor has 3 wires. The red wire for positive voltage, the white wire for the output signal and the black wire for ground [7]. The pH calibration process requires pure buffer solution. At least three buffer solutions are required, namely, acidic, neutral, and alkaline. In the present project, seven buffer solutions are used, ranging from 4.01 to 10.01.The relationship between pH and voltage is obtained by plotting the graph [8]. The relationship of the pH to the voltage is as below:

$$\text{pH} = (4.505 * \text{voltage}) - 6.698 \quad (2)$$

DISSOLVED OXYGEN SENSOR

The output of the Dissolved Oxygen sensor is between 4mA and 19mA. The range of detection is between 0% and 100% of dissolved oxygen. The accuracy of the sensor is between ± 0.5% of full scale. The operating voltage is between 10V and 36V DC voltage. The current drawn by the sensor is 11.8mA plus the sensor output. The minimum warm up time is 10 seconds. The sensor can be operated in temperature between -40 °C and +55 °C. The diameter of the probe is 1 ¼" and the long of the probe is 11". The weight of the probe is 1 lb. The dissolved oxygen sensor is a three-wire sensor. The red wire is used for positive voltage, the white wire for the

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output signal and the black wire for ground [7]. The Dissolved Oxygen Calibration process requires at least two solutions, with one solution containing 0% oxygen, and another containing 100% oxygen. For this calibration process, we used the 0%-oxygen solution as a minimum point of calibration, and 99.8% gas oxygen will be pump into the tap water as a maximum point of calibration. The relationship between percentage of dissolved oxygen and voltage is obtained by plotting the graph [8]. The relationship of the percentage of dissolved oxygen and the voltage is as below:

$$\text{Dissolved Oxygen (\%)} = (38.92*\text{voltage}) - 38.88 \quad (3)$$

WATER LEVEL SENSOR

The output of the water level sensor is in the current form which range from 4mA to 19mA. The sensor is capable to detect the depth of water up to 3 feet maximum. The accuracy of the sensor is ±0.1% of full scale at constant temperature and ±0.2% over 32° to 70°F range. The sensor can be operated by DC voltage from 10V to 36V. The current drawn by the sensor is same as sensor output. The recommended warm up time is 3 seconds minimum. The allowable operating temperature for the sensor is between 0 ° (Not frozen) and +185 °F. The size of the probe is 0.82" diameter and 7.5" long. The weight is 110g. The sensor has 2 wires. The power wire (red wire) must be connected to positive supply terminal of the data logger or of the battery. The 4-20mA signal wire (black wire) is connected to the data logger's input terminal [7]. The water level calibration process requires a column of water. The closer to the depth of the maximum range of the sensor which is 3 feet, the better the calibration will be. The sensor was placed into the column of water. Then, the depth of the sensor which is the distance from the tip of the sensor to the top of the column of water was recorded. The current drawn by the sensor also must be recorded. The voltage signal is obtained by connecting the output signal wire to the shunt 260Ω resistor. The relationship between water level and the voltage is as below:

$$\text{Water Level (inches)} = (9.584*\text{voltage}) - 9.283 \quad (4)$$

SIGNAL CONDITIONING

The signal conditioning is a stage to condition the output from the sensor so that the output can be read by the Analog to Digital Converter (ADC) and can be well processed by the microcontroller [9]. The water quality sensor from Global Water Instrumentation such as temperature sensor, pH sensor, Dissolved Oxygen sensor and Water Level sensor produce output in the form of current ranging from 4mA to 19mA. 4mA to 19mA is an industrial standard signal for process control monitoring [7]. For this project, the ADC only accept output from the sensor in the form of voltage between 0V to 5V. Hence, Sensor output must be converted to a voltage signal by reading the voltage across a precision resistor in series with the signal wire. The output is 1.04–4.94 volts DC because Ohm's Law states that V=IR, particularly if the 4–19 mA signal is dropped across a 260 ohm resistor.

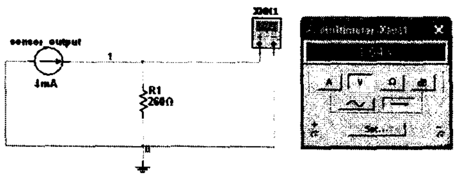

Figure 2: Minimum output signal from sensor across shunt resistor

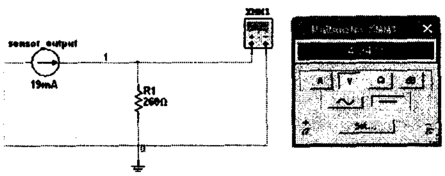

Figure 3: Maximum output signal from sensor across shunt resistor

MICROCONTROLLER AND FIRMWARE

In this project, microcontroller from Cypress, CY8C29466-24PXI (PSOC-Programmable System on Chip) is used. The microcontroller is responsible for getting data from the 12 bit ADC (Analog to Digital Converter) and for sending the data to the computer through UART (Universal Asynchronous Receiver/Transmitter). The microcontroller contains 12 analog modules and 16 digital blocks. The size of flash memory is 32kbyte and the size of RAM is 2kbyte [10]. These sizes of memory are enough to run this monitoring application.

Firmware is a source code to command the microcontroller on what the microcontroller should do. All the user modules which are utilized in this project such as UART, PGA (Programmable Gain Amplifier), ADC and LCD (Liquid Crystal Display) must be initialized first before the modules can be used. Global Interrupts must be enabled so that the certain parameter of ADC and UART module in Global Resource can be turned on. When the ADC is turned on, the ADC will always waits for any data to be sampled. When the ADC gets the data, the ADC will read the result and clear the flag and then waiting for the next data again. Then, the raw data will be converted into the real value by using the formula obtained from the calibration above. Finally, the real value of temperature, pH, Dissolved oxygen and water level will be displayed on LCD and hyper terminal via UART. This process will run continuously as the microcontroller is turned on.

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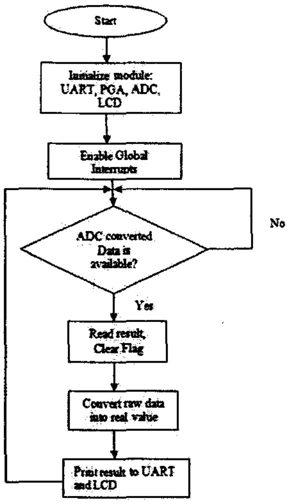

Figure 4: Flowchart of the source code.

SYSTEM RESOLUTION

Resolution is one of the important criteria in designing the monitoring system. It shows the smallest change that the designed system can measure. The number of bits of ADC will determine the system resolution. The higher the resolution of ADC, the smaller the changes that can be detected by the system [9].The resolution can be expressed as below [11]:

$$\text{Resolution} = \frac{V_D}{V_S * 2^{(n-B)}} * E \qquad (5)$$

Where

V_D = Full Scale Voltage of the ADC

V_S = Full Scale Voltage of the signal from the sensor

E = Maximum unit parameter can be measured by the sensor

n = ADC resolution

B = Polarity of the ADC. Set B=1 is for bipolar, and B=0 for unipolar.

The system ADC has a unipolar of 5V full-scale range and 12 bit ADC resolution. The step size of the ADC is 1.22 mV per bit. Output of temperature sensor, ph sensor, dissolve oxygen sensor and water level sensor are from 4mA until 19mA. The 260Ω of shunt resistor is connected to 12 bit ADC with 5V full scale unipolar range. By using ohm law, the voltage across the shunt resistor will range from 1.04V until 4.94V. This voltage is considered as input voltage to the ADC. By using the above equation, resolution for each sensor can be calculated. The temperature sensor can detect temperature between –50°C until 50°C. Hence the resolution of the temperature sensor is 0.03°C. The pH sensor can detect pH from 0 until 14. By substituting the value in the equation above, the resolution for pH sensor is 0.004. Same as dissolve oxygen sensor where it can detect the percentage of dissolve oxygen from 0% until 100%. The resolution of the dissolve oxygen sensor is 0.03%. For water level sensor that can detect from 0 until 36 inch depth, the resolution of the sensor is 0.01 inch. The system cannot measure any changes that are smaller than the resolution value.

RESULTS AND DISCUSSIONS

DATA RELIABILITY TEST

The data reliability test is very important to ensure the data measured by the system is accurate and reliable. The data reliability test can be achieved by analyzing the differences between the data displayed by the system and the several established meter in the market. The study was conducted by using Statistical Package for Social Science software (SPSS) to determine whether the difference is significance or not. The significance difference indicates that there is a difference among the data displayed by the system and several established meter while not significance difference indicates that the data displayed by the system is almost same with the established meter [12]. The data is compared at 95% confidence interval.

TEMPERATURE SENSOR DATA

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The temperature data displayed by the designed system is compared with 2 digital thermometer which are brand Hanna and brand Eutech. The Hanna HI 98150 portable digital thermometer is capable to detect the temperature from -20.0°C to 120.0°C. The resolution is 0.1°C and the accuracy is ±0.2°C at 20 °C (excluding probe error) [13]. The Eutech Instrument pH +5 is capable to detect temperature in a range from 0 °C to 100°C. The resolution is 0.1 °C and accuracy is ± 0.5 °C. The tap water will be the sample in this test. The temperature sensors from the designed system, thermometer Hanna and Eutech were immersed in a beaker of tap water. After the sensors and the both digital thermometer are stabile, the data are recorded as in the table below.

Table 1: Temperature of tap water

Tap water's Temperature in Degree Celcius (°C)			
NO.	SYSTEM	HANNA	EUTECH
1	30.5	30.6	30.6
2	30.5	30.5	30.4
3	30.5	30.4	30.3
4	30.5	30.3	30.2
5	30.4	30.3	30.1
M	30.5	30.4	30.3
SD	0.0447	0.1304	0.1924

From the test of normality, the data is normal and from the test of equal variance, the data is equal variance. Thus, Tukey HSD test is used to do multiple comparison tests for the 3 factor above which are the designed system, Eutech and Hanna [12]. From the result, there is no significance difference between the data displayed by the designed system and Eutech (p=0.195). There is no significance difference between the data displayed by the designed system and Hanna (p=0.771). There is no significance difference between the data displayed by the Hanna and Eutech (p=0.499). In simple words, the data displayed by the designed system is not much difference with the data displayed by digital temperature meter brand Hanna and Eutech.

PH SENSOR DATA

The data reliability of the pH sensor is determined by investigating the difference among the data displayed by the designed system with 2 digital pH meters which are brand Eutech and brand Adwa. The Hanna HI 98150 portable digital pH meter is capable to detect the pH from -4.0 to 20.0 pH. The resolution is 0.1pH and the accuracy is ±0.1pH [13]. The Eutech Instrument pH +5 is capable to detect pH in a range from 0 to 14. The resolution is 0.01 and accuracy is ± 0.01.The 10.01 pH buffer solutions will be sample for this test. The buffer solution is bought from Hanna Instrument with accuracy of ± 0.01. The buffer solution has calibration certificate which indicating the buffer solution has passed the calibration test. The pH sensor from the designed system, pH meter brand Hanna, and pH meter brand Eutech are immersed in a beaker of pH 10 buffer solution. After the sensors and the two digital pH meters are stabile, the data are recorded as in the table below.

Table 2: pH 10 buffer solution

pH 10 buffer solution			
NO	SYSTEM	EUTECH	HANNA
1	9.55	10.01	9.98
2	9.79	10.01	9.98
3	9.05	10.01	9.96
4	10.37	10.01	9.97
5	10.32	10.02	9.95
M	9.82	10.01	9.97
SD	0.5521	0.0045	0.0130

From the test of normality, the data is not normal and from the test of equal variance, the data is not equal variance. Thus, Tamhane test is used to do multiple comparison tests for the 3 factor above which are the designed system, Eutech and Hanna [12]. From the result, there is no significance difference between the data displayed by the designed system and Eutech (p=0.978). There is no significance difference between the data displayed by the designed system and Hanna (p=0.994). In simple words, the data displayed by the designed system is not much difference with the data displayed by digital pH meter brand Hanna and Eutech.

DISSOLVED OXYGEN SENSOR DATA

The data reliability of the dissolved oxygen sensor is determined by analyzing the difference among the data displayed by the system with 2 digital dissolved oxygen meters. The dissolved oxygen data displayed by the designed system is compared with 2 digital dissolved oxygen meter which are brand YSI 52 and brand YSI pro 20. YSI pro 20 dissolved oxygen meter capable to detect dissolved oxygen in the range between 0% to 500% air

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saturation. The accuracy is ± 2% of the reading or ±2% air saturation, whichever is greater. The resolution is 0.1% or 1% air saturation. The YSI 52 dissolved oxygen meter capable to detect dissolved in the range from 0% to 200% air saturation. The accuracy is ± 1.1% air saturation. The resolution is 0.1% air saturation [14].The tap water with aeration will be the sample in this test. The dissolved oxygen sensor from the designed system dissolved oxygen meter brand YSI 52 and dissolved oxygen meter brand YSI pro are immersed in a beaker of tap water with aeration. After the sensor and the both digital dissolved oxygen meters are stabile, the data are recorded as in the table below.

Table 3: Percentage of dissolved oxygen in a beaker of tap water with aeration

Dissolved Oxygen in Percentage (%)			
NO	SYSTEM	YSI 52	YSI pro 20
1	84.6	93.0	79.9
2	80.9	94.0	82.4
3	85.8	94.0	83.4
4	81.4	94.0	85.2
5	81.4	94.0	86.3
M	82.8	93.8	83.4
SD	2.2231	0.4472	2.4946

From the test of normality, the data is normal and from the test of equal variance, the data is not equal variance. Thus, Tamhane test is used to do multiple comparison test for the 3 factor above which are the designed system, YSI 52 and YSI pro [12]. From the result, there is no significance difference between the data displayed by the designed system and YSI pro 20 ($p=0.970$). There is significance difference between the data displayed by the designed system and YSI 52 ($p=0.001$). In simple words, the data displayed by the designed system is not much difference with the data displayed by dissolved oxygen meter brand YSI pro 20 but there is significant different with the data displayed by the dissolved oxygen meter brand YSI 52. However, there is significance difference between the data displayed by dissolved oxygen meter brand YSI 52 and brand YSI pro ($p=0.002$).

WATER LEVEL SENSOR DATA

The data reliability of the water level sensor is analyzed by investigating the percentage difference between the data displayed by the water level sensor and the actual depth of the water. The samples for this test are the depth of water in the 28.75 inches tong. The water level sensor was immersed in the 28.75 inches tong. After the water level sensor stabile, the data is recorded as in the table below.

Table 4: Sensor reading of water depth in 28.75 inches barrel

BARREL WITH 28.75 INCHES WATER DEPTH	
NO	SENSOR READING (INCHES)
1	28.75
2	28.64
3	28.59
4	28.54
5	28.51
M	28.61
SD	0.0945

The percentage difference between the depth of the barrel and the sensor reading is calculated by using the formula below.

Percentage Difference (%) = [(Actual Depth-Average Sensor reading)/ (Actual Depth)]* 100 (6)

Percentage Difference (%) = [(28.75-28.61)/ (28.75)]* 100
Percentage Difference (%) = 0.49%
The percentage difference is just 0.49%. Thus, the data displayed by the design system is almost accurate with the actual depth of the water.

SYSTEM IMPLEMENTATION

The developed monitoring system is implemented in the 2 tank at Aquatic Research Centre in University Sains Malaysia (USM) main campus. One tank contains fish and another tank has no fish. Thus, 2 set of monitoring system is set up at the 2 tank respectively. One computer as a database server is located in a laboratory. The

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sensors are immersed in the both tank. The both tank contain 1 ph sensor, 1 temperature sensor, 1 dissolved oxygen sensor and 1 water level sensor. The microcontroller send data every second but the data logger will display data every 1 minute. The both monitoring system are run continuously non-stop.The both tanks are same in size, volume and shape. The both tanks are rectangular in shape. The length is 9.25 feet, the width is 4.25 feet and the height is 3.28 feet. According to the fishery stocking density standard, 1 square feet can accommodate comfortably for 9 fishes. Thus, this fish tank can accommodate comfortably for 353 fishes. However, for this project, only 173 fishes are put into the tank. The project started by putting 173 baby catfishes into the tank. The average weight of the baby catfishes is around 17.24g each. The fishes are fed with the fish pallet. The quantity of the fish pallet given to the fish everyday is equal to 5% of the fish's average body weight. The fish will be cultured in the tank until the average body weight reach 167g each. This is the standard market size for the catfish which is 1 kg contain 6 fishes. Another tank which has no fish is filled up with the tap water. The both tank has no aeration and no water change.

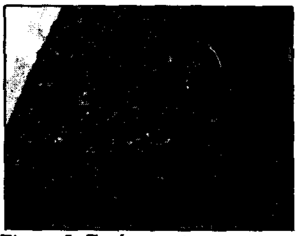

Figure 5: Tank contain sensors and catfishes

Figure 6: Tank contain sensors and no fish

The designed monitoring system has been implemented since 1 August 2011 until in the end of November. The system has been implemented in the 2 fish tank which one tank has catfishes and another one only contain water. The data for both tanks is collected every 1 minute continuously non-stop within 4 months. The objective of the system implementation is to see the robustness of the system in the tropical weather which is sometime hot and sometime damp. During the operation of the system in the fish tanks, there is no major problem occurred. The data can be received by the database safely and displayed in the data logger without any error. Even thought the Aquatic Research Centre always black out, the designed system do not experience any serious problem in term of short circuit, hot power regulator or malfunction of the sensor and the electronic circuit. Furthermore, the designed system no needs to recalibrate after the system is restarted due to black out during this 4 months of operation. This is better than the portable meter which need user to recalibrate every time to do measurement of the sample in order to get accurate readings. The water quality graphs of the both tanks are plotted over time in a day as below.

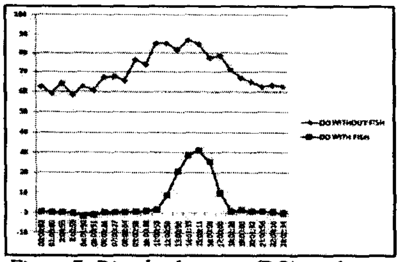

Figure 7: Dissolved oxygen (DO) reading in percentage (%) for both tanks in a day

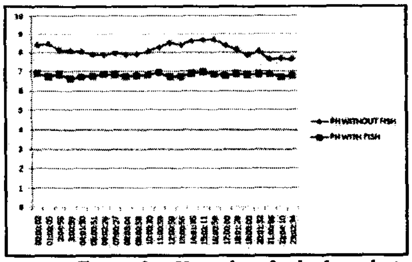

Figure 8: pH reading for both ranks in a day

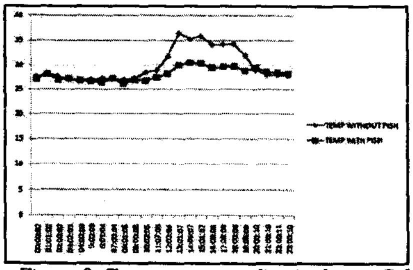

Figure 9: Temperature reading in degree Celcius (° C) for

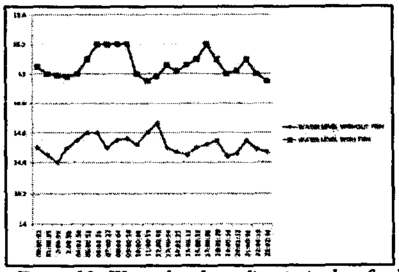

Figure10: Water level reading in inches for both tanks in a

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both tanks in a day	day.

CONCLUSIONS

Four waterproof sensors were successfully integrated in a system to monitor water quality parameters, namely, temperature, pH, water level and dissolved oxygen. From the data reliability test, the data measured by the designed monitoring system is reliable and almost accurate with the established portable meter in the market. Thus, the designed continuous monitoring system can replace the traditional techniques of measuring water quality which are by using water quality test kit or by using water quality portable meter since the traditional techniques have many drawbacks. The system can be applied in the field to help fish farmers collect data continuously and remotely. Continuous monitoring of water quality is critically important to fish farmers to ensure that their fish live in a good habitat.

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Low-Dropout Regulator in an Active RFID System Using Zigbee Standard with Non-beacon Mode

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Abstract. The use of the low-dropout (LDO) voltage regulator in reducing current consumption in the active tag RFID system using the ZigBee standard was studied. The tag was set with a cyclic mode configuration with non-beacon data transmission mode, and was programmed to sleep for 1.5 s and wake up for 5 s to check for signals coming from the reader. The LDO voltage regulator from the TPS7800 series with ultra-low quiescent current was used in the experiments. Two sets of experiments were conducted using tags with and without LDO voltage regulators, respectively. The current consumed by the active tag was measured, and the results showed that the current consumption was reduced to 32% if the LDO was used to regulate the input voltage from 3 V to 2.2 V. The current consumption remained stable although the voltage source dropped from 3 to 1.8 V. The transmission range also increased when the LDO was adopted in the system.

Keywords: Low-dropout regulator (LDO), Active RFID tag, ZigBee.

1 Introduction

ZigBee is designed for low power consumption, low cost, and various wireless networking applications [1]. In addition, it provides wireless personal area network (WPAN) in the form of digital radio connections between computers and related devices. It is applicable in home automation, smart energy telecommunication, and personal and home application. ZigBee builds on the IEEE 802.15.4 standard, which details the physical layer and MAC layer for low cost and low data rate for the personal area network. The physical layer supports three bands, namely, 2.45 GHz, 915 MHz, and 868 MHz. A total of 16 channels are available in the 2.45 GHz band, 10 channels in the 915 MHz band, and a single channel in the 868 MHz band. All the channels in the frequency range use the direct-sequence spread spectrum (DSSS) access mode. The physical layer supports on/off operation, functionalities for channel selection, link quality estimation, energy detection measurement, and clear channel assessment.

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The MAC layer provides two types of nodes, namely, the reduced function devices (RFDs) and the full function devices (FFDs). Normally, the RFD is integrated with the sensors or actuators such as light switches, temperature sensors, and lamps. The FFD is used as a coordinator or a network end device, whereas the RFD is used only as an end device.

Star topology and peer-to-peer topology are the two types of networks supported by IEEE 802.15.4. The working concept of star topology is similar to a master-slave network concept. The FFD has the role of a PAN (Personal Area Network) coordinator. The other nodes can be RFD or FFD and can only communicate with the PAN coordinator. In peer-to-peer topology, the FFD communicates with the other FFDs through an intermediate FFD, thus allowing communication outside of its radio coverage area. The communication now forms a multi-hop network, and the PAN coordinator administers the network operation.

The PAN coordinator operates the network with a super-frame (beacon) or without a super-frame (non-beacon) [2]. In communication without super-frame (non-beacon), the PAN never sends beacons, and communication occurs based on the unslotted CSMA-CA. The end device periodically wakes up and polls coordinator for any pending message. The coordinator is always on and ready to receive data. Once it receives a signal from the end device, the coordinator sends the messages or signals that no message is available.

Radio frequency identification (RFID) is a telecommunication application, which uses ZigBee technology [3]. Specifically, it can be utilized in asset inventory, in which star topology with non-beacon mode can be applied. For instance, when the reader sends a command to all tags, the tags should respond immediately once they receive the signal. A missing response indicates that the tag or asset is unavailable. A movement sensor can be integrated with the tag as well. The movement of the tag or the asset can generate a stimulus triggering the tag to immediately send a signal to the reader. The reader then sounds an alarm to notify that the asset has moved to another place.

In asset inventory, low power consumption and longer battery lifetime are important factors that ensure battery life efficiency, thus delaying battery replacement. One of the methods to reduce power consumption is to put the tag in the sleep mode when there is no communication activity. In the sleep mode, the current consumption is only a few microamperes, but in idle mode, the current consumption can reach a few miliamperes. Another method to reduce power consumption is the use of a low dropout (LDO) voltage regulator, which minimizes the output saturation of the pass transistor and its drive requirements [4].

This paper discusses the use of the LDO TPS7800 series with ultra-low quiescent current in an active RFID system to reduce power consumption. In addition, the effect on the transmission range was investigated. The tag was programmed in the cyclic non-beacon mode, and two sets of experiments were performed to observe the significance of the LDO in the RFID system. The first experiment was conducted without the LDO, while the second experiment was with the LDO. The current was measured in both experiments, and analyses were based on the current consumption and transmission range in both experiments.

2 Hardware Development

The two main components of an active RFID system are the tag and the reader [5]. Basically, the reader contains a module consisting of a transmitter, a receiver, a control unit, and a coupling element of the antenna. Fig. 1 shows a block diagram of the reader, which consists of a ZigBee module (Xbee module), a single LED indicator, a reset button, and a voltage regulator. The Xbee module operates at 2.45 GHz with a data rate of 250 kbps. The working voltage of the module was between 1.6 V and 3.3 V. The Max3232 converts at the data level between the Zigbee module and the host (PC). A voltage regulator (LM1117) was used to regulate the input voltage from 9 to 3.3 V. The LED indicator demonstrated the status of the reader and a button was used to reset the reader.

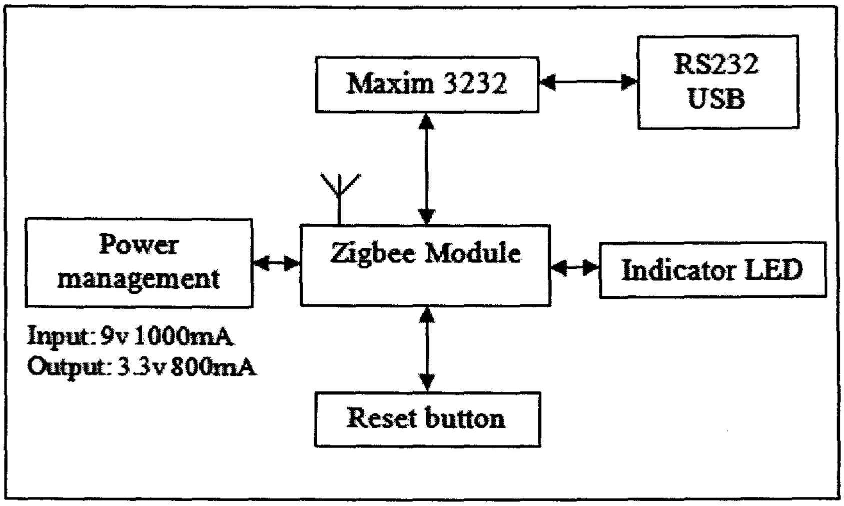

Fig. 1. Block diagram of the reader

The reader has its own channel to communicate with the tags. It searches for its channel continuously if the channel is in conflict with other readers [6]. In one system, the tag's address must be the same as that of the reader. The identity of the tag can be programmed until 20 characters, implying that every system can consist of up to 1,048,576 tags. The tags respond to the reader when they are in the coverage zone, depending on the output power levels of the reader.

Fig 2 shows the block diagram of an RFID tag using periodic data communication. The tag consisted of a power management circuit and a ZigBee module. The tag was programmed with a cyclic mode configuration, during which the tag slept for 1.5 s and woke up for 5 s to check whether or not there was a signal from the reader. The tag responded if there was a signal from the reader; it resumed its sleep mode if there was no signal from the reader after 5 s.

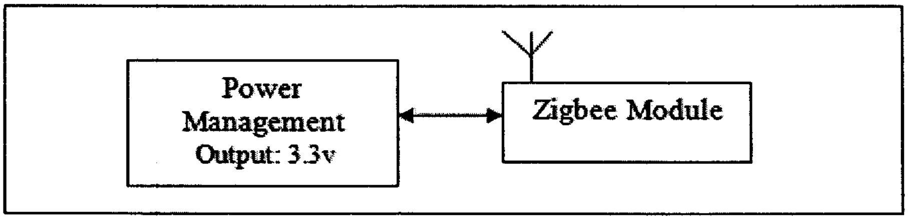

Fig. 2. Block diagram of the RFID tag using periodic data communication

Fig. 3 shows the block diagram of the tag with the LDO device. The tag was programmed under sleep mode configuration. The LDO, which was connected to a power source, was used to minimize current consumption. The output voltage of the LDO was used to supply power constantly to the ZigBee module.

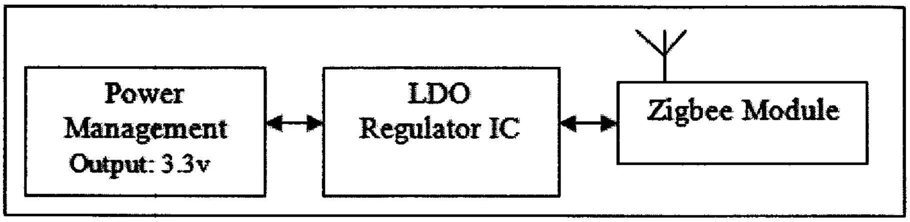

Fig. 3. Block diagram of combination of the LDO and the tag using periodic data communication

Fig. 4 shows the circuit, which controls the output voltage of the LDO. Input and output capacitors were used to stabilize the circuit and were connected to the ground. A feedback pin was used to adjust the output voltage of the LDO, with feedback voltage at 1.216 V. The output voltage varied from 1.2 V to 5.1 V. The output voltage of the LDO was calculated using Equation 1.

$$V_{out} = V_{fb}\left(\frac{R_1}{R_2} + 1\right). \tag{1}$$

The values of R1 and R2 should be chosen in order to get approximately 1.2 μA current divider. The recommended value of R2 is 1MΩ. Using Eq. 1, R1 can be calculated as follows:

$$R_1 = \left(\frac{V_{out}}{V_{fb}} - 1\right) \times R_2. \tag{2}$$

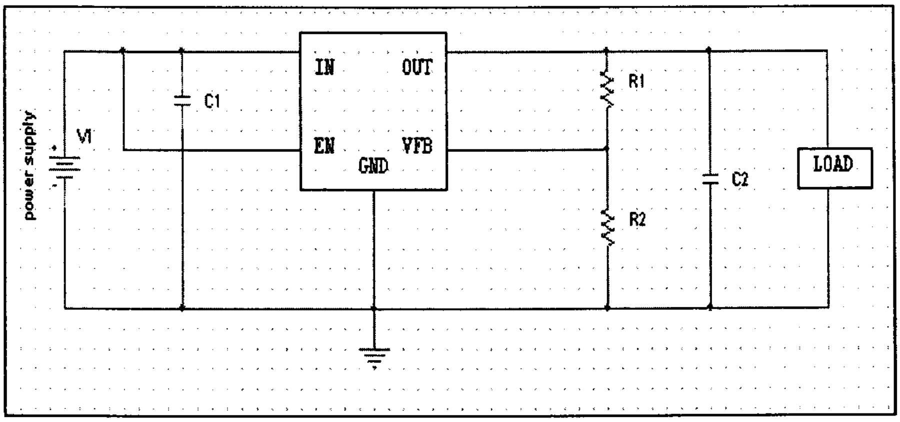

Fig. 4. Block diagram of the LDO circuit

3 Experimental Setup

The first experiment determined the current consumed by the tag at different voltage levels without LDO. The current was measured directly from the source, as shown in Fig. 5.

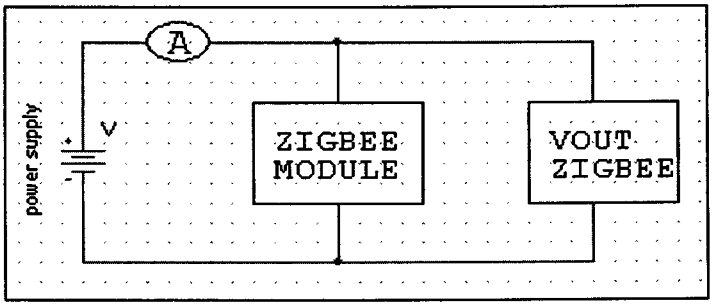

Fig. 5. Experimental setup for tag periodic data communication without LDO

The voltage varied from 1.8 V to 3.3 V. In the experiment, the reader sent a command to the tag; when the tag received the signal, it responded to the reader by sending message "Tag 1," and the message was displayed on the PC.

The second experiment was carried out with LDO. The output voltage of the LDO was set to different values ranging from 1.8 V to 3.3V. The currents consumed by the circuit at these different voltage values were measured. The tag used input voltage from the LDO. Similar to the first experiment, the reader sent a command to the tag; when the tag received the signal, it sent a message of "Tag 2" to the PC. The experiment is shown in Fig 6.

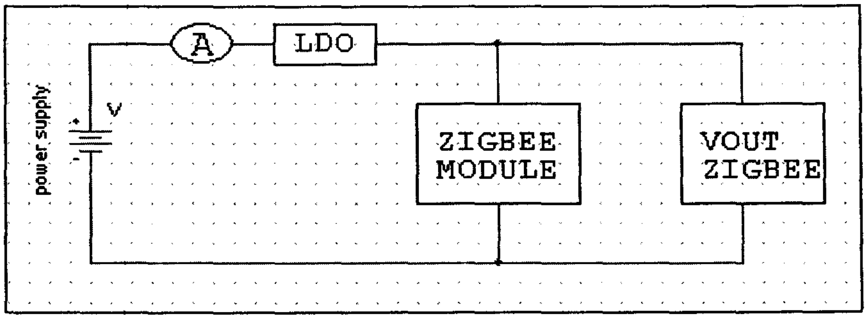

Fig. 6. Experimental setup for tag periodic data with LDO

4 Results and Discussion

In the experiment, an association pin checked whether or not the tag was ready for communication. After a wake up, the tag began to find a channel to communicate with the reader. After acquiring the channel, the tag was associated to the network and was considered ready to transmit or receive data. Fig. 7 shows the voltage signal at the associated indicator pin, where the tag is in sleep mode for 1.5s (logic '0') and wake up for 5s (logic '1'). During the wake up period, it is ready to communicate with the reader for 5 s. After 5s, it goes back to sleep mode.

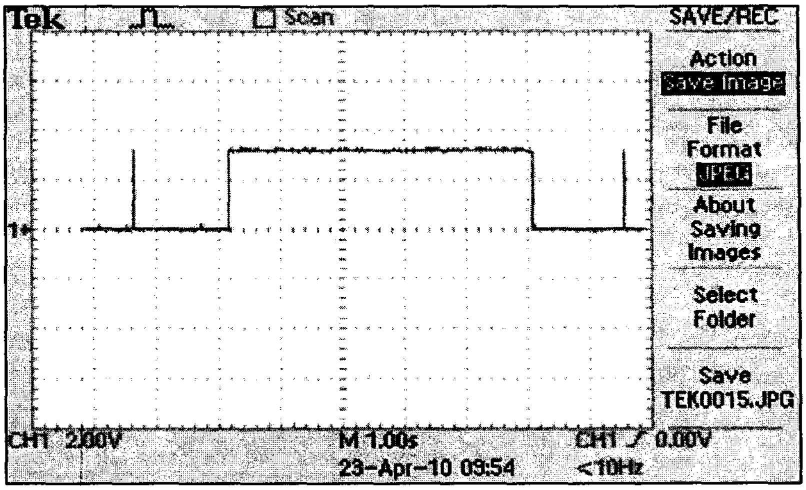

Fig. 7. Voltage signal at the associated indicator pin for the tag with periodic data communication

Table 1 shows the tabulated results for the experiment without LDO. The data show that when the input voltage increases, the current also increases. The lowest

Table 1. Current consumption versus output voltage

Voltage (V)	Current, I ($^{Tx}/_{Rx}$) (mA)
1.8	11.05055
2	11.6649
2.2	11.4328
2.4	13.11755
2.6	14.25075
2.8	15.20865
3	16.31115
3.2	16.87370
3.3	17.58765

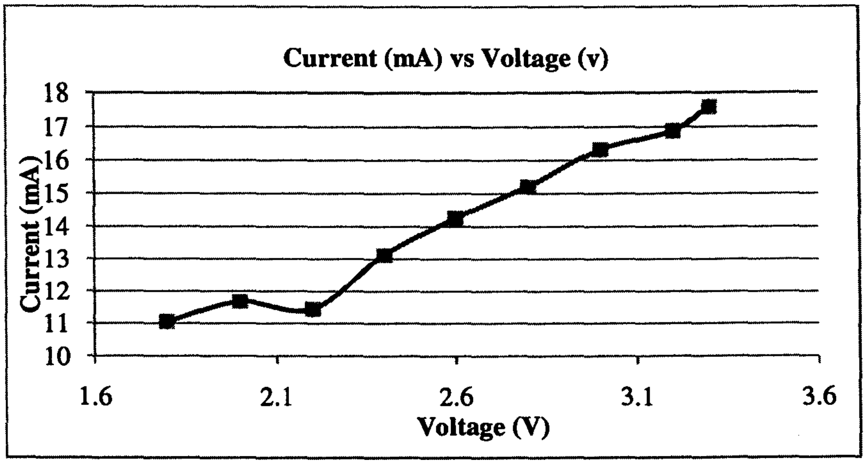

Fig. 8. Current consumption during transmit mode (without LDO)

input voltage to power up the circuit is 1.8 V. Fig. 8 shows the graph of the Current consumption during transmit mode (without LDO).

Table 2 shows the tabulated data for the experiment with LDO. Figure 9 shows the graph of the results.

Table 2. Current consumption versus output voltage

	Input Voltage								
V	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.3
(LDO) = 2.2v	11.5	11.8	12.0	11.5	11.8	12.1	12.4	12.0	12.2
(LDO) = 2.4v	11.0	11.1	12.6	12.5	12.9	13.0	12.2	12.8	12.4
(LDO) = 2.6v	11.3	11.4	12.4	13.1	13.5	13.8	13.8	13.9	13.9
(LDO) = 2.8v	11.5	11.6	12.4	12.9	13.8	14.3	14.7	14.6	15.4
(LDO) = 3.0v	11.2	11.4	12.4	12.8	14.4	15.2	15.9	16.3	15.6
(LDO) = 3.2v	11.0	11.9	12.0	12.1	14.2	15.5	16.4	17.2	16.7
(LDO) = 3.3v	11.7	11.4	12.2	12.7	14.4	15.7	15.9	17.0	17.7
Without LDO	11.1	11.7	11.4	13.1	14.3	15.2	16.3	16.9	17.6

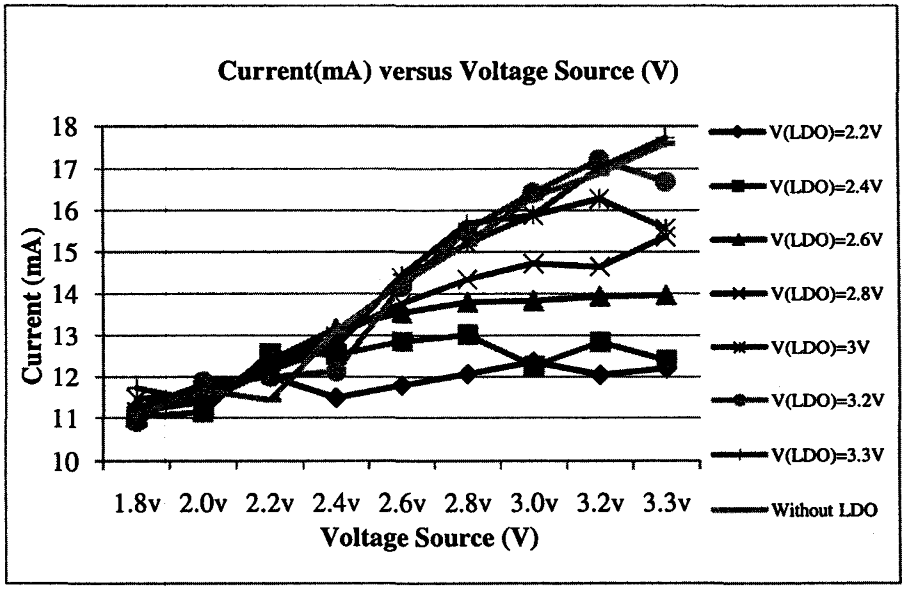

Fig. 9. Current consumption versus input voltage source at different values of output voltage from LDO

The graph shows that the current increases if the voltage source increases, especially at a higher output voltage from the LDO. However, the current is almost constant when the output voltage from LDO is set to 2.2 V. This is because 2.2 V is the optimum working voltage for this application. As shown in Fig. 10, the current of the tag with LDO is nine times more stable than the tag without LDO. Although the voltage source from the battery drops from 3.3 to 1.8 V, the current is still maintained at around 12 mA. The data also show that if the tag is using a 3 V battery, by using LDO, the current consumption can be reduced until 32%, which is quite significant in this application.

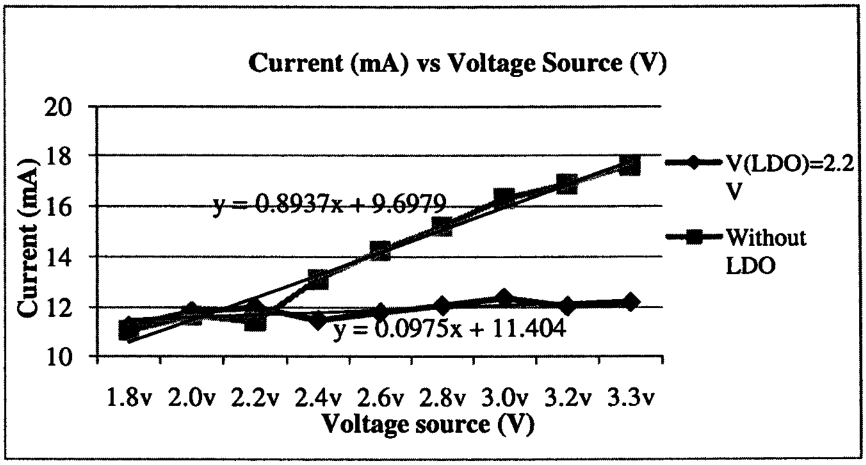

Fig. 10. The comparison between the currents of the tag with and without LDO

5 Transmission Range

Apart from measuring current, the experiments also measured the transmission range. This is done in order to see whether or not the LDO has influenced the transmission range. A different output voltage from the LDO was set, while the input voltage source was fixed at 3 V. The experiment was conducted in the lab, which established that the transmission range was in indoor range. The output power level of the tag was set to 3 dBm.

Fig. 11 shows that the maximum distance is 67.5 m, with an output voltage of 2.2 V from the LDO. The optimum working voltage for this application is 2.2 V, thus giving the longest distance for the transmission range.

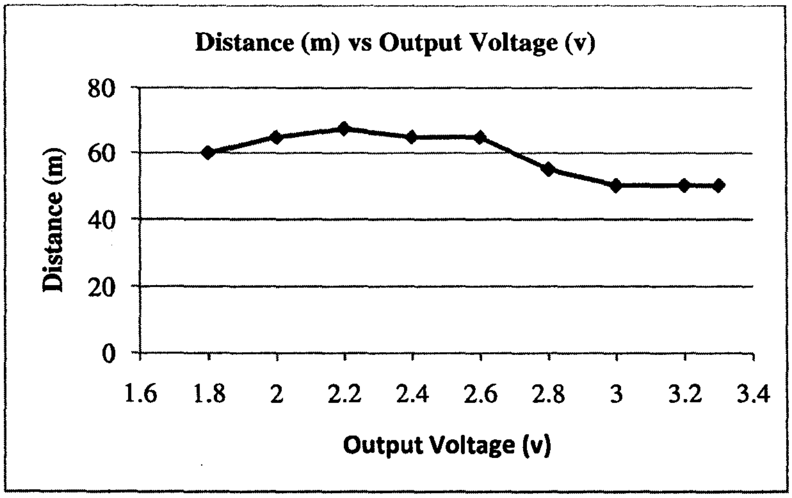

Fig. 11. Distance versus output voltage

In the experiment without LDO, the voltage source was supplied directly to the RFID tag. The input voltage was varied from 3.3 to 1.8 V. The experiment was conducted in a lab, and the output power level of the tag was set at 3dBm.

The results show that the maximum transmission range is 38.9 m, which is 42% shorter than the range of the tag with the LDO voltage regulator. The graph in Fig 12 shows that the transmission range is almost constant until the input voltage drops to 2.2 V, and the tag is unable to transmit any signal at the voltage level of 1.8 V.

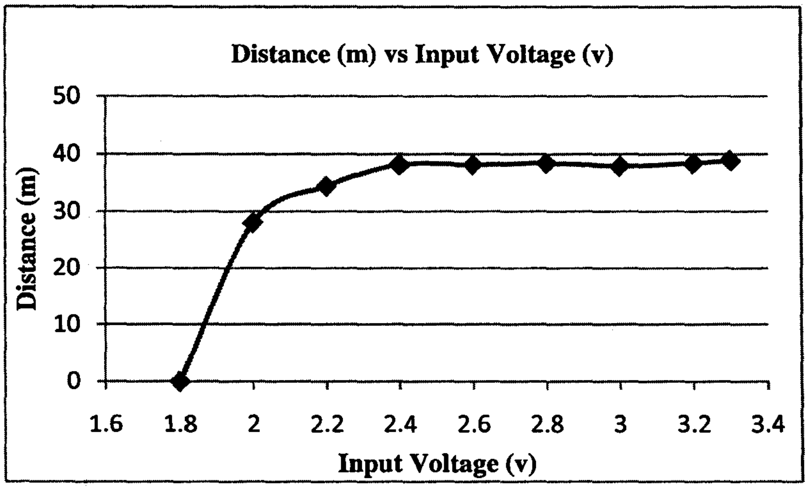

Fig. 12. Distance versus output voltage

6 Conclusion

This paper discusses the use of the LDO in an active RFID tag for the star topology network with non-beacon mode. The tag was configured under the cyclic mode, in which the tag slept for 1.5 s and woke up for 5 s. The LDO from the TPS7800 series with ultra low quiescent current was used in these experiments. Using the LDO, the current consumption remained constant even though the voltage level decreased. The minimum voltage level for the working tag was 1.8 V, and the optimum voltage level for the TPS7800 was 2.2 V. The LDO voltage regulator also reduced the current consumption in this application, where the data showed that current consumption was reduced until 32%, which proved to be significant for this application. Moreover, the indoor transmissions range of the active tag also increased by 42% when the LDO voltage regulator was adopted in the system.

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Designing a 12Volt DC Power Supply of Lithium Ion Battery in Parallel Connection By Using One Single Charge Controller

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***Abstract*— Lithium ion battery is designed to perform as a portable 12Volt D.C power supply . This power supply was tested to recharge a parallel of lithium ion battery by using one single charge controller. This experiment aimed to prove the concept of solar photovoltaic to charge a lithium ion battery for water quality monitoring system. This type of system is considered a low voltage application. Charge controller proposed in this experiment will charge a lithium ion battery to their maximum capacity, protect it from thermal hazard and overcharging. A reference voltage of 4.2V as the nominal voltage is set and the methods which are used in this project are constant-current (CC) and constant-voltage (CV) . The main idea of this research to show that a charge controller is selected, to perform a charging process, based on state of charge of the charge controller.**

I. INTRODUCTION

Cedec started their exploration in manipulating energy from solar. Nowadays most of projects need a portable electricity and this research is important in terms of application at certain places without electricity. In this project of water quality monitoring system, normally no power supply are provided at the workplace. We try to design a new model of power supply by using lithium ion battery. Charge controller is very important to ensure energy from sun are stored in lithium ion battery and this is call a capacity of battery. The state of charge from charge controller will identify performance and capacity we can stored in lithium ion battery. Lead acid is type of storage that is commonly used in solar technology. However, in terms of the size and number of duty cycle, lithium ion is preferred. Challenge to develop a charging part and deliver a 12 V output need to be proved since a lithium ion comes with 3.75V. In order to compare the benefit of both batteries, the complete system for powering a load by lithium ion battery should be considered, including production of energy and capacity of storage.

Figure 1 and 2 show comparison block diagram between lithium ion battery and lead acid battery in connection with solar system. Both diagrams show that solar system need input from solar, charge controller and storage (battery). Charge controller for lead acid battery are already established and readily available in market. Compare to lithium ion system, charge controller that available in market only with ability to charge single battery of 3.75V. Lithium ion charger can be found in 4.2V and 8.4V. It is difficult to find a charger to support 12V system. In this thesis we applied a boost converter to step up the voltage. Three elements that determine the efficiency of the system are solar panel efficiency, charge controller efficiency and booster efficiency.

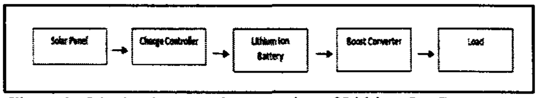

Figure 1 : Block Diagram of Connection of Lithium Ion Battery with Solar System.

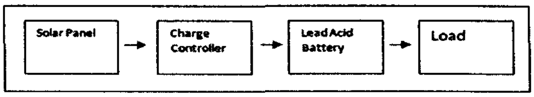

Figure 2 : Block Diagram of Connection of Lead Acid Battery with Solar System

Lithium ion battery is preferred not only because of number of duty cycle and power during delivery but the size is small and can be fixed with the instrument board. Renewal of electricity could be provided from wind, hydroelectric or nuclear power plant but these sources only centralized at certain area and not widely distributed in Malaysia. Compare to solar energy it is widely distributed and sunlight arrive at the atmosphere around 1367kWm-2 to 1776kWm-2 and

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this is called solar constant [1] . This shows that solar energy is suitable to be applied in our country. Solar PV can be widely used in many types of application . The system of water quality monitoring system in this experiment is required to provide a continuously 12V DC power supply to the load. 5 sensors are used and data will be collected by sensors and centralized by microcontroller. Data will be then transmitted by using transmitter (xbee) to control room where receiver of xbee will respond to receive data to be stored in database.

Proposed system are shown in flow chart below. It starts with power generated from solar and sent to charge controller. Charge controller will identify a suitable voltage to perform. Charge controller use methods of constant voltage (CV) and constant-current(CC) to perform a charging process[2]. A parallel of lithium ion battery is put together and charged by using one single charge controller before it is boosted to 12V by using boost converter and delivered to load.

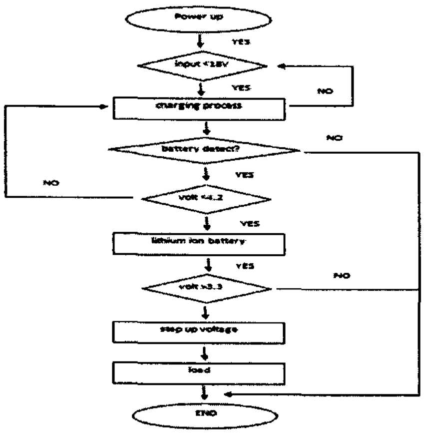

Fig. 3 : Flow Chart of The System

Performance of charge controller is based on state of charge. State of charge depends on current and voltage. Charge stored in a lithium ion is a sum of charge increase.

$$charge\ increase = current \times time \qquad (1)$$

Charge increase which is stored in lithium ion is measured in unit of ampere hour. Total performance of charge controller depends on how many charge increase from charge controller delivered to lithium ion battery. Total of charge increase will be devided with capacity of battery to get state of charge. All of this formula are apply in table 1.

$$Total\ Ampere\text{-}Hour = Ic41 + Ic42 + Ic43 + \dots\dots + Ich"n" \qquad (2)$$

$$SOC = \frac{Total\ mAh}{Capacity\ Battery\ (mAh)} X100\% \qquad (3)$$

TABLE I
State of Charge

Time	Volt	Current	Charge Increase	Ampere-hour	State of Charge
t1	V1	I1	Ich1	Ich1	%
t2	V2	I2	Ich2	Ich1+ Ich2	%
t3	V3	I3	Ich3	Ich1+ Ich2+Ich3	%

II. Experiment

A. Load Measurement And Consideration

Load consumption is very important to estimate size of solar panel, battery capacity, charge controller and battery arrangement. Power consumption is referred to current flow in the circuit and voltage of each component. Total power of load will combine and all of this will affect all of the estimation. Type of sensor and instrument are listed in Table 2. This measurement based on serial connection input wire with multimeter and the load was tested one by one. Data from measurement also compared with datasheet.

TABLE II
Data From Measurement And Datasheet

No.	Type of instrument/Sensr	Current (measurement)	Current (Datasheet)
1	Temperature	16mA	19mA
2	PH	26mA	35.6mA
3	Dissolve Oxygen	26mA	30.8mA
4	Ammonium	1mA	1mA
5	Water Level	6mA	19mA
6	Xbee (transmitter)	35mA	30mA
7	Instrument Board	40mA	40mA
8	Total	145mA	175mA

Fig. 4 shows a diagram of load. Basically power supply need to supply three main parts which is control board, xbee transmitter part and six sensors.

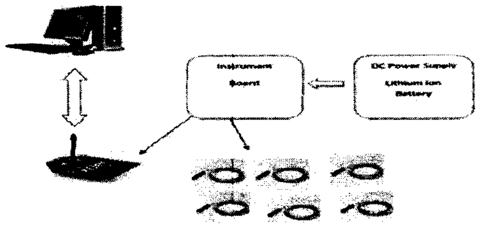

Fig. 4 : Diagram of the load

Referring to table 2, current usage in the instrument is 145mA. Sometime it fluctuates from 170mA to 174mA especially XBEE module and it lasted for a few seconds. As an assumption we take 200mA for further estimation. Calculation of load consumption is based upon capacity of battery. Current and voltage should be multiplied to get a value of wattage. In this experiment, all instruments use 12V input and current estimation in this measurement is 200mA. In 24 hours instrument need a 57.6W of power where a power supply need to standby for one day. Normally we must multiply with 1.5 or 2 times than a power demand. In the battery side, we had spend 4 unit of lithium ion battery 3.75V, 6800Ah. Total for one cell are 25.5Watt and the total power estimate in this experiment are 102Watt. 42hour (min) to 47.6hour(max).

$$Power\ Demand = Current\ X\ Voltage\ X\ 24hour \quad (1)$$

$$Time = \frac{Battery\ Capacity\ (mAh)}{Load\ (mA)} \quad (2)$$

B. Lithium Ion Battery Powered By Solar Photovoltaic

Lithium ion battery modules are connected in parallel,. Battery 3.75V,6800mAh was tested in this experiment. 1 unit battery include 4 unit of lithium ion cells. With 4 unit, 16unit of lithium ion cell are involve in this experiment. Table 3 show a specification of the battery. To prevent a battery from short circuit, lithium ion battery modules were immobilized in custom made plastic. All the connection of the battery was connected in a connector board. This is to ensure a balance output from all the batteries. The positive and negative terminals of the battery module were connected directly to the charge controller and another side were connected to the boost converter part. For voltage and current measurement will use a Fluke multi-meter or by using multimeter by tapping at the point of connector at the booster part as show in figure 5.

TABLE III
Battery Specification

Specification	Value
Cell Type	Lithium Ion
Type No	GP15203
Model No	800040
Nominal Rating	3.75,6800mAh
Charge Voltage	4.2V
Charge Current	0.15A(min),3.1A(nominal),5A (Max)
Cut Off Voltage	2.7(min),2.8(nominal),3.0(max)

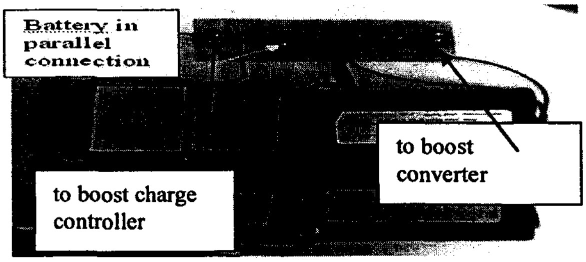

Figure 5 : Connection of the batteries

C. Solar Photovoltaic (PV)

A stand alone PV module SPM050--M has been used to charge a lithium ion battery by using charge controller. Solar panel will integrate with charge controller. This model of solar panel is suitable with temperature in Malaysia where manufacturer develop a solar panel based on Malaysia temperature. This solar panel also applicable in Asian countries. Temperature during test is 25 degree celcius. This is important to avoid solar panel from damage. Temperature rise will make solar panel short circuit.Table 4 show a specification of solar panel where it is designed for Malaysia temperature.

TABLE IV
Specification of Solar Panel

Parameter	Value
Model	Monocrystalline silicon solar cells
Number of cells	36(4×9)
Dimensions (mm)	630 x550x 30
Weight (kg)	6.5
Max Power Pm (W)	50
Max Power Voltage Vm (V)	18.68
Max Power Current Im (A)	2.68
Open-Circuit Voltage Voc (V)	22.32
Short-Circuit Current Isc (A)	2.86
Cell Efficiency (%)	14.8
Module Efficiency (%)	11.4
Maximum System Voltage (V)	DC715V
Power Tolerance (%)	±3
Series Fuse Rating (A)	10

D. Charge Controller Powered a Lithium Ion Battery In Charging Process

Charge controller function is to charge lithium ion battery. With an exact nominal voltage, lithium ion can be charged till full charge. A few charge controllers have been tested to identify a high efficiency of charging. Performance of charge controller MCP73841 and MCP1630 reference design (Fig. 6), have been compared during charging process base on state of charge (SOC) [2]. In this experiment, battery is designed based on load demand. Referring to Table 5 show a state of charge (SOC) of charge controller MCP1630 is 89% from a full charge for lithium ion battery. In one day average it can store +- 10% 90watt.

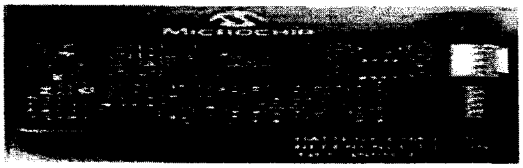

Fig 6 : Microchip Lithium Ion Charger MCP1630

Charge controller uses a method of combination constant-voltage (CC) and constant-current (CV) to charge a lithium ion battery [3]. It begins with identifying a voltage of lithium ion battery. The lithium ion battery will send back the value of battery to start charging. This shows a two way communication between lithium ion battery and charge controller. Charge controller has been tested and it is found that it can charge lithium ion batteries at one time as long as it is connect in parallel. Compared with other charge controller, most of them only charge below than 1A. This causes difficulty in performing a charging process for a large scale of battery. Adjustment of the circuit is needed to increase the current and consideration about safety is needed to ensure battery safety.

TABLE V
State of Charge

Time	Voltage	Current	Charge Increase	Amper e-hour	State of Charge
8.00	3.71	2.02	2.02	2.02	7%
9.00	3.75	2.04	2.04	4.06	14.9%
10.00	3.81	2.02	2.02	6.08	22.4%
11.00	3.84	2.04	2.04	8.12	29.8%
12.00	3.91	2.04	2.04	10.16	37.4%
1.00	3.95	2.02	2.02	12.18	44.7%
2.00	4.01	2.03	2.03	14.21	52.3%
3.00	4.08	2.04	2.04	16.25	59.7%
4.00	4.12	2.02	2.02	18.27	67.2%
5.00	4.16	2.00	2.00	20.27	74.5%
6.00	4.20	2.04	2.04	22.31	82%
7.00	4.24	2.02	2.02	24.33	89%

E. Battery Module Test And Battery Connection

In this experiment data was collected (table 5) in every hours continuously by manual. However one of the issues regarding charge controller is, charge controller cannot charge a serial connection. In Fig. 7 shows a connection of battery and possible point we can charge. Only in parallel connection, lithium ion battery can be charged. Charge controller only can charge at minimum number of battery in parallel. A fault will happen where short circuit occur when charge controller charge in serial connection. Even we put a diode to block, charge controller is not working and battery cannot be charged. In this experiment, since we connect a lithium ion battery in parallel,. step up voltage regulator has been applied to boost up voltage to 12V DC output before it is delivered to load

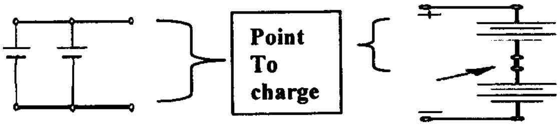

Figure 7: Connection of battery

F. Boost Converter

To boost up a voltage, we need to consider the efficiency of the boost converter system. When we apply the boost converter, power will loss and give effect to the power estimation. Voltage regulator type step up had been used, LM2577 function are boost up voltage, flyback and forward converter switching regulators. The device such as LM2577 can boost up voltage 12V, 15V and to several voltage by adjusting a component used . Regarding formula

$$Vout = 1.23V(1+R1/R2) \quad (3)$$

Output from voltage regulator had been set up to 12 V by setting the resistant 18kohm and R2 with 2kohm. The output is around 12.3V with 800mA output. Important parts which we have to consider in boost converter are switching diode and inductor. Input voltage from lithium ion battery referring to nominal current is 3.1A a. Scotty diode 3A and inductor 100uH with high resistant are selected. This is important to avoid from component blow when operating with high input of current.

III. RESULT AND DISCUSSION

Solar panel 50watt monocrystalline had been tested to the power supply. Input from solar panel will be maximumly used by charge controller to charge a string of battery in parallel connection. From lithium ion battery voltage from 3.75 had been boost up to 12V before it delivers to load. In the load part, input will get from sensor and data will be processed by microcontroller before it is transmitted by using transmitter of XBEE. Data will received by transmitter of receiver (XBEE). Data will be processed by using software part and stored in database and compiled with the analysis which can be viewed in specific website for commercialization. Fig. 8 shows a load of water quality monitoring system. All sensors are connected and inputs are directly connected to the power supply. Power supply will support power to load in continuous without disturbance.

Fig. 8 : Instrument Board (load)

Fig. 9 show lithium ion power supply. This model had been tested at University Science Malaysia and Sekolah Kebangsaan Tok Mahang at Kulim Kedah Malaysia as our base for experiment. For 1month testing, it is successful and every day power supply was in good condition. This project also had been tested at few Arowana fish farming at Perak for agriculture project. This data is very important to ensure the condition of clean water. Power supply is ensured to be working at all time.

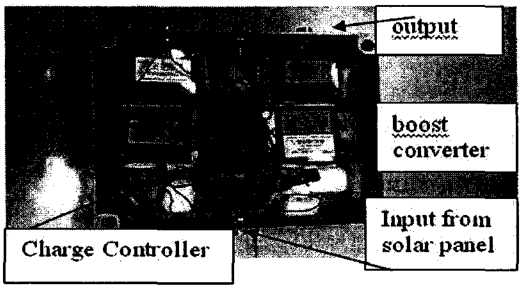

Fig. 9 : Power Supply Lithium Ion Battery

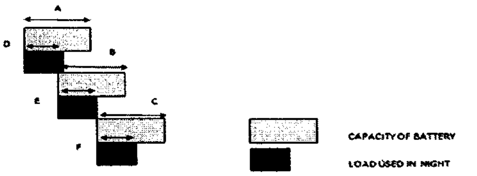

Fig. 10 : Illustration of charging and discharge for development of power supply by using lithium ion battery.

Referring to Fig. 10, A B and C are sample of testing and D E and F are situations where battery discharge by load. Sample are taken every day for three days. In yellow side show a capacity of the battery and charging for the next day. In red side shows battery used during night. Load use energy around 13hours without continuously charging. This is important to ensure a SOC of the battery can support the system continuously. Battery capacity 102W and requirement of the load for water quality monitoring system are 57.6W/day, So the balance can be stored inside the battery in case of any disturbance to solar panel. And battery are designed for 48hours base on watt between battery and load estimation. Estimation range of power supply must be multiply with 1.5 to 2.00 for backup system in unexpected condition such as raining and device faulty.

Power Adsorb(charge controller) = 2A X 3.75V X10hour (4)

Referring to SOC, proposed charge controller can charge 89% of energy every day. Everyday charge controller can store energy around 75Hh/day to 90Wh/day.

TABLE VI
Statistical Data, Sample for 1 Day of Integrate Lithium ION Battery with Load

Time	Hours	Output	Solar Input	Li-Ion (V)	Power (W)
7.000P.M	0	12.5	0	4.17	113.424
8.00P.M	1	12.5	0	4.17	113.424
9.00P.M	2	12.5	0	4.16	113.152
10.00PM	3	12.5	0	4.15	112.68
11.00P.M	4	12.5	0	4.14	112.608
12.00AM	5	12.5	0	4.12	112.064
1.00A.M	6	12.5	0	4.11	111.792
2.00A.M	7	12.5	0	4.11	111.792
3.00A.M	8	12.5	0	4.106	111.683
4.00A.M	9	12.5	0	4.1	111.52
5.00A.M	10	12.5	0	4.09	111.248
6.00A.M	11	12.5	0	4.08	110.976
7.00A.M	12	12.5	0	4.08	110.976
8.00A.M	13	12.5	1	4.09	111.248
9.00A.M	14	12.5	1	4.1	111.52
10.00A.M	15	12.5	1	4.106	111.683
11.00A.M	16	12.5	1	4.11	111.792
12.00P.M	17	12.5	1	4.116	111.952
1.00P.M	18	12.5	1	4.12	112.064
2.00P.M	19	12.5	1	4.13	112.336
3.00P.M	20	12.5	1	4.14	112.608
4.00P.M	21	12.5	1	4.15	112.88
5.00P.M	22	12.5	1	4.156	113.043
6.00P.M	23	12.5	1	4.16	113.152
7.00P.M	24	12.5	1	4.17	113.424
8.00P.M	25	12.5	0	4.16	113.152

Referring to data (Fig.6), power increases up to 113W compared with the assumption of 102W from power supply. It increased because lithium ion battery can increase up to 4.2 and several cases of lithium ion battery can achieve up to 4.4V. In this lithium ion battery can increase up to 114.24W. With a load of 2.4Wh, this power supply can support around 47.6h and approximately 2days energy without solar input. With 89% of charge controller efficiency, it will ensure efficient power storage. This power supply is ready for production and to be delivered to end user.

IV. CONCLUSION

Charge controller has been successfully implemented where it used method of constant current and constant voltage to charge a lithium ion battery. Boost up converter with less power losses and consistent boost voltage of 12V for the output, it increase efficiency of this development of power supply. By studying on state of charge we can know a performance of system and capacity of lithium ion battery. This is important to ensure battery are not deep discharge. Deep discharge will effect to the life cycle of battery. Discharge below than 50% of capacity are better if we do 80% of discharge. Lithium ion battery is expensive but with a good performance ,capacity, small size and power deliver that is greater than lead acid, lithium ion battery is proven beneficial to designer to design a power supply. This power supply already done with development and ready for production stage.

V. REFERENCE

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Designing a 12Volt DC Power Supply of Lithium Ion Battery in Parallel Connection By Using One Single Charge Controller

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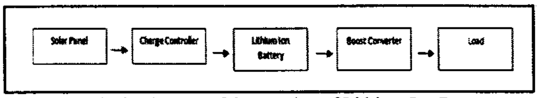

Figure 1 : Block Diagram of Connection of Lithium Ion Battery with Solar System.

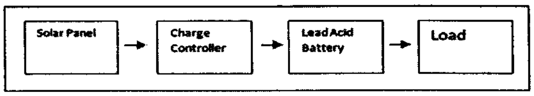

Figure 2 : Block Diagram of Connection of Lead Acid Battery with Solar System

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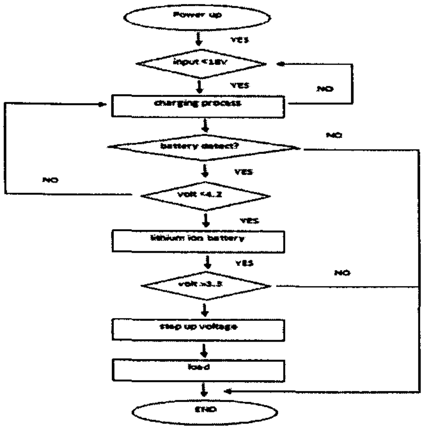

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$$\textit{Total Ampere-Hour} = Ic41 + Ic42 + Ic43 + \dots\dots\dots + Ich"n" \quad (2)$$

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t1	V1	I1	Ich1	Ich1	%
t2	V2	I2	Ich2	Ich1+ Ich2	%
t3	V3	I3	Ich3	Ich1+ Ich2+Ich3	%

II. EXPERIMENT

A. *Load Measurement And Consideration*

Load consumption is very important to estimate size of solar panel, battery capacity, charge controller and battery arrangement. Power consumption is referred to current flow in the circuit and voltage of each component. Total power of load will combine and all of this will affect all of the estimation. Type of sensor and instrument are listed in Table 2. This measurement based on serial connection input wire with multimeter and the load was tested one by one. Data from measurement also compared with datasheet.

TABLE II
Data From Measurement And Datasheet

No.	Type of instrument/Sensr	Current (measurement)	Current (Datasheet)
1	Temperature	16mA	19mA
2	PH	26mA	35.6mA
3	Dissolve Oxygen	26mA	30.8mA
4	Ammonium	1mA	1mA
5	Water Level	6mA	19mA
6	Xbee (transmitter)	35mA	30mA
7	Instrument Board	40mA	40mA
8	Total	145mA	175mA

Fig. 4 shows a diagram of load. Basically power supply need to supply three main parts which is control board, xbee transmitter part and six sensors.

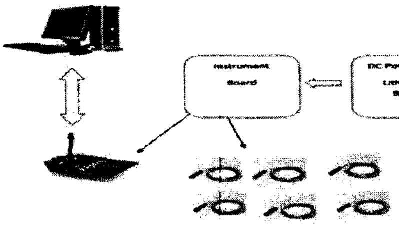

Fig. 4 : Diagram of the load

Referring to table 2, current usage in the instrument is 145mA. Sometime it fluctuates from 170mA to 174mA especially XBEE module and it lasted for a few seconds. As an assumption we take 200mA for further estimation. Calculation of load consumption is based upon capacity of battery. Current and voltage should be multiplied to get a value of wattage. In this experiment, all instruments use 12V input and current estimation in this measurement is 200mA. In 24 hours instrument need a 57.6W of power where a power supply need to standby for one day. Normally we must multiply with 1.5 or 2 times than a power demand. In the battery side, we had spend 4 unit of lithium ion battery 3.75V, 6800Ah. Total for one cell are 25.5Watt and the total power estimate in this experiment are 102Watt. 42hour (min) to 47.6hour(max).

$$Power\ Demand = Current\ X\ Voltage\ X\ 24hour \quad (1)$$

$$Time = \frac{Battery\ Capacity\ (mAh)}{Load\ (mA)} \quad (2)$$

B. Lithium Ion Battery Powered By Solar Photovoltaic

Lithium ion battery modules are connected in parallel,. Battery 3.75V,6800mAh was tested in this experiment. 1 unit battery include 4 unit of lithium ion cells. With 4 unit, 16unit of lithium ion cell are involve in this experiment. Table 3 show a specification of the battery. To prevent a battery from short circuit, lithium ion battery modules were immobilized in custom made plastic. All the connection of the battery was connected in a connector board. This is to ensure a balance output from all the batteries. The positive and negative terminals of the battery module were connected directly to the charge controller and another side were connected to the boost converter part. For voltage and current measurement will use a Fluke multi-meter or by using multimeter by tapping at the point of connector at the booster part as show in figure 5.

TABLE III
Battery Specification

Specification	Value
Cell Type	Lithium Ion
Type No	GP15203
Model No	800040
Nominal Rating	3.75,6800mAh
Charge Voltage	4.2V
Charge Current	0.15A(min),3.1A(nominal),5A (Max)
Cut Off Voltage	2.7(min),2.8(nominal),3.0(max)

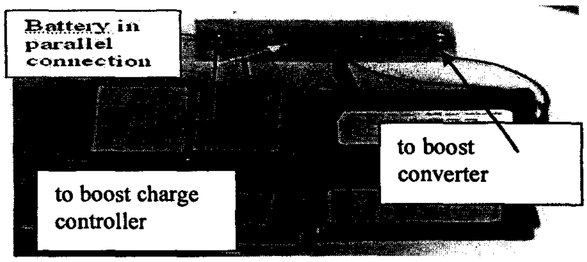

Figure 5 : Connection of the batteries

C. Solar Photovoltaic (PV)

A stand alone PV module SPM050--M has been used to charge a lithium ion battery by using charge controller. Solar panel will integrate with charge controller. This model of solar panel is suitable with temperature in Malaysia where manufacturer develop a solar panel based on Malaysia temperature. This solar panel also applicable in Asian countries. Temperature during test is 25 degree celcius. This is important to avoid solar panel from damage. Temperature rise will make solar panel short circuit.Table 4 show a specification of solar panel where it is designed for Malaysia temperature.

TABLE IV
Specification of Solar Panel

Parameter	Value
Model	Monocrystalline silicon solar cells
Number of cells	36(4×9)
Dimensions (mm)	630 x550x 30
Weight (kg)	6.5
Max Power Pm (W)	50
Max Power Voltage Vm (V)	18.68
Max Power Current Im (A)	2.68
Open-Circuit Voltage Voc (V)	22.32
Short-Circuit Current Isc (A)	2.86
Cell Efficiency (%)	14.8
Module Efficiency (%)	11.4
Maximum System Voltage (V)	DC715V
Power Tolerance (%)	±3
Series Fuse Rating (A)	10

D. Charge Controller Powered a Lithium Ion Battery In Charging Process

Charge controller function is to charge lithium ion battery. With an exact nominal voltage, lithium ion can be charged till full charge. A few charge controllers have been tested to identify a high efficiency of charging. Performance of charge controller MCP73841 and MCP1630 reference design (Fig. 6), have been compared during charging process base on state of charge (SOC) [2]. In this experiment, battery is designed based on load demand. Referring to Table 5 show a state of charge (SOC) of charge controller MCP1630 is 89% from a full charge for lithium ion battery. In one day average it can store +- 10% 90watt.

Fig 6 : Microchip Lithium Ion Charger MCP1630

Charge controller uses a method of combination constant-voltage (CC) and constant-current (CV) to charge a lithium ion battery [3]. It begins with identifying a voltage of lithium ion battery. The lithium ion battery will send back the value of battery to start charging. This shows a two way communication between lithium ion battery and charge controller. Charge controller has been tested and it is found that it can charge lithium ion batteries at one time as long as it is connect in parallel. Compared with other charge controller, most of them only charge below than 1A. This causes difficulty in performing a charging process for a large scale of battery. Adjustment of the circuit is needed to increase the current and consideration about safety is needed to ensure battery safety.

TABLE V
State of Charge

Time	Voltage	Current	Charge Increase	Amper e-hour	State of Charge
8.00	3.71	2.02	2.02	2.02	7%
9.00	3.75	2.04	2.04	4.06	14.9%
10.00	3.81	2.02	2.02	6.08	22.4%
11.00	3.84	2.04	2.04	8.12	29.8%
12.00	3.91	2.04	2.04	10.16	37.4%
1.00	3.95	2.02	2.02	12.18	44.7%
2.00	4.01	2.03	2.03	14.21	52.3%
3.00	4.08	2.04	2.04	16.25	59.7%
4.00	4.12	2.02	2.02	18.27	67.2%
5.00	4.16	2.00	2.00	20.27	74.5%
6.00	4.20	2.04	2.04	22.31	82%
7.00	4.24	2.02	2.02	24.33	89%

E. Battery Module Test And Battery Connection

In this experiment data was collected (table 5) in every hours continuously by manual. However one of the issues regarding charge controller is, charge controller cannot charge a serial connection. In Fig. 7 shows a connection of battery and possible point we can charge. Only in parallel connection, lithium ion battery can be charged. Charge controller only can charge at minimum number of battery in parallel. A fault will happen where short circuit occur when charge controller charge in serial connection. Even we put a diode to block, charge controller is not working and battery cannot be charged. In this experiment, since we connect a lithium ion battery in parallel,. step up voltage regulator has been applied to boost up voltage to 12V DC output before it is delivered to load

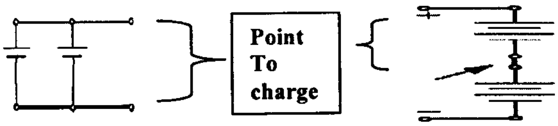

Figure 7: Connection of battery

F. Boost Converter

To boost up a voltage, we need to consider the efficiency of the boost converter system. When we apply the boost converter, power will loss and give effect to the power estimation. Voltage regulator type step up had been used, LM2577 function are boost up voltage, flyback and forward converter switching regulators. The device such as LM2577 can boost up voltage 12V, 15V and to several voltage by adjusting a component used . Regarding formula

$$Vout = 1.23V(1+R1/R2) \quad (3)$$

Output from voltage regulator had been set up to 12 V by setting the resistant 18kohm and R2 with 2kohm. The output is around 12.3V with 800mA output. Important parts which we have to consider in boost converter are switching diode and inductor. Input voltage from lithium ion battery referring to nominal current is 3.1A a. Scotty diode 3A and inductor 100uH with high resistant are selected. This is important to avoid from component blow when operating with high input of current.

III. RESULT AND DISCUSSION

Solar panel 50watt monocrystalline had been tested to the power supply. Input from solar panel will be maximumly used by charge controller to charge a string of battery in parallel connection. From lithium ion battery voltage from 3.75 had been boost up to 12V before it delivers to load. In the load part, input will get from sensor and data will be processed by microcontroller before it is transmitted by using transmitter of XBEE. Data will received by transmitter of receiver (XBEE). Data will be processed by using software part and stored in database and compiled with the analysis which can be viewed in specific website for commercialization. Fig. 8 shows a load of water quality monitoring system. All sensors are connected and inputs are directly connected to the power supply. Power supply will support power to load in continuous without disturbance.

Fig. 8 : Instrument Board (load)

Fig. 9 show lithium ion power supply. This model had been tested at University Science Malaysia and Sekolah Kebangsaan Tok Mahang at Kulim Kedah Malaysia as our base for experiment. For 1month testing, it is successful and every day power supply was in good condition. This project also had been tested at few Arowana fish farming at Perak for agriculture project. This data is very important to ensure the condition of clean water. Power supply is ensured to be working at all time.

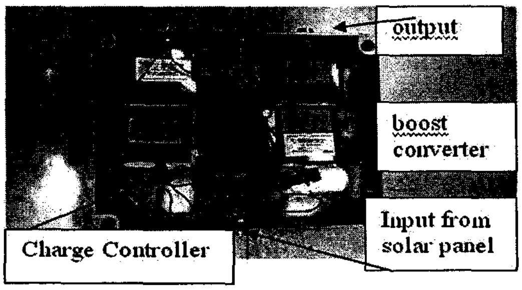

Fig. 9 : Power Supply Lithium Ion Battery

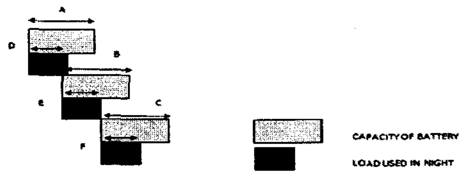

Fig. 10 : Illustration of charging and discharge for development of power supply by using lithium ion battery.

Referring to Fig. 10, A B and C are sample of testing and D E and F are situations where battery discharge by load. Sample are taken every day for three days. In yellow side show a capacity of the battery and charging for the next day. In red side shows battery used during night. Load use energy around 13hours without continuously charging. This is important to ensure a SOC of the battery can support the system continuously. Battery capacity 102W and requirement of the load for water quality monitoring system are 57.6W/day, So the balance can be stored inside the battery in case of any disturbance to solar panel. And battery are designed for 48hours base on watt between battery and load estimation. Estimation range of power supply must be multiply with 1.5 to 2.00 for backup system in unexpected condition such as raining and device faulty.

Power Adsorb(charge controller) = 2A X 3.75V X10hour (4)

Referring to SOC, proposed charge controller can charge 89% of energy every day. Everyday charge controller can store energy around 75Hh/day to 90Wh/day.

TABLE VI
Statistical Data, Sample for 1 Day of Integrate Lithium ION Battery with Load

Time	Hours	Output	Solar Input	Li-Ion (V)	Power (W)
7.00OP.M	0	12.5	0	4.17	113.424
8.00P.M	1	12.5	0	4.17	113.424
9.00P.M	2	12.5	0	4.16	113.152
10.00PM	3	12.5	0	4.15	112.68
11.00P.M	4	12.5	0	4.14	112.608
12.00AM	5	12.5	0	4.12	112.064
1.00A.M	6	12.5	0	4.11	111.792
2.00A.M	7	12.5	0	4.11	111.792
3.00A.M	8	12.5	0	4.106	111.683
4.00A.M	9	12.5	0	4.1	111.52
5.00A.M	10	12.5	0	4.09	111.248
6.00A.M	11	12.5	0	4.08	110.976
7.00A.M	12	12.5	0	4.08	110.976
8.00A.M	13	12.5	1	4.09	111.248
9.00A.M	14	12.5	1	4.1	111.52
10.00A.M	15	12.5	1	4.106	111.683
11.00A.M	16	12.5	1	4.11	111.792
12.00P.M	17	12.5	1	4.116	111.952
1.00P.M	18	12.5	1	4.12	112.064
2.00P.M	19	12.5	1	4.13	112.336
3.00P.M	20	12.5	1	4.14	112.608
4.00P.M	21	12.5	1	4.15	112.88
5.00P.M	22	12.5	1	4.156	113.043
6.00P.M	23	12.5	1	4.16	113.152
7.00P.M	24	12.5	1	4.17	113.424
8.00P.M	25	12.5	0	4.16	113.152

Referring to data (Fig.6), power increases up to 113W compared with the assumption of 102W from power supply. It increased because lithium ion battery can increase up to 4.2 and several cases of lithium ion battery can achieve up to 4.4V. In this lithium ion battery can increase up to 114.24W. With a load of 2.4Wh, this power supply can support around 47.6h and approximately 2days energy without solar input. With 89% of charge controller efficiency, it will ensure efficient power storage. This power supply is ready for production and to be delivered to end user.

IV. CONCLUSION

Charge controller has been successfully implemented where it used method of constant current and constant voltage to charge a lithium ion battery. Boost up converter with less power losses and consistent boost voltage of 12V for the output, it increase efficiency of this development of power supply. By studying on state of charge we can know a performance of system and capacity of lithium ion battery. This is important to ensure battery are not deep discharge. Deep discharge will effect to the life cycle of battery. Discharge below than 50% of capacity are better if we do 80% of discharge. Lithium ion battery is expensive but with a good performance ,capacity, small size and power deliver that is greater than lead acid, lithium ion battery is proven beneficial to designer to design a power supply. This power supply already done with development and ready for production stage.

V. REFERENCE

[1] Mohammad Ilyas , Arunasala Pandy, Syed Idris Syed Hassan," UV-B radiation at Penang",Journal, Atmospheric Research, 1998

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[3] K.M. Tsang,W.L. Chan, "A simple and low-cost charger for lithium-ion batteries, Journal of Power Sources,2009

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STUDY ON EMBEDDED POWER MANAGEMENT SYSTEM FOR WATER QUALITY MONITORING SYSTEM

by

YEE MING CHUNG

Thesis submitted in fulfillment of the requirements for the degree of
BACHELOR OF ENGINEERING (ELECTRONIC ENGINEERING)

June 2012

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1. I am a Senior Lecturer of UNIVERSITI SAINS MALAYSIA, an institution of higher learning with an address at Collaborative Microelectronic Design Excellence Centre (CEDEC), Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia, (hereinafter referred to as "USM").

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