Wireless Data Acquisition and pH and Conductivity Levels Prediction using Genetic Algorithm for Hydroponics

M. D. Pabiania, *Member, IAENG*, F. S. Caluyo, N. B. Linsangan, *Member, IAENG*

Abstract**—Wireless data acquisition and monitoring is a growing technology that offers a variety of applications even in the field of hydroponics. Hydroponics is a technique of growing plants in nutrient solutions using various types of media other than soil and is a very promising technology that is becoming popular in the Philippines most specifically in urban farming. This study is primarily concerned with the measurement, monitoring, wireless transmission, and logging of pH and conductivity parameters of a Hydroponic System using Global System for Mobile Communication (GSM) protocol. In this study, the correlations between plant height and pH level , and between plant height and conductivity for a number of plants were determined by applying linear regression analysis on the data obtained through measurements made during the plant growth period of twenty one days. Genetic Algorithm (GA) optimization was used in this study for selecting and recommending pH and conductivity levels of the nutrient solution to sustain and maximize plant growth.**

Index Terms**— Hydroponics, pH, Conductivity, GSM, Genetic Algorithm**

I. Introduction

Hydroponics is a promising technology that is becoming popular in the Philippines in the area of agriculture, specifically in urban farming. It is the most advanced technique of growing plants in mineral nutrient solutions using other forms of growing medium such as perlite, coir, gravel, and vermiculite other than soil [6]. The term hydroponics was coined by Dr. W. F. Gericke in 1936 from the Greek words “hydro” which means “water” and “ponos” which means “labor”. This method was first used in the 16th century [7] and is widely gaining popularity due to its environmental, health, economic and social benefits [5]. Hydroponics is widely adapted to all sorts of farming whether outdoors, indoors or in greenhouses and is considered as a good method of food for the future. There are many types of hydroponic systems available such as wick, water culture and ebb and flow [8], but all of these systems maintain the same parameters like pH, conductivity, and temperature in order for the plants to grow.

There are some existing studies [1] that have been conducted on the effect of pH and conductivity levels on growth, development, and yield for a wide range of crops. According to these studies, the pH of the nutrient solution in the roots of the plant for a hydroponic system determines the availability of the various elements for uptake by the plant while the conductivity level of the nutrient solution in a hydroponic system affects the fruit flavour, shelf-life, texture, yield, firmness, plant appearance, water content of tissues and gaseous exchange.

The pH and conductivity parameters of a hydroponic system are needed to be maintained in the nutrient formulation to ensure that the plants can absorb the minerals and be high yielding. Since the pH and conductivity requirements vary for each plant, therefore, specific measurement of acidity or alkalinity and conductivity of nutrient solutions needs to be maintained in order to sustain plant growth. Most hydroponic systems apply the conventional way of measuring pH and conductivity by constantly dipping the pH and conductivity meters manually to the nutrient solutions; but the setback for this type of system is that it usually involves close supervision. In addition, the proper timing in dispensing the nutrient solution for the hydroponic system is also a concern most especially if a certain range of parameters goes out of bounds.

This study designed and implemented a wireless pH and conductivity measurement, monitoring, and data logging system for a Hydroponic system and developed a method for determining the relationships of pH and conductivity levels to the height of the plant. The objectives of the study were (1) to design and create a prototype that can read the pH and conductivity levels of a nutrient solution and send the measurements using a wireless module via GSM technology to a personal computer; (2) to design and construct an ebb and flow hydroponic system with the associated timing module for irrigation; (3) to design the software and database for data logging of pH and conductivity levels transmitted by the wireless module using GSM technology; (4) to develop a method to measure and monitor the pH and conductivity levels of the nutrient solution and to log all the measured data for a hydroponic

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M. D. Pabiania is with the Computer Engineering Department of Mapua Institute of Technology at Laguna, Malayan Colleges Laguna, Pulo Diezmo Rd., Brgy. Banay-Banay, 4025 Cabuyao, Laguna, Philippines. (Phone: (+6349)832-4055; fax: (+6349)832-0017; e-mail: mdpabiania@ mcl.edu.ph)

F. S. Caluyo is with the School of Electrical, Electronics and Computer Engineering, Mapua Institute of Technology (e-mail: fscaluyo@mapua.edu.ph).

N. B. Linsangan is with the Computer Engineering Department of the School of Electrical, Electronics and Computer Engineering , Mapua Institute of Technology (e-mail: nblinsangan@mapua.edu.ph).

system; (5) to wirelessly transmit, receive, and record data in a database; (6) to control the timing in the dispensing of the nutrient solution to the hydroponic system; (7) to determine correlation between the pH, conductivity and plant height using linear regression; and (8) to create a method for choosing the appropriate pH and conductivity range of the nutrient solution in a hydroponic system using genetic algorithm. The wireless data acquisition of measured nutrients' pH and conductivity can significantly help an urban farmer monitor the pH and conductivity in a remote location as well as to control the irrigation of the hydroponic system.

The scope and limitations of the study are as follows: The study focuses only on measuring and monitoring the pH and conductivity levels of the nutrient solution for a Lettuce plant in a Hydroponic system. The pH meter that was used can read values ranging from pH 0 to pH 14 while the conductivity meter can only measure 1 µS/cm to 1999 µS/cm. This study is not concerned about algorithms other than genetic algorithm. The experiments were done in a hydroponic system under outdoor conditions and only changes in pH and conductivity were measured and monitored via GSM. The genetic algorithm was simulated using MATLAB.

The pictorial representation of the conceptual framework of the design as shown in Figure 1 illustrates the different parts of the system implementation. These are: Wireless Data Acquisition (Hardware), Instrumentation (Wireless pH and Conductivity module), Hydroponic System (Ebb and Flow technique), and Data Monitoring and Logging System (Software).

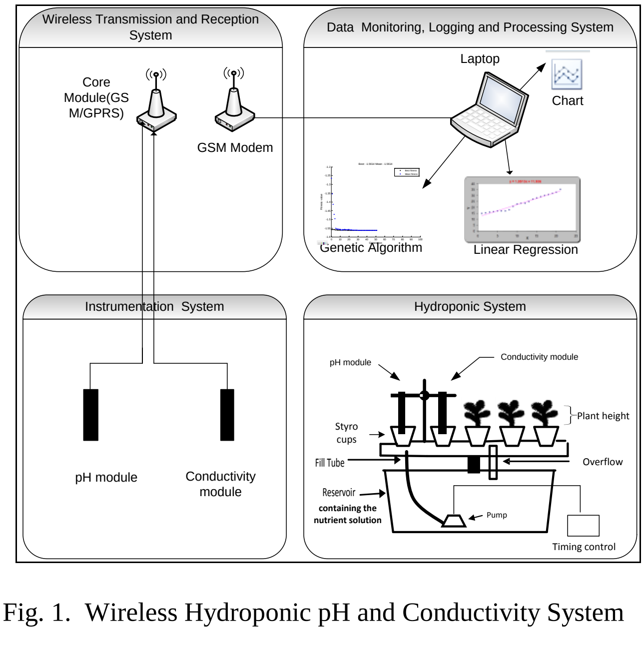

Fig. 1. Wireless Hydroponic pH and Conductivity System

Figure 1 shows the basic building blocks and provides an illustration of the conceptual framework of the wireless hydroponic pH and conductivity level system. The main system components are the hydroponic system, the instrumentation system, the wireless transmission and reception system, and the data monitoring, logging and processing system. The conductivity module measures the nutrient concentration in the nutrient solution while the pH module measures the acidity or alkalinity of the nutrient solution. These measurements are then sent by the core module wirelessly to the personal computer for screen output.

II. METHODOLOGY

This section describes the method, materials, and equipment used in attaining the objectives of the study. Figure 2 illustrates the procedural steps. Explanations are provided in the discussions that follow.

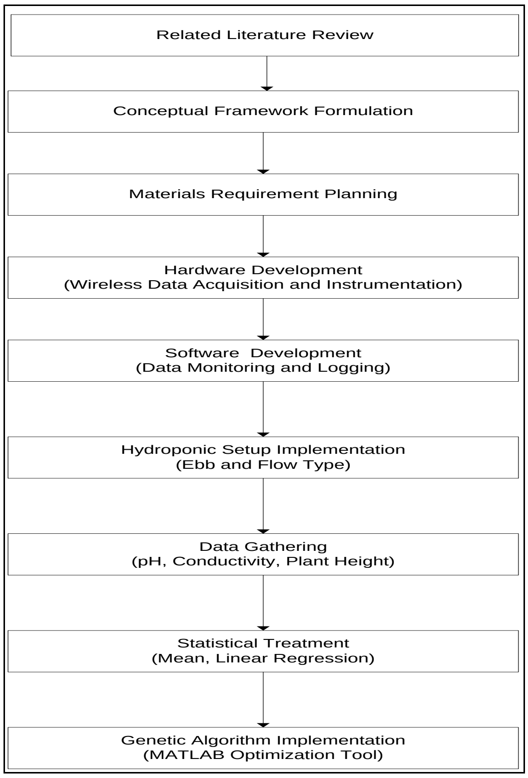

Fig. 2. Methodology

The first step involved a review of the literature related to the study to conceptualize and develop the design. The problem statement and the conceptual framework were then formulated, after which planning and selection of materials needed in the development of the modules was done. The development of the hardware design came fourth, followed by the development of the software design. Next was the setting up of the hydroponic prototype. The seventh step involved the conduct of a series of experiments on the hydroponic system using pH values in the range of 5 to 7, and electrical conductivity level in the range of 1500 to 1999. In the eighth step, the pH and conductivity were correlated with plant height using linear regression. The ninth and final step involved the prediction of the pH and conductivity values that can maximize the height of the plant using Genetic algorithm.

Figure 3 shows the block diagram of the principal hardware and software components interconnection between the various system elements such as the core, conductivity, and the pH level modules. The timing module for the dispensing of the nutrient solution to the hydroponic system was done separately and is not depicted in the figure. The detailed steps in implementing the timing module and the wireless acquisition system to measure pH and conductivity levels are as follows: The schematic diagram was created using the software Target 3001. Printed circuit board (PCB) layouts were automatically generated from the schematic diagram by choosing an option in Target 3001. The programs for the module Programmable Interface Controller (PIC) microcontrollers were created and compiled in PIC BASIC (Beginner's All-purpose Symbolic Instruction Code). The program programs were compiled using Proton PICBASIC to create the hex file. PICkit 2 programmer was used to import the hex file and burned it into the microcontroller. The prototype underwent testing and troubleshooting. The testing of the pH and conductivity modules were done by connecting it to the ports of the core and then the serial port of the core module was connected to the serial port of the PC. The pH and conductivity modules were checked whether they are sending the output to the core module via the HyperTerminal application using Windows XP. The timing module was also tested by connecting it to the submersible pump. The setting of the timing was done using three push-buttons and the set time can be seen through the Liquid Crystal Display (LCD) which serves as the User Interface (UI).

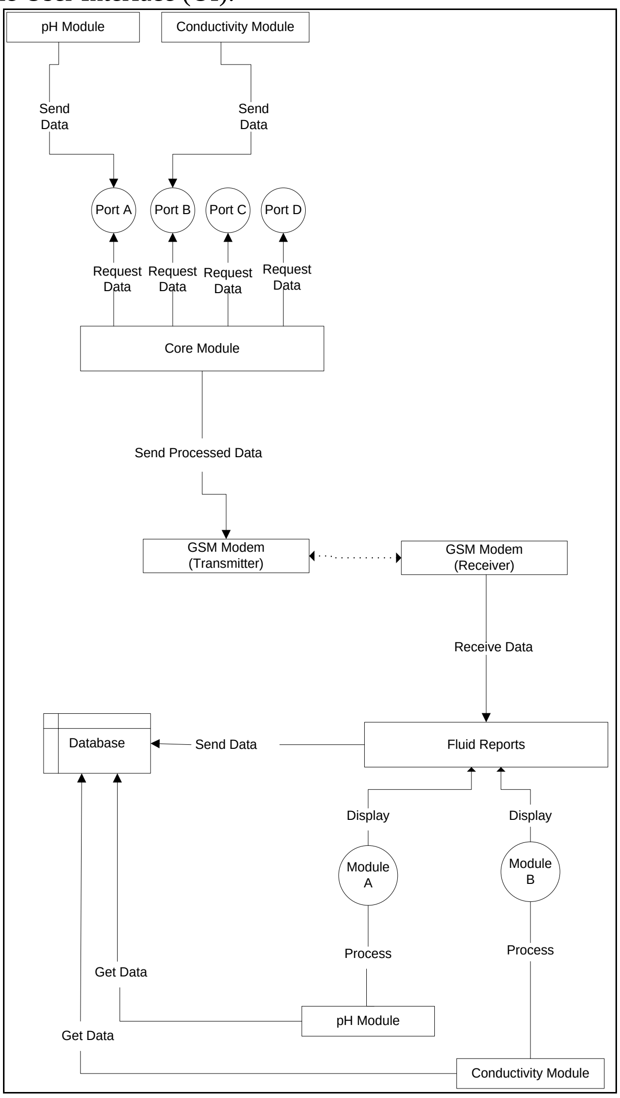

Fig. 3. Block Diagram of Wireless Data Acquisition and Instrumentation

A recent study on the technologies for wireless data acquisition and monitoring of environmental parameters [4] presented wireless technologies, specifically GSM protocol, as reliable and efficient solutions for remote data acquisition, supervisory and control systems in the measurement of light intensity, temperature, pressure, and humidity. The results of the study proved to be significant in acquiring environmental parameters and the possibility of applying this second generation of communication protocol turned out also to be very promising for hydroponic systems.

The core module has 4 ports that can be used for acquiring data. The pH and conductivity modules can be connected to any one of these ports. The core module also houses the GSM which uses MAX232 for communication interface. Once the core module receives data from the pH and conductivity module, it transmits the data to the GSM. The GSM transmits the data to another GSM modem connected to the PC and the PC in turn, displays the received data in the form of a chart for both pH and conductivity levels. The four ports of the core module are the SENSOR DATA0 to SENSOR DATA3. Each port has 4 wires for Tx, Rx, Vcc and GND. Ports B0 to B5 and ports D6 to D7 of PIC16F877A were used to accept digital input for SENSOR DATA0 to SENSOR DATA3 while Ports C6 and C7 were used for asynchronous transmit and receive to the GSM module. Figure 4 illustrates the program flowchart of the reporting application.

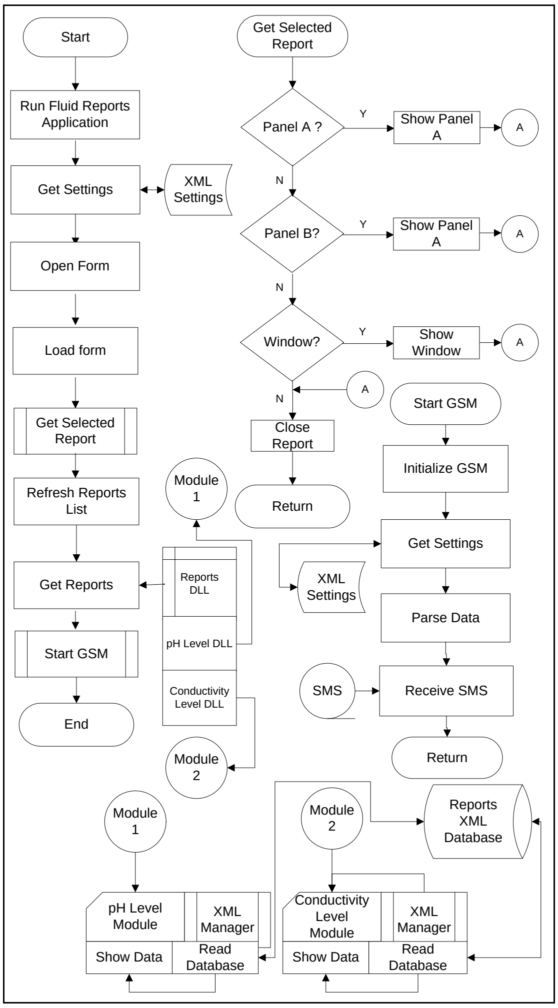

Fig. 4. Process Flowchart of the Reporting Application

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The conductivity and pH Level modules which use PIC microcontrollers receive the conductivity and pH level readings from the output of the corresponding meters. The readings were then forwarded to the core module microcontroller and subsequently forwarded to the GSM modem to the system software that handled processing of data for output to a personal computer. The programming language used in developing the software is C# programming language. No separate database management software or other proprietary database solutions like Structured Query Language (SQL) or Microsoft Access was used to avoid dependencies on those solutions. The database was created using Extensible Markup Language (XML) files stored and arranged in a hierarchy of dynamic directories. The hierarchy of the directories is specific to this application only, and arranged according to the combination of the type of the report data and the date. This method of data storage is ideal since the application is not database resource intensive. The hydroponic ebb and flow system implemented in the study as shown in Figure 5 uses a fill tube which is connected to the submersible pump. The fill tube pumps the nutrient solution to the plants while the overflow tube returns the nutrient solution to the reservoir.

Fig. 5. Hydroponic System

As the basis of the study, Romaine lettuce was transplanted and placed in a styro cup after 2 weeks. It was approximately in its 2-3 leaf stage. Each batch consists of 15 Romaine lettuce placed in a styro cup and placed on every hole with a diameter of approximately 7 cm. The size of the styro box is approximately 87 cm (length) x 43 cm (width) x 8 cm (height) as shown in Fig. 5. The styro box containing the Romaine lettuce uses 150 ml of SNAP A mixed with 36 liters of tap water with another 150 ml of SNAP B after mixing the solution. The pH and conductivity of the nutrient solution inside the styro box were measured everyday by dipping the pH and conductivity modules on the nutrient solution for 21 days. The height of each plant was measured from the medium to the tallest leaf. The pH and conductivity levels were measured per plant on a daily basis in order to determine the growth rate of the plant as well as the changes in the pH and conductivity parameter.

The study used mean, linear regression, and correlation coefficient formulas [9] to compute for the mean pH and EC or each plant per batch, growth rate per plant on a daily basis from day 1 to 21, and the correlation of pH and EC to the height of each plant using Equations 1, 2, and 3, respectively. Microsoft Excel was used to facilitate computations for the given equations.

Mean: $\bar{x} = \sum x / n$ (1)

Linear Regression: $\hat{y} = a + bx$ (2)

Correlation Coefficient: $r = y \sum x)(\sum y)/([n\sum x^2(\sum x)^2][n\sum y^2- (\sum y)^2])^{1/2}$ (3)

In order to draw conclusions from the above equations, the following hypotheses were formulated:

H0 (Null Hypotheses):

1. There is no correlation between pH and plant growth.
2. There is no correlation between conductivity and plant growth.

H1 (Alternative Hypotheses):

1. There is linear correlation between pH and plant growth.
2. There is linear correlation between conductivity and plant growth.

In formulating the conclusion, if F<Fcritical; H0 is accepted. If F>Fcritical, H0 is rejected. If correlation coefficient |r| =0.7 to 1, it means there is strong correlation; if |r| =0.4 to 0.6, it means there is moderate correlation; if |r| =0.1 to 0.3, it means there is weak correlation; and if |r| =0, it means there is no correlation.

Haupt [3] defined genetic algorithm as the most commonly used combinatorial optimization technique based on Darwin Theory of evolution to search for an optimal value involving three basic operators: selection, crossover and mutation. According to them, the method was developed by John Holland over the course of the 1960s and 1970s and finally popularized by one student named David Goldberg who was able to solve a difficult problem involving the control of gas-pipeline transmission for his dissertation. Ferentinos [2] used genetic algorithm in their study of adaptive design optimization of wireless sensor networks. They used genetic algorithms as the optimization tool in developing an appropriate fitness function to incorporate many aspects of network performance which include the status of sensor nodes, network clustering with the choice of appropriate cluster heads and the choice between two signal ranges for the simple sensor nodes. Since hydroponics system is also multi-objective, the implementation of genetic algorithm can be very useful for pH and conductivity level prediction.

III. RESULTS AND DISCUSSION

In this study, correlation was used to determine whether a linear relationship exists between pH and plant height and between conductivity and plant height. The correlation coefficient r was computed using the formula, $r = n\sum xy - (\sum x)(\sum y)/([n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2])^{1/2}$. In order to determine the significance r, a test of significance was conducted declaring H0 or Null Hypotheses as follows: (1) There is no correlation between pH and plant height and (2) There is no correlation between conductivity and plant height. H1 or Alternative Hypotheses, on the other hand, are as follows: (1) There is linear correlation between pH and plant height and (2) There is linear correlation between conductivity and plant height.

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Table 1 shows that there is correlation between pH and plant height for Plants 3 to 15. Since F is greater than the Fcritical, this means that the null hypotheses H0 are rejected.

Table 1. Correlation between pH and Plant Height for Batch 2 Romaine Lettuce

Plant #	pH and Plant Height $\alpha = 0.05$ (Two-tailed)				
	Correlation(r)	Interpretation	F	Fcritical	Decision
1	0.5267	Moderate Correlation	3.07142	5.31766	Accept H0
2	0.4094	Moderate Correlation	1.81194	5.11736	Accept H0
3	0.6424	Moderate Correlation	7.72711	4.84434	Reject H0
4	0.6091	Moderate Correlation	7.07733	4.74723	Reject H0
5	0.6386	Moderate Correlation	8.26221	4.74723	Reject H0
6	0.634	Moderate Correlation	8.0649	4.74723	Reject H0
7	0.6413	Moderate Correlation	9.08264	4.66719	Reject H0
8	0.7451	Strong Correlation	13.7304	4.84434	Reject H0
9	0.7289	Strong Correlation	11.3353	4.9646	Reject H0
10	0.7069	Strong Correlation	9.98681	4.9646	Reject H0
11	0.7786	Strong Correlation	15.3967	4.9646	Reject H0
12	0.7632	Strong Correlation	13.9517	4.9646	Reject H0
13	0.7276	Strong Correlation	12.3711	4.84434	Reject H0
14	0.6235	Moderate Correlation	8.9017	4.60011	Reject H0
15	0.7028	Strong Correlation	10.7389	4.84434	Reject H0

Table 2 shows that there is correlation between conductivity and plant height for Plants 1 to 15. Since F is greater than the Fcritical, this means that the null hypotheses H0 are rejected.

Table 2. Correlation between Conductivity and Plant Height for Batch 1 Romaine Lettuce

Plant #	Conductivity and Plant Height $\alpha = 0.05$ (Two-tailed)				
	Correlation(r)	Interpretation	F	Fcritical	Decision
1	0.6303	Moderate Correlation	7.90771	4.74723	Reject H0
2	0.5533	Moderate Correlation	5.73558	4.66719	Reject H0
3	0.4765	Moderate Correlation	4.70045	4.494	Reject H0
4	0.6912	Moderate Correlation	10.9757	4.74723	Reject H0
5	0.6381	Moderate Correlation	8.23993	4.74723	Reject H0
6	0.5972	Moderate Correlation	8.86953	4.494	Reject H0
7	0.5186	Moderate Correlation	5.14967	4.60011	Reject H0
8	0.6307	Moderate Correlation	9.91021	4.54308	Reject H0
9	0.5969	Moderate Correlation	8.85613	4.494	Reject H0
10	0.5048	Moderate Correlation	4.78758	4.60011	Reject H0
11	0.6024	Moderate Correlation	7.97351	4.60011	Reject H0
12	0.5290	Moderate Correlation	6.21808	4.494	Reject H0
13	0.5655	Moderate Correlation	7.05224	4.54308	Reject H0
14	0.6556	Moderate Correlation	9,80155	4.66719	Reject H0
15	0.6188	Moderate Correlation	9.92881	4.494	Reject H0

The set of data used for the genetic algorithm was generated from these two batches of the Hydroponic Lettuce experimental setup by selecting the mean pH and conductivity levels and their corresponding growth rates. Table 3 shows the pH and the corresponding growth rate in centimeters per day which is represented by grph. The values for the growth rate, grph, were obtained using linear regression.

Table 3. pH and Growth Rate Data for the Genetic Algorithm

pH	Growth Rate (grph) cm / day
5.7	1.037
5.8	1.0513
6.3	0.9714
6.4	0.9159
6.5	1.0279

Table 4 shows the conductivity in μS/cm and the corresponding growth rate in centimeters per day which is represented by grec. The values for the growth rate, grec, were also obtained using linear regression.

Table 4. Conductivity and Growth Rate Data for the Genetic Algorithm

Conductivity(μS/cm)	Growth Rate(grec) cm / day
1654	0.7831
1657	0.9273
1658	0.9519
1659	0.913
1661	0.9247
1662	0.9714
1663	0.8961
1667	0.7351
1672	1.0279
1673	1.0682
1675	0.8403
1676	0.9123
1716	1.037
1718	1.0513

In this study, the activation functions for pH and conductivity were assumed to be fifth degree polynomials of the form:

$$grph(ph)=a_1(ph)^5+ a_2(ph)^4+ a_3(ph)^3+ a_4(ph)^2+ a_5(ph)^1+ a_6(ph)^0 \quad (4)$$

$$grec(ec)=b_1(ec)^5+ b_2(ec)^4+ b_3(ec)^3+ b_4(ec)^2+ b_5(ec)^1+ b_6(ec)^0 \quad (5)$$

MATLAB curve-fitting tool was used to determine the coefficients of the polynomial function. Using the curve-fitting tool and the data in Table 3, the coefficients of the polynomial grph were obtained as follows:

a(ph)=[1.188186986465944e+000 -.864222143597542e+001 2.586529452934475e+002 -1.037103900951420e+003 1.558128585323997e+003 0];

These coefficients were needed for creating the function z for the Genetic Algorithm MATLAB M-file for pH,

$$z = - (grph) \quad (6)$$

Figure 6 shows the graph of Growth Rate versus pH for the genetic algorithm implementation.

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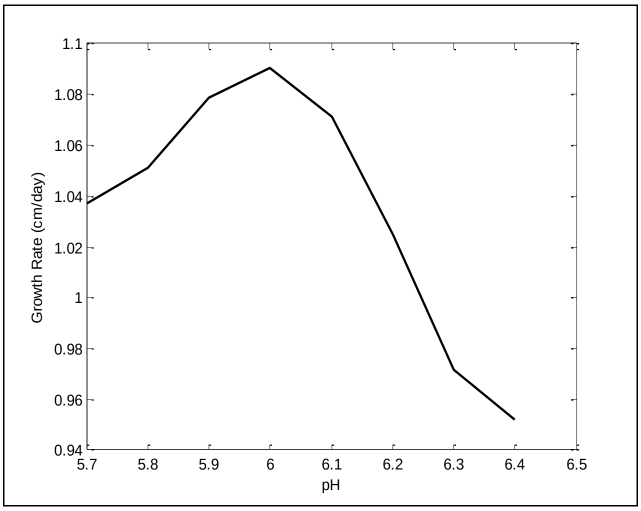

Fig. 6. Graph of Growth Rate vs pH

Applying the data shown in Table 4 to the MATLAB curve-fitting function yielded the coefficients b (ec) of the grec polynomial functions as follows:

b(ec) = [3.570679883760974e-008 -3.009393558485720e-004 1.014476386138255e+000 -1.709817897694960e+003 1.440797022861894e+006 -4.856135870480161e+008]

These coefficients were needed for creating the function z for the Genetic Algorithm MATLAB M-file for Conductivity,

$$z = -\,(grec) \qquad (7)$$

Figure 7 shows the graph of Growth Rate versus Conductivity for the genetic algorithm implementation.

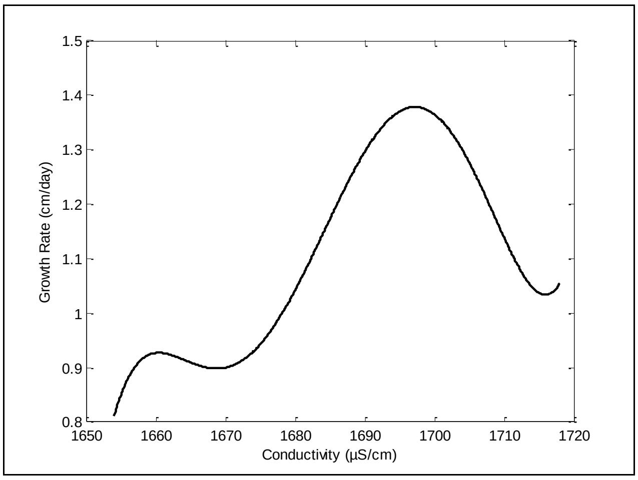

Fig.7. Graph of Growth Rate vs Conductivity

The genetic algorithm implementation generated a final pH value of 5.924. The final point generated for conductivity is 1697. 214 µS/cm. The final points are the recommended optimal value for the pH and conductivity parameters that corresponds to maximum plant growth.

IV. CONCLUSION

This section presents the conclusion that this study on wireless data acquisition and pH and conductivity levels prediction using genetic algorithm for hydroponics arrived at. The objectives of the study were successfully met, as follows: (1) design and implementation of pH and conductivity levels measurement; (2) design and implementation of wireless system using GSM protocol;(3) design and implementation of data logging, monitoring, and processing of pH and conductivity levels measurement using C# for the application, and XML for the database; (4) design the timing control of the dispense of the nutrient solution to the hydroponic system; (5) determining correlation between pH and plant height and conductivity and plant height, using linear regression; and, (6) predicting the optimal pH and conductivity level of the nutrient solution in a hydroponic system using genetic algorithm. Further, the study was able to prove the following hypotheses: (a) There is linear correlation between pH and plant growth; (b) There is linear correlation between conductivity and plant growth.

REFERENCES

[1] T. Alexander, A. Knutson, M. Harrington. *The Best of Growing Edge*, New Moon Publishing, Inc., pp. 11, 43, 2000.

[2] K. P. Ferentinos, T. A. Tsiligiridis. *Adaptive design optimization of wireless sensor networks,* Computer Networks: the International Journal of computer and Telecommunications Networking Volume 51, Issue 4, 2007.

[3] R. L. Haupt, S. E. Haupt. *Practical Genetic Algorithm*, John Wiley & Sons, Inc., p. 22, 2004.

[4] J. Wang, "Fundamentals of erbium-doped fiber amplifiers arrays (Periodical style—Submitted for publication)," *IAENG International Journal of Applied Mathematics*, submitted for publication.

[5] I. Lita, I. B. Cioe, D. A. Visan, and I. Dorobantu. *Technologies for Wireless Data Acquisition and Monitoring of Environmental Parameters*, Electronics Technology, ISSE, 2009.

[6] G. Low. *Integral Hydroponics,* Integral Hydroponics, p. 4, 2002.

[7] H. M. Resh. *Hydroponic Food Production,* Woodbridge Press Publishing Company, p. 119, 2001.

[8] K. Roberto. *How to Hydroponics, Futuregarden*, p. 12, 2003.

[9] G. F. Van Patten. *Hydroponic Basics*, Van Patten Publishing, p. 44, 2004.

[10] R. E. Walpole, R. Myers, S. L. Myers. *Probability and Statistics for Engineers and Scientists*, Pearson Prentice Hall, 2006.

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