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***Abstract*—There have been numerous technological advancements in the field of agriculture in recent years. One of which is hydroponic farming – a soil-less method of cultivating crops using nutrient enriched water. While hydroponic farming has numerous advantages, the methods are more complicated than those of conventional farming. Possibilities of system failure are higher due to added factors of growing. An Arduino-based automated data acquisition system (DAQ) was developed to easily diagnose and troubleshoot the system. This paper presents the design, construction, and calibration of the DAQ system that can log six different growing conditions – air temperature, relative humidity, water temperature, water level, pH level, and light intensity. Results showed that the sensors were properly calibrated and accurate based on standard instruments. Additionally, plot curves of each parameter were generated from the collected data in the system.**

Keywords—smart farming, hydroponics, data acquisition system, Arduino

I. Introduction

Growing crops and vegetables is no easy task, more so with hydroponics. There are a lot of variables and external factors that could affect the success or failure of the yield. The traditional way of determining which factors led to yield quality is through observation and manual measurements which are both ineffective and insufficient. In the age where information is readily available, the accurate collection and presentation of data is essential in maintaining the integrity of the farming system. These data are facts and statistics collected together for reference or analysis. Information in general is a prerequisite to produce backed-up and evidential outcomes which could significantly improve yield quality.

Smart farming is becoming a part of the technological advancements brought about by globalization. Smart farming involves the incorporation of information and communication technologies into machinery, equipment, and sensors for use in agricultural production systems. New technologies such as the internet of things and cloud computing are expected to advance the developments by introducing more robots and artificial intelligence into farming [1]. Big data has a large impact on Smart Farming since it is being used to provide predictive insights in farming operations, drive real-time operational decisions, and redesign business processes for game-changing business models. As such, farming process will become more data-driven and data-enabled. Most operational activities will be achieved through machines wherein humans still take part in the process. Through the integration of smart farming, yield is further optimized and maximized due to the existence of big data and smart farming that integrates several automated technologies to minimize human intervention [2].

The emergence of big data has revolutionized the motion of things in the world today. Big data is data sets that are so big and complex that traditional data-processing application software are inadequate to deal with them. The analytics of big data is fraught with both negative and positive potential. According to Pence (2014), the amount of data being produced is already incredibly great and current developments suggest that the rate will only increase in the near future. [3] However, this data is also plausible to create privacy problems. Computing power and cost of storage has increased, the data cap that posed a challenge before can now be easily handled by a computer. Data scientists are increasingly using data quantities in Peta and Zeta bytes and big corporations and organizations are foreseeing that Big Data has a big potential to create value in multiple ways [10]. Big data is also seen as a powerful tool to address various societal issues, but it has also dystopian rhetoric wherein it poses risks on security, decreased civil freedom, widening inequality, to name a few [10].

II. Smart Hydroponic Farming

A. Significance

Hydroponic farming has made several breakthroughs in the modern and urban farming scene. Smart farming has also been incorporated in different farming methods in order to improve agriculture through modern technologies. Significant developments have been made by integrating smart farming into hydroponic systems. Hence, large amounts of collected can be analysed by a Wireless Sensor Network (WSN) by sending data to the cloud and controlling values such as temperature, light, humidity among others [12]. The Internet of Things (IoT) refer to a network of objects, equipment,

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vehicles, buildings, and other electronic sensing devices including software for connecting into the network for information exchange. The IoT's devices contain Radio Frequency Identification (RFID), various sensors and computing notes. The system needs to have an internet connection for the transportation of data between devices. The merging of the physical world with computer systems and virtual resources-available on the Internet provide value-added information and functionalities for end-users [13]. At present, farmers need agricultural information and pertinent knowledge to make decisions and to satisfy informational needs. Through Information and Communication Technology (ICT), farmer enquiries can be addressed in order to widen farming opportunities. Since hydroponic farming has been proven to be a sustainable form of farming, the addition of smart technologies pushes its sustainability further by being low-maintenance and high yield that is best suitable for urban conditions. Urban farmers are able to carry on with their busy schedules while maintaining their crops at the palm of their hands because of IoT. Hence, it has pushed the boundaries of technology by incorporating major breakthroughs into a then traditional practice.

The significance of smart farming with the use of hydroponics mainly encompasses the intelligent and efficient design of the system which would be most importantly be found in its potential application to the advancement of urban farming. This study addresses the current problems of hydroponic systems regarding land area limitations, ease of handling and operations, weather-proofing, and pest control. Along with these technical issues that this study would address, societal issues on food quality assurance and food security would also be touched on. With these issues stated, the main goal of smart farming is to optimize, as well as maximize, the yield of hydroponic systems with the integration of technology to go along with it.

B. *Current Studies and Innovations*

In the current 21st century, where new technological discoveries and innovations have abounded in several differing areas of interest that affect the present society, it comes as no surprise that farming—and hydroponic farming, in particular—would be subject to these advancements.

In particular, a 2017 study entitled "Applied Internet of Thing for Smart Hydroponic Farming Ecosystem (HFE)" integrates both the monitoring and controlling characteristic into their system architecture through the use of sensors and relays, respectively. In their prototype, the factors that were monitored were the air temperature and humidity, pH level, electrical conductivity (EC), and temperature of the water, and also the height and flow rate of the water through the use of ultrasonic and water flow sensors. Meanwhile, through the use of relays, the controlling factor of their prototype included the manipulation of the air temperature and humidity, and the nutrient concentration. The study by Ruengittinum, et al., in addition to the monitoring and controlling system, built a smart phone application which would be able to alert the user of the changes being experienced by the HFE and, also, be able to manage the controlling devices in the system [8].

Another study was developed by Kyaw and Ng (2017) by applying smart technology to aquaponics - a hydroponic growing method that utilizes natural fertilizer from fish waste. Similar to any smart systems, their design used sensors to gather data and actuators to control parameters. They also utilize cloud storage for their data analysis and mobile application for convenient system control. Their system was able to produce linear regression models which helped in the analysis of plant growth and fish growth [6].

III. SYSTEM DESIGN

The goal of the data acquisition system was to automatically measure and log different growing conditions in the outdoor hydroponic system. The Arduino-based data logger was designed to collect six different parameters using five sensors, store the data in an SD card, and display system performance in real-time.

A. *Materials and Architecture*

Different growing conditions required different sensors. Fig. 1 shows the schematic diagram that was used to construct the monitoring system. A DHT11 sensor was used for ambient temperature and relative humidity, one-wire water temperature sensor for reservoir temperature, pH Pro Meter Sensor for reservoir pH level, ultrasonic ranging sensor for reservoir water level, photo resistive sensor for light intensity. A DFRobot Arduino Mega 2560 was used as the microcontroller. A 4x20 LCD module was integrated to allow real-time access to system performance. An SD module and DS3231 real-time clock module were necessary for data logging.

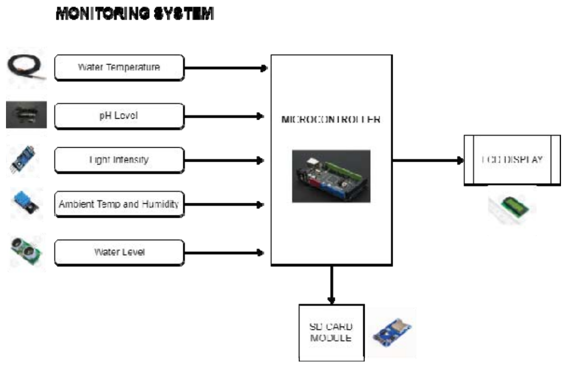

Fig. 1. DAQ System Architecture

B. *Data Logger Setup*

The data acquisition system shown in Fig. 2 was strategically placed at the middle of the hydroponic system. Water temperature sensor, and pH sensor were immersed in the reservoir. The ultrasonic sensor coupled with a plastic mount was installed on the side of the Styrofoam reservoir with proper adhesive. Light sensor was installed near the plants. The ambient temperature – relative humidity sensor was placed outside the data logger box.

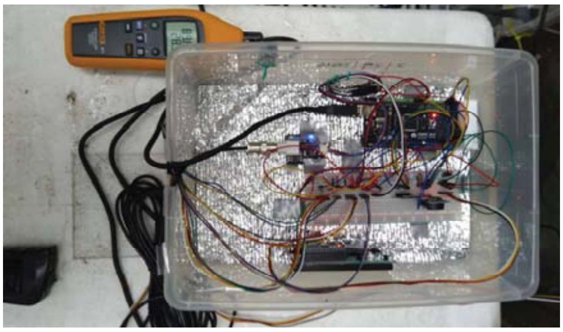

Fig. 2. Actual Data Acquisition System Prototype

C. Sensor Calibration

All sensors were tested then pre-calibrated through the program to ensure that the DAQ system is accurate and consistent. pH sensor was calibrated by immersing the probe in a pH buffer of 4.0 and 7.0 then adjusting it through the Arduino IDE program. Similarly, the DHT11 sensor was calibrated by adjusting its code based on the measurement values from a Fluke thermohygrometer. The data logger had an initial run where it was validated every 10 minutes for 2 hours based on standard instruments. Specific sensors such as the DHT11 were incapable of showing decimal values which decreased accuracy, however during the run, corresponding measurements showed that the percent error of all sensors were below 5%, therefore the data logger was ready for actual installation in the hydroponic system.

IV. System Validation

Since this research focuses on designing of an automated data acquisition system from scratch, it is necessary to validate and compare results with other standard measuring instruments.

A. Instrumentation

The instrumentation for the DAQ validation consists of various measuring devices required to manually attain necessary data. A tape measure was used to measure the water level in the reservoir. A digital thermometer measured the temperature of the water at that instant. A Fluke digital thermo-hygrometer measured the ambient temperature as well as the relative humidity of the system. A pH meter was responsible for measuring the pH level of the water that goes through the system. The tip of the pH meter was submerged in the water and it is stirred for five to ten seconds before the reading is recorded.

B. Instrument Calibration

To have an accurate reading from the instruments used to validate the system, individual calibration of the meters was done before data gathering. For instance, the pH meter used a pH buffer calibration solution of 4.0 and 7.0. The tip of pH meter was rinsed with water then dried. It was then dipped in the 7.0 solution first, while slowly adjusting the screw found behind the meter to change the value displayed on the LCD to match with the solution. After which, the same procedure was repeated with the 4.0 solution. For the thermo-hygrometer device, the researchers assumed that it was properly calibrated since it was constantly used and maintained by the technicians of the Mechanical Engineering Laboratory of the university. The digital water thermometer on the other hand was validated using a Fluke thermocouple device which was also borrowed from the laboratory.

V. Results and Discussion

The data acquisition system was programmed to log data every 5 minutes. A total of 7602 data points was collected during 27-day growing period. These data points were then plotted in Microsoft Excel to generate the plot curves for performance analysis shown in Fig. 3 to Fig 8. Growing parameters were fluctuating due to outdoor weather conditions.

Fig. 3 shows the air temperature log of the monitoring system which spanned for 27 days. It could be observed that there is a regular increase and decrease in temperature which denotes the daily change in air temperature in the Philippines. The peak temperature was usually between 12pm to 1pm. The mean air temperature for the whole growing cycle was at 29.07°C. Fig. 4 shows the relative humidity log of the system. Normally, relative humidity varies depending on the time of the day. When the air temperature is the same as the dew point temperature, relative humidity is 100%. Relative humidity therefore increases when the temperature falls toward the dew point. It is at its peak during sunrise and lowest when the air temperature is highest which is at midday. The mean relative humidity of the system was 89.09% Fig. 4 accurately shows this relative humidity trend. It also shows that the peak sensor value of 95% was always reached due to frequent occurrence of rainfall during the growing period. Similar to Fig. 3, Fig. 5 shows the consistent fluctuation of the temperature of the water in the reservoir. The temperature also varies depending on the time of the day. Mean water temperature was 28.34°C. Fig. 6 on the other hand shows the light intensity log of the system. The log presents the time of day where the hydroponic system receives the peak sunlight. Fig. 7 indicates that the pH level of the reservoir was stable with an average of 8. Sudden decrease of pH level at the start was due to addition of pH down solution during the first week of the growing cycle. Fig. 8 presents the water level log of the reservoir for 27 days. Typically, the water level should be decreasing over time as the plants grow bigger. However due to bad weather conditions, the plants did not reach maturity and were not able to properly absorb water from the system, thus having a relatively stable water level value. Furthermore, rainwater was able to penetrate the hydroponic channels which slightly increase the water level in the reservoir.

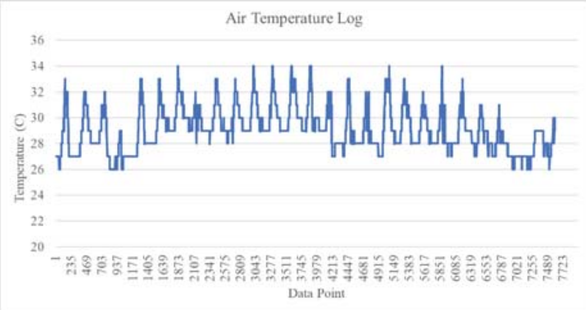

Fig. 3. Air Temperature Log from DAQ for 27 days

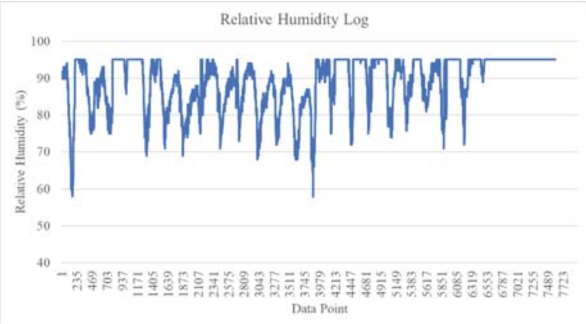

Fig. 4. Relative Humidity Log from DAQ for 27 days

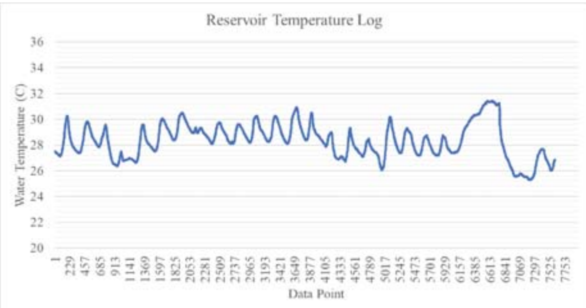

Fig. 5. Reservoir Water Temperature Log from DAQ for 27 days

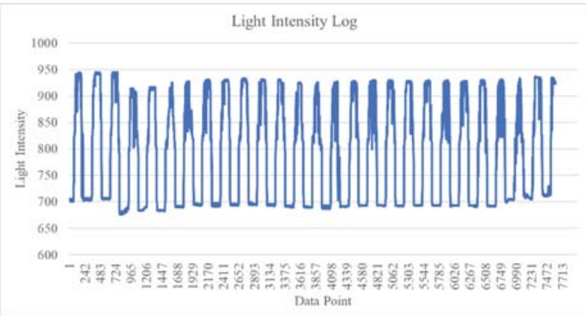

Fig. 6. Light Intensity Log from DAQ for 27 days

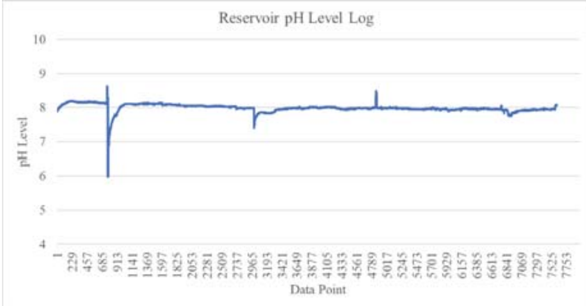

Fig. 7. Reservoir pH Level Log from DAQ for 27 days

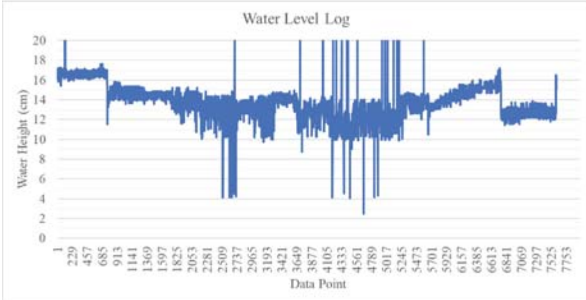

Fig. 8. Water Level Log from DAQ for 27 days

During the 27 days growing period, the data acquisition system was manually checked every three days. Each sensor had its equivalent measuring instrument to countercheck the sensor values. Table. 1 shows the average percent error of each growing condition based on their respective standard instrument. The percent error for each sensor was below or near five percent, therefore the sensors are considered accurate.

Table I. Average Percent Error of DAQ Sensors

Growing Condition	**% Error**
Water Level	5.100
Water Temperature	1.450
Ambient Temperature	4.448
Relative Humidity	3.224
pH	2.456

VI. Conclusion

The data acquisition system was an essential aspect in the success of the hydroponic system as its assembly and construction helped significantly in the research and analysis of the system. The data gathered by the sensors that was stored in the SD card showed fluctuations in environmental conditions occurring in the system in real time which proved ease in system monitoring. The DAQ showed the performance of the hydroponic tower in terms of air temperature, water temperature, water level, relative humidity, light intensity, and pH level, which was all shown visually in the graphs and charts generated in Microsoft Excel. With those graphs, trends of the system were straightforwardly observed and problems or areas for improvement were easily identified.

Moreover, the generated graphs are confirmed to be accurate as the data acquisition system was validated by comparing it with several standard instruments. The different parameters that were measured using the sensors showed a relatively low computed percent error–close to or less than 5%. Evidently showing that the sensors were calibrated and tested since its values were within the acceptable range for accuracy. With this, the information gathered from the SD card is confirmed to be reliable and accurate.

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