November-December 2019
ISSN: 0193-4120 Page No. 5192 - 5199

Internet of Things Applied to Solar-Powered Smart Agricultural Monitoring System: A Prototype Development

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Abstract

This paper introduces the prototype development of plant monitoring and smart irrigation using Internet of Things (IoT). The main purpose of development is to provide a utility model prototype with a combined technology in monitoring a vegetable farm for irrigation system. In the process of development, an adaptive process from traditional irrigation was utilized to illustrate and verify aspects of smart irrigation's conceptual design. A Circuit board was designed and developed to position the GSM and wi-fi modules, microcontrollers, relays, transistors, capacitors and other circuit devices. A photovoltaic energy was utilized in driving the circuit board to complete its electrical function. The IoT devices used were soil moisture sensors, Arduino microcontroller, Global System for Mobile Communications (GSM) module, Wi-Fi module, and solenoid valves. Cloud computing coupled with the use of several development software like Hypertext Preprocessor (PHP), MySQL database and Arduino Integrated Development Environment (IDE) were utilized.

The developed prototype was built at the nursery of the City Agriculture office of Cauayan City, Isabela, Philippines. Technical aspects were evaluated by Information Technology Experts and was validated using quality standards on IoT Application Quality Management (IoT-AQM) in terms of functionality, reliability, efficiency and portability. Costs associated in the development of the prototype were presented together with the materials used. Solar-powered smart irrigation system is one of the answers of traditional irrigation system in the Philippines. It is one of the solutions to a water shortage in vegetable farming where outcomes tell us that this result can be executed for a lessening of water loss and decrease the manpower necessary for farming. It is recommended that the Philippine government should initiate small projects using solar energy for every barangay so that vegetable farmers can gradually adopt the concept and practice precision farming.

Keywords: *Cloud Computing, IoT devices, Smart Irrigation, Utility Model Prototype*

I. INTRODUCTION

Population growth and urbanization are main concerns of the World today where hunger and poverty are still evident to some developing countries. According to Food and Agriculture Organization, food produce cannot augment the number of hungry people specially the poorest of the poor. It is the reason why the world needs sustainable agriculture and food security for the purpose of eliminating hunger. It was also an issue that water resource availability is expected to diminish while, simultaneously, a widespread increase in the risk of flooding is anticipated.

TEST Engineering & Management

November-December 2019
ISSN: 0193-4120 Page No. 5192 - 5199

Agriculture plays a big role in the development of the Philippine economy and attainment of inclusive growth. Irrigation is an important component of the agricultural system. Over the years, despite receiving the bulk of major public investments, the country's national irrigation systems have always performed below expectations. This poor performance according to AGRIMAG magazine was due to overly optimistic technical and economic assumptions, inadequate water supply, inappropriate designs, and difficulties in operation and maintenance. An article states that one of the problems raised today is that Agricultural land in the Philippines is being developed into industrial areas, shopping malls and subdivisions (De Guzman, 2018).

Agriculture in the Philippines has always been associated with manual labor and backward traditional farming methods (Mogato, 2018). However, progress is already creeping into the sector slowly but surely. In the past few years, both the government and the private sector made efforts to address self-sufficiency in important food staples through the introduction of hybrid seeds, innovative farming techniques and technology to the agriculture sector. Farmers may be reluctant to invest in an uncertain climate with more constraints and it will take time. Department of Agriculture however said that, farmers adopting technologies is an investment where some of the benefits are for society, and for the rewards to flow continuously, guidance must be given to them.

According to Organization for Economic Co-Operation and Development, adopting technologies for sustainable farming is the key for food security. This was contradicted by Farming First Science Innovation that Innovation is not only driven by technological advances, but also through novel ways of organizing farmers and connecting them to the information they need. Farming First (2019) insisted that many smallholder farmers around the world still farm the same way their ancestors did thousands of years ago. Traditional farming approaches may continue to work for some, but new practices can help many to substantially improve yields, soil quality and natural capital as well as food and nutrition security. The use of modern farm equipment and agricultural sensors, devices, machines, and aerial images, and GPS technology allow agriculture to be more productive.

The Department of Agriculture (DA) has started its solar-powered irrigation projects in different areas of the country, harnessing both surface water sources and solar energy, and at the same time offsetting the use of harmful fossil fuels and the need to extract water from underground water sources (Flora, 2018). The first solar-powered irrigation system according to Gabrido (2019) was located in Laguna, Philippines where the area was surrounded with water but then farmers are still suffering from agricultural drought. In addition, the use of solar-powered irrigation systems can also save farmers more money (Mogato (2019), a negative result was reported that in some part of Mindanao, a solar-powered smart irrigation system failed during El Nino (Bacongco, 2019). Solar technology in the Philippines has just begun and there is still huge room for growth although solar photovoltaic cells are costly, there is a significant lowering of costs. The main reason of humanity in shifting to solar energy is its ability to produce energy that has no limitation, aside from the best reason that solar power is free and clean: no continue to drilling and exploration costs, no spills that can harm the environment because there is no greenhouse gas emissions.

The adaption of Smart technology in farming according to Gopal & Ravi (2017) is an aid to meet the growing demand for sustainable agriculture and food security. Farmers and agricultural companies are embracing technology for analytics and greater production capabilities. Agriculture being one of the largest sources of livelihood in the countryside is exposed to periodic droughts and floods, and even farmers lack agricultural training, market access, and marketing networks.

In this study, traditional farming is transformed through the utilization Internet of Things

November-December 2019
ISSN: 0193-4120 Page No. 5192 - 5199

(IoT). It is where microcontrollers, sensors and actuators were used to interact with the environment, reacts automatically to the real-world events and communicate among themselves using the language of computers. The exchanging of data is influenced by the processes that create services and trigger actions with or without human intervention. Apachos and Sadowski (2018) stresses the used of advanced management concepts where technology is combined with traditional farming that revolutionized the way farmers are able to manage their farms especially in irrigation utilizing combined technologies to monitor crops and by responding appropriately to their needs.

Conceptual Framework

As the researcher is aiming to bridge the stated gap, the study utilized the adaptive process in developing IoT systems from Hussein, Li, and Radermacher (2017) where the process and concept of traditional farming is the basis of transformation into a modernized farming utilizing the Internet of Things (Zhao, 2010) concept. It was observed that the use of microcontrollers, sensors and actuators when networked makes works easier. By adopting IoT and using Adaptive Gateways for dIverse muLtiple Environments (AGILE) methodology for system development, the researcher came up with the development framework for creating a utility model that served as guide in the development of a smart agricultural irrigation and monitoring system.

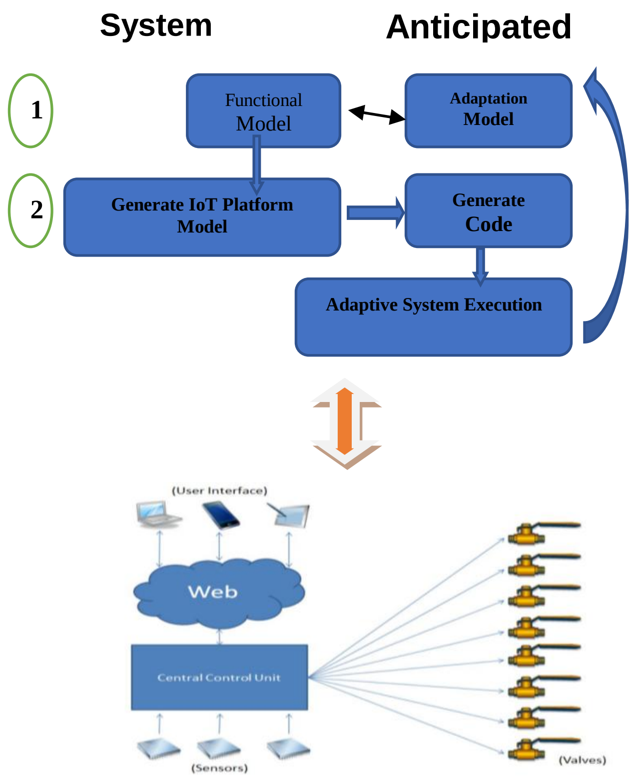

Figure 1. Adaptive Process for Developing IoT Applications (Hussein, Li, and Radermacher, 2017)

To ease the development of adaptive IoT systems, a two-phase process was used. In the first phase, a traditional system model was created to specify the system functionality and its adaptive behavior in order to generate an IoT platform model using the Internet of Things (IoT) devices. In phase two, building the structure which composed of functional services like sensors, GSM and wi-fi modules used to monitor and gather environment data required by the functional services. The Utility Model

TEST Engineering & Management
November-December 2019
ISSN: 0193-4120 Page No. 5192 - 5199

was coded corresponding to the design model using an IoT application as a composite structure of agricultural irrigation and monitoring. This coding control parts of the system like switching the water pump to ON/OFF. A second pattern was adopted to specify which information is provided to the end-user of which the use of cloud computing is utilized for the distribution of needed information.

Statement of the Problem

This study aimed to design and develop a utility model for Internet of Things Applied to Solar-Powered Smart Agricultural Monitoring System: A Prototype Development.

Specifically, it aimed to answer the following:

1. What are the processes involved in the design and develop a solar-powered smart agricultural monitoring system utility model prototype?
2. What is the extent of compliance of the developed smart agricultural monitoring prototype in terms of the overall features and system performance using the Quality Model Standards for Evaluating IoT Applications Kim (2016)?
   a. functionality;
   b. reliability;
   c. efficiency; and
   d. portability?
3. What are the system costs associated with the development of the smart irrigation system prototype?

I. METHODOLOGY

Research Design

The study made use of descriptive survey and research system development to develop and evaluate a utility model for Internet of Things Applied to Solar-Powered Smart Agricultural Monitoring System.

The utility model for Internet of Things Applied to Solar-Powered Smart Agricultural Monitoring System was designed, developed and tested for vegetable garden with an area of 100 square meter located at the Farmers Training and Education Center of the City Agriculture located at Cabaruan, Cauayan City, Isabela. It has 5 vegetable beds planted with vegetable varieties. The developed prototype was implemented and evaluated by twenty three IT Experts who have relevant experiences in IoT applications, Information Systems, System Analysis and Design and Development, Web Specialist, Network Administrators as well as Software Engineering with practical development project relevant to IoT applications and Embedded Systems from Isabela State University Cauayan Campus. Evaluation of compliance of the technology developed was based on the criteria for Quality Standards for Evaluating IoT Applications adopted from Kim (2016) in terms of functionality, reliability, efficiency and portability.

Weighted Mean and Descriptive Interpretation were utilized to present the evaluation of the IT Expert participants on the extent of compliance of the developed utility model prototype. The evaluation of the participants was then analyzed using the following range:

Weight	Range	Description
5	4.20 - 5.00	Very High Extent
4	3.40 - 4.19	High Extent
3	2.60 - 3.39	Moderately Extent
2	1.80 - 2.59	Low Extent
1	1.00 - 1.79	Very Low Extent

III. RESULTS AND DISCUSSIONS

The prototype was designed by applying the concept of adaptation from manual and traditional irrigation and monitoring. Some of the major hardware and software parts of the Internet of Things Applied to Solar-Powered Smart Agricultural Monitoring System. Fig. 1 presents the circuit diagram of the prototype.

TEST Engineering & Management

November-December 2019
ISSN: 0193-4120 Page No. 5192 - 5199

A. Circuit Diagram

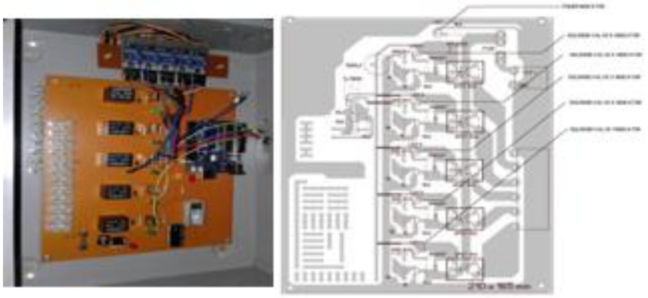

Figure 2. The Circuit Board and Block Diagram Showing the Concept of the Control Unit

Circuit diagram shows the circuit graph that serves as the blueprint plan indicating the lay-out and positions and the capacity of relays, transistors and capacitors used in the development of a utility model for Internet of Things Applied to Solar-Powered Smart Agricultural Monitoring System. It contains Arduino microcontroller and Arduino Board where wires of sensors, GSM module, Wi-Fi module and solenoid valves were connected.

B. The Logic Design

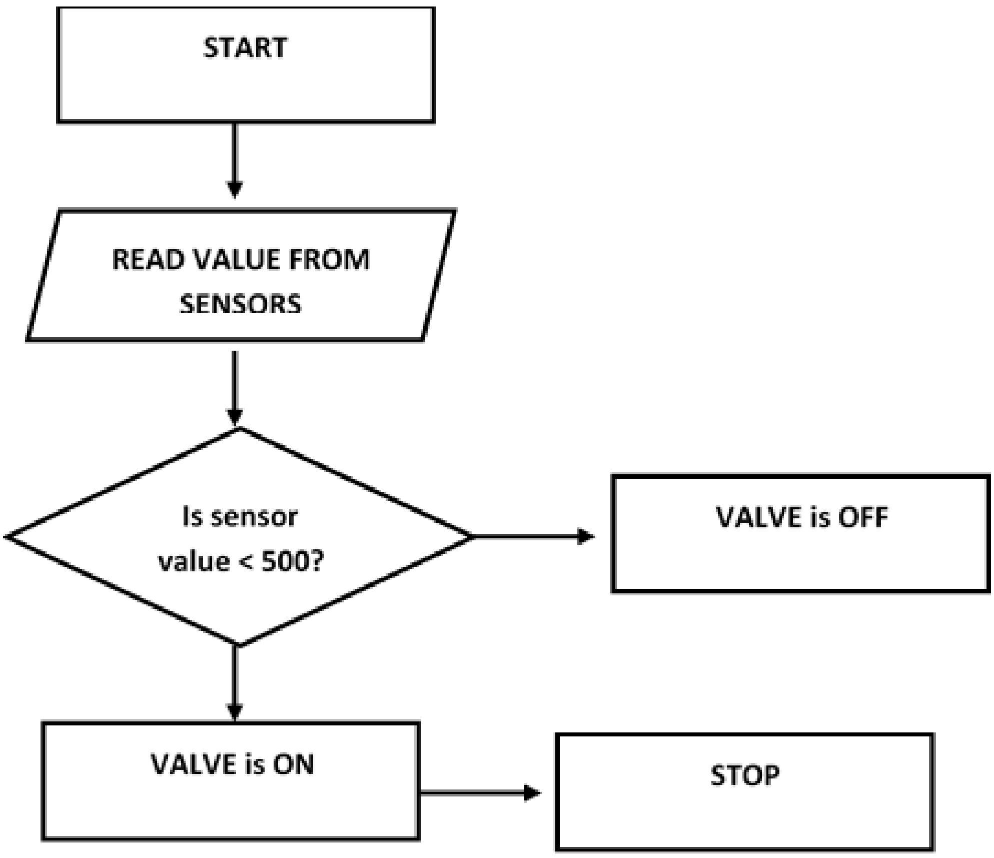

Figure 3. Internet of Things Applied to Solar-Powered Smart Agricultural Monitoring System Fuzzy Logic Design

Table 1. Hardware and Software Minimum Requirements

A. Hardware	Minimum Requirement
➢ Arduino Board	Arduino Uno and Arduino Mega ATmega328
➢ GSM Module	GSM 900a Dual-Band 900/ 1800 MHz. GPRS multi-slot class 10/8. GPRS mobile station class B. Compliant to GSM phase 2/2+ Class 4 (2 W @ 900 MHz) Class 1 (1 W @ 1800MHz) Dimensions: 24x24x3mm. Weight: 3.4g. Control via AT commands (GSM 07.07 ,07.05 and SIMCOM enhanced AT Commands) SIM application toolkit.
➢ Solar panel	50w Polycrystalline 5V
➢ Solenoid valve	½ inch diameter 12V Naturally closed
➢ Sensors	5V
➢ Wi-fi module	SIM 900A. Ethernet shield Operating voltage 5V (supplied from the Arduino Board)
➢ Wi-Fi connection	5mbps
➢ Back-up battery	12V
➢ Relays	5V
B. Software	**Minimum Requirement**
➢ Arduino programming and IDE, C-based programming	Server Side: ○ Php ○ MySQL ○ Apache

Table 2. Weighted Mean and Descriptive Interpretation of the Quality Standards of the IoT Application Developed in Terms of Functionality, Reliability, Efficiency, and Portability .

Quality Standards for IoT Applications	General Weighted Mean	Descriptive Interpretation
1. Functionality	4.73	Very High Extent
2. Reliability	4.63	Very High Extent
3. Efficiency	4.33	Very High Extent
4. Portability	4.75	Very High Extent

Functionality of the Developed Utility Model Prototype. After several testing on the capability of the system, the IoT application for smart irrigation system fit the needs of the farmers using IoT devices. The GSM module attached to the micro controller successfully send messages to the farmer. The Wi-Fi module collected data from sensors are processed giving actual monitoring through a web application dashboard. The solenoid valve acted with an ON/OFF state once the sensors detected a dry soil. The IoT application was able to interact with the specified systems through sensor network and IoT device.

Quality Standards of the IoT Application Developed Based on Reliability. The system utility model prototype has the capability for device mobility and the correctness of the information processing in different stages of a process. The fusion of different embedded technologies is reliable for its functions and results. This means that connectivity and network of the system performs well.

Quality Standards of the IoT Application Developed in Terms of Efficiency. The application has the capability for device mobility and the correctness of the information processing in different stages of a process.

Quality Standards of the IoT Application developed in terms of Portability. System utility model prototype can be easily installed in a specified environment. Capability of parts can be easily replaced in conformance with other parts. Integrated parts of the developed protype can be easily replaced in such a way that it is always available from the local market. The product can be adapted at any kind of farm irrigation at any type of agricultural system.

Table 3. System Costs Associated with the Development of the System

QUANTITY	UNIT	DESCRIPTION	UNIT PRICE	TOTAL PRICE
A. DRIP IRRIGATION				
12	Meter	Drip hose	30	600.00
5	Pc	Solenoid valve ½ DC 12V normally closed	250	1,250.00
3	Pc	PVC ½ blue pipe	450	1,350.00
1	Pc	Water regulator, connecting to water tank		
1	Pc	PVC 2" blue pipe	180	180.00
5	Pc	Tee pipe 2" for water tank	445	445.00
10	Pc	End cap	80	800.00
5	Pc	Elbow pipe ½	60	300.00
			Sub Total	4,950.00
B. IoT Devices				
15	Pc	Soil Moisture Sensor	120	1,800.00
1	Pc	Adaptor 9v	120	120.00
1	Pc	50 watts Solar Panel	2,500	2,500.00
1	Pc	Arduino Uno microcontroller set	3,000	3,000.00
1	Pc	GSM module-Sim 900A	1,500	1,500.00
1	Pc	Wifi module	250	250.00
1	Pc	Solar battery	1,700	1,700.00
			Sub Total	9,770.00
C. OTHERS:				
1	Pc	Circuit board with diodes, resistors, transistors, wires	3,000	3,000.00
1	Pc	Solar battery	1,700	1,700.00
1	Pc	Circuit board housing	2,000	2,000.00
			Sub Total	6,700.00
		Total Cost of Materials in Pesos		21, 495.00

Figure 4. Prototype Design of Internet of Things Applied to Solar-Powered Smart Agricultural Monitoring System

November-December 2019
ISSN: 0193-4120 Page No. 5192 - 5199

I. RECOMMENDATIONS

Based on the findings and the conclusions of the study, the following are strongly recommended:

1. There should be a series of soil analysis before planting crops that will best suit on the soil. For proper irrigation and monitoring of crops growth, the system should also include fertilization analysis on crops. For future improvement of the system, online monitoring on the actual - camera and physical appearance of the crops should be given treatment and suggestions from the system.
2. To be fully functional on the developed prototype, there should be a "school in the farm" project of the Philippine government that would start from the municipal agriculturist educating barangay or unit officials on the conduct of IoT in agriculture. Although it takes time to educate and train small-time farmers in the community, there should be a rigid training on their part starting on the usage of Internet and its functions to render reliability of the concept of IoT application. Efficiency on the developed utility model should inculcate in the minds of the farmers that modernized concept of farming will help them in anyway to increase crop production and help them manage their farms easily. Microcontrollers, sensors and agriculture IoT parts are readily available in the market, agriculturist should include educating small-time farmers of the readily available stores and counterparts of the system parts of IoT irrigation and monitoring.
3. Farmers should be educated for them to know that solar panels will be lasted for long-term basis and that it could give them a payback period of shorter time. The initial cost is high but eventually they can see the crop yield and effect in succeeding years of using the system. Farmers must be educated that the sun energy is free and it would give them less hazards for the environment and their family when used to energized their farm needs. Lastly, the proposed system can be enhanced by adding up machine learning algorithms, capable to study and recognize the necessities of the crop, this would aid the agriculture field to be an automatic system. The inspections and outcomes tell us that this result can be executed for a lessening of water loss and decrease the manpower necessary for farming.
4. The Philippine government should initiate small projects using solar energy for every barangay so that vegetable farmers can gradually adopt the new method of irrigation system in farming. Agricultural cooperatives should offer helps specially trainings to continuously embrace the free energy from the sun for sustainable farming.
5. The IoT utility model prototype for agricultural irrigation and monitoring could be built and be implemented anywhere in the Philippines.

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