TEST Engineering & Management

March - April 2020
ISSN: 0193-4120 Page No. 5011 - 5019

Design and Development of a Solar Powered Smart Irrigation System: An Adaptive Process Model

Rose Mary A. Velasco
Isabela State University, Cauayan City, Isabela, Philippines
rosemary.a.velasco@isu.edu.ph

Article Info
Volume 83
Page Number: 5011 - 5019
Publication Issue:
March - April 2020

Article History
***Article Received**: 24 July 2019*
***Revised**: 12 September 2019*
***Accepted**: 15 February 2020*
***Publication**: 27 March 2020*

Abstract

This paper shows the prototype design of a smart irrigation system using Internet of Things (IoT) for monitoring a vegetable farm. It is a model prototype for a small community or a barangay where vegetable farmers can utilize it for a more productive vegetable output. An adoptive process of development was utilized from traditional irrigation transforming into a modernized irrigation system through an adaptive process. Hardware and software specification requirement were identified as well as input and output requirements. A machine learning application was used where a manual concept was modeled for a development of its counterpart. A block circuit diagram illustrates the function of smart irrigation system that contain the Global System for Mobile Communication (GSM) and wi-fi modules, microcontrollers, relays, transistors, capacitors and other circuit devices. A photovoltaic power supply was utilized to drive the circuit board for the electronic functions. 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 smart irrigation prototype was built at the nursery of the City of Cauayan, Isabela, Philippines. Technical aspects were evaluated by Information Technology Experts and was validated using quality standards on IoT Application Quality Management (IoT-AQM). The Philippine government is promoting the utilization of solar energy to help farmers for a more produce for the purpose of sustainable farming and food security. It is recommended for small projects of every barangay so that vegetable farmers can gradually adapt the modernize methods of irrigation system of farming in the Philippines

Keywords; *Cloud Computing, IoT devices, Smart Irrigation, adaptive process, machine learning*

I. INTRODUCTION

Agriculture plays a big role in the development of the Philippine economy. From backward farming where famers used to till their lands using their bare hands and mean traditional tools for a minimum produce. Irrigation system type is not improved because small time farmers are just waiting for rainfalls to start cropping while wrestling with the national calamity brought by climate change. Agricultural technology is among the most revolutionary and impactful areas of modern technology today driven by the fundamental needs for food, for feeding an ever-growing population. It is an eye opener that farming needs modern farm machineries with the aid of Internet of Things to help farmers produce more yields where most of the previous works were performed by number of people and animals.

Technology is working its way into farming, with an array of wireless, app-driven devices (Hammill, 2017). Most of these control systems have the ability to regulate the frequency of irrigation, recording every minute and the duration. Advancements in sensor technology to measure or estimate moisture in soil have taken place with time. Nowadays, adopting technologies for sustainable farming is the key for food security. It is a challenging and dynamic issue for farmers, extension services, agri-business and policy makers as stated by Ekekwe (2016). He emphasized the use of agricultural machineries that have been designed for practically every stage of the agricultural process. These machines have massively increased farm output and dramatically changed the way people are employed and produce food worldwide. The main key together with microcontrollers, sensors, and modules for an IoT application to transform agriculture is the Internet. According to Abuseta (2015), an application of sensors was utilized to collect outside and actual data. IoT devices will further process the gathered and sending it to the Internet in order to apply the planned actions based on codes and programs. The application of IoT was actually experienced in our everyday living especially electronic devices used at home, workplaces, in a neighborhood where IoT devices were connected and provide data which is accumulated and analyzed for the benefit of everyone using it. Embedding these IoT and microcontrollers give a big impact in the work and lives of the people. Agriculture is not an excuse to these applications because government and private sectors are working hand in hand around the globe to combat famine as everybody is wading for climate change.

Solar Energy is one way of helping farmers in a number of ways, like increasing agricultural products by not spending too much on diesel for generator sets thereby reducing pollution. Solar energy can cut a farm's electricity and heating bills. 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). Not all places play to good role on the use of solar power, a negative result was reported that in some part of Mindanao where a solar-powered smart irrigation system failed during El Nino (Bacongco, 2019).

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. The main reason why there is a growing demand of sustainable agriculture is because of the overpopulation and the after effect of urbanization. A high demand for sustainable farming is needed to feed the people especially those who are in the urban areas that were not able to plant vegetables and other root crops because of limited land area. These vertical and rooftop farming are now in-demand to maximize the use of the rooftop buildings to produce food.

In this study, traditional farming is transformed through the utilization Internet of Things (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. In a speech delivered by Socioeconomic Planning Secretary Ernesto Pernia during the annual meeting of the National Academy of Science and Technology, said that “the Philippine agriculture could be a lucrative industry with the right investments in technology and development” (www.philstar.com). Agriculture in the Philippines has always been associated with manual labor and backward traditional farming methods (Mogato, 2018). Meanwhile, Mogato added that the department of agriculture announced that Filipinos

March - April 2020
ISSN: 0193-4120 Page No. 5011 - 5019

cannot use primitive farming methods forever. It is the reason why the Philippine government today through the Department of Agriculture (DA) and the National Irrigation Administration (NIA) are giving all the supports to every farmer to embrace the use of solar-powered smart irrigation systems. The real challenge, however, is how to make these farmers pick up a smartphone and analyze the data to increase their farm yield.

The province of Isabela is an agricultural province that produces variety of crops and agricultural products sustaining the needed food to its local folks. In case of calamity brought by climate change, the province of Isabela is making its way to help nearby provinces by giving agricultural products as an emergency help to the victims. The Philippine government is in assisting farmers to gradually adopt the smart irrigation techniques. This is one-way or another could further strengthen the agricultural part of the province as a way of helping farmers. With the aid of research and development, adapting these modern technologies in farming could give a lucrative industry that can foster food security in the province as well as to the entire country.

Conceptual Framework

The use of embedded design with microcontrollers, sensors and actuators when networked makes works easier. This machine learning technology is an adoption of IoT using Adaptive Gateways for dIversemuLtiple Environments (AGILE) methodology for system development. In this way the researcher came up with the development framework for adapting and creating a model prototype in the development of a smart agricultural irrigation and monitoring system. Figure 1 illustrates the adaptation process.

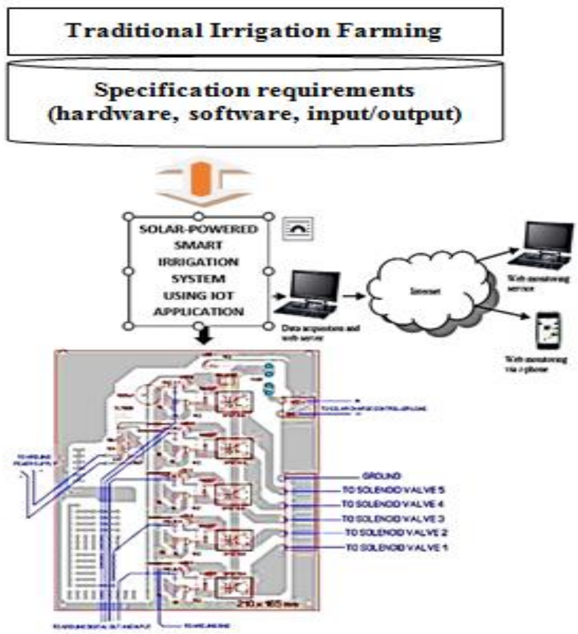

Figure 1. A Concept diagram of an Adaptive Process of Smart Irrigation System with a Schematic Representation of the Embedded Design

Traditional farming was modeled to create a smart irrigation system. Embedding IoT devices in the development is part of the machine learning technology for IoT application system. The programs for the functions of these actuators were uploaded into the Internet where the system will function as one in the cloud. The dashboard interface application was developed to monitor the action of the solar-powered smart irrigation system. This dashboard interface will monitor and control the irrigation system.

The status of soil moisture and the solenoid valve will be displayed on a developed application using a dashboard. The IoT application is the product of an connections from the microcontroller to other IoT devices like GSM and Wi-Fi modules. In a matter when the moisture sensor detected the condition of the soil as wet, then the microcontroller sends the instructions to the relay to switch off the motor using a solenoid valve. Furthermore, the system was developed by interfacing with a Global System for Mobile Communication (GSM) modem to give report by way of text messaging on the time each

Published by: The Mattingley Publishing Co., Inc.

TEST Engineering & Management
March - April 2020
ISSN: 0193-4120 Page No. 5011 - 5019

plot is watered.

In this system, all the data gathered from the sensors and the outside environment using various parameters are given to the Arduino Uno and Arduino Mega microcontrollers as an analog input. A preset value of soil moisture sensor is fixed in the microcontroller and was programmed basing from a Management Allowable Depletion (MAD), (awqa.org). When the soil moisture goes beyond the particular threshold value, the microcontroller will give a go signal to the solenoid valve to automatically irrigate the plots and once the required amount of water is fulfilled, the solenoid valve will automatically close or stop. The Microcontroller transmits that information gathered from the soil moisture sensor in the internet in the form of wi-fi module using the ESP8266 model attached. The use of solenoid valve which is naturally closed automatically trigger water pump going to the water pipe to satisfy soil water content and moisture. The circuit board runs completely with solar energy where solar controller and a battery back attached to the microcontroller board. All these components are located inside a weatherproof Circuit box to protect them from any climate change. This concentrator sends all the gathered data to the cloud for further processing and for the purpose of monitoring The Circuit board was designed with Arduino where the circuit schematic is as shown for each specific value like the transistors and relays needed to send and control data for the soil saturation and readings. All data and values were set and programmed using Arduino IDE uploaded in the cloud, for remote operation. Farmers can monitor the data for each value by SMS or short messages using a cellular phone and by the web application when connected to the Internet. This means farmers can monitor sensor's actions when was the turn ON or OFF of the solenoid valve depending on the average or threshold value assigned for the crop. It is usually at 50% of soil MAD value of the allowable water allowed. In real-time mode, the microcontroller uses average soil moisture sensor readings for 15 minutes to determine if to open or close the solenoid valve. ESP 8266 is the wi-fi shield module used which is a self-contained wireless network processor that simplifies the implementation of long-range wireless or Internet connectivity.

II. METHODOLOGY

The prototype was designed by applying the concept of adaptation from manual and traditional irrigation and monitoring. Hardware and software requirements as well as the input and output parts must first be identified according to functions. Fig. 1 presents the circuit diagram of the prototype where a schematic representation of the embedded design life cycle (Berger, 2002) using AGILE Methodology for embedded system was utilized.

Phase 1.

- Product specification. Hardware and software components for the system development were identified.
  - Soil Moisture Sensors.
  - Web Services.
  - Remote Control.
  - Web Application with Scalable Interface.

PHASE II. Partitioning of the design into its software and hardware components.

The Circuit Diagram

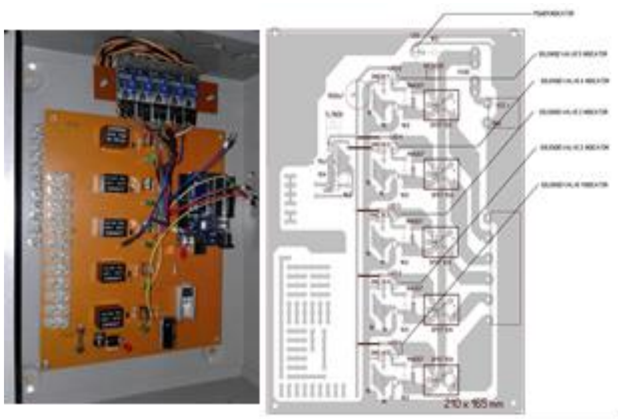

Figure 2. The Circuit Board and Block Diagram Showing Embedded IoT devices of the smart irrigation process

Published by: The Mattingley Publishing Co., Inc.

March - April 2020
ISSN: 0193-4120 Page No. 5011 - 5019

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 adapting a Solar-Powered Smart Irrigation System. It contains Arduino microcontroller and Arduino Board where wires of sensors, GSM module, Wi-Fi module and solenoid valves were connected. The output of soil sensor circuit is directly connected to the circuit board and Arduino. A LED indicates the process of supplying water into the vegetable plots and a collection of data given by a sensor triggered by a sensor circuit. The LED's ON state indicates the trigger of a solenoid valve to supply water. The LED's state OFF indicates moisture presence in the soil. GSM module is used for sending SMS to the user. In the circuit board and control diagram, the researcher was able to utilize the SIM 900A GSM module. A voltage regulator is used to power the SIM 900A GSM module which has an operating voltage rating of 5V with 12v in the slot of the board. A 5V relay is used to control the solenoid valves for water pump gates which is naturally closed vale and state. The relay is driven by a Transistor which is further connected to Arduino.

The transistors remain on its ON state when the two probes of the soil moisture detected a moisture from the soil and the pin from the Arduino remains low causing a message of SMS to send a "Normal" condition of the soil, and the solenoid valve will remain closed. On the other hand, if there is no Moisture in soil then the transistor will remain Off The Arduino turns "On" the water motor and also sends message to user about "Low Soil Moisture". And solenoid valve will be turned ON. Solenoid valve will automatically turn off when there is enough moisture in the soil. Software requirements needs Arduino Integrated Development Environment (IDE), PHP programming, Apache for web support MySQL for database and the serverside programming where Arduino language use a C/C++ code.

The study uses Windows as the operating system, Apache as the web server, MySQL as the relational database management system and PHP as the object-oriented scripting language in web development to create a dynamic web page content.

1)Arduino- is used for controlling whole the process of the Solar-Powered Smart Irrigation system.

2)Soil Moisture Sensor – was used to detect the moisture content of the soil.

3)WIFI Module - The ESP8266 Wi-Fi was utilized which is a self-contained (system on chip) SOC with integrated TCP/IP protocol to give microcontroller access to Internet

4)Solar Panel - is to convert solar energy into DC electrical energy generally of 12V, which is further used for the rest of the circuit board.

5)Solar Battery – is an electric device used to store electric current which is produced from the solar panel and supplied to the corresponding loads in the circuit board.

6)Charge Controller. This device is used especially at night to maintain proper charging voltages of the different IoT devices.

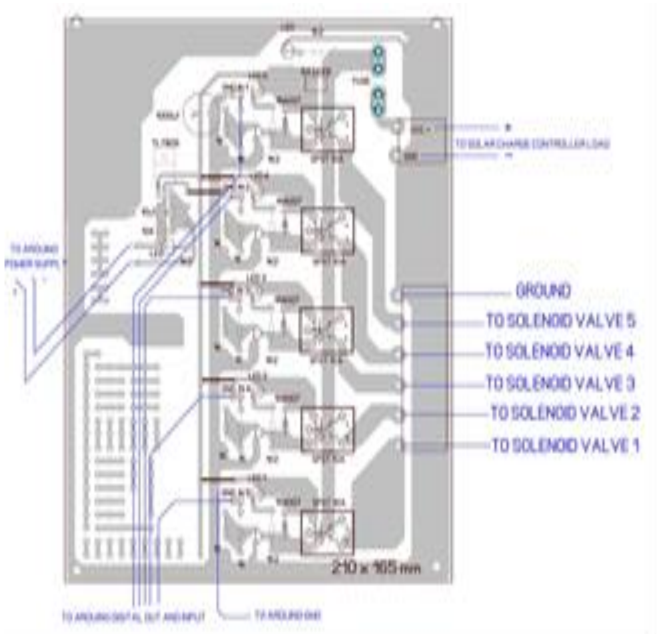

Figure 3. Solenoid Valves connection

Published by: The Mattingley Publishing Co., Inc.

March - April 2020
ISSN: 0193-4120 Page No. 5011 - 5019

The relay board needs to be powered continuously by connecting the 5V and GND on the relay board to the 5V and GND on the SD shield using jumper wires. Design positioning of solenoid valves are ideal for applications where power is limited, because continuous power is not required to maintain the open position. To reduce power consumption, an internal magnet can hold the solenoid in the open position. These valves also require a short pulse (50 ms) to open or close, which can be delivered using a 9V battery. To open the valve, the red wire from the valve needs to be connected briefly to the positive wire of the power supply (9V battery in this case), and the black wire to the negative one. To close the valve, the polarity needs to be reversed, meaning that the red wire from the valve needs to be connected to the negative side of the power supply and the black wire to the positive side. We used four relays to build an H-Bridge, which can be used to do this

III. RESULTS AND DISCUSSIONS

The result of design and development of a smart irrigation system is a community-based prototype.

Figure 4. Solar-Powered Smart Irrigation System

The study was built with microcontroller and sensor parts, which were collected using operational or runtime period using Integrated Circuits (IC). Two copper wires are injected into the soil to sense the soil condition, whether it is dry or wet. A microcontroller was used to control the entire system by detecting the sensors and parts. When the sensors detected the soil condition as dry, the comparator directs the command to the microcontroller, it repeats the cycle to drive water to the crops using solenoid valve. The table below shows the hardware and software minimum requirements as being used in the study.

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 and IDE, C-based programming	Server Side: o Php o MySQL o Apache

Table 1. Hardware and Software Minimum requirements

Published by: The Mattingley Publishing Co., Inc.

Figure 5. Prototype Output Design of the Solar-Powered Smart Irrigation System

The programs for the functions of these actuators were uploaded into the Internet where the system will function as one in the cloud. The dashboard interface application was developed to monitor the action of the solar-powered smart irrigation system. This dashboard interface will monitor the irrigation system.

Furthermore, the system was developed by interfacing with a Global System for Mobile Communication (GSM) modem to give report by way of text messaging on the time each plot is watered. Some of the features are shown.

A. Application Features

Graphical User Interface (GUI). The IoT application has a simple Graphical User Interface embedded within the php program, Mysql and Apache with Arduino IDE

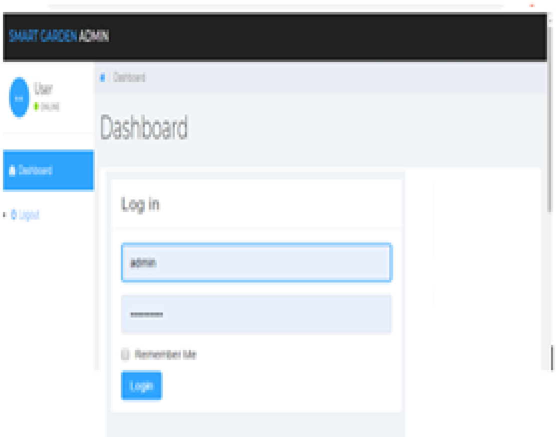

Figure 6. Log-in Window

Log-in window is the main form of the application. For monitoring purposes, it was generated to view the act of the solenoid valve's ON/OFF State. Opening the application needs a user login for user's identity and password in order to see how modules and actuators monitor.

Figure 7. Live Data Window

The Live Data Window shows how saturated the soils are. It means that monitoring is done through the actuators report for the valve to continue watering or not. If soil reaches 10% for sand and 50% for clay, it is fully saturated. Tension at Manageable Allowable Depletion (MAD) is typically -50 to -70 centibar. Volumetric Water Content (VWC) at this point can range from 5% to 40%. Any moisture content below this level is in the 'Stress' zones.

Figure 8. Dashboard Monitoring Window for Solenoid Valve

Published by: The Mattingley Publishing Co., Inc.

March - April 2020
ISSN: 0193-4120 Page No. 5011 - 5019

Dashboard Monitoring shows what part of the farm are undergoing for watering. As the solenoid Valve opens, it shows an ongoing process of watering, an “ON” status will show on the dashboard. The monitoring windows shows 5 plots are being monitored.

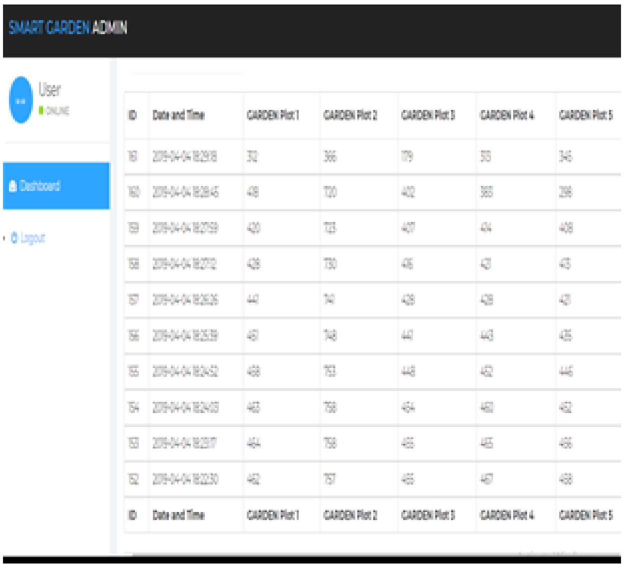

Figure 9. Dashboard Window Monitoring for solenoid valve and sensor function monitoring

A summary of monitoring within the day for all the plots showing the time and percentage of soil saturation.

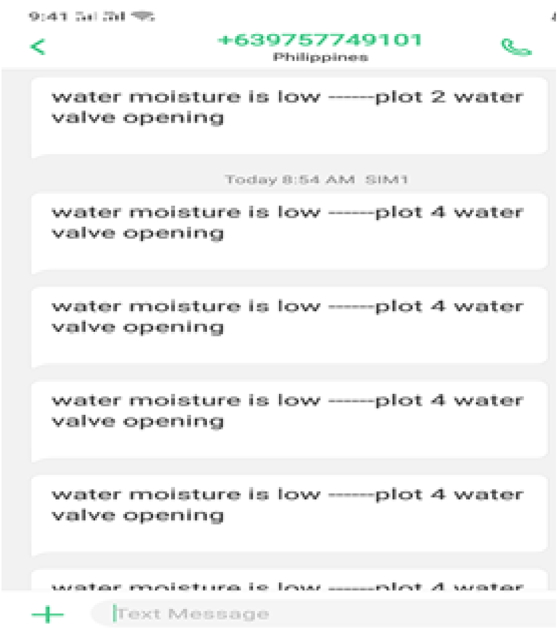

Figure 10. Text Messaging /SMS Monitoring

A GSM module was used in order to monitor the watering of the vegetable farm in case the end user is not connected to the Internet. It displays a text message for monitoring. A sim card was inserted at the GSM module slot located at the circuit board for this purpose.

IV. RECOMMENDATIONS

Based from the evaluations on the design of the developed system prototype, the following are strongly recommended:

1. There should be more improvement on the design for bigger and wider area that could be maintained. For future improvement of the system, online monitoring on the actual - camera and physical appearance of the crops should be given with treatment and suggestions from the system.
2. 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.
3. 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.
4. The designed system will result for a lesser maintenance of the vegetable farm with lesser water loss and farmers will do other works necessary for farming.
5. 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.
6. The IoT utility model prototype for

Published by: The Mattingley Publishing Co., Inc.

agricultural irrigation and monitoring could be built and be implemented anywhere in the Philippines.

REFERENCES

[1]. Abuseta, Y. (2018). Towards an MDD Based Framework for Self Adaptive IoT Applications Development. International Journal of Computer Science and Software Engineering (IJCSSE), Volume 6, Issue 11, November 2017. ISSN (Online): 2409-4285. www.IJCSSE.org Page: 273-283

[2]. Ekekwe, N. (2018). Nanotechnology and Microelectronics: Global Diffusion, Economics and Policy. John Hopkins University, USA

[3]. Flora, I. (2018). DA starts solar irrigation program. Retrieved at https://www.sunstar.com.ph/article/1742079

[4]. Gabrido, J. (2019) Laguna's first solar-powered irrigation gives hope to town's agricultural future. Philippine Information Agency. https://pia.gov.ph/features/articles/1019322

[5]. Hammill,R. (2017). How does your garden grow? With high-tech apps and robotics. Retrieved from https://www.kansascity.com/living/liv-columns-blogs/kc-gardens/article138322458.html#storylink=cpy

[6]. Hussein, M., S Li, S., and Radermacher. A. (2017).Model-driven Development of Adaptive IoT Systems. http://ceur-ws.org/Vol-2019/modcomp_3.pdf

[7]. Mogato, A. (2018). In the Philippines, technology is seeping into agriculture. Retrieved at https://www.bworldonline.com/in-the-philippines-technology-is-seeping-into-agriculture/

[8]. Pernia, Ernesto (2018). Keynote Address of Socioeconomic Planning Secretary Ernesto M. Pernia at the Asia Pacific Forum 2017. Retrieved from http://www.neda.gov.ph/tag/neda-director-general-ernesto-pernia

Published by: The Mattingley Publishing Co., Inc.