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Remote Sensing Device for Water Level and Discharge Monitoring of Agricultural Irrigation Canal

Jibsam F. Andres[1], Michael E. Loretero[2], Benjie R. Martinez[3]
[1]DEng candidate of University of San Carlos, Talamban, Cebu City 6000, Philippines and Associate Professor of Western Philippines University, Aborlan, Palawan, 5302, Philippines, andresjibsam@gmail.com
[2]Professor of University of San Carlos, Talamban, Cebu City 6000, Philippines, meloretero@usc.edu.ph
[3]Faculty,Western Philippines University, Aborlan, Palawan, 5302, Philippines, benjiemartinez@gmail.com

Abstract*—Efficient water management is an effective tool in the agricultural aspect. This was implemented by monitoring water depth and discharge supplying water to agricultural fields along irrigation canals. The same method was needed in studying agricultural irrigation canals as small-scale water source of energy. To provide access on continuous water profile monitoring, the fabrication of a remote sensing monitoring device was conducted and experimentally observed for data validation. The device was supplied by solar power, to provide the power requirement of its hardware including an ultrasonic sensor, a microcontroller, and a wireless communication system. The device was also used to measure the temperature and humidity of the area location. Data monitoring uses Arduino program. Through microcontroller, the whole system of the device gathered and processed the data and sent it to the registered cellphone number through SMS. The accuracy of the data measurement of the device was validated through simultaneous manual measurement of the water level. Results show that at a 5% level of significance, there is no significant difference between the manual measurements to the device measurement only when the ultrasonic sensor was at 100 centimeters and 120 centimeters above the water floor level. The study then recommended the use of monitoring devices as primary data in assessing the water power capacity of the stream specifically the agricultural irrigation canal as a small-scale water resource as well as for the water management techniques in the irrigating agricultural area.*

***Index Terms*—agricultural irrigation, remote sensing, water discharge, monitoring device**

INTRODUCTION

AGRICULTURAL irrigation canals exist all over the country and were managed by the farmers as associates under the National Irrigation Administration (NIA) [1]. The proper management of agricultural irrigation requires information on the volume and or water discharge to be delivered at the specific monitored area. This water flow discharge is the basic information needed for proper irrigation management of crops. However, this basic information was not updated [2] and stated that no flow data in the location of the study since flow gauging activities were discontinued in 1980. In irrigation management, water discharge should be controlled and should deal with maintaining a desired water level, not a desired water flow [2].The Philippines is a tropical country that is abundant in water. However, the country still has a water crisis. Many have written about the emerging water crisis in the Philippines and believe that the solution to this problem lies in improving the efficiency of water management including in agriculture [3].

Importance of Water Profile

Continuous data collection is recommended in determining water availability from rivers and rainfall to account for climatic and terrestrial changes [4]. In the Philippine setting, the National Irrigation Administration (NIA) uses the 5-year moving average to determine river discharge. This is the probable amount of water that will be available that is estimated primarily from the analysis of river and rainfall data [4]. However, data on stream flow are observations that are not being performed regularly and therefore outdated data are used to predict water availability.Also, water flows or discharges has a great part in the food sufficiency activity. Successful farming activities rely on the flows or discharges as well as the amount of rainfall is also an important variable to be monitored. These water discharge and rainfall data are water profiles of information. This data of information should be considered important for making decisions about the management and operation of the irrigation system [4].

The water management project of the Philippine government was an old program implemented by the National Irrigation Administration. One of the basis was Memorandum Circular (MC) #032 and MC #046-A series of 1974. These memorandum circulars were reiterated with MC #043 and MC# 049 series of 2006. These memorandum circulars required the installation of measuring devices in all National Irrigation Systems for water management. Measuring device installation in all National systems of one rain gauge per water-master division and one direct reading measuring device (staff gauge) per gatekeeper section were required [5].The necessity of upgrading the system in monitoring water management is the same requirement for the assessment of small-scale water resources as a source of energy on-site. With these, the study aims to fabricate a water level measuring device. The device will be free for replication and is suited for remote area applications. The device is powered by solar energy and the hardware contains sensors. To make the device end-user friendly, the system of the device could send data which are the water level and water discharge to the user through text messages (SMS).
As the study on small-scale water resources as a source of energy continues, the consideration of water at agricultural irrigation canals was significant as a readily accessible water resource. With this, the water profiling of existing irrigation canals is important for hydropower characterization. This water profile will be a data basis for computing the water capacity of small-scale water resources. The application of water profiling using a remote sensing device provides data both for agricultural irrigation water management and also for the assessment of small-scale water resources as a source of energy. To validate the accuracy and validity of the device's measurement, the study conducted a simultaneous manual measurement. This further determines the exact orientation of the ultrasonic sensor that accurately measures the water level and water discharge.

Solar Powered Water Monitoring Device

Several monitoring devices for the water profile are necessary to properly improve water management. The fabrication of a water monitoring device consists of electronic parts such as solar panel(s); sensors; converter; and microcontroller.For remote areas which a daily and continuous manual monitoring is needed, the application of a solar-powered device was highly recommended. Electrical power from solar panels is generated through its cells made of semiconductor materials like silicon or cadmium telluride. The light falling on this material energizes its electrons and develops energy to create a flow of electrical current. A typical solar panel combines dozen of solar cells in an electrical circuit to produce a usable voltage, which can provide instant power or could be stored in batteries for later use.The amount of electric power produced by the solar panel is dependent on the light intensity of the sun. Since solar energy doesn't work well on cloudy days and not at all at night, the common solution is to back up solar power installation with batteries that store extra power until it is needed at a later time

Microcontroller and Sensors

The system of the device to monitor the water profile of the irrigation canal uses the microcontroller. The microcontroller was mainly designed to precisely measure, store, and send instrument output, including real-time communication for the monitoring system [7]. It uses lower power consumption [8], is very easy to assemble the program, and is technically economical [9].
Water quantities such as temperature, humidity distance, or height may be measured using available electronic sensors. Level sensors are used in highly sophisticated environmental and industrial applications that measure remote bodies of water: ponds, streams, canals, and even oceans. Data could be collected by transmitting measurements to a centralized management system via cellular, satellite, or radio communications. The digital system of sensors provides accuracy, long-term durability, and rapid time-to-first-measurement speed that makes water profile remote monitoring more convenient [10].
For remote areas where data monitoring is dangerous, the application of wireless sensors is highly commended. Furthermore, wireless technology reduces maintenance complexity and costs [11]. Wireless sensor network (WSN) is an important technology in the present day. It performs with low-power electronics in the field of micro-sensor technology. WSNs provide a great amount of excellent, and supervision applications, especially for a critical environment like monitoring a body of water [12].
A sensor with an ultrasonic system is a very popular sensor used in many applications, especially in measuring distance or sensing objects. The Ultrasonic Transmitter transmits an ultrasonic wave. This wave travels in the air and when it gets objected to by any materials it gets reflected toward the sensor.

This reflected wave is observed by the Ultrasonic receiver module and is translated by the program installed in the system.

Mobile Communication Techniques

Mobile phones have almost become an integral part of human lives serving multiple needs of everyone [9]. Modern mobile phones can send and receive Short Message Service (SMS) with appropriate Attention (AT) commands originating from the microcontroller. The circuit of a microcontroller is designed and used to control and interface hardware devices. Through it SMS is generated, received, decoded, and displayed. The complete system for the SMS gateway can be set up for many applications. Some examples are Smart Home Systems and Remote Data Collection Systems. The Main program communicates to Mobile Equipment (ME) via Global System for Mobile (GSM) protocol is applied to send and received SMS. Typical ME can be a mobile phone or a GSM modem with the capability to interface with a microcontroller [13]. GSM modem is a specialized type of modem that accepts a SIM card and operates over a subscription to a mobile operator, just like a mobile phone [14]. The AT command protocol is used to communicate over a serial line discipline. The AT commands are the basic commands that communicate with the GSM mobile phone [13].

GSM remains for Global System for Mobile Communication. As of now, it is an advanced innovation for cellular utilized for transmitting portable voice and information. Meandering is the capacity to utilize a GSM telephone number in another GSM [15]. The General Packet Radio Service (GPRS) is a packet-oriented mobile data service used in 2G and 3G cellular communications systems and (GSM) communications [16].The automatic water level controller is a Smart system as all processes occur automatically with continuous updates by the controller, to the user, via GSM techniques such as SMS Notification [17]. From various levels, the signal is given to a microcontroller built-in A/D converter and it converts the signal into digital data by programming [13].The methodology of GSM-SMS, data transmission, and communication are performed by the GSM-SMS methodology. The format of a short message is suitable for monitoring the area and field data collection. The communication of a GSM network is performed between the intelligent terminal and the management center. The system of GSM methodology is considered as has excellent features. These are its wireless system, capacity to transmit data, ease of procedure to operate, low expenses, and high reliability. The system structure of the monitoring system is designed for each module. This system takes the liberty of the GSM network to represent remote communication in the form of messages [12].The water detector detects the water level and then sends the signal to the microcontroller unit. The microcontroller circuit sends the signal to the GSM modem and then the GSM modem sends an SMS to the person in-charge mobile phone. The mobile number of the user has been set in AT command of the microcontroller and sends alert messages of the status of the current water level [18].

METHODOLOGY

Conceptualization of the Study

The conceptualization of the study started with the related literature and with the actual need on site. The assessment using updated water profile data initiates the study to fabricate a monitoring device suited for remote areas and local independent applications. Related to these, the present situation of National Irrigation Administration in Palawan was also looking for possible technology for the monitoring of water discharge as mandated in the Memorandum Circular #032 and MC #046-A series of 1974 and MC #043 and MC# 049 series of 2006. This was an immediate installation of a monitoring device in all water resources of the NIA including the water discharge and rainfall precipitation.Monitoring of the water profile requires daily on-site observations. It includes the measurement of several quantities to compute such as water discharge. This technique is needed for water management like an agricultural irrigation system. The continuous data collection used for monitoring was also applicable both in the irrigation water management and energy assessment. To achieve the objectives of the study, the prototype device includes the GSM module to send data to the end-users at the desired intervals. The target result of the study includes the use of water level and water discharge monitoring which was also primary data needed for the hydropower assessment.

System Configuration

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The power needed for this prototype water profile monitoring device is supplied by a solar panel. As shown in Figure 1, the solar energy is then banked to the 12-V battery controlled and protected by the charge controller. The system uses the DC-to-DC converter to provide the rated voltage needed in every part of the device. The solar power supplies energy to the Arduino UNO with ATMega328p board set-up to control sensors DHT11 that measure the temperature and humidity and JSN-SR04T-2.0 that detects the water depth and SIM900A GSM modules that send data and DS1307 real-time clock module for real-time monitoring. Using the printed circuit board, the GSM modules and temperature and humidity ultrasonic sensors are connected to the microcontroller. All readings such as the temperature and humidity and the reading of the ultrasonic sensor are sent to the microcontroller. The processed data in the microcontroller are then sent to the recipient through the GSM modem. Data will be sent in real-time using the DS1307 real-time clock connected to the monitoring device.

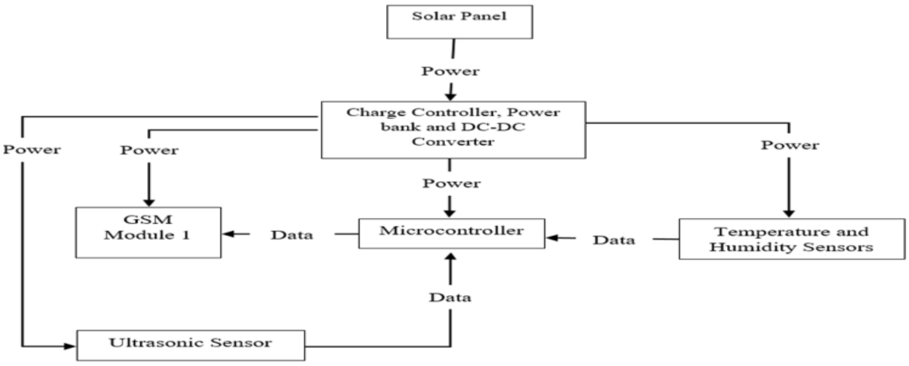

Fig. 1. System Flow of Monitoring Device

The power needed for this prototype water profile monitoring device is supplied by a solar panel. As shown in Figure 1, the solar energy is then banked to the 12-V battery controlled and protected by the charge controller. The system uses the DC-to-DC converter to provide the rated voltage needed in each component of the device. The microcontroller gets the time from DS1307 real-time clock module on what time will GSM module based on the time set on the program to send data from the temperature and humidity reading by the DHT11 sensor and calculated water level based on the distance read by the ultrasonic sensor.

The localized monitoring device has a free source system accessible for improvements. As shown in Figure 2, the cycle of the monitoring device on sending data circulates in the parts of the monitoring device, cellular site, data banking, and data recipients. Processed data as in data banking could be validated as it is part of its maintenance. The processed data are accessible for reprogramming as it is the maintenance in the part monitoring device. This so-called maintenance affects the data received by the recipient. This flow of cycle in Figure 2 was local maintenance to be performed in the monitoring device for the validity of the data gathered.

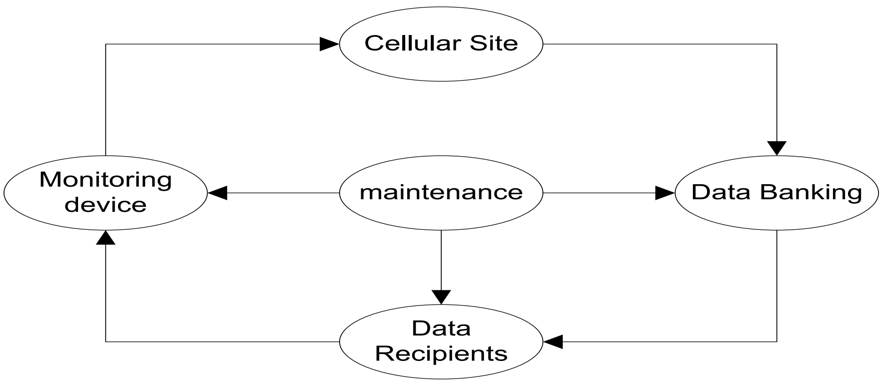

Fig. 2. Localized Data Monitoring System

Water Discharge Equivalent

Besides the agricultural water irrigation management, the data for the monitored water level of the irrigation canal is a based-line data of the study to measure and assess the water power capacity of irrigation canals. Water level refers to water flow depth and water discharge. The data monitoring uses sensors which means no physical contact between the monitoring device and the body of water. This method shows that there will be no measurement of the velocity of the water. Thus, the discharge measurement uses the weir method [19] as shown in equations (1) and (2) below. The depth of water for the weir method is the overflow depth or the blockage height h, to which the upstream flow is backed up above the weir crest [19]. Since the installation of a weir crest along the irrigation canals is not allowed for the operation of the water delivery, the study used the depth of the flowing water as the height h, of the weir method's discharge formula. The equivalency of overflow height h, using water flow depth was verified through trials of the experiment. The trials of the experiment were conducted specifically at the location where the monitoring device will be installed. Therefore, the weir method formula for water discharge was then corrected by multiplying it by the adjustment factor [19], Af, as shown in equation (3).

$$Q = cLh^{1.5} \quad (1)$$

$$c = 1.828\left(1+\frac{0.0012}{h}\right)\left(1-\frac{\left(\frac{h}{L}\right)^{1/2}}{10}\right) \quad (2)$$

$$Q_C = (A_f)cLh^{1.5} \quad (3)$$

where Q is the water discharge (m/s); Qc = corrected water discharge (m/s); c is the weir method discharge coefficient; L = is the opening width of the weir (m); h = is the overflow depth of the water (m); Af = is the adjustment factor. The Af, [19] was formulated using the equations that determine the percent error of the method used in the device. As shown in equations (4) to (7), Af equation (7) is used to correct the water discharge as the final measurement read sent through SMS of the device.

$$PE = \left[\frac{Method's\ Value - Established\ Value}{Established\ Value}\right] x100 \quad (4)$$

$$Method's\ Value = Established\ Value\left(\frac{PE}{100}+1\right) \quad (5)$$

$$(Method's\ Value)(Af) = Established\ Value) \quad (6)$$

$$\boldsymbol{Af} = \left[\frac{1}{(^{PE}/_{100})+1}\right] \quad (7)$$

Water Depth Reading of Monitoring Device

The water depth equivalent to computing the water discharge by the device was the height, h as shown in equation 1 above and Figure 3 below. This mathematical equivalent was uploaded to the program in the microcontroller using Arduino UNO. Aside from the DHT11 sensor that reads the ambient temperature and humidity, the JSN-SR04T-2.0 an ultrasonic sensor was used to measure the depth of water flowing through the irrigation canal. Two (2) heights were considered in measuring the height, h of the water using JSN-SR04T-2.0 sensor. As shown in Figure 3, JSN-SR04T-2.0 sensor detects the water surface as the height *L*, while height, *T* is given as the object or ground below the water surface. Height, *T*, could be adjusted and experimentally tested at 60 cm., 100 cm., and 120 cm. as discussed in 2.5. below. As a process of measuring the data, the signal detected by this sensor will be sent back to the microcontroller. Through the program uploaded in the microcontroller, the system will compute the flowing depth of water as shown in equation (8) and water discharge using equation (3). The computed values will be sent through SMS at the specified time. The number of measurements per day is editable in the program of the microcontroller. In this study, the device will send the data every 9:00 AM and 3:00 PM daily to the identified mobile number. Resetting the program in the microcontroller may happen in case of long or continuous unfavorable weather. To make the data measurement of the device collected and sent in consistent real-time, the device uses DS1307. This electronic part sent the data from the device to the recipient in real-time.

$$h = T - t \quad (8)$$

where h = is the depth of flowing water (m.); T = is the height from the sensor to the water floor (m.); t = distance from the sensor to the water surface (m).

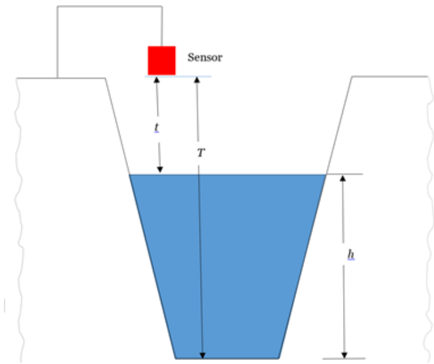

Fig. 2. Water Depth Measurement of the Device

Validation of Data Measurement

Readings and measurements of the device were validated through experimental testing. The depth of water measured by the device was compared to the manual measurement. These two measurements were performed simultaneously. Testing of the device for data validation was conducted for three (3) consecutive days. The three (3) height adjustments of the ultrasonic sensor in the device were implemented per day such as 60 centimeters, 100 centimeters, and 120 centimeters high. These height adjustments are equal to the depth *T* as shown in Figure 3 above. Each day of testing measures and sends data every 15 minutes, every 10 minutes, and every 5 minutes per height adjustment. The gathered data using manual measurement and the depth measured by the device sent through SMS was statistically evaluated. Statistical analysis is to test the significant difference between manual to device measurements setting the manual measurement as the reference of validation.

Solar Panel and Battery Sizing

The solar panel(s) and battery sizing are important to make sure the needed and required power of the device will be supplied without interruption. When designing the number and size of photovoltaic (PV) modules, its location will be the starting point because PV's performance is directly related to the amount of sunlight it receives which is called solar irradiance [20]. Solar irradiance is the sunlight intensity in Watts per square meter falling on a flat surface at the specific location of the application. In the Philippine settings, it is recommended that the measure of solar irradiance that reaches the PV surface at any given time is equivalent to around 4.5 – 5.5 kWh/m^2/day [20], [21].

Another thing to consider in PV and battery sizing is the Days of Autonomy (DA) and Depth-of-Discharge (DoD). Days of Autonomy is the design of a battery storage system to provide the necessary electrical energy which was normal for a period equivalent to 7 days without any sunshine. But for a time period considered as a moderate level of storage, autonomy applications may use 3 to 4 days of storage [20]- [23]. While the allowable Depth-of-Discharge (DoD) is the maximum fraction of capacity that can be withdrawn from the battery. The typical value of the Depth-of-Discharge of a good and new battery is 0.8 [20] - [23].

The battery and PV sizing is computed using the equations (9) and (10) as,

$$E_{bat} = \frac{T_l\ x\ DA}{DoD} \qquad (9)$$

$$PV = \frac{T_l}{DI} \qquad (10)$$

where = battery capacity (Whr/day); Tl = is the total Watt hour per day (Whr/day); DA = is the number of recommended Day of Autonomy (3 days); DoD = is the Depth-of-Discharge of the battery (80%); PV=is the photovoltaic size; DI = is the Daily Insolation (5.42 Watts/m^2).

RESULTS AND DISCUSSION

ENERGY CONSUMPTION

The tabulated load of the remote sensing device that monitors the water profile of the irrigation canal is computed as shown in Table I. Though most of the electronic part of the device doesn't consume energy continuously, the total tabulated load shown in Table I was computed considering the rated operating value of each component is continuous for 24 hours. This is to make sure that the solar panel and battery sizing will sufficiently supply the need of the device. The total computed load of the device was 7.746 Whr per day. To make the operation uninterrupted, the size and number of the solar panel(s) and battery were then computed. Table II shows the total 2.42 AmpHr energy needed in the operation recommends one (1)-12VDC, 3 AmpHr battery. The peak power was computed to 2.878 watts and was then recommended one (1)-5 Watt peak PV panel.

TABLE I.

SUMMARY OF LOAD COMPUTATION

Parts	Rated Voltage	Quantity	Rated Ampere	Operation hours	WattHr / Day
JSN-SR04T-2.0	DC 3-5.5V	1	.8mA	24	1.056
SIM900A	3.4-4.5V	1	1.5mA	24	0.162
Arduino	5V	1	50mA	24	6.0
DHT11	3-5.5V	1	2.5mA	24	0.33
DS1307	5.5V	1	1.5mA	24	0.198
Total					7.746

TABLE II.
SOLAR PANEL AND BATTERY SIZING

Total Load (Whr/day)	Total Energy Operation (Amp.Hr)	Recommended Battery Size (Amp.Hr)	Peak Power (Watt Peak)	Recommended PV Size (Watt Peak)
7.746	2.42	3	2.878	5

System of the Monitoring Device

As shown in Figure 4 below, the monitoring device contains electronic parts like sensors, real-time-clock, Arduino UNO, a charge controller, and a battery confined as a device's system inside the enclosure. The device's system was energized using the 5-WPeak solar panel and is stored to a 12V, 6.5AmpereHour battery. At the real-time 9:00 AM and 3:00 PM, the device activates the ultrasonic sensors (JSN-SR04T-2.0) that measure the depth of water. Data are processed in the Arduino microcontroller and sent through the Smart telecom network and will be received by the person in charge through SMS.

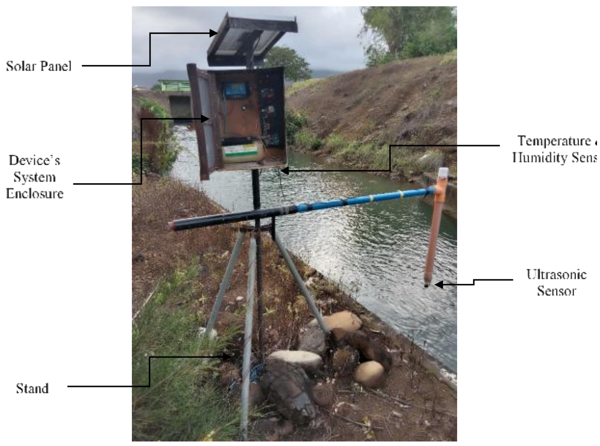

Fig. 4. Automated Water Level and Discharge Measuring Device

The ultrasonic sensor shown in Figure 4, was designed to be adjusted from 60cm to 120 cm in height. The adjustment was used to determine the most effective height setting of the sensor in measuring the depth of water.Needed data such as the depth and discharge of flowing water was read by the ultrasonic sensor and then processed through the program uploaded to the Arduino microcontroller. The device converted the depth of flowing water into a water discharge using equation (3).

Validation of Monitored Data

Monitored data are the gathered data both from the device measurement and manual method of measurement. The simultaneous measurement of the electronic device and manual method were performed to compare how realistic the device measurement making the manual method the reference or the true measurement. As shown in Figure III, the result of data validation was performed with the three (3) settings of the sensor's height during the experiment. These are 60cm height, 100 cm height, and 120 cm height. Water depth measurement observed ten (10) replications of each height setting both for device measurement and manual measurement simultaneously. This data validation was conducted for three (3) consecutive days.

The following are the meaning of abbreviations used in Table III;

H1S - the water depth readings of sensors at the first height setting which was 60 cm;
H1M - the water depth readings of manual method at first height setting which was 60 cm.;
H2S - the water depth readings of sensors at the second height setting which was 100 cm.;
H2M - the water depth readings of manual method at first height setting which was 100 cm.;
H3S - the water depth readings of sensors at the third height setting which was 120 cm., and
H3M - the water depth readings of the manual method at the third height setting which was 120 cm.

TABLE III
HYPOTHESIS TEST SUMMARY OF WATER DEPTH MEASUREMENT

Sensor's Height Variations	Null Hypothesis	Test	Significance	Decision
Height1=60 cm	The median of differences between H1S and H1M equals 0	Related Samples Wilcoxon Signed Rank Test	0.00	Reject the null hypothesis
Height2=100cm	The median of differences between H2S and H2M equals 0.	Related Samples Wilcoxon Signed Rank Test	0.343	Retain the null hypothesis
Height3=120cm	The median of differences between H2S and H2M equals 0.	Related Samples Wilcoxon Signed Rank Test	0.115	Retain the null hypothesis

Asymptotic significance are displayed. The significance level is 0.05.

Since the data does not satisfy the assumption of normality based on Kolmogorov-Smirnov and Shapiro-Wilk Test, the non-parametric test – Wilcoxon matched pair test was used to determine the significant difference of the two independent variables, the device, and manual measurements. As shown in Table 5 above, statistical significance level α = 0.05 at the 60 cm height setting of the device rejects the hypothesis that there is no difference between the readings of the device and manual measurement. Table 5 further explains that at 100 cm and 120 cm settings, the data measured using the device reading and manual method has no significant difference.

CONCLUSIONS AND RECOMMENDATIONS

The study recommends the use of this remote sensing device to monitor the desired number of data needed for studies. The daily monitoring eases using this system. It minimizes time spent on a survey, the system is programmable, and is a free open source that anybody can access. This system also recommends as it does not limit the number of devices to be fabricated especially when data is an actual collection localized based.The result of this study, further recommends that the ultrasonic sensor of the device should be in its proper height setting for an accurate reading. Experiment and statistical results show that the device has an accurate reading of water depth measurement at height settings of the ultrasonic sensor equal to *T* (Figure 3) which is 100cm to 120 cm from the floor or ground level. This height configures to provide realistic readings of water profiling.The water depth measurement of the device was converted into water discharge programmed in the device through the Arduino Uno and sent the data via SMS. For further validation of the converted water discharge data, this study recommends an additional experiment that will determine first the water discharge profile of the irrigation canal conducted at different water depths manually. The experiment of validation should be replicated at different locations of the irrigation canal to establish the adjustment factor needed to convert the water depth into water discharge.

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Jibsam F. Andres was born in Narra, Palawan, Philippines on June 14, 1976. Degree: BS in Electrical Engineering (1998) from Palawan State University. MEng (2017) from University of San Carlos.
He is an associate professor at Western Philippines University, Aborlan, Palawan. He presented research outputs at International Conferences and published research in the International Journal of Engineering Research and Technology, Kne Publishing, Civil Engineering and Architecture, Natural Resources and Conservation, and Universal Journal of Agricultural Research. He is also a member of the International Association of Engineering since 2017.

Michael E. Loretero was born on September 2, 1977, in Cebu City. Degree: BS in Mechanical Engineering from the University of San Carlos, MEng in Mechanical Engineering from the same University, and Ph.D. Mechanical Engineering from the National Taiwan University of Science and Technology.
He is working at the University of San Carlos and department chair of the Department of Manufacturing and Mechanical Engineering. His recent journal publications had written in the International Journal of Renewable Energy Development, Applied Sciences, and International Journal of Applied Engineering.

Benjie R. Martinez was born on November 21, 1982 in Aborlan, Palawan. He finished his BS in Electronics and Communication Engineering from Fullbright College, Puerto Princesa City, Philippines. Being a licensed electronics engineer, he was a part of the Smart Campus project of Western Philippines University. He also presented research outputs at National and International Conferences.