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Design and Automation of a Solar Powered Soil Moisture Monitoring System (SPSMMS)

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Abstract

A solar powered soil moisture monitoring system (SPSMMS) was developed and evaluated at Cavite State University (CvSU) Main Campus, Cavite. The study evaluated the operating performance of the fabricated SPSMMS in terms of sensitivity of sensors, accuracy of reading, and transmission system efficiency. The device was fabricated using locally available materials. Its overall dimension in terms of length, width and height is 0.36m x 0.31m x 2m, respectively. The device is composed of the main frames, automation system, power system. The automation system is composed of main parts such as Arduino Mega2560, resistor type sensors, GSM module, data logger, and RTC. The system reads the moisture level every one (1) hour and thirty (30) minutes and send SMS every three (3) hours of operation. The study has two (2) installations placed in the crop production area of CvSU. The soil moisture was at the highest in the first installation compared from the second installation due to different environmental conditions. Installation 1 was placed in a fully irrigated area, slightly shaded, and vegetated. While, installation 2 was placed in a fully open, not vegetated, and not well irrigated. The total fabrication cost of two (2) devices is PhP 31,866.00. The total operating cost per year of the SPSMMS was compared to the standard soil moisture meter (Extech Meter Model) which is PhP 11,520 .00 and PhP 87,600.00, respectively.

Keywords: Soil moisture, Solar powered, Monitoring system, Automation

Introduction

Agriculture is a major player in the human appropriation of water resources (Green et al., 2015). About 70% of global freshwater withdrawals are used for irrigation to sustain global crop production (Rockström et al., 2017). In fact, irrigated areas account for 18% of global croplands but contribute to about 40% of global food production (Chartzoulakis and Bertaki, 2015; Food Agriculture Organization, 2019). At the same time 40% of global irrigation practices are unsustainable because they deplete environmental flows and/or groundwater stocks (Wada and Bierkens, 2014; Rosa et al., 2018).

Automation through an IoT system could be an effective approach to improve a conventional surface irrigation system operation. An automated surface irrigation system refers to its operation with timers, sensors or computers or mechanical appliances with minimal manual involvement. Many researchers have reported that automation in irrigation projects using an intelligent irrigation controller and wireless sensor network could save water up to 38% (Al-Ghobari et al., 2017, Bowlekar et al., 2019). Automation is a smart technique to deal with the problem of high labor requirements and low water application efficiency of surface irrigation systems. There are many soil moisture sensors such as gypsum block, tensiometer, time-domain reflectometer, granular matrix sensor, dielectric probe is available commercially for soil moisture measurement and they could usually be used for manual or integrated with automatic irrigation control systems through an IoT system (Pramanik et al., 2021, Hardie, 2020, Vera et al., 2021).

Internet of Thins is the network of physical objects or "things" electronics, sensors, software and network connectivity where embedded with which enables the objects to gather information and exchange data. It empowers the farming system to use modern technology to address problems in monitoring and labor requirements. New innovations and cost efficient IoT applications are serving the agriculture sector to advance the standard, amount, sustain the ability and cost effectiveness of agricultural production. The IoT based automation system sensing, processing, communicating and activating the computer devices which make the task of closing and opening of valves/gates of irrigation and drainage system as per required or shift (Sales, et al., 2015).

Water scarcity makes the management one of the most critical challenges faced in arid and semi-arid regions. Water management and increased water use productivity are among the most effective management decisions for preserving water resources, particularly in irrigated agricultural lands. Agriculture sector is the largest freshwater consumer (Dhawan, 2017., FAO, 2017). Enhancing the irrigation efficiency may perhaps save a large amount of water which be used to carry an extra area under irrigation. Surface irrigation remains the most commonly used method in for irrigating the crops and pastures areas in Asian countries and the world due to its low cost and low energy requirement (Bjorneberg, 2013). Surface irrigation plays an important role in providing the food, feeds and fiber in many countries. Nevertheless, these systems are frequently accompanying with low irrigation efficiency and high labor cost.

Efficient and effective irrigation systems have the possibility to deliver high rate of application efficiencies (Sivanappan, 2008). Notwithstanding that, mostly of the surface irrigation systems have been functioning with significantly lower and highly variable requirement efficiencies. The surface irrigation remains a leading method used in many countries (Raine, 2006). It is expected that the research for improving the application effectiveness of surface irrigation will endure. The parameters and variables that greatly affect the performance of irrigation was grouped in three categories: first is the field geometry (length, width, slope, furrow cross-section, etc.), second is the field conditions (infiltration and roughness relations), and the third is the management variables (soil moisture deficit, time of irrigation, flow rate and the cut-off time) (Clemmens, 1992). Increasing the application efficiency more would come around by handling each irrigation system through variable inflow rates and irrigation time cut-off in actual to deliver the optimum requirement of the prevailing farm conditions.

Water management comprises understanding of water release patterns and storing of water in the soil. This information on storing and releasing also requires considerations about physical, biological and chemical properties of soils in the farms (Zwartendijk et al., 2017). The soil properties strongly affected the processes, which take place among others, soil remains with high temperature or cool, dry or saturated, aerobic or anaerobic, crumbly or rigid, high in porosity or compacted, gathered or distributed, impervious or permeable, eroded or conserved, saline or unsalted and rich in nutrient or percolated. The last controls whether the soil moisture content enough or high for several crop varieties as well as in different production system and whether it can suitably help as an effective converter for environmental pollutants, rather than as a spreader. The moisture content of soil similarly referred to as water content and it is an indicator of the amount of water present in soil. Moisture content in the soils is the relationship of water quantity in a portion to the quantity of soil particles (Lin et al., 2005).

In the absence of rainfall, water is supplied to farmland by artificial means for plant growth and to increase crop productivity is irrigation. Irrigation has been pressured to produce more with lower supplies of water. Several innovative practices in irrigation were tested and can gain economic advantages while reducing environmental burdens such as water abstraction, energy utilization and contaminants. Human has been using water for the irrigation since ancient times. The important civilizations of the world have developed based on irrigation management. Usually, groundwater and surface water were used for the irrigation and when water is available in these sources, it is taken away artificially by flowing it for supplying water in required quantity to crops is an action of irrigation. Most of the time, the source of irrigation is not being used efficiently and counts as waste. These wastes will represent a large sum of money, since in every crop there is only a substantial amount of water needed for its optimal growth. And in determining the growth of crops and their health, measuring the soil moisture or the amount of water that is held in spaces between soil particles will be needed. On the other hand, for approximately the last one hundred years, people lived without any conveniences like a speck of technology. The society has been dramatically changed with the evolution of technology, since immense opportunities are being provided by technologies which play an important role in human life. The access to education, medicine, industry, transportation has been simplified due to modern day technology, and in today's generation, even in agriculture the presence of technology has been efficiently utilized. Therefore, looking beyond to the importance of knowing the exact soil moisture with the support of the advanced technology so that no more water will be wasted and will lead to an increased and intensified production which will ultimately improve agricultural productivity.

The study evaluated the designed and automated a solar powered soil moisture monitoring system. Specifically, it aimed to design a solar powered soil moisture monitoring system (SPSMMS), evaluate the performance of the device in terms of sensitivity, efficiency and accuracy; and determine the fabrication cost of the device.

Materials and Methods

Design Considerations and Materials

Design Considerations

The soil moisture monitoring system was designed and fabricated in consideration from the following factor: ease of monitoring through GSM and possibility of cloud integration; reliability and stability of fully monitored system; could stand and tolerate harsh environment condition; less labor using the system; could be operated by one person; and the lower cost of fabrication.

System Components and Materials

The materials used in the study were Arduino Mega, Liquid Crystal Display interface, SD card interface, GSM module interface, Real Time Clock, Soil Moisture Sensor. DC-DC Mod 180KH179, solar panels and storage batteries.

SPSMMS Design Requirements

The SPSMMS shall be able to measure the soil moisture content in terms of percentage, store that data gathered and transmit the data via GSM module, and shall improve the proper monitoring and application of irrigation water. The solar power system shall be able to supply the required power for the device to run or operate in 24 hours.

Total Power Requirement (TPR). The total power required was calculated based on the electrical load of all the components installed. The total power required per day in watts will be calculated by multiplying the number of hours of operation per day.

TPR = total power load, Watts x no. of Hrs.-operation/day

Battery Capacity (B_C). The battery capacity was determined by multiplying the total electrical power required by allowable discharge level in percentage. Take note that battery would be allowed to discharge up to 50% level of its charge.

B_C = (Total Electrical Power requirement, W) / (battery allowable discharge level, %)

Battery Bank Size (B_{bs}). The ratio of the battery capacity and battery voltage rating that was used by the system.

B_{bs} = Battery capacity / (battery voltage rating)

Battery Requirement (B_R). The number of batteries required (piece) to power the SPSMMS and was determined by the ratio battery bank size (watt-hour) and bank size (ampere-hour/ piece).

$B_R = B_{bs}$ / Battery size

Number of Solar Panels (N_{SP}). Number of solar panels can be determined by dividing the total electric power requirement (watt-hr) by solar power rating (watts) and effective sunshine duration (hr/day).

N_{SP} = (total electric power requirement) / (solar power rating x effective sunshine duration)

Principle of Operation

The SPSMMS has four (4) sensors attached 20 cm apart from each other starting with Sensor 1 which is 10 cm below the ground level; Sensor 2 at 30 cm below the ground level; Sensor 3 at 40 cm below the ground level. Every sensor was programmed with Arduino to do its function which is to read the moisture content in the soil. Attached in the Arduino was an RTC (real time clock), card reader, and a GSM module. The GSM module is connected to a 5.1-V buck converter that is directly connected to the battery. The card reader saves the data gathered every 1 hour and 30 minutes, while the GSM module sends a text message containing the data, time and soil moisture content in percent, every 3 hours for the span of 7 days during the test. A 12-volt solar panel served as the main power source of the system in order to charge the battery so that it can still power the system even in night time. While in the day time, the solar radiation from the sun will be received by the solar panel in order to power the system. Attached in the solar panel is a solar charger that will regulate the voltage flow in the system and a 12V-50AH battery size.

Acquisition of Materials and Fabrication

The different components and materials of SPSMMS were purchased from local supplier in the Philippines meeting the design specifications. On the other hand, materials used for frames were provided by the fabricator. The 2-meter steel tube with 4 holes with 0.5-inch embedded every 20cm from the bottom. A box having a dimension of 0.2m x 0.1m x 0.09m was attached in the steel tube for storage of automated components. Lastly, a 0.36m x 0.31m x .05m frame for solar panel was placed above the steel tube.

Calibration

The SPSMMS was calibrated before installation in the field. Nine soil samples were collected from the installation area with different soil moisture conditions ranging from very dry to wet concurrently with soil moisture sensor reading. The soil moisture was determined using the gravimetric method. After weighing the fresh weight, samples were oven-dried at 105 ºC for 24h. The device was also calibrated with the use of standard soil moisture meter. Same soil sample with the same volume of soil with different moisture level was also measured at the same time with sensor and soil moisture meter in order to solve for the equation needed for the calibration. The linear equation gathered through sensor-soil moisture meter graph was then inserted in the program to finally calibrate the sensors.

Preparation of the Site and Installation

A one (1) cubic meter of soil was dug in two separate locations for the installation of device. After digging the 2-meter steel tube frame of 2 device were installed. The figure 1 shows the installation or set-up of first and second SPSMMS devices. The dug opening must be necessary for a single person to go down for the set-up of sensors and every verification made during the testing. Device 1 was installed in a vegetated area specifically in the vegetable gardens planted with lettuce that cropping season. The area has a clay loam type of soil, wherein irrigation was maintained daily. While, Device 2 was installed in a non-vegetated and partially shaded area near the coffee plantation with sandy clay type soil, wherein irrigation was limited and not well maintained.

Figure 1. Site Location of SPSMMS installations

Preliminary Testing

A preliminary testing of the device was conducted at CvSU-crop production area (14.1920° N, 120.8729° E) to determine the conditions of all installed components. All the components were carefully checked and tested before the devices permitted to operate for a day. Adjustments and modification were done after the preliminary testing until the desired functionality of the device was attained.

Final Testing

The final testing of the SPSMMS was conducted at CvSU-crop production, Indang, Cavite. The SPSMMS was designed to automatically monitor the soil moisture level in a specific area and sending it through SMS via GSM, all the data gathered was stored through a data logger. The 2 devices were tested separately with two (2) different soil types mainly clay and sandy loam.

Performance Parameters

Sensitivity of the Sensors. The time of recording of standard soil moisture meter was compared with time of recording of the calibrated soil sensors to determine the sensitivity of the system. The criteria for the evaluation of sensitivity of process control system was based on the timeliness of response (Borres et al., 2019), as presented in table 1. The accuracy of reading in this study were then compared to the reading of sensors on the system to the actual reading of the standard soil moisture meter. These were done to determine the accuracy of the calibrated sensors.

Accuracy of Reading. In this study, comparison of reading of sensors on the system to the actual reading of the standard soil moisture meter were also done to determine the accuracy of the calibrated sensors.

Table 1. Sensitivity evaluation of automation components of the system

SPSMMS Components	LEVELS OF SENSITIVITY
Sensor	Highly Sensitive (HS) the response time of the sensor is within 5 secs.
Data logging	Highly Sensitive (HS) can be adjusted in the program
Data transmission	Moderately Sensitive (MS) depending on the signal of telecommunication services on the area

Highly Sensitive (HS): when the system responds within 5 seconds; Moderately Sensitive (MS): when the system responds within 5-10 seconds; Less Sensitive (LS): when the system responds within 10-30 seconds

Transmission System Efficiency. The real time record of data by the SD card logger was compared with the data received through GSM in order to identify the data transmission systems efficiency and this expressed in percentage (%).

Transmission efficiency (%) = (number of SMS received) / (number of data logged)

Data Gathering

The following parameters were observed and gathered in the study: one week rainfall data was gathered in meteorological station; time of precipitation to compare the actual time to the real-time-clock of the system; moisture content to monitor the water in the soil as well as to compared it in the moisture content observed using standard soil moisture meter for verification; data sent from GSM was also gathered to be compared to the information in the data logger and soil texture in the area of installation.

Data Analysis

The regression analysis was used describe the corelation between the SPSMMS device and the standard soil moisture meter. The characteristics of moisture content using four (4) sensors installed in different depth ranges were also compared and analyzed.

Cost Analysis

Cost Benefit Analysis is used for systematic approach in estimating the strengths and weaknesses of alternatives. It is use to determine options which provide the best approach in achieving benefits while preserving savings. The operational cost of SPSMMS was compared to the operational cost of commercially available soil moisture meter used in this study.

Results and Discussions

Design of the SPSMMS

The SPSMMS is a device that was designed specifically for automation and instrumentation to be used in controlled irrigation purposes. The monitoring system enables the user to keep the moisture content in the soil under observation through data logger and GSM module that send SMS to the user as presented in figure 2. It is a stand-alone monitoring system that is able to run 24 hours 7 times a week. The device was also designed specifically to withstand the heavy rain as well as sunny temperature given that insulators are installed inside the automation box. The design was provided with solar panel holder, metal sheet box to store and protect the battery and other electronic parts. The design component specifications were presented in table 2 and the table 3 for the specifications and description of automation system.

Main Frame

This part used to support and carry all the components of the automation device, storage battery and solar panel. It is made up of steel tubing with 2-in diameter. It has 2m effective height with four holes on the lower portion for sensor installations. The first hole is 0.10m below from the ground level where the first sensor was installed; second hole was made 0.30m depth from the level; third hole was in 0.50m depth; and last hole was made at 0.70m depth from the ground level.

Solar Power and Electronic Box Frame

This was composed of the solar panel frame, automation parts box, and stand. The solar panel frame was made up of angle bars with 0.36 m x 0.31m x 0.06m in length, width, and thickness, respectively. The power requirement was provided by the design photovoltaic system. The automation box was made up of iron sheet with 0.20m x 0.09m x 0.20m, respectively. For stability purposes, a stand was designed to have four (4) angle bar legs with 0.60m in length and is foldable. The design was specifically for the ease of transportation and transfer of installation.

Power Source

Based on the design requirement, the device was powered by a 12V-10W solar panel, 12V-50AH battery, and 12V solar charger for continuous power supply, storage, and voltage regulator. The system can be used for continuously, 24 hours a day, 7 days a week.

Automation System

The automation system performs mainly on the moisture content detection and real monitoring, transmission and data logging. The system performs can also perform different tasks by automatically linking or adding different tools such as water pump, solenoid valve for automated irrigation, and other application for real time monitoring and decision making. It requires lower electricity and telecommunication connection. The system may integrate other sensors to monitor environment factors and collect data such as air temperature and humidity.

Resistor Type Sensor. A resistor type sensor that measures the volumetric water content in soil. Four (4) sensors were installed in the system specifically at depths 10cm, 30cm, 50cm, and 70cm below the ground level, respectively. A resistor type sensor delivers information in the form of the electrical resistivity of a material or electrical resistance of a device. The resistivity makes an opposition of a specific material to the flow of a current once the electrical field is applied; this may also depend on the properties of the material. The change in physical/chemical conditions of the resistive sensor, caused by the physical quantity of concentration, results in differences in its resistivity (Depari, 2018).

Arduino mega 2560. A low-cost microcontroller based on Arduino. It is the heart of the system where all inputs and outputs are processed. The board can operate on an external supply ranging from 6 to 20 volts. If the board is supplied with less than 7V, the 5V pin may supply less than five volts and the board may perform unstable functions. If the power supply is more than 12V, the voltage regulator may overheat and may cause damage to the board. The recommended range is 7 to 12 volts for Mega2560.

LCD IC2. A device attached to Arduino mega 2560 that is used to display the readings from the serial monitor. This device make display easier. Using it can reduce the difficulties of monitoring of data. The development of Arduino library for I2C LCD, the user just only needs a few lines of the code to achieve complex graphics and text display features in the project.

SD Card Module. A Secure Digital Memory Card that designed to provide high-capacity memory in a small size. The data displayed in LCD was saved through data logger (SD Card) every one and a half (1 ½) hour. The SD card module allows the device to communicate with the memory card and write or read the information store on them. The module interfaces in the (serial peripheral interface) SPI protocol. To use the module with Arduino the make needs the SD library. The library is installed on the Arduino application by default.

SIM800L GSM module. A global system for mobile communication electronic device which is used for offline alert sending through SMS. This module was installed in order to convert the data logged to an SMS received every three (3) hours. This module is a miniature (global system for mobile) GSM modem that can be integrated into a large number of IoT projects. This module can be used to accomplish almost anything that a normal cell phone can do such as sending SMS messages, making a phone calls and connection to the internet via GPRS.

DS1307 RTC module. A real time clock system which maintains the accurate recording of time with the data recorded. The system was attached with an RTC in order to maintain the accurate reading of time of the device. The module is built with high capability DS1307 RTC chip and the AT24C32 EEPROM, both of which have been around for a while and have good library support. The heart of this module is a low-cost, very precise RTC chip from Maxim. This module handles all the timekeeping functions of device and communicates with the microcontroller over I2C.The DS1307 module track the seconds, minutes, hours, days, dates, months, and even years. It operates in whichever a 12-hour or 24-hour format and has an AM or PM indicator.

DC-DC Buck Converter. This is connected to the GSM module and battery in order to lower the voltage input into the GSM module. A DC-to-DC power converter steps down the voltage while stepping up current from its power supply (input) to its load (output). It is a class of switched-mode power supply (SMPS) naturally holding at least two semiconductors and at least one energy storing element, a capacitor, inductor, or the combination of two. In reducing voltage ripple, filters made of capacitors are usually integrated to such a converter's output and input.

Table 2. Specifications and description of SPSMMS components

PARTS	SPECIFICATION
Solar Panels	Maximum Power: 10 W Dimension: 335 mm x 280 mm x 25 mm Weight: 1.3 kg; Open Circuit Voltage (VOC) 21.6 V Short Circuit Current 0.66 A; Power Allowance Range 5% Max Power Voltage 16.96 V; Max System Current 0.5 A Max System Voltage 300VDC; Number of Cells 36 Year Efficiency 25 years
Charge Controller	Dimension 18.25 x 12.25 x 6.5 in Rated Voltage 12V 24V Auto Application Solar System Controller Rated Current 60A; Max. PV Voltage 50V Stand-by power consumption <12.5mA
Battery	Model/Brand: CJ3 GP Series; Voltage Per Unit: 12 V Capacity: 50 Ah @ 20hr-rate to 1.75V per cell @ 25°C (77°F) Weight (kg): Approx. 2.40kg. (5.29 lbs.) Maximum Discharge current (A): 100A/130A (5sec.) Float charging voltage: 13.5 to 13.8 VDC/unit, Average at 25°C (77°F) Recommended Maximum Charging current limit: 2.16A

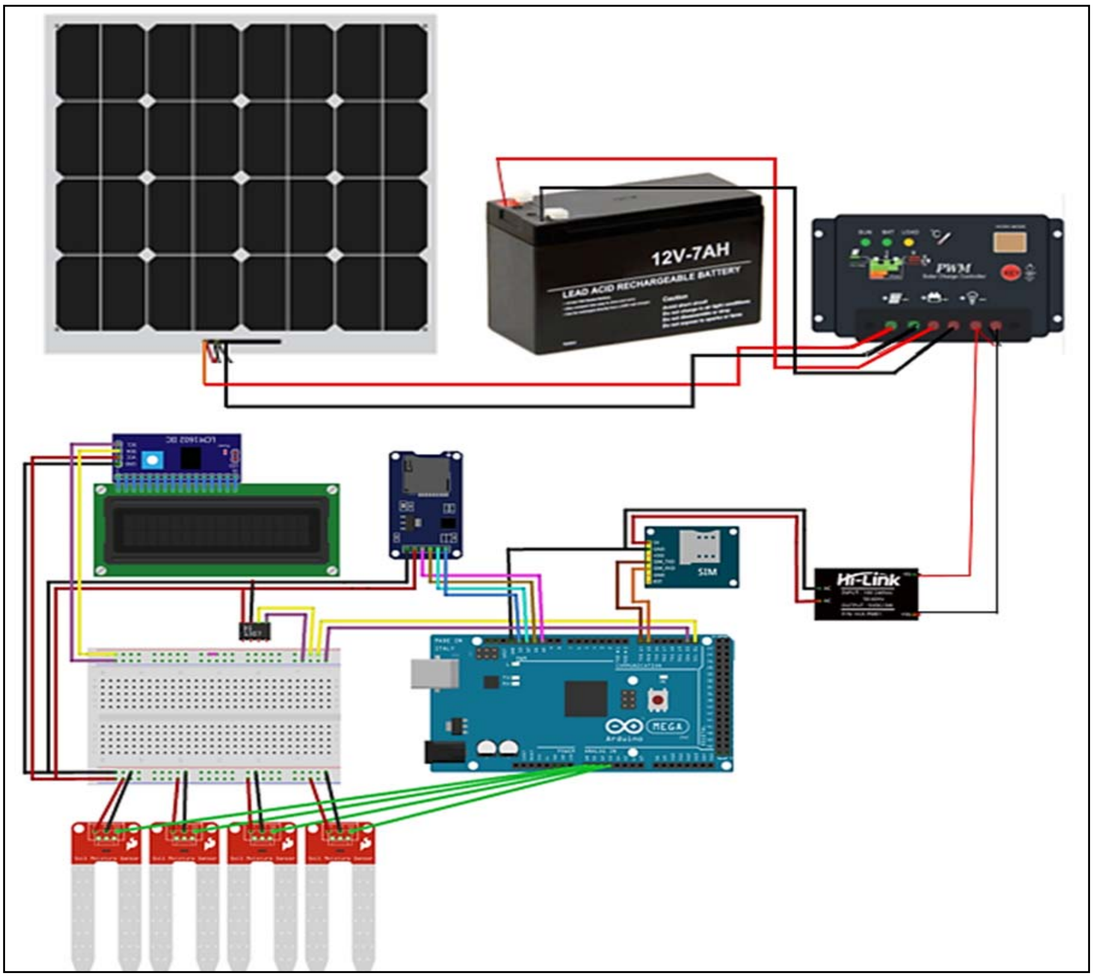

Figure 2. Diagram and flow chart of SPSMMS

Table 3. Specification and description of components installed of automation system

PARTS	SPECIFICATION
Arduino Mega	Microcontroller: ATmega2560 Operating Voltage: 5 V; Input Voltage: 7-12 V Input Voltage (limits): 6-20 V; Digital I/O Pins: 54 Analog Input Pins: 16 DC Current per I/O Pin: 40 mA
GSM/GPRS Module	Chip: sim800L Supports Real Time Clock Supply voltage range 3.4V ~ 4.4V Low power consumption, 1mA in sleep mode Compact size 23mm x 35mm x 5.6mm Micro SIM Card
SD Card Module	Brand Name: WeMos Install Style: Plug-in; Input Voltage: 3.3V/5V With all SD SPI Pins out: MOSI, SCK, MISO and CS
Real Time Clock (RTC)	DS1307

PARTS	SPECIFICATION
	Power Input: 5 V Battery: LIR2303 Rechargeable Lithium Battery PCB Dimension: 25x28x8.4mm
Serial Monitor	LCD, 12C, 16 x 2 display Supply Voltage: 5 V; Interface: I2C /TWI x 1 Adjustable Contrast
DC-DC Buck Converter	Measure range: 0~40V; Voltmeter error: ±0.05V Input voltage: DC 4.0 ~ 38V; Output current: max 5A Output voltage: DC 1.25V ~ 36V continuously adjustable. Output power: up to 75W, more than 50W Conversion efficiency: up to 96% Operating frequency: 180KHZ Load regulation: S (I) ≤0.8%; Voltage regulation: S (u) ≤0.8%
Soil Moisture Sensor	VCC: 3.3V-5V GND: GND DO: digital output interface (0 and 1) AO: A N A L O G output interface Panel PCB Dimension: 3 x 1.5 cm Soil Probe Dimension: 6 x 2 cm

Performance Evaluation of SPSMMS

Accuracy

The Comparison of measurement results between the soil moisture meter and the SPSMMS 1 is shown in Figure 3. The R^2 between the value measured by the soil moisture meter and soil moisture content from SPSMMS were 0.9827, at 10 cm soil depth; 0.84264, at 30 cm soil depth; 0.95866, at 50 cm soil depth; and 0.9534, at 70 cm soil depth. The results indicated that the measurement of accuracy of the installed sensors were comparable with the standard soil moisture meter and met the requirements for the application. The second device, comparison of measurement results between the soil moisture meter and the SPSMMS 2 was shown in Figure 4. The R^2 between the value measured by the soil moisture meter and soil moisture content from SPSMMS were 0.97271, at 10 cm soil depth; 0.94013, at 30 cm soil depth; 0.9766 and, at 50 cm soil depth; and 0.96683, at 70 cm soil depth. This indicated that the measurement accuracy of the installed sensors was comparable with standard soil moisture meter and met the requirements for application.

Monitoring of crops is one the most important stage in the farms where the farmers must be careful about since it is the initial stage where the crops can simply be experience soil moisture depletion, affected by pest and diseases. If that happen the whole crops may die at the early stage. Addressing such problems, the farmer should accurately track and analyse the status of soil moisture, crop health and the environmental condition. The best way to solution this challenge is to get accurate data in the field and apply precision agriculture and automation.

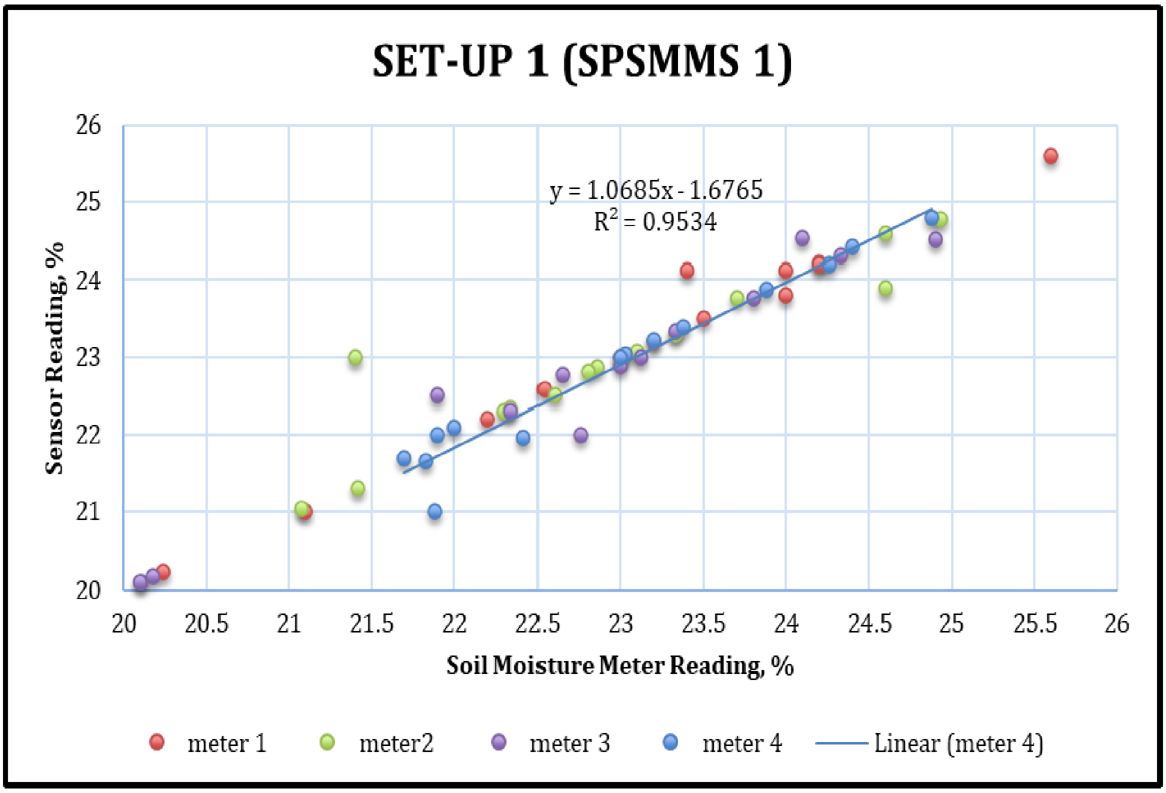

Figure 3. Accuracy of integrated sensors in the first set-up

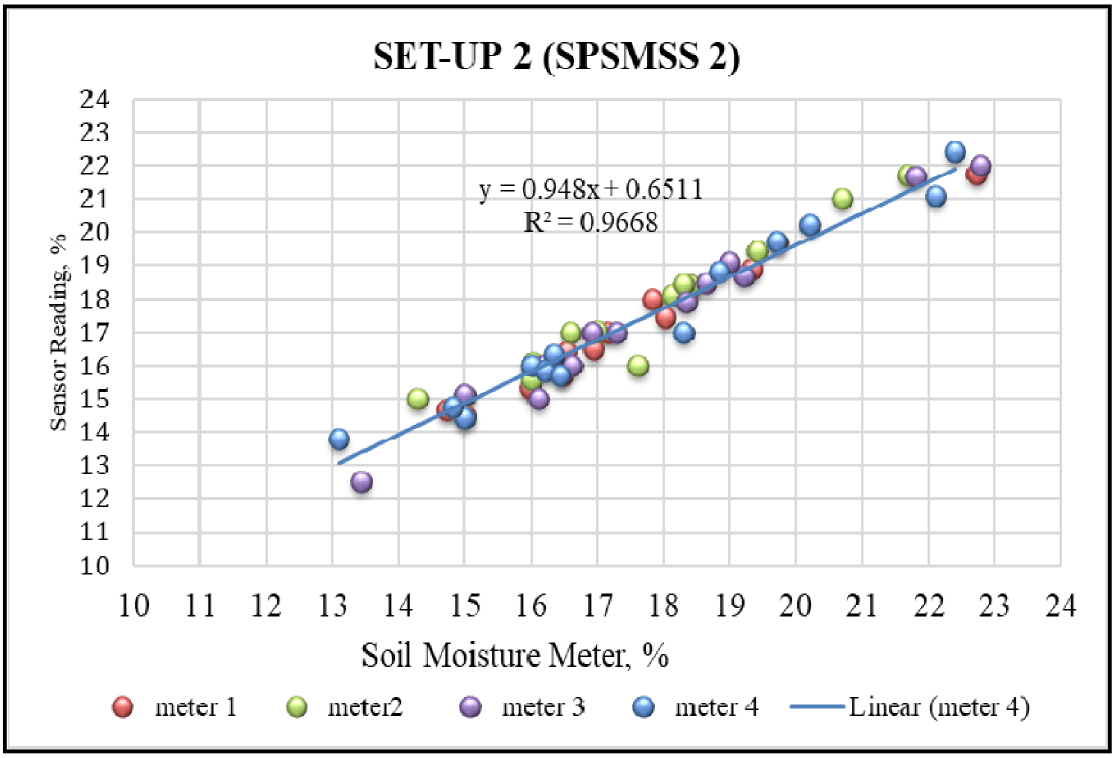

Figure 4. Accuracy of integrated sensors in the first set-up

Automation Sensitivity

The sensitivity of the micro-controller and the moisture determination of the system was evaluated based on the timeliness on how the sensors change from its previous state to a final settled value within a tolerance band of the correct new value. There are four sensors in each device. The values on the LCD were observed if it had changed the moment the sensors are placed in a different environment. The range of time duration for sensitivity was shown in table 2.

Table 2. Performance of SPSMMS process sensitivity

Parameters	Sensor 1	Sensor 2	Sensor 3	Sensor 4
Response in ≤ 5 sec, HS	✓	✓	✓	✓
Response in > 5 ≤ 10 sec, MS				
Response in > 10 ≤ 30 sec, S				
Response in > 30 sec,				

Note: HS- highly sensitive, MS- moderately sensitive, S- sensitive

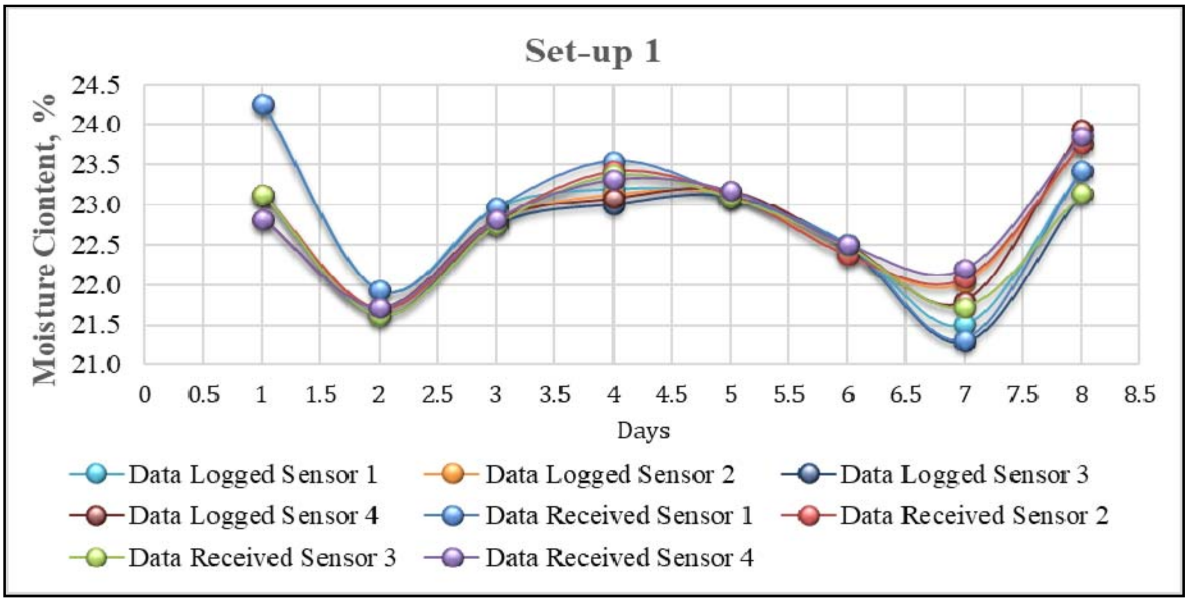

Figure 5. Comparison of data logged and data received (Installation 1)

Note: 1- 10cm form ground level; 2- 30cm form ground level 3- 50cm form ground level; 1- 70cm form ground level

Data Logging and Transmission System Efficiency

The total number of data received by the cellular phone (09057338645) from the first device was 54 text messages out of 56 messages it has supposed to received. The missing messages were data from 02:00.00 PM and 05.00.00 PM of April 8,2019. For the second device the total number of data received by the cellular phone (09161805966) from the second device was 53 text messages out of 56 messages it has supposed to receive. The missing messages were data at 08:00.00 AM, 11.00.00 AM and 02.00.00 PM of April 8,2019. Based from the result, the device 1 is more efficient than device 2 having efficiency of 96.43% and 94.64%, respectively. The major factors such as interference, air traffic, and location of the device was the causes of unsent messages through SMS. The results of analysis on data transmission were shown in the figures 5 and 6, there were no significant changes in the data when the time sent, and data logged was with the same time. However, there are times that when the delay in SMS is too long, the data transmitted became higher or lower by almost +0.1%. It can be stated that the delay was caused not only by the signal in the area but as well as the looping of the system in the micro-controller for both set-ups. In this process, the sensor readings observed were sent to the network platform through a medium (Arduino). The network layer performs all the required activities and gives desirable response.

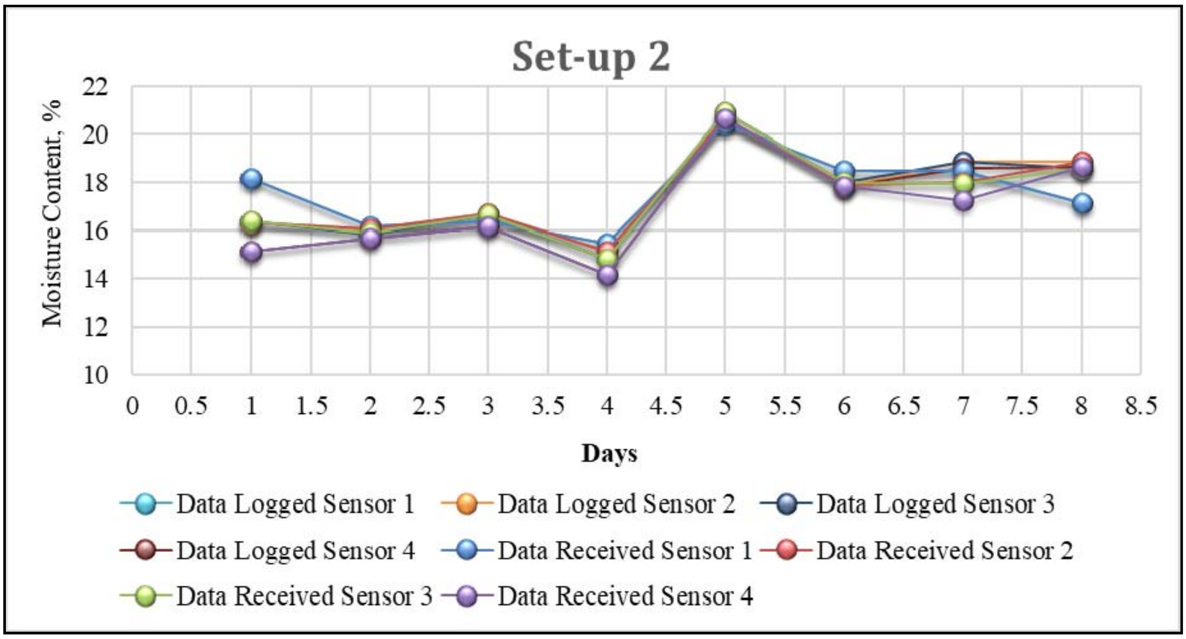

Figure 6. Comparison of data logged and data received (installation 2)
*Note: 1- 10cm form ground level; 2- 30cm form ground level 3- 50cm form ground level; 1- 70cm form ground level

Battery Performance

This graph shows the usage of power of the battery by the device. The decrease of voltage with the contrast with time was shown in figure 7. This is important for the researcher would understand the behaviour of the battery without recharging to the solar panel. This showed that the 10-Watt 12 Volt 50 AH battery lasted until 21 hours without the help of solar power. The test was done until the battery was at 50% power. For the first hour the battery reading was 11.81 volts (95.24% of the battery). On the tenth hour, the battery reading was at 6.23 volts (49.76%) of the battery.

Cost Analysis

The total direct expenses for the fabrication and installation of SPSMMS cost amounted to PhP 31,886.00. The amount includes the controller unit, construction of setup, and consultation to a programmer. One of the latest and available soil moisture sensors in the market is the Soil Moisture Meter Model MO750, which costs PhP 8,000 while the SPSMMS costs PhP 15,930.00 per unit. The total daily operational costs of are PhP 269.02 and PhP 59.93, respectively. The main difference that caused the Soil Moisture Meter Model MO750 to cost higher is the labor cost per year which is PhP 87,600 compared to PhP 11,520 from the SPSMMS.

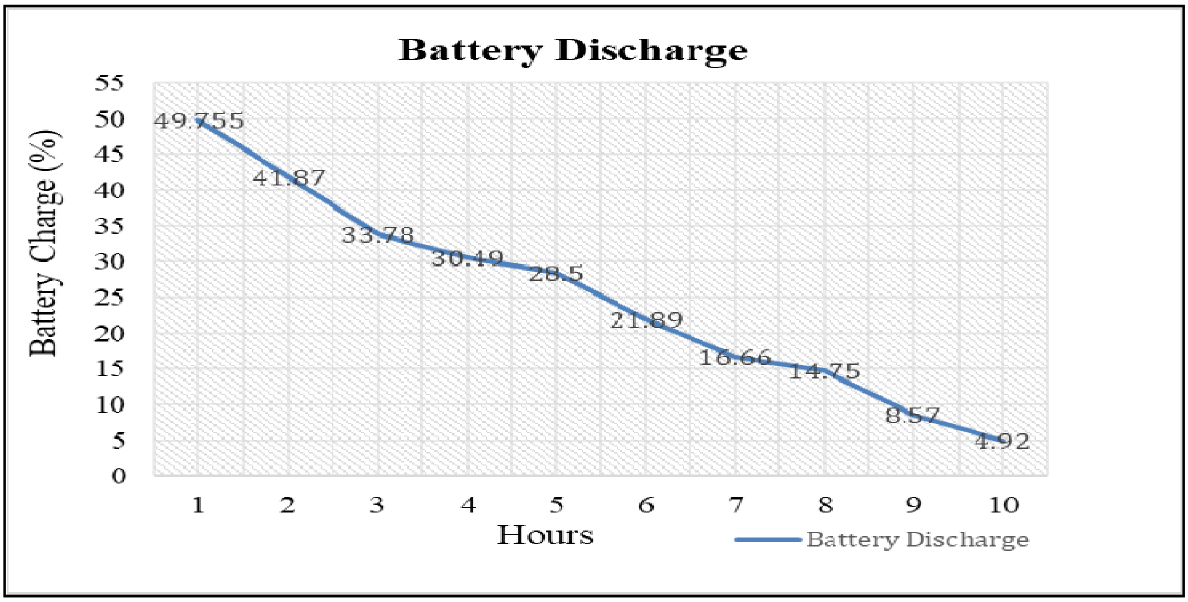

Figure 7. Battery Discharge Rate

Conclusion

The general objective of the study was evaluated the designed and automated a solar powered soil moisture monitoring system. Specifically, it aimed to design a solar powered soil moisture monitoring system (SPSMMS), evaluate the performance of the device in terms of sensitivity, efficiency and accuracy; and determine the fabrication cost of the device. Based on the result of the study, the following conclusions were drawn: the SPSMMS was design according to the structural specifications and field requirement; the design able to stand heavy rains with strong wind as well as sunny days; photovoltaic system specifications were able to stand the total required power to enable the automation of the system's components; the SPSMMS was programmed according to the design specifications with high accuracy, highly sensitivity, and high efficiency in terms of transmitting data via GSM for ease of monitoring; the efficiency of transmitting data was dependent upon the time of looping of the micro-controller; sensitivity of the device in terms of reading the data was way faster in average than the standard soil moisture meter; and the SPSMMS cost only PhP 31,866.00 for two (2) devices with locally available parts cheaper compared to commercially available handheld soil moisture meter. The SPSMMS was verified reliable and efficiency in real-time monitoring of soil moisture up to 1 meter depth with high endurance and accuracy, thus this device is recommended to farms and research.

In smart farming wireless sensors act as main supports. The data provided by the sensors decides the important steps and results in good farming practices. In this system the dominant part of the architecture is the network layer. This layer allows the integration of IoT that enables the smart devices in the farm in a convenient manner. The SPSMMS is recommended to be a part of this system and the integration of cloud in the device for the storage of information.

References

Al-Ghobari, H.M. Mohammad, F.S., El Marazky, M.S.A., Dewidar, A.Z. (2017). Automated irrigation systems for wheat and tomato crops in arid regions, Water SA 43 354–364, doi: 10.4314/wsa.v43i2.18 .

Bjorneberg, D.L. (2013). Irrigation Methods, Reference Module in Earth Systems and Environmental Sciences, Elsevier, ISBN 9780124095489, doi:10.1016/B978-0-12-409548-9.05195-2.

Borres, E.C., Sayco, T. B., Espino, A.N. and Sacdalan, JP. C., (2019) IOP Conf. Series: Earth and Environmental Science 301 (2019) 012004. doi:10.1088/1755-1315/301/1/012004.

Bowlekar, A.P., Patil, S.T., Kadam, U.S., Mane, M.S., Nandgude, S.B., Palte, N.K., (2019). Performance evaluation of real time automatic irrigation system on the yield of cabbage (Brassica oleracea L.), Int. J. Pure Appl. Biosci. 7160–165, doi: 10.18782/2320-7051.7433.

Chartzoulakis, K., & Bertaki, M. (2015). Sustainable water management in agriculture under climate change. Agric. Agric. Sci. Procedia 4, 88–98. doi: 10.1016/j.aaspro.2015.03.011.

Clemmens, A.J. (1992). Feedback control of basin irrigation system, J. Irrig. Drain. Eng. 118 (3) 481-196, doi:10.1061/(ASCE)0733-9437(1992)118:3(480).

Dhawan, V. (2017). Water and agriculture in India. Federal Ministry of Food and Agriculture, (2017) 1-28.

Depari, A. (2018). Advanced interfaces for resistive sensors. 10.1016/B978-0-08-102055-5.00008-5.

Food and Agriculture Organization (FAO), (2019). FAOSTAT. Food and Agriculture data [WWW Document].

FAO, (2017) Water for Sustainable Food and Agriculture: A report produced for the G20 Presidency of Germany, Food and Agriculture Organization of the United Nations Rome.

Hardie, M. (2020). Review of novel and emerging proximal soil moisture sensors for use in agriculture, Sensors 20 6934, doi: 10.3390/s20236934.

Lin H., Bouma J., Wilding L.P., Richardson, J.L., Kutilek M., Nielsen DR. (2005). Advances in hydropedology. Advances in Agronomy. 2005;85:1-89. ISSN: 0065-2113.

Pramanik, M., Khanna, M., Singh, M, Singh, D.K., Sudhishri, S., Bhatia, A., Ranjan, R. (2021). Automation of soil moisture sensor-based basin irrigation system, Smart Agricultural Technology, Volume 2, 100032, ISSN 2772-3755, https:// doi.org/10.1016/ j.atech.2021.100032.

Raine, S.R. (2006). The future of irrigation technologies and practices is here now, keynote address, in: Proceedings of the Irrigation Australia 2006 Conference, Brisbane, Australia.

Rosa, L., Rulli, M. C., Davis, K. F., Chiarelli, D. D., Passera, C., and D'Odorico, P. (2018). Closing the yield gap while ensuring water sustainability. Environ. Res. Lett. 13:104002. doi: 10.1088/1748-9326/aadeef

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., et al. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. Ambio 46, 4–17. doi: 10.1007/s13280-016-0793-6.

Sales, N., Remédios, O., Arsenio, A. (2015). Wireless sensor and actuator system for smart irrigation on the cloud, in: Proceedings of the IEEE 2nd World Forum on Internet of Things (WF-IoT), pp. 693–698, doi: 10.1109/WF-IoT.2015.7389138.

Sivanappan, R.K. (2008) Status, scope and future prospects of micro-irrigation in India, in: Proceedings of the Workshop on micro-irrigation and sprinkler irrigation system, 28-30, pp. 1–7. CBIP New Delhi.

Vera, J., Conejero, W., Mira-García, A.B., Conesa, M.R., Ruiz-Sánchez, M.C. (2021). Towards irrigation automation based on dielectric soil sensors, J. Hortic. Sci. Biotechno, l1–12.

Wada, Y., van Beek, L. P. H., van Kempen, C. M., Reckman, J. W. T. M., Vasak, S., and Bierkens, M. F. P. (2010). Global depletion of groundwater resources. Geophys. Res. Lett. 37, 1–5. doi: 10.1029/2010GL044571.

Zwartendijk, B.W., Van Meerveld, H.J., Ghimire, C.P., Bruijnzeel, L.A, Ravelona M., Jones JP.G. (2017). Rebuilding soil hydrological functioning after swidden agriculture in eastern Madagascar. Agriculture, Ecosystems & Environment. 239:101-111.