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Design of a smart energy efficient IoT wireless node

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Abstract. The Internet of Things (IoT) is gaining greater effect in our life from day to day. Wireless sensor networks (WSN) are embedded into the "Internet of Things" and power saving is one of the problems that it faces. This study introduces a new circuit design for a DC-DC Buck-Boost converter for controlling the output voltage of Energy Harvester (EH) via adaptive Neuro-Fuzzy inference systems (ANFIS) controller. It has proven that there is an effective changes regarding settling time almost being zero, overshoot being negligible and steady state voltage. As an application for the proposed design, an implementation for Precision Agriculture (PA) self-sustainable Wireless Sensor-Node (WS-N) with low power consumption has been presented. A solar power management for Precision agricultural in internet of things system proved to enhance cost-efficiency and increased lifetime for the device. The simulation results are determined by means that of MATLAB/Simulink software. The cloud service of Blynk IoT has been implemented to monitor the collected data on real time. Data on solar cells, batteries and soil were regarded reliable and precise.

1. Introduction

As an evolving concept, the IoT is seen as the next big thing that can have a major impact on the world's future. By implementing the recent IoT methods in the practice of agriculture, traditional farming methods can be essentially altered in every aspect. Modern wireless technology developments have revolutionized how farmers can interface with their farms and track their productivity. Advanced management ideas can be used by using latest technologies to supervise crops and by responding properly to their requirements. One strategy is known as Precision Agriculture (PA) [1], where technology is mixed with traditional farming methods. It is possible to achieve higher precision and control of crop growth and livestock farming through the use of PA in farming. By using latest technologies to support agriculture, farmers are able to boost effectiveness and decrease expenses as directly more exact remedies can be implemented by regulating the many elements of their farm management.

Fields are managed without the use of contemporary technology in traditional farming applications [14-16]. In order to retain adequate effectiveness, a higher quantity of experience is needed. When using traditional farming methods, choices such as planting, harvesting, and irrigation involve the use of

present weather conditions and historical data to determine the optimal harvesting method. In contrast, PA utilizes techniques such as sensors, actuators, Global Positioning System (GPS), robots, and software for information analysis to restrict the quantity of labor applied by farmers and to boost the quantity of care provided to plants if necessary.

This paper's primary focus is on implementing a self-sustainable WS-N in IoT for PA, Since standard sensor nodes are loaded with independent batteries of limited capacity and durability. Due to harsh environments, the energy recharge will be expensive and complicated after energy drainage. A more sensible alternative is to provide EH such as solar photovoltaic (PV) within each node that allows the sensors to be loaded in their environments by the EH alone. There are two methods for handling the harvested energy; harvest-store-use and harvest-use-store. The first approach is to store all the energy collected from EH straight into the battery and then power the nodes. Though, the inefficiencies of the batteries only generate some of the harvested energy that can be stored, resulting in power waste. The second approach is to power the node directly from the EH and to store the remaining energy in the battery, from which to be drained if the energy harvested is not adequate. The approach of harvest-use-store will be used for power management. DC-DC Buck-Boost converters were suggested to regulate the EH output voltage. To deal with the temperamental consistent difference in collected energy to keep up settled balanced-out output energy while the input data may be incomplete or imprecise [2], Neuro-Fuzzy Controller (NFC) is utilized in DC-DC Buck-Boost converters [3-5] to manage and control with the output voltage. There are several controllers that can be used to manage the output voltage of DC-DC converters such as classical controllers (PID), Fuzzy Logic Controller (FLC) [3], and PID-like Fuzzy controller [5, 6], et cetera. Among these, NFC based method for controlling has been demonstrated more better looked at than every single other methods, it offers adaptability in taking linguistic data input sources and can adjust to any system [7-9]. Neuro-Fuzzy takes the benefits of accepting the linguistic data inputs from the FLC and the versatility from neural networks. The simulation results for the proposed method compared to other controllers, in this chapter between PID-like Fuzzy and NFC are presented in MATLAB/Simulink. In addition, through Blynk IOT cloud service the status of the solar cell system, battery and the moisture of the soil are being monitored.

2. Buck-Boost Converter (B-BC)

2.1. The new Proposed Buck-Boost Converter design
The proposed system depends on the structure of the NFC, adaptive Neuro-Fuzzy inference systems (ANFIS), this technique joins the learning capacities of artificial neural systems and the ability of fuzzy logic to deal with imprecise data [7-12]. Figure 1 describes the value of duty cycle by adding the value of ideal duty cycle (D_{cyci}) to the percentage of duty cycle error (D_{cyce}) for regulating the harvester output voltage. DCYCi 's value is provided in equation (2), where VOUT is substituted by SetPoint voltage (VSP) in reference to the Equation (1) of the duty cycle (D_{cyc}).

$$D_{cyc} = \frac{V_o}{V_o + V_i} \tag{1}$$

$$D_{cyci} = \frac{V_{SP}}{V_{SP} + V_i} \tag{2}$$

There are two inputs to the Neuro-Fuzzy controller; tracking error (E) and sequential change (ΔE) as shown in Figure 2, and the MATLAB simulation with ANFIS is presented in Figure 3. The value of E is obtained as the difference between set-point/reference while ΔE value is obtained as a difference between successive steps that is;

$$E = V_{SP} - V_{OUT} \tag{3}$$

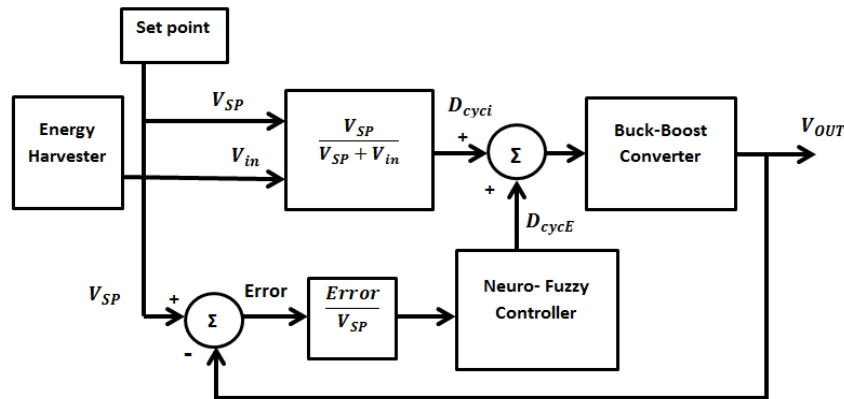$$\Delta E = E_{current} - E_{previous} = E(t) - E(t-1) \tag{4}$$

Figure 1. Buck Boost's proposed system architecture.

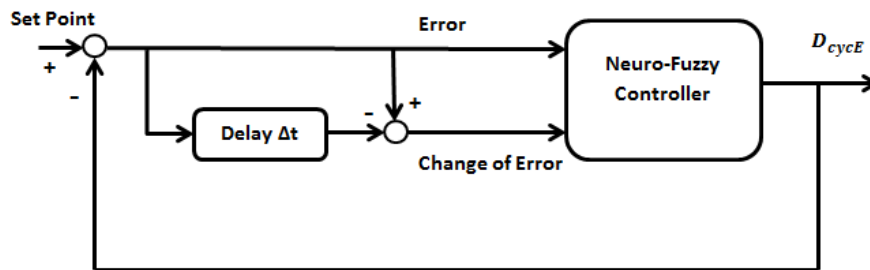The value E is normalized then applied to the controller.

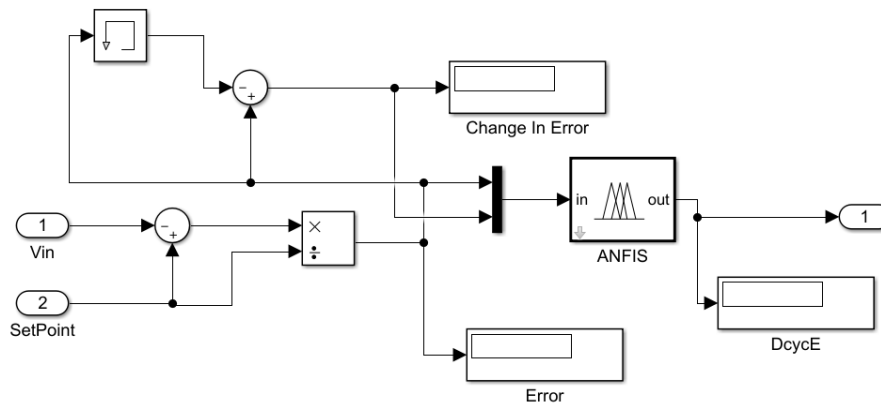**Figure 2.** Neuro-Fuzzy control system's block diagram.

Figure 3. MATLAB Simulink's Neuro-Fuzzy control system.

2.2. Neuro-Fuzzy Implementation

The implementation of ANFIS in MATLAB/Simulink can be expressed by flowchart as shown in Figure 4, The training is done offline using ANFIS tool box in MATLAB, it can be summarized into four simple steps; Loading Data, Generating Fuzzy Inference System (FIS), Training FIS, and Testing FIS [7].

First step Loading Data; the input and output data is collected from PID-like Fuzzy controller, the total number of the data sets is 36079x3, the first two columns includes the value E and ΔE, while the third column includes the value of D_{CYCE}.

Second step Generating FIS; The FIS is generated via Grid partition with number of membership functions (MFs) equals to 3 (N, Z, P) for the MF of E, where N means Negative, Z means Zero and P means Positive.

Third step Training FIS; the FIS is trained for 100 epochs and with error tolerance equals to 0.1.

Fourth step Testing FIS; the FIS is tested according to the data loaded. The advantages of this method are its rapid tracking speed and high tracking accuracy.

2.3. The Proposed System Simulation and Results

In this paper; MATLAB/Simulink is used to design and simulate Neuro-Fuzzy Controller in comparison to PID-like Fuzzy Controller. The MATLAB/Simulink Neuro-Fuzzy Controller model for B-BC is shown in Figure 4 and Figure 5 shows the algorithm flow chart.

With the use of conventional methods such as PID-like Fuzzy Controller, it is found that the settling time and peak overshoot are high, on the other side, efficient adjustments have been observed with the use of Neuro-Fuzzy Controller, i.e. settling time is nearly zero and peak overshoot is negligible. The steady state error and rise time are found in a small range as compared to other methods. Hence, Neuro-Fuzzy Controller gives better controlling outcomes over PID-like Fuzzy Controller. The results of Neuro-Fuzzy controller and PID-like Fuzzy Controller of the B-BC are shown in Table 1, also in Figure 6 comparison between PID-like Fuzzy and Neuro-Fuzzy are shown within the duration of 0.5 seconds at voltage set point of 5v. It shows the implementation of different V_{in} values to B-BC. Neuro-Fuzzy Controller has achieved satisfying results in terms of less oscillation, less tracking error and very short rise time. There was no need for sensitivity analysis since the neural network was used to optimize the system and its performance to set the fuzzy system parameters.
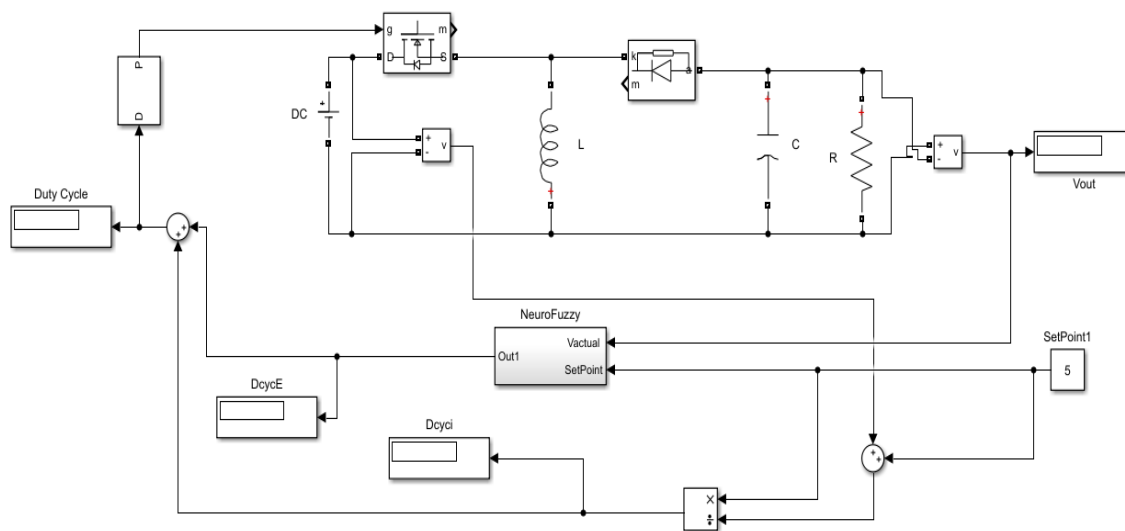

Figure 4. Neuro-Fuzzy Controller for B-BC

Table 1. Results from controllers of the B-BC at 5V Reference Voltage

Controller	PID-like Fuzzy			Neuro-Fuzzy		
	3v	5v	7v	3v	5v	7v

DcycE	0.0367 ~ 0.0898	0.0213 ~ 0.0898	0.0144 ~ 0.0898	0.0456	0.0423	0.0396
Dcyci	0.625	0.5	0.4167	0.625	0.5	0.4167
Steady state voltage (v)	5	4.99	4.99	5	5	5
Settling time (sec)	0.6	0.7	0.9	0.13	0.07	0.08
Maximum Overshoot (v)	NO	0.1	0.3	NO	NO	0.1

3. Proposed System Design

3.1. Hardware Design

In figure 7, it describes how the solar cell, Buck-Boost Converter, battery and water pump motor of PA operates; it is a circuit design of Solar Power Management for Precision Agriculture (SPM-PA) in internet of things system. The circuit diagram can be explained as follow:

- Arduino UNO input (UNO I/P)
  - Pin 1: R1 and R2 work as a voltage divider for the solar cell voltage coming from CELL_1 and CELL_2 directly to UNO I/P pin 1 for safety operation and not damaging the board.
  - Pin 2: R3 and R4 work as a voltage divider for the voltage coming from the BATTERY directly to UNO I/P pin 2 for safety operation and not damaging the board.
  - Pin 3: It is input pin from the soil sensor, to determine the moisture of the soil.
  - Pin 4: The output voltage (Vo) is used to get the value of tracking error (e) and its incremental change (Δe) to be used in Buck-Boost Converter Controller to determine the value of duty cycle (D_{cyc}) in order to control and manage the solar cell voltage and keep it 5v.

- Arduino UNO output (UNO O/P)
  - Pin 1: It is the value of duty cycle (D_{cyc}) of the controller for Buck-Boost Controller, to control and manage the solar cell voltage and keep it 5v.
  - Pin 2: When UNO O/P pin 2 is high, transistor Q1 will be switched ON and will lead to the power from CELL_1 and CELL_2 charging the battery through regulator U2.
  - Pin 3: When UNO O/P pin 3 is high, transistor Q2 will be switched ON and will tends to the power from BATTERY to the load.
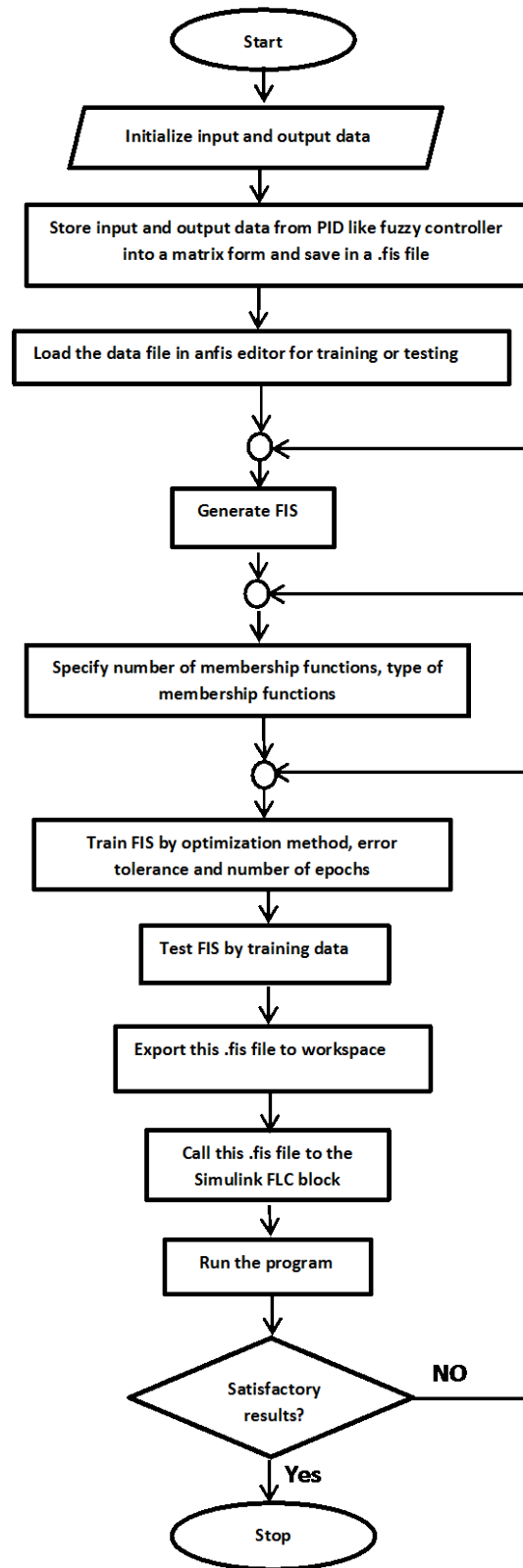 - Pin 4: When UNO O/P pin 4 is high, transistor Q3 will be switched ON will lead to pump motor turning ON.

Figure 5. Flowchart for implementation of proposed Neuro-Fuzzy algorithm
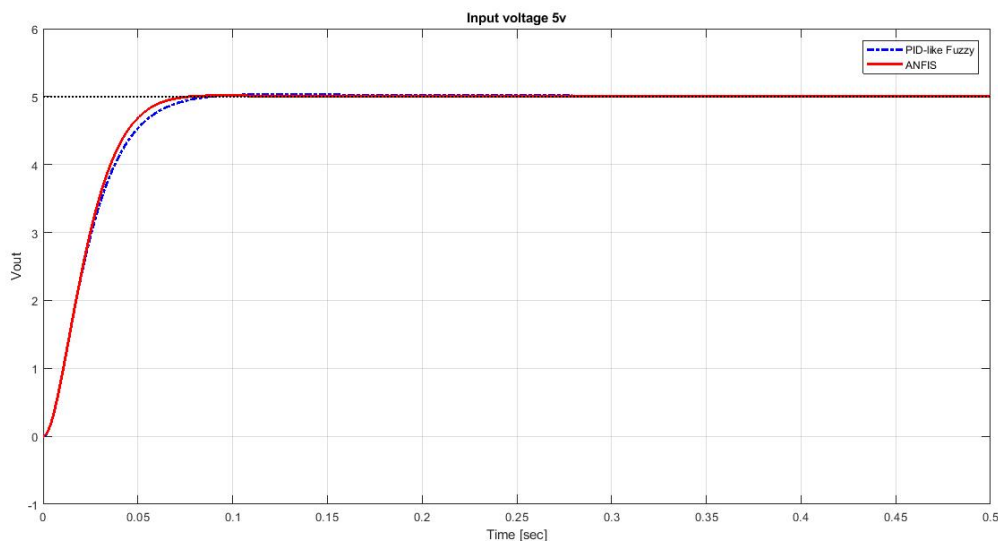
Figure 6. Output voltage comparison between PID-like Fuzzy and Neuro-Fuzzy
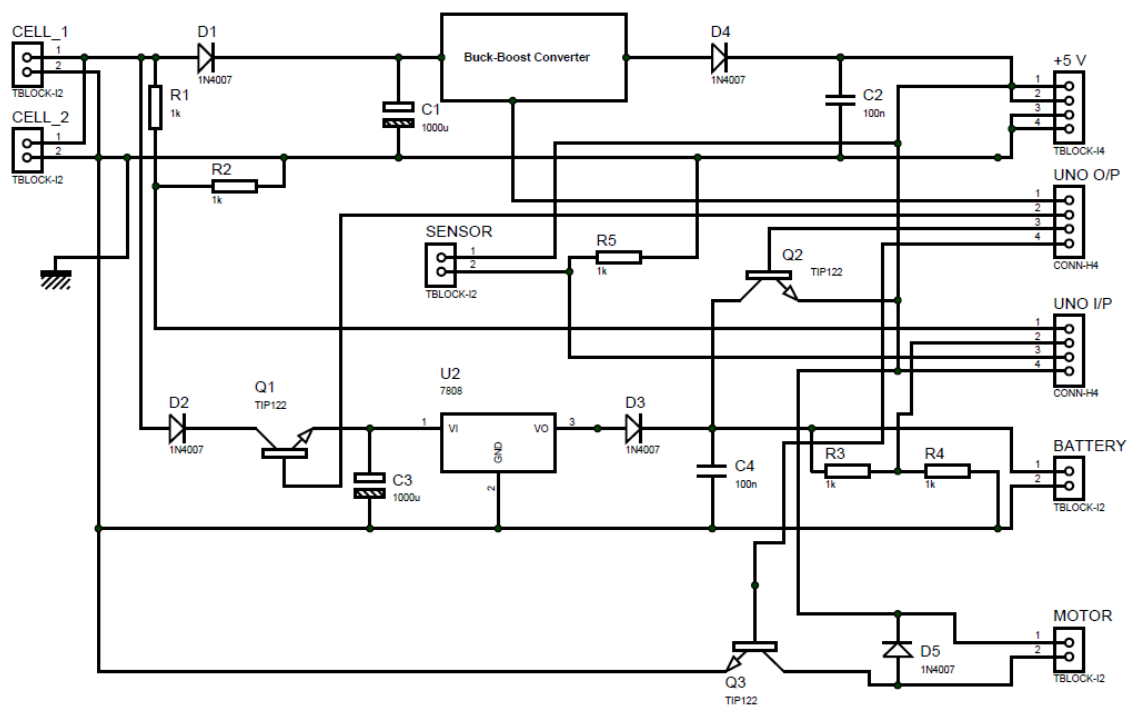

Figure 7. SPM-PA IoT circuit design.

3.2. Proposed Software Design

The software implementation can be divided into two parts; B-BC Controller and Solar Power Management for Precision Agriculture (SPM-PA). The first part, BBC controller has two inputs; tracking error (E) and its incremental change (ΔE). The value of E is normalized before being applied to the controller by diving it to set-pint voltage. The output of the B-BC Controller is percentage error duty cycle (D_{cyce}), where the ideal duty cycle (D_{cyci}) is added to percentage error duty cycle (D_{cyce}) for controlling the harvester output solar photovoltaic (PV), and the controlled voltage directly supply the water pump motor for irrigation.

The second part, software implementation of Energy Harvester Power Management for Precision Agriculture is expressed by flowchart in figure 8, where input/output pin of Arduino UNO is initialized and set, and then the values of Solar cell, battery and soil moisture data are read through (UNO I/P) as shown in figure 7. The solar cell voltage value that was read is then compared with minimum Cell voltage (MCV) which is the minimal amount of voltage that allows the motor to work efficiently with the sunlight. If Cell voltage is less than MCV then the solar cell will not charge the battery neither will load the Arduino. But if the Cell voltage is higher than MCV, then in case the battery arrived to minimum voltage level (MBV) it will load the battery till its full. And also while the solar cell level higher than MCV it will check the soil moisture level, if it the soil is dry according to Moisture data (M-data) that was collected then the water pump motor will run and irrigate the soil.

Finally all the data that is collected are sent through NodeMCU in real time which can be shown using mobile devices via Blynk services (app). NodeMCU is an IOT platform open source.

4. Proposed Hardware Implementation

4.1. *The Requirements*

This section focuses on hardware implementation of self-sustainable Wireless Sensor Node for PA, to save energy and prolong the lifetime of the battery. But at the same time the design of the hardware must be cost-effective and affordable. The hardware that is used and their purpose are discussed in Table 2. In Table 3 describes the software that is used for coding in Arduino UNO and NodeMCU. Table 4 illustrates Blynk [13], which is a platform service to connect the NodeMCU and the mobile app. it is used to monitor the data of solar cell, battery and soil moisture on the mobile app.

Table 2. Hardware and usage purpose

Hardware	Usage purpose
2 x Solar Cell panels 5Watts 9V	Transform light into energy
6v,4Ah Battery	Store solar energy
NodeMCU (ESP8266-12E)	Send Solar cell, Battery and Humidity data into internet via WIFI connection
Moisture Sensor	sensor is used to detect the amount of moisture present in the soil
5v Pump Motor	Used for water irrigation
Arduino UNO	Software code implementation for SPM-PA
SPM-PA system module	Buck boost, charger, motor driver

Table 3. Software and usage purpose

Software	Usage purpose
C++ on Arduino	Programming language on NodeMCU

Table 4. Service and protocol and usage purpose

Service and protocol	Usage purpose
Blynk App	IoT cloud service

4.2. The proposed Concept Diagram

In this research paper, the studies aim to expand their use as green energy resource and an alternative for a case study in the solar cell system for a smart energy efficient agriculture. The IOT is applied to measure and monitor the status of solar energy, battery and moisture. All data can be monitored in real time on mobile devices. Furthermore, as an IOT cloud service, all the data status of solar cell, battery and soil are preceded into a Blynk. All data on cell phones can be tracked in real time.

As explained in previous figure 7 for SPM-PA in IoT system module, it describes how the circuit design for the solar cell, Buck-Boost Converter, battery and water pump motor of PA operates and manages between them. In figure 9, it explains the whole concept diagram of SPM-PA in IoT.

The Battery will supply power and load Arduino via SPM-PA circuit, to be able to operate the rest of the system without shutting down. Among them controlling and managing solar voltage coming from solar cell via Buck-Boost Converter to stabilize the solar voltage to 5v to operate the water pump with efficiency. In order to increase the output current, two solar cells with 5 watts are connected in parallel.

Through the connection between Battery and SPM-PA, the battery level is determined by the code written in Arduino to charge the battery from solar cell.

The collected data of solar cell, battery and soil are sent from Arduino to NodeMCU serially, NodeMCU was used as a WIFI hardware to link the IOT to the access point of the router. This enables it to connect to the internet. Blynk was a service used to send data to an internet to show those information on smartphones in real time.

4.3. Implementation and Results

Arduino UNO, SPM-PA cicuit system and NodeMCU were put together in a small waterproof container as shown in figure 10.

All embedded devices are placed in containers that are waterproof. The solar panel, battery, device container and water pump are put in a handheld board as shown in figure 11 which describes the picture of the IOT solar system. The solar panels were designed to a 45 degree angle to the direction of sunrise.

The setup is designed to show the use IoT power management in precision Agriculture. From previous discussions, Blynk is known as a platform service to connect the NodeMCU and the mobile app. It is used to monitor the data of solar cell, battery and soil moisture on the mobile app that can be displayed in real time online.

The status of the current usages with the solar cell, battery and soil were displayed on Blynk app on mobile as shown in figure 12(a) when the sun at its peak, where solar cell voltage is high and battery level is high but the soil moisture level is low. On the other hand figure 12(b) shows the status at no sunlight, where solar cell level is low, battery level is high and soil moisture level is intermediate. The OFF button displayed in the figure is used to turn the light of the system box on and off to check for the connection.

When the soil moisture level is very low a notification was automatically displayed on mobile screens as shown in figure 13. Blynk's cloud service is an IOT app. Android and IOS support it. Solar-cell, battery and soil data can be presented every 2 senods in this study or when there are activities such as low or dry soil battery level.
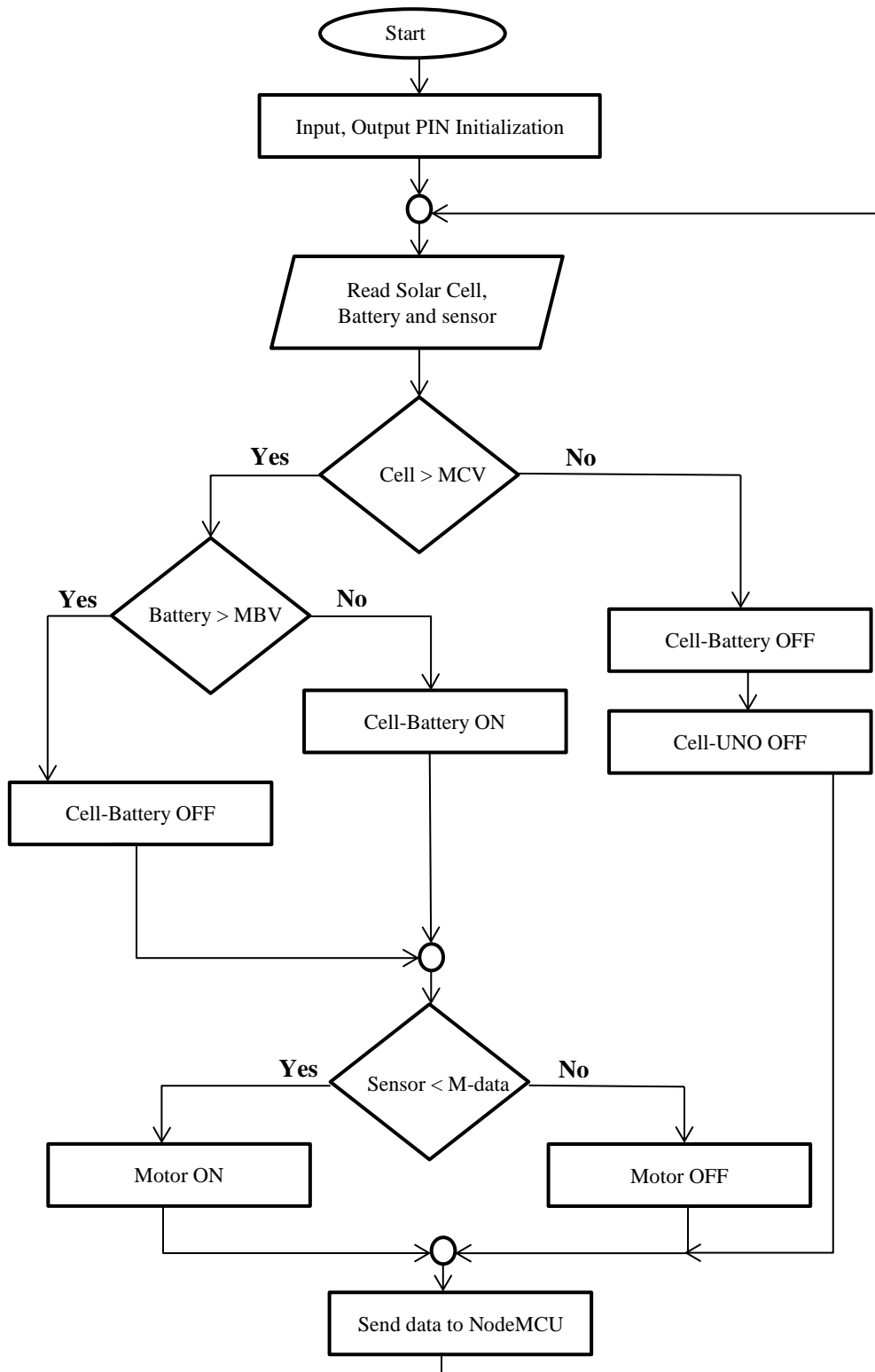
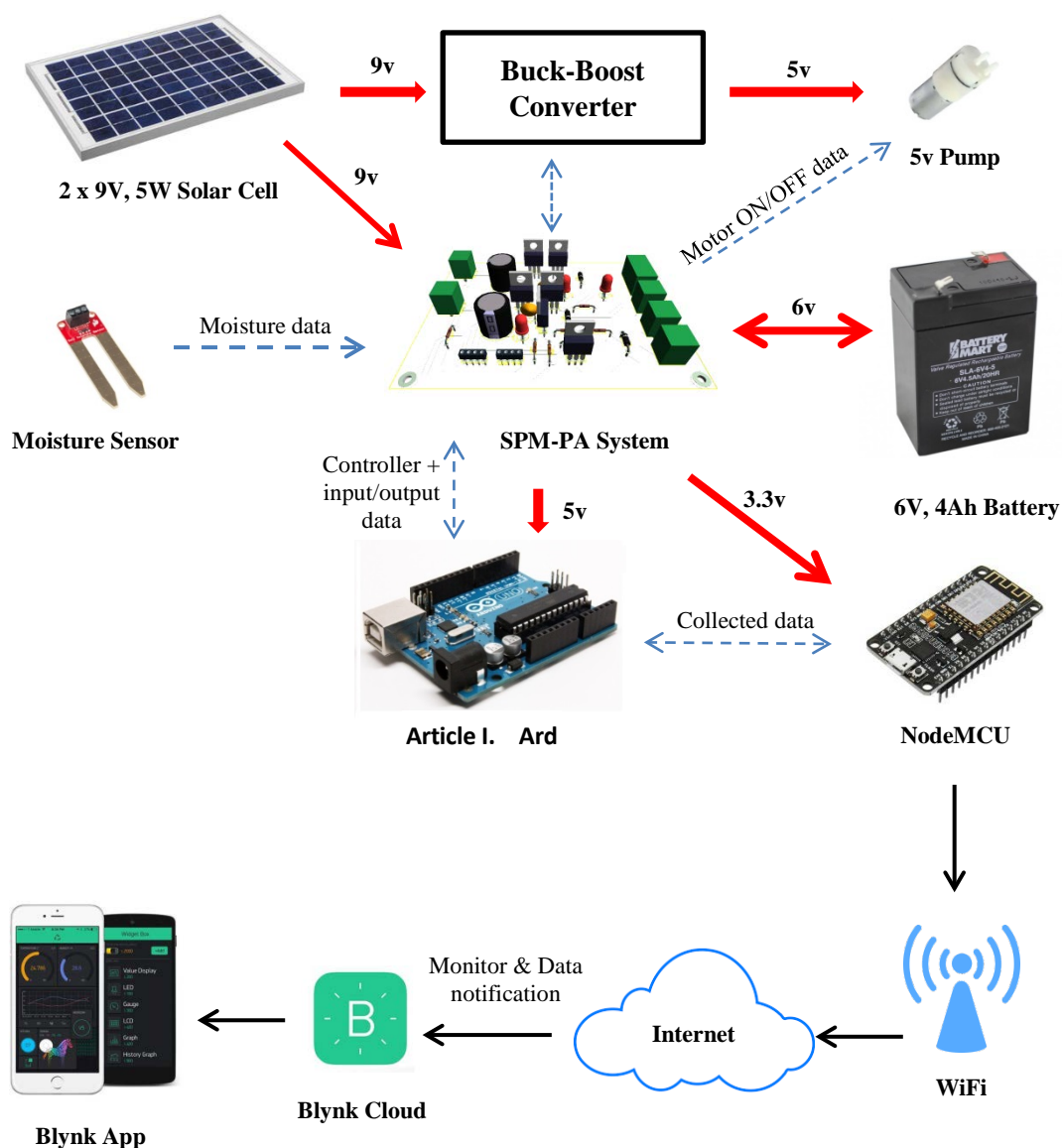**Figure 8.** Flowchart of software implementation of SPM-PA.

Figure 9. Concept diagram of Solar Power management System for Precision Agriculture in IoT

This work is a case study to incorporate as an alternative energy source for the PA model of a solar-cell device. Famers can therefore use this solar system in isolated areas. The status of solar-cell, battery and the soil were needed to be monitored on mobile devices. A total power usage was 19 watts as shown in Table 5.

Table 5. Power consumption per day

	Usage (Hours/Day)	Power rating (Watts)	Total daily used (Watts)
Water pump	0.4	2.5	1
Microcontrollers	24	0.75	18
			19

The daily usage of solar-cell system can be calculated as 19 watts, 5 hours for solar charging. Two panels of 5 watts were used which gives a total of 10 watts. The energy storing size of the battery can be calculated as Ah (Amp-hour) = total energy usage / battery voltage, Ah = 18/ 6 = 3 Ah, therefore the 4 Ah battery was applied to this case study. The average amount of time it takes to charge a solar-cell is approximately 5 hours. The battery was 4 Ah, which means that the battery was able to provide 6 volts X 4 Ah = 24 watts and the daily maximum system usage is 19 watts.
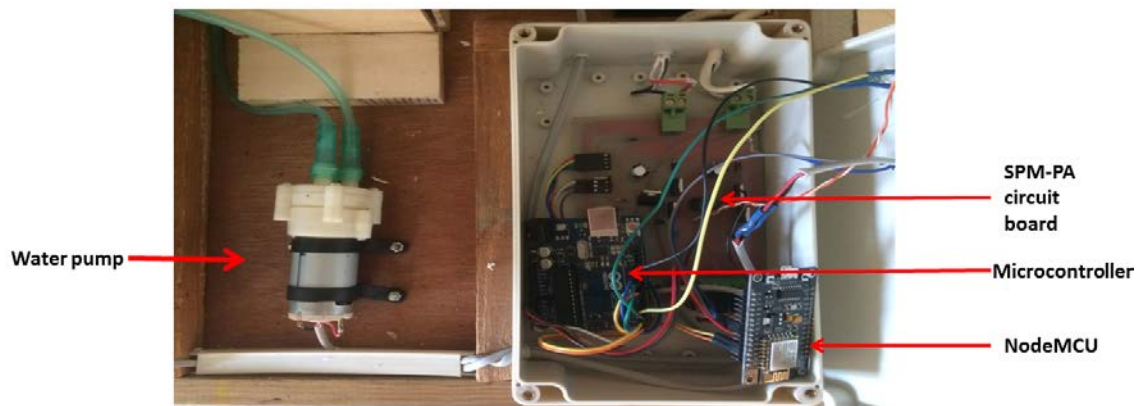

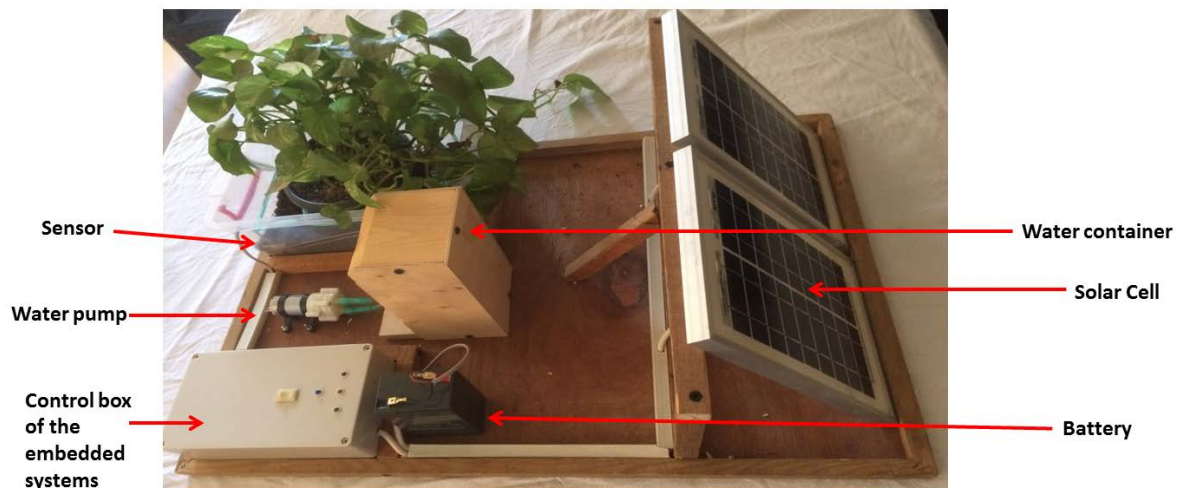**Figure 10.** Electronic devices inside the box

Figure 11. Prototype Solar Power management System for Precision Agriculture in IoT

Application example supposes that it will be used for smart agriculture. Table 6 shows comparison of the average power consumed of the proposed system and the other discussed systems, the water pump is consuming 0.5 current as written in datasheet.

Table 6. Average power conception of the load

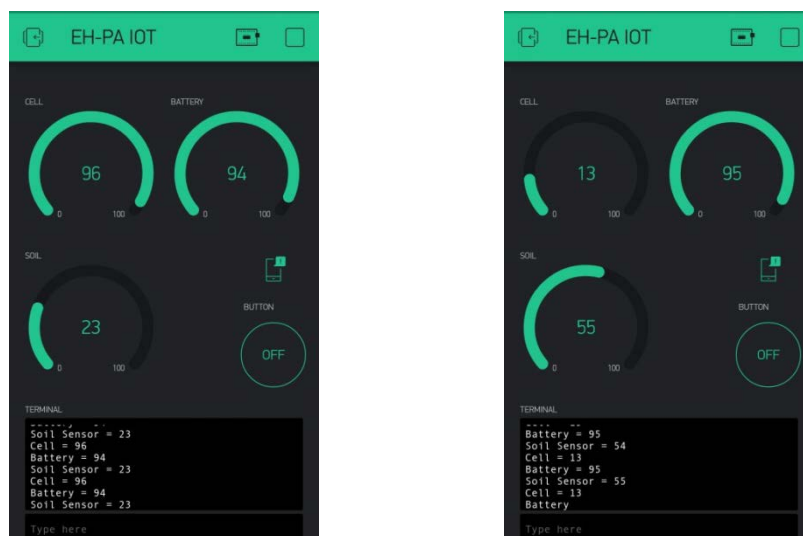|	Fuzzy	PID-like Fuzzy	Neuro-Fuzzy
Average mean voltage	5.0143	5.0095	5.0063
Power consumption	2.50715	2.50475	2.50315

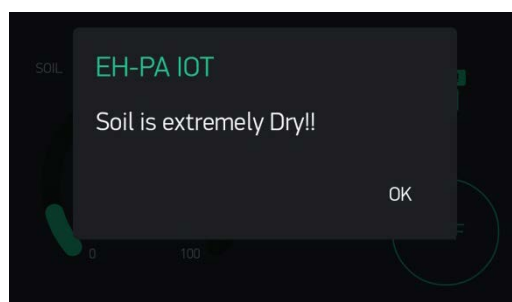**Figure 12.** (a) System in the sun,   (b) System in the shade.

Figure 13. Soil dryness notification on Blynk.

5. Conclusion

In this paper, a solar power management for Precision agricultural in internet of things system to enhance cost-efficiency and increased lifetime for the device was presented as an example and application of the proposed power management circuit. Neuro-Fuzzy Controller was proposed for the use in a new design of a DC-DC B-BC to regulate the voltage coming from Solar cell to the load. SPM-PA circuit was designed to manage between solar cell, battery, sensor and the motor with success. The water pump's functional status was performed properly. The cloud service of Blynk IoT has been implemented to monitor the collected data on real time. Data on solar cells, batteries and soil were regarded reliable and precise.

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