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Green Solar Source for Outdoor Environment Monitoring Using Wireless RF 2.4 GHz for Smart Farm Application

***Abstract**. Green technologies are of great interest as they are frequently culled by domestic households and industrial sectors, especially in intelligent farming applications. The power supply resource is the main factor that is used in an outdoor environment because it is not convenient to use a wall adapter in outdoor conditions. In this study, the quality of the environment monitoring system and green power supply has been developed using solar energy resources, which are more convenient to facilitate the outdoor environment without any wall adapter or external battery added. Thus, a weather monitoring system embedded with solar power source management is proposed to focus on data linkage quality measurement based on received signal strength (RSS). This proposed system involves the application of wireless RF ZigBee-Pro technology based on the IEEE802.15.4 standard using 2.4 GHz in a microwave frequency band. The environment monitoring system consists of multiple biosensors: oxygen (O_2), temperature, and humidity sensors to monitor the environmental condition of a farm area. The monitored information data of the environment monitoring system according to its sensing as mentioned are transmitted to the host station correctly with well-received signal strength indicator (RSSI) value with usage convenience at both of the indoor and outdoor environments. The results indicated that the solar panel kept a maximum current and maximum power of 335.48 mA and 8.76 W, respectively, at noontime. Moreover, the RSSI performance is an essential factor for the wireless communication networking for the environment monitoring system between the solar power and wall adapter supplies, which is suitable for the intelligent farming application. The findings indicated that both power sources' quality is a similar performance at the confidence of 95 %.*

Streszczenie.** W tym badaniu proponuje się system monitorowania pogody z wbudowanym zarządzaniem źródłem energii słonecznej, aby skupić się na pomiarach jakości łącza danych w oparciu o siłę odbieranego sygnału (RSS). Proponowany system obejmuje zastosowanie bezprzewodowej technologii RF ZigBee-Pro opartej na standardzie IEEE802.15.4 wykorzystującej 2,4 GHz w paśmie częstotliwości mikrofalowych. System monitorowania środowiska składa się z wielu bioczujników: tlenu (O2), temperatury i wilgotności, które monitorują stan środowiska na terenie gospodarstwa. Wyniki wykazały, że panel słoneczny utrzymywał maksymalny prąd i maksymalną moc odpowiednio 335,48 mA i 8,76 W w południe. Co więcej, wydajność RSSI jest istotnym czynnikiem dla bezprzewodowej komunikacji sieciowej dla systemu monitorowania środowiska między zasilaniem słonecznym a zasilaczami ściennymi, które są odpowiednie do inteligentnego zastosowania w rolnictwie. Wyniki wskazują, że jakość obu źródeł zasilania jest podobna przy ufności 95%.* (Źródło energii słonecznej do monitorowania środowiska zewnętrznego za pomocą bezprzewodowego RF 2,4 GHz do aplikacji Smart Farm***)

Keywords: RSS, RSSI, ZigBee-Pro, IEEE802.15.4, O_2
Słowa kluczowe: monitorowanie środowiska, ZigBeee, źródła fotowoltaiczne

Introduction

The wireless technologies have become imperative to implement an appropriate wireless protocol such as Bluetooth, ZigBee, UWB, or WiFi [1]. The vast majority of wireless transceivers offer the possibility of measurement a quantity called "Radio Signal Strength," which is the power of the received radio signal. Historically, the RSSI is essential, which impacts the linkage quality in any wireless communication system. It is an average of the signal

received through the different paths and multipath effects, especially the RSSI monitoring system based on real-time measurement. In this study, the RSSI issue is observed on real-time monitoring within 12 hours for a while. It explores the solar energy storage performance of selected solar power sources embedded into the air monitoring module system. On the other hand, the RSSI issue has also been analyzed in the other works for indoor and outdoor environments, such as RFID-based indoor guidance and monitoring systems [2], and the analysis of RSSI-based device-free localization (DFL) for human detection at indoor environment using (IRIS) mote [3].

In this paper, the environment monitoring system embedded with a multi-biosensor using a wireless active RFID sensor is embedded with a humidity sensor compared to the previous work [4]. Based on the operational problem statement in the previous study, it shows that the power supply source was unavailable while testing at an outdoor condition with the expansion plug issue. Thus, an alternative for an appropriate power source is a significant issue to be addressed. Then, the solar power supply is installed into the air monitoring module to solve the problems of battery life and the inconvenience of using an expansion plug in any outdoor condition. The solar source can be produced as electricity energy [5, 6] and is considered the best solution to power up electrical network communication without an external battery and wall adapter being added.

Sequentially, this paper is organized as follows. In section 2, the proposed weather monitoring system with a solar energy source is exhibited. Section 3 describes the experimental results and discussions, which are divided into three sections; Section 3.1 Electrical characteristics of an adopted solar panel; Section 3.1 Relationship of stored solar energy depending on environment factor and Section 3.3 RSSI measurement test. Finally, the conclusion is summarized in Section 4.

Proposed Quality Environment Monitoring Using Solar Source

This section describes the proposed weather monitoring system's composition. It mainly consists of the terminal monitoring module and workstation [4]. This paper focuses on the end device module performance. It consists of three main parts, which are a sensing input, processing, and display unit. The input sensing unit contains O_2, temperature, and humidity sensors, used for sensing the air environment condition with multiple parameters. The processing unit with Arduino Uno microcontroller circuit board contains memory, real-time clock, and embedded with wireless transceiver ZigBee-Pro module. The wireless transceiver sensor is based on the IEEE802.15.4 standard at a microwave frequency band of 2.4 GHz. The last part is the display unit to show the monitored information on board, as shown by the block diagram in Figure 1.

The solar energy source is appropriately designed for outdoor conditions. It is arranged as a power management circuit to properly embed the design into the monitoring tag module with a stable output voltage of 5 V. The solar mainboard has mainly consisted of a solar panel, filter, solar charger, and dc battery. The solar panel adopted Mono-crystalline TO PRAY, which aimed to produce the power of 10 W and voltage of 17.5 V.

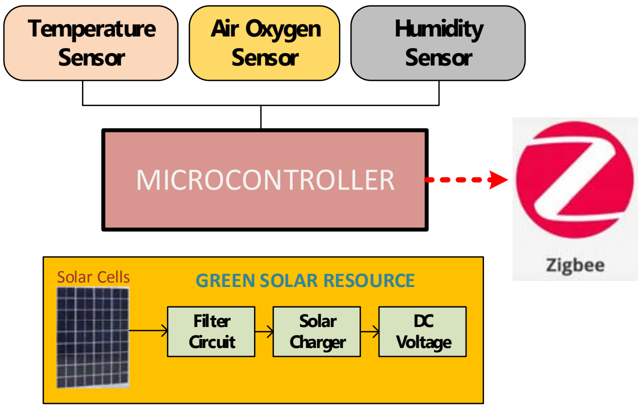

Fig.1 Block diagram of wireless environment monitoring supplied by the green solar resource

The solar power source is added to the weather monitoring system to achieve greener technology development. The first step is to properly design and select a suitable solar panel size for sufficient energy requirement for the tag circuitry that consists of 5 V for the microcontroller board and 3.3 V for the wireless transceiver sensor. Thus, the air monitoring tag can also be used outdoors in good condition, similar to a wall adapter with 220VAC input and 5VDC output. Hence, the solar source is more convenient to be applied in outdoor conditions.

In order to calculate a suitable size of solar panel that can supply for the end tag module, which requires an input voltage supply of 5V and 3.3V using the following equation (1):

$$\text{Size of array} = \frac{\text{Total Load power x Consumed hour}}{\text{Quantity of sunlight within 1 day}} \qquad (1)$$

Solar cells are driving forces in the research for new energy sources because they are renewable and ecologically friendly [5, 6, 15]. The solar cell is a nonlinear device, which can be demonstrated as a current source model with the given I-V characteristic of a solar cell represented by equation (2).

$$I=Isc-Id=Isc-Ios\left(\exp\frac{q(v+I_{RS}}{nKT}\right)-1 \qquad (2)$$

where Isc is the light generated current, Ios is the diode reverse saturation current, q is the electronic charge, K is the Boltzmann constant, T is the temperature, v is the terminal voltage of the module, and Rs is the series resistance.

The monitoring end device tag, as shown by the individual block diagram in Figure 1, consumes total energy of about 5 W. Based on the actual experiment, the solar power collection, and RSSI performances were tested in a football field for 6 hours testing from 9.00 am until 3.00 pm within the same day. The module consumed a total power of 6 hours per day which is equal to 30 W (5 W x 6 hours). The quantification of solar energy from the sunlight per day can be collected for only 6 hours per day because that is the optimum sunny time and suitable for the solar panel to collect the solar energy. The calculated energy based on the solar panel size is to be 8.33 Ah. Thus, the selected size of the solar panel is 10 W, 17.5 V. Then, the model of Mono-crystalline solar panel TOPRAY is adopted because it can cover the used power consumption each day, and it is more suitable and compact in size for portability with the monitoring tag module as shown by the schematic diagram in Figure 2.

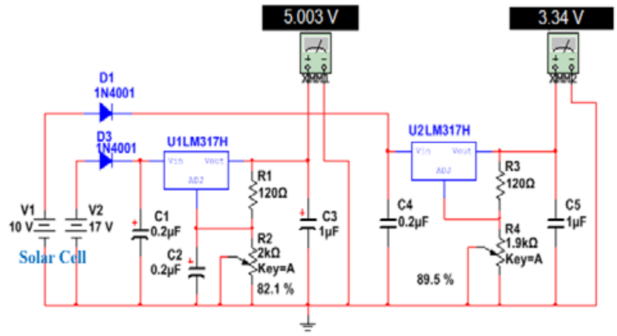

Fig. 2 Solar charger schematic circuit

The LM317 device is used as an adjustable of three positive terminal voltage regulators for supplying a current of not more than 1.5 A and an output range of 1.25 V to 30 V. During operation, and the LM317 develops a nominal 1.25 V reference voltage (VREF) between the output and terminal adjustment. VREF is referred voltage to across program resistor R_1, and since the voltage is constant, the constant current (I_1) then flows through the output set resistor R_2, giving an output voltage of [8]:

$$V_{OUT}= V_{REF}\left(1+\frac{R_2}{R_1}\right)+I_{ADJ}R_2 \qquad (3)$$

Since the 100 µA current from the adjustable terminal represents an error term, the LM317 was designed to minimize IADJ and make it very constant with Line and load changes. All quiescent operating current is returned to the output establishing a minimum load requirement. If there is an insufficient load on the output, the output will rise. Output capacitors are used in the range of 1 □F to 1000 □F for the aluminum or tantalum electrolytic, which are commonly used to provide the improved output impedance and rejection of transients [5].

The circuit requires only two external resistors to set the output voltage. The device features a typical line regulation of .01 % and typical load regulation of .1 %. The proposed solar charger circuit includes the function of current limiting, thermal overload protection, and safe operating area protection. The best selection of suitable power sources must be determined based on the multiple sensors' working conditions. The energy demand of today's intelligent sensors is relatively low (for power supply from the electrical power network), but also relatively high in terms of the long-time operation in external conditions (pure battery operation) [9, 10].

Experimental Results and Discussions

This section demonstrates the experimental results and discussions for the proposed weather monitoring system with solar power source management. The experiments are divided into three parts. Section A shows the measured current, voltage, and power of the adopted solar panel; Section B analyzes the relationship between stored solar energy with environmental factors. Finally is Section C demonstrates the RSSI performance test with differentiation at each period and distance. More details are in the following presentation sequences.

1. Electrical Characteristics

The solar panel model of 17.5V/10W is measured by using a digital voltmeter and ammeter. The energy efficiency is tested in terms of current and voltage based on DC characteristics at 9.00 am, 12.00 am, and 3.00 pm to illustrate the difference of current at different time intervals.

The relationship between current and voltage was measured from the individual solar panel at each time difference, which was tested at a football field in Rajamangala University of Technology Srivijaya Songkhla (RMUTSV), Thailand. The findings indicated that the maximum measured current from the solar panel at the duration of time at 12.00 am, which is higher than at 9.00 am and 3.00 pm with the measured current of 335.48 mA, 303.54 mA, and 179.54 mA, respectively. Moreover, the various calculated powers are also plotted to present the maximum power, as in Figure 3.

Namely, the maximum power measured from solar panels at 12.00 am is obviously higher than that at 9.00 am and at 3.00 pm at the statistical significance level of .05. Namely, the precise time for solar cells' energy storage is at 12.00 am due to the temperature factor [11]. The current and power will be changed over time in one day, but the solar energy stored was still adequate to supply for the terminal module because the monitoring end tag consumed only a small power of 5 W.

Therefore, the following result is to demonstrate the RSSI measurement to prove that the solar power source does impact the stability of communication quality. This is the relationship that was assumed in this study, which is then to be demonstrated in the next section.

2. The stored Energy on Environmental Factors

This section is to specify some of the captured solar power values at various environmental temperatures. The generated power of solar cells is gradually increased according to the temperature level. Whenever the temperature is high, the obtained solar energy increased, as shown by the graph in Figure 3.

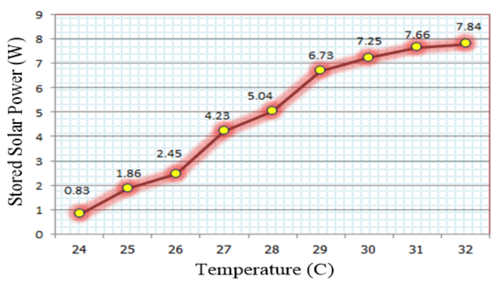

Fig. 3 The storage of solar's power according to temperature variable

The obtained results of stored solar power are consistent with the study of Forero *et al*. [11]. Their study has mentioned the PV solar plant's power and voltage curves, measured under the different irradiances. It is observed that the short circuit current increases with increasing irradiance, whereas the open-circuit voltage decreases when the irradiance decreases. Namely, the decrease of Voc is attributed to temperature effects. During the time which solar panel earns the higher power is about at 11.00 am to 14.00 pm.

The solar panel's characteristic was also tested based on the output of voltage and current parameters to show the relationship of stored power at several environmental factors. The solar panel without any load connected was measured through the voltage and current meters according to the various light intensity values. The obtained results are as shown in Figure 4.

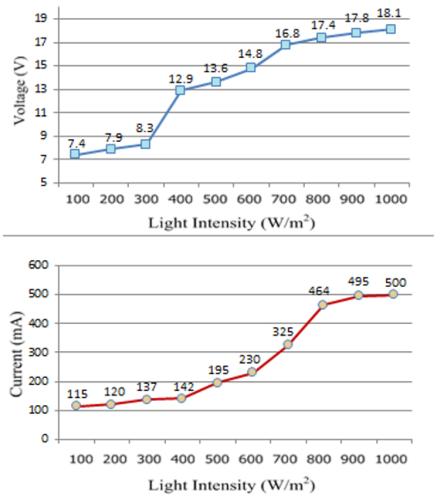

Fig. 4 The production of voltage and current according to light intensity

Figure 4 presents the experimental results of voltage and current levels according to the light intensity. The solar energy will be accumulated into the battery, and it is actually can work even if places in an indoor environment. The prototype can still work even it only receives the fluorescent light from the household area. Therefore, the proposed prototype can overcome these challenges with different weathering.

3. RSSI Performance Test

In this assessment, the RSSI performance test is evaluated to analyze the proposed wireless weather monitoring system's link quality. The WSN communication system is based on the star network topology, in which it consists of a coordinator or point-to-point communication. In this test, the end device tag is set up to communicate to the coordinator with a distance of 1 m. Thus, packets will only communicate between the end device tag and coordinator. Typically, all packets will go through the coordinator and become bottlenecked, and there is no other alternative route to the destination, whereby there are many end device tags. In this tryout, the end device is only prepared for one tag to investigate the RSS performance with low rate delivery packet and the low time interval between messages to compare the efficiency of both power supply sources, a solar and wall adapter. The coordinator is always asking the requesting command to the end device, which senses the weather environment for the temperature, oxygen, and humidity parameters. This stage confirmed that the completed information is appropriately delivered to the host station, making it easy and convenient for the user through a monitoring station. Simultaneously, the user can also automatically communicate and monitor a weather condition's status based on the WSN platform according to the data flow in Figure 5.

The end node can connect directly to the coordinator with an open global standard for wireless communication based on the IEEE802.15.4 standard or known as "ZigBee". The wide area can be covered with good quality of received signal strength (RSS). The space among nodes must be as far as possible to reduce the number of nodes. However, the large field environment experiences some attenuation due to the weather condition or the factor of battery power supply quality. In this experiment, the power supply sources are the priority and given the essential consideration to prove that the solar power source requires as much efficiency possible to be applied in any device module.

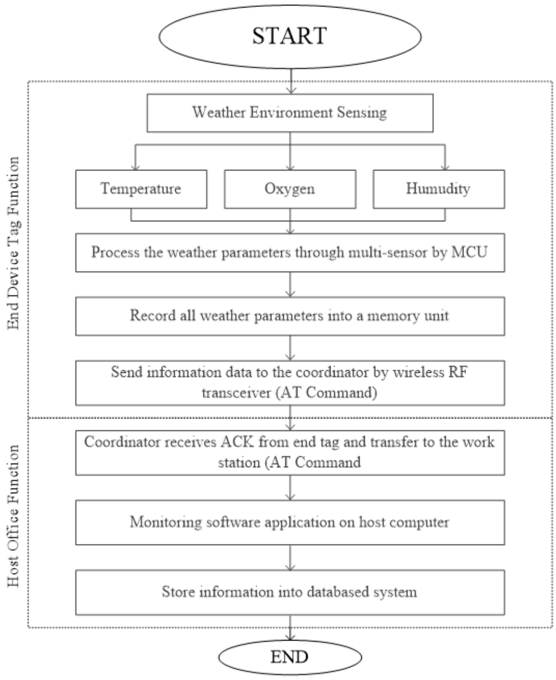

Fig. 5 Data flow process of the end tags and the coordinator

The concept of defining and changing distance tests in RSSI measurements is performed in this work. The analysis of the properties of RSSI is done based on the real experimental outdoor test. The trend of logarithmic decay and fluctuations are consistent with the distribution. Namely, the obtained results illustrated that the proposed newly designed model's idea could give us a more precise result.

Please assume that the transmission power is known and is set up at the highest transmit power of 18 dBm. Then the strength of the received signal to get the RSSI value is measured. Here the propagation model is evaluated in terms of the distance [17], and the expression of this equation model is:

(4) $$P_d = P_{do} - 10\mu \lg\left(\frac{d}{d_o}\right) + x_\sigma$$

D is the distance, and it can be calculated using the distance between the end device node and the coordinator; μ is the path loss exponent and is commonly dependent on the environment condition during testing time. Then, the x_σ is defined in dB and is the standard deviation of zero mean value; Pdo is a Do meter's signal strength value. In case the do is determined at 1 meter and a common intensity value A to Pdo, the equation can be then converted to Pd = A-10μ lg d [18]. Therefore, the measured distance can be shown as the following equation:

(5) $$d = 10^{A-Pd/10\mu}$$

The received radio signal degrades its strength as the inverse square of distance "d" traveled between two wireless sensors, which is given by:

(6) RSSI = -10 x n x log(d) + S

Thus,

(7) RSSI = (-m x D)+ S

where D = log(d), m = 10 × n, S = constant. The terminal device (transmitter) and the reader (receiver) modules are placed at a distance of 100 m apart in the experiment. The qualification of wireless transceiver sensors can communicate with each other for indoor 90 m and outdoor 1500 m (LOS). Thus, the selected space of 100 m is the best distance to show the obtained RSSI compared with longer distance testing clearly. The RSSI values are captured using the X-CTU software with real-time monitoring of 60 minutes, and each value is averaged by ten times of data collection. The findings are indicated by the graph form, as shown in Figure 8.

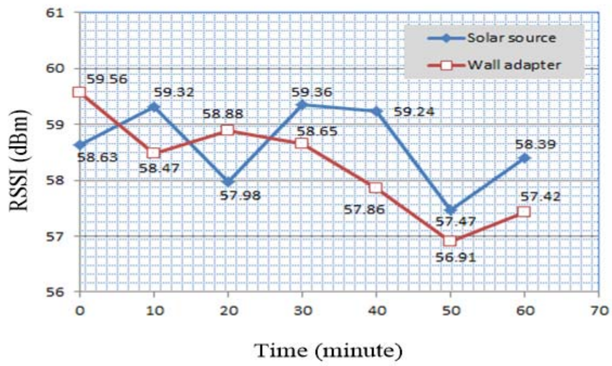

Fig. 6 The measured RSSI values at different test times

The solar power and wall adapter sources have given the averaged RSSI values of 58.61 dBm and 58.25 dBm, respectively, with no difference at statistical significant of .05 (reliability 95 %). In this test, the transmitter and receiver devices are placed with a distance gap of 100 m, and the received RSSI values gave no significant differences throughout the testing for 60 minutes. In contrast, Li Panxing and Wang Tong (2015) studied the transmit power and distance variables showing a significant disturbance when the nodes' distance is increased [12].

Moreover, the RSSI values are measured to analyze wireless communication's link quality using a solar energy source compared to a wall adapter supply. The air monitoring device terminal is placed away from the reader every 15 m, which started from near each other at 0 m and end of the test at 150 m. The air monitoring module was set up with the transmitted power at the highest level of 10 dBm to communicate wirelessly to the work station through a reader. Thus, the obtained results are presented in Figure 7.

The averaged RSSI values obtained by the solar power source and wall adapter are 45.95 dBm and 45.86 dBm, respectively, in which there is no RSSI difference at statistical significant of .05 (reliability of 95 %). This is another performance test of the proposed alternative solar energy source embedded into the environment monitoring system, working in the outdoor environment.

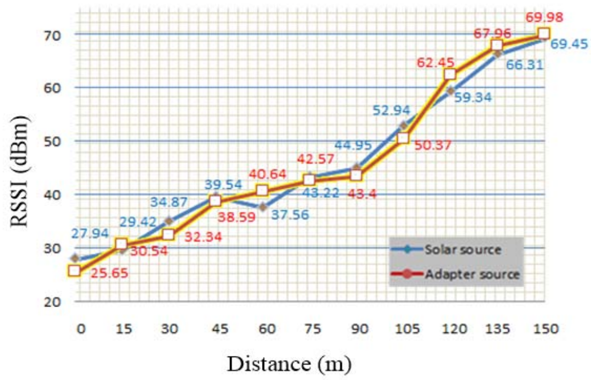

Fig.7 Comparison of the measured RSSI from solar source and adapter

This section's obtained results are also consistent with Tanakorn's study (2021) [13] on distance measurement based on the RSSI of ZigBee. The results have claimed that the errors increased according to the distance. This is why the RSSI value decreased when the test distance was increased because it was affected by error and path loss [14]. Furthermore, it is also consistent with the comparison of indoor and outdoor for RSSI-based positioning using 433, 868, or 2400 MHz ISM bands, which found that the measured RSSI is inversely proportioned with the distance at both indoor and outdoor environments because the weaker influence of propagation environment on longer radio waves [15]. This paper proposes a weather monitoring system embedded solar power source, which works with a wireless sensor network platform. It can operate effectively without any problem regardless of the battery life or reduce the inconvenience of using an external power outlet in outdoor conditions. Furthermore, the future development work is to improve the solar power source to be of higher quality performance and can be applied to be used in any application of embedded end device.

Conclusions

This study investigates the environment monitoring system tested using solar power resources instead of wall adapter power source. The outdoor power source has tested the efficiency of RSSI performance of the proposed device and transmitting data via a wireless sensor network platform. The proposed green technology application applies the solar energy resource to solve the battery life problem in outdoor conditions. This proposed environment monitoring device with a green design power source confirms that it can work effectively for outdoor conditions. It is remarkably renewable energy of the future world and appropriately used for home, academic, and industrial sectors.

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