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A Study on Low-Power Sensor Node based on Event-based Sampling Using Renewable Energy in Greenhouse

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Abstract

In the paper, we proposed low-power sensor node that applied to perform events-based sampling algorithm and to harvest energy through irrigation equipment applicable in greenhouse environment. The system composition to achieve such a goal could be divided into three parts of sensors, data processing and control, and this paper suggests a solution to an unnecessary wasting energy problem by using the event-based sampling to effectively reduce data exchange between the control system composition. Sensor node based on energy harvesting are implemented through micro-hydro generators connected to the irrigation equipment and it is confirmed that transmitting or receiving stable data is possible, reducing energy consumption of sensor node by the algorithm.

Keywords*: Event-based, Low-power Sensor Node, Renewable Energy, Energy Harvesting, WSN*

1. Introduction

Recently, ICT technology is applied to various areas such as smart home, smart building, wellness & exercise, wearable and etc., based on Wireless Sensor Network (WSN). Collection of sensed data and control by ZigBee among WSN applicable to implementation of IoT is widely used [1]. The wireless sensor network (WSN) technology has been used throughout the entire industries, and it tries to improve productivity by applying to the greenhouse environment to monitor conditions of crop growth in real time, controlling mechanical devices based on data collected from sensor nodes to adjust environment variables.

In addition, the WSN technology is composed of numerous sensor nodes in the network area, and has very limited resources. As a method to reduce data exchange in order to use such limited resources efficiently, the data-aggregation technique and the event-based sampling strategies are being researched to decrease power consumption caused by data transmission, which are techniques minimizing the use of communication modules to obtain energy gain because the number of data exchange is more decreased than the time-based sampling strategies [2 - 5].

Generally, sensor node in WSN technology is supplied by charged power like batteries, without external supply. Research of effective Wireless communication where the greatest weight is placed among total energy consumption, research of sensor node to provide power by using new renewable energy as external power supply and others are studied [6 - 12].

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In the paper, the method is suggested, which is to make permanent operation possible by supplying electric power to sensor node utilizing irrigation equipment that is a source of new renewable energy applicable in greenhouse to implement automatic control and monitoring of greenhouse environment by using WSN technology. By installing micro-hydro generator at the irrigation equipment, energy production is possible and sensor node based on energy harvesting is developed. By investigating amount of new renewable energy acquired from irrigation equipment and applying event-based algorithm to minimize power consumption in sensor node, energy consumption in whole sensor network is reduced and stable transmission and reception of data is possible. It is expected that this results in reducing electric consumption in greenhouse.

2. Implementation of Sensor Node based on Energy Harvesting

Renewable energy-based sensor node is proposed in this paper, we solve the problem of power issue of sensor node to continue an existing permanent operation by obtaining the energy through the irrigation device which can be utilized in a greenhouse. Figure 1 shows structure of proposed system for auto control system in greenhouse.

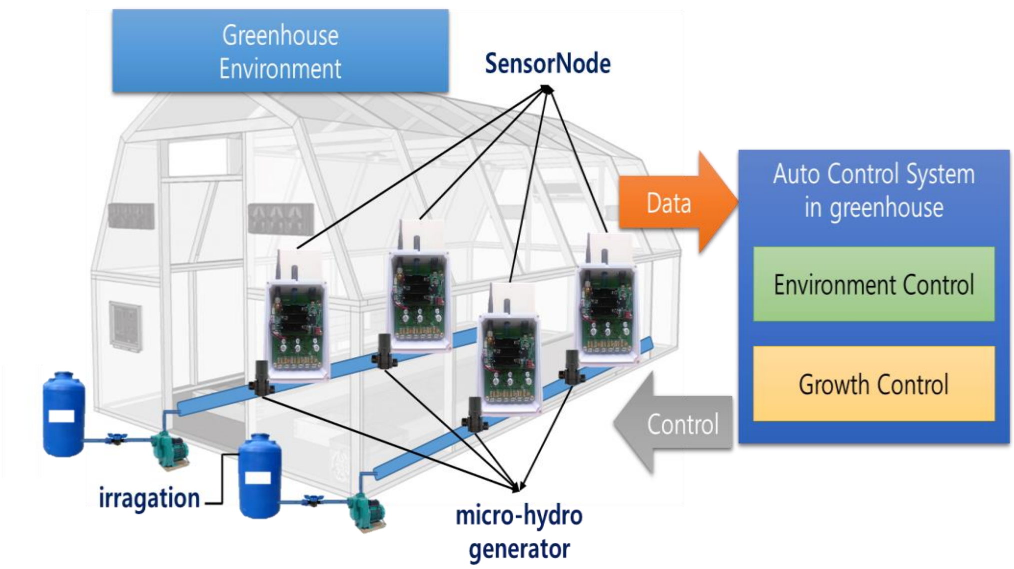


Figure 1. Overall Proposed System

2.1. Development of Sensor Node Based on Energy Harvesting

In order to harvest the energy from the irrigation device using a micro-hydro generator. The construction of sensor nodes based on renewable energy shows Figure 2. It is possible to produce electricity until around 125mW at 2bar in micro-hydro generator installed using irrigation equipment.

Power management is to supply stable electric power to sensor node and power monitoring is available to monitor current and voltage of micro-hydro generator and secondary cell through MCU of sensor node by using MAX9938. It is used for suggested algorithm and Maximum Power Point Tracking (MPPT). We used MPPT algorithm for applying micro-hydro generator [10]. But our micro-hydro generator is rectified to supply power. So we used MPPT algorithm based on Perturb and Observe (P&O) method.

DC/DC converter supplies stable 3.3 voltage to sensor node using commercial IC, LTC3401, by 97 percent efficiency of rectification. LTC4412, power switch makes it possible that stable switching is available between energy from new renewable energy and super capacitor or battery. Super capacitor, which is utilized as primary cell, provides DC/DC converter with stable energy and is used for the first charging element.

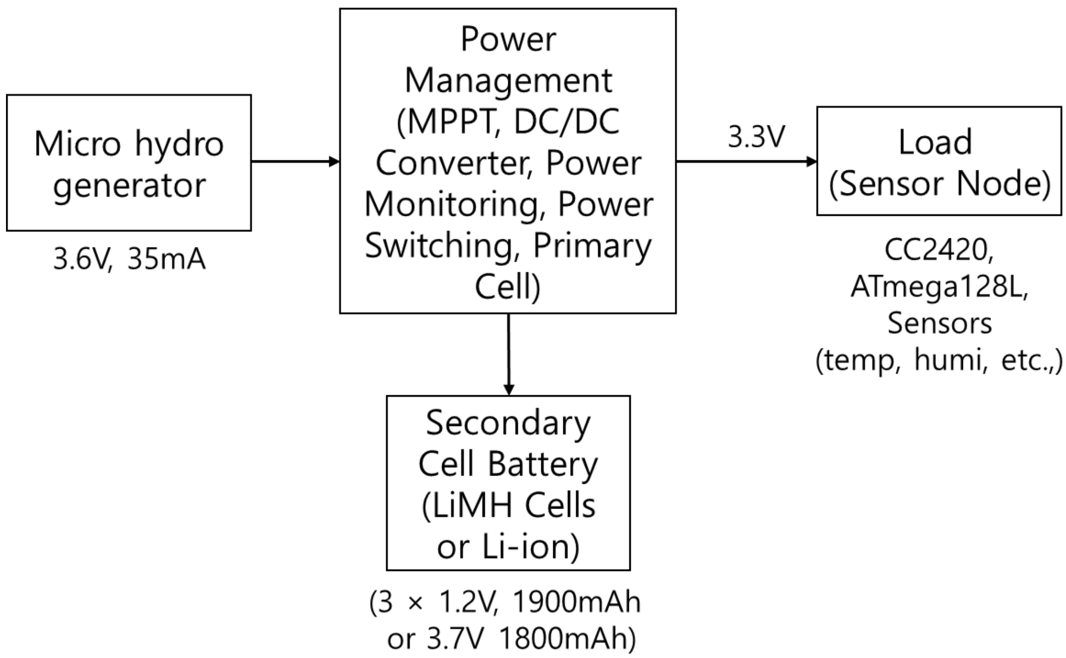


Figure 2. Block Diagram of Sensor Node Based on Energy Harvesting

The secondary cell keep charging and discharging, which is an element to be utilized when new renewable energy is disconnected.

By sensor node, it is available to get values such as temperature, humidity, illumination and others and the sensor node consist of Atmega128L MCU, CC2420 ZigBee chip and others. The specification of sensor node based on new renewable energy is indicated in Table 1.

Table 1. Sensor Node Specification

Input Voltage		2.2 ~ 5.5V
H/W	Communication	Ti CC2420 IEEE 802.15.4(Zigbee) 2.4GHz RX 19.7mA; TX 8.5 ~ 17.4mA @ 3.3V (2.1 ~ 3.6V)
	MCU	Atmega128L (0~8Mhz) @ 3.3V(2.7 ~ 5.5V)
	Primary Cell	Super Capacitor 2.7V/10F + 2.7V 3F
	Secondary Cell	3.6V (1.2V/1900mAh Ni-MH AA * 3) or 3.7V(Li-Ion * 1/1800mAh)

Sensor	Temp/Humi : Sensirion SHT71
OS	TinyOS v2.x (NesC)

2.2. Communication Algorithm Based on Event Sampling

It should be considered about environmental variables necessary for controlling of growing environment and various sensors should be deployed for this. The design of energy harvesting circuit should be accomplished to efficiently use limited resource of renewable energy. Accordingly, sampling method is utilized, which is based on events to collect environment information that is energy efficient from sensor in system of controlling greenhouse environment.

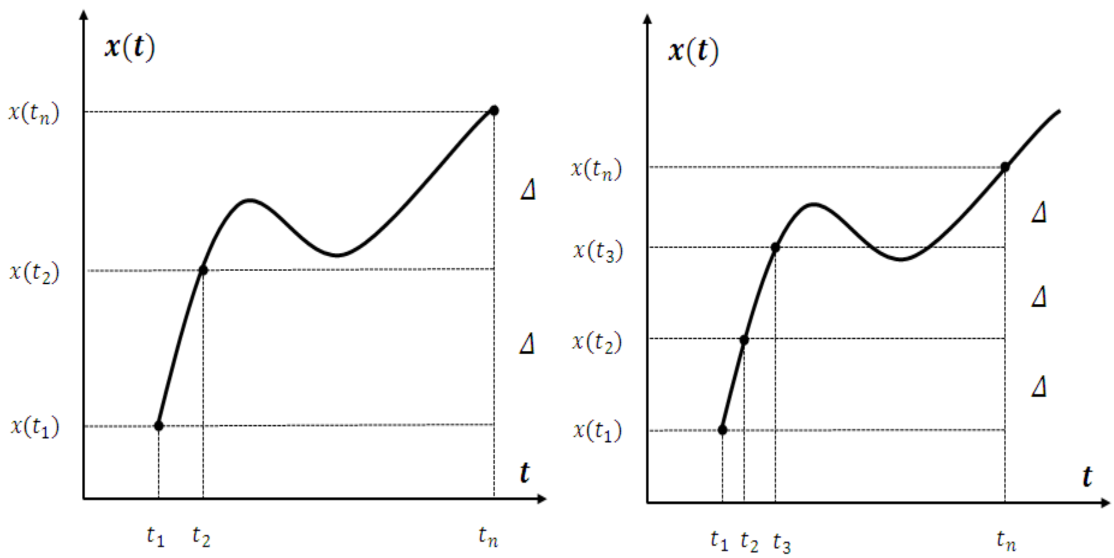


Figure 2. Event-based Sampling by Different Delta Values

Therefore, it is arranged the event-based sampling technique following constant variation between consecutive signals in Figure 3 as Eq. (1) [3].

$$|x(t_n) - x(t_{n-1})| \geq \Delta \quad (1)$$

Where, $x(t_n)$ and $x(t_{n-1})$ mean current and the last acquired values, respectively. In addition, the event-based sampling technique is arranged as the method identical to Eq. (2).

$$\sum_{n=0}^{k} |x(t_n) - x(t_{n-1})| \geq \Delta \quad (2)$$

The event-based sampling technique could minimize measurement errors by applying a mathematical scheme that uses a linear prediction algorithm to predict the future values as a finite linear combination of the previous and current input signal values and the previous output signal values in the system. This prediction model is arranged as Eq. (3) by the Taylor expansion of signals [5].

$$\hat{x}(t_n \mathrm{T}) = \mathrm{x}((t_{n-1})T) + \dot{x}\left((t_{n-1})T\right)T + \ddot{x}\left((t_{n-1})T\right)\frac{T^2}{2} + \cdots \quad (3)$$

Where, *T* means the sampling period of data, if two terms are taken from the right hand sides of Eq. (3) and apply approximation, it becomes as Eq. (4).

$$\begin{aligned} \hat{x}(t_n \mathrm{T}) &\approx \mathrm{x}((t_{n-1})T) + \dot{x}\left((t_{n-1})T\right)T \\ &\approx \mathrm{x}((t_{n-1})T + \frac{\mathrm{x}((t_{n-1})T) + x((t_{n-2})T)}{T}T \\ &\approx 2\mathrm{x}((t_{n-1})T) + x\left((t_{n-2})T\right) \end{aligned} \quad (4)$$

If the event-based sampling technique, which uses a linear prediction algorithm following constant variations between current acquired values and predicted ones, is arranged by using Eq. (4), it becomes Eq. (5).

$$|\mathrm{x}(t_n) - \hat{x}(t_n)| \geq \Delta \quad (5)$$

In addition, the event-based sampling technique, which uses a linear prediction algorithm, is arranged by the same method as Eq. (6).

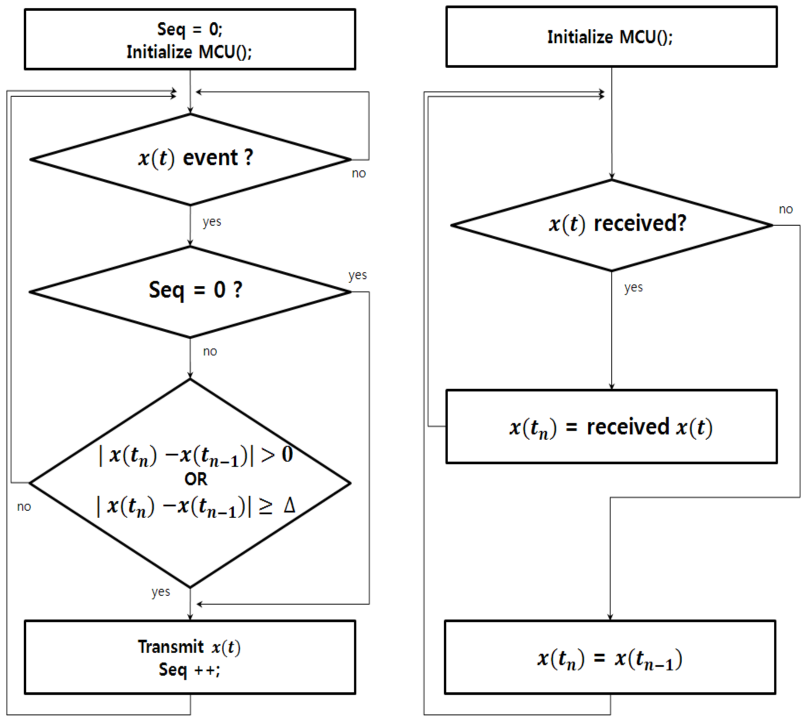
$$\sum_{n=0}^{k} |\mathrm{x}(t_n) - \hat{x}(t_n)| \geq \Delta \quad (6)$$

The event-based sampling technique could properly cope with the environmental change caused by running devices in a greenhouse because it decides whether or not data is sent based on the measured values, and it could effectively reduce the use of communication modules to avoid unnecessary wasting of energy because it could prevent from sending continuous data duplication.

Figure 4 is a flow chart for implementing the event-based sampling technique in Eq. (3). The data transmission algorithm in Figure 4 (a) sets seq, error variables and the MCU when initializing of sensor nodes. It generates the sensor data acquisition event every 5 seconds after running the sensor nodes, if the seq variable is “0”, it increases the seq after sending the first acquired data to the base node. Since then, values acquired by the sensor data acquisition event is decided whether or not to send the data depending the base value of after calculating a difference between current data and the last acquired data to accumulate.

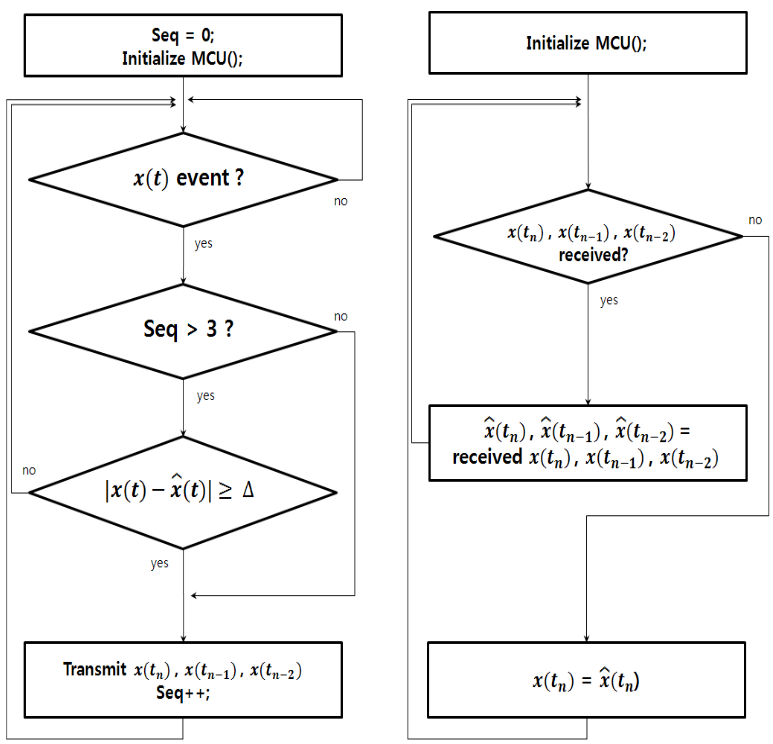
The seq is increased if data is sent, and the error variable, which is the integrated data, is initialized as “0”. The data receiving algorithm in Fig. 4 (b) replaces current data with the received value when receiving data, and maintains the last acquired value when not receiving data.

Figure 5 shows a flow chart for implement method of event-based sampling by using linear prediction (LP). When sensor node is initially started up by data transmission algorithm of Figure 5 (a), variables of Seq and MCU will be initialized. The event of collecting data of sensor is generated every 5 seconds after starting up sensor node. To predict x(tn) data after initial start-up of sensor node, transmit x(tn), x(tn-1), x(tn-2) to base node. x̂ (tn) will be calculated in sensor and base node by using previously measured values and according to threshold value of Δ, by judging whether data is transmitted or not in sensor node, transmit x(tn), x(tn-1), x(tn-2) to base node. The base node that received data, replaces predicted x̂(tn), x̂(tn-1), x̂(tn-2) with received data. Next data will be predicted by using this.



(a) Transmit flow (b) Receive flow

Figure 3. Event-based Sampling Flowchart



(a) Transmit flow (b) Receive flow

Figure 4. Event-based Sampling Flowchart using Linear Prediction (LP)

Figure 6 shows structure of data for packet transmission. For data transmission error detected by inserting the Cyclic Redundancy Check (CRC) field in the transmitter and the receiver using the CRC16. And, after adding the error ±0.1 of the reference value of the data error detected by the request when the Δr value Δ correction to the sensor nodes, to determine whether or not the retransmission.

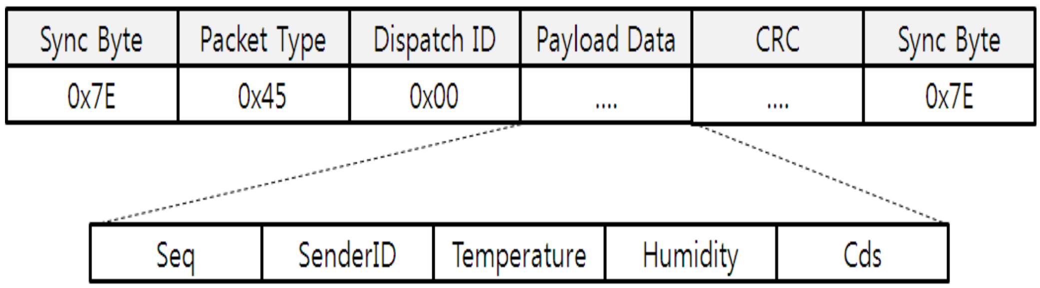


Figure. 5 Packet Structure

3. Experiment and Results

3.1. To Compare and Analysis of Power Consumption Between Time-based and Event-Based

Figure 7 is temperature data inside the greenhouse measured at intervals of 5 seconds for about 5 hours by applying the sampling technique described in this paper, and Figure 5 is temperature data outside the greenhouse. In order to acquire data depending on variations of temperature, a small fan heater is installed in the greenhouse model and controlled to maintain temperature between 25℃ ~ 30℃.

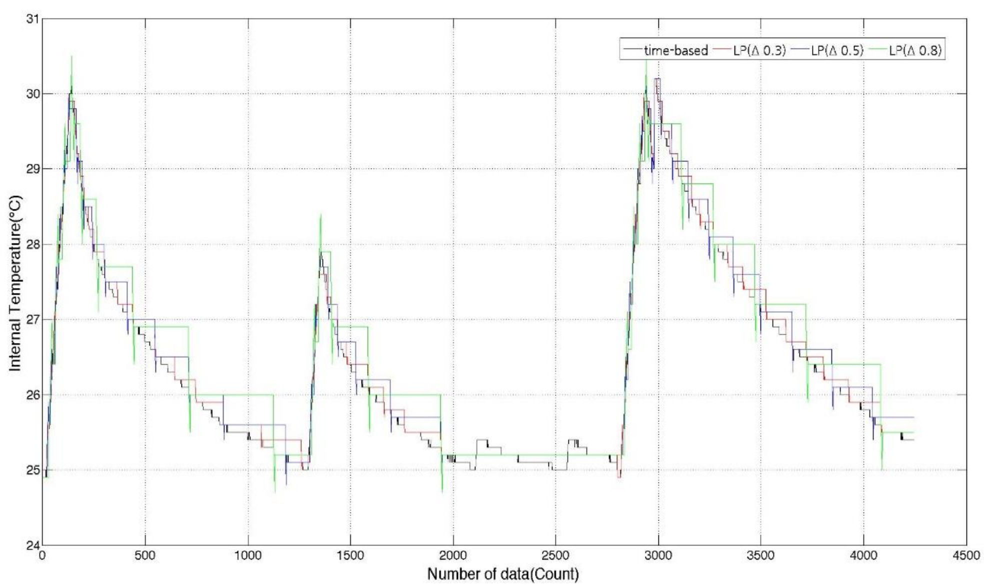


Figure 6. Simulation Results of Temperature Data by to Compare Time-based and Event-based Sampling in Greenhouse

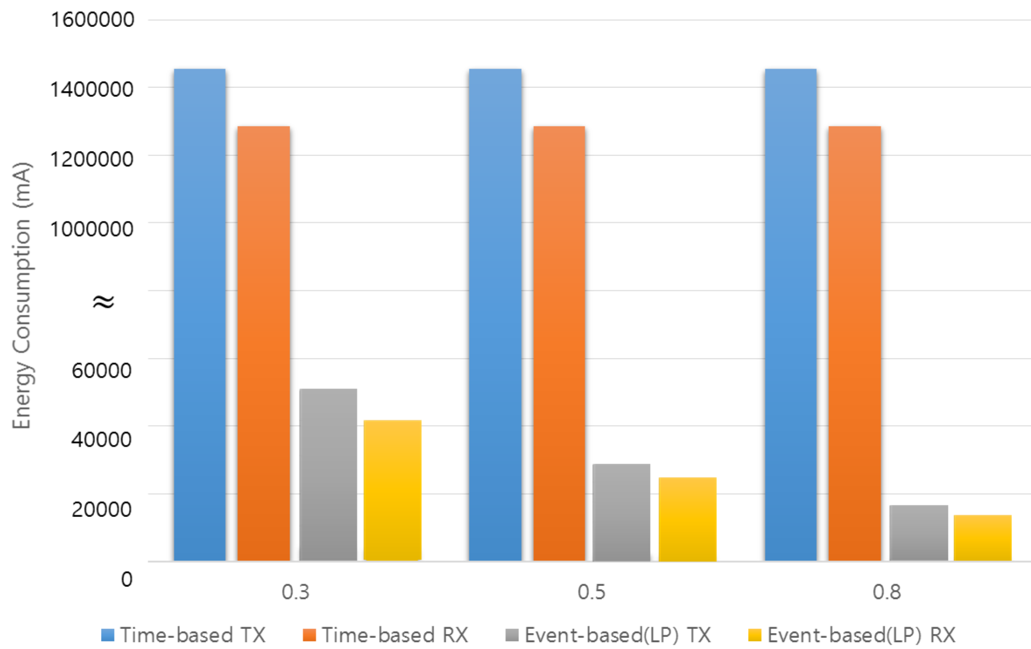


Figure 7. Simulation Results of Energy Consumption by to Compare Time-Based and Event-based Sampling in Greenhouse

Figure 8 shows test result of energy consumption of zigbee. This is the temperature data of greenhouse measured every five seconds for five hours applying the sampling method explained. As shown in Table II and Figure 5, when the threshold value of Δ is 0.3, data is transmitted 73,846 times by time-based method and data is transmitted 2,488 times by LP method. Also, when the threshold value of Δ 0.5 and 0.8, respectively data is transmitted 1409 and 835.2.

CC2420 from Chipcon, which is used for zigbee Communication of base node, consumes 17.4mA every data transmission by maximized frame length and 19.7mA every data reception by maximized frame length.

As shown in Table 1, it could be known that time-based and event-based LP techniques have low energy consumption when measuring temperature outside the greenhouse.

Table 2. To Compare Sampling of Zigbee Module Between Event-based (mA)

Δ			Time-based	Event-based (LP)
Temperature	0.3	RMSE	0	0.1486
		Consumption	73846	2488
	0.5	RMSE	0	0.2282
		Consumption	73846	1409
	0.8	RMSE	0	0.3993
		Consumption	73846	835.2

3.2. Sensor Node Operating Based on Energy Harvesting

The harvesting-based sensor node suggested in the paper utilizes irrigation equipment. The water pressure used in greenhouse is around 1 ~ 4 bar. In the paper the test is performed using micro-hydro generator that can produce maximized 125mW at around 2bar. The test is performed making environment similar to irrigation equipment of micro-hydro generator. How data is transmitted and received syncing with sink node connected to PC and harvesting-based sensor node is shown in Figure 9 and 10.

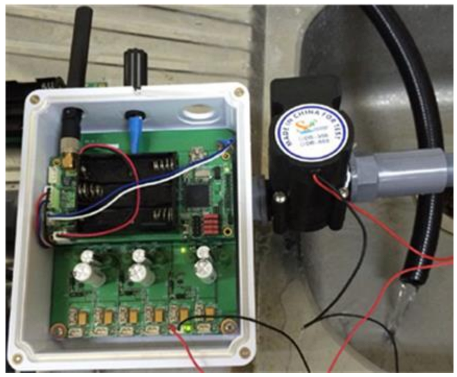


Figure 8. Test Result of Operating Sensor Node using Micro-hydro Generator

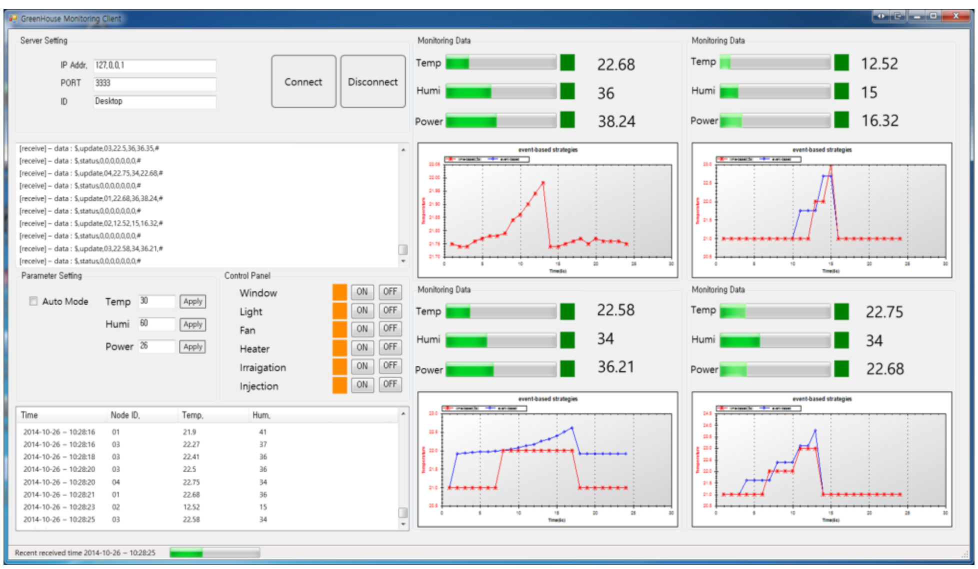


Figure 9. Test Result of Monitoring Program by Sensor Node

4. Conclusion

Our world and lives are changed by doing research of building IoT based-system by using WSN technology. The more precise and profitable market can be made by applying such WSN technology to agriculture. In this paper used the event-based sampling technique to acquire energy-efficient environmental information from sensors in the system for controlling the environment of greenhouses. As a result of measuring data after applying the event-based sampling technique to the system, comparing to the time-based data acquisition method, the number of times to send data was decreased by 95.1% in average for temperature data in greenhouse. Also, we implemented system to possible harvest renewable energy using irrigation equipment.

This result shows that the reduced number of times to send data is more increased as the variation of data becomes lower, and because it is not much affected by external environment's change, it is effective if applying to the greenhouse environment with a low variation of data. It is expected that power is supplied to sensor node by utilizing irrigation equipment as new renewable energy and the power issue happened in WSN environment will be worked out.

Future work, it is supposed to investigate new renewable energy that can be efficiently applied in greenhouse to be able to place various sensors into right places for measuring environmental variables necessary for controlling of green house, applying sensor node suggested in the paper in farms. And, we will make MPPT algorithm for AC micro-hydro generator. When the construction of such WSN system is finished, service based on location information also will be provided.

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References

[1] "Industrial Wireless Sensor Market", ON World Inc., **(2014).**

[2] Y. Tsividis, "Event-driven data acquisition and continuous-time digital signal processing", in Custom Integrated Circuits Conference (CICC), 2010 IEEE, **(2010)**, pp. 1–8.

[3] M. Miskowicz, "Asymptotic effectiveness of the event-based sampling according to the integral criterion", Sensors, **(2007)**.

[4] A. Pawlowski, J. L. Guzman, F. Rodriguez, M. Berenguel, J. Sanchez and S. Dormido, "The influence of event-based sampling techniques on data transmission and control performance", in Emerging Technologies & Factory Automation, 2009. ETFA 2009. IEEE Conference on, **(2009),** pp. 1–8.

[5] Y. Suh, "Send-On-Delta Sensor Data Transmission with A Linear Predictor," Sensors, **(2007)**.

[6] D. Park, B. Kang, K. Cho, C. Shin, S. Cho, J. Park and W. Yang, "A Study on Greenhouse Automatic Control System Based on Wireless Sensor Network", Wireless Personal Communications, vol. 56, no. 1, **(2011),** pp. 117-130.

[7] C. Park and J. Yeo, "Solar Cell-based energy harvesting system for power supply of wireless sensor node", Journal of Computer & Communication, vol. 10, no. 1, **(2014),** pp. 7-11.

[8] C. Park, C. Shin, Y. Cho and J. Park, "Design and Implementation of Event-based Sampling Strategies for Reduced Data Transmission in Greenhouse Environment", Advanced Science and Technology Letters, vol. 9, **(2012).**

[9] H. Cho, Y. Cho, C. Shin and J. Park, "A Study on Renewable Energy Harvesting and Circuit Design Based on a Maximum Power Point", International Journal of Multimedia and Ubiquitous Engineering, vol. 8, no. 2, **(2013),** pp. 111-122.

[10] L. Belhadji and S. Bacha, "Adaptive MPPT Applied to Variable- Speed Micro-hydropower Plant", IEEE Transaction on Energy Conversion, vol. 28, no. 1, **(2013).**

[11] M. Andersson, D. Henriksson, A. Cervin and K.E Årzén, "Simulation of Wireless Networked Control Systems", Proceedings of the 44th IEEE Conference on Decision and Control, and the European Control Conference 2005, Seville, Spain, **(2005)** December, pp. 476-481.

[12] Y. Lee, H. Kim, O. R. Chowdhury, C. Shin, Y. Cho and J. Park, "The Study on Small Generator using a Hydraulic for Sensor Node", International Journal of Control and Automation, vol. 7, no.3, **(2014),** pp. 243-250.

