IoT based Growth Monitoring System of Guava (*Psidium guajava* L.) Fruits

Slamet W[1], M Irham N[1] and Sutan M S A[1]

[1] Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, Bogor Agricultural University, Indonesia

E-mail: slamet_ae39@apps.ipb.ac.id

Abstract. Growth monitoring of plant is important especially to evaluate the influence of environment or growing condition on its productivity. One way to monitor the plant growth is by measuring the radial growth (i.e., the change of circumference) of certain part of plant such as trunk, branch, and fruit. In this study we develop an internet of things (IoT) based monitoring system of radial growth of plant using a low-cost optoelectronic sensor. The system was applied to monitor radial growth of guava fruits (*Psidium guajava* L.). The principle of the developed sensor is based on the optoelectronic sensor which detects alternating white and black narrow bar printed on reflective tapes. Reflective tape was installed encircling the fruit. The movement of reflective tapes will follow the radial growth of the fruit so that the infrared sensor on the optoelectronic would response reflective tapes movement. This device is designed to measure object continuously and long-term monitor with minimum maintenance. The data collected by the sensors are then sent to the server and also can be monitored in real-time. Based on field test, at current stage, the developed sensor could measure the radial growth of the fruits with a maximum error 2 mm. In term of data transfer, the success rate of the developed system was 97.54%. The result indicated that the developed system can be used as an effective tool for growth monitoring of plant.

1. Introduction

Monitoring the growth of crop radials is essential to observe the effects of environmental conditions or agronomic practices/treatment on the productivity of fruit crops. One way to monitor the plant growth is by measuring the radial growth (i.e. the change of circumference) of certain parts of plant such as trunk, branch, and fruit. There are various commercial measuring tools that have been developed to measure the growth of plant part radials such as dendrometer [1-2]. It offers advantages such as fine resolution and equipped with temperature compensation features which result in high measurement accuracy. However, it also has some limitations in the application such as expensive, large size, and the sensors must be supported by additional frame to avoid the possibility of the sensor overload the tree itself. Another limitation is that it is difficult to move the sensor from one tree to another because it has to be re-calibrated first. Therefore, the development of alternative sensors that can overcome these weaknesses until now is still an interesting topic. One of them is an optoelectronic based measuring tool as reported in [3]. This tool offers a practical and cost-effective radial growth measurement alternative.

This research tries to integrate such an alternative radial growth sensor and Internet of Things (IoT) technology. The use of IoT enables monitoring can be done in more flexible manner both in the local area and in the remote places by using internet. IoT has received a lot of attention and has been widely applied in various areas including agriculture [4]. Through this integration, it is expected that growth data can be monitored continuously even in real-time and data can be accumulated in the database so that it can be better managed and utilized. As an example of application cases, the proposed monitoring system is used to monitor the growth of guava fruits (*Psidium guajava* L.) var. crystal. Recently, guava fruits var. crystals has become popular. Through the development of this monitoring system, it is expected that farmers can study the characteristics of guava growth and its relationship with environmental factors (i.e. temperature, air humidity, light intensity, and rainfall) and also agronomic practices, so they can develop an appropriate cultivation techniques that can give an optimal results both qualitatively and quantitatively.

2. Materials and methods

The developed monitoring system including two main components: optoelectronic based radial growth sensor and data handling (i.e. transmission and display) system. Reflective Optical Sensor (Vishay CNY 70), and reflective tape with printed alternating white and black color is used as growth sensor. Reflective tapes are deliberately designed with narrow patterns with 0.5 mm width, so once the tape fully moves (i.e., due to the growth of the fruit) from the black pattern to the white one and vice versa, it means that the circumference increase by 0.5 mm. The growth sensor, as shown in figure 1, was developed with some modification from the previous work [1]. The main modification made here is the change of data reading method. In the previous study, data readings were performed periodically over a period. In the previous work, the readings were done at intervals of 5 min and the obtained values of the counters were saved at every full hour onto its EEPROM chip. In this study the sensor readings are done every color change on the reflective tape from black to white and vice versa. In addition for an efficient use of energy, the sensor works in two modes of operation that is normal and sleep mode. By default, the sensor will work in sleep mode but when there is a change in the reflective tape color reading then this change will trigger the sensor to run normal mode, i.e. transmitting data for a few seconds (± 8 seconds) and then return to sleep mode.

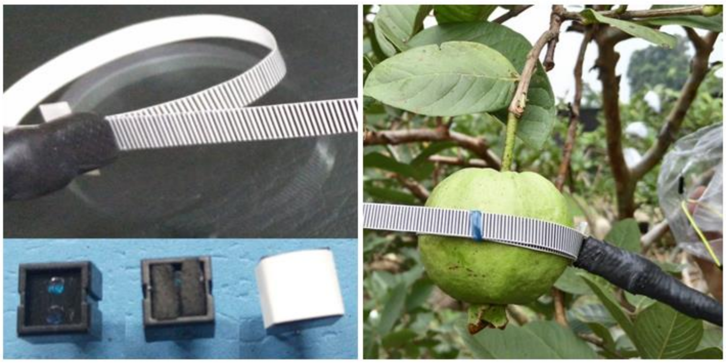

Figure 1. Optoelectronic based radial growth sensor: a) reflective tape; b) optoelectronic sensor; and c) field application for growth monitoring of guava fruit.

Before conducting the test in the field, testing is done to read the change of analog signal through the sensor. The reading is done by manually moving the reflective tapes every 1 minute. The test is performed to determine the threshold value. It is one of the critical task that will affect the overall system including measurement accuracy and operation mode (normal/sleep). The data of sensor readings is shown in figure 2. From the data, it is suggested that value of 0.7 – 0.8 Volt can be used as a proper threshold value.

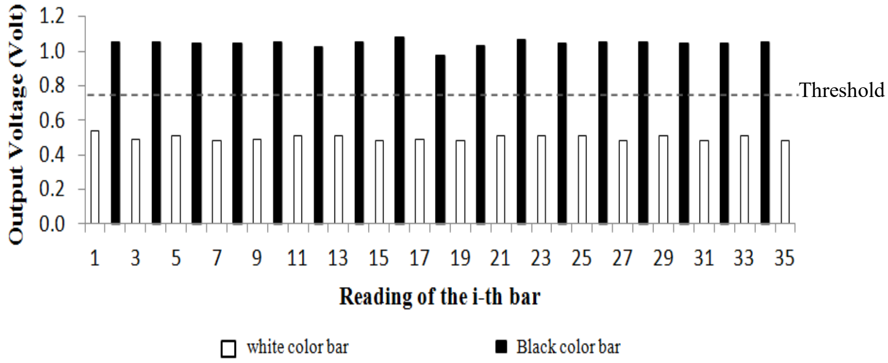

Figure 2. Determination of threshold value between black and white bars.

At each measurement point (sensor node) there is an electronic circuit consisting of growth sensor, microcontroller (Arduino nano), and RF Communication module. Meanwhile, on the coordinator, there is an electronic circuit consisting of microcontroller (Arduino Uno), RF communication module and GPRS Shield SIM900. In this case, XBee S2 modules with effective range up to 120 m for the line-of-sight outdoor condition are used. As an energy source, each circuit is equipped with 3.7 V, 5800mAh Li-Ion Battery 18650. The sensor node and the coordinator communicate using the RF module, and then all of the compiled data will be sent by the coordinator to the server and will be then processed and displayed on the display unit. In this case, ThingSpeak is used. It is an Internet of Things (IoT) platform that has been widely used to develop IoT applications especially to collect and store sensor data in the cloud. Data acquired by sensors can be sent to ThingSpeak from wide-range of available hardware such as Arduino, Raspberry Pi, etc. The data is then can be further visualized and analyzed. The data can be easily accessed from PC or mobile devices (smartphone and tablet) as long as it has an internet connection. The network architecture is shown in figure 3 below.

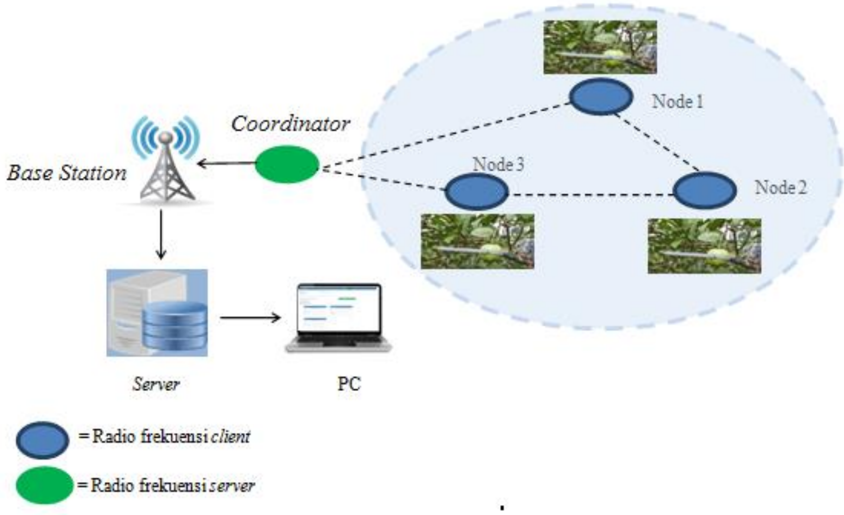

Figure 3. Schematic of network architecture.

The prototype of the developed system was tested in the field for monitoring the growth of guava fruits. The test was carried out for 30 days at Agribusiness Development Station (ADS) Bogor Agricultural University in Cikarawang, Bogor, Indonesia. There are several parameters evaluated including accuracy of the sensor, power consumption and success rate of data transfer.

3. Results and discussion

The developed prototype of growth monitoring system is shown in figure 4. The system is then installed for field test as shown in figure 5. Reflective tapes associated with optoelectronic sensors are installed around the fruit so that when the fruits grow reflective tapes simultaneously move to follow the fruit growth. Then the cable and all circuits are wrapped to avoid the rain. The sensor will read reflective tape displacement through black-and-white bars printed on reflective tapes. At the time of the bars moving from black to white or from white to black, the RF client is tasked to send the readout data to the RF server. The RF server then receives the data and sends it to the ThingSpeak network host via a GPRS signal.

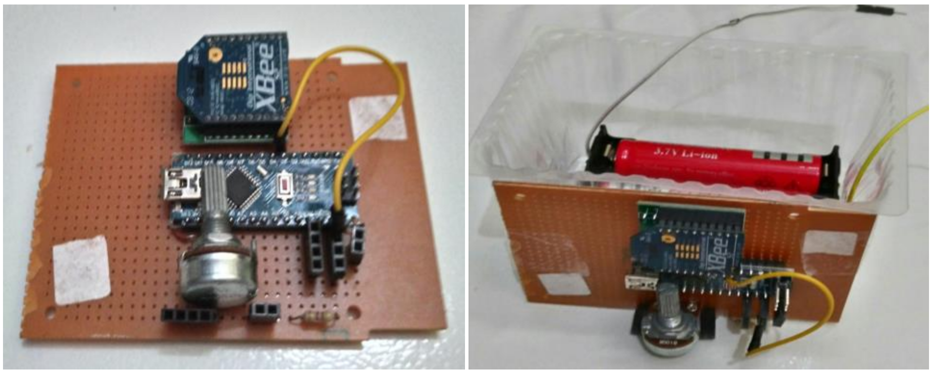

Figure 4. A prototype of the sensor connected to RF module.

Figure 5. Installation of the sensor for field test.

Before mounting the sensor on the guava fruit, the initial circumference (C_0) is measured and used as an input in the program run by the microcontroller. The results of circumference measurement using the developed system are shown in table 1. As shown in table 1, the measurement result using the developed sensor (C_t) shows a good agreement with the manual measurement (C_a) with an average error of 1 mm. The errors that occur are due to the growth of guava which is not perfectly round, causing a gap and affect the sensor reading. The error occurs, however, is relatively low and is still acceptable.

Time series data of guava fruits growth as displayed in the ThingSpeak platform are shown in figure 6. From the graph, there are differences in chart trends observed from different sensor nodes. This is due to the guava fruits measured are not uniform regarding age and the initial circumference. Each sensor (node 1, node 2, and node 3) was installed on fruits with age of 1, 1.2, and 1.3 months after flowering with an initial circumference (C_0) of 170 mm, 189.5 mm, and 160.5 mm respectively. In the measurement conducted for 30 days, the data indicated that the average radial growth rate of guava fruit is around 1 mm/day with a maximum error of 2 mm. When approaching the harvesting time , the radial growth rate slows down by an average of 0.5 mm/day.

Table 1. Accuracy of circumference measurement using the developed system

	C_0 (mm)	Ct (mm)	C_a (mm)	Error
Node1	170.5	196.0	197.0	1 mm
Node2	189.5	198.5	198.5	0 mm
Node3	160.5	192.0	194.0	2 mm
Average				1 mm

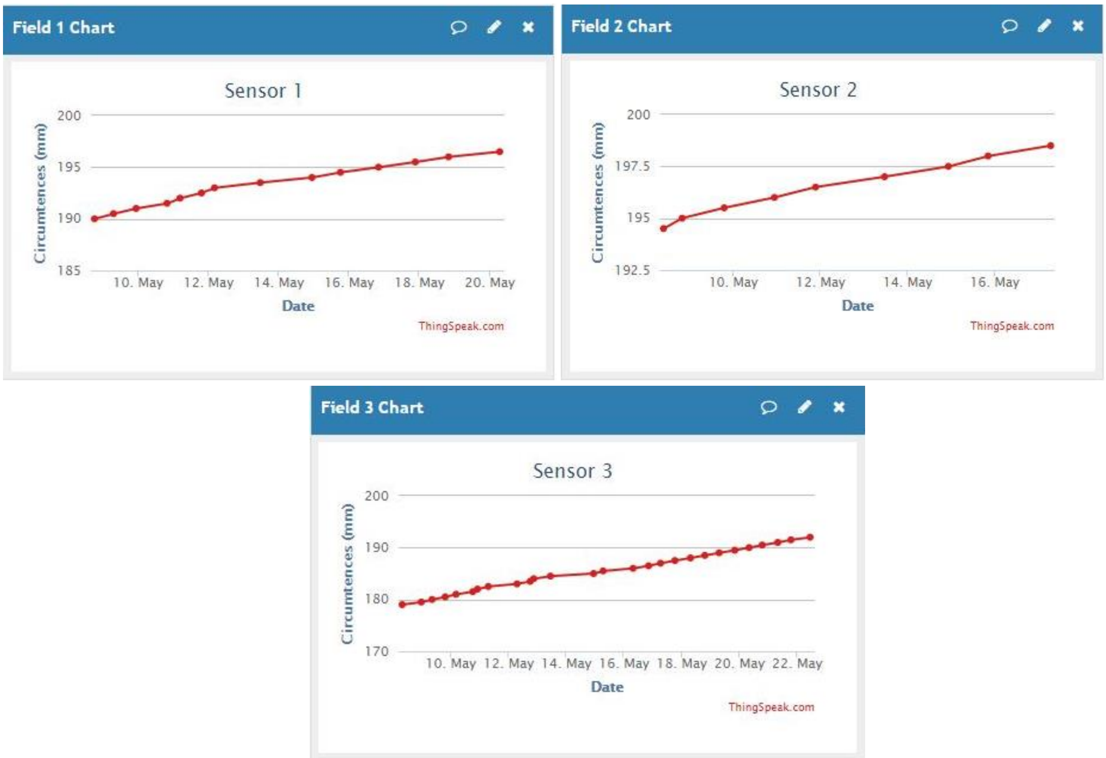

Figure 6. Display of the growth data of guava fruit on ThingSpeak platform.

In the implementation, the sensor node must be active all the time. Therefore the power supply (i.e., battery) must be well planned to avoid replacement in the middle of the measurement. It is because the replacement of the power supply may cause a disturbance to the data recording and the measurement will repeat from the initial value as input in the program run on the microcontroller. Therefore, an accurate calculation of power consumption on the node sensors is important. Table 2 below shows daily power consumption data on sensor node and server. In this study on each sensor node used 3 Li-Ion battery 18650 mounted in series with 3.75 Volt and 5800 mAh capacity for each battery. In total, the energy capacity of the battery is 65.25 Wh. Therefore based on the average daily energy consumption of each sensor node which is 1.127 Wh/day (table 2). Theoretically, the average battery life can be expected to reach of 58 days (almost 2 months).

Table 2. Power consumption of sensor node (client) and server.

	Mode	Power (W)	Daily Energy Consumption (Wh)
Node 1	*sleep*	0.046	1.111
	Normal	0.351	0.001
Node 2	*sleep*	0.048	1.149
	Normal	0.350	0.001
Node 3	*sleep*	0.047	1.120
	Normal	0.350	0.001
Server	Normal	0.470	11.281

Another important measure needs to be evaluated is the performance of data transmission. Success rate of data transmission can be observed from the total of data successfully transferred from the sensor node to the server/network host. The success rate can be seen in table 3 below. Based on table3, the system being built has a success rate with an average of 97.54%. This is due to certain condition when the server fails to receive the data. The data failed because the server failed to distinguish client data when logged in simultaneously. However, failing data has no significant effect on the measurement because the server will continue to receive data from the client and re-read it so that the graph displayed on the ThingSpeak network host will return to normal.

Table 3. Success rate of data transfer.

	Transferred Data	Received Data	Failed/Un-received data	Success rate (%)
Node 1	53	52	1	97.61
Node 2	55	55	0	100.00
Node 3	50	48	2	95.00
		Average		97.54

However, for a longer period of monitoring, it is possible that the reading error will accumulate and increase significantly. Therefore further investigation on the error is necessary to be done. Another important thing to be considered is the possibility of error on data transfer due to unstable network connection which is not uncommon in rural area. This issue has become an interesting challenge in the implementation of IoT-based technology in agriculture. An alternative solution to overcome this issue has been reported in several studies such as framework proposed in [5].

4. Conclusions

IoT based growth monitoring system using optoelectronic sensor has been successfully developed and used for monitoring growth of guava fruits. The developed system has been tested in the field for 30 days and showed a good performance, indicated by high measurement accuracy (1 mm error), 97.54% success rate of data transfer, and long battery life (almost 2 months). The developed system can be used as an alternative for monitoring the (radial) growth of plant.

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