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Portable Photosynthetic Sensor: An Important Tool for Greenhouse Gas Reduction Campaign

เครื่องวัดการสังเคราะห์แสงของพืช: เครื่องมือสำคัญในการรณรงค์ลดก๊าซเรือนกระจก

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Abstract

Carbon dioxide (CO_2) is one of the most significant greenhouse gas that affect global warming. CO_2 reduction in the atmosphere through plant absorption could be one solution to solve this global situation effectively and sustainable. Thus, CO_2 absorption analysis potentially needs an accurate photosynthesis measuring instrument for the planning of planting projects and appropriate area selection in order to aid the solution. This research was focused on design and create a portable photosynthetic sensor using many processing sensors as were required in the influential plant photosynthesis factors. The sensor was designed to display realtime value all parameters and the net photosynthesis via LCD monitor. In evaluating, the study compared the value from each sensor with standard gases and commercial tools then analyzed with statistical methods. The net photosynthesis obtained from the sensor was compared to the reference data collected using a commercial instrument in the same plants. The results of analysis shown that all sensors and the portable photosynthetic sensor had a high precision and accuracy similar to commercial instrument. Moreover, this invention can be takeplace an expensive commercial instruments and can be used as a tool for reduce an atmosphere CO_2 effectively.

Keywords : Net photosynthesis; CO_2 absorption; NDIR

บทคัดย่อ

คาร์บอนไดออกไซด์ (CO_2) เป็นก๊าซเรือนกระจกที่เป็นตัวการสำคัญที่ก่อให้เกิดภาวะโลกร้อน การลดปริมาณ CO_2 โดยการดูดซับของพืชเป็นหนึ่งในวิธีการที่จะสามารถแก้ไขปัญหาสถานการณ์ของโลกได้อย่างมีประสิทธิภาพและยั่งยืน ซึ่งการที่จะศึกษาถึงศักยภาพในการดูดซับ CO_2 ของพืชนั้นจำเป็นต้องอาศัยเครื่องวัดการสังเคราะห์แสงของพืชที่มีความแม่นยำสูง เพื่อใช้ในการวางแผนการปลูกพืชให้เหมาะสมกับพื้นที่ ซึ่งงานวิจัยนี้มีวัตถุประสงค์เพื่อออกแบบและสร้างเครื่องวัดการสังเคราะห์แสงของพืชแบบพกพา ที่อาศัยการตรวจวัดจากหลายเซนเซอร์ที่เป็นปัจจัยในธรรมชาติที่จะส่งผลต่อกระบวนการสังเคราะห์แสงของพืช โดยจะมีการแสดงค่าในแต่ละพารามิเตอร์ และค่าการสังเคราะห์แสงสุทธิออกมาในรูปแบบเรียลไทม์ ผ่านทางจอ LCD รวมถึงการทดสอบประสิทธิภาพโดยการเปรียบเทียบค่าที่อ่านได้จากแต่ละเซนเซอร์เทียบกับก๊าซมาตรฐาน และมิเตอร์วัดเฉพาะที่มีจำหน่ายในเชิงพาณิชย์ ด้วยวิธีการทางสถิติ และเมื่อนำเครื่องวัดการสังเคราะห์แสงของพืชที่สร้างขึ้นไปทำการวัดค่าการสังเคราะห์แสงของพืชเทียบกับค่าอ้างอิงที่วัดได้จากเครื่องมือที่มีจำหน่ายในเชิงพาณิชย์ ในพืชชนิดเดียวกัน ซึ่งจากการวิเคราะห์พบว่าเซนเซอร์แต่ละตัวที่เลือกใช้ และเครื่องวัดการสังเคราะห์แสงของพืชที่สร้างขึ้นมีความแม่นยำไม่แตกต่างจาก เครื่องมือที่มีจำหน่ายในเชิงพาณิชย์ อีกทั้งเครื่องมือที่สร้างขึ้นยังสามารถนำไปใช้เพื่อทดแทนเครื่องมือที่มีจำหน่ายในเชิงพาณิชย์ที่มีราคาแพง และยังสามารถประยุกต์ใช้ในการวางแผนเพื่อลด CO_2 ในบรรยากาศได้อย่างมีประสิทธิภาพ

คำสำคัญ : การสังเคราะห์แสงสุทธิ; การดูดซับคาร์บอนไดออกไซด์; NDIR

Introduction

Carbon stock in the tree, biomass and wood products have a long useful life time that is the best way to reduce carbon dioxide (CO_2) as fixed carbon. Forest are important carbon sink, because trees use CO_2 as a growth substrate. About half of the biomass of trees (in dry weight) is carbon, which is stored in all parts of the tree under the photosynthesis process. However the abilities to absorb CO_2 in forest area are different depending on the species age, and environment [1]. These variations are the interaction between factors, including the age of plant, structure and the arrangement of leaves, characteristics and distribution of stomata, growth of the canopy, leaf area, chlorophyll and genetic characteristics of plants [2].

For most plants that undergo C3 and C4 photosynthesis, stomata open at sunrise and close in darkness, allowing for entry of CO_2 needed for photosynthesis during the daytime. Bright light often induces a wide opening of the stomata. In general, high temperatures cause stomata to close probably due to water stress. Then these environmental factors, for instant: light intensity, temperature, relative humidity, and amount of CO_2 also affect plants photosynthesis process [3].

This invention could be applied in various activities, for instant at present there are several activity that promote planting to reduce CO_2 in the atmosphere. However, we could not know which plant reduces CO_2 effectively. This tool can be measure the CO_2 exchange that compare between daytime and night time of each plant to find out the type of plant that can extract a high amount of CO_2 from the atmosphere during daytime and release the least at night. This information can be used as a database to plan planting campaigns that reduce CO_2 from the atmosphere more effectively.

Materials and Methods

The photosynthesis compartments

The portable photosynthetic sensor consists of several sensors such as CO_2, light intensity, temperature, and relative humidity sensors. The performance of each sensor was shown in Table 1.

Leaf chamber is the closed system chamber that clipped on the leaf to take reading CO_2 exchange rate of the stomata under photosysthesis and respiration processes. The leaf chamber was designed to be cylindrical shape with 2.5 centimeters diameter and 2 centimetres height.

All sensors were working under command codes and processing data by Arduino micro controller. The Arduino boards can be used to control the devices input or output. Moreover, this tool also supports the connection to a variety of devices including digital and analog (e.g., getting values from the sensor, control device output as follows: flash, motors, relay). It composes of 14 digital input/output pins and 6 analog input and support many operation systems [4].

The photosynthetic calculation

The photosynthesis rate of plant can commonly be calculated by using the following equation [5].

$$P_n = 2005.39 \times \left(\frac{V \times P}{T_a K \times A}\right) \times (C_i - C_o)$$

where Pn is the net photosynthesis in µmol/(m^2-s)

V is the volumetric air flow in the pneumatic line expressed in liters per minute (l/m)

P is the pressure in Bar

$T_a K$ is the air temperature in Kelvin

A is the leaf chamber area in cm^2

C_i is the leaf chamber intake CO_2 concentration in ppm

C_o is the exhaust CO_2 concentration in ppm

Table 1 The specifications of all sensors using in this work

Sensor	Model	Range	Accuracy
CO_2 (ppm)	K-30	0-5000	±30
Temperature (˚C)	DHT11	0-50	±2
Relative humidity (%)	DHT11	20-80	±5
Light intensity (LUX)	BH1750	0-65535	

Configulation of portable photosynthetic sensor

The configulation of the photosynthetic sensor is setting up as shown in Fig. 1. Each sensor are connected to the microcontroller detecting the ambient parameters. For the CO_2 concentration, the tube from the leaf chamber will transport the residual CO_2 the NDIR Carbon dioxide sensor with the flowrate about 0.3-1.0 liters per minute [6] using an air pump and flow meter. The photosynthetic value will be complied using ambients and CO_2 data under operating command of the microcontroller.

The Operation of photosynthetic sensor

In order to understand the operation of this tool, the process was shown in Fig. 2. Once a measurement command was received by the smart sensor node, it was necessary to acquire the measurements of 4 parameters from primary sensors which consisted of concentration of CO_2, temperature, relative humidity and light intensity at the data acquisition stage. After that, two responding variables were used to calculate the net photosynthesis. These parameters including the net photosynthesis were set to print out in real time, and this would be repeated every two seconds.

Validation of the sensors

The individual sensors are tested for the precision and accuracy of each sensor and the commercial instrument and certified standards of CO_2. These sensors efficiency were to evaluate with 2 parts as follows.

Part one was to compare the efficiency of CO_2 sensor with standard CO_2 at concentration 995 and 1000 ppm. The process started with connecting the CO_2 sensor to the Arduino board. Later, the commercial standard of CO_2 at 995 ppm was absorbed from storage tank to gas sampling bag. The CO_2 at 995 ppm was to release from gas sampling bag pass through the CO_2 sensor to measure the concentration. This procedure also conducted for CO_2 at 1000 ppm. The processes would be repeated measurement, collected data and analyzed the efficiency with statistical methods.

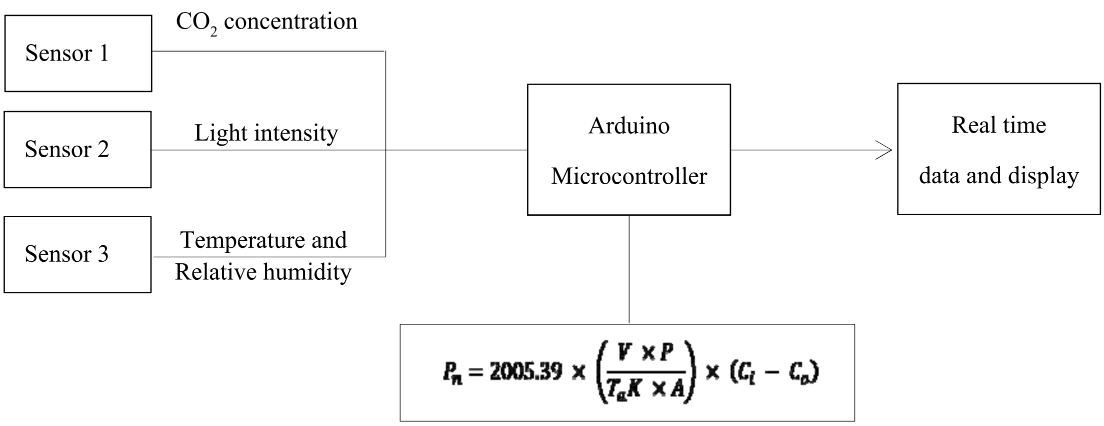

Figure 1 Components of the photosynthetic sensor

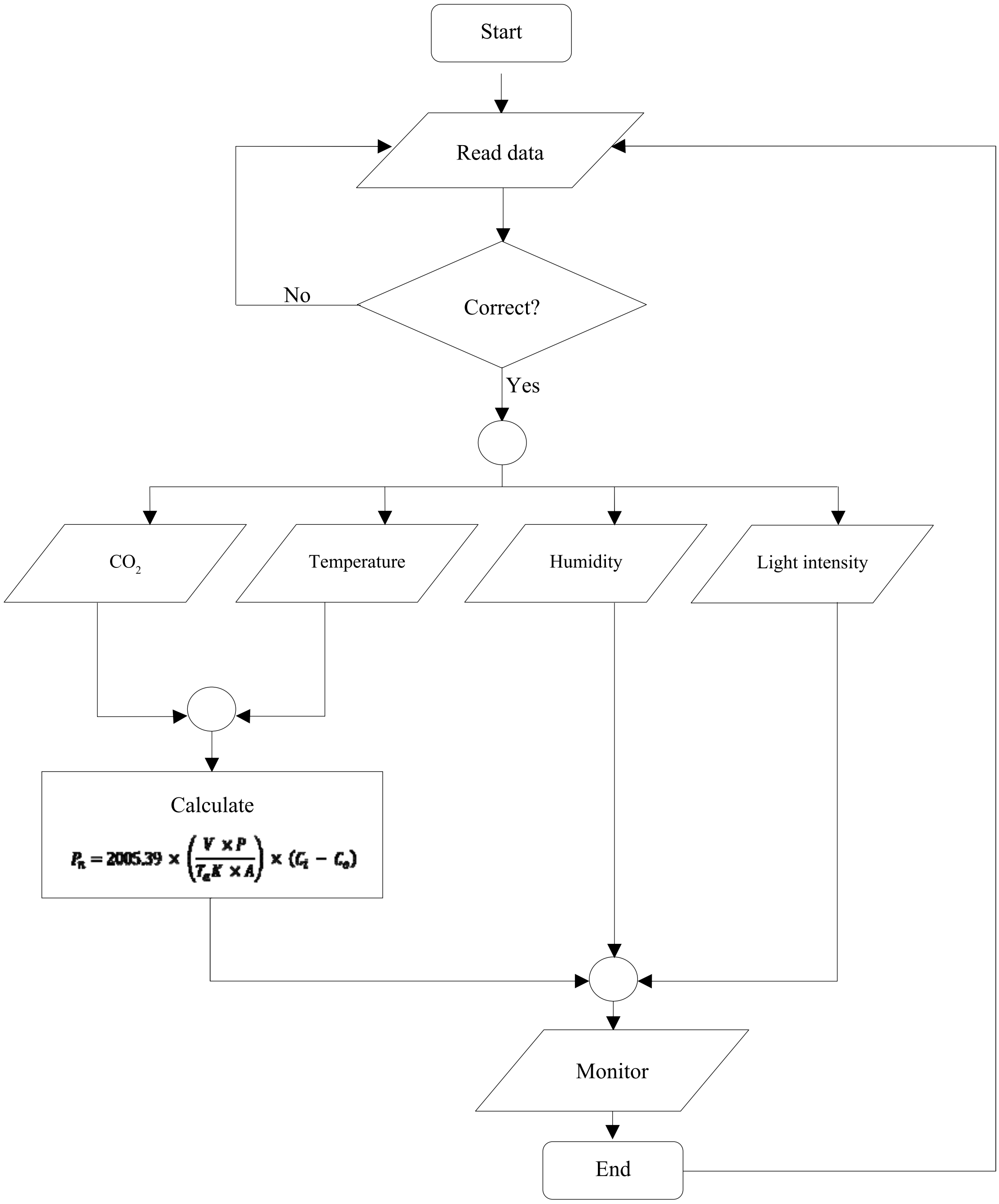

Figure 2 The process diagram and the operation of photosynthetic sensor

Part two compare the efficiency of temperature relative humidity, and light intensity sensor with commercial tools. The process started with each sensor was to connect with the Arduino board. After that, put each sensor and commercial tools in the box in closed system to compare as followed: temperature sensor (model DHT11) with Technol Seven D617 meter and Custom Ahlt-100 meter, relative humidity sensor (model DHT11) with Custom Ahlt-100 meter and light intensity sensor (model BH1750) with Custom Ahlt-100 meter. The processes would be repeated measurement, collected the data and analyzed the efficient with statistical methods.

Validation of the invention

The portable photosynthetic sensor efficiency evaluation was compared to the reference data [7] that collected from commercial instrument. The net photosynthesis measurement was to conduct in the same plants as reference. Later, the photosynthesis data from the handheld photosynthetic sensor was to collect, analyze and compare to reference data with statistical methods.

Results and Discussion

The portable photosynthetic sensor is capable of acquiring and fusing the primary sensor to measure CO_2, temperature, relative humidity, and light intensity.

The invention worked by attaching the leaf chamber to a pinch of leaf on a plant as shown in Fig. 3, and used an air pump to circulate CO_2 from the leaf chamber to a CO_2 sensor for measurement. At the same time, the other sensors, i.e. the temperature, relative humidity, and light intensity sensor, also used to collect the environmental data. These results were used to calculate the net photosynthesis in µmol/(m^2-s). After that, the overall result would be displayed in real time via LCD monitor.

Figure 3 Photograph of the portable photosynthetic sensor

Table 2 Validation and efficiency of the sensors

Parameters	**Reference materials**	**Significant (P-value)**
CO_2	Standard 995 ppm	0.73
CO_2	Standard 1000 ppm	0.07
Temperature	Technol seven and Custom Ahlt-100	0.48
Relative humidity	Custom Ahlt-100	0.54
Light intensity	Custom Ahlt-100	0.15

Several parameters were significantly greater than 0.05 (95% confidence level). Therefore, it could be implied that the performance efficiency of these sensors and commercial tools were not accuracy different, due to the values from each sensor being relatively constant and with a high accuracy.

Table 3 Comparison the net photosynthesis of plants from commercial [7] and invention (±SD in parentheses)

Type	Commercial	Invention	Significant
	(μmol/(m^2-s))		(P-value)
Oyster plant	6.4	3.1 (±0.51)	0.00
Aglaonema	3.2	3.1 (±0.62)	0.38
Mango tree	7.0	7.3 (±0.90)	0.47
Teak	9.1	10.5 (±2.82)	0.10
Maize	47.0	46.5 (±0.84)	0.09

When compared the performance efficiency between the portable photosynthetic sensor with reference data [7] from a commercial instrument by statistic methods. The significant or P-value of plant photosynthesis data, which consists of; oyster plant, aglaonema, mango tree, teak, and maize was 0.00, 0.38, 0.47, 0.10, and 0.09, respectively. From the data found that each plant has a P-value greater than 0.05 (95% confidence level). This could be indicated that the net photosynthesis of these plants when using the invention was not significant different from the reference data [7], but the P-value of oyster plant was less than 0.05. Due to the oyster plant species in this research was a dwarf species which different from the reference data [7] which used a wild type of oyster plant. Then the difference of species of plant would directly affect the plant photosynthesis rate. Therefore, the physical difference of leaf size was one of the reasons that plant photosynthesis values differentiated. In addition, the difference in the physical condition, including external factor also affect the plant photosynthesis process. As a result, could be implied that plant can be fully effective in optimal condition.

Besides, the portable photosynthetic sensor could identify the plant into two groups, C3 and C4 plants. The CO_2 absorption and net photosynthesis of C3 plants was different from C4 plants, due to the C3 plants being able to fix CO_2 just once, whereas C4 plants could fix CO_2 twice. Thus, C4 plants have a higher photosynthesis values than C3 plants. However, when compared in the long term and in term of CO_2 absorption. The C3 plants being perennial plants with many leaves and have a long lives, thus it could be absorb CO_2 more than C4 plants.

When compared the cost of the portable photosynthetic sensor with the commercial instrument, it was found that the cost of invention representing 0.25% of the sale price of the commercial instrument.

Conclusion

The invented of portable photosynthetic sensor was functioned and realiable similar to commercial sensor. The photosynthetic value are useful data to describ how we can success the CO_2 reduction campaign. The conclusion remarks could be summarized as follows:

1. This invention consist of several sensors, which had a high precision and accuracy. The photosynthesis value are display in real time which can be observed the plant photosynthetic continuously with high precision and accuracy.

2. The portable photosynthetic sensor has a high performance equivalent to commercial tools, while it has lower cost.

3. It could apply as a controller for the suitable condition in the greenhouse, And it could use as a perfect tool for planning and managing for CO_2 reduction.

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