Developing IoT Wireless Sensor Network for Respiration Storage Chamber

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***Abstract*— The role of fresh fruit and vegetables respiration rate is a main postharvest handling. This research designed an internet of things (IoT) respirometer to measure respiration activities of fruit and vegetables. The respirometer consisted oxygen (O_2), carbondioxide (CO_2) and humidity sensors, microcontroller, esp32, nextion display and respiration chamber. Sensors node generate data and processed by NodeMCU esp32 and the respiration data transferred by internet network and cloud database. The O_2 sensor interfenece was less 0.1%, CO2 sensor accuracy ±70 ppm of reading, SHT-30 accuracy ±2% and temperature ±0.3ºC. The respirometer based IoT system provides a real-time measurement and good fit data measurement that was tested for oyster mushroom storage.**

***Keywords*— Esp32, IoT, respirometer, tested**

I. Introduction

Fresh vegetables and fruits are defined as a living material because continous respiration after harvest and during storage [1]. Respiration behavior of fresh fruit and vegetables have a unique respiration rate depending on environmental factors such as humidity, temperature, light radiation and gas composition. Measuring respiration is a key of postharvest handling because many nutritional of organic substances such as sugar, amino acids, organic acids and fatty acids breakdown during fruits and vegetables respiration for producing energy via oxidation [2]. Respiration rates for oxygen (O_2) and for carbondioxide (CO_2) are defined as the rates of consumed O_2 or produced CO_2 per kg fresh produce per hour [3], [4] so the measurement of respiration rate could be achieved by measuring O_2 and CO_2 concentration in the package or storage chamber during storage.

Combination of gas chromatograph and electrochemical gas sensors are the most popular respiration measurement that collect O_2 and CO_2 concentration data [5]–[7]. This method produces discrete data that must be treated carefully as biological processes are not static and much dynamic [4]. Other method, respiration measurement uses flowing and flushing system. Premixed gas prepares at mixing tank that contains gas mixture of any proportion compressed air, oxygen, carbondioxide and nitrogen. The premixed gas is constantly streaming through the gas distribution board and passing pre-calibrated capillary flow meters to regulate the gas flow rate into each respiration chamber. Gas mixture composition entering and leaving the chamber is regularly monitored CO_2 and O_2 concentrations by a hypodermic syringe. Collected gas samples are analyzed using a gas chromatograph equipment [8]. Thus, development of semiconductor produced many gas sensors including O_2 and CO_2 sensors. Non-invasive detection and measurement of CO_2 and O_2 can be supported with a low-cost optical sensor. The flourescence based sensor for O_2 detection provided with a high suitable in food storage and packaging applications. Measuring O_2 concentration using direct sensor is certainly be cost effective while compares to carrying out regular product sampling for routine gas headspace analysis. The cost measurement is estimated from \$0.15-\$0.15 [9].

A novel wireless sensor system (WSN) for monitoring respiration rate and oxygen production was introduced for horticulture crops. The WSN enable determining of oxygen consumption and respiration rate in the chamber during of fresh cut brocolli cloret storage. However, the WSN did not work measuring the oxygen level at concentration lower 5% and unabled measuring CO_2 level [10]. Moreover, monitoring and controlling purpose for WSN can be supported by arduino based electronic control [11]. Our previous work designed low budget respirometer chamber based on WSN. The arduino microcontroller USB port was used to record respiration parameter such as O_2 and CO_2 concentration as well as temperature. The data measurement transferred using wireless communication by Xbee S2C on radio frequency. User interface was developed using labView to present real-time gas concentration in the respiration chamber during mangoes storage [12]. The drawback of low budget respirometer data tranferring is limited by distance between sample and computer.

Recently, internet is expanding and being a challenging to support research activities such as WSN, radio frequency identification and various smart communication technologies [13]. A wide spectrum in internet of things (IoT) application development has been applying in agriculture for example soil, crop, macroclimate monitoring [14]. Hence, IoT is a key part in development precision agriculture where IoT provide communication technology between different object or device via a wireless networks system [15]. As a kind of network technology, ioT senses the information from different sensors and encourage to exchange information [16]. Applying IoT in smart and precision agriculture has been reported many researching in a different research area such as drip irrigation system through web-based [15], remote monitoring system to control the door climate condition through light emitting diode [17], encourage WSN real-time water saving management and decision harvesting time based on fruit maturity [18], automated food grain monitoring system for warehouse [19]. Demanding a wireless sensor network is increasing, multitasking work, real-time, high speed measurement and data acquition so WSN application is also driving for low cost [20].

Developing previous work, the IoT network was applied to optimize data acquisition of respiration chamber using wireless sensor network. The goal of the present researh was to develop wireless sensor network IoT for improving respiration chamber chamber. Design of real-time continous data O_2, CO_2, temperature and humidity in a closed respiration vassel was recorded using third party platform. The WSN IoT respiration chamber work was to obtain respiration rate of chilli under varying storage temperature.

II. MATERIAL AND METHODS

A. Sensors

Oxygen sensor has measuring range 0 to 100%, output signal I2C, working pressure 0.5-2.0 atm and working voltage 3.35-5V DC, temperature range -20C-50C, non condensing, respon time 5 s and compatible with ESP32, raspberry pi and arduion (DF Robot, China). Carbondioxide sensor type NDIR GC-0018 Sprint IR with gold-plated optics, power input 3.3-5V DC, measuring range 0-100%, serial communication 9600/8/1/N (Michigan, USA). Temperature and humidity sensor used SHT-30 with a range operation 0-100% RH, power input 2.2-5V DC, I2C communication, response time 8 s (ADA Fruit, China).

B. Microcontoller and Communication

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. Specifications of the Arduino UNO R3 are as follows: microcontroller: ATmega328, operating Voltage: 5 V, input voltage 7–12 V, input voltage (limits): 6–20 V, digital I/O Pins: 14 (of which 6 provide PWM outputs), analog input 6 pins, DC current per I/O Pin: 40 mA, DC current for 3.3 V pin: 50 mA, flash memory: 32 KB of which 0.5 KB is used by the bootloader, SRAM: 2 KB (ATmega328), EEPROM: 1 KB (ATmega328) and clock Speed: 16 MHz [21]. ESP32 is powerful SoC (System on Chip) microcontroller with integrated Wi-Fi 802.11 b/g/n, dual mode Bluetooth version 4.2 and variety of peripherals. It as well offers programmers a powerful toolkit with dual cores,240 MHz, 520 Kbyte SRAM and peripherals including: I2C, DAC, ADC, I2S, SPI, UART, 34 physical GPIO pins [22].

C. Respiration Chamber

The chamber material made from 0.5 cm polyprophylene plastic which can withstand below 5 Bar air pressure. Tube lid was embedded three sensors (O_2, CO_2 and SHT-30) to measure the gas concentration, temperature and humidity. The lid sensors were tightened with seal O-ring to avoid gas leakage [23]. Data from the sensors were transmitted automatically to an arduino microcontroller. The arduino directly connected to Esp32 for data transferring to a computer unit or mobile phone.

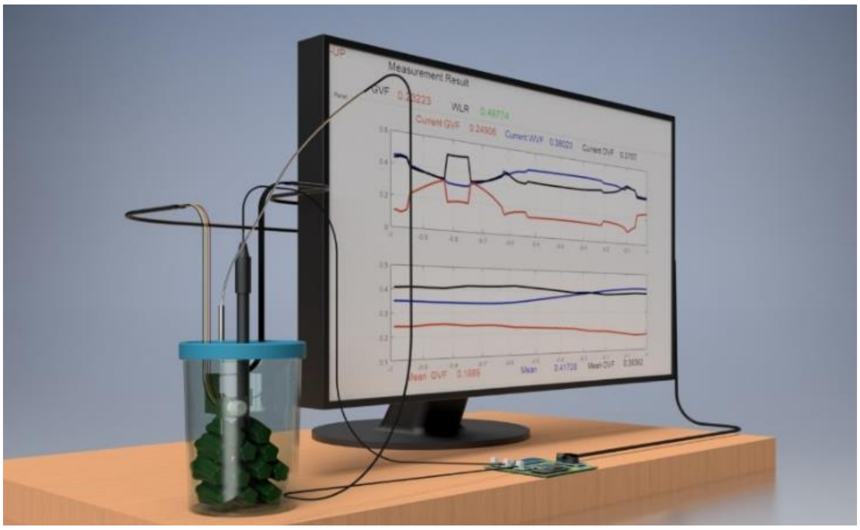

Fig. 1. WSN respirometer hardware for monitoring changes temperature, RH, O_2 and CO_2.

Our previous work investigated that the gas leakage is possible at the wiring lane microhole and be tackled by sealent adhesive [12]. The respirometer chamber leakage was tested by air flushing through inlet valve until pressure gauge 1 Bar and subsequently dipped in the water to investigate any bubbles formation. Then, lack of bubbles indicates no leakage the respiratory chamber and the instrument ready to use for experiment.

D. Sensors Calibration

Arduino platform software provided alogorithm coding for every sensor which used for monitoring respiration chamber. The algorithm of SHT-30 was developed from Ada Fruit library and did some correction during calibration test. The SHT-30 calibration was done in the permeable chamber which streamed pure gas (N_2) until the pressure gauge 1 Bar as 0% humidity. Then, condensed water was filled in the permeable chamber as closed to 100% humidity. The calibration measurement resulted humidity value between 1.5-98.3%. Next, the oxygen sensor calibration was apllied by three condition as follow, 1) measuring the oxygen concentration at ambient air (result 21.8%); 2) measured pure oxygen gas in the permeable chamber (result 99.9%); and 3) measured pure nitrogen gas in the permeable chamber (result 0.2%). Last carbondioxide calibration, the carbondioxide sensor calibration was apllied by three condition as follow, 1) measuring the carbondioxide concentration at ambient air (result 500 ppm); 2) measured pure carbondioxide gas in the permeable chamber (result 980,000 ppm); and 3) measured pure nitrogen gas in the permeable chamber (result 0 ppm).

III. Result and Discusion

The respirometer applied four sensors type including O_2, CO_2, SHT family and industrial digital pressure sensor. Calibrated sensors were embedded above the lid of permeable respirometer chamber where those sensors calculating the amount of ouput parameters (% O_2, ppm CO_2, ^oC temperature, % RH and kPA). The SHT-30 sensor was calibrated by purging a pure gas N_2 (99.9% purity) through permeable inlet pipe continously. The SHT-30 measured value ±1.5% as 0% RH and 99.3% as 100% RH. The O_2 sensor measurement for pure N_2 streaming and read 99.5% for 99.9% pure O_2 streaming. The CO_2 sensor detected 400 ppm at ambient air, 0 ppm at pure N_2 and O_2 streaming. Those sensors wes assemblied in the respirometer lid and the parameters measurement were stored in the microsd-card as primary data storage. IoT application work by real time analog data processing and transferring to cloud database using NodeMCU32 and can be accesed to devices (computer or mobile phone). The devices able to monitor data measurement using third party such as cayenne or thinkspeaks. A power adapter 5 V supplied electricity for the microcontroller. The microcontroller supplied electricity power to sensors and NodeMCU32.

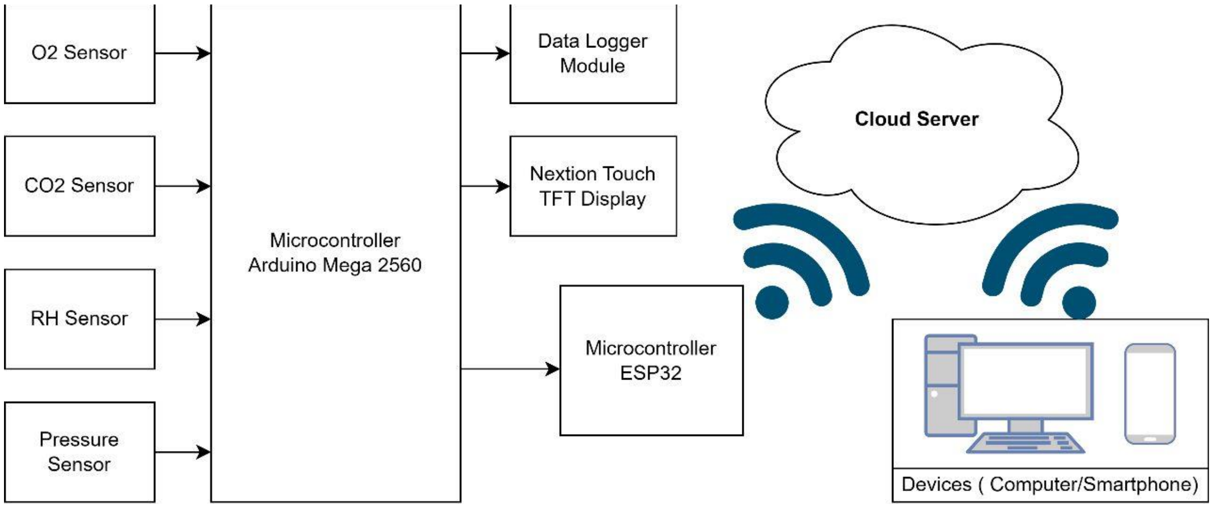

Fig. 2. Respirometer Based IoT Esp32

A. Respiration Chamber IoT Hardware

Sensors encourage IoT application in agriculture system because its provide converting real-world signals and the digital representations. Sensor selection is a main step for developing IoT system as well as best performance [14]. In this reseqarch, industrial grade sensors were chosen in terms of fulfilling stability and endurability, reading concentration ranges, interface to the microcontroller, power consumption and operating voltages. SprintIR-W100% CO_2 sensor has a measurement range until 100% whereas other sensors operate less than 50000 ppm (5%). As a non-dispersive infra red (NDIR) sensor type, the SPRINTIR-W100% operate at 3.3 V and provides a simple practical connection to the arduino microcontroller which operating voltage until 5 V. The advantage of NDIR sensor is low consumption energy consumption [24]. NDIR CO_2 sensor are popular for the real-time measurement due to provide provide long-term stability and low power consumption [20]. The SprintIR-W100 has a good performance to measure the CO_2 gas twenty measurements per second which suitable both in medical and biological process application [25].

AO2 CITIcel oxygen sensor used an electrochemical sensor measuring range 0-100%. The oxygen sensor working voltage between 3.3-5.0V DC, I2C signal output and operating humidity 0-99% (non-condensing). The electrochemical sensor converts free oxygen into a measurable electical signal which the oxygen concentration is normally propotional to the maghitude. The electrochemical sensor inform the gas concentration by coupling a chemically selective layer by recognition element to electrode as an electrochemical tranducer [26]. AO2 CITIcel oxygen sensor has a built-in calibration algorithm on the signal board that can quickly perform single-point or double-point calibration so as to accurately measure the oxygen or O_2 concentration in the environment. Based on the principle of electrochemistry, the sensor probe comes with strong anti-interference ability, high stability and sensitivity, and up to two years of service life. It is compatible with mainstream controllers such as Arduino, ESP32, Raspberry Pi, etc.

SHT30 is a true I2C interface and consists our wires: Brown/Red = VCC (3-5VDC), Black = Ground, Yellow = Clock, Green/Blue = Data. A digital format makes a simple use and the application does not ant data conversion [27]. The SHT30 had an accuracy measurement at ±0.3 °C with a repeatability of 0.06 °C for temperatures between 10 °C and 55 °C, and accuracy of ±3% with a repeatability of 0.13% for relative humidity values between 10% and 90% [28].

The respirometer based IoT is composed four layers as follows: 1) data acquisition; 2) data transmission; 3) data processing and 4) data application. The data acquisition is the initial IoT architecture that showed data collecting from real condition in the repiration chamber such as the gas concentration (O_2 and CO_2), humidity and temperature. Then, the data transmission is a network layer providing communication process from data acquisition to the microcontroller for data processing. Hence, the data processing layer has function for collecting, analysing, processing and managing raw data from previous layer into output processed data. Last, the data application represents user interface to monitor the respiration chamber dynamics. This research applied Esp32 for real-time data acquisition all of sensors that being used for measuring the gas composition and temperature, humidity in the permeable respiration chamber. The Esp32 allows collecting the O_2 and CO_2 concentration and sends to a cloud server. The data measurement can be monitored real-time on the computer or smartphone device based on internet protocol.

B. Respiration rate measurement

The respiration chamber was treated for oyster mushroom storage that monitored respiration activities during 4200 minutes storage at ambient temperature. Data acquisition from CO_2 and O_2 sensors presented the concentration of the gas in the respiration chamber as period of storage. The IoT respirometer design work properly and do not interference by the wifi signal or both systematic and random error. Based on the data measurement, the pattern of oyster mushroom respiration activities had a similarity to previous researchers work.

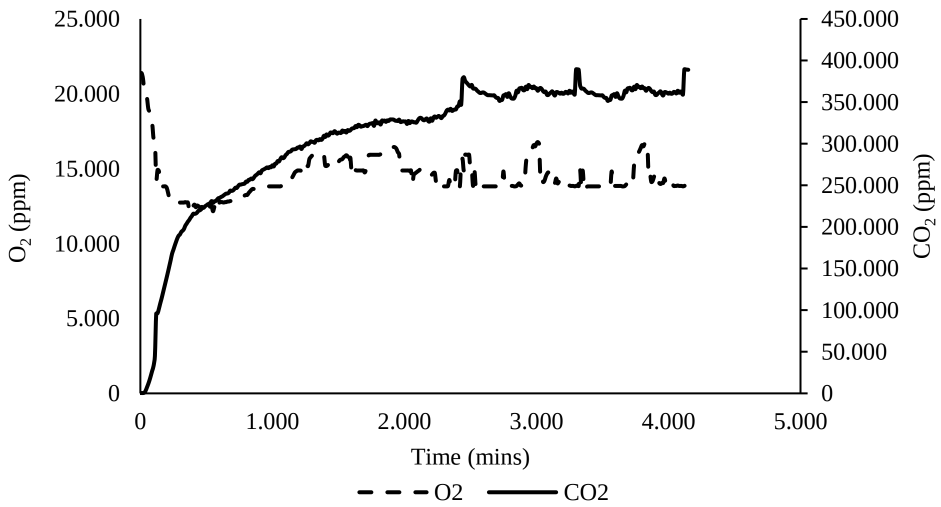

Fig. 3. Respiration oyster mushroom in the respirometer Based IoT Esp32

The data respiration of oyster mushroom showed a first order as modelled in the modified atmosphere storage at various temperature storage [29]. From the fig 3, the gas production (CO_2) and gas consumption (O_2) calculated fast respiration rate at initial storage due to stress after harvesting [30]. The collected data can be further analyzed to determine respiration rate (RR) where RRO_2 was about 4,67 ml/kg.h and $RRCO_2$ was calculated at 240,47 ml/kg.h.

IV. Conclusion

Respirometer based an IoT system provides a real-time measurement for repiration research activites in the storage field. Applying Esp32 is compatible with arduino microcontroller and effectively for data transmission to the computer device using wifi or internet prototcol. The Esp32 is low energy consumption and low budget to encourage application IoT based system. During the application, the data acquisition of respiration measurement work properly to transmit sensors (O_2 and CO_2) reading. The respirometer was tested for oyster mushroom and resulted a good data measurement.

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