Design and Development of Real-Time Plant Process Control Monitoring System in Organic Fertilizer Production

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Abstract. In this applied research, a plant controller with capacity of 300 litres has been developed. The system provides graphical user interface (graphics and tables) using Visual Basic program to show and monitor the fermentation process. Communication between the software and hardware is established through microcontroller's interface. The microcontroller acts as the main controller which controls the humidity, temperature, pH, aerator, heater, exhaust fan, and the speed of the motor. Temperature and humidity sensor (DHT-22), Methane Gas sensor (CH), Carbon Gas sensor (MQ7), and Nitrogen Gas sensor (MiCS-2714) are used in this system. The domestic waste raw materials such as vegetables and sugar cane waste are thinly sliced while the fruits are grinded. Temperature, humidity, and pH readings are collected as reference parameters prior to the process starts. During the anaerobic digestion process, temperature is kept at 40°C ±1 while plant's tube is maintained at 40°C. When the temperature falls to 39°C, the heater is switched on, when the temperature reach 40°C the heater is switched off. This research is carried on using two kind of mixture models which are: mixture model X (mixture of vegetables, fruits and sugar cane waste) and mixture model Y (same as X with additional rice husk). The mixture model X and Y C/N's ratio is in compliance with SNI-7030-2004 standard. The real-time plant controller system proposed in this research is successfully.

1. Introduction
Domestic waste problem has known to be a classical challenge in many places ranging from big cities to small villages. The increasing number in population and urbanization, inefficient waste process as well as human behavior are the main contributors for the problem. One of the popular solution to reduce the end product of domestic waste is to turn the waste into organic fertilizer through composting process. The aim of this research is to make innovation by developing a real-time monitoring system in a plant reactor for organic fertilizer production that fully compliance to SNI-7030-2004. This system can detect and measure the critical values of gasses, temperature, humidity, and pH during the production process of organic fertilizer. This system also suitable to be use as a learning platform for Control System Process in universities. Through USB connection, the system is connected to a computer. The reading and measurement sensors are shown in graphical user interface (GUI) in real-time. The system also capable to show the previously recorded measurements by displaying the data from database.
2. Literature study

2.1. Organic fertilizer
Organic fertilizers are fertilizers mostly or wholly composed of organic materials derived from crop residues, or animals that have undergone engineering in the form of solid or liquid used to supply organic materials, possessing physical, chemical, and biological properties of soil (Regulation of the Minister of Agriculture, No.28/permentan/sr.130/5/2009 in 2009 [1]. Organic fertilizers are the final product and intermediate result of the alteration or decomposition of parts of plant and animal waste. Organic fertilizers come from organic materials containing various elements. It is often characterized by the presence of nitrogen in the form of organic compounds that will be easily absorbed by plants. Organic fertilizers leave no inorganic acid in the soil and have high levels of organic C-compounds [2]. Organic fertilizers are mostly available in nature (naturally occurring), e.g. compost, manure, green manure, and guano (Sumekto, 2006) [3]. Organic fertilizers are generally produced from the composting process so often referred to as compost. According to J. H. Crawford (2003) [4], compost is the result of incomplete and artificially accelerated decomposition by populations of various microbes in warm, humid, aerobic or anaerobic environments (Nyoman P. Aryantha.dkk, 2010) [5]. To produce compost, one need to regulate and control the natural process so that the compost can be formed faster. This can be done by making a balanced mixture of ingredients, adequate water supply, aeration set, and the addition of the activator. Composting methods have evolved so that attempts to manipulate factors that can accelerate the rate of composting process can be achieved. "Ideally, a technology capable of increasing the rate of rapid composting is a technology that is considered better" [6]. Good compost quality is determined by the decomposition process of organic material that has occurred perfectly so as not to adversely affect the plant. According to (Nyoman P. Aryantha, et al, 2010), the quality of the compost is good if: 1. Colored dark brown to black similar to the color of the soil, 2. Insoluble in water, 3. C / N ratio, depending on the raw material and the degree of humification, 4. It works well if applied, 5. Its temperature is more or less the same as ambient temperature, 6. No smell.

2.2 Microcontroller
A microcontroller is a functional computer system of a digital electronic device that has input and output, and control with programs that can be written and erased in a special way. Microcontroller used in products and tools are controlled automatically, and for a microcontroller to work, it requires an external component which is then called a minimal system. To make a microcontroller’s minimal system, a system clock and reset are required. Some microcontrollers already provide internal clock system, so they can run without any external circuitry. The point of building a minimal system is to have a microcontroller that can be used to run an application. A microcontroller chip would not be meaningful if it only stands on its own. Basically, a minimal AVR microcontroller system "Alf (Egil Bogen) and Vegard (Wollan) ’s Risc processor” has the same principle [7].

2.2.1 AVR ATMega328 Features
ATMega328 is an Atmel microcontroller with RISC architecture (Reduce Instruction Set Computer) in which every data execution process is faster than CISC (Completed Instruction Set Computer) architecture. ATmega328 microcontroller has a Harvard architecture, which separates the memory for program code and memory for data to maximize work and parallelism. The instructions in the program memory are executed in a single path, by the time one instruction is done the next instruction is already taken from the program memory. It is this concept that allows instructions to be executed in every single clock cycle. 32 x 8 multi-purpose bit registers are used to support operations on the ALU (Arithmetic Logic Units) which can be done in one cycle. Six of the multi-purpose registers can be used as three sets of 16-bit pointer registers in indirect addressing mode to retrieve data in data memory space [9] [10].
The three 16-bit pointer registers are called registers X (combination of R26 and R27), register Y (combination of R28 and R29), and register Z (combination of R30 and R31). Almost all AVR instructions have a 16-bit format. Each program memory address consists of 16-bit or 32-bit instructions. In addition to the above-mentioned multi-purpose register, there are other registers mapped with a 64-byte memory mapped I/O technique. Some of these registers are used for special functions such as registry control Timer/Counter, Interrupt, ADC, USART, SPI, EEPROM, and other I/O functions. These registers occupy the memory at address 0x20h - 0x5Fh [7][11].

![Figure 1. Atmega AVR architecture](image1)

![Figure 2. Atmega328 pin-out](image2)

### 2.2.2. Arduino Uno

Arduino is an ATmega328 based microcontroller board, has 14 input/output pins where 6 pins can be used as PWM output, 6 analog inputs, 16 MHz crystal oscillator, USB connection, a power jack, ICSP head, and reset button. Arduino able to support the microcontroller; it can be connected to a computer using a USB cable. Arduino is a minimum system microcontroller board that is open source. Apart from being open source, another advantage of Arduino Uno is its simplified programming language. On the Arduino board itself, there is the USB loader that makes it easy to program the microcontroller inside the Arduino. The USB port is the main tools to write the program and it can be used as a serial communication port. Arduino provides 20 pin I/O, which consists of 6 analog input pin and 14 digital input/output pin [7][12].

![Figure 3. Arduino Atmega328 Board](image3)
2.2.3. Power
Through a USB connection, the Arduino can be supplied with a DC power supply adapter or battery and the power is automatically selected. The adapter can be connected by plugging the adapter jack on the input supply port connection. The Arduino board can be operated using an external supply of 6-20 volts. The board can become unstable with the 5V supplied in the adapter jack, it will supply less than 5 volts and vice versa if using more than 12V, the voltage to the regulator can get very hot and cause damage to the board.

2.2.4. Memory
ATmega328 has 32 KB flash memory to store code, also 2 KB used for the bootloader. ATmega328 has 2 KB for SRAM and 1 KB for EEPROM [9].

2.2.5. Input and Output
Each of the 14 digital pins on Arduino can be used as input or output, using the function pinMode(), digitalWrite(), and digitalRead(). The input/output operates at 5 Volts. Each pin can generate or receive a maximum of 40mA current and has an internal pull-up resistor (disconnected by default) 20-50 Kilo Ohms.

2.2.6. Communication Arduino Uno
Arduino has a number of facilities to communicate with computers, other Arduino, or other microcontrollers. ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on this board channels the serial communication via USB and appears as a com virtual port for software on the computer. The firmware of the ATmega16U2 uses a standard USB COM driver, and no external drivers are needed. However, on Windows, the file .inf is required. The Arduino software includes a serial monitor that allows simple textual data to be sent to and from the Arduino board. RX and TX LEDs on the board will blink when data is being sent via USB-to-serial chip and USB connection to computer (but not for serial communication on pins 0 and 1). A Serial Software library allows for serial communication on any Uno's digital pins. The ATmega328 also supports I2C (TWI) and SPI communications. The Arduino software includes a wired library to simplify the use of the I2C bus, while for SPI communications, it uses the SPI library [7] [9] [12].

2.3. Gas Sensors
A sensor is something that is used to detect a change in the physical or chemical environment, while a gas sensor is a device designed to detect one or more types of gas. The gas sensor functions to measure the air pollutant gaseous compounds, such as Carbon Monoxide, Hydrocarbons, Nitrooxides, Methane and others. In this research used temperature / humidity sensor (DHT22 sensor) [13], pH level, the aerator, heater, exhaust fan, motor speed. Sensor installed: methane gas CH4; carbon gas (MQ7); Methane gas (MQ4); gas Nitrogen (MiCS-2714).

2.3.1 DHT22 Sensor
DHT22 or also known as AM2302 is a sensor that can measure the temperature and humidity of the surrounding air. The DHT-22 sensor is selected because it has a wide measurement range of 0 to 100% of humidity and -40 degrees Celsius to 125 degrees Celsius for temperature. This sensor also has a digital output (single-bus) with high accuracy and precision in terms of measurement [13].

2.3.2. MQ4
MQ-4 has the ability to detect the concentration of methane (CH) gas in the air. Sensors can be used to detect flammable gases. This sensor requires a power supply of 5V. The detection range against natural gas/methane is 300 to 10000 ppm.
2.3.3. MQ7
MQ-7 is a gas sensor used to detect Carbon Monoxide (CO) gas. This Hanwei China-made sensor consists of AL2O3 ceramics, a thin layer of SnO2, electrodes and heater combined with a crusty layer made of plastic and stainless. The MQ-7 sensor packs are available in two types: metal and plastic. This sensor can operate at temperatures from -100 C to 500 C and consume less than 150 mA at 5 V. Gas detection distance: 10 - 1000 ppm CO gas.

2.3.4. PH Sensors
The main working principle of the pH meter is located in probe sensor in the form of glass electrode by measuring the amount of H3O + ion in solution. The tip of the glass electrode is a layer of glass as thick as 0.1 mm in the form of a round (bulb). The bulb is paired with a non-conducting glass cylinder or elongated plastic, further filled with a solution of HCl (0.1 mol / dm3). In HCl solution, submerged a long silver electrode wire on the surface formed AgCl balanced compound. The constant number of HCl solutions in this system makes the Ag/AgCl electrode has a stable potential value. The pH sensor core is present on a glass bulb surface which has the ability to exchange positive ions (H +) with measured solutions. The glass is made up of silicon dioxide molecules with a number of alkali metal bonds. At the time this glass bulb was exposed to water, the SiO bond will be protonated to form a thin membrane HSiO + according to the following reaction:

\[ \text{SiO} + \text{H}_3\text{O}^+ \rightarrow \text{HSiO}^+ + \text{H}_2\text{O} \]

3. Research Methods
Stages of research methods used in the manufacture of monitoring system tools in real time are:
1) Problem analysis: waste management model that is not accurate and optimal.
2) Needs analysis: make innovative model tool monitoring system in real time that can work and able play a role in detecting process to produce organic fertilizer according to SNI-7030-2004 standard
3) Literature study: Composition of mixture of compost material that is not similar then the decomposition is relatively quick when compared with similar materials, the smaller the material the faster the process of decomposition of materials, at an optimum temperature of 30-45 °C, pH in the range of 6.5 - 8.0, the water and oxygen content (O₂) idea is 50-70%, the higher N (N) content, C / N ratio, C / N depends on the type of garbage,
4) The design of the tool consists of:
   (a) Mechanical Design of the reactor Plan: Reactor model of the fertilizer process by elaborating the form of the concrete mill as a place to make organic fertilizer from organic garbage, picture 3.1 below is set up the plan shape of the reactor.
   (b) Realtime system module control and programming tool design: Realtime monitoring system consists of 3 parts,
      1) Instrument field,
      2) Control board and
      3) Reactor monitor software operated in PC.

![Figure 4. Plant reactor process](image)
b.1. **Field Instrument:** Figure 5 is a Field instrument block containing sensor instruments such as DHT22, MQ4, MQ7, pH sensor meter, nitrogen gas MiCS2714 and Arduino. The function block instrument field is for the overall measurement of test variables. The instrument field requires a voltage of 12V, the voltage obtained from the supplied DC jack, the sensor data is processed by the microcontroller and then sent through the male USB port. Figure 6 assembles the instrument field and designs the series circuit of the instrument field into the PCB.

b.2. **Control Board:** Figure 7 is a Control Board block containing, among others, USB socket interface using USB, 12 Volt DC source, 1 phase MCB, 3 phase contactors and three relays to be connected to load of motor, exhaust fan, aerator and heater. The control board block function is to receive sensor data from the instrument field through female USB port, and transmit sensor data with relay control data to PC or reactor monitor application via USB C port. Control board also serves to control actuator like motor, ex. Fan, heater, and aerator in accordance with the command of the software or in accordance with the sensor field data instrument. For aerator use 12 Volt DC voltage.

![Field Instrument Block Diagram](image)

**Figure 5.** Field Instrument Block Diagram

![Schematics and Design of PCB Field Instrument](image)

**Figure 6.** Schematics and Design of PCB Field Instrument
3.1. Series Installation panel
The panel installation consists of a series of controls and power circuits

![Panel Installation Diagram](image)

**Figure 7.** Panel Installation Diagram
a) Control circuit b) Power circuit

4. Results and Discussion
4.1 Monitoring System in real time
The working principle of the design and implementation is when the monitoring system tools in real time by creating a program for graphical user interface as a display and be a good information in the form of gas data values or graphic images displayed in the GUI. Figure 8 shows the GUI display on the laptop / PC which is connected to the USB of the instrument board and control board field of the microcontroller. The instrument board field of the components, DHT22, pH, MQ4, MQ7 coupled sensor instrument will detect the value of gases, temperature and humidity using pH meter, MQ7 sensor and MQ4 sensor.

![GUI Display](image)

**Figure 8.** The GUI display contains value data information which has been detected by instruments of sensors and graphics
4.2. Plant Reactor

For temperature conditions have been determined that ± 40°C as a reference point, and if the temperature ≤ 39°C then the heater will work to provide heat and affect the room temperature reaches 40°C and after obtaining the value then the heater will off. When the temperature ≥ 41°C, exhaust fan works to remove excess heat from the reactor plant's reactor room and the aerator will also work to assist the restoration of the spray by spraying water into the reactor plant room. After reaching the temperature of 40°C the exhaust fan and aerator are stop working. The software on the design of the device, it's built using C language with the Code vision AVR compiler. The whole as well as the software to access parts of the system is arranged in the Arduino UNO Atmega328. As for the real time flowcharts of the system monitoring system in the research with the Title Design of Real Time Process Control System in the Making of Organic Fertilizer is shown in Figure 9.

![Flow chart of the system](image-url)

**Figure 9.** Flow chart of the system
4.3. Sensors Reading Algorithm
To detect temperature / humidity and humidity using DHT22 sensor, acid, neutral and alkaline condition using pH meter, carbon CO monoxide gas content using MQ7 sensor and methane gas content using MQ4 sensor. Instrument temperature, humidity and gas sensor works based on voltage change according to the number of environmental conditions and the gas content received by the sensor surface. Using the Internal Arduino Adjustment Algorithm where the algorithm for converting analog to digital data through ADC Internal Arduino Uno encompasses several parameters and registers are set. Understanding Delay here is the delay time of the internal control ADC on a microcontroller that is used for the conversion process. The process is arranged based on the ADC configuration of the designed clock, meanwhile to know the ADC conversion process is in the ADCSRA register on the 4th bit, i.e. the bit will be 0 when the ADC conversion is completed and logic 1 (high) if the conversion process is in progress. The conversion result The ADC is then stored in the ADCH register for the MSB bit (bit 8 and bit 9) while the low bit (LSB) is stored in the ADCL register IE bits 0 through 7 so that data can be retrieved from the register, then the 4th bit ADCSRA bit is manually created as a sign on the ADC's internal controller that the ADC data has been read. In Arduino programming, ADC reading system through Arduino software has been packaged into a simple command, analog reads (analog input) so that the parameter setting in ADC register has been done automatically on Arduino UNO. The value of environmental conditions and gas content contained in the area the plan region of the reactor will be readable to reach the value of the environment and the reactor plant room system. The bulkhead to find the gas volume inhaled are required the formula: \( V = A \cdot \omega \cdot t \), with \( V \) = volume (plant) of the gas, \( A \) = cross-sectional area, \( \omega \) = velocity swivel, \( r \) = radius of cross section, and \( t \) = time. The test results are shown in Figure 10.

![Figure 10. Information Table of the results of sensors reading.](image)

5. Conclusions and Suggestions
In this research, a real time monitoring system has been designed in the manufacture of organic fertilizer consisting of: 1) Design Real-Time Monitoring System by applying DHT22, pH meter, MQ4, MQ7 and MiCS2714 and 2) Design Reactor Plant by locating low-speed stirring motors, exhausts, aerators and heater. In Real Time Monitoring System testing, the applied sensor instrument is running well and can measure the intended object. All sensor instruments have analog outputs so that the required ADC processing is programmed into the microcontroller. Graphical user interface software (GUI) program design of the real time monitoring system has been able to display the measured value
of gas, graphical display and instrument of the applied sensors have been able to function for the measurement of gas. While testing the reactor plant, the motor with low speed has been reduced 4 times the initial rotation of 1500 rpm has dropped to 300 rpm by placing the gear box. This low rotary motor is enabled to reverse the object of organic fertilizer inside the reactor plant to be well mixed and the placement of exhaust fan, aerator and heater have also been running. As for suggestions in this applied research, it takes sufficient time to try to maximize the performance result of real time monitoring system design tool in making this organic fertilizer, it is necessary to support the involvement of related government institution both in moral and material support.

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