

PID Control Design for Biofuel Furnace using Arduino

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Abstract

The target of the Indonesian government in 2025 is increasing the use of renewable energy up to 23%, one part of potential renewable energy in Indonesia is biofuel. Biofuel requires raw materials of plant or animal oil with or without catalyst, it does not require the raw material of ethanol or methanol. The product is similar to gasoline and diesel that came from crude oil. Potential oil-producing plants in Indonesia are Palm Oil and Nyamplung (*Calophyllum inophyllum* L.). The process of making biofuel from this material is done by heating the reactor or furnace with temperature range of 350-500°C. To reach the stability of furnace temperature, it requires temperature control systems and one of them is PID. Arduino microcontroller is an open source and user friendly platform for hardware and software. The control system that designed by using arduino is capable to control the furnace temperature from 200°C to 400°C and it is using a 6000 watt heater. The best system response is achieved when $K_p=15$, $K_i=15$ and $K_d=1$. With these parameter values, the system has the lowest overshoot response of 16%, so it is safe for biofuel furnace, even though the rise time value is 146 s, settling time of 429 and steady state error is equal to 2.87%.

Keywords: biofuel furnace, PID control, temperature control

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1. Introduction

The geographical condition of Indonesia as the largest archipelagic country in the world is a big challenge in developing renewable energy. According to the annual report, the renewable energy in Indonesia has not been used optimally, where in 2015 only 5% and 95% remaining is a portion of fossil energy [1]. The Indonesian government's target in 2025 is increasing the use of renewable energy up to 23%, so some efforts should be made to support this planning. The government target is also manifested in government regulations of Ristekdikti No. 13 of 2015 on Strategic Plan of the Ministry of Research, Technology and Higher Education Year 2015-2019, where one of the focus fields are energy [2]. One part of the renewable energy is biofuel, biofuel can be produced from plant oil [3]. Indonesia's forest area has an area of 120 million hectares and made it more suitable if the oil comes from plants [1].

Biofuel has several advantages over biodiesel which seen from the used raw materials. Biodiesel requires raw materials of plant or animal oil, alkaline and acidic catalysts, as well as additional feed stocks of ethanol or methanol which are already fuel. Biofuel only requires raw materials of plant or animal oil with or without catalyst; it does not require ethanol or methanol. The product is similar to gasoline and diesel that came from crude oil [2, 3]. Biofuel can be mixed with gasoline or diesel and can be applied to the machine without modify the engine. This happens due to the biofuel is similar to the mixture of diesel and gasoline. This is an interesting topic and it has made many researchers are interested to do some research on biofuel that used plant oil as raw materials. Potential oil-producing plants are Palm Oil and Nyamplung (*Calophyllum inophyllum* L.). This plant produces palm oil or nyamplung oil. Other types of this oil are: bintaro oil (*Cerbera manghas* L), kemiri sunan oil (*Aleurites trisperma* Blanco) and other vegetable oils.

The process of making biofuel from this material is carried out by heating the reactor or furnace with a temperature range of 350-500°C to become biofuel [3-5]. In several studies [4] it was explained that the temperature regulation and the flow rate of the produced catalyst has a different percentage of the composition of biogasoline, biokerosine and biodiesel. The highest biodiesel is produced at a temperature of 400°C by 60%, and the lowest at a temperature of

300% by 38%. In the temperature range of 300-400°C, the higher the temperature of the biodiesel composition, the higher and the lower the biokerosene composition [4]. For this reason, in order to make heating temperature of the furnace stable, controlling the temperature of the furnace is important so the formation of biofuels results can be achieved.

Heat is generated by heater to raise the temperature of the furnace to the desired temperature needed for the process. Heat can be produced by combustion of a fuel as in [6, 7] or by conversion of electrical energy as in [8, 9]. Control of furnace heating temperatures by using electrical energy can be done by various methods. The furnace induction control has been implemented [10] by regulating the PWM (Pulse Width Modulation) signal for the electric input of the heater. Research on the furnace temperature control is using Proportional Integral (PI) [11], that research proves the simple PI Controller is able to control the furnace temperature in a simulation procedure effectively. PID (Proportional Integral Derivative) control application also has been done in the previous research [11-13] but still in the form of modelling and simulation.

In its implementation, the PID controller can be applied by using a Personal Computer with the Labview program as in [14, 15]. Control design with Intelligent PID causes wasteful use of memory because it does a lot of calculations, so it is not suitable to apply on portable systems. The PID control for temperature can be applied by using arduino microcontroller, an open source and user friendly platform for hardware and software. The Arduino microcontroller application is widely used for instrumentation, biometric, automation and control systems, arduino is easy, cheap and support with various supporting devices [16-20]. Arduino is also used in temperature control applications as has been done in the previous research. Arduino was used to control a low temperature (0-90°C) and temperature 200-350°C using a 2.5 kW heater [21-23]. The temperature data reading indicator is processed with Arduino. Programming language is using C++, where in arduino microcontroller board there is a downloader to enter the programming language from personal computer to Arduino microcontroller.

This paper proposed a temperature control process with PID (Proportional Integral Derivative) and the system is using an open source microcontroller platform (Arduino). Arduino uno is the cheapest and easiest way to implement PID applications. PID on arduino microcontroller will control the biofuel furnace that have temperatures of 350°C to 500°C using 6 kW heater. This type of system is usually used PLC (Programmable Logic Controller) as a controller. PID control response from Arduino Uno will be read by using Personal Computer via USB port that already included in Arduino.

2. Research Method

This section describes the hardware and software sections for PID control application on biofuel furnace system.

2.1. Biofuel Furnace

In this study the furnace is designed by using aluminium wall, it has length×width×height of 0.5×0.5×0.5m respectively with a thickness of 0.05m. To heat the furnace room, this research is used an electric heater with a capacity of 6000 watts. Filter heater (wire niklin) is installed around the wall of the furnace room, so the heating temperature can be distributed evenly. Inside the furnace room there is an aluminium box that has a dimension of 0.3×0.2×0.2m as a container of the material to be processed. On the outer wall there was a panel that containing the controller circuit with Arduino Uno and it equipped with lights indicator, circuit breaker and LCD viewer. Furnace also has a wheel at the bottom to make the movement more flexible.

2.2. Control Design

Figure 1 shows the block diagram of furnace temperature control by using Arduino. In this work Type-K thermocouple is selected to sense the temperature with the range of -200°C to 1350°C [24]. MAX6675 is used to convert the thermocouple reading into a digital signal. MAX6675 is 12-bits analog-to-digital converter (ADC) and has cold-junction compensation for sensing and correction, digital controller, and compatible SPI communications. Before entering ADC input, thermocouple signal is processed in signal conditioning with noise damper. Signal conditioning circuit converts the output of thermocouple into voltage [24-26]. Based on previous research, the thermocouple and MAX6675 works with an accuracy better than 2°C [26].

The PID controller algorithm was implemented on Arduino UNO in order to turn on and off the heater to keep the furnace temperature to a certain value. The Arduino UNO receives the values of three PID parameters (K_p , K_i , K_d) and the desired furnace temperature values from the potentiometers that connected on ports A3, A4 and A5. The values of these PID control parameters are displayed on the LCD screen to facilitate readability. When the process is running, the system will calculate the the gap between the desired temperature and the actual temperature of the furnace. The controller will produce the duty cycle value of the PWM signal (Pulse Width Modulation), it will be forwarded to the heater through 40A SSR (Solid State Relay) with working voltage on 280 to 480 VAC, while the input coil is 3 to 38 Volt DC. SSR is chosen as switching circuit because it can directly use CMOS voltage level even TTL voltage level is used to break a high current, so the circuit becomes simpler [27]. Control design in this study is simpler than previous studies that use Intelligent PID on Personal Computer devices with the Labview program [15].

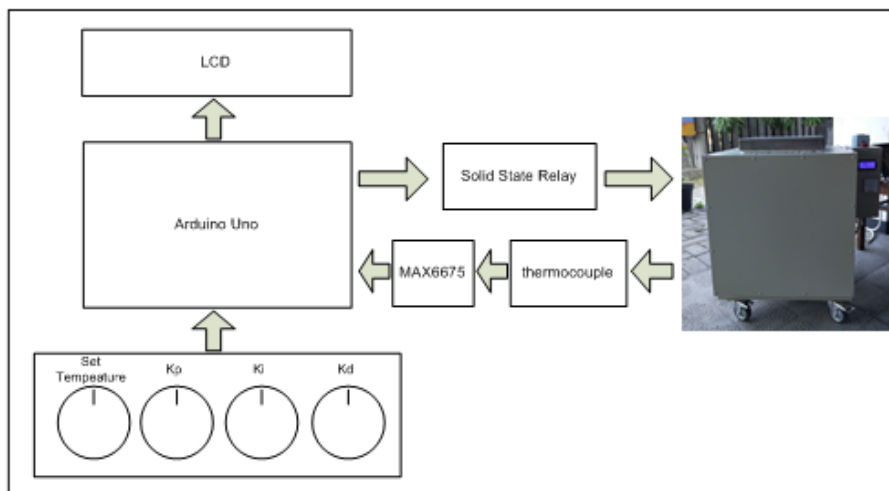


Figure 1. Hardware design

Inside the panel there is an amperemeter as a current consumption indicator that used by the system. For safety reasons in the panel there is also a circuit breaker to overcome short circuit and overcurrent problems. Figure 2 shows the used instrument images inside the panel in this study.

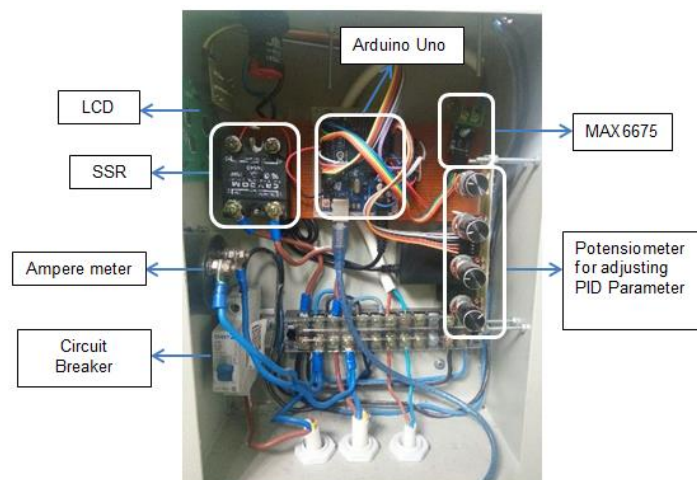


Figure 2. Realization of PID control design for biofuel furnace

2.3. Implementation Steps of PID Control System

In order to PID controllers able to produce a good system response, it is necessary to set the values of K_p , K_i , and K_d parameters. The value of the PID control parameter is determined manually by entering some variation of the combination of K_p , K_i , and K_d , this method is usually called the trial and error method. The controller response can be explained by how it responds to steady state error, overshoot size, rise time and settling time. Before test procedure, PID algorithm will be inserted in arduino, flowchart of PID control on Arduino is presented in Figure 3.

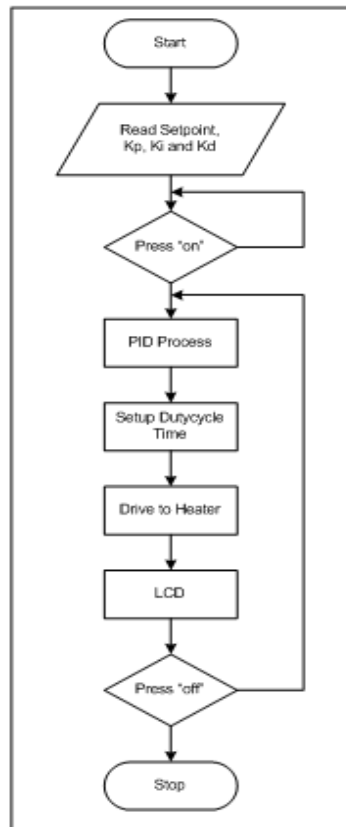


Figure 3. Flowchart of PID control system

The steps of the PID control program for the Bio fuel furnace as in the flowchart can be explained as follows:

- Turning on the furnace at 220V and with a load of 6000 watt.
- Press ON button.
- Read the desired set point value to control the temperature of the analog input port A2.
- Read the desired values of K_p , K_i , K_d parameters that will affect to the output value of temperature control, this reading is done through the analog input ports A3, A4 and A5.
- Read thermocouple sensor data on MAX6657.
- PID output will set the SSR on/off.
- The PID output will be deactivated by digital port D7.
- LCD as the display for Set point, K_p , K_i , K_d and thermocouple sensor readings.

3. Results and Analysis

To determine the performance of the system, the test is done by setting the temperature setpoint of 350°C, and gives some combination of different values of K_p , K_i and K_d control

parameters. In this study we were tested 10 different PID control parameters. Some test results are shown in Figures 4-6.

To speed up the testing process, preheating was done in the furnace room with the initial temperature of 200°C. After the furnace temperature reaches the initial temperature, the process of measuring and controlling the heater by using the PID control begins. Each test process was done with different parameters, furnace space is cooled first until it reaches the initial temperature, after controlling step can be reactivated. At the time of the test, heater signal that generated by the controller can also be monitored in real-time.

In Figure 4 the system is tested by assigning control parameters of $K_p=10$, $K_i=15$ and $K_d=1$. On the test results, it can be seen that the system response requires rise time of 142 seconds, and has an overshoot of 17.8% or 412°C. The system reaches the steady state at 577 seconds. From the graph, it is also explained that the time decreases the furnace temperature more slowly than the raising time, which is about 400 seconds. This is happen due to the system does not have a mechanism to reduce furnace temperatures (such as cooling fans [24]). The only way to reduce is turning off the heater until the temperature of the furnace room is below the set point. This system is also release the heat naturally through the furnace wall. Response also shows the system rising and falling around the set point value with the steady state error of 2.89%.

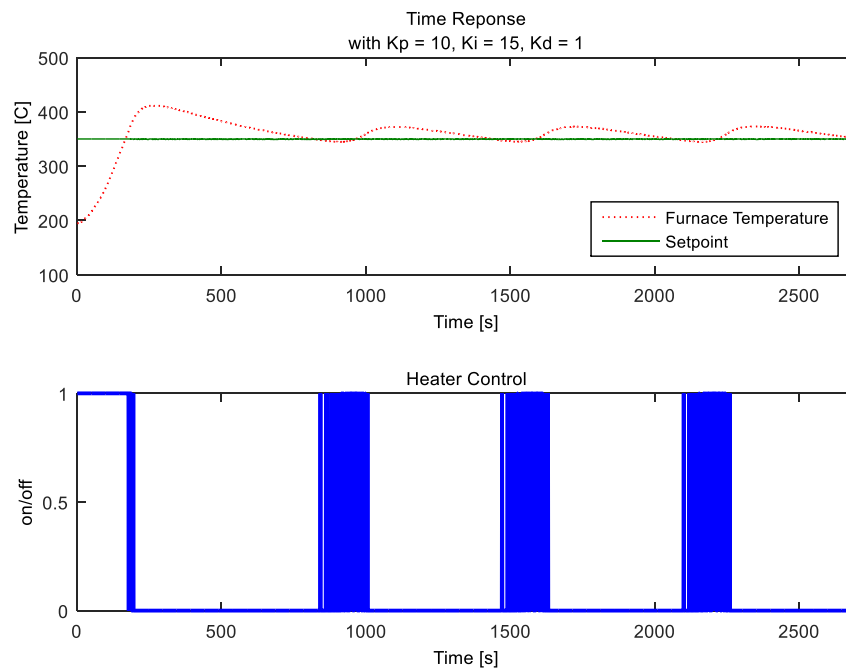


Figure 4. Temperature Change Response, with PID Parameter Value of $K_p=10$ $K_i=15$ $K_d=1$

The result with PID parameter value of $K_p=15$, $K_i=10$, $K_d=1$ that shown in Figure 5, where the system takes time to reach the steady state of 470 seconds, and the rise time is 136 seconds. The system has an overshoot of 16.9% or peak temperature is equal to 409 °C at 240 seconds. In the steady state the system has an error of 2.91%. In this configuration the system provides a better response than the previous parameter value.

Based on Figure 6, the result of system testing with PID control parameter of $K_p=15$, $K_i=15$, $K_d=1$ has a response not much different from the previous test. The system takes a rise time of 146 seconds, and the steady state time of the system is happened at 429 seconds. At steady state time, the system moves up and down around the set point value with the upper deviation of 32°C and the lower deviation of 7°C. The response indicates an overshoot of 16%, with a value of 406°C.

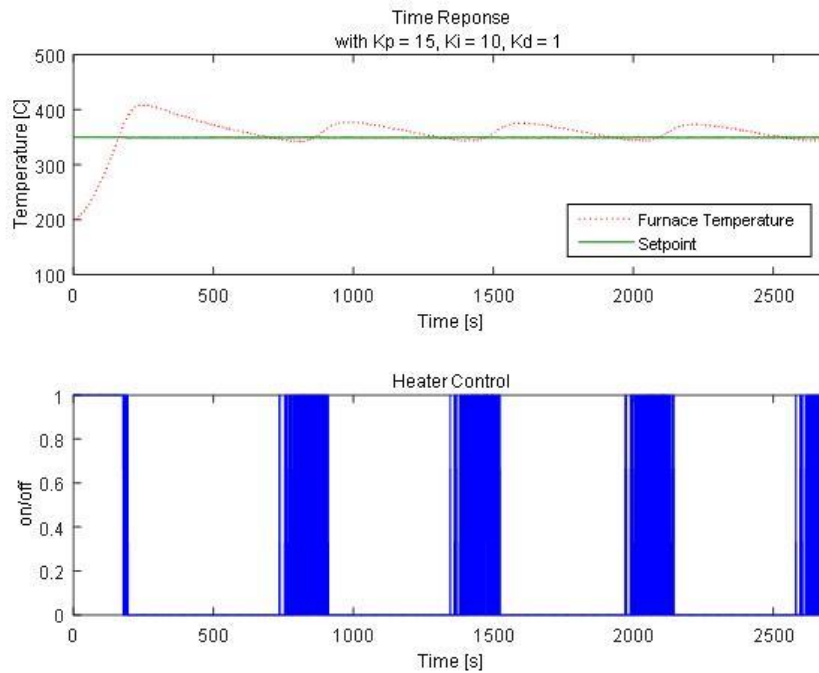


Figure 5. Temperature change response, with pid parameter value of $K_p=15$ $K_i=10$ $K_d=1$

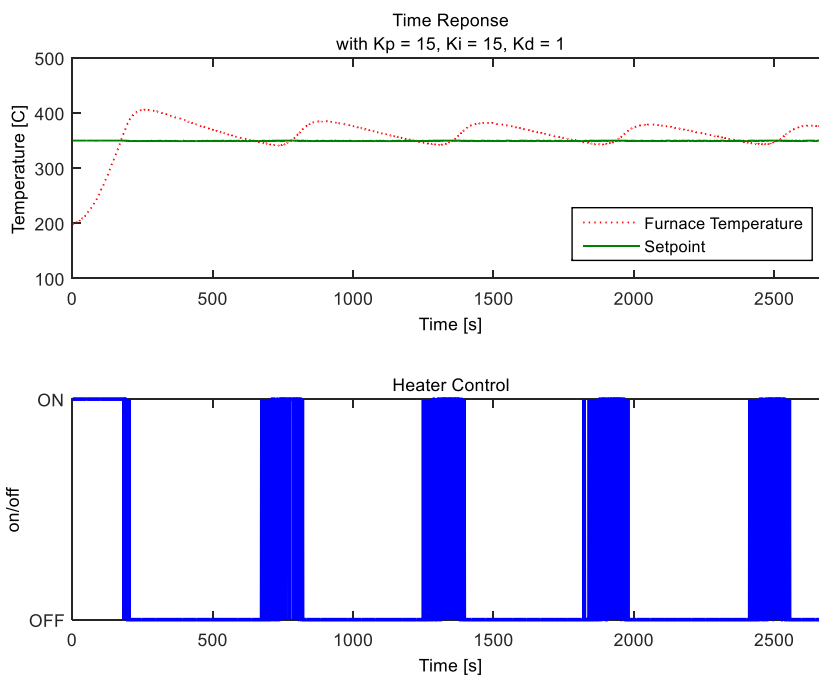


Figure 6. Temperature change response, with pid parameter value of $K_p=15$ $K_i=15$ $K_d=1$

The complete result of PID control testing on biofuel furnace using Arduino Uno is described in Table 1 below. When the PID parameter $K_p=1$, $K_i=1$, $K_d=1$, and $K_p=15$, $K_i=10$, $K_d=1$ the response system is unstable. The room temperature of the bio fuel furnace continues to rise and exceed 450°C , so this test should be stopped.

Table 1. Overall Result of PID Control Testing

Kp	Ki	Kd	Rise time (s)	Settling time (s)	Overshoot (%)	Error Steady State (%)
1	1	1	365		Unstable	
1	2	1	136	708	28	3.8
1	5	1	108	379	19.7	3.34
2	5	1	179	381	18.9	5.46
5	5	1	159	483	20.3	3.99
10	5	1	151	570	20.6	2.84
10	15	1	142	577	17.8	2.89
15	5	1	356		Unstable	
15	10	1	136	470	16.9	2.91
15	15	1	146	429	16	2.87

4. Conclusion

The designed control system by using Arduino is capable for controlling the furnace temperatures from 200-400°C and it is using a 6000 watt heater. The temperature of furnace space is generated by an electric heater, it controlled by a PWM signal that generated by PID algorithm inside Arduino Uno. To monitor the temperature of the furnace space can be seen on the LCD or software on the computer.

From the overall response, the obtained time from the test that has been done, almost the whole system oscillates around the set point. This can be happen due to the slow response of the system. The slow response in temperature is happened because the system is only depending on the natural effect to reduce the temperature. For the future works, we can add a cooling fan to reduce the temperature faster, so steady state errors can be reduced. The best system response is obtained when PID parameter setting $K_p=15$, $K_i=15$, $K_d=1$. With these parameter values, the system has the lowest overshoot response of 16% so it is safe for Bio fuel Furnace, even though the rise time value is 146 s, settling time of 429 and steady state error is equal to 2.87%.

References

- [1] Annex 1 of Presidential Regulation No.22. 2017.
- [2] Regulation of the Minister of Research, Technology and Higher Education of the Republic of Indonesia Number 13 of 2015 on Strategic Plan Year 2015-2019.
- [3] A Budianto, D H Prajitno, A Roesyadi, K Budhikarjono. HZSM-5 Catalyst For Cracking Palm Oil To Biodiesel: A Comparative Study With And Without PT And PD Impregnation. *Sci. Study Res. Chem. Chem. Eng. Biotechnol. Food Ind.*, 2014; 15(1): 081–090.
- [4] A Budianto, D H Prajitno, K Budhikarjono, A Roesyadi, R. Ediati. Biofuel Produced from Nyamplung Oil Using Catalytic Cracking Process with Zn-HZSM-5 Catalyst. *IPTEK J. Proc. Ser.*, 2015; 1(1).
- [5] J C Kurnia, S V Jangam, S Akhtar, A P Sasmito, A. S. Mujumdar. Advances in biofuel production from oil palm and palm oil processing wastes: A review. *Biofuel Res. J.*, 2016; 3(1): 332–346.
- [6] Wei Sun, Xin Li, Jialiang Ye. *Application of fuzzy predictive control in tubular heating furnace system.* in 2010 Chinese Control and Decision Conference. 2010: 2980–2984.
- [7] J Sun, Y Guo, R Gong. *Research on combustion control scheme optimization of steel rolling heating furnace e.* in CCTAE 2010 - 2010 International Conference on Computer and Communication Technologies in Agriculture Engineering. 2010; 3: 56–59.
- [8] M Laciak, P Fazekas, J Kacur. *Monitoring and control of temperatures in electric furnace in PROMOTIC system.* in 2011 12th International Carpathian Control Conference (ICCC). 2011: 239–242.
- [9] I A Yakimov, A. A. Radionov. *Investigation of direct-arc ultra-high power electric furnaces with controlled current by contactless regulator in intermediate circuit of furnace transformer.* in 2017 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus). 2017: 1075–1080.
- [10] R Ristiana. *Modeling and Control of Temperature Dynamics In Induction Furnace System.* in 2015 IEEE 5th International Conference on System Engineering and Technology. 2015: 6–11.
- [11] H Carlborg, H. Iredahl. Modeling and temperature control of an industrial furnace. *Linköping University.* 2016.
- [12] V Mureşan *et al.* *Temperature modeling and control in a tunnel heat-treatment furnace.* in 2016 20th International Conference on System Theory, Control and Computing, ICSTCC 2016 - Joint Conference of SINTES 20, SACCS 16, SIMSIS 20 - Proceedings. 2016: 245–250.

- [13] Y V P Kumar, A Rajesh, S Yugandhar, V Srikanth. Cascaded PID Controller Design for Heating Furnace Temperature Control. *IOSR J. Electron. Commun. n Eng.* 2013; 5(3): 76–83.
- [14] S J Porphy, M. M. Farid. Feasibility Study for Production of Biofuel and Chemicals from Marine Microalgae *Nannochloropsis* sp. Based on Basic Mass and Energy Analysis. *ISRN Renew. Energy.* 2012; 2012: 1–11.
- [15] W A Wali, J D Cullen, S Bennett, A I Al-Shamma'a. Intelligent PID Controller for Real Time Automation of Microwave Biodiesel Reactor. *Int. J. Comput. Inf. Technol.* 2013; 2(4): 809–814.
- [16] A B D Nandiyanto, R Zaen, R Oktiani, A G Abdullah, L S Riza. A simple, rapid analysis, portable, low-cost, and Arduino-based spectrophotometer with white LED as a light source for analyzing solution concentration. *TELKOMNIKA Telecommunication Computing Electronics and Control.* 2018; 16(2): 580.
- [17] M Martin, K Štefan, F. Ľubor. Biometrics Authentication of Fingerprint with Using Fingerprint Reader and Microcontroller Arduino. *TELKOMNIKA Telecommunication Computing Electronics and Control.* 2018; 16(2): 755.
- [18] A Z Jidin, N Mohd Yusof, T Sutikno. Arduino Based Paperless Queue Management System. *TELKOMNIKA Telecommunication Computing. Electronics.and Control.* 2016; 14(3): 839.
- [19] A Jusoh, R Alik, T K Guan, Tole Sutikno. MPPT for PV System Based on Variable Step Size P&O Algorithm. *TELKOMNIKA Telecommunication Computing Electronics and Control.* 2017; 15(1): 79–92.
- [20] I A Taha, H M Marhoon. Implementation of Controlled Robot for Fire Detection and Extinguish to Closed Areas Based on Arduino. *TELKOMNIKA Telecommunication Computing Electronics and Control.* 2018; 16(2): 654.
- [21] R Abdullah, Z I Rizman, N N S N Dzulkefli, S Ismail, R Shafie, M H Jusoh. Design An Automatic Temperature Control System For Smart Tudung Saji Using Arduino Microcontroller. *ARPN J. Eng. Appl. Sci.* 2016; 16(11): 9578–9581.
- [22] Z-A S A Rahman, F S A Hussain. Smart Incubator Based on PID Controller. *Int. Res. J. Eng. Technol.* 2017; 4(3): 2501–2509.
- [23] A. Bayram, S. A. Moammed, and F. Kara, "Design of Heating System Controlled by Arduino," in *4th International Symposium on Innovative Technologies in Engineering and Science*, 2016.
- [24] S Iqbal, G M Mufti, M B Khan, S H. Ansari, S. Naveed. *Advance instrumentation and control of FTS-GTL facility by means of PLC-SCADA system.* in 2014 International Conference on Energy Systems and Policies (ICESP). 2014: 1–6.
- [25] H M Asraf, K A N Dalila, A W M Hakim, R H M F. Hon. Development of Experimental Simulator via Arduino-based PID Temperature Control System using LabVIEW. *J. Telecommun. Electron. Comput. Eng.* 2017; 9(1–5): 53–57.
- [26] H Aripin *et al.* *Automated Temperature Control with Adjusting Outlet Valve of Fuel in the Process of Cooking Palm Sugar.* IOP Conf. Ser. Mater. Sci. Eng. 2018; 336: 012018.
- [27] A St. Leger, . Smith, J Spruce, P Curtiss, G Gibbons, M. Miller. *Load management system for tactical microgrids using solid state relays.* in 2017 North American Power Symposium (NAPS). 2017: 1–6.