Automatic Coffee Grinding and Brewing Process with NUC140 Microcontroller

Febriyandika Tarang Boro, Indra Riyanto
Program Studi Teknik Elektro, Fakultas Teknik
Universitas Budi Luhur
Jakarta, Indonesia
febriyandika78@gmail.com

Krisna Adiyarta
Program Studi Magister Ilmu Komputer
Program Pascasarjana
Universitas Budi Luhur
Jakarta, Indonesia

Abstract—One of the parameters that determine the quality of the coffee beverage is by grinding the coffee beans correctly. In addition to proper grinding process, water temperature settings also become an important part. Grinding and brewing process must be done in a short time so that the taste of the coffee bean is not lost and the quality is maintained. A control system based on PID (Proportional Integral Derivative) is used to maintain proper water temperature. The components used is LM35 temperature sensor, Solenoid Valve, AC dimmer, and DC Motor that is connected to a Nuvoton NUC140 module that serves as the main controller of the system. Temperature control is done by adjusting the voltage of the AC dimmer circuit to heat the element with the PWM changes removed from the microcontroller. The PID parameter is determined using the Ziegler-Nichols method. The test results with Kp = 13, Ki = 116, and Kd = 29 systems have a response with a constant time of 613 seconds and the air temperature can be stable at 90 ° C with a steady state error of 1.1%. Overall, the system can process 8 grams of coffee beans for 5 minutes started from grinding the coffee beans to brewing.

Keywords—coffee grinding; Drip V60; coffee brewing; PID controller; temperature control; microcontroller; NUC140

I. INTRODUCTION

The process of grinding and brewing coffee manually is very inconvenient everyone who wants to enjoy quality coffee. Manually made process also makes the quality of coffee produced can not be consistent, but when compared with the process of grinding and brewing coffee can automatically produce an efficient process and consistent coffee quality. The growth of trend in the society, a coffee machine that can function optimally, from the start of the grinding to brewing process is done automatically is viable. The machine is equipped with a water temperature control system based on PID in order to produce beverage directly after grinding the beans. This is an improvement on most coffee makers that usually receives only ground coffee [1]. During the grinding process, ground materials usually undergo fragmentation processes: abrasion, cleavage, and fracture [2]. For coffee beans, the fragmentation process is mostly cleavage and fracture. Tsamatsoulis developed a PI model between process and control variables and the derived dynamic parameters are used to characterize PID controller [3]. Zhuang and Atherton reviewed about minimizing time weighted integral to obtain optimum settings for PID controller performance [4]. A temperature control using SCR control system is investigated by Suguna [5] for maintaining optimum temperature and minimizes heat loss and lowers power consumption. A complex multivariable grinding control system is developed by Mahdavi and Rasti using Disturbance Observer Mechanism and PI controller for ore grinding [6].

II. SYSTEM DESIGN

The main controller used in this machine is NUC140 microcontroller. The UC1XX series is ARM Cortex-microcontroller with M0 core inside which is suitable for industrial control and application that require special communication function. ARM Cortex M0 is the latest ARM processor with 32-bit performance at a cost equivalent to an 8- bit microcontroller. NuMicro NUC100 Series has an embedded ARM Cortex M0 core with speeds up to 50 MHz, comes with flash memory for 32K / 64K / 128Kbyte program. SRAM of 4K / 8K / 16K-byte and flash memory loader for ISP (In System Programming) of 4K-byte. It also comes with various peripherals, such as GPIO, Timer, Watchdog Timer, RTC, PDMA, UART, SPI / MICROWIRE, I2C, I2S, PWM, LIN, CAN, PS2, USB 2.0 FS Device, 12-bit ADC, Comparator analog, Low Voltage Reset and Brown-out Detector. Fig. 1 shows the block diagram of NuMicro NUC130 / 140 Series [7].

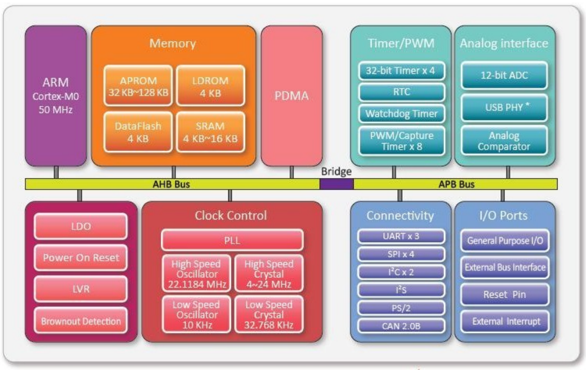

Fig. 1. NUC140 diagram.

The NUC140 is used by Maulana et al. [8] for robotic movement positioning control, in which, three position controllers are used. The basic control principle is adapted to the coffee machine which uses two solenoid valves to regulate the water and ground coffee powder. These valves are each actuated by DC motor that is controlled by the NUC140. The machine uses two solenoid valves to regulate the water and ground coffee powder.

PID controller is a control system that is composed of proportional (P), integral (I) and derivative (D) controllers. The control system has been widely implemented in industrial processes because it is simple, easy to learn, and easy in determining the value of its parameters. The combination between the proportional, integral, and derivative controls on PID control system has a specific purpose. Proportional control excels in fast rise time; Integral control eliminates errors, and Derivatives which can reduce overshoot. When all three combined the resulting control is error-eliminating nature with reduced the rise time, quick settling time, and minimal overshoot. However, in reality the resulting control will not always be perfect as the theory.

The mathematical equation each - each is as follows:

Kp (Proportional Constant) in time domain:

$$U(t) = Kp.(t) \tag{1}$$

in space domain:

$$(s)/(s) = Kp \tag{2}$$

Ki (Integral Constant) in time domain:

$$(t) = Ki\int et\ dt \tag{3}$$

In space domain:

$$(s)(s) = Ki/s \tag{4}$$

Kd (Derivative Constant) in time domain:

$$u(t) = kd.(t)/dt \tag{5}$$

In space domain:

$$(s)/(s) = Kd.s \tag{6}$$

response curve in the s domain can be represented in the equation:

$$(S) / U(S) = \hat{}\ ke\ \text{-}Is / Ts + 1 \tag{7}$$

While the PID controllers transfer function is applied:

$$U(S) / E(S) = 0.6T (s + 1 / L) \hat{}\ 2 / s \tag{8}$$

Determination of Kp, Ki, and Kd values on the PID parameters to be used in the system is by Ziegler-Nochols method. It is one of the solutions to solve problems based on the response characteristics of the plant produced. The value of Kp, Ki, and Kd can be determined without knowing the system equations [9]. By using this method overshoot that occurs a maximum of 25%. Determining the value of lag time L and rise time T is through step response unit that is formed with the help of tangent line at inflection point as shown in Fig. 2.

Determination of PID parameters using Ziegler Nichols method [9] is done by drawing a tangential line on the reaction curve. To get the reaction curve, the experiment is done on the system by determining the initial temperature and reference temperature. In this system the initial temperature selected is 29^{o}C and the reference temperature of 90^{o}C. The following Table I is the experimental data on the heating system.

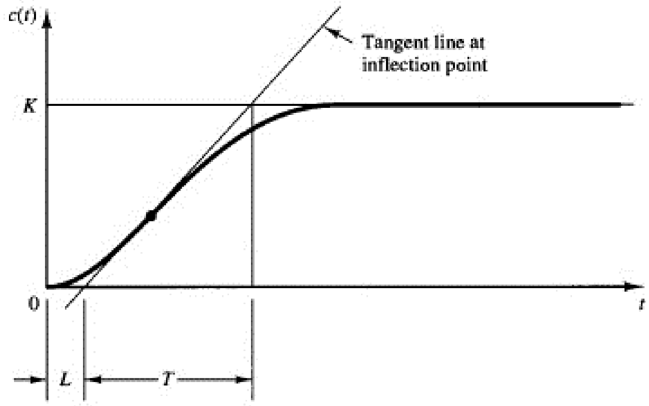

Fig. 2. Ziegler-Nichols graph.

TABLE I. HEATING TIME

Time (s)	Temperature (°C)
0	29
60	34
110	36
160	38
210	49
260	52
310	57
360	61
410	65
460	69
560	76
610	80
660	83
710	85
760	88
910	90

From the results of the test data in Table I, the delay time (L) and time constant (T) values that will be used for tuning the PID parameters by the Ziegler-Nichols method can be determined. The delay time (L) value is obtained from the length of time delay when the system starts running until it shows the initial reaction of temperature rise.

From Fig. 2, while the value of time constant (T) is the midpoint between the initial times of the active system until it reaches the reference temperature. Based on the results of the tangent on the characteristics of the system then obtained the delay time (L) of 58s and time constant (T) of 627s and from Table II, it yields Kp = 13; Ki = 116; and Kd = 29.

TABLE II. ZIEGLER-NICHOLS PID PARAMETER CALCULATION

Kp	Ki	Kd
1.2(T/L)	2L	0.5L
= 1.2(627/58)	= 2(58)	= 0.5(58)
= 12.97	= 116	= 29

III. TESTING AND RESULT

Temperature sensor test provides thermal difference by turning the heating elements by controlling the AC dimmer. Then measure the output voltage at the output of the temperature sensor circuit. The equipment used in the testing is to use a digital multimeter measuring instrument and sensor temperature thermometer comparison. Tests conducted with temperatures between 25 ° C to around 100 ° C and the results are shown in Table III.

TABLE III. RESULTS OF TESTING THE TEMPERATURE SENSOR CIRCUIT

Temperature (°C)		LM35 Output (Volt)
Thermometer	***LM35 Sensor***	
25.9	25.9	0.25
30.1	30.2	0.29
35.7	35.7	0.35
40.5	40.5	0.40
45.2	45.1	0.45
50.7	50.6	0.50
55.4	55.4	0.55
60.3	60.3	0.60
65.2	65.1	0.65
70.6	70.6	0.70
75.3	75.3	0.75
80.2	80.2	0.80
85.5	85.5	0.85
90.1	90.0	0.90
95.2	95.3	0.95
100.3	100.4	1.00

Testing of coffee brewing is done in 3 stages, namely roasting the coffee beans, grinding coffee beans into powder, and brewing the coffee powder. PID parameter testing process is done gradually, this is done based on standardization of brewing technique with Pour over Drip V60 method. V60 is a special filter paper for filtering coffee powder having a slope angle of 60^0.

The first process is roasting the coffee beans from temperature room to 135°C. From Table IV, the microcontroller increases the PWM value for the dimmer in 10-step increments. The dimmer needs 210 seconds to reach roasting temperature and if the temperature exceeds reference value, the microcontroller turns the dimmer off. The beans are roasted for 8 minutes. After roasted, the beans are then ground into coffee powder.

The next step is to pour 30 ml of water on a coffee powder and stand for at least 30 seconds as a blooming process of coffee powder. This stage aims to remove the carbon dioxide content in the coffee powder during the roasting and grinding process, followed by pouring water into the same filter as much as 120ml-240ml according to the desired size and then settled until all the water in the filter flows into the serving glass and only leaving coffee grounds in the filter.

In the brewing process is done by using a DC motor pump controlled by NUC140. The purpose of this test is to know the flow of water that can be produced for every second. With each experiment for 7 seconds, there was a change in the volume of water per second by 36.33 ml in the first experiment, 36.33 ml in the second experiment and 36.67 ml in the third experiment. On average of the three trials got the change of water discharge every second equal to 36.55 ml/s. The water flow information obtained can be used in the NUC140 program to determine the duration of the DC pump work to obtain the appropriate volume of water in the coffee brewing process.

TABLE IV. DIMMER INCREASE

PWM	AC Voltage (V)	Temperature (°C)
40	40	30.80
50	45	35.13
60	50	40.88
70	57	45.20
80	65	50.34
90	75	55.40
100	90	60.78
110	95	65.20
120	100	70.48
130	115	75.21
140	120	80.20
150	125	85.93
160	130	90.38
170	140	95.55
180	150	100.14
190	160	105.87
200	170	110.40
210	175	115.32
220	180	120.94
230	185	125.50
240	190	130.30
250	210	135.10

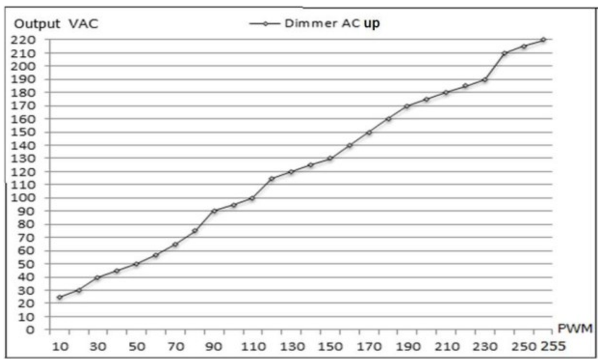

Fig. 3. Dimmer Up Graph characteristics.

TABLE V. COFFEE MAKING DURATION

Coffee (g)	Roasting (s)	Grinding (s)	Blooming (s)	Brewing (s)	Total time (s)
8	250	240	31	51	572
8	240	240	31	51	562
12	360	240	36	56	692
12	350	240	37	57	684

From the Table V it can be seen that in each experiment performed with the initial temperature of the water at 25°C and the temperature reference of 90°C, brewing time increases as roasting time is shorter. From the start of roasting to complete the brewing takes time around 600 seconds or 10 minutes.

IV. CONCLUSION

Based on the results of the testing and analysis of all parts of the grinder and automatic coffee brewing can be concluded that the NUC140 microcontroller can perform its intended function to control the coffee making process. The PID parameters obtained by the Ziegler-Nichols method are Kp = 13, Ki = 116, and Kd = 29 has succeeded in producing a system with a very small overshoot of 1%.

REFERENCES

[1] Spinel s.r.l, “Improvement of espresso coffee dispensing machines using single-dose ground coffee,” Patents Office Journal, 2166905, Government of Ireland, 2017.

[2] V. Monov, B. Sokolov, and S. Stoenchev, "Grinding in Ball Mills: Modeling and Process Control," Bulgarian Academy of Sciences Cybernetics and Information Technologies, vol. 12, no. 2, pp. 51-68, 2012.

[3] D.C. Tsamatsoulis, “Optimizing the Control System of Cement Milling: Process Modeling and Controller Tuning Based on Loop Shaping Procedures and Process Simulations,” Brazilian Journal of Chemical Engineering, vol. 31, no. 01, pp. 155-170, January 2014.

[4] M. Zhuang and D.P. Atherton, “Automatic tuning of optimum PID controllers,” IEE Proceedings D – Control Theory and Applications, vol. 140, issue 3, pp. 216-224, May 1993.

[5] R. Suguna, V. Usha, and S. Chidambaram, “A Temperature Control by Using PID Based Scr Control System,” Journal of Electronics and Communication Engineering, vol. 9, issue 2, pp. 51-55, March 2014.

[6] M. Mahdavi and J. Rasti, “Improving the Multivariable Control of the Ore Grinding System using Disturbance Observer Mechanism and the PI Controller,” Bull. Env. Pharmacol. Life Sci., vol. 4, issue 1, pp. 225-236, 2015.

[7] Nuvoton, NuMicro NUC140 Data Sheet, 3rd ed., vol. 2. Nuvoton Technology Corporation, 2012.

[8] A. Maulana et al., “PID Controller-based Object Tracking and Speed Control System for Wheeled Soccer Robot,” Indonesian Symposium on Robotic Systems and Control, July 2017.

[9] J.G. Ziegler and N.B. Nichols, “Optimum settings for automatic controllers,” Trans. Of the A.S.M.E., vol. 64, 1942, pp. 759-768.