Based Fuzzy Logic Temperature Control for a Coffee Roaster Machine

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Abstract. The aim of this research is to control the temperature of roasting process to be stable. The temperature controller is needed in process of coffee roasting because of high and low temperature is very influential on the process. This paper presents the development of the coffee roaster machine where the temperature is controlled using fuzzy logic control algorithm. The temperature is sensed using PT100. The fuzzy control algorithm computes the controller output based on error and the rate of error. The fuzzy control algorithm is implemented using MATLAB. A PLC Omron is used and interfaced with PC Desktop, so that a real-time control can be conducted. A HMI is used so that a roaster machine operator can easily operates the machine. A complete PLC system and mechanical design are discussed in this paper. Experiments were conducted to verify the performance of the controller. From the experiment results, the desired temperature can be controlled with relatively small error, 0.52%. It can cause the temperature of the process relatively stable.

1. Introduction
Roasting process is a heat transfer process without media such as oil or sand in order to get a specific taste. The process of coffee roasting is time consuming and temperature sensitive process. One of the factors influencing chemical reactions in coffee bean is temperature [1, 2]. Roasting precise timing and temperature are required to produce the desired taste, flavor, and acidity of the roasted coffee beans. A temperature controller is needed to regulate the temperature of process to be stable.

There are many modes of temperature controller like ON/OFF, proportional derivative (PD) and proportional integral derivative (PID) [3]. In recent years, Fuzzy control have become popular and have been vastly used in different fields of engineering.

Fuzzy logic method is an appropriate way to map an input space into an output space. Fuzzy logic method is one method that can be used in the production process such as temperature control systems on the coffee roaster. In the process of controlling the temperature, fuzzy logic method has a flexible reading range of the temperature response to changes that occur because of the truth in the fuzzy logic is the degree of truth whose value between 0 and 1 so that the fuzzy logic have tolerance for data that is not appropriate [4, 5].

Fuzzy logic method has many advantages than conventional method. It has better performance in terms of overshoot and settling time and increases of robustness of the system [6].

This research is designed by using Programmable Logic Controller (PLC) and Human Machine Interaction (HMI). PLC is industrial computer which consists central processor unit, input output
interface, memory, and programming device [7-10]. HMI is used to control and monitor which helps to assure the balanced of control system [8].

In this paper, temperature control system of roasting process is designed using fuzzy logic method, with a PLC and HMI which are used to interface with PC Desktop and help operator to operate the machine. The temperature will be set to 70°C.

2. Method

2.1. Fuzzy logic controller

System development method is based on the results of the data obtained. The process is among others that determine fuzzy association, fuzzification, rule base, and defuzzification.

Fuzzification is a process for converting non fuzzy variable (numeric variables) into variable fuzzy (linguistic variable). In other words Fuzzification is a mapping point numeric (crisp point) into fuzzy number.

Fuzzy rule contains the rules linguistically representing the expertise of the plant. Fuzzy rule are many ways shows an expertise in a code, the most common format are as follows:

- Rule format IF-THEN.
  **IF** Premise **THEN** Conclusion
  The premise of facts and decisions will be taken. If the statement is more than one then can use a logical "AND" or "OR".

- Relation Format
  Basically the same as IF-THEN rules just zoom simpler for using lines that are interconnected.

- Tabular Format
  Tabular Format simpler than the format of relations, linguistic variables are on the outer side of the table while the inside describe on the decision.

Defuzzification process is a reasoning process membership degree output is converted back into a numerical value.

Two methods which commonly used defuzzification are:
- Maximum of Mean (MOM), this method is defined as:

\[
  v_o = \sum_{j=1}^{J} \frac{v_j}{J}
\]

where:
- \(v_o\) = output value.
- \(J\) = max value.
- \(v_j\) = max output value to-j.
Center of Area (COA), this method is defined as:

$$v_o = \frac{\sum_{k=1}^{m} v_k \mu_k(y_k)}{\sum_{k=1}^{m} \mu_k(y_k)}$$

- $v_o$ = output value.
- $m$ = quantization level.
- $v_k$ = element to- $k$.
- $\mu_k(.) = $ element degree member of fuzzy set $k$.

2.2. Hardware design

A coffee roaster machine were designed on the mini plant-based PLC, where the PLC was used as a plant control of temperature so that it will work automatically and can be monitored through HMI. We can set up some design of the plant into an HMI system, where subject have the role of temperature monitoring and controlling. Figure 2 shows diagram block of PLC Based Fuzzy Logic Temperature Control for a Coffee Roaster Machine.

**Figure 2.** Block diagram system design.

Resistance Temperature Detector (RTD), it is known as the detector temperature where it is a tool used to determine the value or magnitude of a temperature or temperature by using sensitive elements from platinum wire, cooper, or pure nickel. PT100 RTD is the most popular type used in the industry. PT100 RTD types used in a temperature range of -50°C up to 230°C. PT100 has some advantages is for instances: high accuracy, high temperature resistance.

Output of fuzzy is regulated by servo motor. It is a motor used for position or speed control in closed loop control systems [9].

2.3. Software design

The process of software design is divided into two processes, namely the design of the controller software and system monitoring software. Software for the controllers are designed with the aim that
the roaster machine can move as planned. The controller software in the form of ladder diagram and algorithm design fuzzy logic. The monitoring software that is designed HMI automation embodiment of the system, figure 3.

![Figure 3. HMI display design.](image)

The design of the software on the machine using the coffee roaster NB-Designer software as a monitor of the process flow of coffee roaster machines.

Design of fuzzy algorithms using MATLAB. The algorithm was created in MATLAB will be brought into the basic language or code that can be read by a PLC controller.

2.3.1. fuzzification. Fuzzification is a process undertaken to transform a real variable fuzzy input to fuzzy controller (that) can be mapped to the appropriate type with fuzzy sets. Fuzzification process consists of the determination of fuzzy membership functions for input and output variables. Fuzzy membership functions used triangular shape. In this system, fuzzy has two inputs and one output. Its inputs are defined by error and delta error. In figure 4 is shown the block diagram of fuzzy logic system presented in MATLAB as fuzzy editor.

![Figure 4. Fuzzy editor.](image)
Variable input error is composed of three triangular-shaped membership functions. Error membership functions of the temperature were obtained from the sensor readings with a temperature range 0°C to 140°C used for coffee roaster. Variable error input value is negative if the temperature value is greater than the desired set point value. Error membership function in Figure 5 consists of low, medium and high.

![Figure 5. Membership error coffee roaster.](image)

For the error rate input variable (dE) has two membership functions are positives and negatives with the range of -5 to 5 as shown in Figure 6.

![Figure 6. Membership delta error.](image)
Fuzzy output variables in the form of degrees in servo motor which has three membership functions that can control the valve on the gas, the output variable membership functions, namely Low, Medium, High in the range of 0° servo motor is up to 180°. The output membership function triangular shaped as in Figure 7.

![Output membership function](image)

Figure 7. Output membership function.

2.3.2. Determination rule base. Fuzzy Rule Base contains statements fuzzy logic, Fuzzy Rule Base shaped IF-Then statement stating revelation condition. Fuzzy Rule Base/ preparation of this very influential in decision-making stage performed by the plant. Based on the basis of fuzzy rules on the design process of this title fuzzy rules created using heuteristik method, the method is based on the knowledge of the behavior of the system. Rule fuzzy formed using tabular format as shown in Table 1.

| $e$ \ $\Delta e$ | Low | Medium | High |
|------------------|-----|--------|------|
| NEGATIVE         | Medium | Low | Low |
| POSITIVE         | High | Low | Low |

Table 1. Fuzzy rule table.

The overall rule that has been formed can be shown on the rule viewer as seen in Figure 8 for the rule viewer coffee roaster.
3. Results and discussion

3.1. PT100 temperature sensor test
Testing the temperature sensor PT 100 is performed to determine whether the performance of the sensor is in conformity with the desired or not. The temperature sensor PT 100 is used to determine the temperature in the engine of coffee roaster machine, with a temperature set point that has been incorporated into the program. Roasted and a coffee roaster set point used is 70°C. The tests performed on the PT 100 is by comparing the temperature readings using a thermometer and measure the output voltage generated by the temperature sensor PT 100 with and without gain, the result presented in Figure 9.

3.2. System controller test
Results of testing the fuzzy logic control is loaded with the load and un-load can be seen in Figure 10 below.
Based on the curve, we found delay time is 3.35 minutes, rise time is 6.7 minutes, peak time is 18.5 minutes at a temperature of 71.3°C. They found that the maximum value is relatively small overshoot i.e. 1.85% of the results using fuzzy logic controller does not experience an error that is too large so that the temperature can be maintained. Error Steady State gained is 0.52% of the results using fuzzy logic controller does not experience an error that is too large so that the temperature can be properly maintained.

Servo response for the fuzzy logic implementation of roasted coffee beans found to curve round at the beginning of opening 180° servo which then reaches the temperature set point rotation servo begins to fall, then will open up again if the temperature decreases, and always will maintain the stability of the temperature according to the set points.

4. Conclusions
PLC Based Fuzzy Logic Temperature Control for a Coffee Roaster Machine is successfully demonstrated in this paper. The temperature sensor PT100 can be used good with the gain of 50x because it is in accordance with the ability of the PLC. PLC Based Fuzzy Logic Temperature Control for the roasting process have results error 0.52%.

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