Maintaining the Quality and Aroma of Coffee with Fuzzy Logic Coffee Roasting Machine

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Abstract. With the increasing global demands of coffee, Indonesia need to increase their coffee beans supply and improve the quality to maintain its position in the international coffee industry. One of the most important coffee pre-processing, coffee bean roasting, is underdeveloped in Indonesia. Indonesia coffee farmers prefer to use the traditional cauldron to roast their coffee beans. Roasting coffee beans using traditional cauldron is inefficient and resulting unequal roasted level for the coffee beans. In this study, we proposed atemperature control system based on fuzzy logic for coffee roaster machine. The system controls the temperature in accordance with the demanded roasting level. A thermal camera is attached inside the roasting chamber to monitor the heat on the roasted coffee beans. The thermal camera is integrated with a stirring mechanism to equalise the heat among the beans.

1. Introduction

Based on the data from the International Coffee Organisation (ICO), global coffee consumption and production has gradually increased over the years [1]. As the world’s demand in the coffee industry increased and the consumers became more selective in coffee quality, Indonesia has to increase their coffee beans supply and improve the quality as well. Aside from the coffee cultivation and plantation aspects, coffee beans processing is important to be considered in producing a high-quality product. Since coffee beans processing has a huge role in determining the quality of the coffee beans [2].

Roasting coffee beans is one of several coffee beans processing. It is also a key process to create a desirable coffee beans roasting level, where each level has its characteristic. The roasting process begins with steam cooking which causes the coffee beans to have unique scent and flavour. This unique scent and flavour depend on the temperature and the length of the process [3]. Coffee beans characters including species, types, origins, length of time between harvesting and roasting, size of the beans, age of the plants, and water content of the beans are also determining the result of roasting process. However, high quality coffee beans with mishandling of this process could produce poor roasted coffee beans [2, 4].
Unfortunately, in Indonesia, the coffee plantation is dominated by small farmers who cannot afford modern roaster machines. The available roaster machines provide poor results such as non-uniform roasted levels. Another method used by the farmers to roast their coffee beans is using a cauldron. The coffee beans are heated in a cauldron using a standard stove as a heater. When the coffee beans are roasted, the farmers have to stir the coffee beans manually to ensure the heat on the coffee beans are uniform. It is difficult to maintain heat on the cauldron which may cause an undesired roasting level of the coffee beans. Despite the difficulties, the farmers prefer to use the cauldron to roast their coffee beans since it is more convenient.

In this study, we proposed a fuzzy logic-temperature control system for coffee beans roasting machine. The sensor is expected to improve the quality of the roasted coffee beans by helping the farmers to get the desired uniform roasting level. By using the sensors, the coffee roaster can also be considered as an Internet of Things (IoT), which is being massively deployed in developing countries [5].

2. Literature Review
To make sure the roasting process runs smoothly, four important keys need to be considered; roasting temperatures, duration, roasting types and stirring. According to Pinebrook team, there are four roasting levels depending on the roasting temperature, light roast (180 °C to 205 °C), medium roast (210 °C to 220 °C), medium-dark roast (225 °C to 235 °C) and dark roast (240 °C to 250 °C) [6]. Besides determining the scent and the flavour of the coffee, the roasting level affects the colour of the roasted coffee beans. It will change from green or light brown to cinnamon-brown with an oily surface. When the coffee beans are roasted, the water in the beans is evaporated and the material in the coffee beans are decomposed because of the heat [7]. This phenomenon is called pyrolysis. During pyrolysis, carbohydrates in the beans are caramelized or decomposed, especially sucrose and cellulose [8, 9]. Volatile compound and carbon dioxide are also formed during this process [10]. The proteins content is denatured, and the crude fibre is reduced as well in this process [11]. Coffee beans reach peak ripeness in roasting when the colour of the beans become cinnamon brown depending on its level [10]. When the coffee beans become blackish, it will break easily, and the process must be stopped immediately.

There are two types of the roasting process, namely open and closed. Closed roasting process causes the roasted coffee beans to have a higher acidic level due to water retention and various types of volatile acids [12]. The closed roasting process also makes the roasted coffee beans to have sharper scent since the compound that carries the distinctive scent of coffee do not evaporate much. Furthermore, the coffee will less prone to outside odours such as fuel and combustion residue.

In addition to the temperature and types factors, stirring during the roasting process is also very important with the aim of homogenizing the temperature of the beans [13-15]. After the roasting is complete, the stirring still needs to be done to prevent the occurrence of continuous heating which can cause the coffee beans become hollowed.

3. Method
In this study, we developed a temperature control system based on fuzzy logic [16] for a coffee roasting machine. The system controls the temperature in accordance with the demanded roasting level. The roasting levels and its temperature are listed below:

- light roasted ranged from 193 °C to 199 °C
- medium roasted ranged from 200 °C to 212 °C
- dark roasted ranged from 213 °C to 220 °C

After the roasting process, the roasted coffee beans have its unique scent, colour and flavour based on its roasting level.

Besides the temperature control system, the prototype we developed is also equipped with a thermal camera. The camera is mounted inside the roasting chamber to monitor the coffee beans temperature uniformity. Inside the chamber, there is a stirring mechanism with Pulse Width
Modulation (PWM) motor to stir the coffee beans. The output from the thermal camera controls the motor to equalize the heat among the coffee beans. The prototype we developed follows the diagram in Figure 1. While the fuzzy logic on the control system is illustrated in Figure 2.

4. Result and Discussion

Figure 3 shows the physical form of our roasting machine prototype. The roasting chamber is the blue cylindrical compartment. On top of it is an opening to put the coffee beans. On the side, there is a 5 kg Liquefied Petroleum Gas (LPG) gas can and the PWM motor with a fuzzy logic microcontroller on the top of it. All the parts are securely placed in the orange metal frame.
The electronic circuit of the fuzzy logic system is shown in Figure 4. The fuzzy logic is embedded in the main controller, ATMega 32 microcontroller. This fuzzy logic determines the speed of the PWM motor and the fuel valve, resulting roasted coffee beans with uniform desired roasting level. The specification of this prototype is listed in Table 1.
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Table 1. Technical specifications of the prototype.

| Part                     | Specification                        |
|--------------------------|--------------------------------------|
| Roasting Chamber         |                                      |
| Roasting Chamber Material| MS plate                             |
| Inlet Material           | Stainless steel                      |
| Roasting Chamber Dimension| D = 500 mm; L = 940 mm               |
| Total Weight             | 75 kg                                |
| Capacity                 | 30 kg per batch                      |
| Fuel                     | LPG or kerosene                      |
| Controller               |                                      |
| Microcontroller          | Atmel ATmega 32                      |
| Display                  | LCD 1608 16 x 8 Dot Matrix           |
| Temperature Sensor       | Thermocoupler K type                |
| Thermal Camera range     | -20°C – 1000°C                      |
| Interface                | Optocoupler MOC3023                  |
| Fuel Valve               | Servo driven valve                   |
| Valve Controller         | L298N servo driver                   |
| Stripper Controller      | 5A / AC PWM Zero crossing            |
| Power Supply             | Switching Power Supply 220V- 12DC/10A|

5. Conclusion

This study proposed practical, efficient and affordable coffee roasting machine for farmers and medium-scale coffee industries. The coffee roasting machine is implemented with a fuzzy logic-temperature control system. The fuzzy logic is embedded in ATMega 32 Microcontroller which is connected to the temperature sensor and thermal camera to monitor the uniformity of heat transfer in the coffee beans. The microcontroller is also connected to the PWM motor and fuel valve to control the temperature. The motor stirs the coffee beans if the thermal camera detects unequal heat transfer among the coffee beans.

This proposed equipment is suitable in Indonesia coffee industry. Since the majority of Indonesia coffee farmers is a small farmer who cannot afford the modern coffee roasting machine. This proposed roasting machine is also able to produce uniform roasting level coffee beans. To further improve the coffee roaster performance in the future, it is promising to integrate Deep Learning in the coffee roaster. Deep Learning has been proved to excel in analysing the heat pattern included in remote sensing images [17].

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