Design of Automatic Dough Feeder Control System on Modified Cassava Flour-based Noodle Extrusion using Fuzzy Logic Controller

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Abstract: Production of modified cassava flour-based noodle has been done by many researchers using the extrusion process. An extruder, an extrusion-based machine had been developed by Research Center for Appropriate Technology to produce modified cassava flour-based noodle. The unstable feeding rate of the dough caused the motor had fluctuation load during driving the main screw of the extruder. The main impacts were the throughput of the noodle had become unstable too, the quality of the noodle also have an effect regarding the density of the noodle, and the worst case was the higher feeding rate of the dough means heavier load for the motor and can lead to jam of the extrusion process and damage of the main motor. In this paper, an automatic dough feeder has been designed to control the feeding rate of the dough to the extruder using Fuzzy Logic Controller (FLC). The inputs of the FLC were error and delta error of the main motor current and the output of the controller was the rotational speed of the dough feeder motor. The design and simulation were done using Matlab toolbox.

1 INTRODUCTION

Modified cassava flour (mocaf) is a derivative product of cassava flour which uses the principle of cassava cell modification by fermentation for 12 - 72 hours. This flour has the advantage of having a higher protein content and better physicochemical properties compared to cassava flour. Mocaf product development has been carried out in terms of improving the quality of mocaf (Kardhinata et al., 2019; Kurniati & Aida, 2012; Nusa, Suarti & Alfiah, 2015) and increasing production (Hamidi & Banowati 2019). One of the uses of mocaf is to substitute wheat flour, which is not produced in Indonesia, in making noodles. Some research on the use of mocaf as a noodle-making material has been done by many researchers (Afifah & Ratnawati, 2017; Indrianti et al., 2014; Yulianti, Sholichah & Indrianti, 2019).

In line with the research on these mocaf flour-based noodle products, the development of extruder equipment as equipment to produce mocaf has been widely developed. One of them, in 2013 the Research Center for Appropriate Technology began developing a single screw-type extruder machine (Siregar et al. 2013). The main aspect of a single screw extruder was the screw pump or screw press, where the food dough is compressed to form a semi-solid mass in a cylindrical chamber (barrel) using a single screw that is driven by an electrical motor and forced out through a limited opening (die) at the tip of the barrel (Riaz, 2000). When the food is heated, it is called extrusion cooking or hot extrusion. The heat used in the cooking process can come from the steam injection (directly), from the heating jacket (indirectly), and can also be done by heating the dough before being put into the extruder, as well as the heat energy arisen from the friction of the dough during the extrusion process (Riaz, 2013).

On the process of making noodles, the dough, a mixture of mocaf and other ingredients went through the cooking process before being fed into the extruder machine. The heating process was a critical step for pre-gelatinization to maintain the noodle strands because mocaf is a gluten-free flour which not able to form a cohesive dough structure5. As a result, the dough material from the extruder was a half-cooked dough that had an irregular shape and size. The feeding process of the dough into the extruder machine was done manually by the operator so that the feeding rate the dough becomes unstable. This can give result in variations in physical characteristics of the noodles produced.

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The use of fuzzy logic as a controller had been done by many researchers. It was said that fuzzy logic has been used in many industrial control applications. It had several advantages including simple and low cost for installation, capability to handle non-linear systems (Abeykoon et al., 2011), free plant models (Albertos & Sala, 2004; Driankov, Hellendoorn & Reinfrank, 1993; Fileti et al., 2007). Some studies related to the use of a fuzzy logic controller (FLC) include FLC in the washing machine to control the voltage for the inverter claimed can reduce the time, electricity consumption, and washing water (Wulandari & Abdullah, 2018). An FLC also was used to control the expansion volume of dough pieces similar to its standard conditions during the proofing process claimed can provide significantly better result, not require a mathematical model and had better to reject any than PID controller (Yousefi-Darani, Paquet-Durand & Hitzmann, 2019). PID-fuzzy algorithms were applied to a polymerization process control and compared to conventional PID controllers, proved to be more suitable and reliable (Fileti et al., 2007).

Regarding the many advantages of the fuzzy logic controller mentioned above, in this study, an FLC was designed to control the speed of feeding noodle-based mocaf doughs that have non-uniform shapes so that it is expected to provide motor workload to the extruder constantly to produce homogeneous noodle products.

2 MATERIALS AND METHODS

The extruder that was used in this research had a specification which showed in figure 1.

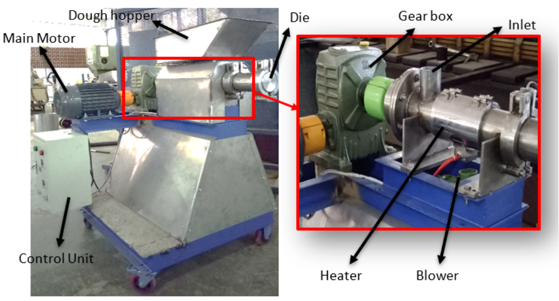

Figure 1: The extruder used in this research.

The Extruder was developed by the Research Center for Appropriate Technology on 2018, the scale down from the corn base noodle extruder Prototype 1 (Putra, Novrinaldi & Kurniawan, 2013; Siregar et al., 2013). The main motor was a three phases induction motor which had a nominal power of 5 HPs. The motor was connected to a 40:1 reducing gearbox system which operated at 1500 rotations per minute. The motor was electrically driven by a Variable Speed Drive (VSD) inverter. The extrusion process was set at 75 °C which measured by a thermocouple sensor located on the barrel. Both a heater and a blower were placed to control the temperature to its set point.

A preliminary experiment was done to investigate the optimum current of the motor which referred to the optimum load of the motor. There were 3 measurements using 3 same dough set of 2 kgs. The productions of noddle were conducted according to the proper process and the feeding of the dough to the extruder was done manually by the operator. During the extrusion process, the current measurements of the extruder motor were done using a clamp ampere and were recorded every 30 seconds. This experiment gave an optimum value of motor current which set as a setpoint to the proposed system.

The automatic dough feeder system was designed to eliminate the inconsistency feeding rate of dough which done manually by the operator. The system was consisted of dough crusher and a motor drive screw to feed the dough to the extruder automatically. The proposed dough feeder system is shown in figure 2.

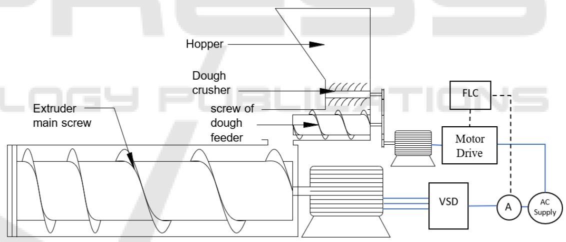

Figure 2: Illustrated design of dough feeder system.

The rate of dough feeding was done by controlling the angular speed of the feeder motor. The angular speed of the motor was controlled based on the feedback of the main motor load which was represented by the current measurement. The control system of the proposed feeding system was Fuzzy Logic Controller (FLC). Figure 3 shows the block diagram of FLC. The design and simulation of the FLC system was done using Matlab R2016a software (Trial Version).

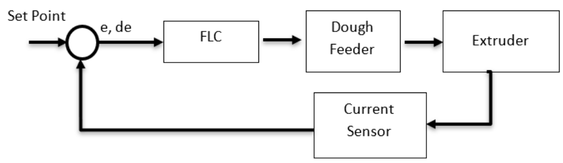

Figure 3: Block diagram of FLC.

Inputs of FLC were error and delta_error which can be represented as follow,

$$e(t) = SP - I_s(t) \quad (1)$$

$$de(t) = e(t) - e(t-1) \quad (2)$$

where setpoint (SP) is the average current of the main extruder motor. The steps of designing FLC as follow:

2.1 Fuzzification

In the fuzzification process, each input value consisting of crisp numbers is mapped in a fuzzy set by determining the degree of membership in each FLC input as described in the curve graph as follows

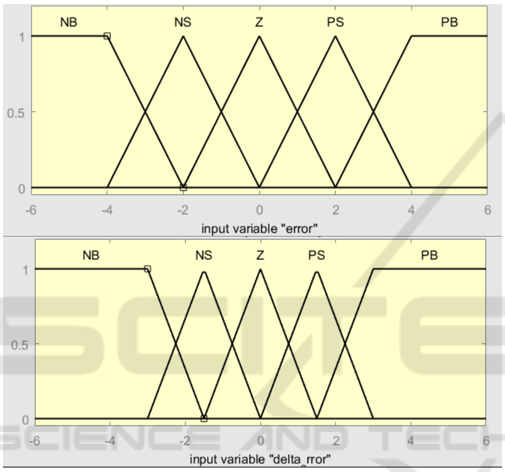

Figure 4: Membership function of error (top) and delta_error (bottom).

2.2 Determining Fuzzy Rules and Inference System

Table 1: Fuzzy rules pair set.

e / de	NB	NS	Z	PS	PB
NB	VS	VS	S	S	N
NS	VS	S	S	N	F
Z	S	S	N	F	F
PS	S	N	F	F	VF
PB	N	F	F	VF	VF

Remark:
NB = Negative Big
NS = Negative Small
Z = Zero
PS = Positive Small
PB = Positive Big
VS = Very Slow
S = Slow
N = Normal
F = Fast
VF = Very Fast

Each pair of the fuzzy set uses a logical AND operator, so a set of fuzzy rules is obtained as shown in Table 1, where the implication process uses Min rules and the aggregation process uses the max method, commonly known as the Min-Max method (Mamdani Method). There were totally 25 rules made of error and delta_error membership function pairs.

2.3 Defuzzification

The defuzzification process used in the Mamdani method is the center of gravity method, where the output value of crisp is calculated based on the center of gravity of the aggregation of the fuzzy sets of each output produced, as follows:

$$Z^* = \frac{\int Z.\mu_c(Z)dz}{\int \mu_c(Z)dz} \quad (3)$$

The membership function of output is described in Figure 5 as follows,

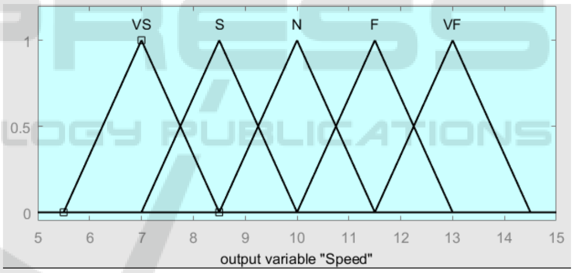

Figure 5: Membership function of output.

3 RESULT AND DISCUSSION

Based on the result of the preliminary experiment of the main motor current measurement during the mocaf-based noddle production process, the measurement data can be showed in Figure 6. It can be showed that the average motor current is about 9 Ampere, that becomes the setpoint. In measurements 1 and 2, there is a time span in which the motor got shut down due to overload. Recorded motor currents before shutting down were at 13 ampere and 15 amperes. Therefore, the proposed system should have a range of the motor current not exceed 13 Ampere.

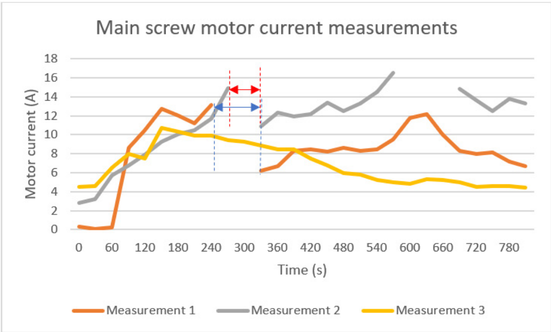

Figure 6: Measurement of motor current during noodle production.

Applying set point and all fuzzy parameter described above into Matlab fuzzy toolbox would give simulation the calculation of the output based on given inputs as shown in Figure 7.

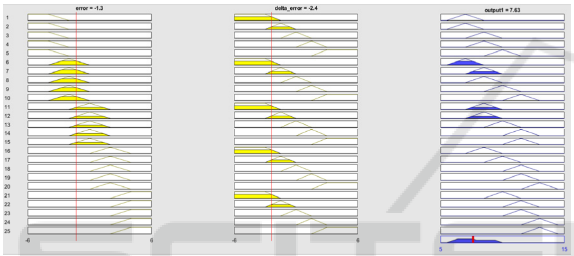

Figure 7: Simulation of the proposed fuzzy at error -1.3 A and delta_error -2.4 A.

Each crisp value of inputs will be mapped into its membership function. Each pair of input membership function will be mapped into the output membership function based on the fuzzy rules. And all output membership function will be aggregated and calculated into crisp value of output based on formula (3). On the example above, error -1.3 ampere and delta_error -2.4 amperes will give output rotation speed of the feeder's screw at 7.63 Rpm. Figure 8 shows a surface response relationship between inputs and output. During the positive value of error and delta_error the controller gives a higher value of the output, which means the load of the main motor was low and need to be fed dough faster. On the other hand, whenever error and delta error had negative values the output gave less value, which means the load of the main motor was high and need to be fed by dough slower. The FLC maintained the rate of dough feeding to its proper value based on the set point.

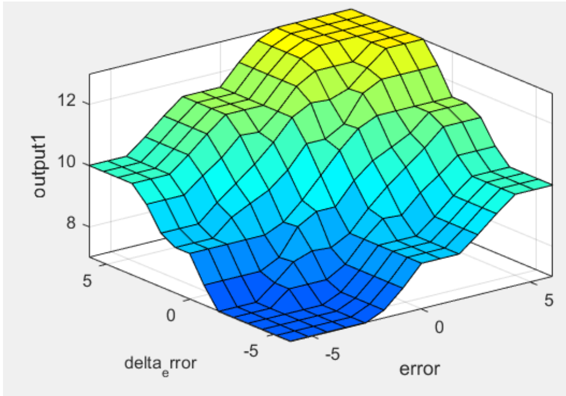

Figure 8: Surface response relationship between inputs and output.

4 CONCLUSIONS

A FLC was applied to control the feeding rate of dough on an extruder during noodle production was proposed and simulated under Fuzzy toolbox on Matlab. The controller determines the rotational speed of the screw-feeder motor based on the main motor current on extruder which describes the load of the motor. It is shown that the FLC can maintain the feeding rate of dough on the extruder by manipulating the screw speed of the feeder system. The controller performances can be further improved by improving the model's accuracies, adding more fuzzy rules, etc. The implementation of the proposed controller on the dough feeder of the extruder together with different fuzzy parameter setting and method will be addressed under future work.

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