Fuzzy Logic Control of Food Frying Process: An Optimization of Traveling Speed of the Conveyor Belts

P.B. Osofisan, Ph.D.* **and M.O. Falodun, B.Sc.(Eng.)**

Department of Electrical Engineering, University of Lagos, Lagos State, Nigeria.

*E-mail: tosofisan@yahoo.com
famikecontrols@hotmail.com

ABSTRACT

Conveyor belt systems have been significantly improved for decades and now are playing a critical role in large-scale continuous transport systems such as industrial food frying operations. Appropriate adjustment of the speed of the conveyors in the transportation of frying products in food frying process control is very important,. The flow of food materials must be automated and progressive in steps of modeling the system, design of a controller and then implementation using a programmable logic controller based on fuzzy logic.

To meet these requirements, an optimization of traveling speed of the conveyor belts was developed and analyzed. A two-stage control over food frying process was suggested. The input values to the first stage of the controller are the values of thermal power necessary for heating raw product (Q_2) and for heating frying oil (Q_3). The input values to the second stage of the controller are frying oil temperature (T_3) in the fryer tub and traveling speed of conveyor belt (V_{P1}) and (V_{P2}). Controlling heat streams in the first stage aims at obtaining the oil temperature necessary to achieve desired properties and taste values in fried food.

The effectiveness of these controllers is demonstrated for different operating conditions of the conveyor speeds ($Vp_{1,2}$) drive system.

(Keywords: conveyors, Petri nets, fuzzy logic, tracking, optimization and servomotor control)

INTRODUCTION

In conventional food frying process lines, food items or materials are transported to various parts (or workstations) by the conveyor belt, and these food items are often required to be disengaged from the moving conveyor at each workstation for processing. As shown in Figure 1, when the food material arrives at the workstation, it is removed from the conveyor by a positioning mechanism, and then put back for transport to the next workstations after the required processing has been completed by the processing mechanism beside the conveyor. In this way, the processing mechanism is permanently fixed beside the conveyor.

The whole process costs time not only during processing, but also during removal, sorting, re-positioning, and returning of the food item or product. In addition, transportation of the frying item from one station to the next also adds more time to the process, in effect lengthening the entire processing time and hence decreasing the average efficiency of the production. This explains the need to decrease the removal, processing, and returning time of the frying item in order to maximize processing/frying efficiency.

To combat the hindrances to high productivity mentioned above, this paper presents a fuzzy logic control and position tracking control system that essentially consists of a moving conveyor (equipped with a processing mechanism), which is driven by a servomotor [1]. This process is automated and eliminates the need to stop the frying items (material) at each station. A specific feature of this kind of processing in food production lines is that of accomplishing the task in the way of simultaneously transporting and processing the food material. Using the concept of trucking and working (Figures 1 and 2), not only could the time of positioning and/or removal of food products be spared, but also a continuous production flow could be maintained. Thus the savings in the process time would increase the productivity in food frying production lines.

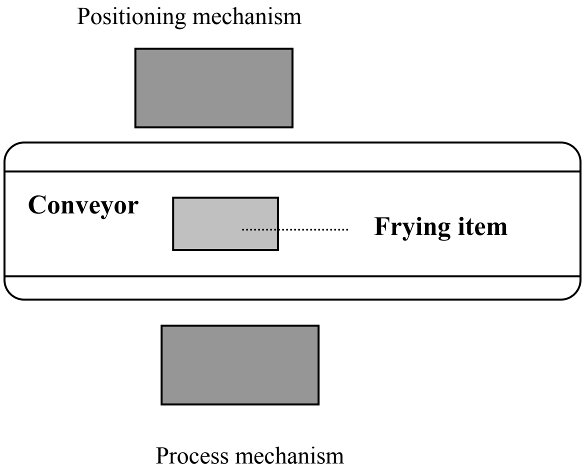

Figure 1: Schematic Diagram of a Traditional Frying Processing Flow Line.

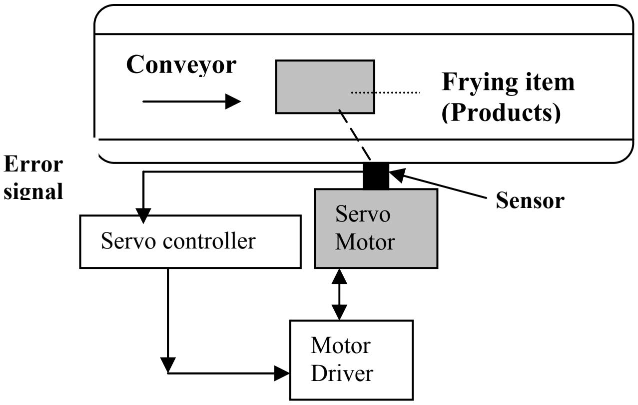

Figure 2: Schematic Diagram of a Position Tracking System.

The conventional control engineering approach would require rigorous mathematical modeling while the fuzzy logic could simplify the solution by employing operator approach experience as the expert.

To deal with multiple input variables, a controller must make use of a mathematical model of the process to be controlled. For the multi–variable food frying control system or strategy, such a mathematical model could be the relationship between the thermal power necessary for heating raw products, and for heating frying oil, frying oil temperature and traveling speed of conveyor belts. In most real – world applications, the mathematical relation between the different variables cannot be easily described.

Keeping single figures of the processes constant is easy in most cases. Controlling the optimal operation point for the plant does involve multiple variables. Because of the difficulties involved with deriving mathematical models, automated control is rare and human operators often adjust the set points of the individual PID controllers. Fuzzy control seems to accomplish the same control quality with less complexity.

In contrast to conventional design techniques, fuzzy logic enables the design of such multi – variable control strategies directly from human operator experience (as an expert) or experimental results.

Using such existing knowledge and circumventing the effort of rigorous mathematical modeling, the fuzzy logic design approach delivers an efficient solution faster. Fuzzy control becomes attractive because this technique requires less computational power and demands less operational memory than conventional PID compensation.

FUZZY LOGIC CONVEYOR SPEED INTERACTIONS IN FOOD FRYING PROCESSES

A typical commercial fryer is around 10-12 m. long, and is about 30 cm. deep. Hot oil is pumped continuously at one end of the fryer, and the cooled oil is removed from the other end of fryer.

The cooled oil coming out at the exit of the fryer is then passed into a heat exchanger where it is heated back to the required temperature and then pumped back into the fryer on the front end. A small oil makeup stream is added to replenish oil exiting the fryer with the product. Figure 3 shows schematic overview of this process and conveyor speed interactions in food frying process control system.

The decision making rules and the membership function for the variables of the fuzzy controller (i.e. submerged conveyor speed (V_{p1}), take out conveyor speed ($V_{p2)}$ and the oil temperature (T_3) has to be formulated.

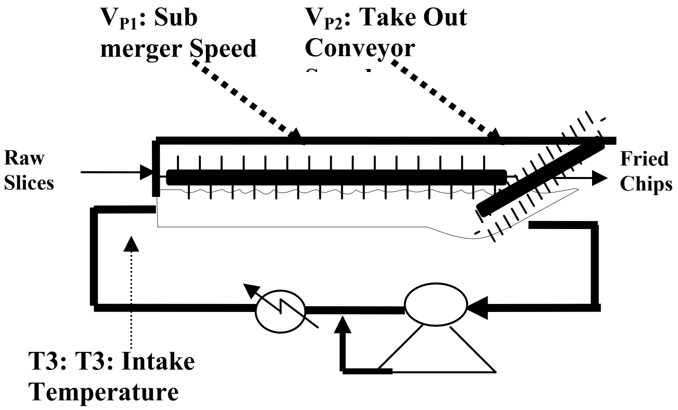

Figure 3: Schematic Overview of the Conveyor Speed Interactions in Frying Processes.

The decision making rules and the membership function for the variables of the fuzzy controller (i.e. submerged conveyor speed (V_{p1}), take out conveyor speed (V_{p2}) and the oil temperature (T_3) has to be formulated.

In this study, attention is focused on the manipulated variables like submerged conveyor speed, V_{P1}, take out conveyor speed, V_{P2}, the obtained oil temperature T_3 and the optimization control of these variables. Adequate manipulation of these variables gives the desired properties and taste qualities to the fried products.

Figure 4 shows the design of two-stage food frying control [6]. Level 1 of two-stage food frying process control aims at controlling the heating speed of the raw material and fat while level 2 controls the efficiency of the frying which is the output (food quality). The input to this stage (level 2) are the oil temperature (T_3) and the conveyor speeds $V_{P1,2}$ which Petri Nets and fuzzy logic were targeted to solve for optimal performance.

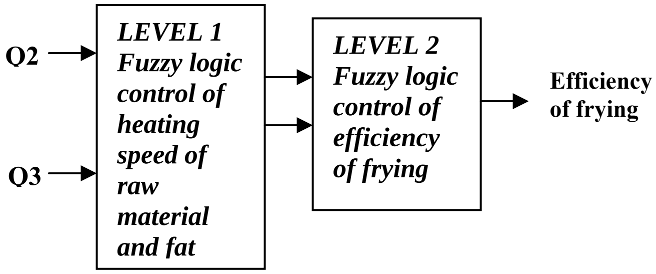

Figure 4: Design of Two-Stage Food Frying Control (Rywotycki R., 2003) [6].

The values of thermal power necessary for heating raw material (Q_2) and for heating oil (Q_3) are given at the input to the controller. As the result of thermal energy supply, frying fat in the tub of the fryer reaches a temperature (T_3). The chief objective of controlling heat streams at the stage 1 is to reach the oil temperature that gives the desired properties and taste qualities to the fried products. According to the assumed procedure the food quality is assessed using fuzzy evaluation obtained from surveys (consumer cards) carried out among consumers who classify the tested products as:

(a) Very Good
(b) Good
(c) Neutral
(d) Poor
(e) Bad

The efficiency of frying process depends on the obtained temperature (T_3) of fat and on the travel speed ($V_{P1,2}$) of the fryer conveyor belts. Within a temperature range characteristic for a given kind of food and the travel speed of fryer conveyor belts, an appropriate quality food of varying consistency, durability, taste and smell values, color, and outer appearance are obtained. The fuzzy controller model for submerged conveyor speed V_{P1} and take out conveyor speed V_{P2} were designed.

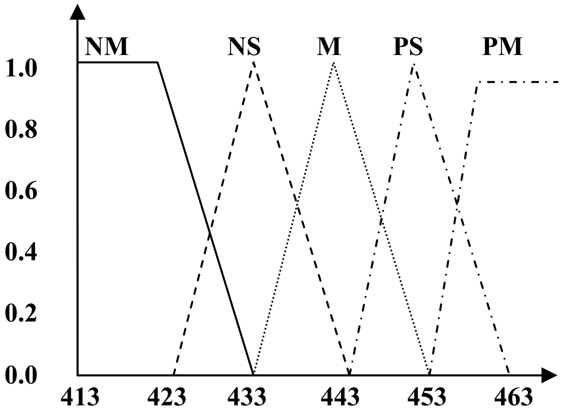

Figure 5: Membership Functions for the Value of "oil temperature T3".

The food quality is achieved by adjusting the speed of the conveyors involved in the transportation of the frying items. The approach in such cases is progressive in steps of modeling the system, design of a controller and implementation using a programmable logic controller based on fuzzy logic. In this application the objective is speed control of two conveyors, which are used for frying products. The fuzzy controller model for conveyors could be extended to conveyors of more than two different speeds. The strategy is to optimize the speed of a motor-driven belt conveyor so that an optimal output of the frying products is achieved. Items are carried out at intervals in both the submerged conveyor V_{P1} and take-out conveyor V_{P2}. The speeds of both conveyors are controllable. The objective of the application of the dual submergers and oil inlets is to provide improved controllability.

The key variable associated with product quality are moisture content, oil content, and color; all of which can be measured in real time at the outlet. Second loops ensure that process variables such as oil bath level, oil temperature, and oil flow are maintained at desired values. Because part of the oil leaves the fryer with the fried chips, it is continuously replenished with fresh oil at controlled amounts, thus simultaneously suppressing oil rancidity in the fryer.

A POSITION TRACKING SYSTEM

The schematic diagram of the position tracking control system for improving production efficiency is shown in Figure 2. As seen in the diagram, the working table moves parallel to the conveyor flow and is controlled by the servo controller via a reflective optical sensor, allowing the table *to* track the moving frying products.

Figure 6 is a block diagram of the closed-loop control system. The working table is initially at a home position waiting for the arrival of frying products. When a product (pack of frying items in a box) is sensed, the servo controller calculates a correct distance, and adjusts the motion of the working table (position of an observer) through the servo motor to track the frying items correctly with respect to the carrying plate of the conveyor belt.

Once the speeds of the frying item and the working table are synchronized, the processing mechanism mounted on the working table begins implementing the desired tasks. From the point of view of an observer sitting on the working table, the frying items under processing look stationary. After the processing is complete, the working table quickly returns to the home position and then waits for the next carrying plate to repeat the process. The optical sensor used in our setup for synchronizing control is an analog output type photoelectric switch, the OMRON type E3SA [4]. This is a reflective sensor, often used in frying production lines as an on/off switch, which is here used to sense the leading edge of the incoming carrying plate of frying items on the conveyor. Thus the tracking system of Figure 2 is in no way coupled with the conveyor, making it useful for many applications.

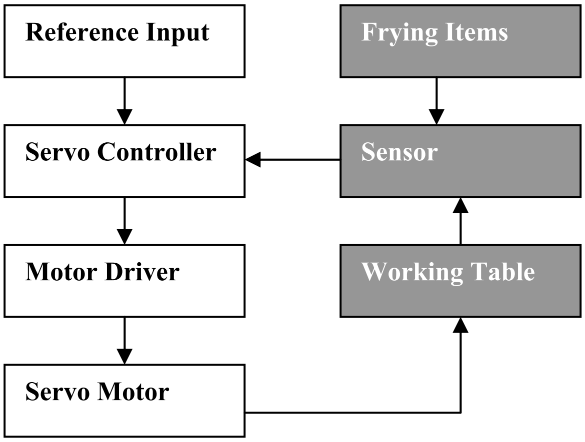

Figure 6: Block Diagram of the Tracking Control System.

FUZZY CONTROLLER MODEL FOR CONVEYOR SPEEDS, V_{P1} AND V_{P2}

An important aspect of the fuzzy controller model for this process is that it should lend itself to further conversion to ladder logic programming. Fuzzy modelling in a normal case refers to the description of the operator's input/output control actions using fuzzy rules. This description will not suit a discrete event system where events are distributed over time and are not continuous. Hence, fuzzy concept itself will have to be fused at the modeling stage to involve a supervisor [2, 3,5]. For this to happen, the definition of the variables involved is revisited to suit the modeling syntax. Say, for example the submerged conveyor speed (V_{P1}) is to be controlled. Then, the following three variables have been taken into consideration:

1) The submerged conveyor speed (V_{P1}).

2) The take out conveyor speed (V_{P2}),

3) Distance of frying item on the considered conveyor from the sensor (S_L).

The first variable is modeled as in Figure 7 (P.R. Venkateswarwn and Jayadev Bhat, 2006). The three inputs to the FPN (Fuzzy Petri Net) are the fuzzified inputs (μ (z) values) for the variable speed of the submerged conveyor speed (V_{P1}). The range has been divided into Low (0.15-0.30), Medium (0.30-0.60), and High (0.60-0.90). The values considered for Low, Medium and High respectively for the purpose of calculation (as will be given in table later) are 0.20, 0.50 and 0.80.

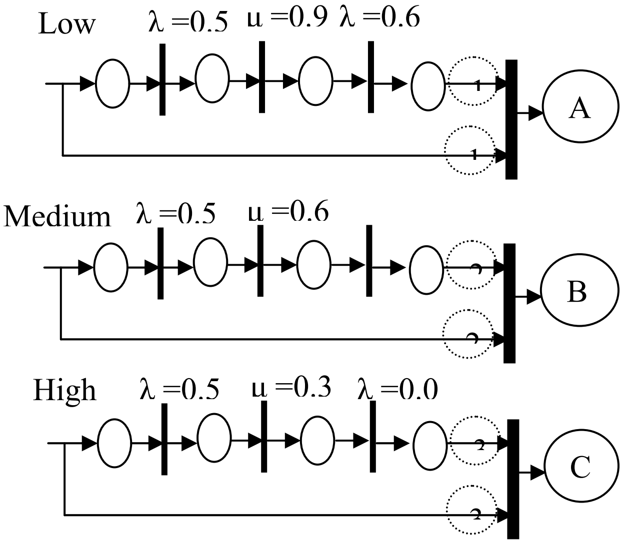

Figure 7: FPN model for the variable the submerged conveyor speed (V_{P1})

The weights are assumed as per the implementation mechanism. Initially they are assumed to be unity. The threshold value λ is used as cut off factors, i.e. values equal to or more than that are only accepted. In case of calculations the threshold value has been assumed to be 0.50. This value has been taken to consider the maximum input membership value for any input.

The certainty factor μ says how certain the occurrence of an event is multiplied to by the input value and gives us a final output (i.e. it acts as a probability factor). In the model, various values of μ have been assumed to ensure that the output range can be divided into the three sections, as has been mentioned. A μ value of 0.30 keeps the output range within the defined Low range of 0.15-0.30. The second λ value of 0.00 along with μ = 0.30 in case of the conveyors has been taken to denote that all the values can be passed. μ = 0.60 keeps the output range between the prescribed range of 0.30 and 0.60 for Medium. In this case also all values are allowed to pass. The μ value of 0.90 keeps the output range as 0.45-0.90. Here the λ value of 0.60 has been considered.

The range for High is 0.60-0.90 and hence this λ ensures that the range is accounted for properly. While calculating the speed of the submerged conveyor speed (V_{P1}) the variable for the submerged conveyor speed (V_{P1}) are taken as follows: μ value for the Low input is taken to be 0.90 with a corresponding λ value of 0.60 and High input is taken to be μ =0.30 with a λ of 0.00.

The values are selected to get a definite set of value for the centroid such that there is a well defined set of output value which can be defuzzified to get the appropriate output speed values. The fuzzy Petri Net model of the other component can be worked out as shown in Figures 8 and 9.

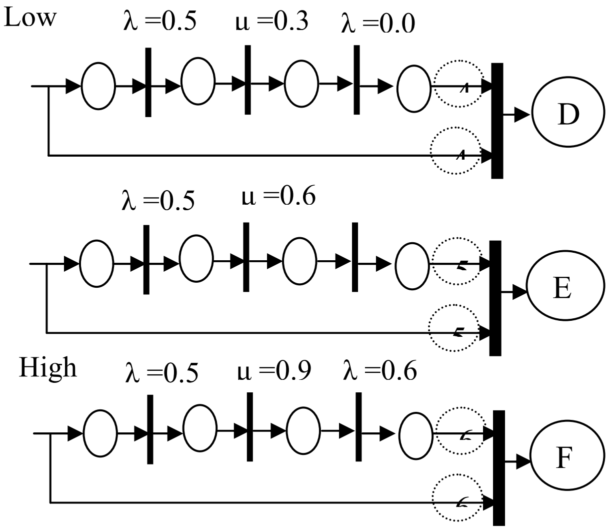

Figure 8: FPN model for take out Conveyor Speed (V_{P2})

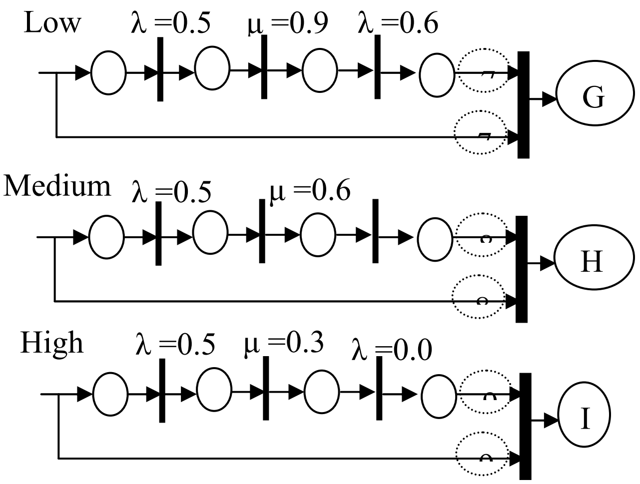

Figure 9: FPN Model for Distance of Frying Item on Concerned Conveyor While Determining Speed.

Figure 10 is the summation function, which is needed to calculate the numerator, and denominator of the Centriod. The centroid can be calculated from the equation:

$$Z^* = \frac{\sum \mu(z).z}{\sum \mu(z)} \quad \textbf{(1)}$$

Where Z^* is the defuzzified values of membership values μ (z) of variable z - with respect to the values of the model the centroid is defined as J/K.

FUZZY LOGIC SIMULATION RESULTS FOR V_{P1} AND V_{P2}

The resulting mode was simulated by calculation since the model does not have many variables, all calculation were done manually. The formalism yields satisfactory performance for the assumed value as in tables 1, 2 and 3. It has to be standardized as a procedure and tested for all cases.

The values shown in the three tables were determined using the calculations required for the centroid function. The centroid values for the cases shown are fuzzy value, which when interpreted will give speed as in table 4 for example, the first row of the Table 1 is taken for interpretation. The inputs are the speed of the conveyor (which is low) and the distance between the frying item and the output (which is small). This means that the item will reach the base station of the takeout conveyor, V_{P2}, in a short time, before that short time, the submerged conveyor belt, V_{P1}, should complete the operation, Hence; the expected speed of submerged conveyor (V_{P1}) is High.

The centroid value is 0.6, which translates to a speed of very high. Similarly, the system can be interpreted for all values. The control of the speed of takeout conveyor (V_{P2}) can be modeled on the same lines.

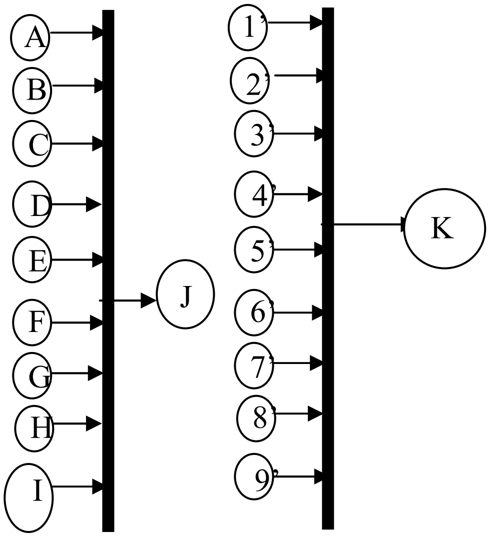

Figure 10: The Representation of the Σ μ (z) . z for the FPN Model of the System.

Table 1: Output speed of V_{P1} when Present V_{P1} Speed is Low.

C_R	D_B	∑μ(z) .z(N)	∑μ(z)(D)	(N)/(D)
Low	Small	1.44	2.4	0.6
Medium	Small	1.68	2.4	0.7
High	Small	1.92	2.4	0.8
Low	Medium	1.2	2.4	0.5
Medium	Medium	1.44	2.4	0.6
High	Medium	1.68	2.4	0.7
Low	Large	0.96	2.4	0.4
Medium	Large	1.2	2.4	0.5
High	Large	1.44	2.4	0.6

Table 2: Output Speed of V_{P1} when Present V_{P1} speed is Medium.

C_R	D_B	∑μ(z). Z (N)	∑μ(z)(D)	(N)/(D)
Low	Small	1.2	2.4	0.5
Medium	Small	1.44	2.4	0.6
High	Small	1.68	2.4	0.7
Low	Medium	0.96	2.4	0.4
Medium	Medium	1.2	2.4	0.5
High	Medium	1.44	2.4	0.6
Low	Large	0.72	2.4	0.3
Medium	Large	0.96	2.4	0.4
High	Large	1.2	2.4	0.5

Table 3: Output Speed of V_{P1} when Present V_{P1} Speed is High.

C_R	D_B	∑μ(z). Z (N)	∑μ(z)(D)	(N)/(D)
Low	Small	0.96	2.4	0.4
Medium	Small	1.2	2.4	0.5
High	Small	1.44	2.4	0.6
Low	Medium	0.72	2.4	0.3
Medium	Medium	0.96	2.4	0.4
High	Medium	1.2	2.4	0.5
Low	Large	0.48	2.4	0.2
Medium	Large	0.72	2.4	0.4
High	Large	1.96	2.4	0.5

Table 4: Linguistic Interpretations of Centroid Values.

Values	Linguistic Term
0.2	Very low
0.3	Low
0.4	Medium
0.5	High
0.6	Very High
0.7	Very Very High
0.8	Very Very Very High

Figures 11 and 12 show tracking error plotted at the conveyor speed of 4.68cm/s and 13.26cm/s respectively.

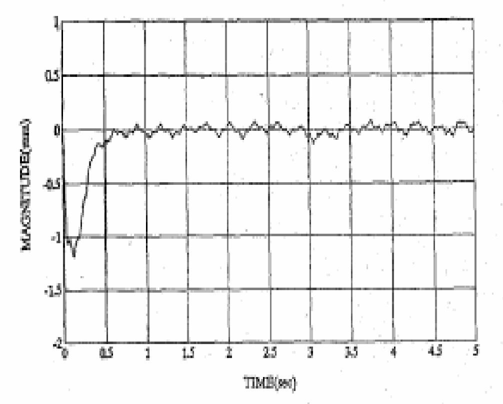

Figure 11: A Tracking Error Plot at the Conveyor Speed=4.68cm/s.

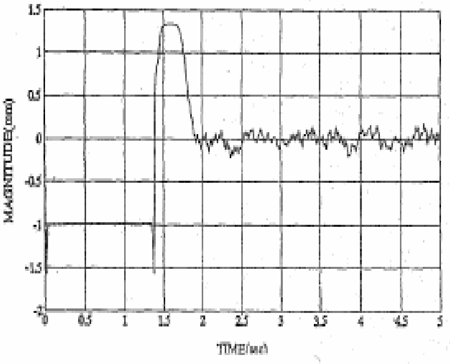

Figure 12: A Tracking Error Plot at the Conveyor Speed=13.26cm/s.

Figure 13 shows an example of modified membership function of frying process efficiency for the input values: thermal streams Q_2 and Q_3 and conveyor belt traveling speed $V_{p1,2.}$ For practical applications a precise value should be calculated, i.e. the ultimate response of the controller, using formula [6]:

$$m = \int^{99}\int^{\mu(w)} d\mu dw, W_{ster} = \frac{1}{m}\int_{0}^{99}\int_{0}^{\mu(W)} w d\mu dw \qquad \textbf{(2)}$$

for center of mass “m” of the Figure 13 “response of fryer controller” limited by the membership function curve and X-axis.

As seen from the Figure 14, the actual rotor speed overlaps the variable speed reference. The performance of the design controller is evaluated in the presence of load changes.

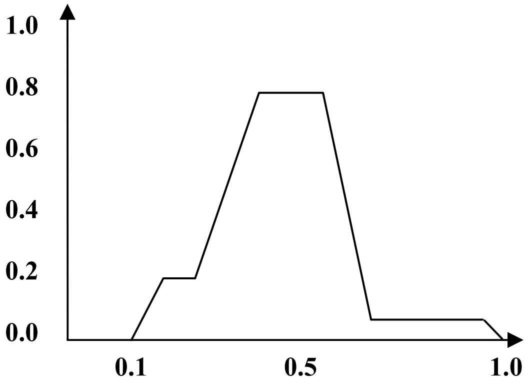

Figure 13: Response of Fryer Controller [6].

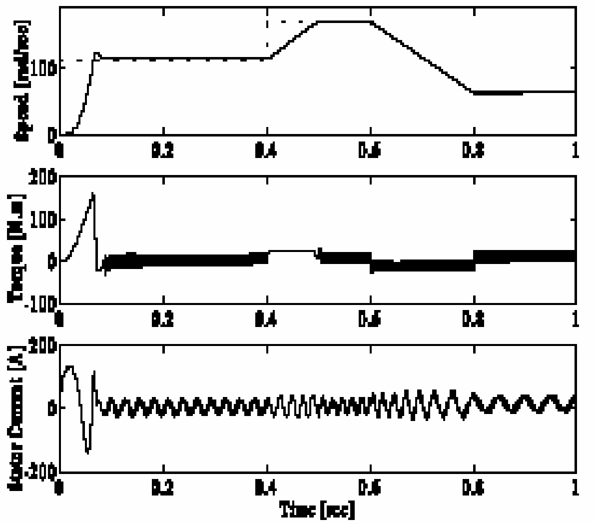

Figure 14: Drive system responses under a variable speed reference.

The drive system is tested under a variable speed reference and load torque changes simultaneously. The result of Figure 15 reveals a good control with zero steady state errors and no fluctuations in the drive response. By changing the operating point, the controller is expected to adjust its feedback and integral gains are achieved as shown in Figure 16.

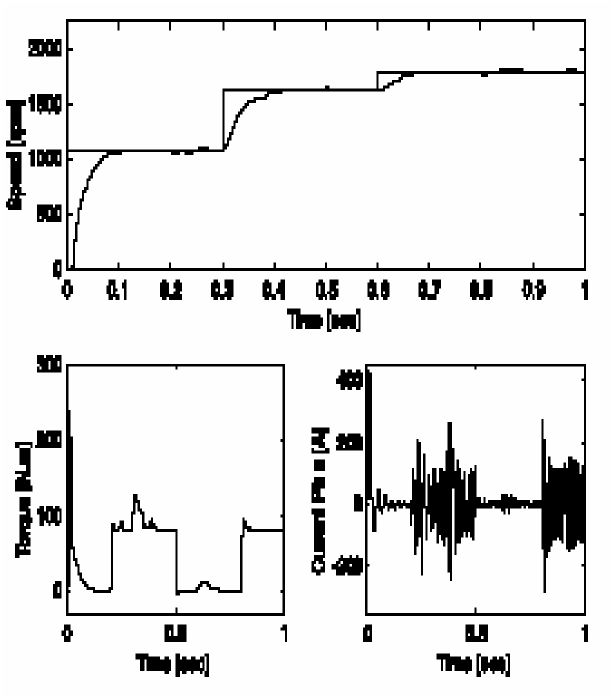

Figure 15: Speed Responses under Load Torque Variations.

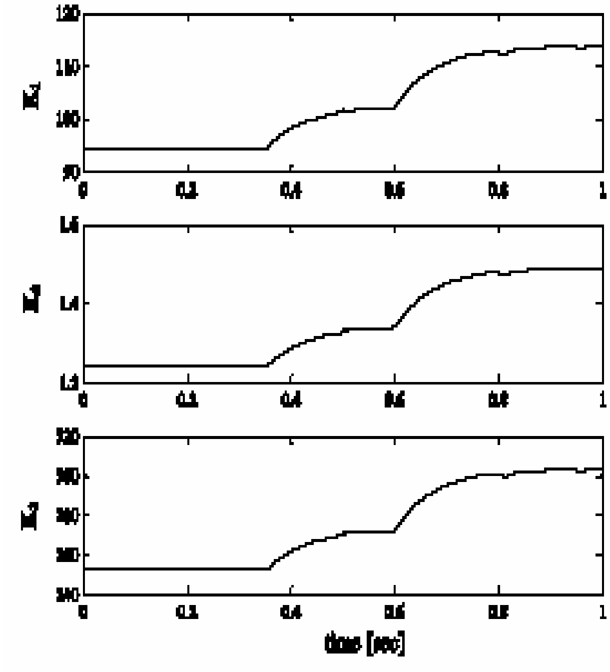

Figure 16: Controller Gains Variations.

CONCLUSION

The effect of the takeout conveyor shows that by increasing the takeout conveyor speed the color darkened, the moisture content remained the same, while the oil content increased. By reducing the residence time of the product in the takeout conveyor, less oil was allowed to drip off from the product surface resulting in higher oil content during cooling. In the takeout conveyor the product is not in the oil but is still under the fryer hood thus maintaining its temperature higher than the ambient temperature.

The decrease in temperature of the oil also causes the viscosity at the surface of the product to increase thus making it more difficult for the oil to drip off the product's surface. Therefore, an increase in the takeout conveyor speed resulted in more oil in the final product. Color changes in this case could be the result of density reduction of the product as oil content increased thus resulting in lighter color (more yellow).

Since controlling heat streams in the first stage produce the necessary oil temperature (T_3) in the fryer tub and the traveling speed of conveyor belts ($V_{P1,2}$) to achieve desired properties and taste values in the fried food, therefore frying process efficiency depends on the oil temperature and on traveling speed of the conveyor belt of the fryer. Necessary rules of the decision-making process were construed to form a basic for the fuzzy logic controller. It was found that there is a possibility of increasing frying process efficiency by optimization of the traveling speed of the conveyor while maintaining required food quality features. Fuzzy logic systems behave favorably well when compared to the conventional PID system.

The fastest response was obtained with the submerged speed, and the slowest one with the oil temperature. Oil content reacted very fast to changes in submerged speed and takeout speed, but slowly to oil temperature changes.

(T_3) - oil temperature: 188-193C

(V_{P1}) - submerged speed: 50-75%

(V_{P2}) - takeout conveyor speed: 30-90%

Also, the paper presents a position tracking control for use in food frying production lines. The concept of synchronous tracking and working is of great industrial applicability, and has positive effects on shortening production time and increasing frying process efficiency.

REFERENCES

1. Lee, C.H. 1993. “Performance Improvement of a Synchronous Tracking Control System,” Master’s thesis, National Cheng Kung University: Tainan, Taiwan.

2. Chirn,, J.L. and D.C. Mc Farlane. 2000. “Petri Net Based Design of Ladder Logic Diagrams”. Submitted to: *Control 2000*. Cambridge, UK.

3. Ramadage, P.J.G. and W.M Wonham’ 1989. “The Control of Discrete Event Systems.” *Proceedings of IEEE*. 77(1):81 – 98.

4. OMRON Inc., 1992. *The OMRON Handbook: Best Control Machines, 1lth ed.* Japan,.

5. Valette, R. 1995. “Petri Net for Control and Monitoring: Specification, Verification and Implementation, Workshop”. *Analysis and Design of Event –Driven Operations in Process Systems*: London, UK.

6. Rywotycki, R. 2003. “Food Frying Process Control System”. *Journal of Food Engineering*. 59:339 – 342.

ABOUT THE AUTHORS

Dr. P.B. Osofisan, obtained his B.Sc.(Eng) and M.Sc.(Eng) in Electrical Engineering from the University of Stuttgart, Stuttgart, Germany. He earned his Ph.D. in Control Systems Engineering from the same University. He then worked in a cable manufacturing plant as the Production/Quality Control Manager for over 15 years, before he joined the University of Lagos as Senior Lecturer in Electrical and Electronics Engineering Department. His research interests include the application of Fuzzy Logic Theory and Neural Network in the process control of industrial processes.

Mr. M.O. Falodun, obtained his B.Sc.(Eng.) degree from the Federal University of Technology, Owerri in Imo State of Nigeria. He is currently concluding his M.Sc.(Eng.) program from the University of Lagos, Lagos, Nigeria.

SUGGESTED CITATION

Osofisan, P.B. and M.O. Falodun. 2007. “Fuzzy Logic Control of Food Frying Process: A Conception of Frying Process Control”. *Pacific Journal of Science and Technology*. 8(2):286-294.

Pacific Journal of Science and Technology