Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 11 (5): 867-872, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.867.872

Utilization of Fuzzy Controller for Laboratory Scale Convective Fruit Dryers

[1]Farshad Arvin, [2]Shyamala Doraisamy and [3]Marjan Javanmard
[1]Department of Computer Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[2]Faculty of Computer Science and Information Technology, University Putra Malaysia, Selangor, Malaysia
[3]Department of Food Science and Technology, Science and Research Branch, Islamic Azad University, Tehran, Iran

Abstract: In the present study, a fruit dryer system that is controlled based on fuzzy logic is presented. A laboratory scale cabinet was developed which includes four sensors in different lengths for monitoring the cabin temperature and humidity. Fuzzy base controller is a new monitoring technique in food industrial machines that utilize sensors captured values as its input parameters to make a suitable decision according to temperature values. Furthermore, to implement the fuzzy system, a microcontroller base monitoring system is developed. Microcontroller captured temperature samples and converted them in to digital values. Output of the fuzzy controller will control the speed of the fan and power of the heater. Several performed results indicated the amenability of the proposed monitoring system as a drying machine main controller in different drying curves. Fluctuation of the cabin temperature with fuzzy control was smoother than non-fuzzy control. Nevertheless, fuzzy control has a significant influence on the power consumption as well.

Key words: Fuzzy control, fruit dryer, microcontroller, convective dryer, heat transfer

INTRODUCTION

Historically, drying was used as a method to preserve food. Extraction of fluid substances from material is known as drying by this means that water is removed from solids to a certain level with different techniques (Barrett *et al*., 2005). Therefore, drying is moisture migration from material in a specific period. Drying system is the aspects that effect the drying procedure, namely, moisture content of the material that is intended to be dried the heating temperature (Ceylan *et al*., 2007).

In dehydration process there are two stages of moisture loss first the phase that water is evaporated and then after the evaporated water will be extracted. Hence, drying is important in chemical and food processing. Throughout the drying procedure high energy levels are consumed this is because of removal of moisture from the body this phenomena makes drying a high energy consuming procedure (Ivanova and Andonov, 2001; Teeboonma *et al*., 2002).

Fruits drying attributes is dependent on a number of factors like sorption equilibrium, density and thermal properties. Design of any kind of heating process required knowledge about the materials density and thermal attributes. Shrinkage since throughout drying changes will take place in volume and internal porosity. These changes will lead to modification in shape and size of the final product, mass transfer and dielectric properties (Carsky, 2008; Desmorieux *et al*., 2008).

In general, the air drying graphs are composed of two stages: the first phase is the constant rate in which free water is evaporated this period is controlled by the heat given to the material and mass transfer rates so principally the boundary layer has the main responsibility for the transport mechanism (Barrett *et al*., 2005). The second phase is termed as the falling rate, which is a complicated phenomenon due to the fact that the controlling factor is the transport resistance within the particles to de, dried. Subsequently; these finding can led to the conclusion that both exterior and interior conditions are influential on the drying procedure.

Increasing amounts of fresh fruit waste and consumer demand for dried fruits made the manufacturers interested to produce dried fruit products (Kiranoudis *et al*., 1997). Accordingly to reduce the moisture content there a number of different types of dryers designed. Batch fruit tray dryer with hot air flow has been widely used among other techniques for fruit dehydration (Das *et al*., 2001). This technique is based on transportation of hot air in between the trays that material rests on. Obviously, higher circulation rates result in high rates of and mass transfer from the fruits body.

Corresponding Author: Farshad Arvin, Department of Computer Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

Moreover, increase in temperature will have a direct effect on the quality indicators, namely; color, shape, texture and nutrient components (Das *et al*., 2001).

Nowadays, fuzzy base controlling systems has been increased for industrial applications. The fuzzy controller causes to achieve higher quality products with optimal energy consumption. In previous works decision making was performed based on non-fuzzy controller. Dryer machine usually captures different locations of cabin temperature as its inputs and produces suitable output signals to control its modules such as heater and fan.

The present study gives an overview on applying fuzzy principles on dryers. The fuzzy base monitoring basics were implemented on fruit dryer platform with laboratory scale. Cabin is equipped with 4 temperature sensors which samples are captured using microcontroller processor of controller. The captured samples are converted to digital value by analog to digital converter module of microcontroller. These values will be inputs parameter of fuzzy controller and it provides two output signals for fan and heater. Fuzzy controller outputs are between 0 and 1 which a mapping function is required to change output values as controlling signals.

MATERIALS AND METHODS

Drying process: Drying is an energy consuming process that results in evaporation of the water of the fruit body and removal of the moisture content. In hot air dryers the heat required for the drying process is supplied by hot air which cycles through the dryer and contacts the product in our case fruit (Lewicki, 2006; Wang *et al*., 2007). The fruit dryer designed is a cabinet types drier and basically batches type equipment. The trays are rectangular shape with the dimension of 40×40 cm. The fruit dryer was tunnel shape and constructed of stainless steel with an area of 0.5×1×1.5 m. The dryer consists of a heating control unit which supplies the drying energy by an electrical heater, an electrical fan that creates forced flow of hot air through the trays, measuring sensors and the chamber which has been discussed earlier. The operation can be controlled which this part will be discussed further. The drying hot air was achieved by the electrical heating and controlled by the heating controller unit. The air was heated to the desired temperature then enters to the drying chamber. The temperature controller can alter the air temperature. Furthermore, the air flow rate was varied by utilizing the speed controller of the fans and moreover by adjusting dampers in the dryer design. The air velocity was controlled at approximately 2 cm above the surface of the trays. The drier proposed in this study is manufactured with sixteen trays in each wagon as shown in Fig. 1. As dryer is energy consuming equipment due to requiring electrical energy. So this energy is diverse into heat which increases the air temperature in contact with foodstuff and dries them. Energy consumption is the secondary consideration compared with quality in most of the fruit dryer designs.

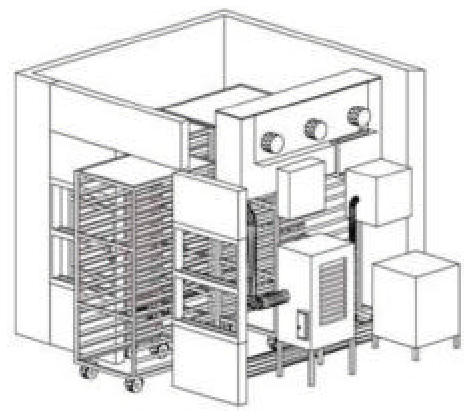

Fig. 1: Architecture of platform dryer system

The change in moisture levels can be calculated by measuring the following formulas:

$$MCWB = \frac{M_w}{M_s} \times 100 \quad (1)$$

$$MCDB = \frac{M_w}{M_{TS}} \times 100 \quad (2)$$

$$M_S = M_W + M_{TS} \quad (3)$$

where, MCWB is the moisture content water basis, MCDB is the moisture content dry basis, M_W is the mass of water, M_S in the sample mass and M_{TS} is the total solid mass.

The change in the moisture level can be calculated by measuring the total mass weight and the weight of water present in the product. The following formula indicates the relationship between the moisture content wet basis and dry basis:

$$(3) \Rightarrow MCWB = \frac{M_w}{M_s} = \frac{M_w}{M_w + M_{TS}} = \frac{\frac{M_w}{M_{TS}}}{\frac{M_w + M_{TS}}{M_{TS}}} \Rightarrow \quad (4)$$
$$MCWB = \frac{MCDB}{1 + MCDB}$$

General equations for heat and mass transfer are shown in Eq. 5 and 6. Moreover, the energy consumption is added in Eq. 7:

$$Q = h_C . A (T_{sur} - T_{\infty}) \quad (5)$$

where, Q is the rate of heat transfer by convection, h_C is the heat conductivity, A is the surface area and T_{sur} and T_∞ are the surface and air film temperature respectively. The T_{sur} and T_∞ are shown in Fig. 2. Since h_C depends on the force convection with increasing the fan air, the velocity will increase; this fact will led to increase in h_C. The conclusion result is increase in the rate of heat transfer.

$$-m_C = k.A\,(wf-wa) \tag{6}$$

where, $-m_C$ is the rate of mass transfer and the reason for its negativity is because of the moisture leaving the object, k is the coefficient of mass transfer, A is the area, w_f saturated vapor pressure of the film and w_a is the partial pressure of the air stream.

$$Q = -m_C \times \lambda \tag{7}$$

where, Q is the energy leaving and ë is the latent heat of evaporation meaning that heat needed to heat 1 kg of sample.

Dryer platform: Platform of proposed controller is a cabinet dryer machine, which equipped with four level sensors. Due to variety of temperature in cabin, controller requires to capture temperature of whole cabin to make a suitable decision. Figure 1 shows the designed cabinet dryer. Pars Dryer Engineering Group co. in Iran developed the studied platform at 2008. It is a convective dryer that was designed as a multipurpose batch dryer.

Developed dryer is controlled by a monitoring interface, which designed with low-cost, low-power and reliable principles. It is a multi-purpose controller that is able to have 16 input sensors. User can define several program using main keyboard and LCD display of board. Fig. 3 illustrates the architecture of main controller of dryer. In previous works (Javanmard *et al*., 2009), this controller was utilized as the monitoring system of batch tea dryer. Controller board is able to provide the output signals in two types, binary signals that are utilized as alarm and on/off command and Pulse-Width Modulation (PWM) to smooth control of instruments such as fan and heater.

Fuzzy controller: Main controller of system is a microcontroller base circuit which is able to convert measured values by temperature to digital level to be used as fuzzy system inputs. The fuzzy control enables a mapping between temperature values and behavior of system. The relative speed of fan is α which is defined between 0 and 1. In zero fans will be turned off and 1 shows the fan must be spinning by maximum speed. To

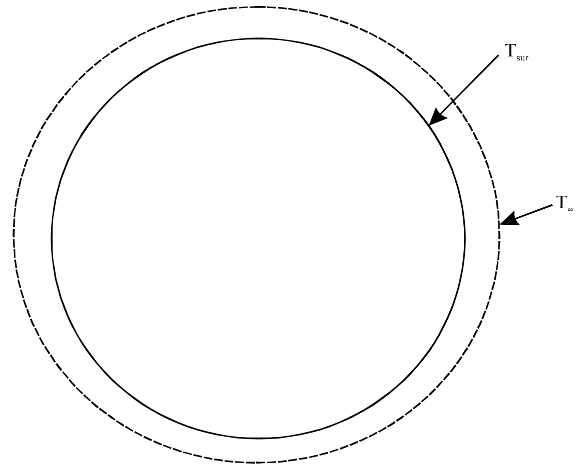

Fig. 2: Surface of fruit and cabin air temperatures

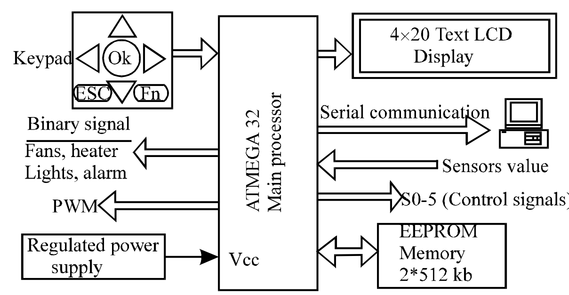

Fig. 3: Schematic of deployed processor for dryer machine

achieve a smooth speed control for fan, Pulse-Width Modulation (PWM) technique is utilized to drive main fan of system (Valentine, 1998). Second deciding will be power of heater, which is shown with α. The output value for α will be in range of 0 and 1. So, the PWM approach is utilized to controller heater temperature. Deployed microcontroller is able to produce PWM signals with different individual channels. System inputs are shown with $T_{1\text{-}4}$ which are placed in different levels of cabinet (T_1 = 5, T_2 = 65, T_3 = 125 and T_4 = 185 cm). Figure 4 shows the fuzzy membership function of input temperature. Three temperature points are selected . The membership of speed control (α) for main fan is shown in Fig. 5 which defined speeds. The fuzzy controller has another output decision for heater power (α) which is shown in Fig. 6.

According to systems outputs which are speed of fan and power of heater, there are two types of fuzzy rules. The defined fuzzy rules for speed controlling of fan are listed as:

- Rule-1: IF (T_1 is C) and (T_4 is W) → FF
- Rule-2: IF (T_1 is T) and (T_4 is W) → MF
- Rule-3: IF (T_1 is W) and (T_4 is W) → TO

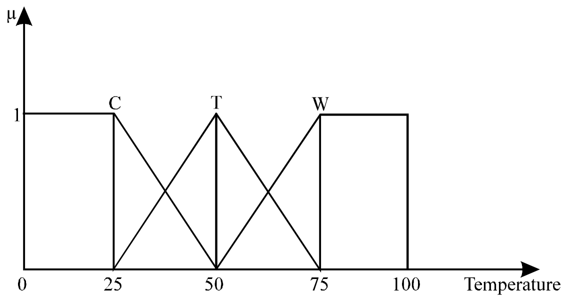

Fig. 4: Membership function for cabin temperature (C: Cool, T: Tepid and W: Warm)

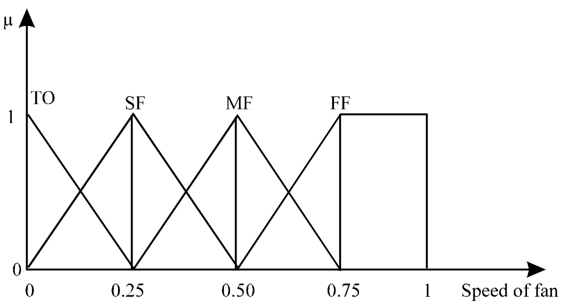

Fig. 5: Membership function for circulation fan speed (To: Turn-off, SF: Slow fan, MF: Moderate fan and FF: Fast fan)

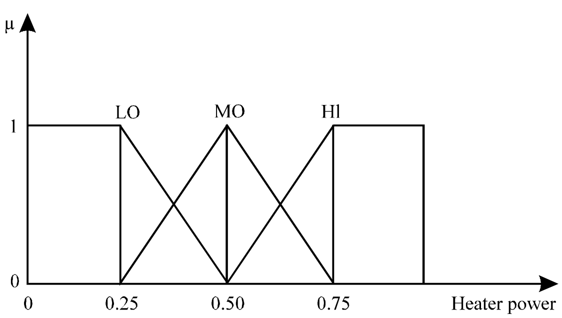

Fig. 6: Membership function for power control of heater (LO: Low power, MO: Moderate and HI: High power)

- Rule-4: IF (T_1 is C) and (T_4 is T) → SF
- Rule-5: IF (T_2 is C) and (T_4 is W) → FF
- Rule-6: IF (T_2 is T) and (T_4 is W) → MF

  …
- Rule-48: IF (T_3 is T) and (T_4 is W) → SF

In order to save the processor time, 48 effective rules are selected. We use C programming language to provide microcontroller program. The next fuzzy decision is the power of heater which is made based on inputs values.

The 18 fuzzy rules are defined for heater output as the following list:

- Rule-1: IF (T_4 is C) → HI
- Rule-2: IF (T_4 is T) and (T_3 is C) → HI
- Rule-3: IF (T_4 is T) and (T_2 is T) → HI
- Rule-4: IF (T_4 is T) and (T_1 is T) → MO

  …
- Rule-18: IF (T_4 is W) and (T_2 is W) → LO

After input intensity estimation, fuzzy function makes its decision and provides two output values between 0 and 1. Next function is the mapping function, which estimate PWM duty-cycle value to control fan and heater. In addition, there are several non-fuzzy decisions, which were defined, in critical behaviors. To prevent high temperature in cabin, a fan that is controlled directly by microcontroller starts to pump hot air of cabin to outside. There is another alarm signal which shows the happened error in system.

RESULTS AND DISCUSSION

The purpose of this study is to reach a fixed temperature in the cabin meaning that the lowest tray and the upper tray will have the same temperature. This fact will lead to having better quality of the final dried fruit product. In the previous work that was controlled with non-fuzzy monitoring, the temperature of trays differed with each other. That caused in a non-homogenous product. Figure 7 shows the captured temperatures with cabin's sensors, which were not changed smoothly due to on and off switching of heater to reach in between the defined temperature, range. In addition, T_1 that is placed in lowest part of cabin had lower temperature than upper sensor that is T_4. Figure 8 illustrates captured temperature values of cabin in fuzzy controller system. As it is clear, after arriving temperature to defined level the all sensors' values were in similar temperature. In addition, the fuzzy commands of heater and fan controller fixed temperature of cabin smoothly.

Power consumption of fuzzy controller was tested during a drying task. At the first time system reached to drying temperature and then using smooth controlling of heater and fan could achieve a approximately fix temperature in cabin. Due to less changing in cabin temperature, the quality of products will be in higher quality. In addition, power consumption will be saved. After reaching drying temperature, heater was not turned on with maximum power. The power consumption of fuzzy system and non-fuzzy system is shown in Fig. 9. As it is

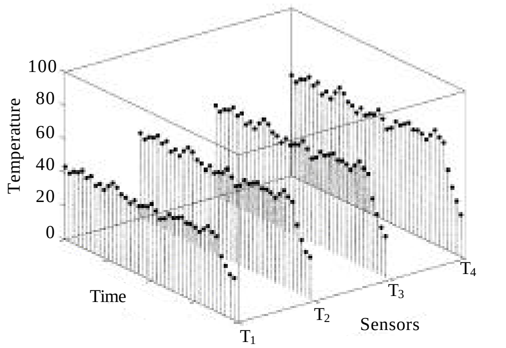

Fig. 7: Captured temperatures of cabin during a drying task with non-fuzzy controller

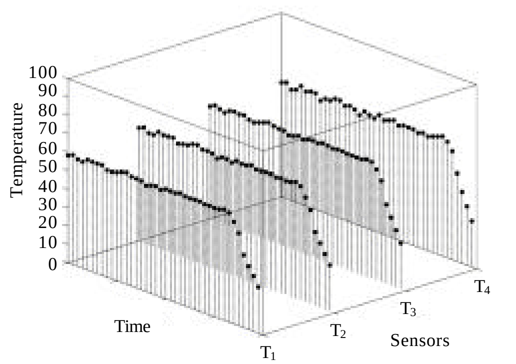

Fig. 8: Captured temperatures of cabin during a drying task with fuzzy controller

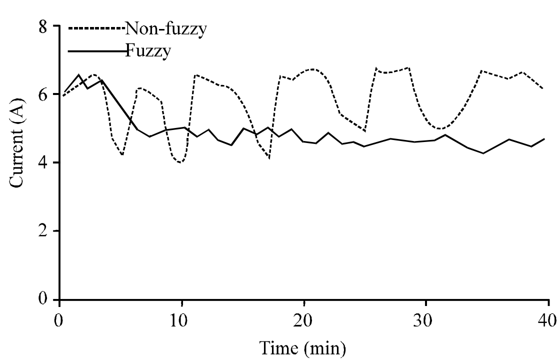

Fig. 9: Power consumption of fuzzy and non-fuzzy controller

clear in results, the fuzzy system had less switching and lower power of heater and fan, which caused to decrease the average power consumption of dryer machine.

The average power consumption of both systems is calculated with following average formula:

$$P = \frac{1}{T_d}\sum_{k=0}^{T_d} i_k \cdot v \qquad (8)$$

where, i is the current of system during a drying task (T_d) and v is the voltage of system which was about 220 V.

Therefore, the average current of system is the important parameter in calculation of power consumption. The average current of non-fuzzy system was about 5.91 A and average current for fuzzy system was about 4.92 A.

CONCLUSION

In this study, a fuzzy base controller system for convective fruit dryer was proposed. Input of fuzzy system was temperature of cabin and outputs were heater power and speed of fan. A microcontroller base controller circuit was deployed for implementing fuzzy system. Temperature values captured using analog to digital converter unit of microcontroller. Output signals were produced using pulse-width modulation technique to smooth control of fan and heater. The results of cabin temperature show the amenability of using the fuzzy control in dryer machines. The power consumption of system was also improved with fuzzy base decision and low power consumption was achieved using proposed technique.

REFERENCES

Barrett, D.M., L. Somogyi and H. Ramaswamy, 2005. Processing Fruits. CRC Press, New York, pp: 841.

Carsky, M., 2008. Design of a dryer for citrus peels. J. Food Eng., 87: 40-44.

Ceylan, I., M. Aktas and H. Dogan, 2007. Mathematical modeling of drying characteristics of tropical fruits. Applied Therm. Eng., 27: 1931-1936.

Das, S., D. Tapash, P.R. Sinivasa and R.K. Jain, 2001. Development of an air recirculating tray dryer for high moisture biological materials. J. Food Eng., 50: 223-227.

Desmorieux, H., C. Diallo and Y. Coulibaly, 2008. Operation simulation of a convective and semi-industrial mango dryer. J. Food Eng., 89: 119-127.

Ivanova, D. and K. Andonov, 2001. Analytical and experimental study of combined fruit and vegtable dryer. Energy Conversion Manage., 42: 957-983.

Javanmard, M., K.A. Abbas and F. Arvin, 2009. A microcotroller- based monitoring system for batch tea dryer. J. Agric. Sci., 1: 101-106.

Kiranoudis, C.T., Z.B. Maroulis, D. Marinos-Kouris and M. Tsamparlis, 1997. Design of tray dryers for food dehydration. J. Food Eng., 32: 269-291.

Lewicki, P.P., 2006. Design of hot air drying for better foods. Trends Food Sci. Technol., 17: 153-163.

Teeboonma, U., J. Tiansuwan and S. Soponronnarit, 2002. Optimization of heat pump fruit dryers. J. Food Eng., 59: 369-377.

Valentine, R., 1998. Motor Control Electronics Handbook. 1st Edn., McGraw-Hill Handbook, USA., ISBN: 0070668108, pp: 700.

Wang, Z., J. Sun, X. Liao, F. Chen, G. Zhao, J. Wu and X. Hu, 2007. Mathematical modeling on hot air drying of thin layer apple pomace. Food Res. Int., 40: 39-46.