

PAPER DETAILS

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Adaptive Neural Network Based Fuzzy Inference System for the Determination of Performance in the Solar Tray Dryer

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Abstract

This study aims to apply the adaptive neural network based fuzzy inference system (ANFIS) were used to modeling the apple solar drying conditions in the solar tray dryer. Apple slices were dried by solar drying techniques as a solar tray dryer, exposure to direct sunlight and in the shade. Drying air temperature, the air humidity, apple slice load, apple slice thickness and solar drying time has been investigated with the prediction of the drying in the solar tray dryer on water loss, drying rate and shrinkage ratio. The model results clearly showed that the use of ANFIS led to more accurate results. The correlation coefficient (R^2) values of the water loss, drying rate and shrinkage ratio were found as 0.9968, 0.9675 and 0.9918, the water loss, drying rate and shrinkage ratio respectively.

Keywords: Anfis, Drying, Solar drying, Solar tray dryer

Research article

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INTRODUCTION

Fresh fruits and vegetables are dried to preserve them for a long time without spoiling due to transportation, lack of storage and supply that may exceed the demand. Drying of foodstuffs at high temperatures negatively affects product quality, samples shrink due to loss of water during the drying process and a decrease in volume is observed. However, while the quality properties of various food products are preserved in the traditional drying process by spreading under the sun, drying of the products takes longer than necessary with this drying technique. If the product is in direct contact with the sun, there is a decrease in the color and nutrient values of the product. The drying method with a solar dryer is a suitable method for the economical drying of food products that are heat sensitive and where color quality and sensory properties are important (Demirhan and Ozbek, 2011; Decareau, 1992; Askari et al., 2008; Cui et al., 2008).

Apple is the high drying temperature and high moisture content. It is clear that the use of solar dryers provide benefits in a shorter time to achieve a better quality of dry products. Since Mersin is a leading province in both agriculture and high sunshine potential, a significant contribution can be made to the agriculture-food economy of the country by benefiting from the heating effect of the sun in the drying process in the field of food.

In this study, apple slices with moisture content which should be removed to safe storing were dried in a solar energy dryer with natural convection. Apple slices were dried using 3 methods; a solar tray dryer, exposure to direct sunlight and in the shade. Drying conditions were chosen as the amount of loaded material; slice thickness, drying time and air conditions in the drying cabinet. The effect of these drying conditions on apple solar drying was determined by water loss, drying rate and shrinkage ratio.

The aim of this study was to test the importance and efficiency of neural networks to model and predict the temperature and moisture transfer during air drying of foodstuff. The model validation was made with experimental solar drying data of apple slices. For predicting effects of the parameters such as the apple slice thickness, drying time, the apple slice load, air temperature and air humidity on water loss, shrinkage ratio and drying rate. ANFIS could be the identification of an input-output relationship between the involved solar drying parameters based on the experimental data.

On the other hand, the model structure based on input and output data during the drying process was developed using adaptive network based fuzzy inference system. This system is an artificial neural network developed by Jang (1993). It is an effective method which eliminates the inefficiency of the parameter definition process in membership functions (MF) in complex systems. Recently, it was widely used in many different field areas, such as maximum power point tracking (MPPT) (Abbasov et al., 2011; Kharb et al., 2014; Esen et al, 2009), face recognition (Sharma and Patterh, 2015), and object tracking (Choi, 2015) which transformed algorithm of ANFIS.

In this study, ANFIS is intended to be used to transform into a prediction algorithm for changes in the drying conditions of apple slices during solar powered drying process. Estimation results showed that a good modeling design was made using ANFIS. In addition, the results of error revealed that ANFIS was successfully performed.

MATERIALS and METHOD

Consists of dryer, solar collector, drying chamber and chimney. Steel perforated shelves are placed inside the dryer room, which can be easily removed and installed. The solar collector heats the air in the dryer by holding the sun rays, while the heated air rises, it dehumidifies the product on the shelves and the moist air is thrown out of the dryer and the drying process is performed (Ozturk, 2008).

Starking Delicious apple was used for the experiments. Apples went through a number of preparation stages before experiments. The apples, which were washed and peeled, were removed from the seeds and then cut into two halves and sliced in slice thicknesses determined as half a circular shape. In order to prevent browning caused by the phenolic compounds found in the apple structure (such as peeling, slicing), apple slices were immersed in a 0.3% citric acid solution (Ceylan et al., 2006).

Excess water of the sliced apples taken from the solution was filtered with the help of strainers and placed on the tray in the solar dryer, direct under sunshine and under shadows. Then, apple samples were measured both weight and volume during the drying period. These experiments were replicated five time to obtain a reasonable average.

The water loss, drying rate and shrinkage ratio were calculated according to the following equations (Aboud, 2013; Ochoa-Martínez et al., 2006).

$$\text{Water Loss} = \frac{M_0 - M_t}{M_0} \quad (1)$$

$$\text{Drying Rate} = \frac{M_0 - M_t}{\Delta t} \quad (2)$$

$$\text{Shrinkage Ratio} = \frac{V_0 - V_t}{V_0} \quad (3)$$

M_0 and M_t in Equations 1 and 2 show the weight of the apple slice before drying and the weights (g) of the apple slice after drying. V_0 and V_t in Equation 3, the sample volume before drying and the sample volume at the end of the drying process (ml). Δt indicates the duration of the drying process. Air temperature and humidity in the drying cabinet were monitored by CEM brand DT-802 model air quality measuring device.

To develop an ANFIS model for estimating the water loss, drying rate and shrinkage ratio, the data set was partitioned into a training set and a test set. Out of 120 data set available, 90 were used for training, and the remaining for testing. The performance function was the regression for analyzing. The network was trained for 100 epochs. The computation was performed in MATLAB 7.0 by the Mathworks Inc. environment.

RESULTS and DISCUSSIONS

In this study, ANFIS is intended to be transformed into a prediction algorithm for changes in the drying conditions for solar drying process. Input variables, the apple load (in1), the apple slice thickness (in2), drying time (in3), air temperature (in4) and air humidity (in5); the output variables (f) were selected in order to determine the moisture loss, shrinkage rate and drying rate. According to these design data, the developed ANFIS model structure is given in Figure 1. An ANFIS system has been arranged for each output variable estimation. The neural network in the ANFIS structure conforms to the following rule.

if (in1 is A_i) and (in2 is B_i) and (in3 is C_i) and (in4 is D_i) and (in5 is E_i) then

$$f_i = \rho_i \text{in1} + q_i \text{in2} + x_i \text{in3} + y_i \text{in4} + z_i \text{in5} + r_i$$

where, A_i and B_i fuzzy set are variables of the parameter set. f_i outputs are output variables calculated from FUZZY field. ANFIS structure used for estimation process, It can be arranged in the following form.

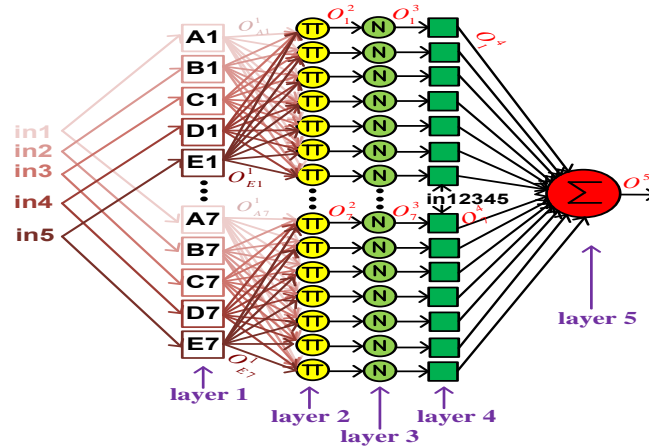


Figure 1. View of the ANFIS model structure developed.

If the layer outputs in the ANFIS system are expressed mathematically,

$$\left. \begin{aligned} O_{A_i}^1 &= \mu_{A_i}(in1) = \frac{1}{1 + \left| \frac{in1 - c_i}{a_i} \right| 2b_i}, O_{B_i}^1 = \mu_{B_i}(in2) = \frac{1}{1 + \left| \frac{in2 - c_i}{a_i} \right| 2b_i} \\ O_{C_i}^1 &= \mu_{C_i}(in3) = \frac{1}{1 + \left| \frac{in3 - c_i}{a_i} \right| 2b_i}, O_{D_i}^1 = \mu_{D_i}(in4) = \frac{1}{1 + \left| \frac{in4 - c_i}{a_i} \right| 2b_i} \\ O_{E_i}^1 &= \mu_{E_i}(in5) = \frac{1}{1 + \left| \frac{in5 - c_i}{a_i} \right| 2b_i} \end{aligned} \right\} \quad (4)$$

$$O_i^2 = \mu_{A_i}(in1) \mu_{B_i}(in2) \mu_{C_i}(in3) \mu_{D_i}(in4) \mu_{E_i}(in5) \quad (5)$$

$$O_i^3 = \frac{O_i^2}{\sum_i O_i^2} \quad (6)$$

$$O_i^4 = O_i^3 f_i = O_i^3 (\rho_i in1 + q_i in2 + x_i in3 + y_i in4 + z_i in5 + r_i) \quad (7)$$

$$O^5 = f = \sum_i O_i^4 \quad (8)$$

and output function statements,

a_i, b_i, c_i, d_i, e_i : The input is the membership function parameters.

$\rho_i, q_i, x_i, y_i, z_i, r_i$: 1st degree is polynomial parameters.

i : $0 < i < 8$

It is defined in the above format.

In order to measure the efficiency of the designed ANFIS system, 30 actual test data were used. These actual data are given in Table 1, and the estimation results obtained. The predicting of the drying efficiency of the of the water loss, shrinkage ratio and drying rate of the solar drying process is modeled ANFIS.

The model was constructed by using the experimental observations as the input set in order to identify the effects of operating parameters on the water loss, shrinkage ratio and drying rate. The data set was divided into two separate data sets randomly, the training data set and the testing data set. The training data set was used to train the proposed ANFIS model, whereas the testing data set was used to verify effectiveness of the trained ANFIS model for the solar drying process. The adequate functioning of the ANFIS depends on the sizes of the training set and the test set. The data set for the water loss, shrinkage ratio and drying rate of the solar drying process available included 120 data. From these, 90 data patterns were used for training ANFIS, and the remaining 30 patterns were used as the test data set for trained ANFIS model.

Table 1. The actual test data based on measurement

in1 (g)	in2 (mm)	in3 (min)	in4 (°C)	in5
11,91	10	270	38,8	35,1
11,8508	10	300	37,2	40,8
13,0422	10	30	31,6	55,3
12,8938	10	60	44,5	31,3
12,7832	10	90	45,9	28,5
13,1514	10	120	38,9	39,3
12,908	10	150	39,7	39,3
12,8168	10	180	42,1	35,8
12,4308	10	210	42	35,2
12,2506	10	240	41	36
11,4712	10	270	53,7	16
11,2594	10	300	50	14,7
10,8878	8	30	31,6	52,4
10,5300	8	60	43	32,1
10,0402	8	90	46,2	29,6
6,49480	4	30	34,6	53,2
6,1158	4	60	42,5	37,3
5,7936	4	90	47,9	27,5
5,3712	4	120	46,7	28,4
4,952	4	150	49,4	25,5
3,6946	4	270	41,8	37,7
3,4198	4	300	41,1	38,6
6,582533	4	30	33	57,1
6,078867	4	60	40,3	41,7
5,5462	4	90	47,5	31,2
5,17505	4	60	42,7	39,3
4,63415	4	90	46,4	32,8
4,2499	4	120	46,3	30,4
3,8507	4	150	45,5	28,7
3,44555	4	180	44,6	27

In this study, an ANFIS model was developed for the prediction of the water loss, shrinkage ratio and drying rate of the solar drying process. The proposed ANFIS model predicts the water loss, minimum shrinkage ratio and drying rate when the apple slice thickness, drying time, the apple slice load, air temperature and air humidity are given. ANFIS model achieved a mean absolute percentage error of output property of only 0.001. The model is expected to be of use for predicting the water loss, shrinkage ratio and drying rate to a satisfactory degree encouraged by these results. The error values based on the difference between the actual data and the estimation data are shown in Table 2.

Table 2. The output and error data based on predicted

Water Loss			Shrinkage Ratio			Drying Rate		
Predicted data	Measured data	% error	Predicted data	Measured data	%error	Predicted data	Measured data	%error
0,169101	0,169095	-0,00374	0,209615	0,209524	-0,04324	0,008553	0,008546	-0,07779
0,174169	0,17416	-0,00509	0,214288	0,214286	-0,00106	0,007892	0,007889	-0,04394
0,033255	0,033254	-0,00281	0,066671	0,066667	-0,00656	0,014202	0,0142	-0,0159
0,045803	0,045802	-0,00215	0,066253	0,066667	0,620337	0,009507	0,009573	0,689835
0,053696	0,053666	-0,05543	0,073208	0,070085	-4,4563	0,008144	0,007611	-7,00247
0,081819	0,081821	0,002323	0,009456	0,009458	0,024611	0,082289	0,082292	0,003931
0,099789	0,099787	-0,00224	0,009174	0,009189	0,165267	0,105	0,105	0,00031
0,105785	0,105794	0,008929	0,008168	0,008164	-0,04567	0,130555	0,130556	0,000677
0,135024	0,135027	0,002095	0,008807	0,008836	0,326047	0,13124	0,13125	0,007576
0,149189	0,149161	-0,01856	0,008493	0,008483	-0,11225	0,144177	0,144167	-0,00713
0,131973	0,131979	0,004399	0,006484	0,00646	-0,36746	0,16025	0,160256	0,003654
0,147986	0,147992	0,003723	0,006534	0,00652	-0,20892	0,167397	0,167399	0,001322
0,056059	0,056059	-0,00048	0,102856	0,102855	-0,00051	0,021527	0,021527	-0,00043
0,087165	0,087166	0,000721	0,118655	0,118648	-0,00609	0,016726	0,016727	0,005397
0,129831	0,129832	0,001023	0,151986	0,151981	-0,00311	0,016383	0,016385	0,011773
0,109689	0,10969	0,000587	0,136902	0,136905	0,002107	0,026566	0,026567	0,002789
0,161846	0,161848	0,001243	0,169039	0,169048	0,005489	0,019751	0,0199	0,749673
0,206264	0,206265	0,000246	0,247023	0,247024	0,000498	0,016648	0,016647	-0,00688
0,264401	0,264402	0,000458	0,29285	0,297619	1,602414	0,015825	0,015642	-1,17121
0,322012	0,322012	0,000127	0,391361	0,391369	0,00194	0,015424	0,015248	-1,15099
0,43595	0,435949	-0,00015	0,527765	0,527778	0,002521	0,009944	0,009942	-0,02494
0,466259	0,466259	-3,10e-5	0,559376	0,559392	0,002858	0,009865	0,009864	-0,01346
0,065776	0,065776	-1,76e-5	0,142855	0,142857	0,0013	0,019267	0,019267	0,002579

0,159608	0,159608	-0,0001	0,149988	0,15	0,008243	0,014332	0,014331	-0,00527
0,24896	0,24896	4,80e-5	0,24026	0,24026	6,02E-06	0,01293	0,012928	-0,01281
0,259821	0,259822	0,000252	0,16666	0,166667	0,004448	0,018926	0,018925	-0,00492
0,336217	0,336217	0,000128	0,324994	0,325	0,001917	0,01697	0,016969	-0,00691
0,403741	0,403742	0,000311	0,350011	0,35	-0,0032	0,015396	0,015394	-0,01116
0,439838	0,439837	-0,00017	0,416653	0,416667	0,003348	0,014897	0,014895	-0,01044
0,507857	0,507858	0,000158	0,50833	0,508333	0,000623	0,014012	0,01401	-0,01687

The ANFIS parameters were optimized using Matlab's Neuro Fuzzy Tool. The input MF function gauss and the output MF function as linear were selected for the optimization process. In addition, the training process was carried out by selecting hybrid. Then, the predictive power of the optimized ANFIS was calculated based on the regression function value.

$$R^2 = 1 - \frac{\sum (y - \hat{y})^2}{\sum (y - \bar{y})^2} \quad (9)$$

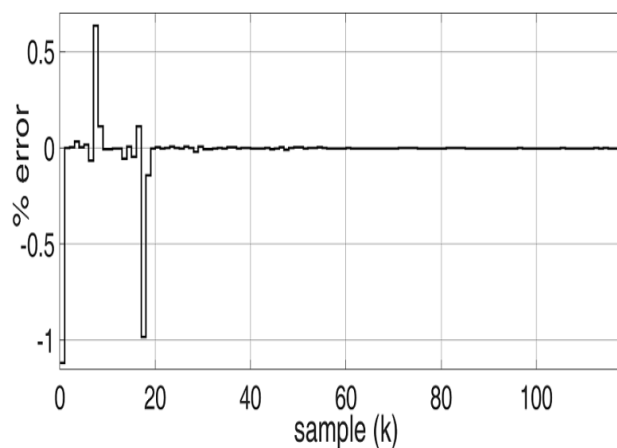
Where,

y: real data

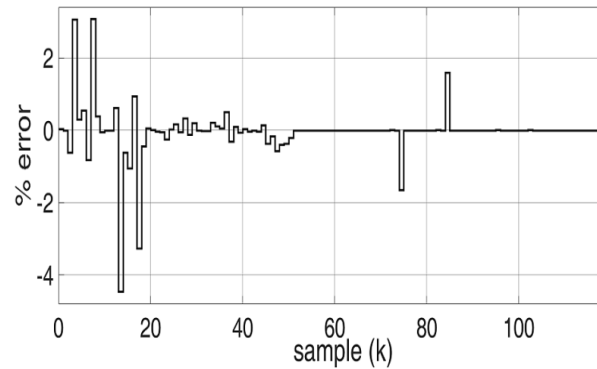
\hat{y} : estimated data

\bar{y} : the average of measured data.

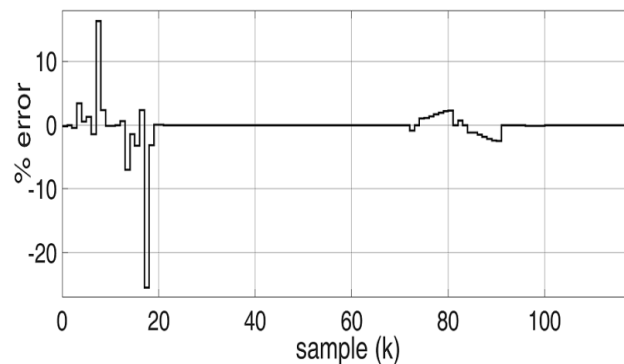
The R^2 values, in the prediction simulation performed were obtained as shown in Figure 2.



$$R^2_{water\ loss} = 0.9968$$



$$R_{shrinkage\ ratio}^2 = 0.9675$$



$$R_{drying\ rate}^2 = 0.9918$$

Figure 2. The R^2 values based on the water loss, shrinkage ratio and drying rate

CONCLUSIONS

The drying of apple slices with a solar tray dryer has been quicker than the direct sunshine and drying in the shade. Both water loss and shrinkage ratio have increased due to increased air temperature in the dryer and it also reduced slice thickness of the apple whilst increasing drying time and amount of loaded material. This study shows that the adaptive neural network based fuzzy inference system modeling can be used to obtain good solar drying modeling of apple slice. The ANFIS modeling was validated with experimental drying data. The modeling must be related to the fact that it is elaborated without any preliminary assumptions on the underlying mechanisms as simply and rapidly. The applications of ANFIS can be used for the on-line state estimation and control of solar drying processes.

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