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PSO-RBFNN Based Optimal PID Controller and ANFIS Based Coupling for Fruits Drying System

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Abstract

INTRODUCTION: Preservation of fruits by drying is one of the general and important traditional technique followed by the process industries. An accurate controller of relative humidity and temperature is required for the fruit drying control system, which determines the quality of the dried fruits.
OBJECTIVES: To design optimal Propositional-Integral-Derivative (PID) controller based on the Particle Swarm Optimization and Radial Basis Functional Neural Network (PSO-RBFNN) for pineapple drying system.
METHODS: A Propositional-Integral-Derivative (PID) controller based on the Particle Swarm Optimization and Radial Basis Functional Neural Network (PSO-RBFNN) was proposed in this paper for pineapple drying system. Also, the coupling relationship of relative humidity and temperature is more complicated due to the fluctuations and non-linearity in the drying system. An intelligent Adaptive Neuro Fuzzy Inference System (ANFIS) coupling model is utilized in this paper to access the coupling relationship between relative humidity and temperature.
RESULTS: The proposed control system has been implemented in the MATLAB and results are compared with PID controller, Fuzzy Logic Controller (FLC) and Fuzzy PID controller for the performance constraints such as settling time, peak over shoot and steady state error.
CONCLUSION: The proposed PSO-RBFNN based PID controller gives better control performance with the highly minimized settling time (42 sec for humidity and 40 sec for temperature) and completely eliminated steady state error and Peak overshoot. Finally, the PSO-RBFNN algorithm based PID controller is concluded as the effective system.

Keywords: Fruit drying, Adaptive Neuro Fuzzy Inference System (ANFIS), Propositional-Integral-Derivative (PID) controller, Particle Swarm Optimization (PSO), Fuzzy Logic Controller (FLC).

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1. Introduction

Today, consumption of dehydrated fruit is extensive and produced in most regions. Almost half of the dried fruits used are traditional dried fruits such as raisins, dates, apples and pears which can be dried in heated wind tunnel dryers or in the sun. Proper drying allows fruits to be preserve for longer period by minimizing the micro-organic substances which is used for food business and self-consumption and also an alternative source for income [1]. The majority of water contents removed from dried fruits either sundry or through naturally or use of dehydrators or specialized dryers. During the drying process the smell, taste and shape of the fruit should not be changed due to water content removal from fruits [2]. Over dried fruits lead to lower weight and also not enough dried fruits can form mould growth which provides lesser income to producers as their earnings are regarding on both qualitative and quantitative means. The quality of dried fruits mainly depends on the temperature and humidity so that they should be controlled to meet the standard quality [3]. Relative humidity and temperature controllers are the main controllers in the fruit drying control system. They are closely related with each other in a fruit drying chamber [4]. But fruits drying is a dynamic, complex, powerfully interactive, instable, sequentially interconnected, highly nonlinear and multivariable thermal process [5]. The drying process has complexity leads to an even more difficult problem due to mass and heat transfers, instantaneous transient coupled momentum, transformations of phase, time-varying structural and physicochemical variations of the dried fruits being dried, intensive biochemical and chemical reactions, abrupt surface hardening and irregular component migration. Additionally, in a typical process of drying, some main constraints including product treatment or formulation and drying conditions which direct the quality of the dried fruits, should be analysed [6].

The important control parameters in the fruit drying process are the temperature and the humidity. For a real fruit drying system, a coupling model was designed for humidity and temperature control systems [7]. However, change in temperature can cause fluctuations of coupled signals which lead to complex and nonlinear humidity variable [8]. The control system should identify and compensate the fluctuations in the humidity which is non-linear and tricky. Thus, an intelligent controller is needed for improve the performance of fruit drying system [9]. This issue directs engineers and scientists to analyse and design intelligent coupling systems for effective way control of relative humidity and temperature. The PID controller is the generally used system for closed-loop control, utilizing a PID is the simplest and easiest method to develop the system for fruit drying chamber control [10]. Moreover, with conventional PID control systems, previous literatures have proposed alternate approaches for controlling the temperature and humidity of the drying chamber [11-13]. The experts fixed conventional PID controller parameters cannot be changed online, which leads to more trouble to attain the expected quality [14]. The conventional PID controller is required to additional advance in the performance to shorten steady state error, peak over shoot and settling time. In [15] RBFNN based PID controller was proposed to control the pineapple drying. Other studies have used FLC controller and FLC-PID controller for the fruit drying system [16]. RBFNN appeared as a better artificial neural network (ANN), have been effectively employed to variety of control applications [17]. The nonlinear parameters' global optima in the hidden layer cannot possibly find by the common RBF training algorithms, and regularly have more hidden layers to attain particular estimation capabilities, which will make maximize a measure for the network and minimize the ability of generalization [18]. A global optimization method based on the group intelligence is called PSO algorithm, so as to find the optimal solution for the solution space, it using mutual effect to carries on the intelligent search [19].

In this paper PSO-RBFNN based PID controller is proposed to advance the performance. The PSO-RBFNN-PID controller structure consists of three major divisions. One is a PID controller engaged for humidity control of indoor and another part is RBFNN which is used for adjusting the parameters of PID and PSO process is utilized to find the constraints and structure in hidden unit of RBF and linear output weights of RBF also [20]. RBF with strong capability for global approximation and fast convergence speed can estimate any nonlinear and continuous networks with arbitrary accuracy and gives improved performance in problem-solving of the nonlinear system. The coupling between humidity and temperature has been implemented by ANFIS coupling model. The human thinking idea is incorporated into the control system by the fuzzy logic and neural network [21]. It is observed that according to the performance constraints like settling time, peak over shoot and steady state error that high accurate humidity and temperature control can be achieved only by PSO-RBFNN based PID controller. to modify the response speed, tracking performance and control accuracy of the system.

The main aim of this paper is to implement a PSO-RBFNN based PID controller for relative humidity and temperature plant models for various fruits drying process. Here, the coupling model between humidity and temperature has been identified by ANFIS. The entire intelligent control system for drying of various fruits like grape, pineapple and mango has been developed. The Fuzzy Logic Controller (FLC), PID controller, PSO-RBFNN-PID controller and Fuzzy PID controller performances were compared and analysed. The paper is organised as follows: section 2 presents the introduction of fruit drying system. Section 3 presents the ANFIS coupling model for temperature and relative humidity controllers. Section 4 proposed the PSO-RBFNN based PID controller for fruit drying. Section 5 shows the simulation results and comparison results of various controllers. Finally, section 6 provides conclusion.

2. System Configuration and Coupling Model

2.1 Proposed Batch Drying Chamber

This paper presents drying of various fruits like Mango, Grape and Pineapple. Some fruits are cut into halves, whole or into some pieces before drying. The fruits of sweet smell and strong like mango and pineapple are cut into pieces of thickness will be less than 1cm or about ¼ inch. For drying of grape, it can be taken as whole. The drying chamber has dimensions about 3.7 feet length, 2.8 feet width and 3.5 feet height. M/S. Vinoth Engineering Company, Coimbatore fabricated the proposed drying chamber. An EYCTHM80X series temperature humidity sensor is the instrument employed to find the relative humidity and temperature. The PID, fuzzy PID, FLC and PSO-RBFNN control algorithms are used in this chamber and real data are measured and compared with simulated results. Approximately 50°C-60°C temperature is fixed in the chamber. The Figure.1 display working model of the proposed Fruits Drying Chamber.

Figure 1. Working model of Proposed Fruits Drying Chamber

2.2 Control of Fruit Drying system

The fruit drying process can be controlled by either conventional controller (PID) or by intelligent controllers like ANN and FLC or by combinations of both intelligent and conventional control strategies. The main drawback of control system is the coupling between relative humidity and temperature. During the pineapple drying process, the fluctuations in the drying chamber is non-linear. Therefore, the fluctuations should be accounted and compensated in the humidity control process. Figure.2 shows the two different control loops of fruit drying control process.

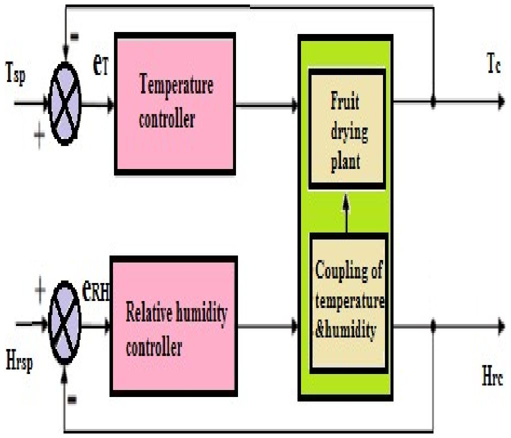


Figure 2. Fruit Drying control system

2.3 ANFIS Coupling Model

During the process of operation, the fluctuations in the humidity are non-linear and tricky. Therefore, the fluctuations in the humidity should be identified and compensated. Because of the coupling is nonlinear and complex, the ANFIS is utilized to design the coupling model between the relative humidity and temperature. ANFIS is a mixture of Fuzzy Inference System (FIS) and ANN. ANFIS employed an algorithm of hybrid learning. A coupling model is needed to develop the complete control system.

The architecture of ANFIS in a forward network contains five layers. The ANFIS employed by an algorithm of hybrid learning. This algorithm is a mixture of gradient rule and least square estimation. In case of the forward pass, to recognize the resulting constraints on the 4th layer, the method engaged is least-square estimation. Similarly, in case the backward pass, propagation of errors is backward and the constraints are modified by the method of gradient descent.

To develop the pineapple drying chamber control system, the ANFIS coupling model is required. The ANFIS architecture consists of five layers. Figure 3 displays the architecture of ANFIS. The coupling model has one input and one output. The input is temperature and the output are relative humidity. A hybrid learning algorithm is used to train the ANFIS coupling model. Gradient rule and least square estimation method are used to derive the hybrid learning algorithm. The errors are propagated backward in the backward pass, and by the gradient descent technique the constraints are updated. To train ANFIS tool in MATLAB, the FIS of the proposed coupling model is linked with a couple of the output and input data gained from the fruit drying chamber. ANFIS produces the FIS by using the obtained output and input data set and the membership functions of the fuzzy are adjusted by Back Propagation Algorithm (BPN). In this study, nine input membership functions are used in the input of FIS model of coupling between humidity and temperature. The intended model of coupling is the temperature as an input and the relative humidity as an output.

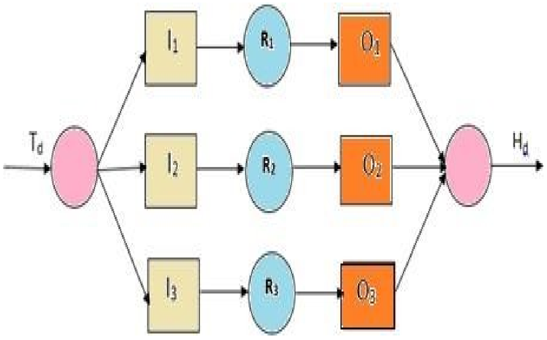


Figure 3. Architecture of ANFIS

The fuzzy rules applied to the ANFIS coupling model are;

1. If I_1 is '- 'ive Big (NB) THEN O_1 is '+'ive Big (PB).
2. If I_2 is 0 (Z) THEN O_2 is Zero(Z).
3. If I_3 is '+' ive Big (PB) THEN O_3 is '- 'ive Big (NB)

3. Design of Pso-Rbfnn Based Pid Controller

A PSO- RBFNN based PID control algorithm is developed to control pineapple drying chamber. The structure of the PSO-RBFNN based PID controller has ANN and PID controller which is used for controlling the humidity, RBFNN which is utilized to tune the parameters of the PID (k_p, k_i and k_d) automatically and PSO is utilized to find the architecture and constraints in hidden layer of RBF, and linear output weights of RBF also. The structure of the PSO-RBFNN based PID controller is presented in the Figure 4. Therefore, the time taken for regulating the PID parameters is very much reduced.

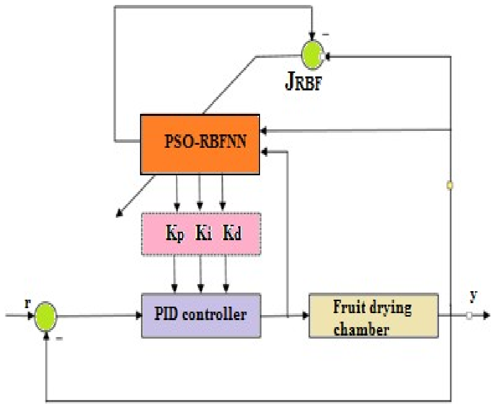


Figure 4. PSO-RBFNN based PID controller

3.1 PID controller function optimization using PSO-RBFNN algorithm

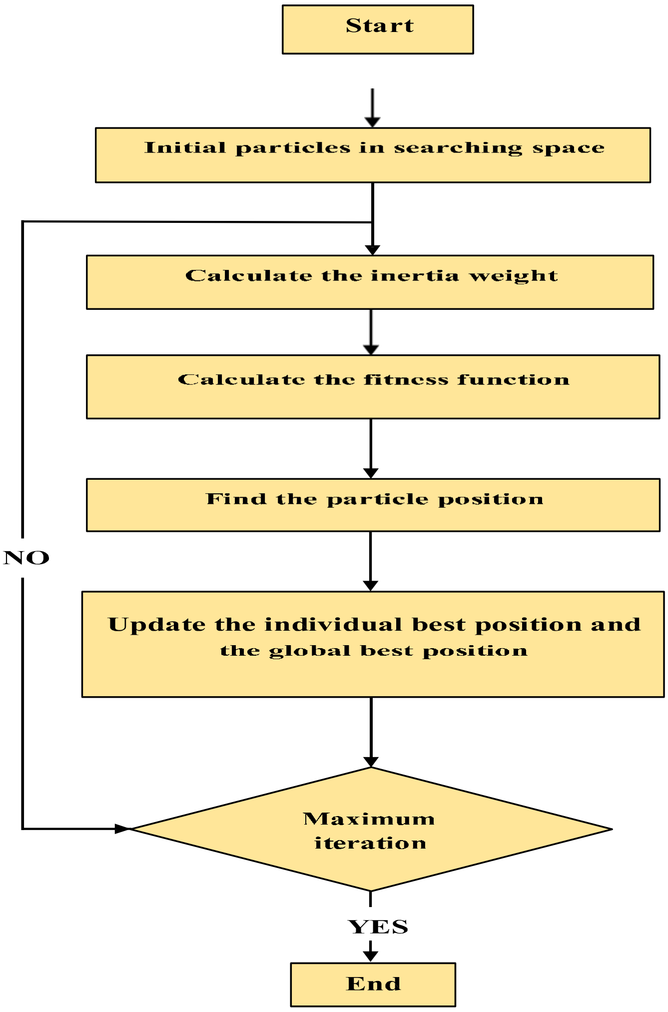


Figure 5. PSO flowchart

Recent researches proposed PSO as AI method utilized for iteratively find the fitness values and optimal locations. The main aim of the process is to simulating the searching behaviours of birds. Figure 5 presents a flowchart showing the PSO.

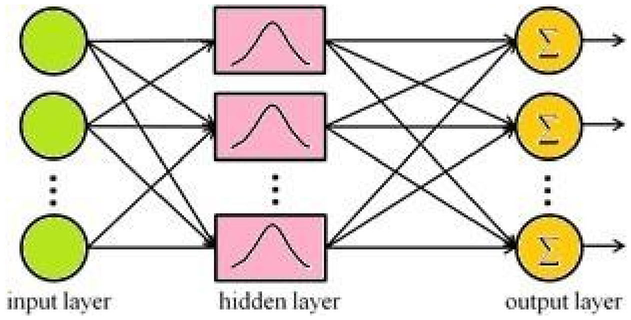


Figure6. Architecture of RBFNN

The RBFNN is a three-layer neural network. Hidden, Input, and output layer are the three layers of RBFNN. In this RBF network two inputs are used. In the PSO-RBFNN PID controller, the data is collected at the sampling rate of k and the output network is calculated. Then the developed RBFNN is ready to tune k_p, k_i and k_d parameters precisely by utilizing the Jacobian matrix. The architecture of RBFNN is presented in the figure.6.

3.2 Procedure for design of PSO-RBFNN based PID controller

The PID controller function optimizing was the objective. The RBFNN flowchart is depicted in the figure 7. The optimization methods for PSO- RBFNN based PID was presented as below.

Step 1: Based on the fruit drying system transfer function, select the control parameter range k_d.

Step 2: Select the values for k_d and the primary PSO particles in space of k_p-k_i parameter. Denote minimal and maximal values for velocity and position. Select the value of maximal iteration.

Step 3: Start the particles movement by utilizing a random velocity and position.

Step 4: Measure the fitness value of IAE for every PSO particle.

Step 5: Select the global and optimal local values for every particle based on the minimal fitness values of IAE, and modify the optimal global and individual positions in parameter space of k_p-k_i.

Step 6: Use Step 3–4 until reach the PSO maximal iteration counts.

Step 7: Alter k_d and use Step 6 until calculate all parameters of k_d.

Step 8: According to the training results of PSO, optimize the control parameters of PID’s operating values, and measure the parameters of RBF.

Step 9: Measure the output and hidden layers values.

Step 10: Use Step 8–9 until reach the RBF maximum iteration counts.

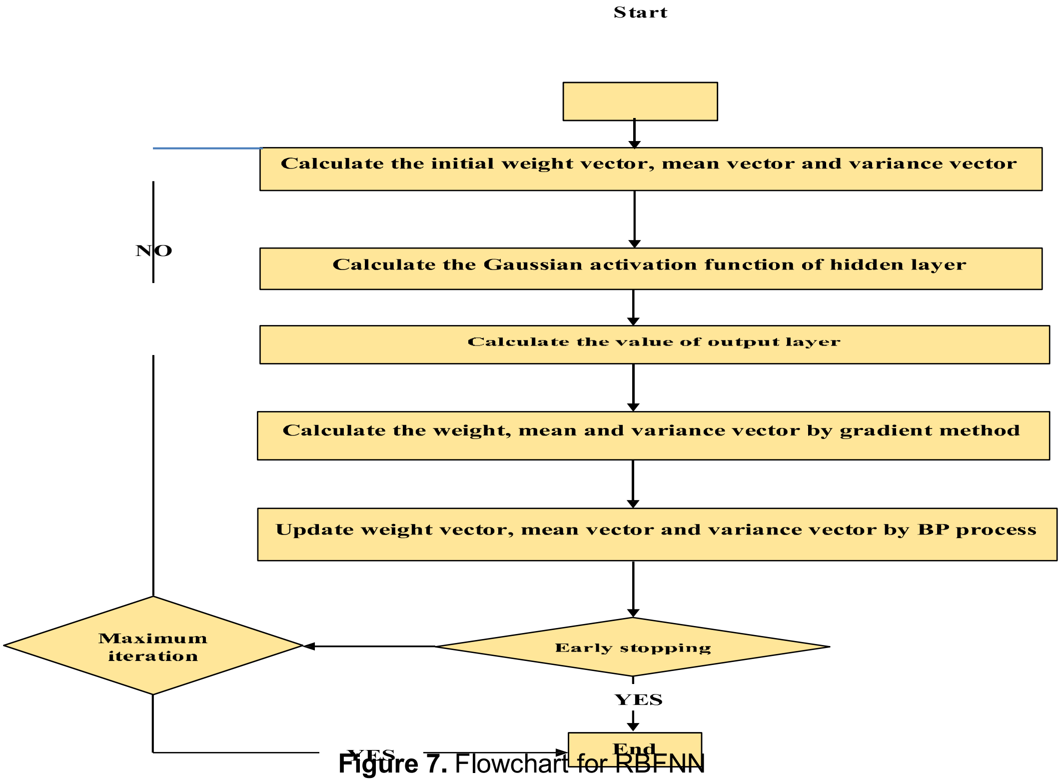
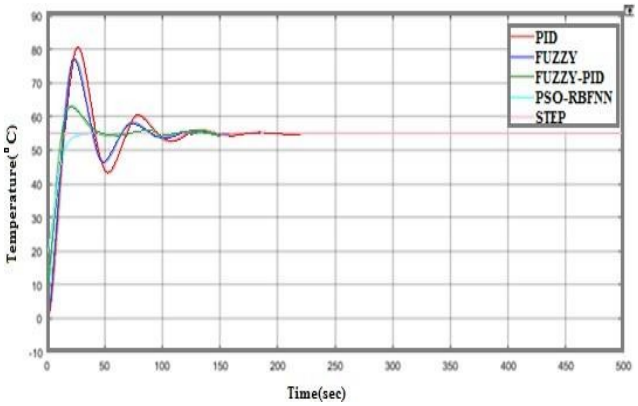


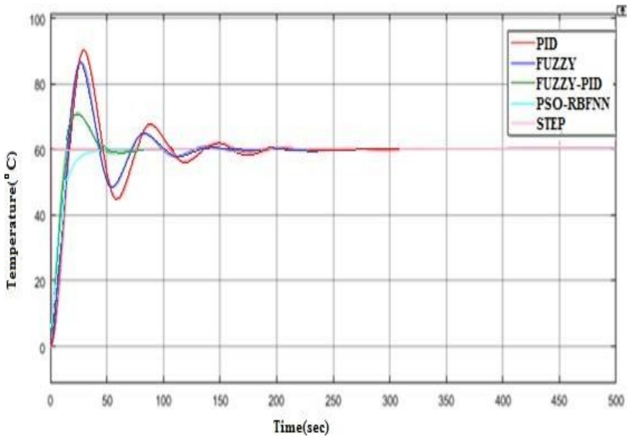
Figure 7. Flowchart for RBFNN

4. Simulation Results and Discussion

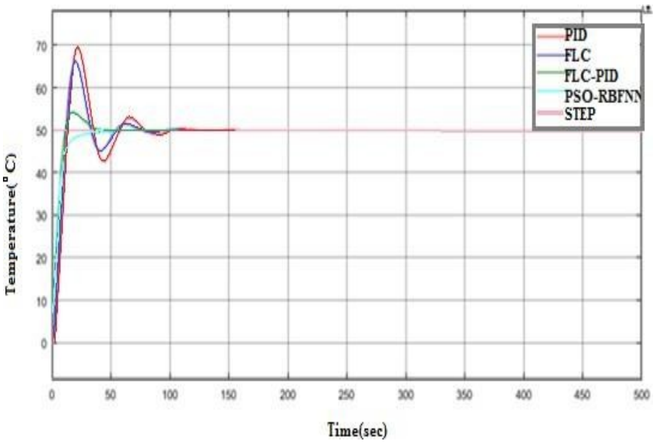
The PSO-RBFNN based PID controller is simulated by using MATLAB and the time response performance has been analysed. On comparing with the PID, FLC, FLC-PID controller the PSO-RBFNN based PID control system gives good control performance. Comparison of all the controllers for temperature control system of grape, mango and pineapple is presented in fig.8(a), (b), (c) respectively. Figure 9(a), (b), (c) presents the comparison of all the controllers of humidity control system for grape, mango and pineapple respectively.



(a)

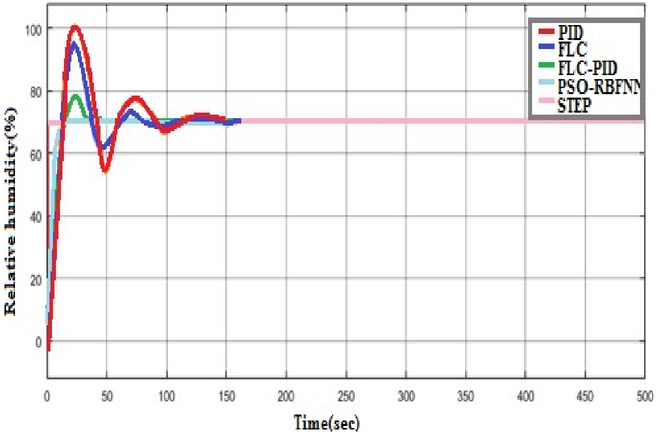


(b)

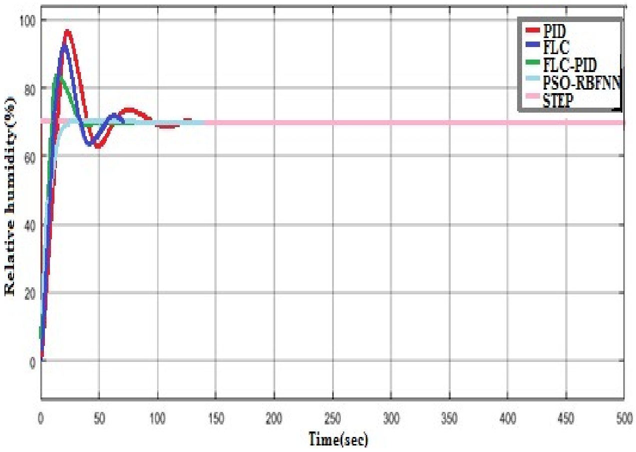


(c)

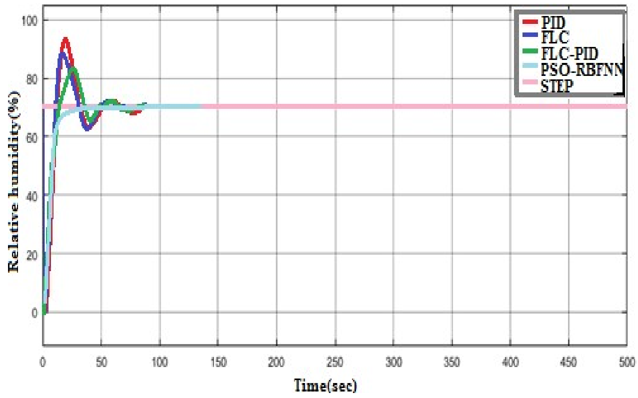
Figure 8. Comparison of all the controllers for temperature control system of (a) grape (b) pineapple (c)mango drying process



(a)



(b)



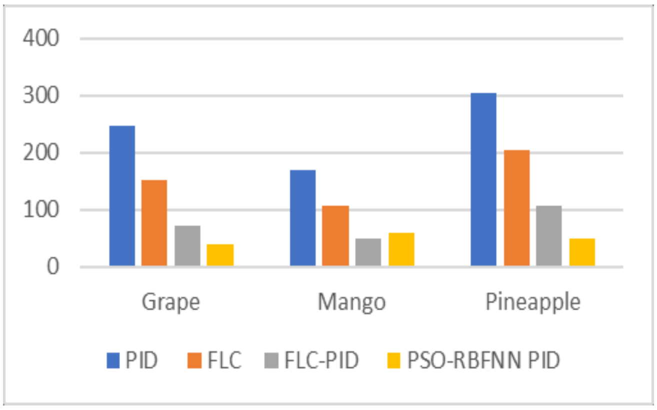
(c)

Figure 9. Comparison of all the controllers for humidity control system of (a) grape (b) pineapple (c)mango drying process

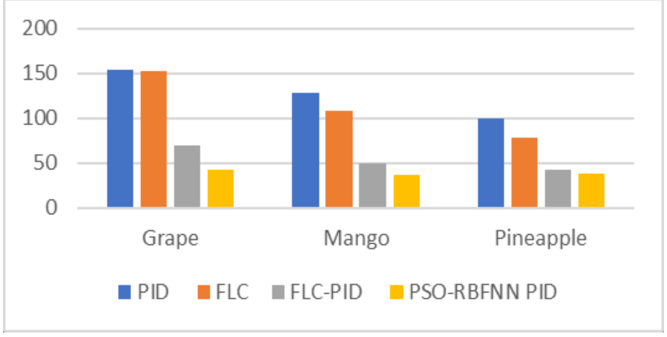
The Performance Analysis of Various Controllers for temperature & humidity control system in the aspect of Settling Time is presented in table.1 and comparison chart for temperature & humidity control in the table.1 is illustrated in figure.10(a), (b) respectively. The settling time is minimum in the proposed controller when compared with other controllers.

Table 1. Performance Analysis of Various Controllers for temperature &humidity Control system in the aspect of Settling Time

Fruits	**Temperature**				**Humidity**			
	PID	**FLC**	**FPID**	**PSO-RBFNN**	**PID**	**FLC**	**FPID**	**PSO-RBFNN**
Grape	248	152	72	40	154	152	70	42
Mango	170	106	50	58	128	108	49	36
Pineapple	304	204	108	48	100	78	43	38



(a)



(b)

Figure 10. Comparison of Various Controllers for (a) temperature & (b)humidity Control system in the aspect of Settling Time

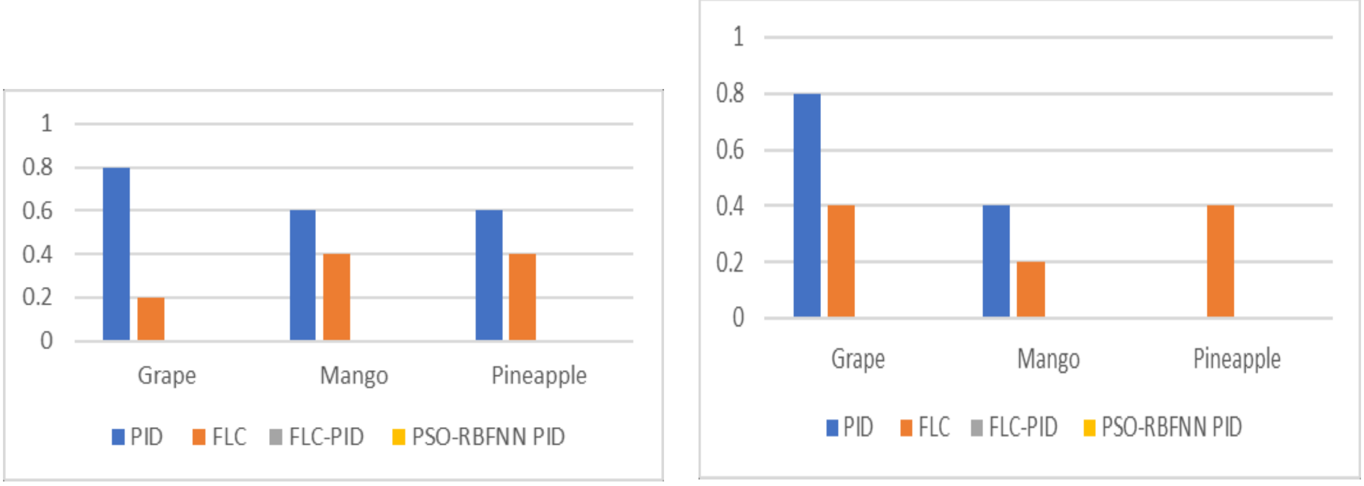
The Performance Analysis of Various Controllers for temperature control system in the aspect of maximum overshoot is presented in table.2 and comparison chart for temperature & humidity control in the table.2 is illustrated in figure.11(a). The maximum overshoot for proposed temperature and humidity controller is completely eliminated when compared to the other controllers.

The PID controller response for the fruit Grape displays that the Peak overshoots (58% for humidity and 48% for temperature), the settling time (154 sec for humidity and 248 sec for temperature) are more and steady state error (0.8% for both humidity and temperature) is existing in the performance. The FLC offers reduced Peak overshoot (40 % for temperature & 35% for humidity) and Settling time (152sec for both temperature &humidity) with significantly minimized steady state error (0.2% for temperature 0.4% for humidity) when compared with PID.

The FPID controller offers reduced peak over shoot (11% for humidity and 13 % for temperature), the settling time (70 sec for humidity and 72 sec for temperature) and completely eliminated steady state error when related to PID & Fuzzy logic controller. The RBFNN- PID controller gives better control performance and accuracy with the highly minimized settling time (42 sec for humidity and 40 sec for temperature) and completely eliminated steady state error and Peak overshoot. Thus, the proposed PSO-RBFNN based controller is an effective control system for fruit drying system.

Table 2. Performance Analysis of Various Controllers for temperature &humidity Control system in the aspect of Maximum Overshoot

Fruits	**Temperature**				**Humidity**			
	PID	**FLC**	**FPID**	**PSO-RBFNN**	**PID**	**FLC**	**FPID**	**PSO-RBFNN**
Grape	48	40	13	0	58	35	11	0
Mango	38	32	10	0	32	31	16	0
Pineapple	52	43	18	0	31	27	13	0



(a)

(b)

Figure 12. Comparison of Various Controllers for (a)temperature & (b)humidity Control system in the aspect of Steady State Error

5. Conclusion

In this paper, the relative humidity and temperature plant models for various fruits drying process have been implemented. The coupling model between humidity and temperature has been identified by ANFIS. The entire intelligent control system for drying of various fruits like grape, pineapple and mango has been developed. The Fuzzy Logic Controller (FLC), PID controller, PSO-RBFNN-PID controller and Fuzzy-PID controller performances were compared and analysed. The performance of PSO-RBFNN based PID controller have reduced settling time (42 sec for humidity and 40 sec for temperature) and completely eliminated steady state error and peak overshoot. Finally, the PSO-RBFNN algorithm based PID controller is concluded as the effective control system for various fruit drying process.

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