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Achieving expected depth of shade in reactive dye application using artificial neural network technique

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Abstract

Achieving the expected depth of shade in the production of dyed goods is a very important aspect. It requires the termination of the process at the right time in other words, correct duration of dyeing should be used. Prediction of this duration for the application of reactive HE dyes on cotton fabric using artificial neural network (ANN) is reported. The results obtained from the network gives an average training error of around 1% in the prediction of the time duration for achieving the correct depth of shade. The trained network gives the same average error % when tested with other reactive HE dyes even when the input parameters selected are beyond the range of inputs, which were used for training the network.

Keywords: Artificial neural network; Neuron; Sigmoid function; Hidden layers; Total dye fixed; Spectral reflectance curve

1. Introduction

Expected depth of shade is one of the very important qualities to be achieved in the dyed goods. In case, the depth produced is different from that of the expected, the product has to be either taken for reworking or rejected.

When goods are taken for dyeing, once the recipe and the conditions of dyeing for a given machine is fixed, the only parameter which needs attention to achieve the expected depth of shade is "the duration of the process". The required dyeing duration for a given situation can be predicted using statistical tools such as multiple regression analysis or computational processors such as artificial neural networks (ANN). Prediction using ANNs is claimed to have better accuracy compared to multiple regression analysis [1,2].

Neural networks are used for modelling non-linear problems and to predict the output values for a given input parameters from their training values. Most of the textile processes and the related quality assessments are non-linear in nature and hence neural networks find application in textile technology. Web density control in carding [3], prediction of yarn strength [4], ring and rotor yarn hairiness [5], total hand evaluation of knitted fabrics [6], classification of fabric [7] and dyeing [8] defects, tensile properties of needle punched non-wovens [2], quality assessment of carpets [9], dye concentrations in multiple dye mixtures [1], modelling of the H_2O_2/UV decolouration process [10], automated quality control of textile seams [11], fabric processability in garment making [12] and evaluation of seam puckering in garments [13] are some of the areas where ANNs have been attempted.

An attempt made on the prediction of dyeing time required to achieve expected depth of shade in the application of reactive HE dyes on cotton fabric using ANN is reported in this paper.

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2. ANN

ANNs are typically composed of interconnected "units" which serve as model neurons. The schematic diagram of typical ANN is shown in Fig. 1. The function of the synapse is modelled by a modifiable weight, which is associated with each connection. Each unit converts the pattern of incoming activities that it reacts with into a single outgoing activity and then broadcasts it to other units. It performs this conversion in two stages. First, each incoming activity is multiplied by the weight on the connection and all these weighted inputs are added together to get a quantity called 'total input'. Secondly, an input–output function transforms the total input into an outgoing activity [14].

The commonest type of ANN consists of three groups or layers of units: (i) A layer of input units connected to (ii) a layer of hidden units, which in turn is connected to (iii) a layer of output units. The activity of the input units represents the raw information that is fed into the network. Whereas, the activity of each hidden unit is determined by the activities of the input units and the weights on the connections between the input and the hidden units. Similarly, the behaviour of the output units depends on the activity of the hidden units and the weights between the hidden and the output units.

3. Materials

The following bleached commercial cotton fabrics were used in this study.

Plain fabric with (a) EPI-80, PPI-94, $35^s \times 37^s$ and 121 gsm and (b) EPI-74, PPI-66, $37^s \times 31^s$ and 104 gsm and a twill fabric with EPI-96, PPI-56, $13^s \times 12^s$ and 291 gsm.

Three reactive HE dyes namely Procion Brilliant Red HE 3B, Procion Green HE 4BD and Procion Brilliant Red HE 7B supplied by Atul limited, Bombay, India were used in this study. Dyeing auxiliaries such as salt (NaCl) and alkali (Na_2CO_3) used were of LR grade. The soap solution used belonged to commercial grade.

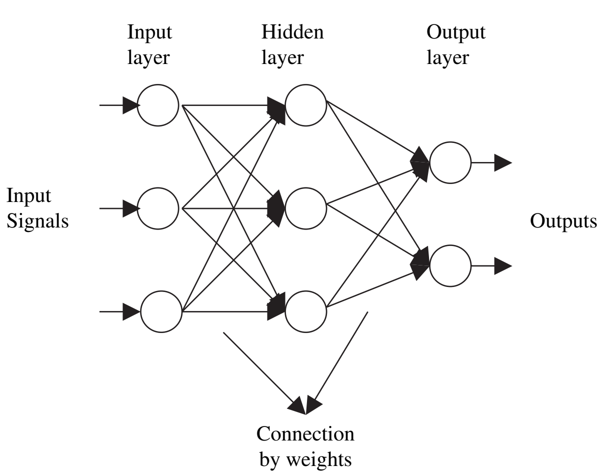

Fig. 1. Schematic diagram of typical ANN.

4. Methods

4.1. Dyeing procedure adopted

Prior to dyeing, the fabrics were pretreated using 10 g/l soap solution at boil for 1 h and washed thoroughly. The pretreated material was introduced in a bath containing the dye and the temperature was gradually raised to 80 °C. The dyeing was continued till the end of the primary exhaustion time. During this duration salt additions were made in three steps. Then, the required amount of alkali was added and dyeing was continued till the end of the fixation time. The parameters used for dyeing for the production of various samples are given in Table 1. Washing of dyed samples were carried out by using alternate cold wash with running tap water for 5 min and hot soaping at 70 °C for 5 min thrice. Finally, the samples were thoroughly washed with running tap water.

4.2. Determination of K/S value

The K/S value was calculated using the formula given below [15] from reflectance value (R) at λ_{max} (Table 2) measured using UV–vis spectrophotometer, U-3210, Hitachi, Japan.

$$K/S = \frac{(1-R)^2}{2R}$$

4.3. Determination of % total dye fixed on the fabric (T)

T of the fabric was calculated using the formula given below [16,17],

$$T = E\left(\frac{K_2}{K_1}\right)$$

where, E is the % dye bath exhaustion; K_1 is K/S value of dyed sample before soaping; K_2 is K/S value of dyed sample after soaping.

The % dye bath exhaustion was calculated using the formula given below from absorbance value at λ_{max} (Table 2) measured using UV–vis spectrophotometer, U-3210, Hitachi, Japan.

$$E = 100\left(1 - \frac{A_2}{A_1}\right)$$

Table 1
Dyeing parameters

Samples	Dyeing parameters					
	% Shade	Liquor ratio	NaCl (g/l)	Na_2CO_3 (g/l)	Primary exhaustion time (min)	Fixation time (min)
Samples for determination of % total dye fixed	3	40:1	80	20	30	30
Training samples	0.5	40:1	40	20	10, 20, 30	10, 20, 30
	1.25	40:1	60	20	10, 20, 30	10, 20, 30
	2.0	40:1	60	20	10, 20, 30	10, 20, 30
	2.75	40:1	80	20	10, 20, 30	10, 20, 30
	3.5	40:1	80	20	10, 20, 30	10, 20, 30
Testing samples	0.25	40:1	35	15	15	15
	1.0	40:1	35	20	15	15
	1.75	40:1	35	30	15	15
	2.5	40:1	45	30	15	15
	3.25	40:1	45	30	15	15
	4.0	40:1	50	30	15	15

where, A_1 is the absorbance of dye solution before dyeing at λ_{max}; A_2 is the absorbance of dye solution after dyeing at λ_{max}.

5. Development of neural networks

The software used in this study was a feed forward back propagation network [18]. In order to carry out prediction, the network was trained with training patterns namely input and output parameters.

5.1. Training patterns

Input and output parameters used for training the ANN and their selection criteria are given below.

5.1.1. Input parameters

(i) K/S values of the undyed fabrics: To reflect the extent of preparation that the fabrics to be dyed has undergone.
(ii) T for a selected % shade: To reflect the dyeing behaviour of dyes on a given fabric for a selected NaCl and Na_2CO_3 concentrations.
(iii) Percentage shades: To reflect the depth of colour produced.
(iv) NaCl concentrations: To reflect the effect on primary exhaustion of the dyes.
(v) Na_2CO_3 concentration: To reflect the effect on fixation of the dyes.
(vi) K/S values of the dyed and washed samples: To reflect the amount of dye present in the samples produced with different depth of shades and corresponding salt and alkali concentrations.

Table 2
λ_{max} values used for absorbance and reflectance measurement

	Procion Brilliant Red HE 3B (nm)	Procion Green HE 4BD (nm)	Procion Brilliant Red HE 7B (nm)
Absorbance	519	625	531
Reflectance	645	491	636

5.1.2. Output parameters

(i) Time for primary exhaustion: To reflect the extent of dye bath exhaustion in the primary stage.
(ii) Time for dye fixation: To reflect the extent of dye fixed on the fabric after completion of the dyeing process but before washing.

5.2. Training of neural network

For training, dyed samples were produced using the dyes Procion Brilliant Red HE 3B and Procion Green 4BD. The neural network was trained by using feed forward back propagation algorithm. For an error back propagation net, the sigmoid function is essentially

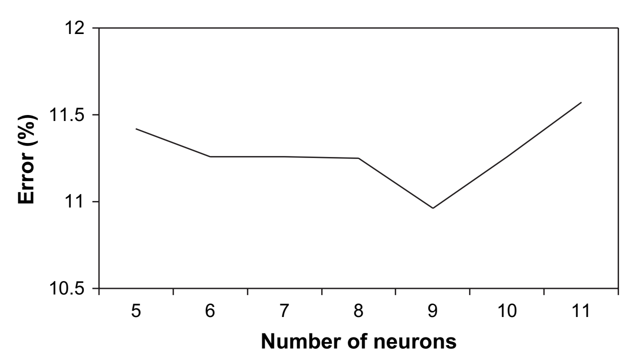

Fig. 2. Effect of number of neurons in hidden layers on error.

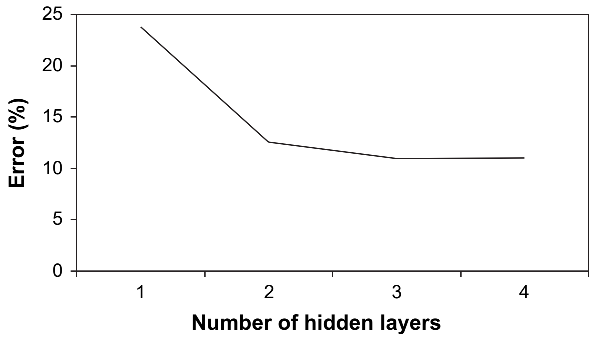

Fig. 3. Effect of number of hidden layers on error.

suitable because it is continuous and monotonically non-decreasing as well as differentiable. One of the most typical activation functions is the binary sigmoid function, which has a range of (0,1) and is defined as,

$$F(x)=1/(1+\exp(-x))$$

Since the binary function has a range of (0,1), the values of input and output parameters have to be scaled down between 0 and 1 by normalizing them with suitable factors. The network was trained using the normalized input and output parameters. Training process of the neural network developed was started with 10,000 preliminary cycles to optimise the ANN prediction accuracy. These cycles were carried out with different network structures and different learning parameter values and the network training errors were obtained which are shown in Figs. 2 and 3. The best structure is the one that gives lowest training error and it is found to be 6/9/9/9/2 in the present case. The neural network structure used in this study is given in Fig. 4. The training of the network was further continued in order to reduce the training error. The average training error of 1.0% was obtained, when 100,000 cycles were used. The training of the network was terminated at this stage since beyond this the reduction in training error was not appreciable.

5.3. Testing of neural network

For testing the prediction accuracy of the neural network a twill fabric with unknown specifications and a dye namely Procion Brilliant Red HE 7B were selected. K/S value of the fabric and the % T of the fabric dyed with above dye were found out. Further, using dyeing parameters given in Table 1, testing samples were produced and K/S values of these samples were found out. It can be observed from the table that for the production of testing samples, % shades were selected beyond the range used for training the network. Followed by this, the input parameters were fed into the neural network and the corresponding output parameters namely primary exhaustion time and fixation time were obtained. These predicted timings along with the actual timings are given in Table 3. It can be observed that the mean absolute error with respect to prediction is around 1%. Using the predicted timings samples were produced keeping the dyeing parameters same as that of the testing samples (Table 1). The spectral reflectance curves of samples produced with actual and predicted timings are given in Fig. 5. As these curves show insignificant difference with respect to various % shades, it can be said that the network developed can be used to predict the dyeing time for achieving expected depth of shade.

5.4. Practical application of the developed neural network

When a target dyed with known reactive HE dye is received, the following steps should be adopted to determine the primary exhaustion time and fixation time.

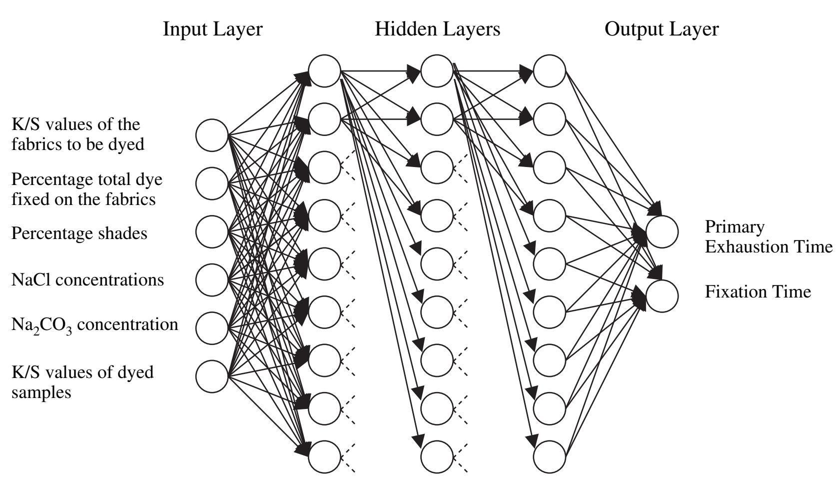

Fig. 4. Schematic diagram of ANN used in the study.

Table 3
Actual and predicted dyeing time

% Shade	Primary exhaustion time (min)			Fixation time (min)		
	Actual	Predicted	% Error	Actual	Predicted	% Error
0.25	15	14.90	0.67	15	14.91	0.60
1.00	15	15.21	1.40	15	15.20	1.33
1.75	15	15.05	0.33	15	15.06	0.40
2.50	15	15.33	2.20	15	15.32	2.13
3.25	15	15.34	2.27	15	15.33	2.22
4.00	15	14.96	0.27	15	14.95	0.33
Mean absolute error			1.19			1.17

(i) K/S value of the undyed fabric and target has to be found out.
(ii) % T has to be found out using the dyeing parameters given in Table 1.
(iii) % Shade to be used for dyeing has to be determined. This can be carried out by developing and using a plot giving relationship between K/S and % shade for the selected dye on a given fabric.
(iv) Fixation of NaCl and Na_2CO_3 concentration based on % shade determined.

When all the above parameters are ready, these values can be fed into the network as the input and the output parameters namely primary exhaustion time and fixation time can be obtained, and dyeing can be started.

6. Conclusions

The neural network trained using the input and the output parameters related to application of reactive HE dyes on cotton fabric gives an average error of 1% with respect to the dyeing time. The trained network also gives the same error % when testing of the network was carried out with a dye and the fabric, which were not used for training the network. This is found to be true

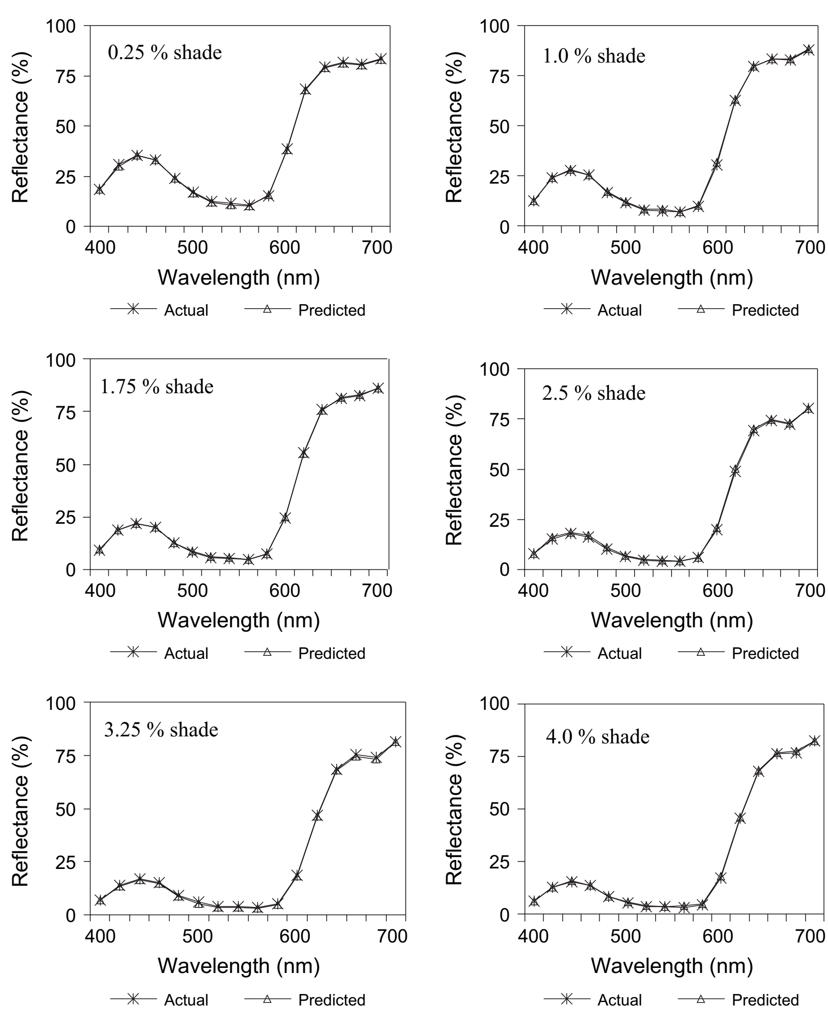

Fig. 5. Spectral reflectance curves of samples dyed with actual and predicted timings.

even when the input and the output parameters selected were beyond the range used for training the network.

Hence, the neural network developed can be used to determine the primary exhaustion time and fixation time for producing the expected depth of shade with high exhaustion reactive dye on cotton fabric.

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