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Modelling of CIELAB values in vinyl sulphone dye application using feed-forward neural networks

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Abstract

Artificial neural network (ANN) technology has developed from the experimental stage into real industrial applications. To achieve this significant transition, careful planning and adjustment are required. This article is concerned with the CIELAB values' prediction based on a neural network developed for cotton fabric dyed with vinyl sulphone reactive dye. The neural network developed is a multilayer feed-forward network. In textile dyeing industry, achieving the required depth of colour is the important task. In this paper, to achieve the required depth of colour, the CIELAB values of the fabric to be dyed were predicted using trained feed-forward neural network. The results obtained from the network gives an average error of around 2.0% for vinyl sulphone dyes used for training the network in predicting the LAB values. The trained network brings out the same error for other dyes as well as for input and output parameters selected beyond the range used for training the network.

Keywords: Colour measurement; Neural networks; Reflectance; Total dye fixed; Whiteness index

1. Introduction

Today, the highly competitive marketplace requires a strong commitment of firms to satisfy customer's expectations. This tendency is even more pronounced for the product appearance. The textile field is especially sensitive to this phenomenon. One of the most important textile characteristics is undoubtedly colour. Among the many quality parameters to be achieved in the dyed goods, achieving the appropriate depth of shade is a very important one. If the depth of colour produced is different from what is expected, the material has to be either taken for reworking or rejection. So to proceed further colour of the dyed goods has to be measured.

For the measurement of colour, standard values are used worldwide, for example as determined by an organisation called CIE. The values used by CIE 1976 are called L^*, a^* and b^* and the colour measurement method is called CIELAB. L^* represents the difference between light (where $L^* = 100$) and dark (where $L^* = 0$), a^* represents the difference between green ($-a^*$) and red ($+a^*$) and b^* represents the difference between yellow ($+b^*$) and blue ($-b^*$). The CIE 1976 L^*, a^* and b^* colour space or CIELAB colour space is defined by quantities L^*, a^* and b^*. This L^*, a^* and b^* values are calculated after dyeing the material and based on this values the material will be either taken for next processing or reworking. The L^* a^* b^* values 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].

In recent days, 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 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

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evaluation of knitted fabrics [6], classification of fabric [7] and dyeing [8] defects, tensile properties of needle punched nonwovens [2], quality assessment of carpets [9], dye concentrations in multiple dye mixtures [1], predicting the dyeing time [10], modelling of the H_2O_2/UV decolouration process [11], automated quality control of textile seams [12], fabric processability in garment making [13] and evaluation of seam puckering in garments [14] are some of the areas where ANNs have been attempted.

Attempt made on the modelling of CIELAB values in the application of vinyl sulphone dyes on a given cotton fabric using feed-forward neural network is reported in this paper.

2. Artificial neural network

Artificial neural network (ANN) is an information processing system that roughly replicates the behaviour of a human brain by emulating the operations and connectivity of biological neurons. From a mathematical point of view ANN is a complex non-linear function with many parameters that are adjusted (calibrated, or trained) in such a way that the ANN output becomes similar to that of the measured output on a known data set. ANNs are typically composed of interconnected "units" which serve as model neurons. 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 in such a way that it reacts with a single outgoing activity and then broadcasts it to other units. It performs this conversion in two stages. First, it multiplies each incoming activity called 'total input'. Secondly, it an input–output function and transforms the total input an outgoing activity [15].

The commonest type of ANN consists of three groups or layers of units such as a layer of input units is connected to a layer of hidden units, which is connected to a layer of output units. The activity of the input units represents the raw information that is fed into the network. 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 hidden units. Similarly, the behaviour of the output units depends on the activity of the hidden units and the weights between the hidden and output units. The schematic diagram of typical ANN is shown in Fig. 1.

3. Materials and methods

Two different types of commercially bleached cotton fabrics were used in this study. Plain fabric with EPI-72, PPI-74, $40^s \times 44^s$ and 112 gsm and a twill fabric with EPI-88, PPI-66, $18^s \times 10^s$ and 262 gsm.

Four vinyl sulphone dyes, namely Remazol brilliant violet 5R, Remazol red RB, Remazol green C 4B and Remazol brilliant red 5B, supplied by Atul limited, Bombay, India were used in this study. Dyeing auxiliaries such as salt (NaCl) and alkali (NaOH and Na_2CO_3) used were of LR grade. The soap solution used belonged to commercial grade.

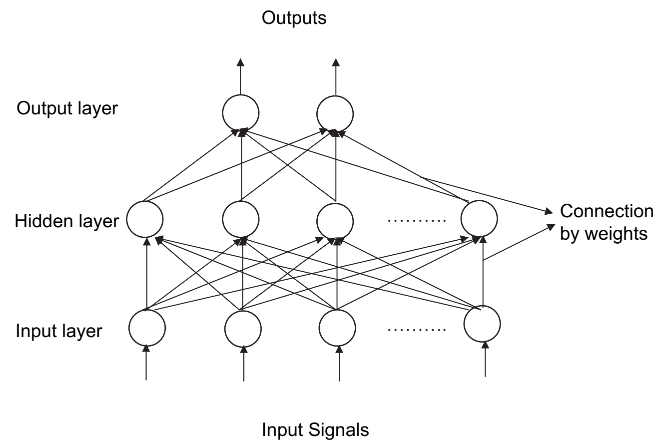

Fig. 1. Artificial neural network.

3.1. Experimental work

3.1.1. Dyeing method for vinyl sulphone dyes

Prior to dyeing, the fabrics were pretreated using 10 g/l soap solution at boil for 1 h and washed thoroughly. The dye bath was prepared by adding the necessary quantity of dye (dyes, namely, Remazol brilliant violet 5R, Remazol red RB, Remazol green C 4B and Remazol brilliant red 5B) in fresh water. The pretreated material was introduced into the dye bath and the temperature was gradually raised to 80 °C. 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 using alternate cold wash with running tap water for 5 min and hot soaping at 70 °C for 5 min twice. Finally, the samples were thoroughly washed with running tap water.

3.1.2. Preparation of dyed samples

Totally 114 samples were produced using vinyl sulphone dyes. For training the neural network, 108 samples and for testing the neural network, 6 samples were produced. Samples were produced using vinyl sulphone dyes for neural network training with different % shades and the recipe used is given in Table 1.

4. Development of neural networks

The software used in this study was a feed-forward back propagation network [16]. In order to carry out prediction, the network was trained with training patterns namely input parameters and output parameters.

4.1. Training pattern

In order to use the neural network for prediction, it has to be trained with known values of input and output parameters. The set of input and output parameters are known as training pattern. The training pattern used in this study is given below.

Table 1
Dyeing parameters

Samples	Dyeing parameters						
	% Shade	*l:m* ratio	NaCl (g/l)	Na_2CO_3 (g/l)	NaOH 72°T_w (g/l)	Dyeing time (min)	
						Exhaustion	Fixation
Samples for determination of % total dye fixed	2	30:1	60	15	2	60	60
Training samples	0.5	30:1	30	15	1	15,30,45	15,30,45
	1.0	30:1	30	15	1	15,30,45	15,30,45
	1.5	30:1	50	15	1	15,30,45	15,30,45
	2.0	30:1	60	15	2	15,30,45	15,30,45
	2.5	30:1	60	15	2	15,30,45	15,30,45
	3.0	30:1	80	15	3	15,30,45	15,30,45
Testing samples	0.25	30:1	25	10	1	20	20
	0.75	30:1	25	15	1	20	20
	1.25	30:1	35	15	1	20	20
	1.75	30:1	50	15	2	20	20
	2.25	30:1	50	15	2	20	20
	2.75	30:1	70	25	3	20	20

4.1.1. Input parameters

The input parameters are selected based on the material, dye and dyeing conditions adopted for dyeing.

Whiteness index of the fabric to be dyed: these values reflect the extent of preparation that the fabric to be dyed has undergone.
Salt concentrations: exhaustion depends on the amount of salt used.
Alkali concentrations (NaOH): dye fixation depends on the alkali concentration.
Alkali concentrations (Na_2CO_3): dye fixation depends on the alkali concentration.
Percentage shades: the depth of the colour achieved in the fabric depends on the quantity of dye taken for dyeing.
Percentage total dye fixed on the fabrics: these values reflect the dye and the fabric properties.
Dyeing time: the dye uptake also depends on the dyeing time.

4.1.2. Output parameters

The output parameters fixed in this study are CIELAB values. The dyed sample will be accepted or rejected based on its CIELAB values. Those values depend on the dye present in the fabric, type of fabric and dyeing conditions. So to produce the expected depth of shade, assessment of L^*, a^* and b^* values is essential.

4.2. Determination of training pattern

4.2.1. Determination of % total dye fixed on the fabric

Percentage total dye fixed on the fabric was determined for vinyl sulphone dyes using the recipe given in Table 1 and using the formula given below [17,18]:

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

where

E – dye bath exhaustion in percentage
K_1 – *K*/*S* value of dyed sample before soaping
K_2 – *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.

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

where

A_1 – absorbance of dye solution before dyeing at λ_{max}
A_2 – absorbance of dye solution after dyeing at λ_{max}.

The *K*/*S* value was calculated using the formula given below [19] from reflectance value (R) at λ_{max} (Table 2) measured using UV–vis spectrophotometer, U-3210, Hitachi, Japan.

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

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

	Remazol green C 4B	Remazol red RB	Remazol brilliant violet 5R	Remazol brilliant red 5B
Absorbance (nm)	614	541	577	489
Reflectance (nm)	497	664	436	642

where
R – reflectance value of the fabric at λ_{max}.

4.2.2. Determination of L^* a^* b^* values

The CIE 1976 L^*, a^* and b^* values of the fabric were calculated using the formula [20] given below:

$$L^* = 116(Y/Y_n)^{1/3} - 16$$

$$a^* = 500\left[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}\right]$$

$$b^* = 200\left[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}\right]$$

where

X_n, Y_n, Z_n – tristimulus values of reference white
X, Y, Z – tristimulus values of dyed sample.

The X, Y and Z values of the fabric were calculated from reflectance measurement at interval of 400 nm-20-700 nm using UV–vis spectrophotometer (U-3210, Hitachi, Japan).

4.2.3. Determination of whiteness index

The whiteness index of the bleached fabric was calculated using the formula [19] given below:

$$\text{Whiteness index} = 100 - (R_{670} - R_{430})$$

where
R_{670} and R_{430} are the reflectance values of white fabric at wavelength 670 nm and 430 nm, respectively.

4.2.4. Determination of ΔE^* value

The colour difference (ΔE^*) value of the fabric was calculated using the formula [19] given below:

$$\Delta E^* = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2}$$

where

$$\Delta L^* = L^*_{\text{sample}} - L^*_{\text{standard}}$$

$$\Delta a^* = a^*_{\text{sample}} - a^*_{\text{standard}}$$

$$\Delta b^* = b^*_{\text{sample}} - b^*_{\text{standard}}.$$

4.3. Neural network training

For training, dyed samples were produced using the dyes Remazol brilliant violet 5R, Remazol red RB and Remazol green C 4B. The neural network was trained using back propagation algorithm. For an error back propagation net, the sigmoid function is essentially suitable because it is continuous and monotonically nondecreasing 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

$$F(X) = \frac{1}{(1 + \exp(-X))}$$

Since the binary function has a range of (0, 1) the values of input and output parameters have to be scale down between 0 and 1 by normalizing them with suitable factors. The network was trained using the normalized input and output parameters of the various dyes. Training process of the neural network developed was started with 5000 preliminary cycles to optimise the ANN prediction accuracy. These cycles were carried out with different network structures and different error tolerance values. The best structure is that which gives lower training error and it is 7/10/10/10/3 (input – 3 neurons, hidden – 10 neurons/layer, output – 3 neurons) in the present study. The training of the network was further continued in order to reduce the training error. Training error of 2.0% was obtained, when 85 000 cycles were used. The training of the network was terminated at this stage as the reduction in training error is not appreciable.

4.4. Testing of the network

Two input parameters, namely % total dye fixed on the fabric and whiteness index of undyed sample, were experimentally found out. Rest of the input parameters were fixed arbitrarily and dyeing was carried out at various % shades using Remazol brilliant red 5B. Recipe used for preparing testing samples is given in Table 1. The above-prepared samples are considered as control and using those input parameters, the output parameters (L^* a^* b^*) were predicted. The CIELAB values of those dyed samples were also calculated using the formula given in Section 4.2.2. The actual and predicted values are given in Table 3. The colour difference (ΔE^*) was also calculated between the actual and predicted values (Table 3). The actual and predicted L^*, a^* and b^* values for

Table 3
Actual and predicted L^*, a^* and b^* values and ΔE^* value

% Shade	L^*			a^*			b^*			ΔE^*
	Actual	Predicted	% Error	Actual	Predicted	% Error	Actual	Predicted	% Error	
0.25	66.03	65.02	1.53	44.34	45.27	2.09	13.53	13.93	2.96	1.43
0.75	59.44	60.32	1.48	50.88	49.93	1.87	16.53	16.06	2.84	1.38
1.25	56.54	55.76	1.38	54.16	55.09	1.72	18.22	18.73	2.79	1.31
1.75	54.53	55.09	1.03	56.59	55.89	1.24	19.59	19.19	2.04	0.98
2.25	53.37	52.92	0.84	58.05	58.65	1.03	20.46	20.83	1.81	0.83
2.75	52.34	52.66	0.61	59.40	58.98	0.71	21.30	21.03	1.27	0.60
Mean absolute error	1.15			1.44			2.29			

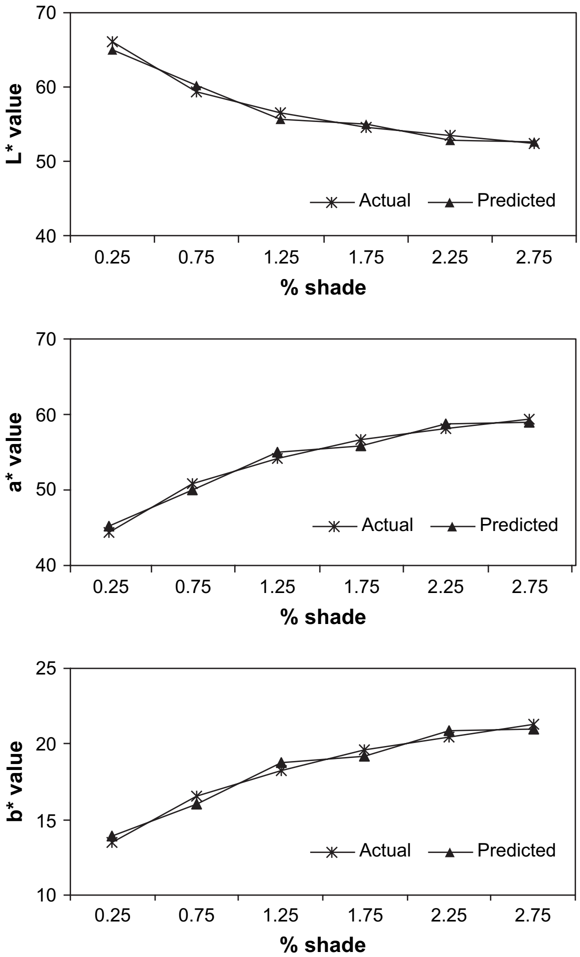

Fig. 2. Actual and predicted L^*, a^* and b^* values for various % shade dyed material.

various % shade dyed materials are also plotted in the graph (Fig. 2).

5. Application of developed neural network

Dyed textile materials are generally accepted when the ΔE^* values are between 0 and 1.5 and the ΔL^* values are between −0.7 and 0.4. If the ΔE^* value is above 1.5 the colour difference between sample and control is very high and it is to be rejected. If the ΔL^* values are less than −0.7 the samples are darker in shade and if they are greater than 0.4 the samples are lighter in shade compared to that of the control sample [21]. So assessment of ΔE^* and ΔL^* values is essential to proceed further. This can be achieved with the developed neural network model.

When a target dyed with known dye is received, the L^*, a^* and b^* values of the fabric to be dyed can be predicted before dyeing itself. To determine those values, all the input parameters have to be found out. When all the parameters are ready, these values can be fed into network as input parameters and the output parameters can be obtained.

6. Conclusion

From the study conducted on the application of neural network for modelling the CIELAB values, the following conclusions are drawn.

The neural network trained using the input and output parameters, gives an average error of 2.0% for vinyl sulphone dyes with respect to the L^* a^* b^* values. The trained network gives the same error percentage given above, while testing the dyes, which were not used for training the network. The trained network brings out the same error percentage, even when the input and output parameters selected were beyond the range used for training the network.

The ΔE^* value between the calculated and predicted values, lies in the acceptable region i.e. between 0 and 1.5. The lightness difference value of most of the above mentioned samples also lies in the acceptable region i.e. between −0.7 and 0.4. All samples can be accepted due to the less ΔE value, even though they have higher lightness difference value.

The neural network model developed can be used to optimise the dyeing parameters for producing the required depth of shade for any type of vinyl sulphone dyes.

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