

Application of multiple linear regression and artificial neural network algorithms to predict the total hand value of summer knitted T-shirts

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A mathematical method, Weighted Euclidean Distance, has been applied for indirect determination of total hand value from the KES system parameters obtained for various summer knitted T-shirts. In this method, the weight of multivariable related to fabric hand has been determined from objective measurements without any resource to subjective evaluation. Artificial neural network with back propagation learning algorithm and multiple linear regression algorithm have been used to construct predictive models for the determination of total hand value of summer knitted T-shirts based on fabric mechanical properties measured on the KES system of each sample as input and total hand value predicted by mathematical model as desired output. The predictive power of optimized models is calculated and compared. The results reveal that the artificial neural network model is very effective for predicting the total hand value and has the better performance as compared to multiple linear regression model.

Keywords: Artificial neural network, KES system, Multiple linear regression model, Total hand value, Weighted euclidean distance method

1 Introduction

The handle of fabric has been recognized as one of the most important performance attributes of textiles intended for use in apparel. Many researchers have justified the use of the objective assessment by stating that the stimuli in fabrics which lead to subjective assessment of hand can be described by specific fabric properties. Among these efforts, Kawabata's method¹ and Fabric Assurance by Simple Testing (FAST)² are the most notable. The precision and wide coverage of fabric properties of the KES and FAST systems are unprecedented, although for most industrial application this system seems to be expensive in terms of purchasing and operating costs and the interpretation of the results is complicated. These limitations make the KES and FAST techniques less suitable for industrial applications, especially in the case of small-scale apparel and textile manufactures. Furthermore, KES and FAST systems are applied mostly for woven fabrics. In knitted fabrics, KES system has represented only one standard method for the weft-knitted fabrics, which are used for winter suiting.

Another remaining problem in Kawabata method is to establish the relationship between the measured properties and the handle preference, which has proven very complex and frustrating³. On the other hand, as the system is based on the preferences of Japanese judges, the unsuitability of the results to markets other than Japan is inevitable, owing to the background-related nature of tactile sensory assessment. Pan and Yen⁴ have introduced a new mathematical approach for calculating hand value from objective measurement without any recourse to subjective evaluations. This objective measure for total hand value is described as a Weighted Euclidean Distance. They reported a high correlation between results of this method and total hand values obtained from Kawabata's equations⁵.

An artificial neural network (ANN) is one of the intelligence technologies for data analysis which has been employed extensively in various textile disciplines ranging from yarn manufacturing, fabric formation and fabric properties. This technique is useful when there are a large number of effective factors on the specific process. In the literature, there are many studies on the use of artificial neural network algorithm, such as that of Beltran *et.al.*⁶ on the pilling tendency of wool knits using ANN model.

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A study was carried out by Tokarska⁷ for predicting the permeability features of woven fabrics. The performance of ANN model was compared with statistical regression and fuzzy regression to develop the predictive models for polyester dyeing⁸. Majumdar *et.al.*^{9,10} compared three modelling methodologies based on mathematical, statistical, ANN models for predicting the breaking elongation of ring- and rotor- spun yarns. ANN model has also been used to predict cotton yarn hairiness¹¹. Guifen¹² developed the artificial neural network model to predict the warp breakage rate in weaving.

Because the definition of total hand value for a fabric is inseparably linked to its end use, the investigation was restricted to the fabric which can be used as summer knitted T-shirt. There is no standard method to determine the total hand value for these fabrics. In the present study, at first the Weighted Euclidean Distance method has been used for indirect determination of total hand value from the KES system parameters obtained for various summer knitted T-shirts. The predictive models with the help of statistical model, i.e. multiple linear regression and artificial neural network (ANN) algorithm with back propagation learning method, have been constructed based on fabric mechanical properties measured on the KES system of each sample as input and total hand value predicted by mathematical model as desired output. Finally, the performance of optimized models was compared.

2 Materials and Methods

2.1 Materials

Thirty-nine (39) specimens were knitted on the

different circular knitting machines. For validity of the presented model, a wide range of the knitted fabrics which can be used as summer T-shirts was studied, considering all factors which are related to fabric hand. These factors are: fibre factor (material type); yarn factors (spinning system, yarn count, yarn twist, combed and carded yarn); fabric factors [fabric structure, tightness factor (Tightness factor = $\text{Tex}^{1/2}/l$, l = loop length, cm)]; and finishing factors (dyeing, bleaching and softening, softener type and condensations).

The mechanical and surface properties of the knitted fabrics were measured using the standard KES-F instruments. For each fabric, each measurement was made twice on three separate samples cut from the center of the knitted fabrics, and six resulting values were averaged. Sixteen properties were measured under standard conditions, including tensile, bending, shear, compression, and surface properties, as well as thickness and weight of the knitted fabrics^{1,13}. Because anisotropy is a consideration in knitted fabrics, eleven of the tests (tensile, bending, shear and surface properties) were measured in both course and wale directions. Averaging of the wale and course measurements was done for further analysis. The range of mechanical properties of the tested specimens is shown in Table 1.

2.2 Methods

2.2.1 Calculation of Weight Distance Value

The Euclidean Weighted Distance (WD) method, as a mathematical model, was implemented to evaluate the handle of fabrics. The processing of the

Table 1—Range of mechanical properties of tested specimens

Mechanical property	Maximum value	Minimum value	Average value
<i>G</i> (Shear stiffness), g/cm.deg	0.76	0.29	0.53
<i>2HG</i> (Hysteresis of shear force at 0,7 grad), g/cm	3.88	1.00	2.43
<i>2HG5</i> (Hysteresis of shear force at 8,7 grad), g/cm	4.28	1.43	2.86
<i>B</i> (Bending rigidity), g.cm ² /cm	20.76	0.88	10.82
<i>2HB</i> (Hysteresis of bending moment), g.cm/cm	36.51	1.60	19.05
<i>WT</i> (Energy in compressing fabric under 5 kPa), g.cm/cm ²	162.02	73.03	117.51
<i>RT</i> (Tensile resiliency), %	30.70	17.00	23.80
<i>LT</i> (Tensile linearity), 1	0.74	0.59	0.67
<i>WC</i> (Compression work), g.cm/cm ²	5.44	3.52	4.48
<i>RC</i> (Compressional resiliency), %	48.09	28.05	38.07
<i>LC</i> (Linearity of compression), 1	0.33	0.42	0.38
<i>MIU</i> (Coefficient of steel/fabric friction), 1	0.30	0.21	0.25
<i>MMD</i> (Mean deviation of MIU), 1	0.020	0.012	0.016
<i>SMD</i> (Geometric roughness), μm	18.50	4.90	11.701
<i>T</i> (Thickness), mm	1.23	0.89	1.06
<i>W</i> (Weight), g/m ²	197.40	118.03	157.70

where Y_{1i} and Y_{2i} are the component of the transformation matrix for the specimen and standard fabric respectively.

2.2.2 Prediction of Fabric Hand Using ANN

The artificial neural network(ANN) technique imitates the behavior of biological neural networks to learn a subject from the data provided to it. An ANN is composed of simple elements, called neuron or processing elements, operating in parallel by biological nervous systems. There are different kinds of structure and learning algorithms, but the feed forward neural network with back-propagation (BP) learning algorithms is more popular. In this structure, the neurons are located in layers and from one layer to another one connected with each other with links to carry the signals between them. There is a weight for each connection link which acts as a multiplication factor to the transmitted signal. An activation function is applied to each neuron’s input to determine the output signal.

Usually, a feed forward neural network consists of several layers of nodes, one input layer, one output layer and some hidden layers in between. In this study, back-propagation with a single hidden layer is also adopted and used (Fig. 1). More details about the feed forward neural networks and back propagation learning algorithm are already reported in literature¹⁴.

The number of hidden neurons and the number of hidden layers are usually adjusted by trial and error. Studies by various researchers have shown that neural networks with one hidden layer are suitable for the majority of applications¹⁵; therefore we have used five different network structures with only one hidden

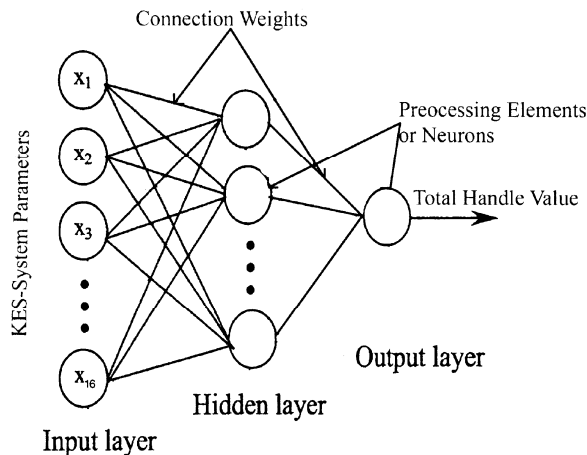


Fig. 1— Structure of single hidden layer neural network

layer consisting of 12,14,16,18 and 20 neurons. All the designed networks have sixteen input units and one output neuron in output layer. The back-propagation learning algorithm was based on gradient descent with momentum. The network parameters were adapted through the presentation of 31 training and 8 testing data. The testing and training data were normalized in such way that they got zero mean and unit standard deviation. After some trials, learning rate and momentum were optimized at 0.05 and 0.9 and the hyperbolic tangent and linear function were applied for hidden neurons and output neuron respectively. The mean square error (MSE) as shown in following equation was used to judge the performance of different models:

$$MSE = \frac{1}{N} \sum_{i=1}^N (y_i - x_i)^2 \quad \dots (8)$$

where N is the number of data sets; y_i , the desired output for i th data set; and x_i , the predicted value for i th data set.

2.2.3 Statistical Model

Regression analysis is a statistical technique for investigating and modelling the relationships between variables and is very frequently used for different fibre/textile issues in recently decades. In this study, a multiple linear regression as a most widely used statistical technique developed from the training data was used to predict the total hand value of samples. The multiple linear regression, as shown below [Eq. (9)], using SAS software was fitted on data. The coefficients of regressor variables was obtained based on forward method.

$$\begin{aligned} \text{Total handle value} = & \beta_0 + \beta_1(LT) + \beta_2(RT) + \beta_3(WT) \\ & + \beta_4(B) + \beta_5(2HB) + \beta_6(G) + \beta_7(HG0.5) + \beta_8(2HG5) \\ & + \beta_9(LC) + \beta_{10}(RC) + \beta_{11}(WC) + \beta_{12}(MIU) \\ & + \beta_{13}(MMD) + \beta_{14}(SMD) + \beta_{15}(T) + \beta_{16}(W) \quad \dots (9) \end{aligned}$$

3 Results and Discussion

3.1 Determination of Primary Hand Feature of Knitted Fabrics

The eigenvalues (C_i) of covariance matrix with their corresponding ratios $W_i^2 = C_i / trV$ are listed in Table 2. So, from Table 2, $p = 5$ is chosen as the number of prior eigenvalues which are justified in the condition shown in Eq. (3).

According to the value of $p = 5$, the transformation matrix Y is then composed with these five eigenvector and after the transformation, the feature matrix Y with five components are derived. The matrix Y is orthonormal, meaning that all its components are uncorrelated with each other and each component reflects one aspect of fabric hand and differs from those by other components. So, the components of matrix Y ($Y[1], Y[2], \dots, Y[5]$) can be named as primary hand values. On the other hand, sixteen mechanical parameters measured by KES-FB instruments reflect five different primary hand features for summer knitted T-shirts.

As there is neither clear definitions nor an objective and reliable calibration for primary hand values, it is difficult to determine the physical meanings of these features directly. This problem does not affect the application of this method. As an expedient choice, however, the correlation analysis is used in this paper to relate these features to mechanical and surface properties of the knitted fabrics. The correlation coefficients between five primary hand features ($Y[i], i=1, 2, \dots, 5$) and the sixteen original mechanical and surface parameters are calculated and listed in Table 3. According to Table 3 and Bishop¹³, the features can be named and defined as follows:

- $Y[1]$ — This is highly correlated with shear, bending and compression properties and

condensed results of these parameters are called ‘firmness’.

- $Y[2]$ — This is highly correlated with compression properties and thickness and condensed results of these parameters can be named ‘fullness’.
- $Y[3]$ — This is significantly correlated with the surface properties, weight and shear and tensile stiffness, and condensed results of these parameters can be designated as ‘crispness’.
- For similar reasons, $Y[4]$ and $Y[5]$ are named ‘roughness’ and ‘stiffness’ respectively.

Therefore, five primary hand features (descriptors), namely firmness, stiffness, fullness, roughness and crispness, associate to evaluate the handle of the knitted summer T-shirts. The WD values of all samples were then calculated according to the formula shown in Eq. (7).

3.2 Artificial Neural Network Model

Table 4 shows the training results of five models after 2000 epochs. By comparing the mean square error of neural network models in predicting the testing data, it can be observed that the neural network model with sixteen neurons in the hidden layer gives the best prediction power in testing data. Figure 2 also shows the learning curve of the neural

Table 3— Correlation between five features and sixteen KES parameters

Property	$Y[1]$	$Y[2]$	$Y[3]$	$Y[4]$	$Y[5]$
<i>LT</i>	0.68*	0.31	0.40*	0.41*	0.56*
$\log WT$	-0.29	-0.51*	0.67*	-0.24	-0.22
<i>RT</i>	-0.79*	-0.29	0.28	0.15	-0.59*
$\log B$	0.84*	-0.12	0.22	-0.33*	0.74*
$\log 2HB$	0.92*	-0.06	0.10	-0.29	0.82*
$\log G$	0.83*	0.28	0.36*	0.14	0.70*
$\log 2HG$	0.96*	0.18	0.03	0.00	0.75*
$\log 2HG5$	0.96*	0.19	0.06	0.03	0.75*
<i>LC</i>	-0.55*	-0.47*	0.11	-0.55*	-0.45*
$\log WC$	-0.17	-0.84*	-0.08	0.05	-0.17
<i>RC</i>	-0.72*	-0.57*	-0.15	-0.14	-0.50*
<i>MIU</i>	0.263	-0.08	-0.52*	-0.55*	-0.40*
$\log MMD$	0.40*	-0.40*	-0.50*	0.34*	-0.52*
$\log SMD$	-0.613*	-0.01	-0.48*	-0.36*	-0.76*
$\log T$	-0.210	-0.82*	-0.26	0.26	-0.31
$\log W$	-0.154	-0.05	0.68*	-0.27	0.38*

*Statistically significant at 0.05 level.

Table 4— Performance of different architectures on training and testing data sets

Model No.	Architecture	MSE	
		Training data set	Testing data set
1	16-12-1	0.2539	0.0025
2	16-14-1	0.2096	0.0019
3	16-16-1	0.1170	0.0012
4	16-18-1	0.3920	0.0005
5	16-20-1	0.2432	0.0004

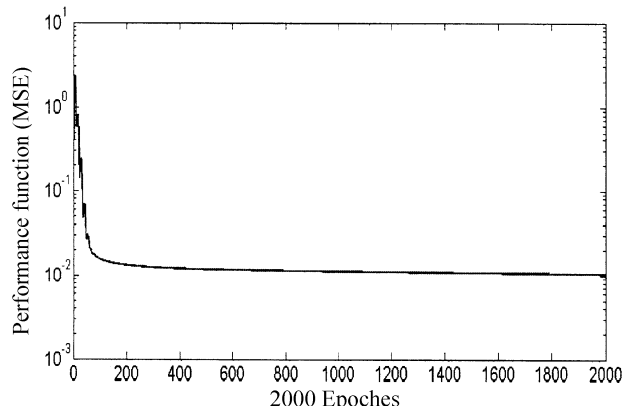


Fig. 2— Leaning curve of model with 16-16-1 architecture

Table 5— Coefficient of regressor variables in multiple linear regression model

Variable	Coefficient estimate	t-value
LT	-0.0281	-1.07
RT	0.1085	1.83
WT	0.0101	1.96
B	0.3824	5.99
2HB	-0.1970	-3.06
G	-1.8293	-0.82
HG[0.5]	1.5276	4.23
LC	0.0648	1.90
RC	-0.1304	-4.47
WC	-0.0560	-0.18
SMD	0.0842	2.30
T	1.9587	1.55
W	-0.8611	-1.22

network for this topology. The MSE curve in this figure shows that the prediction can be accurate. As shown in Table 4, the mean square error of training and testing data is 0.0012 and 0.1170 respectively.

3.3 Statistical Regression Model

Estimated coefficients of regressor variables in this model are given in Table 5. The analysis of variance of fitted model clearly shows the significance of the obtained model at 0.05 significant level. On the other hand, the mean square error of prediction in training and testing data is found to be 0.0973 and 0.2053 respectively.

3.4 Comparing the Predictive Power of Two Models

The difference between the mean square error of prediction in testing and training data was 0.0961 and 0.0883 respectively. Table 6 shows that the minimum error for predicting the testing data set in selected neural network model and multiple linear regression model is 0.84% and 1.10% respectively. In contrast, the statistical model exhibits a maximum errors as high as 15.98% in contrast to 3.55% for the ANN model. This result confirms the good capability of neural network algorithm for modelling this process compared to the multiple linear regression model. The maximum error difference in predicting the testing data between two models is 12.43%. The better performance of ANN model could be due to the nonlinear relationships which are between the input parameters and the desired output.

Table 6— Total handle value predicted by neural network and multiple linear regression model for testing data sets

Sample No.	Total handle value (mathematical model)	ANN predicted (Error%)	Multiple linear regression predicted (Error %)	Error difference
1	8.95	9.05(1.09)	8.08(9.76)	8.67
2	6.50	6.64(2.09)	6.79(4.50)	1.60
3	5.56	5.72(2.87)	5.74(3.35)	0.48
4	4.36	4.28(1.42)	4.48(2.83)	1.41
5	5.37	5.32(0.84)	5.66(5.39)	4.55
6	5.43	5.49(1.10)	5.49(1.10)	0.00
7	3.94	3.80(3.55)	3.31(15.98)	12.43
8	5.43	5.51(1.47)	5.95(9.58)	8.11
Mean error		1.80	6.52	4.72

4 Conclusions

In this study, the feed forward neural network model with 16-16-1 architecture, i.e. sixteen input unit, sixteen neurons in hidden layer and one output neuron, is found better than the multiple linear regression model for the prediction of total hand value of summer knitted T-shirts based on five primary hand features of KES system, namely firmness, stiffness, fullness, roughness, and crispness, as input parameters. The mean square error(MSE) for predicting the testing data is found to be 0.1170 and 0.2053 for ANN and multiple linear regression models respectively. The results show the good capability of ANN algorithm to predict total hand value of knitted summer T-shirts.

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