Applying Artificial Neural Networks to Total Hand Evaluation of Disposable Diapers

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ABSTRACT
The objective hand measurement and also handle of the materials used for disposable diapers has been looked into, with consideration given the aspects of both dermatitis and comfort. In this work, we tried to predict the handle of disposable diapers by their physical properties using a back-propagation network and a stepwise regression. Handle properties of diapers were measured by universal test equipment and hand values of the fabrics were determined by a group of panelists consisting of some textile experts. The optimum construction of neural network was investigated through the change of layer and neuron number. The results showed that the back-propagation network could predict the hand values of disposable diapers with a meaningful difference. These disposable diapers were used to show that the results of neural network were in good agreement with subjective test results.

INTRODUCTION
To study the correlation between the usage properties and their characteristic parameters is of great importance for designing the proper diapers in order to satisfy various special requirements. The development of a model based on existing experimental data becomes necessary to predict material properties.[1] To replace traditional subjective hand assessment of disposable diapers, an objective measurement of quality and performance on the basis of low-stress mechanical properties has been established.

Until now, the Kawabata Evaluation System For Fabrics (KES-F) and Fabric Assurance by Simple Testing (FAST) systems have been the criteria most commonly used to evaluate the total hand value of textiles in textile research and industry.[2] With objective test systems such as the KES-F and FAST for evaluating the mechanical properties of textile surfaces, it is possible to establish hand evaluation software, which helps to clarify objective ratings in mutual communications between different sectors in the industry about the quality of textile materials.[3] But primary hand expressions and total hand value depend on hand experts and can be correlated to cultural backgrounds or to subjective factors. At present, total hand of disposable diapers is primarily evaluated by subjective hand assessment,[4] so hand evaluation systems are somewhat subjective and have several shortcomings when applied to other countries.

There are, however, several problems in determining the total hand value of disposable diapers, such as difficulty of measuring, cultural factor and application method.[5-7] In order to overcome these shortcomings of the evaluation software in the KES-F and FAST systems, variable clustering analysis methods have been investigated. All of these are mainly objective statistical modeling methods exhibiting neither simulation programming, nor automatic calculation of total hand value. Since the handle of disposable diapers obtained from touch and appearance is influenced by the mental and mechanical properties of the expert, it will be more meaningful to rate overall hand values with artificial neural networks (ANN) which has been introduced into this field in recent years.[2]

Inspired by the biological nerve system, ANN uses interconnected nodes (called neurons), where the interconnections are ‘‘weighted’’, to imitate the ability of a human brain. Such a network can learn from experience and find solutions for rather complex, nonlinear, multi-dimensional functional relationships. The main characteristic of this technique, differing from conventional methods, is that the network describing the relationship is trained directly by examples without any prescriptive formulae about the nature of the problem. During the training, the neural network can establish the relation between the reasons (input data) and the consequences (output data) by itself, and a back propagation algorithm is often used as a training rule of networks. ANN has been so far proved to be an efficient analytical tool to solve the problems in a wide range of materials science and engineering.[8,9]

An application of the ANN method is suitable if the following conditions are satisfied:[10]

1. A large database is available;
2. It is difficult to find an accurate solution to the problem by existing mathematical approaches;
3. The data set is incomplete, noisy or complex.

In this paper, we describe the objective total hand evaluation systems for current disposable diapers using ANN. Furthermore, we investigate a linear and a nonlinear approach to establish a relation between total hand value and low-stress mechanical properties of the disposable diapers. In the nonlinear context, we propose the use of an ANN of the generalized regression type, which is shown to yield satisfactory total hand value prediction values after a fairly modest training period. The network performance is verified on a set of real field measurement data.

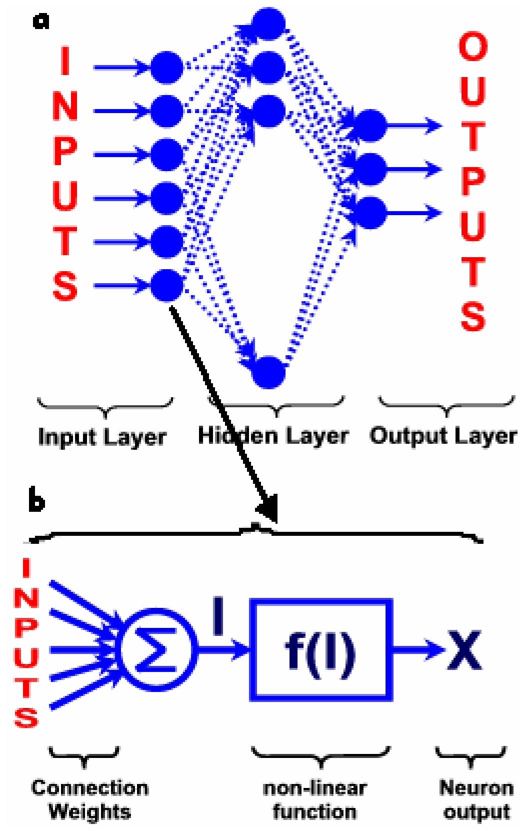


FIGURE 1. a) A typical ANN structure b) a neuron within a neural network[11]

Principle Of Artificial Neural Network

Figure 1 gives a schematic illustration of an ANN. Like its biological counterpart, an ANN is simply composed of many neurons and inter-connections with weights. These mathematical units are conventionally constructed with three layers, i.e. input, hidden and output layer, according to the function. The hidden layer usually contains one or several layers, and the number of neurons in each layer can be different. For the convenience of description, the structure of the ANN is expressed as

$$N_{in} - [N_1\text{-}N_2\text{-}\ldots N_h]_h - N_{out} \qquad (1)$$

where N_{in} and N_{out} refer to the number of input and output parameters, respectively. h denotes the number of hidden layers, and N_1, N_2 and N_h are the number of neurons in each hidden layer.

Each layer, except the input layer, takes the output of the preceding layer as an input, which is modulated by transfer function and weights in the neuron for the output to the next layer. This procedure can be described as

$$X_j^{(n)} = f\left(\sum_i W_{ji}^{(n)} X_i^{(n-1)}\right) \qquad (2)$$

where f(x) is a transfer function which is usually nonlinear. $X_j^{(n)}$ is the output of node j in the n*th* layer, and $W_{ji}^{(n)}$ represents the weight from node i in the (n-1)*th* layer to node j in the n*th* layer. The ANN works like a ‘‘black box’’. An input vector is imported to the nodes in the input layer, and the results are then expected to export at the output layer through a series of computation in the hidden layer. The learning algorithm is based on a gradient search to optimize the performance function of the network, which is generally evaluated by mean squared errors between the predicted and desired values

$$E = \frac{1}{2L}\sum_{t=1}^{L}\left[d(t) - p(t)\right]^2 \qquad (3)$$

where L equals the number of training samples, d(t) is the desired output value, and p(t) refers to the target output value predicted by the ANN for the *tth* sample. For the purpose of minimizing E, the weights of the inter-connections are adjusted during the training procedure until the expected error level is achieved or the maximum iteration is reached.

It should be noted here that the sensitivity factor propagates (S) backwards from the last layer to the first layer [S (n+1) → S(n) → …. → S(2) → S(1)], hence the name back-propagation algorithm is used.[12]

Implementation of Artificial Neural Networks

In practical application for developing the best material, it is necessary to prepare a large enough database of experimental results to develop an ANN with a good performance. The architecture, transfer function, training algorithm and other parameters of the neural network should be carefully set and modified during optimization. Thus, the well-trained neural network can be used to obtain the solutions of new input data in the same domain of the experimental database. This process can be summarized in the following four stages:

1. Collect and pre-process the experimental data;
2. Train the ANN, and optimize its configuration;
3. Evaluate the performance of the ANN, return to stage if the performance is not satisfactory;
4. Use the trained ANN for simulation or prediction.

EXPERIMENTAL MATERIALS

One hundred thirty five samples of commercial disposable diapers were used in this study. The disposable diapers are multi-layer materials consisting of layers of different materials. For all samples, they are composed of coverstock, absorption sheet, back sheet and leg and waist bands produced from polypropylene, wood pulp + super absorbent polymer (SAP), polyethylene, styrene butadiene rubber, respectively. Sheets of disposable diapers differentiated only coverstock back sheet. The thicknesses and SAP/Wood pulp of each sample vary between 8 mm and 14 mm, 0.683 and 0.031, respectively.

Characteristic Parameters

The characteristic parameters of input layers are the major factors for determining the recognition rate. We worked on the proposed method with FAST instruments, which measure the handle properties of the disposable diapers.[13] The FAST system consists of subsystems which have the function of measuring different handle properties such as surface property, compression property, heat transfer property, thickness and weight properties. The details of the eight mechanical and two heat transfer properties of a disposable diapers are given in the *Table 1*.

TABLE I. Mechanical and Heat transfer properties

No	Properties		Description	Unit
1	Surface	MIU	Coefficient of friction	-
2		MMD	Mean deviation of MIU	-
3		SMD	Roughness	N
4	Compression	WC	Compressional energy	J/m^2
5		RC	Resilience	%
6		LC	Linearity	-
7	Thickness	T	Thickness at 0,5 cN/cm^2	mm
8	Weight	W	Weight per unit area	g/m^2
9	Heat transfer	K	Coef. of heat transfer	W/m*K
10		q	Max. value of heat flux	W/m^2*K

Measurement of Mechanical Properties and Subjective Evaluation

Disposable diaper mechanical properties such as friction, compression, heat flux and construction were measured test methods which were described by Yaman et.al.[13] Mechanical properties were measured under the conditions of high sensitivity. All measurements were performed at 65±2% relative humidity and 20±1 ºC. For each sample, 15 measurements were performed. In order to evaluate total hand value of the samples, paired comparison methods were carried out. Subjective evaluation of total hand was performed via touching the samples covered in a box which could not be seen by the evaluators. Total of 50 people, who had textile education (age: 20-30), participated in the evaluation. The range of total hand values varied between 1 and 5 where 1 means the worst and 5 means the best value. The questionnaires were composite with 6 questions; roughness, smoothness, wetness, stiffness, coolness, and touch. High deviations obtained from the subjective evaluation were not included in the evaluation process.[13]

Statistical Evaluation

The data were analyzed using the SPSS 11.0 program by means of stepwise regression analysis. The parameter selection process involved the stepwise regression selection method. We evaluated the contribution of the selected parameters using the partial F test criterion method. We then developed the total hand value translation equation using stepwise regression method with the selected mechanical properties as parameters. We judged the evaluation capability of the translation equation on the basis residual plots presented in the random pattern. A large R^2 value and small mean square error and p-values were needed for a high evaluation capability.

Development Of Neural Networks

For the present study, low-stress mechanical properties were selected as input variables, and total hand values were chosen as output parameters.

In ANN analysis, a multilayer feed forward network with one hidden layer trained by back propagation algorithm was used to predict the total hand values of the disposable diapers. Several analysis were done and it was observed that two hidden layered neural network gave minimum error and higher estimation of coefficient. Developed neural network is given in *Figure 2*. In the input layer of the network, six inputs were used. In first and second hidden layers of the network, twelve and five neurons were selected respectively. As the purpose of the study was to estimate the total hand value of disposable diapers, one output, THV, takes parts in the output layer. While linear transfer function was used in the input and output layers of the neural network, hyperbolic transfer function was used in the hidden layers. The training of the network was performed in two phases. In the first stage, back propagation algorithm was applied for 100 epochs. Learning rate and momentum coefficient used in the back propagation algorithm were set to 0.01 and 0.3 respectively, since decreasing the learning rate did not improve the performance of network. Furthermore the training time increased. In the second stage of the training, conjugate gradient descent algorithm was applied for 20 epochs. Increasing the number of epochs for the second phase of the training did not improve the training and testing performances.

Of the 135 disposable diaper samples, 101 (75 %) samples were chosen as the training set at random, while the rest (25 %) was chosen for the testing set.

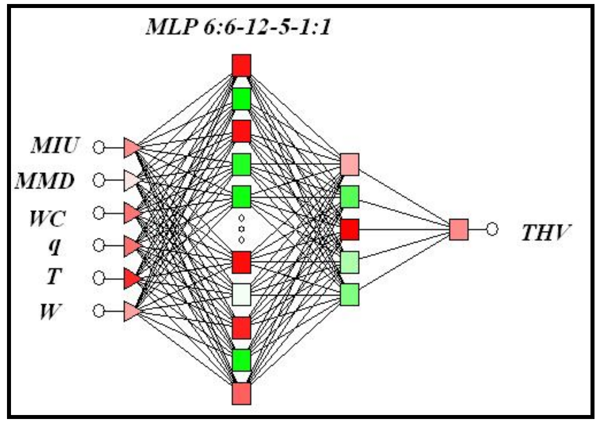


FIGURE 2. The optimum architecture of neural networks

A nonlinear hyperbolic transfer function [$f(x)=(e^{x}-e^{-x})/(e^{x}+e^{-x})$] served in the hidden layers, and a linear transfer function $f(x)=x$ was used in the input and the output layers to avoid limiting the output value to a small range.

RESULTS AND DISCUSSION

Stepwise Regression Analysis

We used the stepwise regression selection method to determine the most obvious properties directly affecting the subjective total hand value. After four steps, we selected four mechanical properties, W, T, K and MMD, as parameters. The translation equation with the stepwise regression method for calculating total hand value (THV_{REG}) was as follows:

$$THV_{REG} = 0.915 - 3.88 \times MMD - 33.1 \times K - 0.168 \times T - 0.00256 \times W$$

The R^2 is 0.609, and each parameter reflects a high significance level. The correlation coefficient between the scatter plot of the subjective and calculated total hand values using the regression equation with four parameters is shown in *Figure 3*.

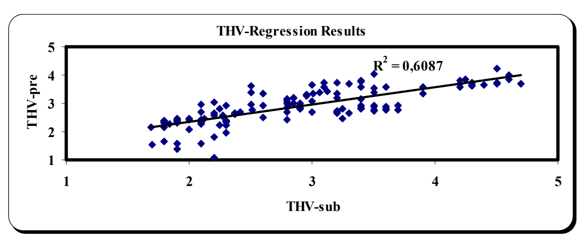
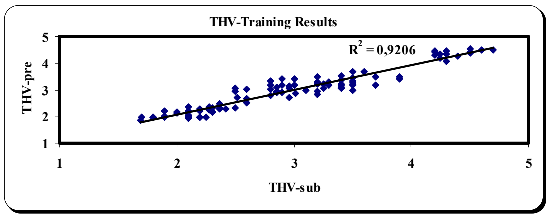


FIGURE 3. The subjective and regression total hand values

Neural Network Analysis

The configuration of adopted architecture of the neural network for disposable diapers overall hand evaluation was shown in *Figure 4. Figure 4a and 4b* compare the predicted and subjective total hand value both training and testing sets. The correlation coefficient R^2 of the predicted (training and testing) and subjective total hand values are 0.92 ($p<0.001$) and 0.79 ($p<0.001$), respectively.



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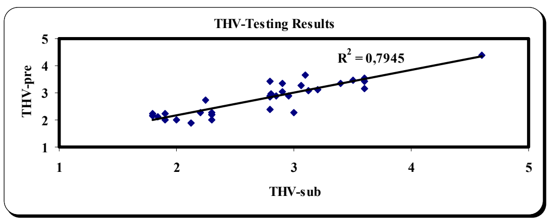

b

FIGURE 4a and 4b Predicted total hand value for training and testing partner of ANN

To examine the significance levels of each variable taken place in the network, sensitivity analysis were performed. Sensitivity expresses the relative contribution of each variable to the overall prediction of the network. Therefore this analysis gives an idea about the significance levels of each variable in the network. The sensitivity is calculated as the ratio of the error with missing value substitution to the original error. If this ratio is high, the deterioration will be high which means that the network is more sensitive to that particular variable. After all sensitivities have been calculated for all variables, they are ranked in order. Thus, the inputs are ranked according to the calculated ratios of each variable. In *Table II*, the sensitivity analysis of the network is given.

TABLE II. Sensitivity analysis of the network

	MMD	W	q	T	MIU	WC
Ratio	4.45	2.85	2.45	1.68	1.24	1.06
Rank	1	2	3	4	5	6

The most important parameter affecting on the total hand values of the disposable diapers as a result of the neural networks is MMD. The second one is weight (W) of the diapers. As a result of the neural networks, there is at least one variable from each mechanical and heat properties.

Comparison Of Total Hand Value Of Neural Networks And Regression With Subjective Test

Ten input parameters, namely MIU, MMD, SMD, WC, RC, LC, K, q, T and W of disposable diaper, were experimentally measured. The above-prepared samples are considered as control and using those input parameters, the output parameters (THV) were predicted.

Using the results from the subjective trial, mean square error was used to compare and verify which method is a good agreement with the subjective test: neural networks and regression analysis (see *Table III).*

From this investigation, mean square errors (MSE) for THV_{sub}-THV_{ANN} and THV_{sub}-THV_{REG} are 0.09 and 0.23, respectively. It was found that the results of subjective assessment were more consistent with neural networks rather than the regression method (see *Table III),* because MSE of THV_{sub}-THV_{ANN} is smaller than MSE THV_{sub}-THV_{REG}.

The summary statistics of ANN are given in *Table III*. It can be seen that even the error values of testing are lower and estimation coefficient values are higher compared to the results of regression analysis. The difference between the RMSE of testing and RMSE error of regression is 0.18. Since THVs values range is 2 to 4.5, this difference in RMSE causes 4-9 % improvement in the estimation of THV of diapers with ANN.

TABLE III. Summary statistics of total, training, and testing set

Summary Statistics of models	Total	Training	Testing	Regression
Mean Square Error	0.06	0.03	0.09	0.23
Root Mean Square Error	0.25	0.18	0.30	0.48
Absolute Error Mean	0.19	0.18	0.23	0.41
Mean Percentage of Absolute Error	0.07	0.05	0.09	0.15
Correlation	0.95	0.96	0.89	0.77
Regression	**0.90**	**0.92**	**0.79**	**0.60**

CONCLUSION

It has been indicated that the technique of neural networks showed better agreement with the subjective test method than regression analysis. Our neural networks method revealed a good coincidence with the results of subjective assessment. Another advantage of our automatic THV evaluator is that it is simple in application, and is applicable for a different textile market or an area if surveyed and for a textile material type. Therefore it can be stated that the neural network approach provides an effective skill for overall hand feeling of bulky materials such as disposable diapers.

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