The Prediction of Needle Penetration Force in Woven Denim Fabrics Using Soft Computing Models

Ezzatollah Haghighat, Saeed Shaikhzadeh Najar, Seyed Mohammad Etrati

Amirkabir University of Technology, Tehran, IRAN

Correspondence to:
Seyed Mohammad Etrati email:elham@aut.ac.ir

ABSTRACT

The aim of this paper was to predict the needle penetration force in denim fabrics based on sewing parameters by using the fuzzy logic (FL) model. Moreover, the performance of fuzzy logic model is compared with that of the artificial neural network (ANN) model. The needle penetration force was measured on the Instron tensile tester. In order to plan the fuzzy logic model, the sewing needle size, number of fabric layers and fabric weight were taken into account as input parameters. The output parameter is needle penetration force. In addition, the same parameters and data are used in artificial neural network model. The results indicate that the needle penetration force can be predicted in terms of sewing parameters by using the fuzzy logic model. The difference between performance of fuzzy logic and neural network models is not meaningful (R_{FL}=0.971 and R_{ANN}=0.982). It is concluded that soft computing models such as fuzzy logic and artificial neural network can be utilized to forecast the needle penetration force in denim fabrics. Using the fuzzy logic model for predicting the needle penetration force in denim fabrics can help the garment manufacturer to acquire better knowledge about the sewing process. As a result, the sewing process may be improved, and also the quality of denim apparel increased.

Keywords: Fuzzy logic, Needle penetration force, Sewing parameters, Denim fabric

INTRODUCTION

It is generally accepted that the garment industry has a great role in economic activities and human daily life [1]. Recently, the application of cotton woven fabrics, especially denim fabrics in apparel products, has considerably increased. Cotton Incorporated [2] reported that the tendency of costumers to wear denim products has increased. The quality of apparel products is very important for costumers. Several factors such as fabric quality, sewing machine parameters, sewing threads, and sewability of fabric have main influences on apparel quality. Among several indexes used to determine the sewability of fabric, needle penetration force, (NPF) is one of the most important ones. The quantitative value of NPF could be used to determine the damage of sewn fabrics during the sewing process, which has negative effects on the quality of apparel [3-4]. The needle penetration force is influenced by several parameters such as the mechanical properties of the textile material, sewing needle size, number of fabric layers, sewing machine speed, and weave pattern [5-7].

In order to predict NPF, some models such as mathematical and finite element methods were developed. Lomov [8] presented a model to predict the needle penetration force in woven fabrics based on fabric structural parameters, geometrical and mechanical properties of yarns. The model shows the existence of a relationship between needle diameter, warp and weft spacing, yarn bending rigidity, and needle penetration force in woven fabrics. In other research, sewing forces were simulated based on needle geometry, fabric properties, and sewing conditions by using finite element model [9].

It is well known that the neural network and fuzzy logic methods are able to model non-linear and multivariable mathematical functions. Currently, several predictive models based on soft computing (fuzzy logic, artificial neural network and neuro-fuzzy) have been used in textile applications [10-11], particularly in the garment industry [12-14]. To forecast the seam pucker in garment manufacture, the artificial neural network was used [15]. The bending stiffness, weight, and thickness of fabric were considered as inputs to a neural network. A neuro-fuzzy method was developed to model the control of sewing machine for complicated interactions with limp materials [16]. Moreover, the foot and disc forces of sewing machines were optimized using the neuro-fuzzy logic. The preciseness of the control system was verified [17]. In a recent study, by implementing fuzzy logic system and sensory evaluation of wearers, the estimation of ease allowance of jean trousers has been optimized [18]. However, there is no research work available predicting the NPF in denim fabrics using the fuzzy logic model.

In this paper, firstly, the FL model is presented to predict the needle penetration force in denim fabrics, and then the performance of FL is compared with that of the ANN model.

DESCRIPTION OF THE MODELS

Fuzzy Logic

Fuzzy logic was presented by Lotfi Zadeh [19] in 1965. It begins with the idea of a fuzzy set. A fuzzy set is a non-crisp set [20]. Fuzzy logic lets elements be members of various sets with varying degrees at the same time. A Fuzzy system includes five steps: fuzzification of inputs, applying fuzzy operator (AND or OR), implication method, aggregation of outputs, and defuzzification [20].

First, in fuzzification process, by utilizing membership function (*MF*), the crisp numerical values convert to fuzzy degree of membership for linguistic expression of fuzzy sets. On the other hand, the scalar values change into fuzzy values. The membership function is a curve, which allows graphically representing a fuzzy set. The input is planned to a degree of membership between interval 0 and 1. There are various types of membership functions such as *Diff. Sigmoidal* (*dsimf*), *Gaussian* (*gaussianmf*), and *Gaussian2* (*gaussian2mf*).

The *diff. Sigmoidal MF* is the difference of two *Sigmoids* membership functions as Eq. (1) [20]:

$$\text{diff. Sigmoidal: } f_1(x;\sigma_1,c_1) - f_2(x;\sigma_2,c_2) \tag{1}$$

where,

$$f(x;\sigma,c) = 1/[1+exp(-\sigma(x-c))] \tag{2}$$

σ: variance, and c: mean

Also, the *Gaussian MF* and *Gaussian2 MF* perform a membership function on the basis of a symmetric *Gaussian* and the combination of two *Gaussian* functions, respectively. For instance, the *Gaussian* curve is defined by Eq. (3) [20]:

$$f(x) = exp(\frac{-(x-c)^2}{2\sigma^2}) \tag{3}$$

After fuzzification, to achieve the defined results of rules (used for formulating the conditional statements, which include fuzzy set), the fuzzy operators are utilized. Then, the implication method is carried out after applying a suitable weight to each rule. The figure obtained from the prior step is input of the implication process, and the output is a fuzzy set. It is necessary to aggregate the fuzzy sets into a single fuzzy set, which is done by the aggregation method.

Finally, in order to get an output as a single number from the fuzzy logic system, the defuzzification process is applied. There are several types of defuzzification methods such as *Centroid*, *Center of Sums*.

In most fuzzy logic systems, the *Centroid* method (Eq. (4)) is usually utilized [21].

$$y = \frac{\int \mu_A(x)xdx}{\int \mu_A(x)dx} \tag{4}$$

where, y is the defuzzified output, and $\mu_A(x)$ is the fuzzy set output after aggregation [21].

In the fuzzy logic system, two types of fuzzy inference, *Mamdani*-type and *Sugeno*-type, are used. However, *Mamdani* method is frequently utilized. In *Mamdani*-type, the output membership functions are fuzzy sets, thus it needs defuzzification. The output membership functions of *Sugeno* system could be linear or constant [20].

Artificial Neural Network

Artificial neural network is regarded as mathematical data modeling technique, which models the complicated relationships between inputs and outputs. The multilayer perceptron neural networks have been implemented nearly 80 percent in applications. Among the several types of networks, feed-forward and back-propagation networks are considerably used [22]. The multi-layer feed-forward networks with differentiable transfer functions are trained by back-propagation. There are various training algorithms for feed-forward networks; in particular, *Trainlm* is much utilized in neural networks.

Mean square error (*MSE*) is a typical performance function, which is used for training the feed-forward networks (Eq. (5)) [23].

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(e_i)^2 = \frac{1}{N}\sum_{i=1}^{N}(t_i - a_i)^2 \qquad (5)$$

where, t_i and a_i are network's target output and network output, respectively; N is number of data [23].

Learngd or *Learngdm* are used as learning functions. There are many forms of transfer functions from a simple linear scaling to nonlinear functions such as *Purelin* and *Tansig*. The efficiency of neural network training is increased when the preprocessing functions are used on the inputs and outputs of networks [23].

MATERIALS AND METHODS

Fabric Samples and Needle Size

In order to predict the needle penetration force, five commercial samples of woven denim fabrics with different weights, commonly used for clothing were prepared (*Table I*). Five *set cloth point* needles with different sizes (80, 90 100, 110, 120 Nm) were selected. This type of needle is used for sewing woven fabrics [24] and is usually applied to lockstitch and chain stitch sewing machines.

TABLE I. Physical characteristics of denim fabrics.

Weight (g/m^2)	300	370	402	421	441
Weave pattern	Twill 3/1				

Measurement of Needle Penetration Force

Measurement of NPF was carried out on an Instron tensile tester 5566 (*Figure 1*). The fabric sample was held on a constructed ring (1), which was mounted on the bottom jaw of the Instron (2). The needle was fastened to the upper jaw (3) by utilizing an eccentric needle bar (4). Hence, it was possible to have different positions on the surface of fabric samples while needle piercing into samples by rotating the ring [14].

In order to simulate the movement of needle in the sewing machine, five cycles of needle penetration were performed for each fabric sample. The needle insertion speed and depth of needle insertion into the fabric structure were 460 (mm/min) and 12 (mm), respectively. According to the different fabric weights, fabric layers and needle sizes (5 different fabrics, 4 various layers, and 5 needle sizes), the number of samples was 100. Each sample was tested five times; therefore, the total number of examined cases was 500.

FIGURE 1. Experimental set up to measure needle penetration force on Instron tensile tester.

A typical result of needle penetration force versus time, obtained by using the Instron tensile tester, is demonstrated in *Figure 2*. In this work, the force that is considered as NPF is the maximum penetration force between five cycles for each sample (point "P" in *Figure 2*). Thus, the average of NPF values for five tested cases of each sample was calculated. *Table II* shows the experimental values of NPF in different cases.

TABLE II. The experimental values of needle penetration force in different cases.

Number of fabric layers															
1				2				3				4			
No.	FW (g/m²)	NS (*Nm*)	NPF (*N*)	No.	FW (g/m²)	NS (*Nm*)	NPF (*N*)	No.	FW (g/m²)	NS (*Nm*)	NPF (*cN*)	No.	FW (g/m²)	NS (*Nm*)	NPF (*N*)
1		80	2.2	26		80	3.5	51		80	4.7	76		80	7.4
2		90	2.5	27		90	5.0	52		90	6.6	77		90	6.3
3	300	100	2.6	28	300	100	5.3	53	300	100	7.2	78	300	100	8.5
4		110	4.5	29		110	7.3	54		110	11.4	79		110	12.2
5		120	4.7	30		120	8.0	55		120	11.8	80		120	15.3
6		80	3.0	31		80	6.0	56		80	7.6	81		80	10.4
7		90	3.5	32		90	6.5	57		90	10.3	82		90	12.4
8	370	100	4.7	33	370	100	8.4	58	370	100	12.4	83	370	100	13.4
9		110	6.6	34		110	12.0	59		110	17.0	84		110	20.0
10		120	7.2	35		120	12.9	60		120	18.8	85		120	21.0
11		80	3.5	36		80	7.1	61		80	9.4	86		80	10.9
12		90	4.7	37		90	9.2	62		90	12.8	87		90	13.8
13	402	100	5.3	38	402	100	10.3	63	402	100	14.5	88	402	100	17.3
14		110	6.9	39		110	14.9	64		110	18.1	89		110	24.0
15		120	9.0	40		120	15.1	65		120	21.0	90		120	25.0
16		80	4.3	41		80	8.0	66		80	11.6	91		80	13.0
17		90	5.4	42		90	10.1	67		90	15.1	92		90	17.5
18	421	100	5.5	43	421	100	10.4	68	421	100	15.2	93	421	100	18.0
19		110	7.2	44		110	13.8	69		110	21.0	94		110	24.0
20		120	9.2	45		120	16.6	70		120	21.7	95		120	26.9
21		80	5.7	46		80	11.6	71		80	15.9	96		80	20.2
22		90	8.0	47		90	15.3	72		90	21.7	97		90	24.4
23	441	100	9.0	48	441	100	15.6	73	441	100	21.8	98	441	100	28.2
24		110	11.1	49		110	20.3	74		110	27.1	99		110	35.7
25		120	12.0	50		120	21.8	75		120	30.4	100		120	39.2

FW: fabric weight, NS: needle size, and NPF: needle penetration force.

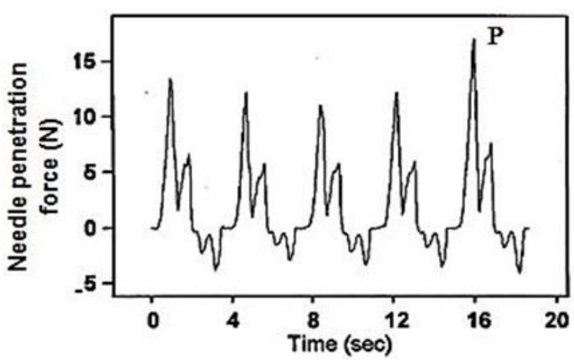

FIGURE 2. A typical needle penetration force versus time

Creating Fuzzy Logic System

By using fuzzy logic toolbox (MATLAB software), the fuzzy system was created according to input parameters: sewing needle size (NS), number of fabric layers (NLF) and fabric weight (FW), and also output parameter: needle penetration force (measured by Instron). Some linguistic fuzzy sets such as semi fine, medium, coarse, low and high were selected for each of the input and output parameters. These linguistic fuzzy sets are able to properly cover the ranges of inputs and output parameters. *Table III* shows the linguistic fuzzy sets given for a specified range of each parameter.

TABLE III. Linguistic fuzzy sets for input and output parameters.

Parameter	Range	Linguistic fuzzy sets
NS (Nm)	80-120	semi fine, medium, coarse
NFL	1-4	low, medium, rather high, high
FW (*g/m²*)	300-450	medium, semi heavy, heavy, too heavy
NPF (*N*)	2.2-40.0	low, rather low, medium, rather high, high, too high

Three types of membership functions (*gaussian2mf*, *gaussianmf* and *dsigmf*) were applied for input and output parameters. *Figures 3-6* show the membership functions for sewing needle size, number of fabric layers, fabric weight, and needle penetration force, respectively. After fuzzification, 48 rules were created. In these rules, 'AND' operation was used. The function '*Minimum*' of the two values was selected for 'AND' operator.

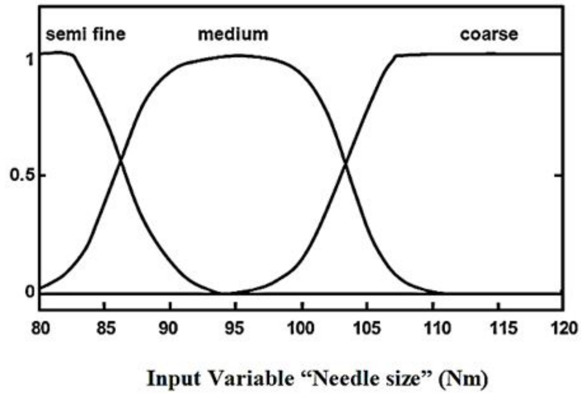

FIGURE 3. Membership function for needle size.

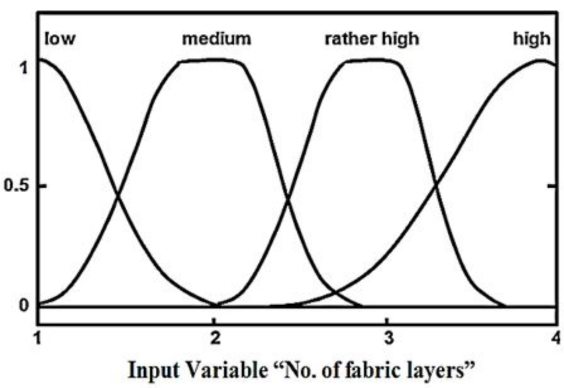

FIGURE 4. Membership function for number of fabric layers.

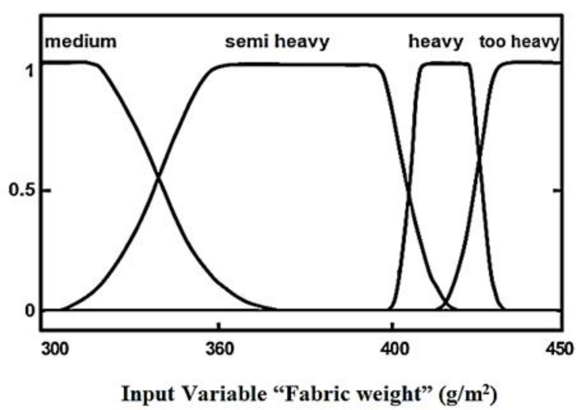

FIGURE 5. Membership function for fabric weight.

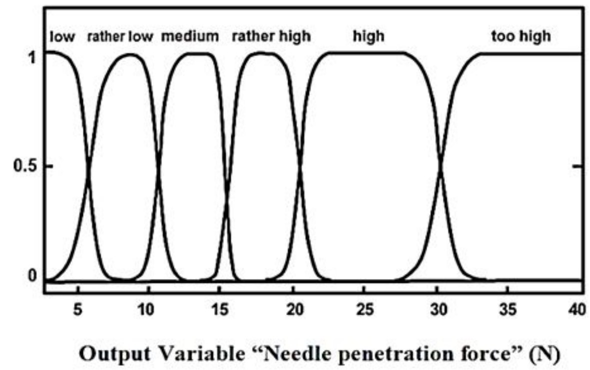

FIGURE 6. Membership function for needle penetration force.

Finally, to have a single crisp number in *Mamdani*-type inference, the *Centroid* method of defuzzification was used. *Figure 7* diagrammatically shows the fuzzy logic system for modeling of NPF.

Moreover, when the values of input parameters such as fabric weight and needle size were changed at different levels, it was possible to forecast the needle penetration force by creating appropriate membership functions or rules.

Artificial Neural Network Model

In order to normalize and scale the input and output values in neural network, before training, the *Mapminmax* preprocessing function was used as follows (Eq. (6)) [11]:

$$x_i = 2\left(\frac{v_i - v_{\min}}{v_{\max} - v_{\min}}\right) - 1 \qquad i=1, 2\ldots n \tag{6}$$

where

x_i : the scaled values into range [-1, 1]; v_i: the values of inputs (outputs), v_{max} and v_{min} are respective maximum and minimum values of inputs (outputs).

For predicting the needle penetration force, the networks *N1and N2* with one and two hidden layers were planned. *Learngdm, MSE, Trainlm, and Tansig* were utilized as learning, performance, training and transfer functions, respectively.

To validate the accuracy of the neural network model, the five–fold cross-validation technique was used. Consequently, the data sets of 100 samples were randomly divided into 5 subsets. Each time, 4 subsets were combined together and applied for training set and another subset was utilized for testing set (training set and test set contain 80 and 20 samples, respectively).

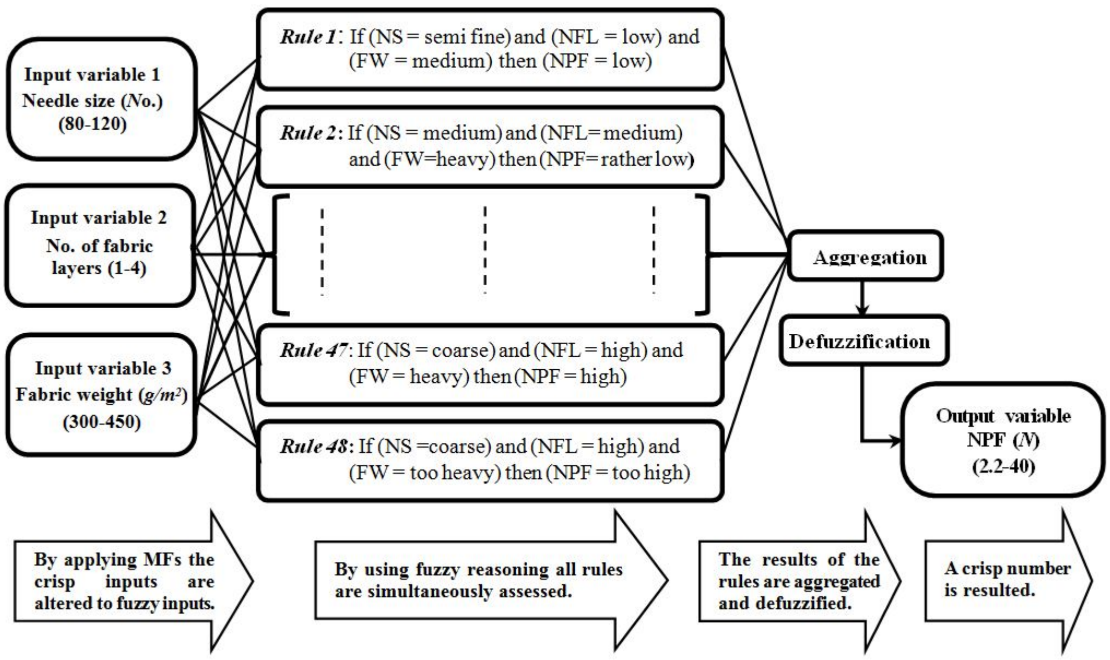

FIGURE 7. Diagram of fuzzy logic system for modeling of needle penetration force.

Accordingly, five sets of training and testing data were formed and each planned network was trained and tested five times.

After training the designed networks with training data sets (80 samples), the performance of achieved networks were evaluated by testing the networks with testing data sets (20 samples). In this study, the MATLAB (R2008b) software was used to plan the fuzzy logic and the neural network models.

RESULTS AND DISCUSSION

Operation of Fuzzy Logic

In this research, the fuzzy logic model was developed to forecast NPF. In order to obtain a proper performance of fuzzy logic system, 4 membership functions and 48 rules were created.

For example according to the first rule (*Figure 7*), when needle size, No. of fabric layers, and fabric weight are semi fine, low, and medium, respectively, the needle penetration force is low. While the needle size is 100 (*Nm*), No. of fabric layers is 3, and fabric weight is 441 (g/m^2), then all 48 fuzzy rules are evaluated simultaneously to determine the needle penetration force, and after aggregation and defuzzification, the final crisp output of fuzzy set is 22.1 *N* (*Figure 8*). As shown in *Table II*, the experimental value of needle penetration force (21.8 *N*) is near to the value predicted by fuzzy logic model (22.1 *N*).

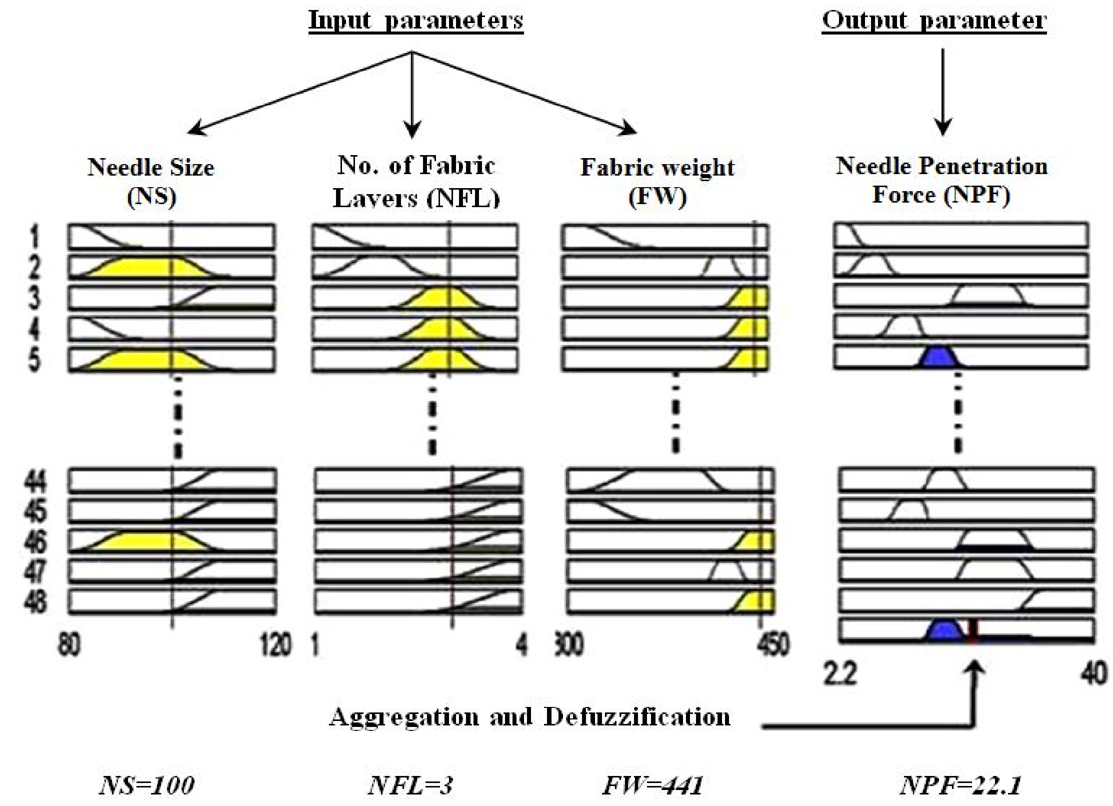

FIGURE 8. Fuzzy rules relating inputs and output parameters in fuzzy logic system.

Influence of Input Parameters on the Needle Penetration Force

The surface plots, obtained from fuzzy logic system, show the relationship between input and output parameters.

By using the surface plots, it is possible to investigate the influences of needle size, No. of fabric layers, and fabric weight on the NPF. The surface plots are shown in *Figures 9-11*.

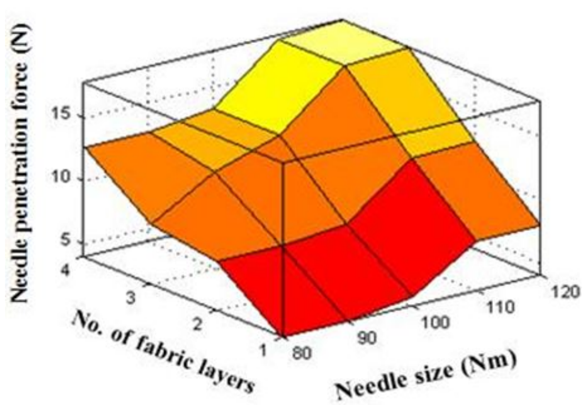

FIGURE 9. Predicted surface plot showing the influence of needle size and number of fabric layers on the needle penetration force.

In *Figure 9,* according to No. of fabric layers and needle size, the average values of NPF in different fabric weights is presented. The same procedure is applied for values of NPF in *Figure 10* and *Figure 11*.

Figure 9 shows that when the sewing needle is semi fine or medium (80-100 Nm) and No. of fabric layers is low (one layer), the needle penetration force is low (around 4 *N*). With increasing of needle size, the needle penetration force increases. The highest values of needle penetration force are observed when the values of needle size and No. of fabric layers are high.

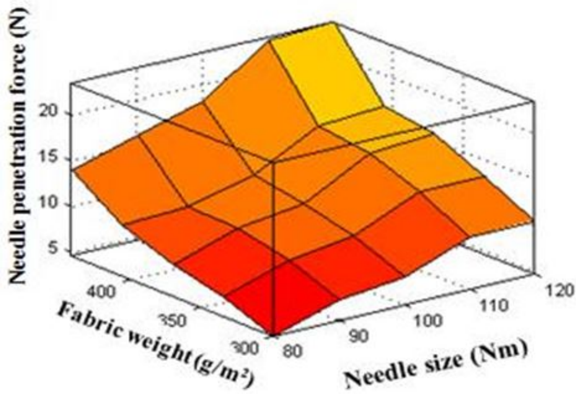

FIGURE 10. Predicted surface plot showing the influence of needle size and fabric weight on the needle penetration force.

According to *Figure 9*, No. of fabric layers has more influence on the needle penetration force than needle size. *Figure 10* shows that the needle penetration force increases with increasing fabric weight and needle size. It can be stated that the effect of fabric weight on needle penetration force is greater than the needle size effect. Greater values of needle penetration force are observed for heavier fabric samples.

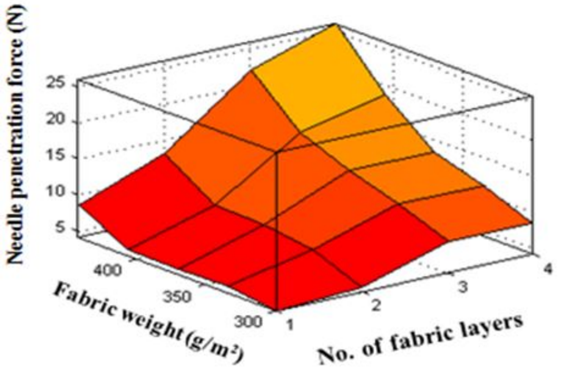

FIGURE 11. Predicted surface plot showing the influence of fabric weight and number of fabrics layers on the needle penetration force.

It is shown that when the fabric is not heavy and No. of fabric layers is low or medium, the needle penetration force is rather low (*Figure 11*).

Considering the surface plots, particularly as depicted in *Figure 11*, it can be realized that the effects of fabric weight and No. of fabric layers on the needle penetration force are more pronounced than the needle size; because, the maximum value of needle penetration force is observed in *Figure 11*.

Validation of Fuzzy Logic System

After creating a fuzzy logic system to predict NPF, it is necessary to verify the preciseness of planned fuzzy system by utilizing the experimental data sets. When the model accuracy is acceptable, it can be used for fabrics with different weights, No. of fabric layers and needle sizes for the specified ranges (*Table III*).

For this purpose, 100 sets of data were used as input data sets in the fuzzy system to achieve output data (predicted values of needle penetration force).

The prediction accuracy of the fuzzy logic model is evaluated by applying *MSE* and correlation coefficient (*R-value*) between the predicted and the experimental values. According to the results, the value of *MSE* is 3.413, and the *R-values* is 0.971 ($R^2=0.944$). It is concluded that the performance of fuzzy logic for forecasting of needle penetration force based on needle size, No. of fabric layers, and fabric weight is acceptable.

Figure 12 shows the correlation between experimental and predicted values of needle penetration force. It can be seen that there is little difference between these values. Moreover, the actual surface plots (*Figures 13-15*) obtained from experimental values is compared with predicted surface plots (*Figures 9-11*). These figures show that there is a good agreement between the actual and predicted surface plots.

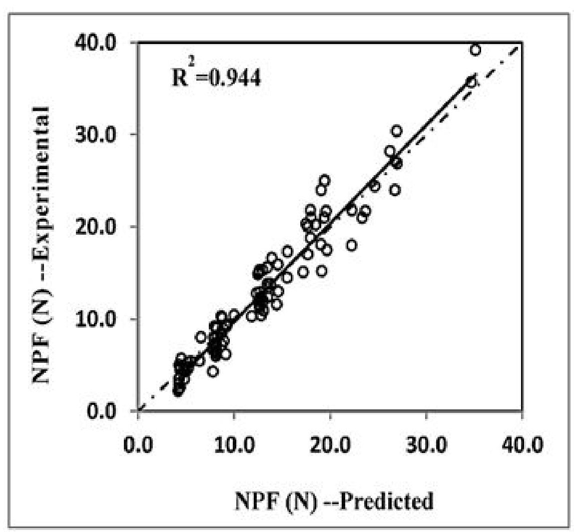

FIGURE 12. The correlation between experimental and predicted values of needle penetration force by fuzzy logic model.

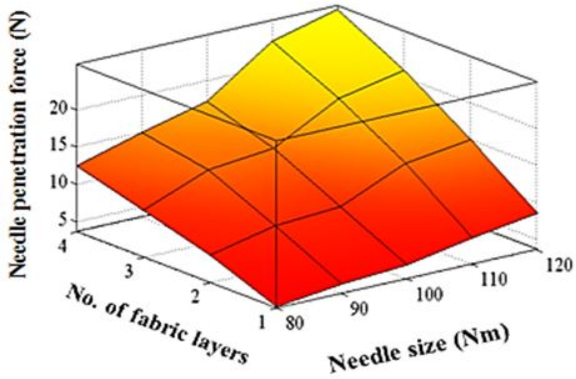

FIGURE 13. Actual surface plot showing the influence of needle size and number of fabrics layers on the needle penetration force.

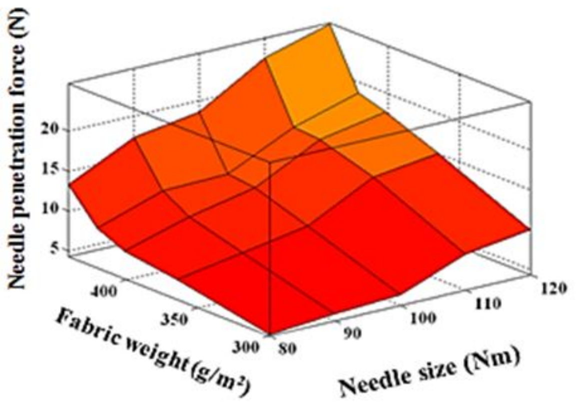

FIGURE 14. Actual surface plot showing the influence of needle size and fabric weight on the needle penetration force.

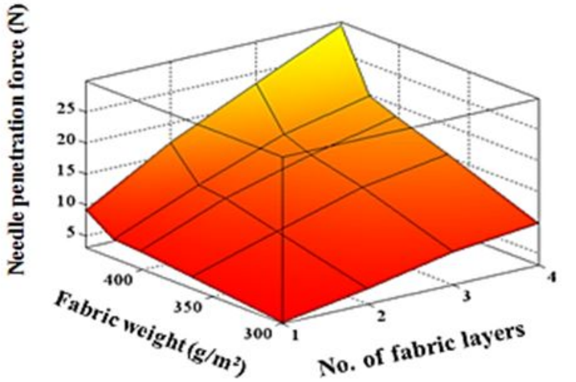

FIGURE 15. Actual surface plot showing the influence of fabric weight and number of fabrics layers on the needle penetration force.

TABLE IV. Performance of ANN models on testing data sets.

Code	Data set	*R- value*	*MSE*
N1	1	0.974	2.725
	2	0.992	0.899
	3	0.984	1.693
	4	0.987	1.357
	5	0.980	4.721
	average	0.983	2.279
N2	1	0.965	3.658
	2	0.995	0.552
	3	0.981	1.871
	4	0.983	3.766
	5	0.980	3.706
	average	0.981	2.711
Total average		0.982	2.495

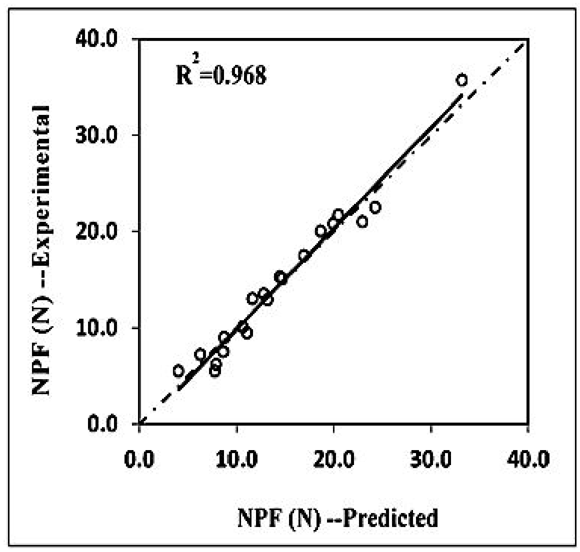

FIGURE 16. The correlation between experimental and predicted (ANN Model; N1) values of NPF on testing data set 4.

Validation of Artificial Neural Network

In the neural network model, the same data used in fuzzy logic model was applied, as explained in section *Artificial Neural Network Model***.** In *Table IV* the values of *MSE*, and the *R-values* obtained by testing the networks (N1 and N2) with five testing data sets are presented.

Figure16 shows the correlation between experimental and predicted values on testing data set 4 in network *N1*. The obtained results show that the difference between performance of fuzzy logic and artificial neural network models in forecasting of needle penetration force is not significant (R_{FL}=0.971 and R_{ANN}=0.982; MSE_{FL}=3.413 and MSE_{ANN}=2.495).

CONCLUSION

In this paper, the fuzzy logic and artificial neural network models are developed to predict the needle penetration force in denim fabrics. The needle size, number of fabric layers and fabric weight are considered as inputs in the models. The results indicate that the needle penetration force in different denim fabrics can be predicted with high accuracy using fuzzy logic and artificial neural network models based on the mentioned parameters. The performance of fuzzy logic in forecasting the needle penetration force is near to the performance of neural network (R^2_{FL}=0.944 and R^2_{ANN}=0.968). The surface plots show that the penetration force increases with increasing of the needle size, number of fabric layers, and fabric weight. However, the influences of fabric weight and number of fabric layers on the penetration force are more considerable than needle size.

The Instron tensile tester is the equipment that is available in many laboratories. This developed experimental set-up and method can help garment manufacturers measure needle penetration force, and also to produce high quality denim products through selecting suitable needle size.

ACKNOWLEDGEMENTS

The authors greatly appreciate Khoy Textile Co. for supplying the woven denim fabrics.

REFERENCES

[1] Guo, Z.X.; Wong, W.K.; Leung, S.Y.S.; Li, M.; "Applications of artificial intelligence in the apparel industry: a review", *Textile Res. J.*, Vol. 81 No. 18, 2011, pp.1871–1892.

[2] Cotton Incorporated; "European views on fiber & denim", available at: http://lifestylemonitor.cottoninc.com/ Supply-Chain-Insights/European-Views-on-Fiber-and-Denim-01-09/European-Views-on-Fiber-and-Denim-01-09.pdf, 2009.

[3] Stylios, G.; Sotomi, O.J.; Zhu, R.; Fan, J.; Xu, Y.M.; Deacon, R.; "A sewability integrated environment (SIE) for intelligent garment manufacture", *factory 2000 - advanced factory automation, fourth international conference on (Conf. Publ. No. 398)*, 1994.

[4] Behera, B.K.; Chand, S. Singh; T.G. Rathee, P.; "Sewability of denim", *International Journal of Clothing Science and Technology*, Vol. 9 No. 2, 1997, pp. 128-140.

[5] Ujević, D.; Rogale, D.; Kartal, M.; Šajatović, B.B.; "Impact of sewing needle and thread on the technological process of sewing knitwear", *Fibres & Textiles in Eastern Europe*, Vol. 16 No. 4(69), 2008, pp. 85-89.

[6] Carvalho, H.; Rocha, A.M.; Monteiro, J.L.; "Measurement and analysis of needle penetration forces in industrial high-speed sewing machine", *J. of the Textile Institute*, Vol. 100 No. 4, 2009, pp. 319–329.

[7] Haghighat, E.; Etrati, S.M.; Shaikhzadeh Najar, S.; "Evaluation of woven denim fabric sewability based on needle penetration force", J. of Engineered Fibers and Fabrics, Vol. 9 No. 2, 2014, pp. 47-59.

[8] Lomov, S.V.; "A predictive model for the penetration force of a woven fabric by a needle", *International Journal of Clothing Science and Technology*, Vol. 10 No. 2, 1998, pp. 91-103.

[9] Mallet, E.; Du, R.; "Finite element analysis of sewing process", *International Journal of Clothing Science and Technology*, Vol. 11 No. 1, 1999, pp. 19-36.

[10] Haghighat, E.; Johari, M.S.; Etrati, S.M.; Amani Tehran, M.; "Study of the hairiness of polyester-viscose blended yarns, part III-predicting yarn hairiness using an artificial neural network", *Fibres & Textiles in Eastern Europe*, Vol. 20 No. 1(90), 2012, pp. 33-38.

[11] Haghighat, E.; Johari, M.S.; Etrati, S.M.; Amani Tehran, M.; "Study of the hairiness of polyester-viscose blended yarns, part IV - predicting yarn hairiness using fuzzy logic", *Fibres & Textiles in Eastern Europe*, Vol. 20 No. 3(92), pp. 39-42.

[12] Jeguirim, S.E.; Sahnoun, M.; Dhouib, A.B.; Cheickrouhou, M.; Schacher, L.; Adolphe, D.; "Predicting compression and surfaces properties of knits using fuzzy logic and neural networks techniques", *International Journal of Clothing Science and Technology*, Vol. 23 No. 5, 2011, pp. 294-309.

[13] Hui, P.C.L.; Chan, K.C.C.; Yeung, K.W.; Ng, F.S.F.; "Application of artificial neural networks to the prediction of sewing performance of fabrics", *International Journal of Clothing Science and Technology*, Vol. 19 No. 5, 2007, pp. 291-318.

[14] Haghighat, E.; Etrati, S.M.; Shaikhzadeh Najar, S.; "Modeling of needle penetration force in denim fabric", International Journal of Clothing Science and Technology, Vol. 25 No. 5, 2013, pp. 361-379.

[15] Stylios, G.; Moore, R.P.; "Seam pucker prediction using neural computing", *International Journal of Clothing Science and Technology*, Vol. 5 No. 5, 1993, pp. 24-27.

[16] Stylios, G.; Sotomi, J.O.; "A neuro-fuzzy control system for intelligent overlock sewing machines", *International Journal of Clothing Science and Technology*, Vol. 7 No. 2/3, 1995, pp.49-55.

[17] Stylios, G.; Sotomi, J.O.; "Thinking sewing machines for intelligent garment manufacture", *International Journal of Clothing Science and Technology*, Vol. 8 No. 1/2, 1996, pp. 44–55.

[18] Chen, Y.; Zeng X.; Happiette, M.; Bruniaux, P.; Ng, R.; Yu, W.; "A new method of ease allowance generation for personalization of garment design", *International Journal of Clothing Science and Technology*, Vol. 20 No. 3, 2008, pp.161-173.

[19] Zadeh L.A.; "Fuzzy Sets", *Information and Control*, Vol. 8, 1965, pp.338-353.

[20] "Fuzzy logic toolbox user's guide", http://www.mathworks. com/help/pdf_doc/fuzzy/fuzzy.pdf

[21] Majumdar A.; Ghosh A.; "Yarn strength modelling using fuzzy expert system", *J. of Engineered Fibers and Fabrics*, Vol. 3 No. 4, 2008, pp. 61-68.

[22] Guruprasad, R.; Behera, B.K.; "Review articles: soft computing in textiles", *Indian J. Fibre Text. Res*., Vol. 35, 2010, pp. 75-84.

[23] Beale, M.H.; Hagan, M.T.; Demuth, H.B.; "Neural network toolbox user's guide", http://www.mathworks.com/help /pdf_doc/nnet/nnet_ug.pdf.

[24] Glock R.E.; Kunz G.I. "Apparel Manufacturing Sewn Product Analysis", fourth edition, Pearson Prentice Hall, New Jersey, 2005, pp. 465-467.

AUTHORS' ADDRESSES
Ezzatollah Haghighat
Saeed Shaikhzadeh Najar
Seyed Mohammad Etrati
Amirkabir University of Technology
Hafez Ave 424
Tehran, 15875-4413
IRAN