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Comparison among artificial neural network, linear and logarithmic regression models as predictors of stretchable woven fabric tightness

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Abstract: This study aimed at comparing the performance of ANN, multiple linear and logarithmic regression models for predicting stretchable fabric tightness. Three different statistical parameters, namely R2 value, mean bias and root mean square errors were used effectively to assess the predictors. From the findings of this study, it was noticed that ANN outperformed both regression models in terms of lower RMSE and MBE and higher R^2 values. It was also found that logarithmic regression model has somewhat better performance compared to multiple linear regression one.
Keywords: artificial neural network, linear, logarithmic regression models, stretchable, woven fabric tightness.

1- Introduction

Woven fabric properties rely mainly upon yarn parameters such as yarn count, twist factor, twist direction, spinning type, and the fabric constructional parameter, namely weave structure, warp density , cover factor, weft yarn density and tightness factor. Tightness factor affects significantly woven fabric properties.

The first work was introduced to describe the woven fabric tightness conducted by Peirce on 1937 [1]. After that and over several years, many researchers such as Brierley [2-5], Love [6], Russell [7], Hamilton [8], Bogaty [9] and Galuszynski [10] have derived different mathematical models of woven fabric tightness. An overview of the tightness of the woven fabric and its application was presented in more details by Seam and El sheikh [11]. A new tightness factor was also presented by them based on a Ashenhurst's [12] work and Love's race track geometry [6]. The advantages, disadvantages and the limitations of this new factor were discussed extensively. Also Milasius [13] and Li [14] presented a new tightness factor which can be determined by a series of equations.

The influence of tightness factor on woven and knitted fabric properties was presented in many papers. It was shown that shielding effectiveness of blended fabrics affected positively by the fabric tightness [15]. Galuszynski [16] stated that weave resistance increases and fabric elastic modulus decreases with woven fabric tightness factor. He also reported that tightness factor can be used to assess and evaluate fabric sewability, seam slippage and dimensional properties. The prediction of stretchable yarn and fabric properties woven from these yarns were extensively examined [17-20]. Serkan [21] has also examined the effect of tightness factor on different properties of stretchable knitted fabrics.

This study aimed to predict the stretchable fabric degree of tightness using ANN, linear and logarithmic regression models. The tightness degree of cotton-spandex stretchable woven fabric was predicted at various levels of spandex ratio and linear density.

2- Experimental work

2.1: Materials

In this study, thirty six woven cotton stretchable fabrics with different weave structures, spandex draw ratio and spandex linear density were woven. Three different weaves namely, plain 1/1, twill 2/2 and satin 5 were woven. All fabric samples were woven from weft and warp yarns of counts 24/1 Ne and 30/1 Ne respectively. The warp and weft densities were constant for all stretchable fabrics at 60 picks/inch and 76 ends/inch respectively. Generally, warp yarns in these fabrics are made up of 100% Egyptian cotton of Giza 90; while their weft yarns are made of core and sheath. The core made up of spandex with different linear densities, i.e. 20, 40 and 80 dtex respectively; while the sheath is 100% Egyptian cotton. Spandex was also subjected to four different draw ratios, i.e. 2, 3, 4 and 5 respectively. The parameters used in this study were detailed and listed in table 1. The characteristics of spandex monofilament that is used as a core of the weft yarn in this study was listed in table 2. Weave structures of the stretchable woven fabrics were depicted in figure 1.

Table 1: Details of the parameters used in this study

Levels of the used parameters		
Weave structure (weave factor)	**Spandex linear density, dtex**	**Spandex draft ratio, %**
Plain 1 / 1 (1)	20	2
Twill 2 / 2 (1.275)	40	3
Satin 5 (1.399)	80	4
		5

Table 2: Main characteristics of the spandex monofilament

Spandex linear density (dtex)	Characteristics		
	Luster	**Tenacity**	**Elongation**
20	**Clear**	**1.6 g/d**	**620 %**
40	**Clear**	**1.4 g/d**	**680 %**
80	**Clear**	**1.28 g/d**	**710 %**

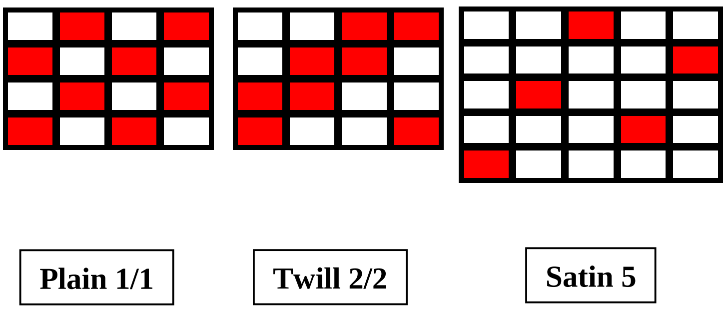

Figure 1: weave structures of the stretchable fabrics used in this study

2.2: Weave factor and tightness calculations

Fabric degree of tightness is also termed as fabric firmness. It is calculated according to the equations (1-3):

$$T = \frac{t_{a1} + t_{a2}}{(t_{m1} + t_{m2})} \qquad (1)$$

Where, T= Fabric degree of tightness

t_{a1}= warp yarn density (end/cm)
t_{a2}= pick density (ppcm)

$$t_{m1,2} = \frac{e}{(e-i)\pi \times d_{1,2}/4 + 2i \times d_{1,2}} \quad (2)$$

Where, $t_{m1,2}$= warp and filling fabric tightness
e = No. of yarns / repeat
i= No. of intersections / repeat

$$d(inch) = \frac{1}{29.3\sqrt{\Phi \times \rho_f \times N}} \quad (3)$$

Where, d = yarn diameter in inch,
ρ_f= density of the used fibers
N= count of yarns (Ne)
Φ = yarn packing factor = 0.6

Weave factor in this study was calculated according to Milasius' weave factor equation [22]. From this equation, the weave factor is 1, 1.275 and 1.399 for plain 1/1, twill 2/2 and satin 5 weave structures respectively.

2.3: Artificial Neural Network (ANN)

In this study, ANN with 3 neurons input layer, 30 neuron hidden layer and one neuron output layer corresponding to one dependent variable, i.e. stretchable fabric tightness was selected.

Before learning, the whole experimental data were segregated into three stets , namely training, validation, and testing patterns as follows: 60% of the patterns were selected for training, 20% were for testing ANN, and the remaining were used for validating the model's performance. The learning method of the ANN is accomplished using Levenberg–Marquardt algorithm. Also the sigmoid, transfer function (equation 4) was used in this study.

$$\text{Sigmoid: } f(x) = \frac{1}{(1+e^{-x})} \quad (4)$$

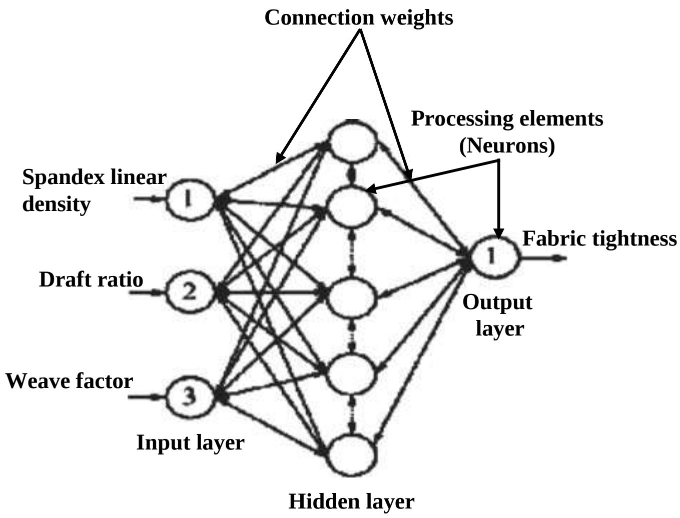

Figure 1: Architecture of the artificial neural network used.

The design of three-layered ANN used in this study was illustrated in figure 1. MATLAB 12 software package was used for processing the artificial neural network under study to predict fabric tightness. The training parameters of the used ANN is listed in table 3.

Table 3. Training parameters of the ANN used in this study.

Parameters of ANN	Value
No. of input nodes	3
No. of hidden nodes	20
No. of output nodes	1
Rule of ANN learning	Levenberg–Marquardt
No. of epochs	1000
Error target	0.0001
Marquardt adjustment	0.01
Minimum performance gradient	0.000001
Learning rate (lr)	0.4

2.4: Performance of ANN and regression models

In this study, RMSE, MBE and R2 value were utilized to assess, evaluate and validate both ANN and regression models. Generally, the lower is the RMSE and MBE, the better is the model prediction performance. On the contrary, when the coefficient of determination approaches one that is the model fits the data very well. The expression for RMSE, MBE and R^2 are as the equations 5-7.

$$\text{Root mean squared error} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2} \quad (5)$$

$$\text{Mean bias error} = \frac{1}{N}\left|\sum_{i=1}^{N}(y_i - x_i)\right| \quad (6)$$

$$\text{Coefficient of determination: } R^2 = \frac{SS_{regression}}{SS_{total}} = \frac{\sum_{i=}^{N}(y_i - \bar{y})^2}{\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad (7)$$

Where N= observation numbers, y_i = values of yarn tensile properties predicted by ANN, and x_i = the actual values of yarn properties, $\bar{x}$ = the mean of N observations of actual values of yarn properties, $\bar{y}$ = the mean of N observations of predicted values of yarn properties.

2.5: Statistical analysis

In this work, multiple-linear and logarithmic regression was used for developing a predictive model of stretchable woven fabric tightness. In this respect, the same sets of the experimental data used for evaluating ANN model were used in a multiple linear and logarithmic regression algorithms. In these predictive models, independent variables were spandex linear density (dtex), spandex draft ratio (%) and the weave factor of the fabrics used. yarns. The following linear regression model correlates the stretchable fabric tightness with the independent variable.

Fabric tightness = 1.306 + 0.0012 * X1 – 0.3962 * X2 + 0.02619 * X3

The logarithmic regression model that correlates fabric tightness with the independent variables has the following form:

Fabric tightness = 0.7959 + 0.0987 * Log (X1) – 1.0858 * Log (X2) + 0.1963 * Log (X3)

Where, X1= spandex linear density (dtex), X2= weave factor and X3= spandex draft ratio.

As seen from the above regression models, linear density and draft ratio of the spandex monofilament which is used as a core in the weft yarns of the stretchable fabrics affected fabric tightness positively. Whereas the stretchable woven fabric tightness was affected negatively by the weave fabric.

4- Results and discussion

Throughout this work, an ANN contains a 3 neuron input layer, 20 neuron hidden layer and one neuron output layer was adopted. This ANN was selected concentrating on tightness of the stretchable woven fabrics. This artificial neural network complies with the experimental data which consists of three inputs and one target. Some of theses experimental results were listed in table 3. The RMSE, MBE and R^2 value were used to assess the performance of the artificial neural network in comparison with multiple linear and logarithmic regression models.

4.1: Fabric tightness

The actual and predicted tightness values of stretchable fabrics using ANN, linear and logarithmic regression methodologies were presented in table 4. Table 5 introduces the performance parameters of the used predicting techniques. The results revealed that artificial neural network yields the best performance with the least RSME, MBE and R2 values compared to regression techniques. The root mean square error of the trained data by ANN, multiple linear and logarithmic regression was 0.00013, 0.02680 and 0.02825 respectively. It can be concluded that ANN method is outperformed than regression methods in terms of RMSE. It was also noticed that the performance of multiple linear regression and logarithmic regression are close to each other to some extent. The values of mean bias error for the artificial neural network, multiple linear regression and logarithmic regression were 0.00009, 0.02431 and 0.02339, which confirms the significant high performance associated with ANN technique regression models. Generally, logarithmic regression model showed better performance compared to linear regression one in terms of RMSE and MBE.

The R2 value discloses the explained variation by the model compared to the total variation. Thus, this parameter is considered the most important one to specify the performance of any tool used for prediction. The higher value of R2 signifies that the model represents the data reliably and it can be utilized with high precision to predict any experimental results. The results of coefficient of determination values of the used predicting techniques were introduced in table 5. It is shown that the R2 value associated with ANN model is very high and approaches one followed by the R2 value of logarithmic regression. This means that artificial neural network is the best model can be used to predict the tightness of the stretchable fabrics. Also it can be noted that the R2 value of logarithmic regression model is somewhat higher than the corresponding value of multiple linear regression. It was determined that coefficient of determination of ANN, linear and logarithmic regression models were 0.999, 0.687 and 0.891 respectively. These values indicate that 0.1% of the variation is not explained by the ANN model, whereas 13.3% and 10.9 % of the variation are not explained by linear and logarithmic regression models respectively. Therefore, it can be said that any nonlinear relationship can be fitted very well by ANN model

Table 4. Fabric tightness predicted by ANN, linear and logarithmic regressions.

Actual value	Linear regression		Logarithmic regression		Artificial neural network	
	Predicted value	Absolute error (%)	Predicted value	Absolute error (%)	Predicted value	Absolute error (%)
0.891081	0.918202	3.043675	0.913853	2.555571	0.895245	0.46729
0.942888	0.970580	2.936931	0.967398	2.599522	0.942888	6.22E-11
0.932118	0.904770	2.933924	0.913431	2.004757	0.932117	5.61E-11
1.084868	1.061310	2.171555	1.064946	1.836369	1.084868	0.00000
0.942888	0.968634	2.730609	0.965751	2.424815	0.942888	6.22E-11
0.968791	0.994823	2.687038	0.984773	1.649649	0.968791	-5.2E-13
0.991933	0.955202	4.244768	0.923853	3.677807	0.991933	1.01E-13

Table 5. Comparison of prediction performance of linear regression, logarithmic regression and ANN models for fabric tightness.

	Statistical parameters		
	(R^2 values)	(MBE values)	(RMSE values)
Linear regression	0.867	0.02431	0.02825
Logarithmic regression	0.891	0.02239	0.02680
ANN	0.999	0.00009	0.00013

From table 4 it can be noticed that the absolute error associated with ANN, ranges between zero and 0.467%, while it ranges between 2.1715 and 4.244% and ranges between 1.649 and 3.677% for linear and logarithmic regression models respectively. This also assures that the artificial neural network has the best predictive performance for stretchable woven fabric tightness compared to regression models.

Figures 2 through 4 depict the actual against predicted values for stretchable fabric tightness using ANN, linear and logarithmic regression models. From these figures it can be seen that ANN model yields measured tightness values with trend better than regression ones. The regression trends obtained by linear and logarithmic regression models are converging to a large extent. It was estimated that the coefficient of correlation between actual and predicted tightness values were found to equal 0.99 and 0.94 for ANN and regression models respectively.

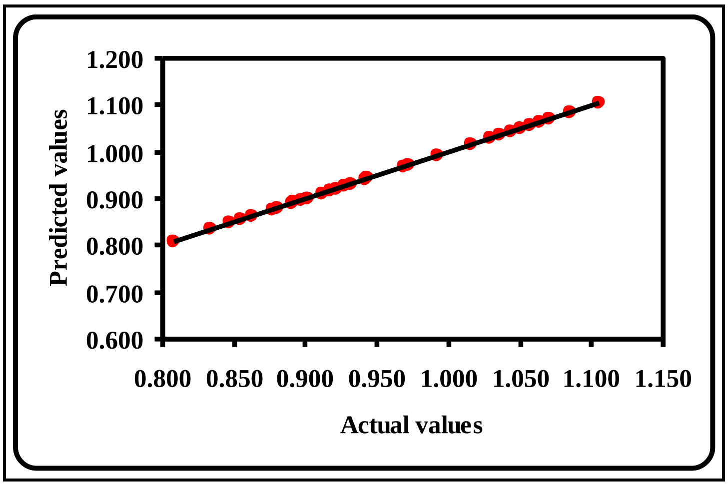

Figure 2: Actual versus predicted values using ANN for stretchable fabric tightness

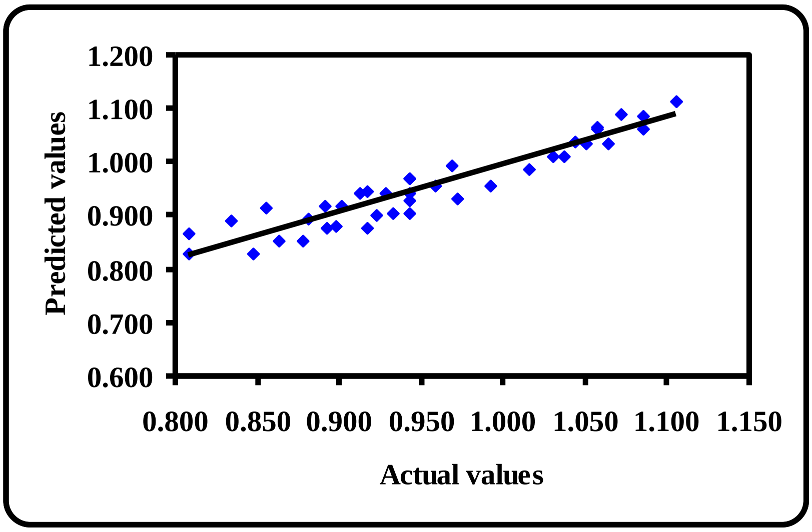

Figure 3: Actual versus predicted values using multiple linear regression for stretchable fabric tightness.

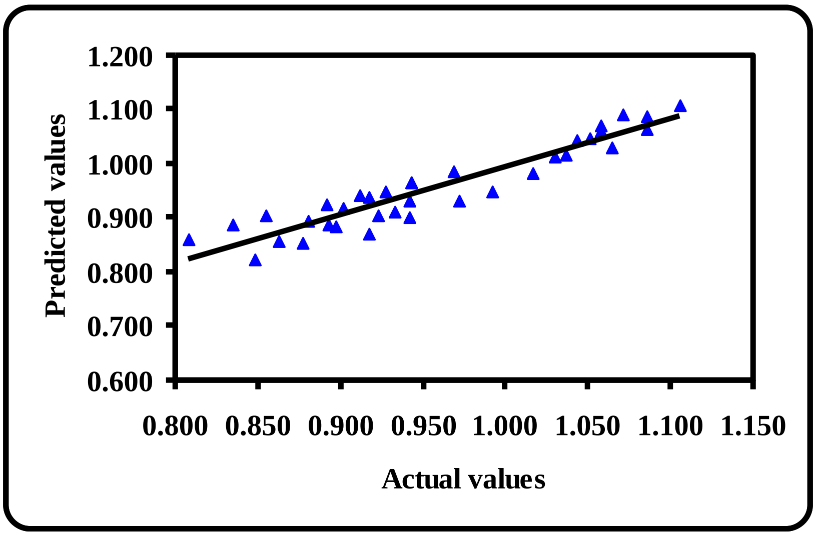

Figure 4: Actual versus predicted values using logarithmic regression for stretchable fabric tightness.

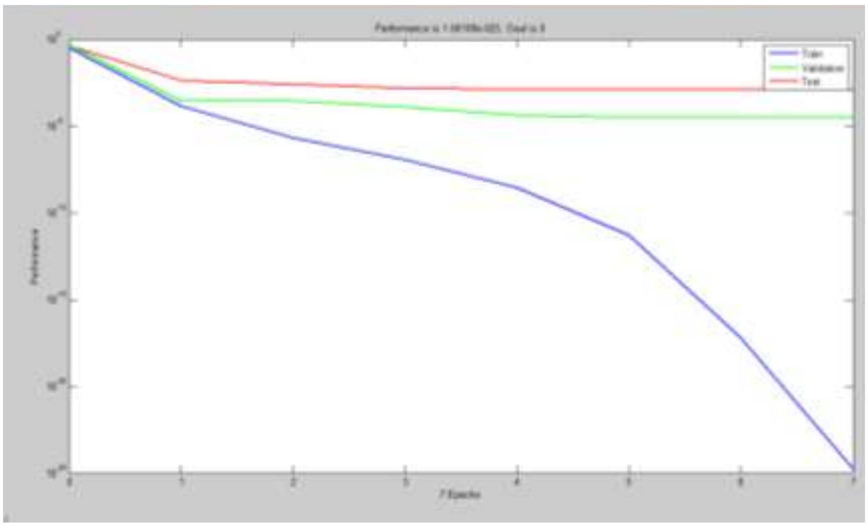

Figure 5: The performance plot of the ANN used to predict the stretchable woven fabric tightness

Figure 5 illustrates the plot of the performance of the ANN used to predict the stretchable woven fabric tightness at training, validation and testing stages. It is shown that this neural network acquires their optimum performance after 7 epochs, whereas the training and validation errors have the comparable characteristics.

5- Conclusion

In general, modeling and predicting woven fabric properties by putting forward the relation between fabric structure and its properties is considered the most remarkable subject for textile engineers, producers and researchers.

Because of their ability to specify highly nonlinear complex problems and their ability to disclose all possible interactions between dependent and independent variables, artificial neural networks are widely used for prediction in textile industry.

Stretchable fabric properties composed of cotton and spandex depend mainly on the types of spandex its draft ratio and linear density. The purpose of this work is to predict stretchable woven fabric tightness at different spandex linear densities, draft ratios and weave structures. The prediction was accomplished using ANN, multiple linear and logarithmic regression techniques. The obtained conclusion is as follows:

- Prediction of stretchable woven fabric by the different predictors tightness was assessed using RMSE, MBE and R^2 values.
- Without regard to particulars or exceptions, artificial neural network yielded high predicting performance compared to regression models. Logarithmic regression model was superior to multiple linear regression one in terms of RMSE, MBE and R^2 vales respectively.
- It was determined that RMSE values of ANN, multiple regression and logarithmic regression models were 0.00013, 0.02825 and 0.0268 respectively.
- Artificial neural network gave the higher R^2 vales compared to other predictors which confirm that it has the best prediction performance. R^2 vales were 0.999, 0.867 and 0.891 for ANN, multiple linear and logarithmic regression models.
- Mean bias error of ANN, multiple linear and logarithmic regression models were 0.00009, 0.02431 and 0.0239 respectively.

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