(REFEREED RESEARCH)

PREDICTION OF DIMENSIONAL CHANGE IN FINISHED FABRIC THROUGH ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

When anti-shrinkage precaution is taken for finishing processes, shrinkage could be observed with cotton and viscose fabrics by 8-15% and 20%, respectively. Therefore, capability of estimation of shrinkage rate for fabrics at the end of finishing would be a significant advantage. This study tried to estimate the shrinkage of single jersey and interlock fabrics at the end of relaxation processes by means of the Artificial Neural Networks (ANN). To that end totally 72 varieties of fabric were manufactured in two groups of the elastane and the non-elastane fabrics. Then, in each of two groups included 36 different varieties on the basis of single jersey and interlock weaving types using six different raw materials in three different densities. The processes were applied to fabrics during finishing process are thermo-fixing, washing, drying and sanforizing process. ANN model was used to predict dimensional change at the end of the sanforizing. For ANN, the two-layer feed-forward perceptron, also called single hidden layer feed-forward neural network was used to estimate dimensional change of width and length. Finally, the ANN exhibited successful performance in prediction of dimensional change in fabrics. The prediction of the dimensional properties produced by the neural network model was proved to be highly reliable (R2> 0.98).

Keywords: Dimensional change, ANN, estimation, finished fabric, finishing

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1. Introduction

Dimensional stability is considered as one of the most important properties of fabrics. Especially, dimensional change problem encountered with jersey fabric emerges as a significant quality issue.

Due to the tensions applied to the fabric during knitting, the shape of the loop changes. When the knitting process is finished and the forces are removed, the loops try to return their natural shape. This change in the shape of the loop is also reflected in the knitted fabric and the shape of the fabric also changes. This change is called fabric relaxation. Dry, wet, wash, full and industrial relaxations are defined by researchers [1].

In the event that no any measure is taken against shrinkage during finishing, cotton and viscose fabrics could be seen shrinkage up to 8-15% and 20%, respectively.

Fabrics are required to be relieved from internal tension and to be processed to prevent swelling in unit section while they are taken in process in finishing facilities. Following measures are taken to avoid fabric tension; operating machines causing minimum tension during finishing as much as possible; giving rest breaks; checking tension during process; using systems such as conveyor bands for transfer of fabrics; applying non-tension mercerization in other words causticization; working with advance based on feed-forward principle during stenter drying; applying anti-wrinkle finishing to fabrics; and machines such as sanforizing machines which ensure mechanical resistance against shrinkage must be employed. The most effective finishing process in gaining dimensional stability is applied the drying operation with heating [2].

Controlling dimensional changes since raw fabric production is essential to prevent the problem of dimensional change. Estimation of dimensional change before manufacturing could allow us to maintain control over dimensional change. Application of the Artificial Neural Networks (ANN) in predictive studies in textile industry has increased recently. ANN has been harnessed in numerous fields such as classification of errors in textile manufacturing; prediction of yarn quality parameters; classification of weaving and knitted fabrics; prediction of fabric behavior characteristics; prediction of garment comfort; air permeability of features of woven and knitted fabrics; prediction of drape of fabric; prediction of concentration of dyestuff; and prediction of color recipe [3-16]. ANN method was also harnessed in prediction of the dimensional characteristics of rib fabrics. In the relevant study, it was emphasized that prediction capability of the model established with the ANN method towards the rib fabric was satisfactory [17-18].

With the effect of tension and wet processes on the finishing process, the fabric will undergo a shape change and will try to return to its natural state at the first time it gets rid of the fabric tension. This is a great inconvenience as it may result in becoming smaller and shrinkage of the garment during use. During the production of ready-made garments, in order to avoid problems in the fabrics coming from the finishing treatments, it is necessary to perform the right shrinkage process from the beginning of the fabric and to control all the processes from the raw fabric. All mechanical stresses and feeds should be kept under control during finishing operations.

In this study, it is aimed to prediciton the dimensional changes of various knitted fabrics by ANN at the end of finishing operations. Firstly, ANN input parameters were determined, then single jersey and interlock fabrics were produced and measurements were taken on raw fabric. After the raw fabric measurement procedures, finishing treatments were applied to the fabrics. Dimensional changes were measured at the end of finishing treatments and dimensional changes were predicted with ANN.

2. Material and Method

2.1 Test and Measurement Plan

Table 1 exhibits test plan, followed standards and measurement points within the scope of the study. The study is planned as follows.

1. Determination of ANN input parameters
2. Production of raw fabrics
3. Raw fabric measurements (after initial and dry relaxation from the knitting machine-Course Density, Areal Density, Fabric Roll Width)
4. Drawing of all fabrics with the dimensional pattern
5. Finishing treatments
6. Finished fabric measurements (Dimensional Change, Areal Density, Fabric Roll Width)
7. Prediction of dimensional change with ANN.

2.2. Fabric Manufacturing and Raw Fabric Measurements

Within the scope of the study, 72 different fabrics were manufactured whose characteristics were showed in Table 2. In order to determine the effect of addition of elastane into fabric on dimensional change; fabrics were manufactured in two distinct groups. Whereas elastane was not included in the first fabric group, 5% elastane was added in the second fabric group. Due to their common application in the industry, cotton, cotton/viscose, viscose, cotton/polyester, polyester and polyester/viscose fabrics were preferred. Polyester fiber and polyester blends which exhibit dimensional stability were also included in the scope of the study. For the single jersey fabrics of Gauge is (E) 28, and machine diameter of is 32 inches. For the interlock fabrics of Gauge is (E) 24, and machine diameter of is 32 inches. Yarn count of all fabrics is 20 tex.

All fabrics were manufactured by means of the three different pile yarn length in dense, medium and loose patterns. The fabrics were coded in a specific order. For instance, the fabric with LS 5 code was no 5. single jersey fabric with lycra form including 5^{th} fiber 100% polyester.

Specimens from 72 different fabrics manufactured were taken from the knitting machines. After that raw fabric measurements were taken as shown in Table 1. Finally, they were applied dry relaxation process by remaining them on a smooth plane surface under standard atmosphere conditions for a week.

2.2.1. Course Density Measurement

The loop stitches, which are 1 cm long of the fabric, were counted by means of a lupe. This measurement was repeated five times at different areas of the fabric for each specimen; and their average value was taken into consideration (TS EN 14971).

Table 1. Test and Measurement Plan

Measurement Point	No	Activity / Tested Characteristics	Test Standard	Measurement Point
1.Raw Fabric (Knitted Fabric)	1	Course Density Measurement	TS EN 14971	Right After Process in the Machine
				After Dry Relaxation
	2	Wale Density Measurement	TS EN 14971	Right After Process in the Machine
				After Dry Relaxation
	3	Areal Density Measurement	TS 251	Right After Process in the Machine
				After Dry Relaxation
	4	Fabric Roll Width	-	Right After Process in the Machine
				After Dry Relaxation
2.Finished Fabric (Finishing)	1	Dimensional Change	TS EN ISO 3759- 2009	After Drying
				After Sanforizing
	2	Areal Density Measurement	TS 251	After Drying
				After Sanforizing
	3	Fabric Roll Width	-	After Drying
				After Sanforizing

Table 2. Fabric Characteristics

Type of Fabric	Fabric Code	Type of yarn	Stitch length (100 needle /cm)	Type of Fabric	Fabric Code	Type of yarn	Stitch length (100 needle /cm)
Single Jersey	S.1	100%Cotton	27	Interlock	İNT.1	100%Cotton	32
	S.2	%50 Cotton - %50 Viscose	27		İNT.2	%50 Cotton - %50 Viscose	32
	S.3	100%Viscose	27		İNT.3	100%Viscose	32
	S.4	%50 Cotton -%50 Polyester	27		İNT.4	%50 Cotton -%50 Polyester	32
	S.5	%100 polyester	27		İNT.5	%100 polyester	32
	S.6	%50 Polyester -%50 Viscose	27		İNT.6	%50 Polyester -%50 Viscose	32
	S.7	100%Cotton	29		İNT.7	100%Cotton	34
	S.8	%50 Cotton - %50 Viscose	29		İNT.8	%50 Cotton - %50 Viscose	34
	S.9	100%Viscose	29		İNT.9	100%Viscose	34
	S.10	%50 Cotton -%50 Polyester	29		İNT.10	%50 Cotton -%50 Polyester	34
	S.11	%100 polyester	29		İNT.11	%100 polyester	34
	S.12	%50 Polyester -%50 Viscose	29		İNT.12	%50 Polyester -%50 Viscose	34
	S.13	100%Cotton	32		İNT.13	100%Cotton	36
	S.14	%50 Cotton - %50 Viscose	32		İNT.14	%50 Cotton - %50 Viscose	36
	S.15	100%Viscose	32		İNT.15	100%Viscose	36
	S.16	%50 Cotton -%50 Polyester	32		İNT.16	%50 Cotton -%50 Polyester	36
	S.17	%100 polyester	32		İNT.17	%100 polyester	36
	S.18	%50 Polyester -%50 Viscose	32		İNT.18	%50 Polyester -%50 Viscose	36
Single Jersey / Lycra (95/5)	LS.1	100%Cotton	27	Interlock / Lycra (95/5)	LİNT.1	100%Cotton	32
	LS.2	%50 Cotton - %50 Viscose	27		LİNT.2	%50 Cotton - %50 Viscose	32
	LS.3	100%Viscose	27		LİNT.3	100%Viscose	32
	LS.4	%50 Cotton -%50 Polyester	27		LİNT.4	%50 Cotton -%50 Polyester	32
	LS.5	%100 polyester	27		LİNT.5	%100 polyester	32
	LS.6	%50 Polyester -%50 Viscose	27		LİNT.6	%50 Polyester -%50 Viscose	32
	LS.7	100%Cotton	29		LİNT.7	100%Cotton	34
	LS.8	%50 Cotton - %50 Viscose	29		LİNT.8	%50 Cotton - %50 Viscose	34
	LS.9	100%Viscose	29		LİNT.9	100%Viscose	34
	LS.10	%50 Cotton -%50 Polyester	29		LİNT.10	%50 Cotton -%50 Polyester	34
	LS.11	%100 polyester	29		LİNT.11	%100 polyester	34
	LS.12	%50 Polyester -%50 Viscose	29		LİNT.12	%50 Polyester -%50 Viscose	34
	LS.13	100%Cotton	32		LİNT.13	100%Cotton	36
	LS.14	%50 Cotton - %50 Viscose	32		LİNT.14	%50 Cotton - %50 Viscose	36
	LS.15	100%Viscose	32		LİNT.15	100%Viscose	36
	LS.16	%50 Cotton -%50 Polyester	32		LİNT.16	%50 Cotton -%50 Polyester	36
	LS.17	%100 polyester	32		LİNT.17	%100 polyester	36
	LS.18	%50 Polyester -%50 Viscose	32		LİNT.18	%50 Polyester -%50 Viscose	36

2.2.2. Wale Density Measurement

The loop stitches, which are 1 cm wide of the fabric, were counted by means of a lupe. This measurement was repeated five times at different areas of the fabric for each specimen; and their average value was taken into consideration (TS EN 14971).

2.2.3. Areal Density Measurement

The weight of the 100 cm^2 fabric specimens prepared with the sample cutter was weighed using a sensitive scale. This measurement was repeated for five different areas of fabrics and their average was taken into consideration (TS 251).

2.2.4. Fabric Width Measurement

The width of all manufactured fabric rolls were measured by tapeline and recorded. This measurement was repeated three times at different areas of fabrics; and their average was considered.

2.3. Fabric Finishing Processes

Following measurements of the raw fabrics used in the empirical study, they were incurred in finishing process to obtain finished fabric specimens. Knitted fabrics were processed according to their fiber types in the same way so as to minimize variation caused by the finishing process (Table 3). The processes were applied to fabrics during finishing process are thermo-fixing, washing, drying and sanforizing process.

Washing process was carried out with 1/6 flotte ratio. The fabrics emerged as a rope in the washing process were squeezed by water in a tube-cutting machine and turned into a dekatur (folded fabric) and dried in a drying machine. Sanforizing process has been applied to the fabrics for dimensional stability. At the end of the sanforizing process, the dimensional change and areal density values were measured and recorded as shown in Table 3.

2.3.1. Areal Density Measurement

The weight of the 100 cm^2 fabric specimens prepared with the sample cutter was weighed using a sensitive scale. This measurement was repeated for five different areas of fabrics and their average was taken into consideration (TS 251).

2.3.2. Fabric Width Measurement

The width of all manufactured fabric rolls were measured by tapeline and recorded. This measurement was repeated three times at different areas of fabrics; and their average was considered.

Table 3. Fabric Finishing Processes

	Raw Expander	Thermo fixing	Wet Treatment	Drying	Sanforizing
Machine	Fabric Expander Machines	Stenter	HT	Drying Machine	Sanfor
Machine Speed (m/min)	60 m/min	15-30 m/min	2 rev./min.	25-30 m/min	15 m/min
Manufacturing Capacity	21 000 kg/day	200kg/hr.	20 000 kg/day	12 000 kg/day	4000 kg/day
Process Temperature (ºC)	-	185-198^{0}C	Washing80^{0}C	120 ^{0}C	120 ^{0}C
Fabric Processing Speed	60 m/min.	24 m/min.	20-25 m/min	20-25 m/min	10 m/min.

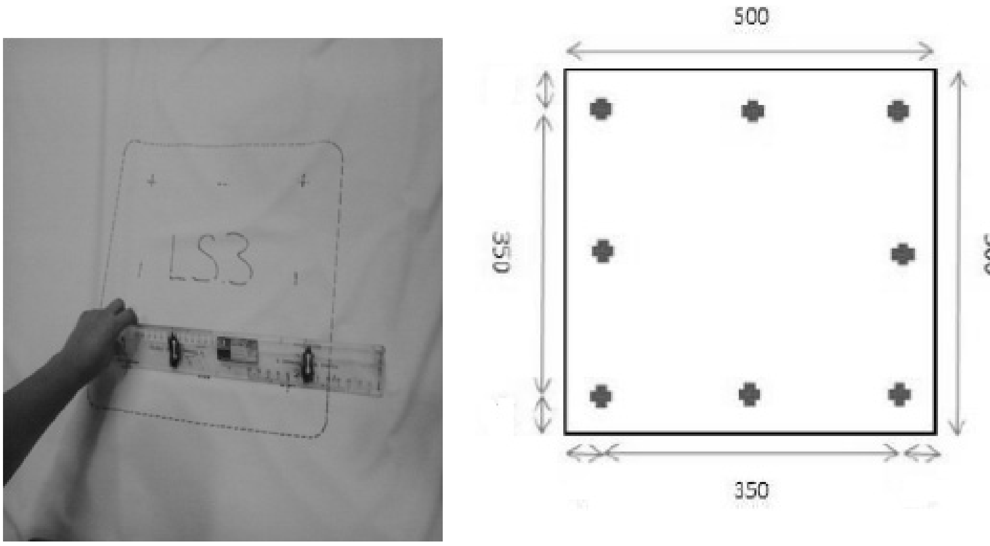

Figure 1. Shrinkage scale (for measuring dimensional change) and signing fabric.

2.3.3. Dimensional Change

In order to determine longitudinal and latitudinal shrinkage or elongation afterwards of the finishing process, dimensional change test was applied to specimens. After each finishing process, the dimensional change was measured (TS EN ISO 3759- 2009). A special pattern was used to determine longitudinal and latitudinal shrinkage or elongation. In the beginning of finishing treatments, all fabrics were drawn on the dimensional pattern (50cm x 50cm) using a permanent marker. After each finishing process, dimensional change was measured by means of a shrinkage scale that is shown in Figure1. Measurements were taken inner borders of the first drawn line on the ruler (35x35 cm).

3. Artificial neural networks and structure

ANN, which is the computer system, is developed by modelling of human brain. Main properties of ANN are automatically creating, deriving and exploring new information using learning like human brain. Technically, the major task of artificial neural networks is to predict an output data set with respect to the entry data set given to them. In accomplishing this task, the network is required to be trained with examples of the relevant incident so that it could make a generalization which enables the system to predict output set corresponds to the similar events [19-20].

In the present study, MATLAB ® Neural Network Toolbox was used for creating Multilayer Feed-Forward ANN that has three layers as input layer, hidden layer and output layer.

In the ANN model, initial weight and bias values were assigned randomly; and task of changing weights was performed online basis. In other words, the established ANN alters weights one unit at each iteration online basis. Whereas sigmoid activation function was used as the activation function, training of the ANN model, commenced with determined network parameter, is continued until certain number of iteration (epoch) (It was set as 1.000 for this study). The activation function employed in the study is a sigmoid function that yields continuous responds in certain pattern with respect to the data entered into the function. These responds are certainly not discrete. Thus, sigmoid function is commonly applied because it refers the most appropriate function for the problems requiring sensitive evaluations. The important point is that function needs to allow derivation operation.

3.1. Input Parameters

Dimensional change in finished fabrics prepared for garment manufacturing is determined by numbers of factors such as raw material, knitting conditions and finishing processes. Before delivered to garment manufacturing facility, fabrics incur sanforizing process at the finishing stage as the last process. To the end of predicting dimensional change at the end of sanforizing process, input data were selected respectively. Raw fabric parameters (at the moment operation on fabrics is completed in the machine in a way that they were processed in the dry relaxation) that could be effective on the ultimate properties of the fabric were selected as *mean areal density*, *fabric width*, *course and wale density.* Additionally, at the finishing process, *areal density*, *longitudinal and latitudinal dimensional change values* in the main *drying process,* the most effective process on the dimensional change, were selected as input parameters. Selected finished fabric input parameters were coded as below for the purpose of digitalization of entry data.

1. *Fabric Code:* 4 types of fabric in S, LS, INT and LINT were coded as fabric 1, 2, 3 and 4, respectively.
2. *Yarn Type:* 100% cotton, 50% cotton – 50% viscose, 100% viscose, 50% cotton – 50% polyester, 100% polyester, and 50% polyester – 50% viscose. Since it these verbal values could not be employed in an artificial neural networks model, they were transformed into digital codes a 1, 2, 3, 4, 5 and 6, respectively.
3. *Stitch length (100 needle/cm) desired*: values determined as 27, 29, 32, 34 and 36 were coded for the ANN model as 1, 2, 3, 4 and 5, respectively.
4. At the end of the machine operation (momentarily)
   a. Areal Density (gr/m^2)
   b. Fabric Roll Width (cm.)
   c. Course Density (course per cm.)
   d. Wale Density (wale per cm.)
5. After dry relaxation
   a. Areal Density (gr/m^2)
   b. Fabric Roll Width (cm)
   c. Course Density (course per cm.)
   d. Wale Density (wale per cm.)
6. After drying
   a. Areal Density (gr/m^2)
   b. Dimensional change (cm –width)
   c. Dimensional change (cm –length)

3.2 Output Parameters

According to the established Network, parameters of finished fabric parameters at the end of the sanforizing process were given below:

1. Dimensional change (cm –width)
2. Dimensional change (cm –length)

In the training period of the Artificial Neural Networks model, the assessment was conducted based on 72 different values from 14 independent input variables and 2 output variables (Figure 1). Whereas 70% of these values were used for training, 15% were for confirmation and 15% were for testing purposes. In other words, randomly selected 50 fabric rolls were used for training, 11 fabric rolls were for confirmation and 11 fabric rolls were for testing.

In the light of information given above, this study examined network performance with respect to different learning rule, training function, momentum coefficient, number of hidden layer and number of nodes in hidden layer in order to determine the optimal ANN performance value. For training purpose of the ANN, Levenberg-Marquardt model was utilized; error was determined by means of the Mean Square Error method. Accordingly, number of hidden layer and cell numbers in hidden layer in the study were determined based on the learning rate and momentum coefficient found frequently in the literature. When learning rate was 0.001; momentum coefficient was 0.8; then, hidden layer was selected 1. In the proposed model, number of neurons of the hidden layer was tried starting from 3 up to 50. Table 6 exhibits structure parameters of the established ANN model.

Given input parameters, dimensional and width change that could arise after sanforizing process were predicted according to the yarn types in “cm”. Table 7 exhibits input values of specimen taken randomly.

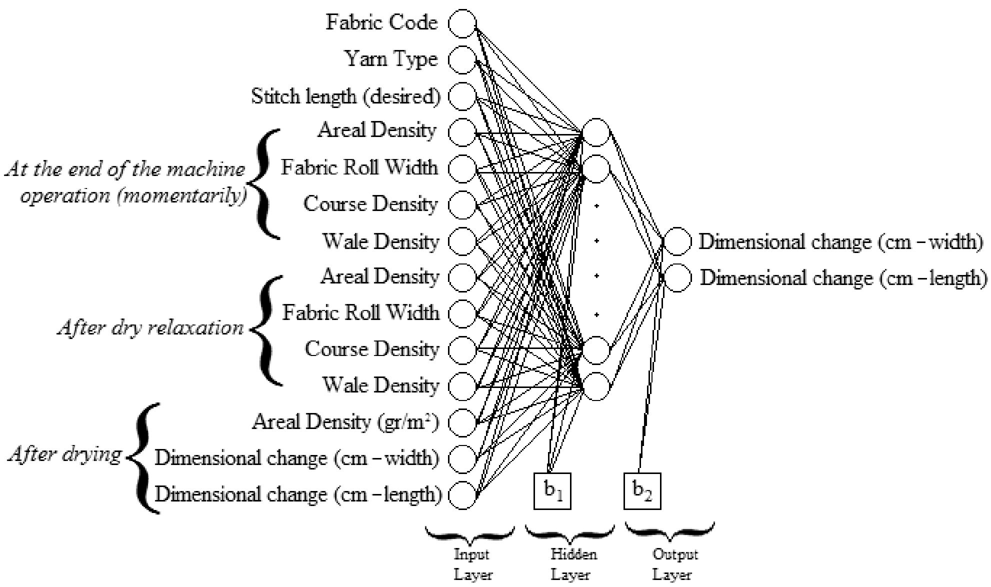

Figure 1. Finished fabric network diagram

Table 6. Artificial neural network parameters

Network Parameters	
Number of İnput Parameters	14
Number of Hidden Layer	1
Number of Neuron in the Hidden Layer	Between 3 and 50
Learning Rate	0.001
Momentum Coefficient	0.8
Number of Iteration	1,000
Number of Output Parameters	2
The Most Successful Network Number of Hidden Layer Neuron	14
The Most Successful Network Number of Iteration	11
The Most Successful Network R^2 Value	0.96132

Table 7. Specimen finished fabric input data

			At the end of machine operation				At the end of dry relaxation process				At the end of drying		
Fabric Code	Yarn Type	Stitch length (100 needle /cm) desired	Areal density(g/m2)	Fabric Roll Width	Course Density (course per cm.	Wale Density (wale per cm.)	Areal density(g/m2)	Fabric Roll Width	Course Density (course per cm.)	Wale Density (wale per cm.)	Areal density(g/m2)	Dimensional change cm -width	Dimensional change cm -length
1	1	1	128	113	22	12	135	112	23	12	140	39,95	52,75
1	2	1	133	114	21	12	143	112	22	12	162	38,85	47,6
1	3	1	135	116	20	12	142	114	21	12	179	37	49,95
1	4	1	130	115	21	12	136	113	22	12	172	41,5	42,5
1	5	1	137	114	20	12	150	112	21	12	199	44,75	40

Given input and output parameters, longitudinal and latitudinal dimensional changes that could arise as a result of sanforizing process were predicted in centimeter with respect to yarn types.

4. Results and Discussion

In order to test consistency of the obtained results, performance value (accomplishment or accurate estimation value) was measured. Thus, the number of node(s) in the hidden layer of the ANN model was increased from 3 to 50 so that the weights of the model yielding the most accurate result could be recorded.

In this article, it was determined that the ANN model gave the most accurate result with hidden layer having 14 nodes (Figure 2). Mean Absolute Error (MAE) value of this ANN model is dimensional width 0.7623 and dimensional change height 1.1619. MAE values of the first 10 sample is shown in Table 8, and all values is plotted in Figure 3.

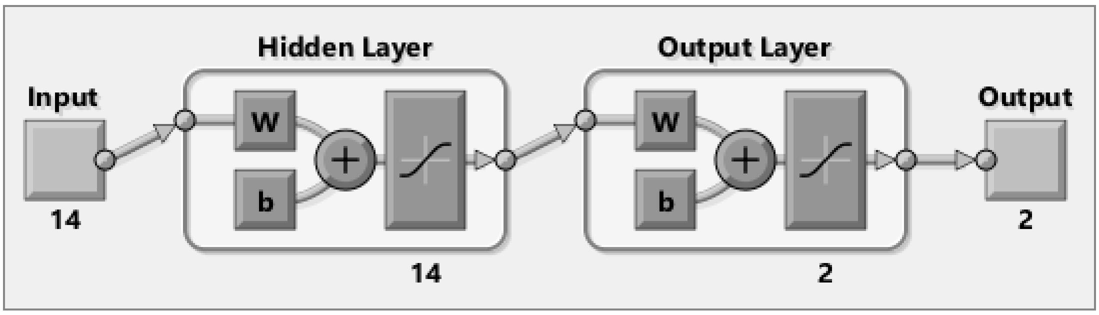

Figure 2. Artificial neural network diagram illustrated for dimensional change in finished fabric

Table 8. Mean Absolute Error Values of First 10 Sample

Sample No	1	2	3	4	5	6	7	8	9	10
Dimensional Change (cm - Width)	0.1760	1.9848	1.0700	2.4036	0.2165	5.7511	1.6119	1.4067	0.4178	3.6911
Dimensional Change (cm - Length)	2.4464	6.7724	1.6965	7.5441	1.0408	3.4202	0.7061	3.7837	0.8337	7.7827

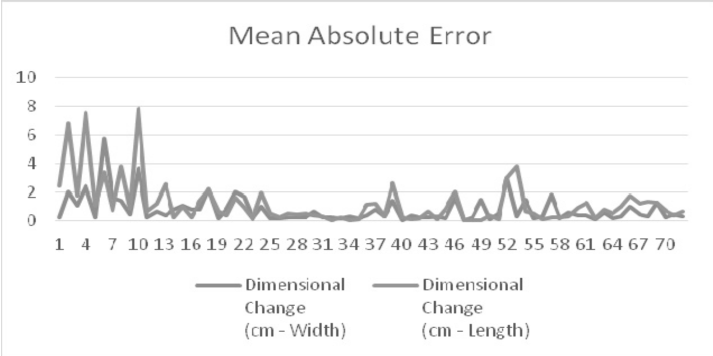

Figure 3. Mean Absolute Error Value of Output

For evaluation of the dimensional change in finished fabrics, output values were digitalized according to measurement results. For instance at the end of the drying process, if shrinkage was measured as -13.2% cm with the 50x50 cm pattern with respect to the fabric input value, the real value was digitalized as 43.50 cm similar to the value at the first raw in Table 8. In other words, width of a fabric with 50 cm original dimension was measured as 43.40 cm at the end of the sanforizing process. On the other hand, the ANN model predicted the output dimension as 43.24 cm. In terms of the fabric width, the difference between the measured and predicted values was 0.16 cm that was considered prediction error of the ANN model. After the raw fabric was incurred all operations following its entry, width of the raw fabric in 50 cm dimension was measured at the end of the sanforizing process as 43.40 cm. On the other hand, the proposed ANN model predicted this dimension as 43.24 cm. Similarly, whereas the length of the fabric in 50 cm original size was measured as 46.70 cm at the end of the sanforizing process, it was predicted by the ANN model as 46.297 cm.

Table 9 exhibits data regarding randomly selected specimen taken at end of processes. According to the table, fabric width and lengths measured at the end of the sanforizing process displayed difference with respect to the one predicted by the ANN.

Given the obtained results through the ANN model, the performance plotting in Figure 4 ceased the iteration after 11 steps according to the MSE (Mean Square Error) method after the best error value (where minimum error occurs) was obtained regarding the Training, Validation and Test values. In Figure 4, after the data was determined for training of the ANN model, test and validation data were run in the ANN model following the training, the smallest of these three values was displayed on the MSE value plotting. In other words, whereas the data isolated for the training purpose were used during training of the ANN model, the most appropriate MSE value was given as validation plotting for the values predicted based on the training, validation and test data during performance testing of the model. Accordingly, it was observed that the model exhibited the best performance at the 11^{th} iteration. This iteration was determined as the most successful prediction model since the model displayed correlation coefficient (R^2) was 0.96132 (Figure 5). It could be observed that the error displayed by the ANN model reduced as number of iteration increased. After the training of the model, correlation coefficient was determined as 0.96132 that suggests strong correlation between the real measurements and predicted values.

Table 9. Data of samples of finished fabrics at the end of processes (in cm)

Measured Value		Predicted Value by ANN		Measured – Predicted (Error)		Mean Absolute Percentage Error (%)	
Dimensional Change Width	Dimensional Change Length	Dimensional Change Width	Dimensional Change Length	Dimensional Change Width	Dimensional Change Length	Dimensional Change Width	Dimensional Change Length
43.4	50.0	43.240	51.582	0.160	-1.582	0.37	3.16
42.5	46.7	41.990	46.297	0.510	0.403	1.20	0.86
38.5	54.5	37.585	56.433	0.915	-1.933	2.38	3.55
44.1	39.35	43.318	38.316	0.782	1.034	1.77	2.63
45.0	39.0	44.661	37.92	0.339	1.080	0.75	2.77

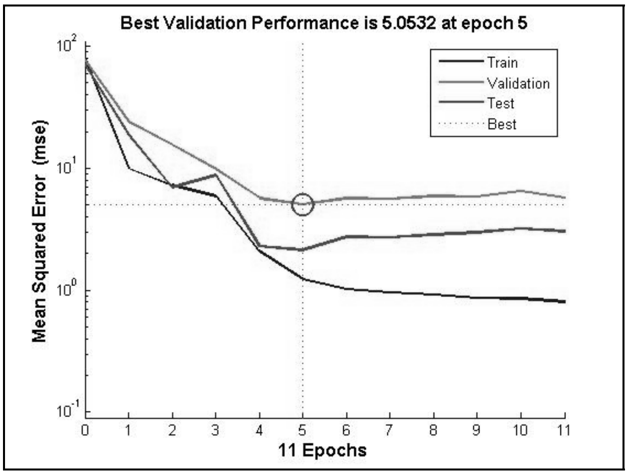

Figure 4. Training of the network yielding the best result for the finished fabric dimensional change.

5. Conclusions

In the ANN model structured for prediction of dimensional change, feed-forward, back propagation, momentum learning rule and sigmoid transfer function were implemented. As a result of the study, it was observed that the ANN model displayed successful predictions regarding dimensional change in finished fabric.

Owing to the tensions subject to finishing process and effect of the wet treatments, dimensional changes would occur in fabrics and they would try to return their very original form as soon they are relieved from these tensions. This situation is considered as a significant nuisance since it would lead shrinkage of clothing after washed. Afterwards of the finishing process, it is required to deliver fabrics with desired shrinkage values to the garment manufacturing stage. In order to avoid garment manufacturers to experience problems with fabrics sent from the finishing facilities, it is required to implement non-shrinkage process on fabrics from the very beginning accurately and to keep all processes under control since the raw fabric stage. It is considered that in case shrinkage prediction methods such as artificial neural networks are utilized for the fabrics with high dimensional change potential, it would be possible to reduce additional precautions necessary to eliminate shrinkage and to increase productivity.

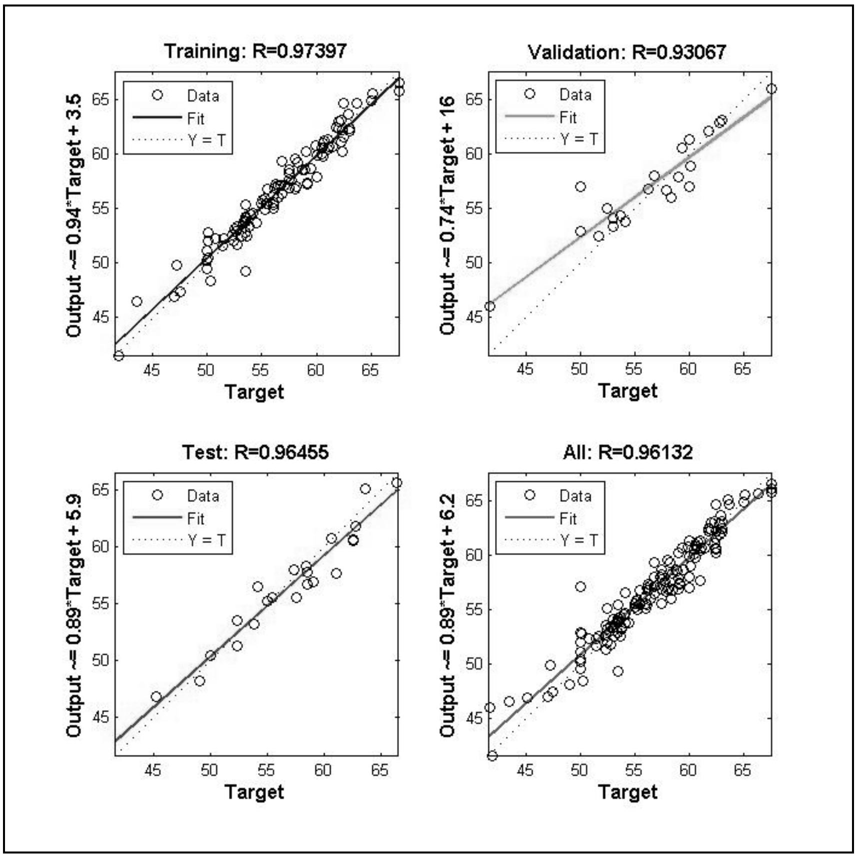

Figure 5. Correlation coefficient of the network

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