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Research Article

Evaluating the Smoothness of the Washed Fabric after Laundry with the Washing Machine Based on a New Type-2 Fuzzy Neural Network

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Clothes laundering are necessary during their cycle life, and the mechanical forces exposed to fabrics during laundering were caused to wrinkle. Therefore, in this paper, the wrinkle of the cotton fabric after home laundering was evaluated based on their characteristic. The washing process was done without any softener as toxic material. For this purpose, experimental and theoretical evaluations were conducted. In experiments, the cotton fabrics in various characteristics were washed by washing machine without any softener in special adjustments. The wrinkle of the samples was rated based on the light line method. Theoretical evaluations were studied by the development of a new type-2 fuzzy neural network. In this model the thickness, weight, warp and weft density per inch, warp and weft Tex as linear density, and cover factor of the fabric in warp and weft directions were considered as input parameters and the wrinkle grade of the washed fabric was output. Analysis of the modeling and experimental results illustrates that when eight mentioned parameters were selected as inputs, the mean square error, root mean square error, and mean absolute error of the model were decreased in comparison of the models with two, four, and six inputs. According to this fact, all of the input parameters have an effect on the wrinkle of the cotton fabric after the washing process.

1. Introduction

In the washing process, the impurities of the fabric are removed, and washing worsens the appearance of the fabric. Therefore, fabric wrinkles are reduced by using a laundry softener. However, softener material leaves your clothes wrinkled, but these have toxic chemical compounds that are harmful to health. These toxic material released to the environment has been observed in other processes of the textile industry such as finishing or dying process. Nowadays, the development of green textiles is the important subject in industrial and academic researches [1, 2]. In this field, research work has summarized the current developments and highlighted those areas where environment-friendly enzymatic textile processing might play an increasingly important role in the textile industry [3]. Other study reported the chemical composition and recent developments in textile finishes, particularly antimicrobial and insect-repellent textile finishes [4]. Formaldehyde-based easy-care finishes are toxic but still used in the textile industry. In other study, low formaldehyde reagents are being developed and tested to replace formaldehyde-based easy-care finishes [5]. According to the results of this research, the higher the resin concentration,the better the washing durability. This is due to the fact that resin decreases the chance of fiber chain displacement.

By daily home laundry, the clothes attract these materials and transfer them on the body skin as the largest organ in our bodies. Chemicals in laundry softener and detergents are caused health impacts such as rashes or serious diseases including cancer [6–8]. Abrasion as an undesirable parameter that damaged the fabrics is made by friction of the surface of fabric. Abrasion causes pilling [9] on the surface of the fabric and deteriorates the appearance of the fabric. During the washing process, the mechanical forces and thermal affect [10] some of the fabric characteristics. Many factors such as the quality of the water, the chemical materials, washing and drying temperature, and other parameters affect the quality of the clothes. Easy wrinkling of the cotton fabrics leads to an undesirable appearance of the cotton clothes. Therefore, ironing of cotton clothes is necessary after washing.

In this paper, the effects of the fabric properties after laundering were evaluated on the wrinkle appearance of the cotton fabrics. By studying the related work to the topic, it was found that some studies have evaluated the different factors of the washing process on the fabrics. Many researches have been done on the parameters that affect the wrinkle degree of fabrics [11]. The structural parameters of the fabric affect the fabric properties. Yarn material influences the wrinkle grade of the fabric. In a special work, the wrinkle of the fabric was measured and evaluated by a new technique of the light line method and image processing [12].

In other research, the effect of the mechanical action was analyzed on the fabric shrinkage and pilling caused during washing [13, 14]. In other studies, a model was developed for the evaluation of the fabric movements and washing efficiency [15–17].

Therefore, in this study, the wrinkle appearance of the cotton fabric after laundry process was evaluated according to the thickness, weight, warp and weft Tex as linear density, warp and weft density per inch, and fabric cover factor in warp and weft directions. This evaluation is the purpose and novelty aspect of the present study. In this article, after experimental evaluations, the models were developed by a new type-2 fuzzy neural network. Computational intelligence has many applications in solving of many engineering and nonengineering problems. Neural networks have been extensively used to the system modeling for control and future prediction [18]. The advantage of neural networks is that they can predict the manner of the systems without a need to the mathematical equations [19]. Much works has been done about applying fuzzy neural network in different areas of textile applications [20, 21].

Methodology and modeling based novelties of this study can be described as follows:

(1) The cotton fabric after the washing process was attempted to be evaluated in wrinkle due to the thickness, weight, warp and weft Tex as linear density, warp and weft density per inch, and fabric cover factor in warp and weft directions.

(2) A novel type-2 fuzzy neural network is presented in this paper.

(3) The proposed type-2 fuzzy neural network receives inputs mentioned above and generate them to one output of wrinkle appearance. This aspect of the type-2 fuzzy neural network was developed for the first time.

(4) The mean square error, root mean square error, and mean absolute error of the model with eight input has the lowest values.

2. Material and Methods

In this paper, the cotton fabric samples with different characteristics are summarized in Table 1. According to this table the material, weaving pattern, fabric thickness, fabric weight, number of warp and weft yarns per inch, warp and weft Tex as linear density, and fabric cover factor in weft and warp direction were measured as fabric characteristics. Laundry of the samples was done by front loading washing machine of the beko with adjustments presented in Table 2. According to the IEC 60456 [22] filling load of washer drum was done by the cotton pillowcases. Additionally, ordinary tap water with soap solution was used to wash of samples at 20°C of temperature. The cotton samples were holed at the 20°C and 60% RH for at least 24 hours in laid flat position.

2.1. Wrinkle Rating. The wrinkle degree of the samples was rated by the light line method [12]. In this method, fabric wrinkle was evaluated and analyzed objectively using a profile light line that is projected on the surface of the wrinkled fabric and the application of the image processing technique developed in this paper. In the mentioned technique, a profile light line which is 0.6 mm in width is projected onto the surface of the wrinkled sample, and an image is captured with the CCD camera in a dark room. The moving plate that carries the sample moves along the X-axis by steps of 2 mm. At each interval, the light reflection of the projected profile light line on the surface of the sample fabric is captured by the CCD camera. Lastly, the final image is processed and extracted to reveal the height values of every point in the graph. The wrinkle ratting results measured by the mentioned method are summarized in Table 1. The standard atmosphere before wrinkle ratting was 65% RH and methodology and modeling-based novelties were 20°C for 24 hours.

2.2. Statistical Parameters. The statistical results of each model such as Mean Square Error (MSE), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE) values are summarized in Table 3. The standard deviation was calculated for the data presented in every column of Table 1 and the results were summarized in the end row of this table. According to the development of the models by the neural network, so the regression coefficient parameter was not calculated for the models. These statistical parameters were described accordingly:

2.3. Standard Deviation

$$\sigma = \sqrt{\frac{\sum \left| x_1 - \mu \right|^2}{N}}. \quad (1)$$

Table 1: The characteristics of the cotton fabric samples.

Material	Weaving	Thickness (mm)	Weight (g/m^2)	Density/inch		Linear density (tex)		Cover factor		Wrinkle ratting
				Warp	Weft	Warp	Weft	Warp	Weft	
Staple cotton	Twill	0.20	70	60	50	15	18	0.38	4.3	2.71
Staple cotton	Twill	0.22	80	62	52	16	19.5	0.40	0.45	2.52
Staple cotton	Plain	0.23	90	68	57	18.7	17.8	0.43	0.42	2.52
Staple cotton	Plain	0.24	97	67	60	22	17	0.47	0.41	2.63
Staple cotton	Twill	0.27	95	64	55	19.8	19.8	0.45	0.45	2.54
Staple cotton	Plain	0.30	86	61	50	21	18	0.46	0.42	250
Staple cotton	Rib	0.32	140	70	58	29	26	0.54	0.51	2.42
Staple cotton	Rib	0.37	130	66	51	28	27	0.53	0.52	2.62
Staple cotton	Plain	0.40	110	56	52	27	24	0.52	0.49	2.51
Staple cotton	Plain	0.45	160	72	62	31	28	0.59	0.57	2.37
Staple cotton	Satin	0.48	180	76	68	33	30	0.57	0.55	2.22
Staple cotton	Satin	0.60	245	86	79	42	32	0.65	0/57	1.93
Staple cotton	Twill	0.62	200	71	66	36	38	0.6	0.62	2.04
Staple cotton	Plain	0.70	260	78	72	52	35	0.72	0.60	1.81
Staple cotton	Plain	0.25	90	59	50	19	20	0.44	0.45	2.55
Staple cotton	Twill	0.31	89	55	55	21	21	0.46	0.46	2.46
Staple cotton	Plain	0.30	130	68	48	26	31	0.51	0.55	2.32
Staple cotton	Plain	0.34	125	61	52	31	24	0.56	0.50	2.34
Staple cotton	Twill	0.42	115	60	60	21	27	0.46	0.52	2.35
Staple cotton	Plain	0.46	158	70	68	29	29	0.54	0.54	2.22
Staple cotton	Rib	0.49	186	76	68	33	32	0.57	0.57	2.10
Staple cotton	Rib	0.55	235	82	78	42	32	0.65	0.56	2.03
Staple cotton	Plain	0.60	201	78	70	36	32	0.60	0.56	2.17
Staple cotton	Plain	0.69	255	84	78	47	50	0.68	0.71	1.98
Staple cotton	Twill	0.26	89	62	52	18	21	0.42	0.46	2.70
Staple cotton	Plain	0.30	93	65	58	17	21	0.41	0.46	2.60
Staple cotton	Plain	0.30	130	69	54	29	23	0.54	0.48	2.25
Staple cotton	Twill	0.29	130	60	50	34	25	0.58	0.50	2.35
Staple cotton	Plain	0.35	128	64	60	28	25	0.53	0.50	2.30
Staple cotton	Plain	0.39	105	55	50	25	25	0.50	0.50	2.40
Staple cotton	Twill	0.47	156	66	66	34	25	0.58	0.50	2.20
Staple cotton	Plain	0.50	178	89	70	28	28	0.53	0.53	2.10
Staple cotton	Satin	0.58	230	80	65	41	39	0.64	0.62	2.00
Staple cotton	Twill	0.60	196	75	70	34	35	0.58	0.59	2.05
Staple cotton	Plain	0.71	266	85	78	49	32	0.70	0.56	1.90
Staple cotton	Plain	0.23	91	60	60	21	17	0.46	0.41	2.70
Staple cotton	Twill	0.33	80	61	50	17	20	0.41	0.45	2.65
Staple cotton	Plain	0.24	90	63	58	18	19	0.42	0.43	2.67
Staple cotton	Plain	0.32	140	67	55	26	32	0.51	0.56	2.40
Staple cotton	Satin	0.36	125	65	64	25	23	0.50	0.48	2.55
Staple cotton	Twill	0.40	110	63	61	22	23	0.47	0.48	2.32

Table 2: Beko washing machine adjustments for laundry of the commercial cotton fabric.

Spinning speed (rpm)	Washing load (Kg)	Temperature (°C)	Washing time (min)	Wrinkle grade
800	0.5	60	30	2.6

Table 3: Performance evaluation of the proposed type-2 fuzzy neural network with several numerical criteria.

Models	2 input	4 inputs	6 inputs	8 inputs
MSE	0.00363	0.00318	0.00296	0.00254
RMSE	0.06024	0.05639	0.05440	0.05039
MAE	0.06548	0.05926	0.05564	0.05091

In this formula, σ is the standard deviation, x_1 is the data point we are solving for in the set, μ is the mean, and N is the total number of data points.

In statistics, the standard deviation is a measure of the amount of variation or dispersion of a set of values. A low standard deviation indicates that the values tend to be close to the mean of the set, while a high standard deviation indicates that the values are spread out over a wider range.

2.4. Mean Square Error

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \widehat{Y}_i\right)^2. \tag{2}$$

In this formula, MSE is the mean squared error, Y_i is the observed values, $\widehat{Y}_i$ is the predicted values, and n is the total number of data points. The MSE is a measure of the quality of an estimator. As it is derived from the square of Euclidean distance, it is always a positive value that decreases as the error approaches zero.

2.5. Root Mean Square Error

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \widehat{Y}_i\right)^2}. \tag{3}$$

The RMSD represents the square root of the Mean square errors mentioned in equation (3). The root mean square deviation (RMSD) or root mean square error (RMSE) is a frequently used measure of the differences between values (sample or population values) predicted by a model or an estimator and the values observed. RMSD is always nonnegative, and a value of 0 (almost never achieved in practice) would indicate a perfect fit to the data. In general, a lower RMSD is better than a higher one. However, comparisons across different types of data would be invalid because the measure is dependent on the scale of the numbers used. RMSD is the square root of the average of squared errors. The effect of each error on RMSD is proportional to the size of the squared error; thus, larger errors have a disproportionately large effect on RMSD. Consequently, RMSD is sensitive to outliers.

2.6. Mean Absolute Error

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n}\left|y_i - x_i\right|}{n}. \tag{4}$$

In this formula, MAE is the mean absolute error, y_i is the prediction values, x_i is the true values, and n is the total number of data points. In statistics, mean absolute error (MAE) is a measure of errors between paired observations expressing the same phenomenon.

2.7. Type-2 Fuzzy Neural Network. In this section, a new type-2 fuzzy neural network is introduced. This new structure has a high ability to approximate any function. There are many adjustable parameters in this type-2 fuzzy neural network that increase the degree of freedom of the model and therefore increase the accuracy of its work. The following Figure 1 shows the proposed type-2 fuzzy neural network structure.

The internal phase of the first layer calculations is given as follows:

$$\begin{cases} \overline{\varnothing}_{ji}\left(u_j\right) = \begin{cases} \left(u_j - c_{ji}^1\right)^2 u_j < c_{ji}^1, \\ 1\, c_{ji}^1 \le u_j \le c_{ji}^2, \\ \left(u_j - c_{ji}^2\right)^2 u_j > c_{ji}^2, \end{cases} \\ \varnothing_{ji}\left(u_j\right) = \begin{cases} \left(u_j - c_{ji}^2\right)^2 u_j \le \dfrac{c_{ji}^1 + c_{ji}^2}{2}, \\ \left(u_j - c_{ji}^1\right)^2 u_j > \dfrac{c_{ji}^1 + c_{ji}^2}{2}, \end{cases} \end{cases} \tag{5}$$

where $\overline{\varnothing}_{ji}$ and $\varnothing_{ji}$ are the upper and lower of the j^{th} input and i^{th} neuron, respectively. Therefore, the outputs of the first layer are as follows:

$$\begin{cases} \overline{\varnothing}_i(u) = \exp\left(-\dfrac{\sum_{j=1}^{n+1}\widetilde{\varnothing}_{ji}\left(u_j\right)}{\sigma_i^2}\right), \\ \varnothing_i(u) = \exp\left(-\dfrac{\sum_{j=1}^{n+1}\varnothing_{ji}\left(u_j\right)}{\sigma_i^2}\right), \end{cases} \tag{6}$$

where $\overline{\varnothing}_i$ and $\varnothing_i$ are the upper and lower of the i^{th} neuron $(i = 1, 2, \ldots, m)$, respectively. $u \in (u_j)$, $j = 1, \ldots, n$ is the input vector, and $c_{ji} \in [c_{ji}^1, c_{ji}^2]$ is the center of all the RBF neurons. It should be noted that the left and right endpoints of the second layer are as follows:

$$\begin{cases} \widehat{y}_l = \dfrac{\sum_{i=1}^{q}\overline{\varnothing}_i(u)c_{w_i}^2\sigma_{w_i} + \sum_{i=q+1}^{m}\varnothing_i(u)c_{w_i}^1\sigma_{w_i}}{\sum_{i=1}^{q}\overline{\varnothing}_i(u)\sigma_{w_i} + \sum_{i=q+1}^{m}\varnothing_i(u)\sigma_{w_i}}, \\ \widehat{y}_r = \dfrac{\sum_{i=1}^{p}\varnothing_i(u)c_{w_i}^1\sigma_{w_i} + \sum_{i=p+1}^{m}\overline{\varnothing}_i(u)c_{w_i}^2\sigma_{w_i}}{\sum_{i=1}^{p}\varnothing_i(u)\sigma_{w_i} + \sum_{i=p+1}^{m}\overline{\varnothing}_i(u)\sigma_{w_i}}, \end{cases} \tag{7}$$

where p and q are the left and right switching points the Type-II fuzzy system, which can be calculated using the trial and error method or the Karnik-Mendel (KM) algorithm. Also, m, w_i, c_{w_i}, and σ_{w_i} are the mean value of the first layer neurons, the weights, the center of weights, and the spread of weights, respectively. Lastly, the general output of the network can be derived as follows:

$$\widehat{y} = \frac{\widehat{y}_l + \widehat{y}_r}{2}. \tag{8}$$

The reduction gradient method is used to teach the network.

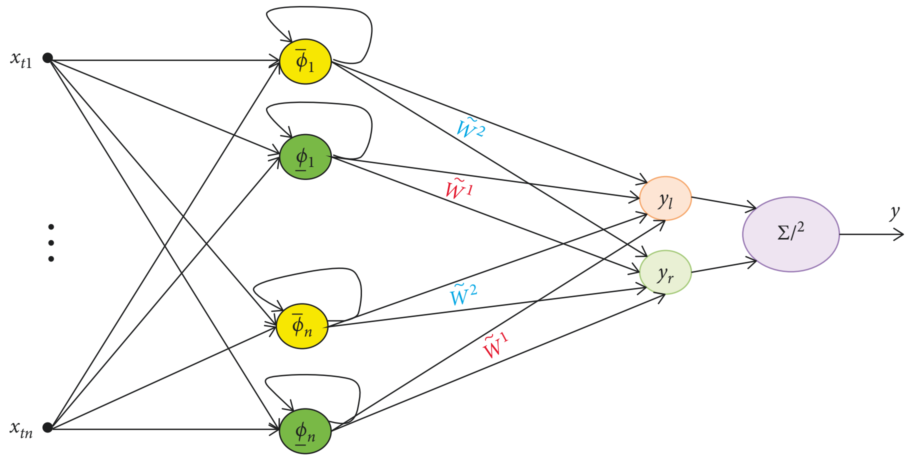

FIGURE 1: The proposed type-2 fuzzy neural network.

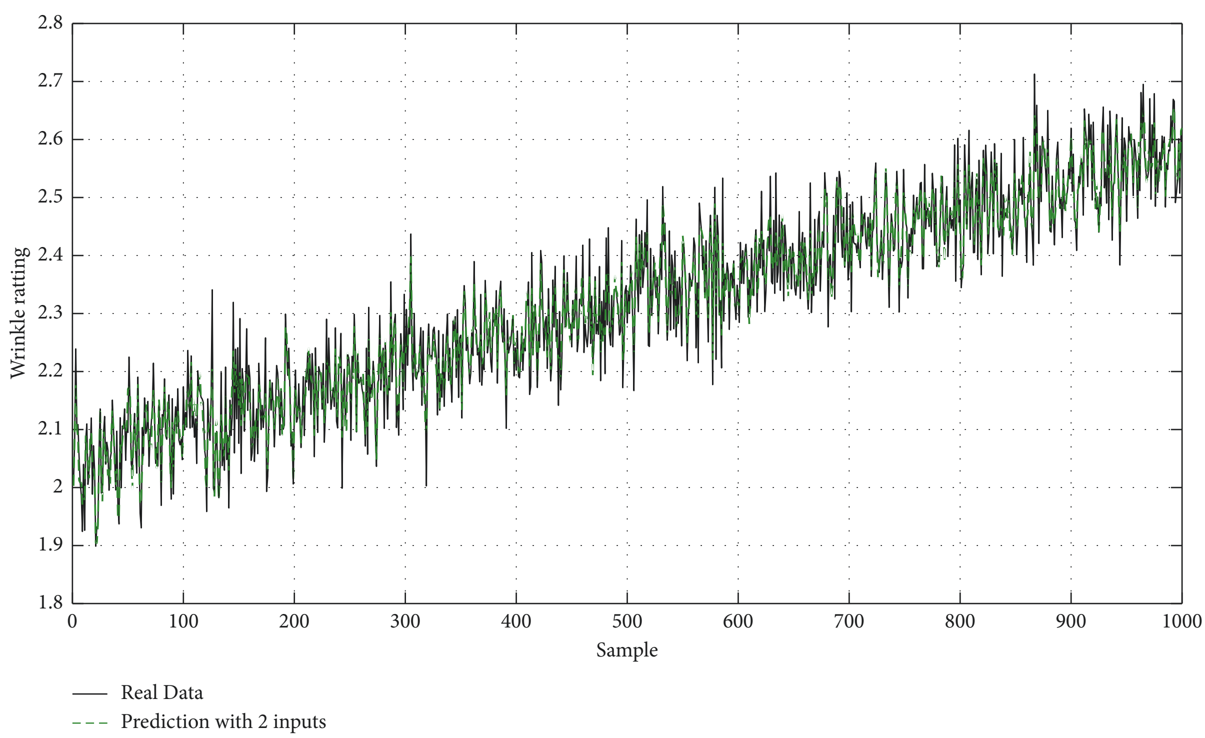

FIGURE 2: Prediction with 2 input.

3. Results and Discussions

Smoothness appearance of the cotton fabric is related to the original position of the fabric after removing the forces loaded on its structure during the home laundry process. Therefore, the structural properties of the fabric and the forces loaded on the fabric during washing affect the wrinkle appearance of the fabric. For this purpose, the wrinkle grade of the cotton fabrics after the laundry was evaluated based on the structural properties of the fabric as following:

3.1. Wrinkle Assessment of the Cotton Fabric by Development of A New Type-2 Fuzzy Neural Network. In this paper, the wrinkle of the cotton fabric after the washing process was analyzed based on the structural fabric properties. For this purpose, the wrinkles of the experimental samples after washing was ratted by the method developed in light line by image processing [13]. In experiments, 1000 tests were conducted. The experimental results for some of the tests are presented in Table 2. For theoretical evaluation, a new type-2 fuzzy neural network was developed in this paper. Structural

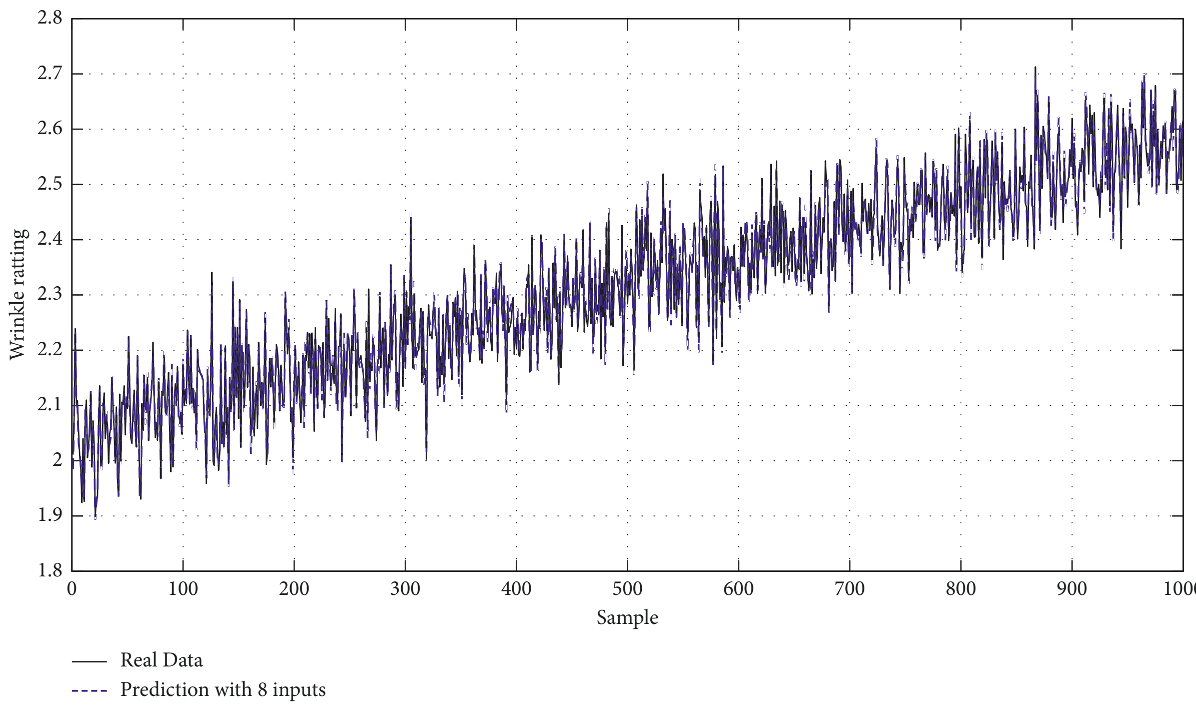

Figure 3: Zoom of prediction with two input.

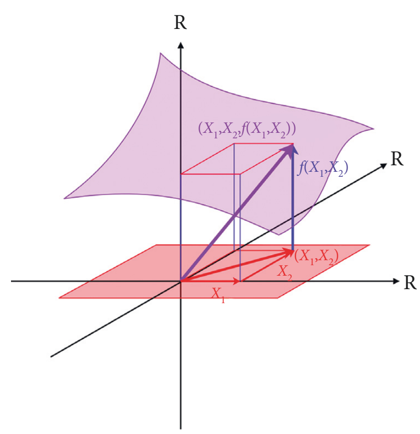

Figure 4: Mathematical function with two variables and one output.

properties of the fabric such as thickness, weight, warp yarn per inch and weft yarn per inch, warp and weft Tex as linear density, and fabric cover factor in warp and weft direction are the input parameters of the models and the wrinkle grad of the samples after washing process is the output parameter.

3.2. Prediction of the Wrinkle Appearance of the Fabric after Home Laundry by the New Type-2 Fuzzy Neural Network with Two, Four, Six and Eight Inputs. Figure 2 shows the wrinkle prediction of the cotton fabric after washing by the model developed with two inputs. Both structural properties of the fabric such as thickness, weight, warp and weft yarn density per inch, linear density (Tex) of weft and warp yarn, and cover factor of fabric in weft and warp direction were selected separately as input parameters and the final modeling result that shows the total manner of the wrinkle grade based on eight input parameters was presented in Figure 3.

According to Figure 3 as zoom of the part of Figure 2 shows that there is a relative relation between the experimental and the prediction results. Total trend of Figure 2 describes that the wrinkle appearance of the fabric after washing process was affected by these input parameters. But according to Table 3 the error values for the model with two inputs are more values. So the prediction results of this model is not same exactly with the experimental results.

In mathematical analysis, a function of several variables is a function with more than one variables. This concept extends the idea of a function of several variables.

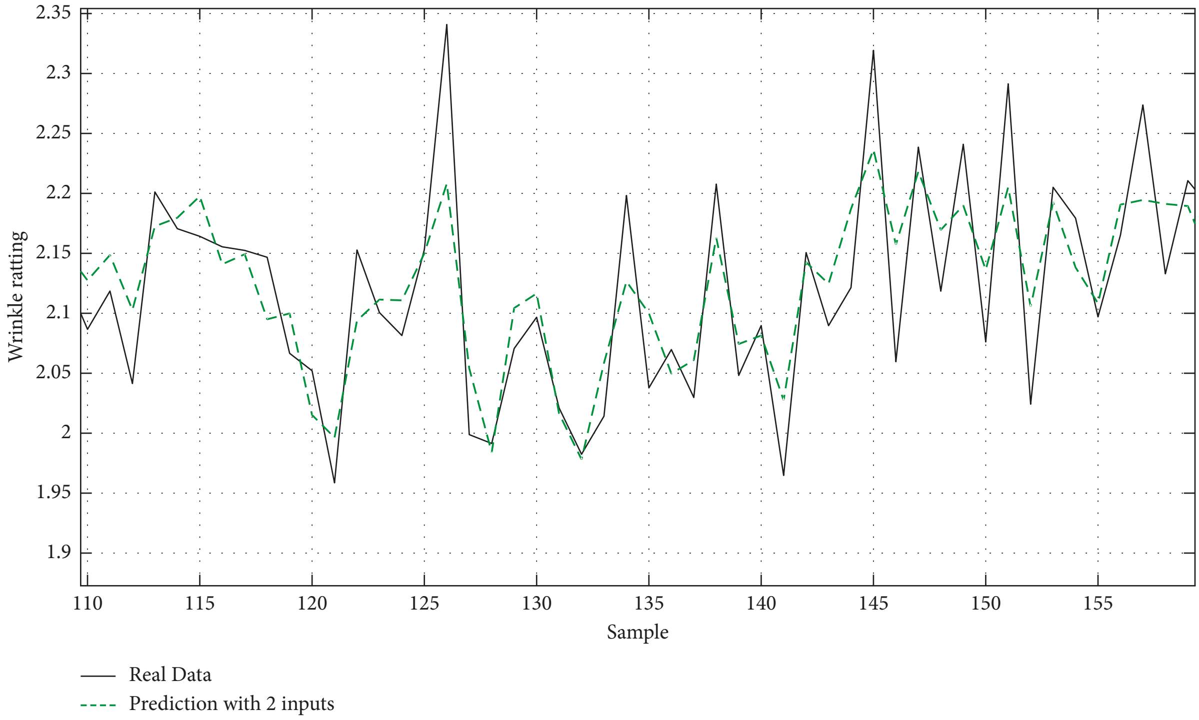

Figure 5: Prediction with eight inputs.

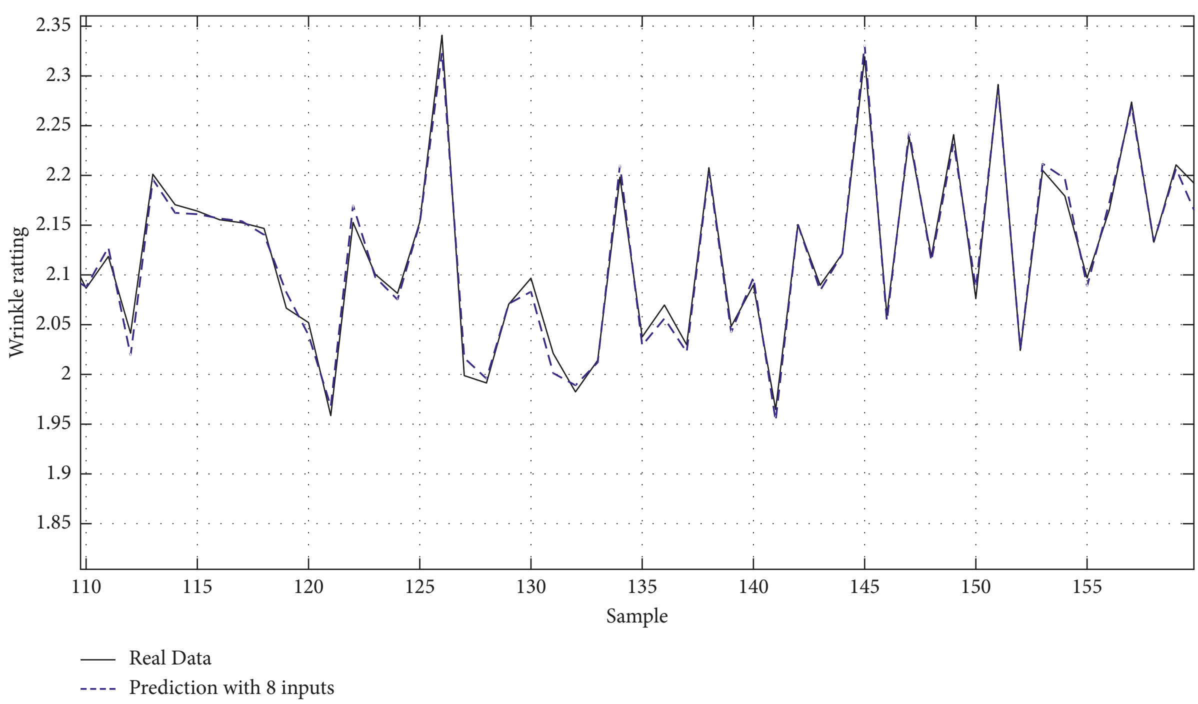

Figure 6: Zoom of prediction with eight inputs.

According to Figure 4, the "input" variables as X_1 and X_2 variables are converted by the function of the F to "output." Therefore, this mathematical system is depending on two variables and the function are determined exactly based on more variables and the function with one or two variable is not able to describe the manner of this system, exactly.

Therefore, in the washing process, the wrinkle appearance depends on all fabric structure parameters and the model developed in this paper should be able to predict the wrinkle of the fabric after washing according to all inputs. According to this fact, the modeling was developed to predict based on the two, four, six, and eight parameters. However, the modeling results are presented in Figures 3–6 for different inputs.

The crease recovery of the twill weave is better than plain [23]. Fabric cover factor is a number that specifies the degree to which the part of a cloth is enclosed by the yarns. It is the percentage of the area covered by the yarns to the total area of fabric. The cover factor of the satin weave is the lowest among the weaves. The plain weave has more cover factor value than the twill weave [24]. That is important to know that these fabrics have nearly similar density and warp and weft linear density for easy assessment and experimentation process. But by different values of the structural parameters such as the thickness, weight, warp and weft yarn density per inch, linear density (Tex) of weft and warp yarn, and cover factor of fabric in weft and warp direction that is need to predict the wrinkle of the fabric by a nonlinear function based on the neural network. The accuracy prediction of the models can be evaluated by the statistical parameters of the models. For this purpose, the statistical parameters of each model such as mean square error, root mean square error, and mean absolute error values are summarized in Table 3. According to the neural network modeling, the regression coefficient parameter was not calculated for the models. The standard deviation values for each column of Table 1 were summarized in the end row of this table. According to Table 3 the mean square error, root mean square error, and mean absolute error values were decreased by increasing the input parameters.

The error values summarized in Table 3 describe that the prediction of the model with input parameters such as thickness, weight, warp and weft yarn density per inch, linear density (Tex) of weft and warp yarn, and cover factor of fabric in weft and warp direction as structural parameters of the fabric is the best and reality among the developed models with the different input parameters.

4. Conclusion

Original position of the fabric after removing the forces loaded on its structure during the home laundry process determines the smoothness appearance of the cotton fabric. Due to effect of the structural properties of the fabric after washing on its wrinkle appearance, the wrinkle grade of the cotton fabrics was evaluated based on its structural properties. Therefore, in this paper, a new type-2 fuzzy neural network was developed for prediction of the wrinkle appearance of the cotton fabric after washing process. For this purpose, structural properties of the fabric were considered as input parameters and the wrinkle grade as output. These mentioned parameters are thickness, weight, warp and weft yarn density per inch, linear density (Tex) of weft and warp yarn, and cover factor of fabric in weft and warp direction. Several models with two, four, six, and eight input were developed, respectively. The experimental and prediction modeling results and the mean square error, root mean square error, and mean absolute error parameters extracted from the models show that when all of the input parameters are considered as input of the model the mentioned error values decrease and the exactly prediction of the model is increased.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request by Dr. Mir Saeid Hesarian.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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