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A Study on Subjective Assessment of Knit Fabric by ANFIS

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Abstract: The purpose of this study was to examine the effects of the structural properties of plain knit fabrics on the subjective perception of textures, sensibilities, and preference among consumers. This study, then, aimed to provide useful information with respect to planning and designing knitted fabrics by predicting the subjective characteristics analyzed according to their structural properties. For this purpose, we employed statistical analysis tools, such as factor and regression analysis and an adaptive-network-based fuzzy inference system(ANFIS), thereby combining the merits of fuzzy and neural networks and presupposing a non-linear relationship. Through factor analysis, we also categorized the subjective textures into 'roughness', 'softness', 'bulkiness' and 'stretch-ability' with R2=70.32 %: and categorized the sensibilities into 'Stable/Neat', 'Natural/Comfortable' and 'Feminine/Elegant' with R2=68.12 %. We analyzed subjective textures, sensibilities, and preference with ANFIS, assuming non-linear relationships; consequently, we were able to generate three or four fuzzy rules using wool/rayon fiber content and loop length as input data. The textures of roughness and softness exhibited a linear relationship, but other subjective characteristics demonstrated a non-linear input-output relationship. Compared with linear regression analysis, the ANFIS exhibited had higher predictive power with respect to predicting subjective characteristics.

Keywords: Knit fabric, Subjective texture, Sensibility, Preference, ANFIS

Introduction

Knitted fabric provides wearers with comfort, due to its stretch-ability, elasticity (the ability to return to its pre-stretch shape), softness of loop structure, and some additional unique properties that serve to satisfy the aesthetic needs of customers who pursue various, strong identities. Therefore, knit fabrics have become highly-valued goods in the area of contemporary fashion materials [1].

However, until now, any research on knit fabric has been limited to its objective and mechanical properties [2,3], and has hardly addressed subjective properties such as texture, sensibility and preference.

Statistical analysis methods, including analysis of variance (ANOVA), various regression models, and others, have been used to explain the subjective textures and sensibilities of textiles. However, the subjective nature of human's is much less linear, being ill-defined and influenced by a variety of factors, so that system modeling based upon conventional statistical methods is not as well-suited [4]. Several investigators have worked on the development of an evaluation and analysis system that better handles subjective data, such as the concept of fuzzy and neural networks [5-7]. In particular, an adaptive network based fuzzy inference system (ANFIS) modeling is based on the fuzzy set theory and neural network method, and is well suited for predicting the subjective handle which contains the non-linearity in mechanical properties and the relationship between sensibility and preference. The remarkable adaptability of ANFIS is attributed to the following facts: 1. It can conduct nonlinear mapping: 2. Though not based on a priori knowledge, the initial parameter settings of ANFIS are reasonable and result in fast convergence to good parameter value. 3. It consists of fuzzy values which actually consisted of local, instead of global mapping. This local mapping facilitates adaptation, thereby reducing output error [4].

Consequently, the primary purposes of the current research were: 1) to analyze the relationship that exists between the subjective properties (such as texture, sensibility and preference) and structural properties (like fiber content and density) by means of ANFIS modeling: 2) to construct models to predict the estimated value of subjective properties using both a conventional statistical method like regression analysis and a less traditional method, ANFIS: 3) to compare the predictive power of these two models : and 4) if possible, to offer substantial information on knit fabric planning.

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Research Method

Test Fabrics

Knit Yarn

The features of pre-ply single yarns for knitting are illustrated in Table 1.

Table 2 shows the properties of 4-ply yarns which are constructed by plying the two kinds of yarns mentioned in Table 1. The ratio of fiber content varies from wool 100 %, wool/rayon 75:25, wool/rayon 50:50 wool/rayon 25:75, and

Table 1. Properties of single yarn

Fiber contents	Yarn tex	Twist number	Twist direction	Remarks
Wool 100 %	18.8	620 tpm	Z	Worsted yarn
Rayon 100 %	19.0	670 tpm	Z	Viscose rayon

Table 2. Properties of ply yarn for knitting

	Fiber contents	First twist (two-plies)	Second twist (four-plies)	Twist no. (direction)	
				First twist	Second twist
1	Wool 100 %	① wool 18.8 tex × 2	① × ①	607 tpm (S)	300 tpm (Z)
2	Wool 75 % Rayon 25 %	① wool 18.8 tex × 2 ② rayon 19.0 tex + wool 18.8 tex	① × ②		
3	Wool 50 % Rayon 50 %	② rayon 19.0 tex + wool 18.8 tex	② × ②		
4	Wool 25 % Rayon 75 %	② rayon 19.0 tex + wool 18.8 tex ③ rayon 19.0 tex × 2	② × ③		
5	Rayon 100 %	③ rayon 19.0 tex × 2	③ × ③		

Table 3. Structural properties of test fabrics

Fabric no.	Avg. loop length (mm)	Wool/rayon contents (%)	Weight (mg/cm^2)	Thickness (mm)	Fabric count	
					Wale/in	Course/in
1	5.5	100 / 0	3.26	0.90	18.7	24.7
2	6.5		2.68	0.87	17.0	20.7
3	7.5		2.35	0.86	15.0	17.8
4	8.5		2.08	0.84	12.7	15.7
5	5.5	75 / 25	3.28	0.88	19.0	25.0
6	6.5		2.76	0.85	17.0	21.0
7	7.5		2.32	0.83	15.0	18.0
8	8.5		2.13	0.79	13.5	14.8
9	5.5	50 / 50	3.32	0.87	19.2	25.5
10	6.5		2.67	0.86	17.0	21.0
11	7.5		2.39	0.81	15.0	17.7
12	8.5		2.07	0.77	14.0	14.5
13	5.5	25 / 75	3.36	0.87	19.5	26.7
14	6.5		2.73	0.85	17.2	21.0
15	7.5		2.33	0.83	15.5	17.0
16	8.5		2.06	0.79	13.8	14.7
17	5.5	0 / 100	3.28	0.86	18.8	26.7
18	6.5		2.80	0.86	17.2	20.8
19	7.5		2.40	0.84	15.0	17.0
20	8.5		2.06	0.76	13.0	14.3

rayon 100 %.

Knitting Conditions and Properties of Fabric

The fabrics were knitted with a regular loop length by means of Digital Stitch Control System (DSDC) established in a computer-automatic flat knit machine (Shimaseiki MFG. company, Model: SES-122RT), that was designed for 12-gauze whole garments. The range of fabrics comprise 20 (5 × 4) different specimens as shown in Table 3 using all five ratios of fiber content and four loop lengths ranging from 5.5 mm to 8.5 mm: 6.5 mm of loop length is standard for most apparel.

Subjective Sensory Assessment

The subjective texture and sensibility descriptions were based on sensory adjectives derived in a preceding study [8]. One hundred female knitting experts were asked their opinion regarding sixteen adjectives describing subjective textures, thirteen adjectives describing sensibilities, as well as preferences of knit fabric. These experts all were in their twenties and thirties, and included knit designers, apparel designers, lecturers, graduate students and saleswomen who sell knitted-apparel. The subjects were asked 1) to freely feel and examine all 20 knit fabrics of a certain size (20 × 20 cm), and 2) to then describe them, using the 16 texture and 13 sensibility adjectives provided. All tests were conducted in June of 2004.

Data Analysis

Statistical Analysis

The data were analyzed using the SPSS 10.1 program by means of factor analysis, applying the criteria of an eigen value of 1 and Varimax orthogonal rotation. To develop the predictive model addressing subjective texture, sensibility and preference according to the structural properties of knit fabric, multi-linear regression analysis was conducted.

ANFIS

Fuzzy theory and neural network theory have been used to develop system that makes it possible to judge and simulate human thinking and emotions. Fuzzy theory has the advantage of presenting a clear and qualitative inference process, but lacks adaptability to environmental change s and learning ability. Neural network theory easily expresses non-linear input and output relationships, exhibits excellent learning ability, but can not show results and learning phase clearly. Recently, ANFIS has been applied to analyze human subjective characteristics as a tool that is complementary to fuzzy models and neural networks. Figure 1 expresses the fuzzy model and structure of ANFIS with two rules that mix together a learning rule to optimize parameters of a fuzzy system on a primary Sugeno system [9].

The fuzzy inference of the model in the above Figure 1 employs a weighted average and assumes a linear relationship and if-then rules. On the assumption that the fuzzy inference system has N inputs, $x_1,.......x_N$, and one output, f, a general rule set with if-then rules can be expressed as

$$i\text{-th rule : If } x_1 \text{ is } A_{i1} \text{ and ....and } x_N \text{ is } A_{iN}, \quad \text{then } f_1 = a_{iN}x_N + ...+ a_{i1}x_1 + a_{i0} \tag{1}$$

Each layer of ANFIS architecture can be expressed by means of a numerical formula as presented below. Every node in layer 1 is an adaptive node with a node output defined by Gaussian -shaped membership function.

$$\mu_{Ax}(x) = \exp\left\{\frac{-(x_j - C_{ij})^2}{2\sigma_{ij}^2}\right\} \tag{2}$$

where $\{C_{ij}, \sigma_{ij}\}$ is a parameter set. Parameters in this layer are referred to as premise (or antecedent) parameters.

Every node in layer 2 multiplies incoming signals; each node output represents the firing strength of a rule.

$$\omega_i = \prod_{i=1}^{N} \mu_{Ax}(x_i) = \mu_{Ax}(x_i) \times \ldots \times \mu_{Ax}(x_N) \tag{3}$$

Every node in layer 3 calculates the ratio of the i-th rule's firing strength to the sum of all rule's firing strength. Outputs of this layer are normalized firing strengths.

$$\overline{\omega}_i = \frac{\omega_i}{\sum_{i=1}^{N} \omega_i} = \frac{\omega_i}{\omega_1 + \ldots + \omega_N} \tag{4}$$

Every node in layer 4 is an adaptive node. In this layer, the parameters a_{i0}, a_{i1}, ..., a_{iN}, will be called consequent parameters

$$\omega_i f_i = \omega_i (a_{iN}x_n + ...+ a_{i1}x_1 + a_{i0}) \tag{5}$$

The single node in the last layer, layer 5, is a fixed node, which computes the overall output as the summation of all incoming signals.

$$f = \sum_{i=1}^{N} \overline{\omega}_i f_i = \frac{\sum_i \omega_i f_i}{\sum_i \omega_i} \tag{6}$$

Therefore, in this case, to generate a predictive model is to identify the premise parameters -C_{ij}, σ_{ij}, and the consequent parameters-a_{i0}, a_{i1}, ..., a_{iN}.

ANFIS expresses inputs as fuzzy membership function like fuzzy model, but adapts neural network theory to some degree, in order to control membership function parameters in layer 1 and consequent parameters via error back-propagation.

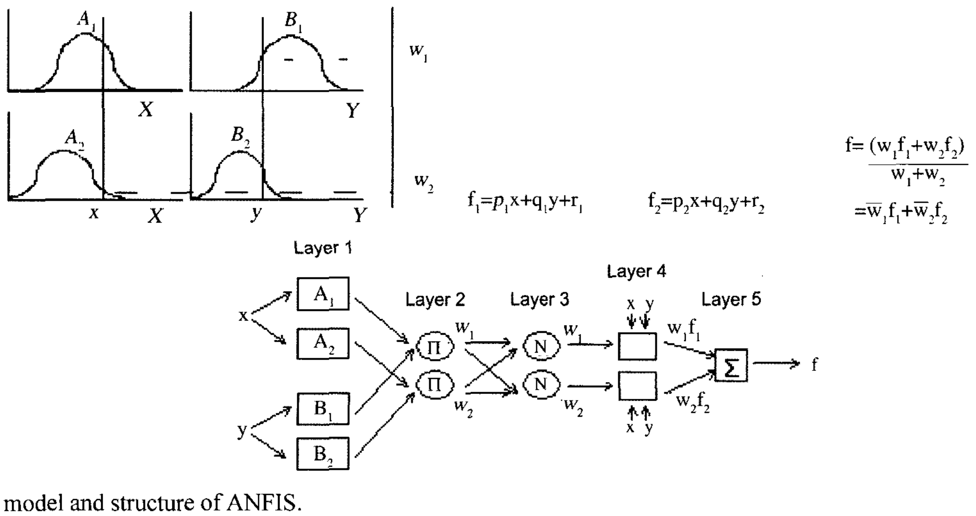

Figure 1. Fuzzy model and structure of ANFIS.

Table 4. Attributes of fuzzy inference

Type	Sugeno (TSK)
And	Product
Or	Probabilistic or
Defuzzification	Weighted average
Implication	Min
Aggregation	Max

ANFIS analysis was done using the Matlab 6.1 program. A clustering process was used when making the fuzzy-neural model: the membership function type was Gaussian; training number is 5; and the width of fuzzy membership function was 1.0. Table 4 shows the attributes of the calculation in ANFIS fuzzy inference applied to develop the predictive model.

Results and Discussion

Assessment Dimensions of Subjective Texture and Sensibility

The results of factor analysis on texture and sensibility of knitted fabrics is shown in Table 5. The 16 pairs of adjectives on texture could be categorized into four core factors; 'roughness', 'softness', 'bulkiness' and 'stretch-ability'. The cumulative variance explained by the model including all four core factors was 70.32 % The specific adjectives for roughness included 'rough' and 'fine hairs on the surface of the fabric': Softness included 'drooping', 'soft', 'loose' and 'light': bulkiness included 'thick', 'voluminous' and 'cushioned' and stretch-ability includes 'extensible' and 'resilient'.

The 13 pairs of adjectives on sensibility could be categorized into three main factors : 'Stable/Neat', 'Natural/Comfortable' and 'Feminine/Elegant'. The cumulative variance explained by these three core sensibility factors was 68.12 %. Adjectives of 'Stable/Neat' included 'clean', 'modern' and 'stable'; 'Natural/Comfortable' included 'natural', 'comfortable', and 'cozy'; 'Feminine/Elegant' included 'feminine', 'elegant', 'intellectual' and 'luxurious'.

The Predictive Model Using ANFIS

To develop the predictive model, data from 17 of the 20 material specimens were used as training data pairs and the 3 remaining specimens were used as checking data pairs to

Table 5. Factor analysis results

	Subjective textures				Subjective sensibilities		
	Roughness	Softness	Bulkiness	Stretch-ability	Stable/ neat	Natural/ comfortable	Feminine/ elegance
Eigen value	2.30	2.14	2.10	1.89	3.78	3.53	2.91
Cumulative perc. (%)	19.18	37.01	54.60	70.32	25.20	48.74	68.12
Cronbach' α	0.79	0.67	0.77	0.76	0.85	0.87	0.87

Table 6. Training variables for fuzzy inference model

Specimen	Structure		Factor score of texture				Factor score of sensibility			Preference
	Wool contents (%)	Loop length (mm)	Roughness	Softness	Bulkiness	Stretch-ablility	Stable/ neat	Natural/ comfort	Feminine/ elegance	
1	100	5.5	0.155	−1.169	0.091	0.244	0.187	−0.121	−0.637	4.316
2	100	6.5	0.375	−0.771	0.343	0.193	−0.153	−0.110	−0.476	4.325
3	100	7.5	0.745	0.122	0.257	0.322	−0.466	0.362	−0.323	3.913
4	100	8.5	0.884	0.569	0.493	0.274	−0.72	0.560	−0.183	3.953
5	75	5.5	0.172	−0.868	0.081	−0.075	0.157	−0.179	−0.043	4.022
6	75	6.5	0.183	−0.518	0.190	0.151	0.208	−0.012	−0.023	4.364
7	75	7.5	0.448	0.160	−0.043	0.155	−0.307	−0.074	0.334	4.333
8	50	5.5	−0.166	−1.009	0.245	−0.079	0.255	−0.323	−0.072	4.425
9	50	7.5	0.410	0.336	−0.139	0.161	−0.263	0.301	0.018	4.023
10	50	8.5	0.486	0.779	0.055	0.056	−0.671	0.387	−0.141	3.933
11	25	6.5	−0.215	−0.047	0.196	−0.005	0.104	−0.098	0.232	4.386
12	25	7.5	−0.195	0.484	−0.128	0.118	−0.048	0.158	0.369	4.325
13	25	8.5	0.023	0.810	−0.361	−0.454	−0.530	0.102	−0.059	3.789
14	0	5.5	−1.159	−0.131	−0.159	−0.509	0.771	−0.446	0.136	4.267
15	0	6.5	−0.947	0.378	−0.360	−0.228	0.537	−0.295	0.448	4.457
16	0	7.5	−0.727	0.707	−0.252	−0.086	0.529	−0.069	0.160	4.150
17	0	8.5	−0.287	1.000	−0.601	−0.356	0.001	−0.101	0.181	3.568

verify each predictive model identified using the 17 training data pairs.

Subjective Textures

Figure 2 through 5 display plots the relationship of fuzzy inference models for each of the four subjective textures, between inputs and outputs. The ratios of wool/rayon fiber content were used as input data and a four factor score for each specimen was used as output data for each fuzzy model The SDE referenced under each plot is the standard deviation

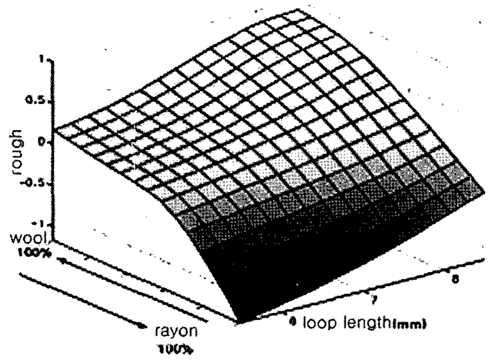

Figure 2. Fuzzy model on texture 'roughness' (SDE = 0.0648).

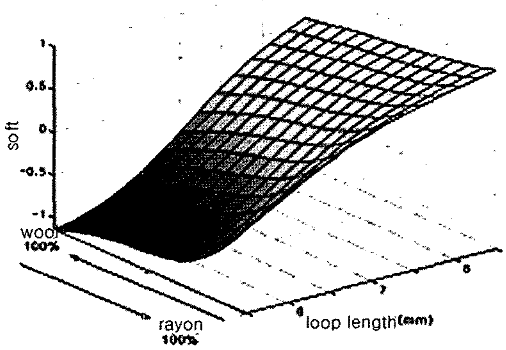

Figure 3. Fuzzy model on texture 'softness' (SDE = 0.0502).

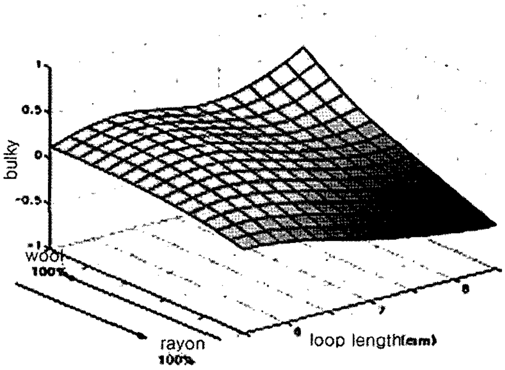

Figure 4. Fuzzy model on texture 'bulkiness' (SDE = 0.103).

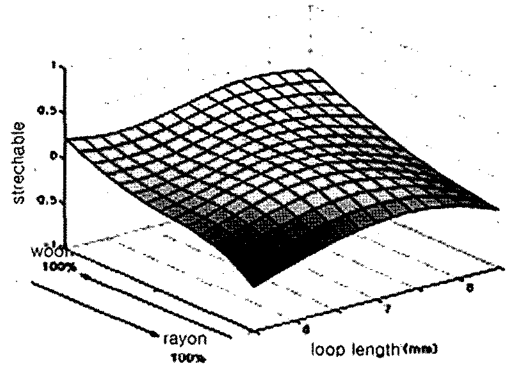

Figure 5. Fuzzy model on texture 'stretch-ability' (SDE = 0.076).

Table 7. Prediction model parameters on subjective texture by ANFIS

Texture factor	Rule	Antecedent parameter				Consequent parameter		
		Input 1 (loop length)		Input 2 (wool/rayon content)		Constant	Input 1 (loop length)	Input 2 (wool/rayon content)
		c	σ	c	σ	a_0	a_1	a_2
Roughness	1	6.48	1.06	75	35.36	−1.041	0.0777	0.0072
	2	8.52	1.04	25	35.36	−2.686	0.2786	0.0119
	3	6.51	1.05	0	35.36	−2.378	0.2096	0.0317
	4	8.50	1.05	100	35.36	1.838	−0.0956	−0.0000
Softness	1	7.50	1.05	50	35.36	−1.422	0.2748	−0.0025
	2	5.49	1.03	75	35.36	−0.339	0.0440	−0.0105
	3	5.49	1.06	0	35.36	−3.496	0.6070	−0.0359
Bulkiness	1	7.49	1.09	50	35.36	−0.047	−0.0487	0.0110
	2	5.50	1.06	75	35.36	−2.146	0.4046	0.0004
	3	8.49	1.07	100	35.36	−7.839	0.7439	0.0192
Stretchability	1	7.50	1.07	50	35.36	1.870	−0.3191	0.0119
	2	5.51	1.08	75	35.36	0.871	−0.379	0.0132
	3	6.49	1.03	0	35.36	-2.153	0.3097	0.0227

estimate:, since standard deviation is mathematically related to standard error, the smaller SDE is, the more accurate the corresponding model is believed to be.

Table 7 summarizes the antecedent and consequent parameters of each rule explained in equations 1 through 5. The prediction result for 'roughness' consisted of four fuzzy rules, for which the model SDE was 0.0648. There was a strongly-linear positive relationship between the inputs, wool/rayon content and loop length, and the output measure of 'roughness'. Compared to the results of ANOVA and a Duncan test in a previous study [10], ANFIS was able to express an interactive relationship visibly between inputs and outputs, but was limited in judging the significance of the effect between them.

The prediction result for 'softness' consisted of three fuzzy rules, with SDE 0.0502. Softness decreased slightly as wool versus rayon content increased, but decreased rapidly as loop length became shorter. The prediction result for 'roughness' consisted of three fuzzy rules, with SDE 0.103. It was less affected by structural properties such as wool/rayon content and loop length, than either roughness or softness, and the relationship between inputs and outputs was less linear. The prediction result for 'stretch-ability' consisted of three fuzzy rules with SDE 0.076. It was hardly affected at all wool/rayon content, but when loop length ranged from 6.0 to 7.0 mm, the stretch-ability score was optimized. The curvilinear pattern suggests that a non-linear and multi-dimensional exists between this last subjective texture and the structural properties.

Sensibilities

The results of the fuzzy models which used wool/rayon

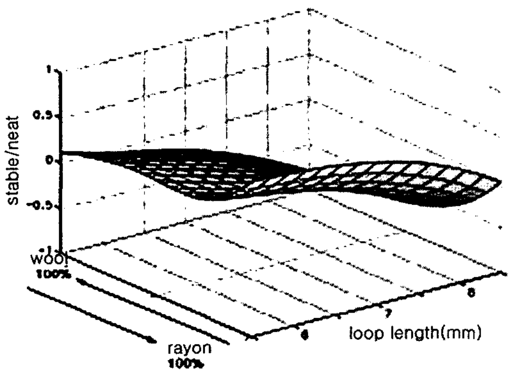

Figure 6. Fuzzy model on sensibility 'Stable/Neat' (SDE = 0.078).

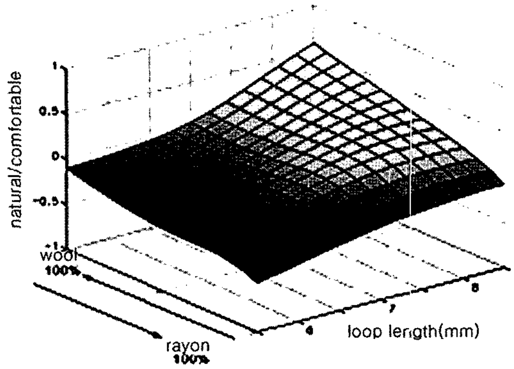

Figure 7. Fuzzy model on sensibility 'Natural/Comfortable' (SDE = 0.089).

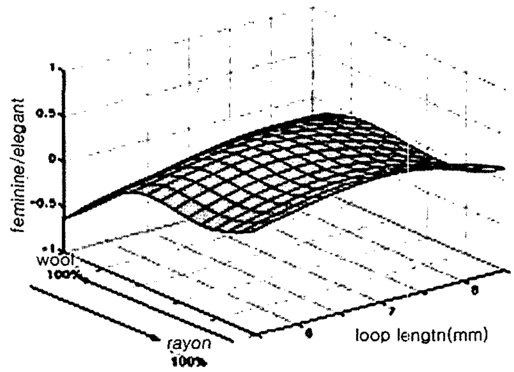

Figure 8. Fuzzy model on sensibility 'Feminine/Elegant' (SDE = 0.109).

Table 8. Prediction model parameters on sensibility by ANFIS

Sensibility	Rule	Antecedent parameter				Consequent parameter		
		Input 1 (loop length)		Input 2 (wool/rayon contents)		Constant	Input 1 (loop length)	Input 2 (wool/rayon contents)
		c	σ	c	σ	a_0	a_1	a_2
Stable/ Neat	1	7.49	1.08	50	35.36	4.173	−0.5512	−0.0020
	2	5.51	1.08	75	35.36	2.573	−0.2952	−0.0084
	3	6.50	1.07	0	35.36	0.497	0.0249	−0.0354
Natural/ Comfortable	1	6.51	1.07	75	35.36	−0.752	−0.0014	0.0064
	2	7.51	1.03	0	35.36	−1.175	0.1553	0.0223
	3	8.51	1.06	50	35.36	−0.578	0.0192	0.0120
Feminine/ elegant	1	7.50	1.04	50	35.36	3.337	−0.4348	0.0052
	2	6.50	1.04	0	35.36	−1.176	−0.2266	−0.0184
	3	6.50	1.04	100	35.36	1.024	−0.0011	1.0240

contents and loop length as inputs and each of the three sensibility factors as outputs are indicated in Figure 6 through 8. And Table 8 indicates the parameters of the fuzzy models on sensibility.

With respect to the sensibility parameter, 'Stable/Neat', three fuzzy rules were developed for which the SDE was 0.078. There was a linear, negative relationship between this sensibility and loop length; but a non-linear relationship between this and wool/rayon content. Little significant change in sensibility was identified within the range of 25 % to 75 % wool. On the other hand, both under 25 % and over 75 % wool, respectively, was associated with significant change, as shown in Figure 6. These result is similar to those observed in a previous study [10].

The fuzzy prediction result of 'Natural/Comfortable' consisted of three fuzzy rules, with SDE 0.089. This sensibility improved on the whole, in accordance with wool/rayon content and loop length. Especially with wool content over 50 %, this sensibility demonstrated no significant change in the case of loop lengths ranging from 5.5 mm to 7.0 mm, but increasing change in cases where loop length exceeded 7.0 mm. With respect to 'Feminine/Elegant', three fuzzy rules were developed with SDE 0.109. Compared to earlier results, this model demonstrated a non-linear relationship between inputs and outputs.

On the whole, sensibility was found to exhibit a stronger non-linear relationship than texture with wool/rayon content and loop length;, consequently, this result indicates the necessity of analysis tools assuming a non-linear relationship for the purpose of defining and predicting subjective sensibility.

Preference

Figure 9 demonstrates relationships that were developed by inserting the input data of wool/rayon content and loop length and the output data of preference of which SDE was 0.133. A non-linear relationship was found between the input data and preference. Under 7 mm loop length, the preference for knit fabric is independent of wool/rayon content, and over 7 mm loop length, a preference for 50~75 % rayon was exhibited.

Comparing the Predictive Power Between Fuzzy and Regression Analysis

To compare the predictive power of the two data analysis tools, we developed a fuzzy model and performed multiple linear regression on subjective properties, including preference using 17 material specimen for training data and 3 specimens for checking data. Training and checking data were chosen randomly and their properties are presented in Figure 6 and 9 respectively.

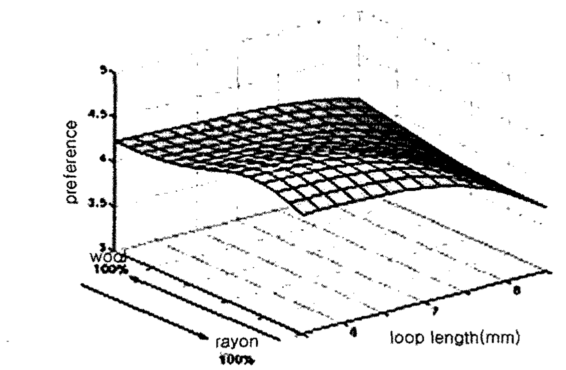

Figure 9. Fuzzy model on preference (SDE = 0.133).

Prediction of Subjective Texture

Table 10 presents the results of multiple regression with respect to subjective texture, for which the predictive data was calculated by means of the structural properties listed in Table 9, as input data. In addition, Figures 10 to 13 depict bar graphs on the prediction of factor scores for each of the four subjective textures ('roughness', 'softness', 'bulkiness' and 'stretch-ability') by ANFIS and regression. The dots in each figure represent the error associated with actual data points; the closer the error value is to zero, the more accurate the model is.

In cases where subjective texture factors have a linear relationship with wool/rayon content and loop length, there was little difference between the errors observed by ANFIS and regression analysis. However, with regard to texture factors such as 'bulkiness' and 'stretch-ability' that show a low-linear relationship with structural properties, the error value of ANFIS was smaller than that of regression. That means that the use of ANFIS is better in predicting the texture than linear regression analysis is.

Prediction of Sensibility

The results obtained by multiple linear regression on

Table 9. Properties of checking variables

Specimen	Structure		Factor score of texture				Factor score of sensibility			Preference
	Wool content (%)	Loop length (mm)	Roughness	Softness	Bulkiness	Stretch-ability	Stable/ neat	Natural/ comfort	Feminine/ elegance	
1	75	8.5	0.618	0.364	−0.060	−0.002	−0.470	0.037	−0.072	4.000
2	50	6.5	−0.122	−0.551	0.070	0.380	0.198	0.008	0.044	4.526
3	25	5.5	−0.475	−0.549	−0.022	−0.306	0.544	−0.186	0.030	4.295

Table 10. The multiple linear regression on a subjective texture (*p<0.05, **p<0.01)

	Factors	Structural properties	*b*	*β*	*t*	R^2	*F*
Texture	Roughness	Constant	−2.312		−11.639**	0.297	169.8**
		Wool content	0.013	0.497	16.76**		
		Loop length	0.237	0.259	8.74**		
	Softness	Constant	−3.123		−16.67**	0.400	268.0**
		Wool content	−0.008	−0.289	−10.55**		
		Loop length	0.508	0.544	19.87**		
	Bulkiness	Constant	0.010		0.046	0.050	21.09**
		Wool content	0.005	0.215	6.25**		
		Loop length	−0.043	−0.046	−1.347		
	Stretchability	Constant	−0.513		−2.15*	0.036	35.2**
		Wool content	0.005	0.196	5.67**		
		Loop length	0.034	0.036	1.05		

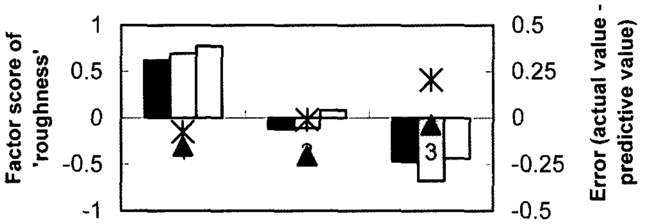

Figure 10. Predictive value and error of 'roughness' Error avg. (regression : 0.097 / ANFIS : 0.132); (■) actual value, (▨) predicitive value by regression, (□) predictive value by ANFIS, (✕) error by regression, (▲) error by ANFIS.

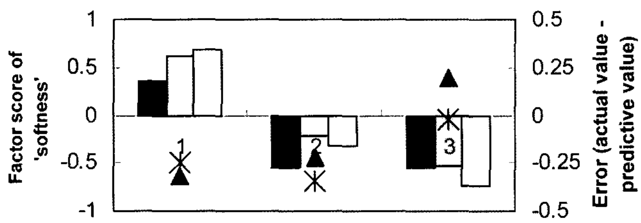

Figure 11. Predictive value and error of 'softness' Error avg. (regression : 0.204 / ANFIS : 0.247); (■) actual value, (▨) predicitive value by regression, (□) predictive value by ANFIS, (✕) error by regression, (▲) error by ANFIS.

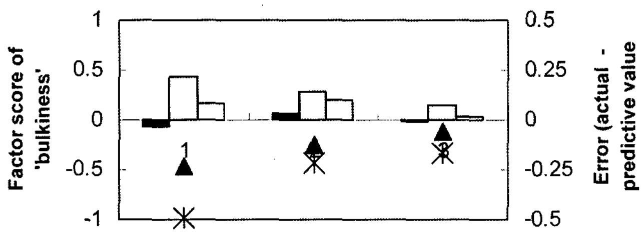

Figure 12. Predictive value and error of 'bulkiness' Error avg. (regression : 0.139 / ANFIS : 0.085); (■) actual value, (▨) predicitive value by regression, (□) predictive value by ANFIS, (✕) error by regression, (▲) error by ANFIS.

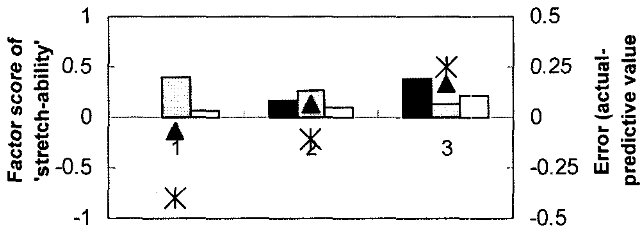

Figure 13. Predictive value and error of 'stretch-ablility' Error avg. (regression : 0.098 / ANFIS : 0.061); (■) actual value, (▨) predicitive value by regression, (□) predictive value by ANFIS, (✕) error by regression, (▲) error by ANFIS.

sensibilities such as 'Stable/Neat', 'Natural/Comfortable' and 'Feminine/Elegant' are demonstrated in Table 11. Bar graphs in Figures 14 to 16 indicate the predictive values for each of the three core sensibility characteristics, and the dots on those figures show the error between actual and predictive values obtained by ANFIS and regression.

'Stable/Neat' has so linear a relationship with loop length and wool/rayon content that the predictive power of regression analysis is strong. The sensibilities of 'Natural/ Comfortable' and 'Feminine/Elegant' have a weak linear relationship; therefore, the predictive power of ANFIS is stronger than that of regression.

Prediction of Preference

Figure 17 indicates the actual values and errors obtained by multiple linear regression and ANFIS on the preference of knit fabrics. To develop the ANFIS and regression models, the data of seventeen specimens were used for training data and the remaining three specimens were used for checking data.

With respect to the errors between actual and predictive values, regression analysis and ANFIS were little different, though, the predictive power of the former was slightly stronger than that of the latter.

Table 11. The multiple linear regression on sensibility (*p<0.05, **p<0.01)

	Factors	Structural properties	*b*	*β*	*t*	R^2	*F*
Sensi -bilities	Stable/ Neat	Constant	2.415		10.93**	0.155	73.92**
		Wool contents	–0.006	–0.246	–7.59**		
		Loop length	–0.300	–0.323	–9.95**		
	Natural/ Comfortable	Constant	–1.541		–6.60**	0.058	24.74**
		Wool contents	0.003	0.131	3.82**		
		Loop length	0.195	0.210	6.134**		
	Feminine/ Elegant	Constant	0.156		0.665	0.044	18.47**
		Wool contents	–0.005	–0.207	–6.00**		
		Loop length	0.017	0.019	0.543		

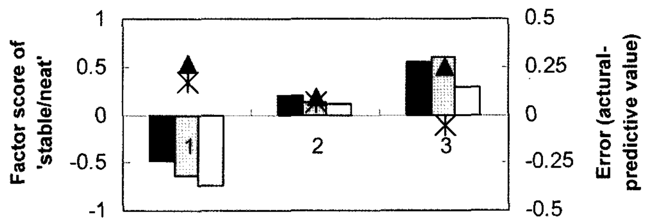

Figure 14. Predictive value and error of 'stable/neat' Error avg. (regression : 0.096 / ANFIS : 0.180); (■) actual value, (□) predicitive value by regression, (□) predictive value by ANFIS, (✱) error by regression, (▲) error by ANFIS.

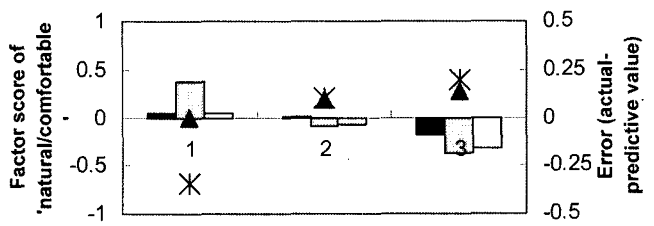

Figure 15. Predictive value and error of 'natural/comfort' Error avg. (regression : 0.214 / ANFIS : 0.078), (■) actual value, (□) predicitive value by regression, (□) predictive value by ANFIS, (✱) error by regression, (▲) error by ANFIS.

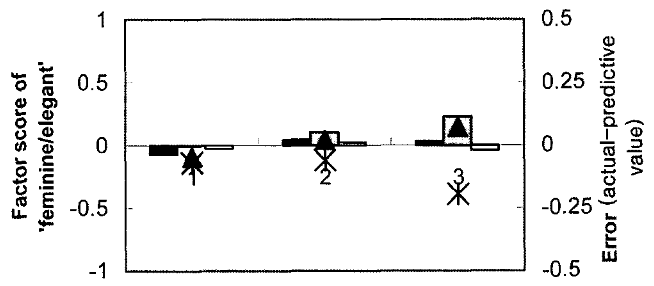

Figure 16. Predictive value and error of 'feminine/elegant' Error avg. (regression : 0.108 / ANFIS : 0.047); (■) actual value, (□) predicitive value by regression, (□) predictive value by ANFIS, (✱) error by regression, (▲) error by ANFIS.

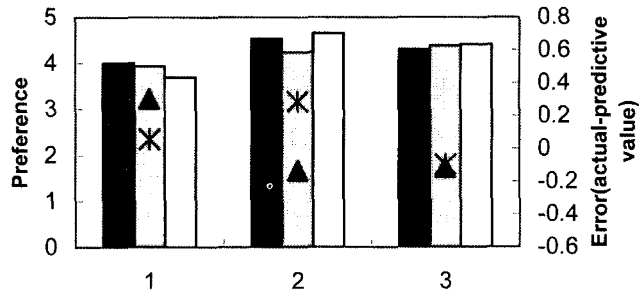

Figure 17. Predictive value and error of preference Error avg. (regression : 0.147 / ANFIS : 0.154); (■) actual value, (□) predicitive value by regression, (□) predictive value by ANFIS, (✱) error by regression, (▲) error by ANFIS.

Conclusions

This study was conducted to provide information that might serve usefully in the planning and design of knit fabrics, by means of predicting subjective characteristics analyzed in reference to structural properties. For this purpose, we employed statistical analysis tools, such as factor and regression analysis and an adaptive-network-based fuzzy inference system (ANFIS), combining the merits of fuzzy and neural networks and presupposing a non-linear relationship. The results are as followings:

Factor analysis revealed that subjective textures are classified into 3 categories with R2=70.32%. These categories were ; 'roughness', 'softness', 'bulkiness' and 'stretch-ability'. Similarly the subjective sensibilities were sub-grouped into 3 categories with R2=68.12%. They were; 'Stable/Neat', 'Natural/Comfortable' and 'Feminine/Elegant'.

In a survey targeting fabric preference, we could not recognize any difference within the entire ranges of wool/rayon fiber content, or at stitch loop lengths of 7.5 mm or less. On the other hand, preference decreases when stitch loop length exceeded 7.5 mm.

Using ANFIS to examine, the relationships among subjective textures, sensibilities, and preferences, we were able to generate three or four fuzzy rules using wool/rayon fiber content and loop length as input data. The textures of 'roughness' and 'softness' had a linear relationship with the structural properties of the knit fabric, but the other subjective characteristics exhibited a non-linear input-output relationship. Compared with linear regression analysis, the predictive model identified by ANFIS was in good agreement, both with the test and checking data sets, especially for non-linear relationship. Therefore, the results of this study demonstrate the necessity of employing proper analysis tools assumption of a non-linear relationship when examining human subjectivity in fabrics.

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