APPLICATION OF FUZZY LOGIC ON OBJECTIVE EVALUATION OF SEAM PUCKER

ỨNG DỤNG LOGIC MỜ TRONG ĐÁNH GIÁ KHÁCH QUAN ĐỘ NHĂN ĐƯỜNG MAY

Nguyen Thi Le, Nguyen Tuan Duc, Ngo Chi Trung, Tran Dinh Khang
Hanoi University of Technology

ABSTRACT

This article presents a new quantitative method of evaluating seam pucker in woven fabric with five shape parameters. This method is proposed using fuzzy logic, based on obtained data from a three-dimensional designed scanning. Measurement data in a parallel direction with the seam line is used to determine five shape parameters, such as amplitudes, wavelengths and wave generating points, which have been determined according to geometric model of Chang Kyu Park. For objective evaluation of seam pucker by AATCC (American Association of Textile Chemists and Colorist) standards, a fuzzy system is constructed from pattern recognition.

TÓM TẮT

Bài báo này giới thiệu phương pháp đánh giá độ nhăn đường may trên vải dệt thoi với năm thông số hình học ứng dụng logic mờ, dựa trên các dữ liệu thu được từ hệ thống quét 3D đã thiết kế. Dữ liệu đo theo hướng song song với đường may được sử dụng để xác định năm thông số hình học của đường may nhăn gồm các bước sóng, biên độ và số điểm sinh sóng theo mô hình Chang Kyu Park. Để đánh giá khách quan độ nhăn theo các cấp độ AATCC, một hệ mờ đã được thiết lập để nhận dạng mẫu.

I. INTRODUCTION

Controlling seam pucker is important for improving garment quality. AATCC standards have been the criteria most commonly used to rate seam pucker in garments [1], and rating results are subjective and the rating system has several shortcomings. In order to overcome these problems, several methods using new instruments, such as photoelectric, Moire', laser, ultrasonic, and CCD camera [2], have been introduced. These methods are mainly objective visual rating methods without explicit information about shape descriptions.

In this study, we present an objective method for evaluating seam pucker in woven fabrics during garment manufacturing by using the fuzzy system (FS) based on obtained five shape parameters, which have been determined from a three-dimensional designed scanning.

II. MEASUREMENT SYSTEM FOR SEAM PUCKER

The measurement system for seam pucker composes of a three-dimensional laser scanner, a simulator, and a fuzzy system, which are connected with a computer. We designed the scanning laser system for measuring the surface profile of seam pucker [3]. The optical sensor measuring range is ± 5mm with 20μm resolution, and its beam diameter is 1mm. The scanning data is a text file, which is used for the simulation and the evaluation of seam pucker by the FS.

Using methods of Charles Loop and Pierre Alliez [4], we have developed a simulator that produces arbitrary puckered shapes when the scanning data is defined. For shape description of seam pucker, we have used a geometric model of seam pucker, which were proposed by Chang Kyu Park[2]. Scanning data enables to define five shape parameters of sample, which are the number of wave generating points, the wave amplitudes, and the wavelengths on the line next to the seam and on the edge line. These parameters are coincident inputs of the fuzzy system.

Using the constructed FS, we could evaluate the arbitrary seam samples. A fabric sewn sample with an unknown pucker grade is first measured using the laser scanning system, and then seam surface and five shape parameters are defined by a simulator. Automatically, the evaluating system generates an input pattern for associative recall. Thus, the

FS recalls the seam pucker of the measured fabric (Fig. 1).

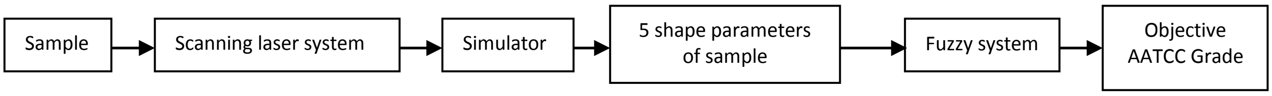


Fig.1 Procedure for Evaluation Method of Seam Pucker

III. FUZZY SYSTEM FOR EVALUATING SEAM PUCKER

Recently, in the textile and apparel manufacturing fields, an advanced fuzzy logic has been adopted to help producing the high quality goods. The intelligent sewing machine based on the neurofuzzy control algorithm has been developed to improve seam pucker and sewability [2].

3.1 Design of fuzzy patterns for FS

A model for objective evaluation of seam pucker according to the AATCC grades was constructed by using fuzzy logic. Inputs are five shape parameters of pucker seam: Start Wave Amplitude - SWA; End Wave Amplitude - EWA; Start Wavelength - SWL; End Wavelength - EWL; No. of Random Wave Generating Points - NRP. System's output is objective AATCC grade (OSS – Objective Seam Smoothness). Relationship between dependent variable (OSS) and independent variables (five shape parameters) is determined based on training data, so that errors are minimum. Designed fuzzy system is expressed as $[v_1,..., v_5, r]$. Where, v_i, $i = 1,\dots 5$ are inputs, r is output. Trial database:

$$DataBase = \{[V_1^k,....,V_5^k; R^k]\}, k = 1,..,M$$

Where, $V_i^k, i = 1,..,5;\quad R^k, k = 1,..,M$, are the values of inputs and output in the k^{th} pattern. M is number of patterns in database. Value of output is generated by Q relation in the k^{th} pattern: $\hat{R}^k = Q(V_1^k,...,V_5^k)$

Where $[V_1^k,...,V_5^k]$ is the vector of input variables, are SWA, EWA, SWL, EWL and NRP in the k^{th} pattern. The total error of the FS is obtained from the sum of all the error of patterns: $e = \sum_{k=1}^{M} E(R^k - \hat{R}^k)$

$E(R^k - \hat{R}^k)$ is the error of the k^{th} pattern. We adjusted Q for $e \to 0$.

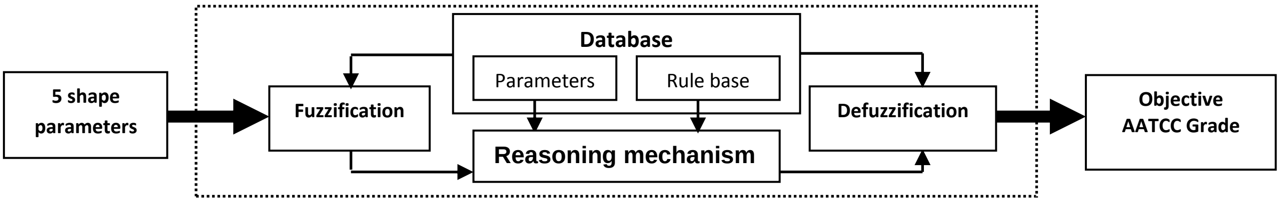


Fig. 2 Structure of fuzzy System for Seam Pucker Evaluation

3.2 Fuzzification and database construction

Definition of fuzzy variables

A fuzzy variable is determined from a **crisp** variable of system (Here, "crisp" is used to describe values or functions that are not "fuzzy"). Crisp variable state vector correlates as a fuzzy variable state vector of model:

Real System $[I_1,I_2,I_3,I_4,I_5;O]$ $\Leftrightarrow$ Fuzzy System [SWA,EWA,SWL,EWL,NRP,OSS]

Fuzzy state vector [SWA, EWA, SWL, EWL, NRP, OSS] is described by vector $[X_1, X_2, X_3, X_4, X_5, X_6]$, every component of fuzzy variable X_i, $i = 1\dots 6$ is determined by parameters:

$X_i = \{x, U, T(x), M(x)\}$

Where x is defined from parameters SWA, NRP, EWA, SWL, EWL, OSS; Universe of discourse $U \equiv [U_L, U_U]$ is defined from real values of crisp variables (I_i i=1,..,5 or O) ; set T(x) is defined from 5 linguistic values [Very_Low, Low, Medium, High, Very_High] ; Membership functions M(x) enable to map the crisp variable in U onto value in T(x) (linguistic values set).

In Fig. 3, five membership functions of a fuzzy variable are defined as triangular and trapezoidal functions, and are also named as five intuitive linguistic values: Very_Low, Low, Medium, High, Very_High; a_i (i = 1, 2,...,6) are constant, which determine the five membership functions for fuzzification of the five shape parameters. These values have been obtained by considering experimental database.

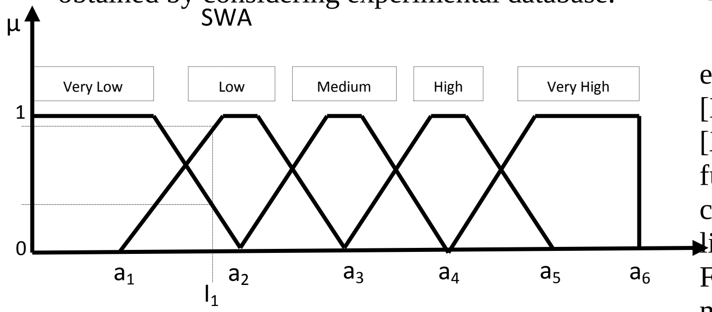


Fig. 3 Fuzzification of $I_1$by membership functions of SWA

Parameterization of linguistic values

Linguistic value set T = [Very_High, High, Medium, Low, Very_Low] is using for expressing a fuzzy variable. The linguistic value is the fuzzy variable X_i, i=1…6, is determined by: $T_i^j = (t, S, p)_i^j$

Where *t* is the name of linguistic value ; S ≡ [S_L, S_U], S $\subseteq$ U. S is a support subset. Crisp value correlates as fuzzy variable and value of membership function $T_i^j(x)$ > 0; set P is defined from parameters of membership functions $\mu_i^j(w)$ of linguistic value, c is defined from crisp value on Universe of discourse U. Membership function is defined from parameters as following:

$$\mu_s^i(w) = \begin{cases} 0, & w \notin S \\ \frac{1}{2}\left(\frac{w - S_L}{a - S_L}\right)^e, & w \in [S_L, a] \\ 1 - \frac{1}{2}\left(\frac{b - w}{b - a}\right)^e, & w \in [a, b] \\ 1, & w \in [b, c] \\ 1 - \frac{1}{2}\left(\frac{w - c}{d - c}\right)^e, & w \in [c, d] \\ \frac{1}{2}\left(\frac{S_U - w}{S_U - d}\right)^e, & w \in [d, S_U] \end{cases}$$

Table 1. Initial parameters of model for SWA variable

	S_L	S_U	a	b	c	d	e
Very_High	2,8	4,2	3,325	3,325	4,2	4,2	1
High	2,1	3,5	2,275	2,625	2,975	3,325	1
Medium	1,4	2,8	1,575	1,925	2,275	2,625	1
Low	0,7	2,1	0,875	1,225	1,575	1,925	1
Very_Low	0	1,4	0,7	0,7	0,875	1, 225	1

Construction of fuzzy rule base

A fuzzy rule base is constructed from experimental data. The *k*th pattern of data base $[I_1,I_2,I_3,I_4,I_5,O]_k$ correlates as state fuzzy vector $[X_1,X_2,X_3,X_4,X_5,X_6]$. The membership degree of fuzzy variable Xi is obtained from the conjunction of all the membership function of linguistic values of crisp variables I_i or O. Fuzzy sets represent linguistic values, which may intersect, and crisp value I_i could tans to one more linguistic value.

$$M_i(I_i) = \{ \mu_i^j(I_i) \neq 0, j \in [1,5] \}$$

We obtained membership degree of input variable and the fuzzy output variable of system in a pattern:

$M_1(I_1) = \{ \mu_1^j(I_1) \neq 0, j \in [1,5] \}$;

$M_2(I_2) = \{ \mu_2^j(I_2) \neq 0, j \in [1,5] \}$

$M_3(I_3) = \{ \mu_3^j(I_3) \neq 0, j \in [1,5] \}$;

$M_4(I_4) = \{ \mu_4^j(I_4) \neq 0, j \in [1,5] \}$

$M_5(I_5) = \{ \mu_5^j(I_5) \neq 0, j \in [1,5] \}$;

$M_6(O) = \{ \mu_O^j(0) \neq 0, j \in [1,5] \}$

Real system: IF ($i_1 = I_1$) AND ($i_2 = I_2$) AND ($i_3 = I_3$) AND ($i_4 = I_4$) AND ($i_5 = I_5$) THEN (o=O).

Fuzzy system: IF (X_1 is T_1^j) AND (X_2 is T_2^j) AND (X_3 is T_3^j) AND (X_4 is T_4^j) AND (X_5 is T_5^j) THEN (O is T_O^j)

A pattern of database can generates linguistic rules because a crisp value can appertains one more linguistic value. We assign a weight w_u^k to a fuzzy rule *u*, which is generated from the *k*th pattern. w_u^k is minimum membership degree of crisp values in this fuzzy rule.

Learning pattern $[I_1,I_2,I_3,I_4,I_5,O]$, after the fuzzification, then:

$M_{SWA}(I_1)$ = {Very_Low, Low};

$M_{EWA}(I_2)$ = {Low, Medium};

$M_{SWL}(I_3)$ = {Very_Low};

$M_{EWL}(I_4)$ = {Very_High};

$M_{NRP}(I_5)$ = { Very_Low};

$M_{SS}(O)$ = {Very_High, High};

While, 8 fuzzy rules are obtained with weights from pattern $[I_1,I_2,I_3,I_4,I_5,O]$. A learning pattern generated a fuzzy rule set. However, fuzzy rules, which are generated from different patterns can coincide because linguistic values of variables in system are a intersection. After subsets are generated from patterns in database, we need conjunct these rule subsets for a rule only appearance one time in rule-base. Weight of a rule in rule base is determined by sum of weights of that rule, which correlates patterns in database (pattern have not generated rule then weight is zero), divided by sum of number of the appearance of this rule in the process of generating fuzzy rules in database.

3.3 Construction of inference mechanism

A crisp input values vector $[I_1, I_2, I_3, I_4, I_5]$, it is obtained a fuzzy set by inference process, is defined by a membership function. This set is defuzzified and a crisp value in output of system is determined. We suppose that, rule base is:

$$\text{RuleBase} = \bigcup_j (IF \bigcap_i A_{ij} \text{ THEN } B_j, w_j),$$

where i =1,…,5, j = 1,…,C

A_{ij} is fuzzy set, which represents linguistic value in component premise. It correlates fuzzy variable X_i in j^{th} fuzzy rule, B_j is fuzzy set, which represents linguistic value of conclusion part correlates output fuzzy variable X_6 of j^{th} rule, w_j is weight of j^{th} rule, C is number of rules in rule-base.

Example: A rule in rule base:

IF (SWA is High) AND (EWA is Low) AND (SWL is Medium) AND (EWL is Medium) AND (NRP is low) THEN (OSS is Very_High), $w_j = 0.6$

After rule-base construction, a crisp input vector $[I_1,I_2,I_3,I_4,I_5]$ correlates an output of inference process. Membership function of output's fuzzy set is determined by:

$$\mu_{RB}([I_1,I_2,I_3,I_4,I_5];O)=\bigcup_j [(\mu_{A1j}(I_1)\wedge\mu_{A2j}(I_2)\wedge\mu_{A3j}(I_3)\wedge\mu_{A4j}(I_4)\wedge\mu_{A5j}(I_5)) \Rightarrow \mu_{A6j}(O)].w_j$$

where j = 1…C

A membership degree to linguistic value is determined with a crisp value of input. Truth value of all of rule's suppositions is determined by fuzzy truth values of component premises. Fuzzy subset of conclusion is generated from Truth values of all of premises by using fuzzy implication, which are *Min* or *Product* operator.

A fuzzy subset is obtained when we apply a rule with crisp variable vector $[I_1,I_2,I_3,I_4,I_5]$. All of fuzzy subsets of rules are associated by fuzzy disjunction. We obtain the only fuzzy subset. Crisp value of output is obtained by the defuzzification from this set.

3.4 Defuzzification

Weighted Sections Method is applied on evaluation of seam pucker for construction of defuzzification module [5]. A linguistic value represents fuzzy variable of output, abscissa r_S^h of center point in maximum space of general membership function $\tilde{\mu}_{n+1}^h(r)$ times a weight w^h is ordinate of center point or maximum value of $\tilde{\mu}_{n+1}^h(r)$. Thence, crisp value represents fuzzy set, which is determined by:

$$\bar{r} = \frac{\sum_{h=1}^{H_{n+1}} w^h.r_S^h}{\sum_{h=1}^{H_{n+1}} w^h}, \quad \bar{r} = \frac{w_A.r_{S_A} + w_B.r_{S_B}}{w_A + w_B}$$

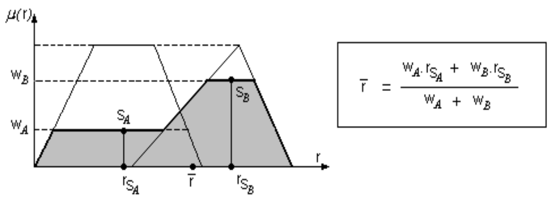


Fig.4 Defuzzification by WSM

3.5 Model Optimism

Action of fuzzy model depend on parameters, which express fuzzy variables and fuzzy operator. Designed fuzzy model includes five independent fuzzy variables (SWA, EWA, SWL, EWL, NRP) and a dependent fuzzy variable (OSS). A fuzzy variable X_i (i=1…6) is expressed by 5 linguistic values {Very_High, High, Medium, Low, Very_Low}. These linguistic values are represented by membership functions, are constructed by seven parameters {S_L, S_U, a, b, c, d, e}. This much, we need N = 6*5*7 = 210 parameters. Action of designed fuzzy model also depends γ in formulas of fuzzy *conjunction* and *disjunction* operators:

$$\mu_{A\cap B} = \mu_A \wedge \mu_B = \gamma \min(\mu_A, \mu_B) + \frac{1-\gamma}{2}(\mu_A + \mu_B);$$

$$\mu_{A\cup B} = \mu \ \vee \mu_B = \gamma \max(\mu_A, \mu_B) + \frac{1-\gamma}{2}(\mu_A + \mu_B);$$

Therefore, we need to find out optimal values of 211 parameters of model for minimum error. Fuzzy error function is determined by [5]:

$$E = \sqrt{\frac{1}{M}\sum_{k=1}^{M}\left(\frac{R^k - \hat{R}^k}{R^k}\right)^2}$$

Where, M is number of pattern in database, R^k is output k^{th} learning pattern, $\hat{R}^k$ is obtained crisp value, while input is crisp value $[V_1^k,...,V_5^k]$.

To do this, Random-search algorithm is applied on determination of raw data of 210 parameters. Hooke-Jeeves algorithm is applied on determination of optimal parameters. Yellow sections algorithm is applied on determination of optimal γ. Conditions of Random-search algorithm are $U_L \le S_L \le a \le b \le c \le d \le S_U \le U_U$. Algorithm is finished while rate of between present comparative error and initial error smaller ℵ, and number of epoch exceeds maximal. Parameters of Hooke-Jeevese algorithm include target function, initial judge point, number of variables, initial step length, the end step length, number of maximal epoch are inserted by user. Algorithm is finished while h < epsilon or k > k_{max}.

IV. RESULTS AND DISCUSSION

Designed program includes main form of menu system, display information TAB and user could interact by functional buttons. The user could interact with database by *Database TAB*, and controls model's parameters by *Parameters TAB*. *Rule Base TAB* enables the user to lay rule-base and error of model on the screen by DataGridView. *Generating Rule Base* in Tab Rule Base enables to generate fuzzy rule-base based of database and parameters of model. *Evaluation TAB* enables to evaluate seam pucker by two methods: to input data from a text file by open function or to input data in text box from user. When the user chosen *Evaluation* function, the program is going to display pucker grade in a Message Box**.** Optimization parameters in Menu *Option* enables to modify parameters of random-search, Hooke-Jeeves algorithms and fuzzy operator γ. Results of optimal process and the error are displayed in Message Box. The trained FS have the knowledge to determine the seam pucker grade. Designed system includes complete functions. The user can modify database and initial information of model. These interfaces enable to train, system optimization and objective evaluation of seam pucker according to simple, fast and user-friendly method.

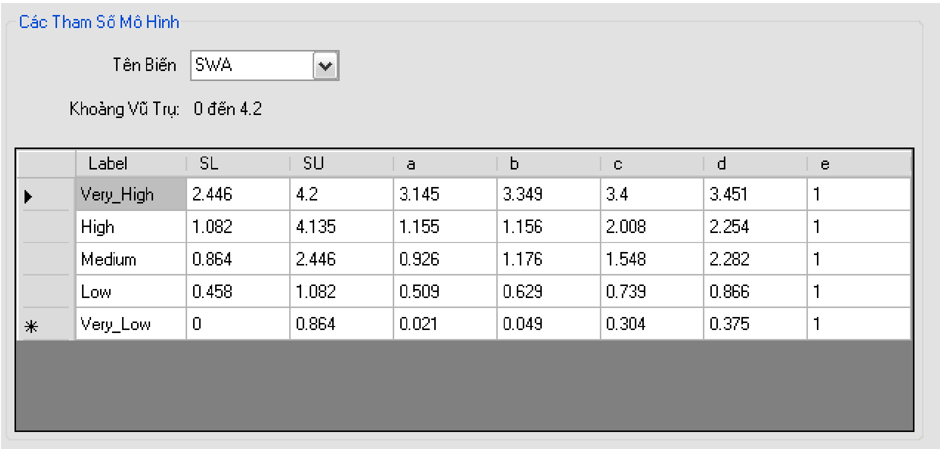
In all, we selected 20 sewn samples as standards and evaluated them with our system. It is obtained 428 rules, error of this model is 18.889% based on database and initial parameters. This data is saved in Box Error Info. The database are shown in Table 2. Optimal parameters are shown in Table 3. Outputs are compared to the pucker grades of target patterns. An objective evaluation method using input pattern was good. Average error of tested samples is 0.1024.

After optimization by using Random Search and Hooke-Jeeves algorithms, the error is 4.368%, decreased by more than 4 times in comparison with an initial model. Number of generated rules is 435 (Fig. 5).

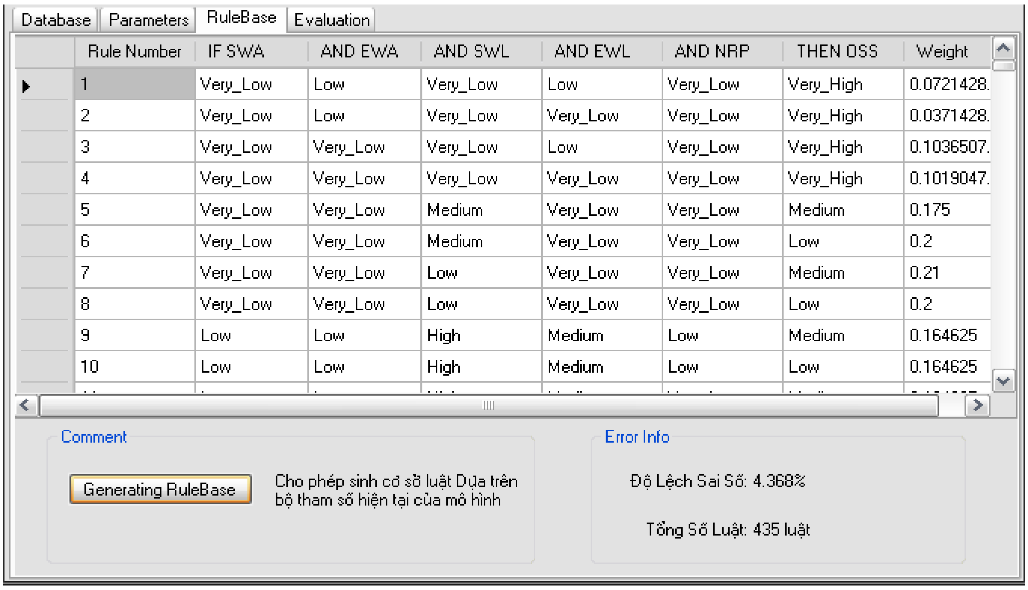
Table 2. Data base with 20 learning patterns

Samp.	SWA (mm)	EWA (mm)	SWL (mm)	EWL (mm)	NRP	AATCC grade	Samp.	SWA (mm)	EWA (mm)	SWL (mm)	EWL (mm)	NRP	AATCC grade
1	2.376	2.332	29.897	36.719	13	1	11	0.594	1.610	25.298	94.495	7	4
2	2.290	3.134	26.659	41.674	14	1	12	0.695	1.131	29.375	56.212	4	4
3	2.049	2.831	20.838	49.897	7	1	13	0.482	1.629	23.774	12.243	4	4
4	1.393	2.012	25.465	39.218	18	1.7	14	0.179	1.588	18.867	8.571	1	4.5
5	0.294	0.804	19.199	8.745	2	2.4	15	1.914	0.248	15.371	8.753	2	4.5
6	1.394	1.98	25.251	33.317	5	2.4	16	0.912	0.488	41.749	28.141	2	4.5
7	0.909	0.283	40.453	12.458	3	2.4	17	0.052	1.023	7.701	27.780	1	5
8	1.049	1.124	20.359	14.86	6	2.7	18	0.150	1.216	9.156	42.251	2	5
9	1.206	0.280	28.835	14.526	3	2.7	19	0.635	0.189	46.333	11.485	6	5
10	2.207	1.080	26.650	67.083	4	2.7	20	0.359	0.380	6.951	19.024	1	5

Table 3. Optimal parameters of SWA



Label	SL	SU	a	b	c	d	e
Very_High	2.446	4.2	3.145	3.349	3.4	3.451	1
High	1.082	4.135	1.155	1.156	2.008	2.254	1
Medium	0.864	2.446	0.926	1.176	1.548	2.282	1
Low	0.458	1.082	0.509	0.629	0.739	0.866	1
Very_Low	0	0.864	0.021	0.049	0.304	0.375	1



Rule Number	IF SWA	AND EWA	AND SWL	AND EWL	AND NRP	THEN OSS	Weight
1	Very_Low	Low	Very_Low	Low	Very_Low	Very_High	0.0721428
2	Very_Low	Low	Very_Low	Very_Low	Very_Low	Very_High	0.0371428
3	Very_Low	Very_Low	Very_Low	Low	Very_Low	Very_High	0.1036507
4	Very_Low	Very_Low	Very_Low	Very_Low	Very_Low	Very_High	0.1019047
5	Very_Low	Very_Low	Medium	Very_Low	Very_Low	Medium	0.175
6	Very_Low	Very_Low	Medium	Very_Low	Very_Low	Low	0.2
7	Very_Low	Very_Low	Low	Very_Low	Very_Low	Medium	0.21
8	Very_Low	Very_Low	Low	Very_Low	Very_Low	Low	0.2
9	Low	Low	High	Medium	Low	Medium	0.164625
10	Low	Low	High	Medium	Low	Low	0.164625

Fig.5 Generated rule base after optimization.

With the same data base and initial parameters, obtained optimal parameters are different, because we used random generated algorithm, generated rule bases in optimal processes are different.

Table 4. Testing results

Samp.	AATCC grade	Evaluated grade by FS	Samp.	AATCC grade	Evaluated grade by FS
1	1.20	1.1919	10	2.96	2.4534
2	1.55	1.9191	11	2.94	2.4512
3	1.43	1.1919	12	4.11	3.9880
4	1.45	1.9191	13	4.22	4.0236
5	2.00	1.9493	14	4.21	4.5188
6	1.90	2.2495	15	4.54	4.3190
7	2.37	1.9191	16	4.95	4.9340
8	2.68	2.2730	16	4.92	4.8790
9	2.88	2.4500	18	4.93	4.7420

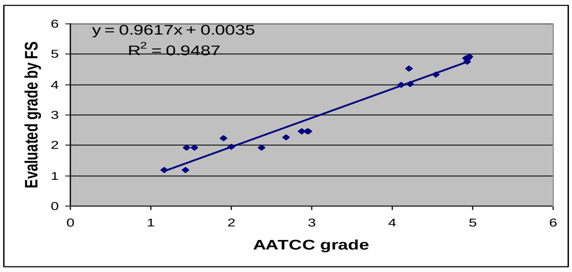


Fig.6 Relationship between AATCC and evaluated grades by FS

We tested 18 puckered samples sewn. Which also were evaluated subjectively by three human experts and objectively by the developed system for comparing the seam pucker grades. The results are shown in Table 4. The correlation coefficient is about 0.9487 (Fig. 6). Average error of tested samples is 0.2343. Statistical hypothesis is tested by *Median* and *Kruskal-Wallis's tests* at the 95% level of significance. The method showed good correlation with subjective evaluation. Designed seam pucker evaluation system assures all requests about calculated speed, function with accept error, friendly interface and user-friendly.

V. CONCLUSIONS

The fuzzy system was constructed for an objective evaluation of seam pucker. Using this system, we could obtain the three-dimensional images, the five shape parameters as well as the objective AATCC pucker grade of samples. This means that the qualitative and subjective evaluation method of seam pucker can be substituted with a quantitative and objective one. Relationship between five shape parameters and objective pucker grade is determined in designed model. Good correlation between subjective and objective evaluations on 18 trial samples of seam pucker using fuzzy system was obtained. This system is using to investigate the effect of fabric properties on seam pucker.

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Contact: Nguyen Thi Le - Tel : (+84)989.731.705, E-mail: ntle-tex@mail.hut.edu.vn
Faculty of Textile, Garment Technology and Fashion Design
Hanoi University of Technology - No. 1, Dai Co Viet road, Hanoi, Vietnam