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Textiles — Three-dimensional measuring apparatus for fabric appearance

Textiles — Dispositif de mesure tridimensionnelle pour évaluer l'aspect des étoffes

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 16323 was prepared by Technical Committee ISO/TC 38, *Textiles*, Subcommittee SC 2, *Cleansing, finishing and water resistance tests*.

Introduction

This Technical Report introduces two approaches, one by Japan and one by Korea, to three-dimensional seam pucker measurements. Other systems are emerging in the area but are not yet widely available. The two approaches were presented for consideration as ISO methodology to TC38/SC2/WG4 (Appearance Retention) in Gothenberg, Sweden on August 2nd-3rd, 2001 and will be processed jointly as a technical report to TC38/SC2. As the systems are further developed, resolution of measurements may improve. Contact the manufacturer for the most recent information on system capabilities.

Background

The American Association of Textile Chemists and Colorists (AATCC) provides a standard method of grading seam puckering based on samples rated on a scale of 1-5, where 1 is the most heavily puckered and 5 is the smoothest (Figure 1). The scale for wrinkles in fabric is comparable, although for this the AATCC provides replicas as samples (Figure 2). Typically, both seam and wrinkle grading is performed by human graders, a subjective assessment prone to both inter- and intra-grader variability.

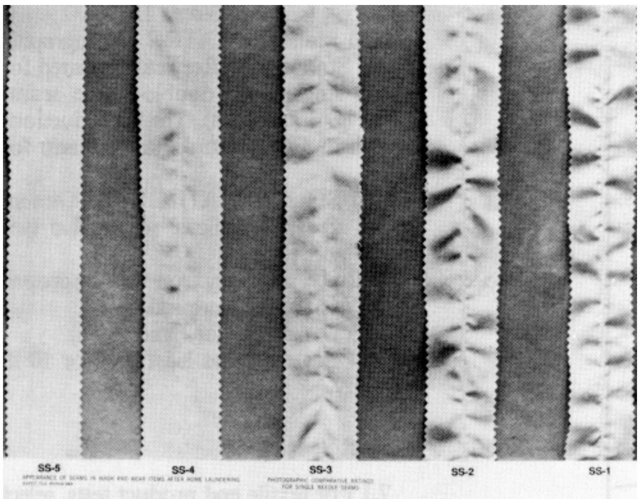


Figure 1 — AATCC sample for single-seam gradings 5 down to 1
(Similar double-seam samples exist)

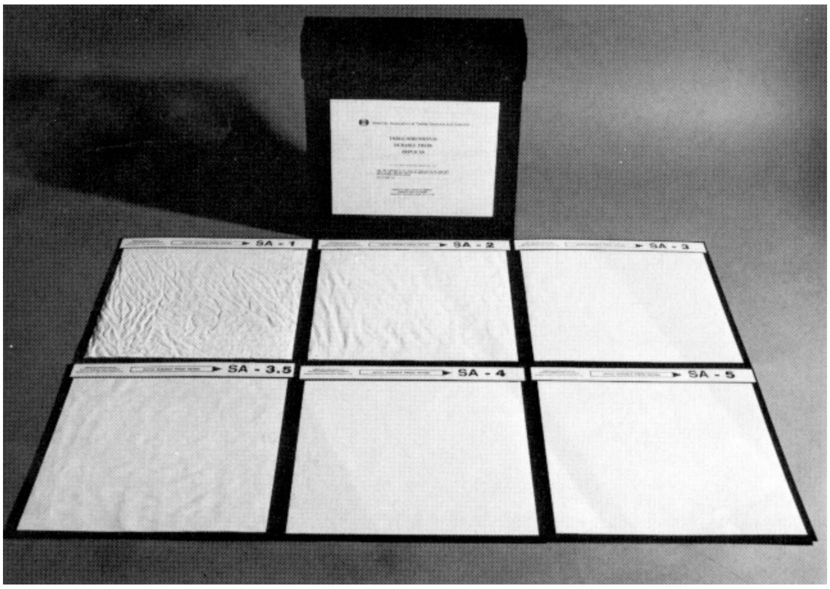


Figure 2 — AATCC wrinkle replicas for gradings (left to right, top to bottom) 1, 2, 3, 3,5, 4 and 5

Comparison

These Japanese (Method 1) and Korean (Method 2) systems are intended to supplement the subjective visual grading of the appearance of seams with a reliable and reproducible instrumental method.

Method 1, detailed in Annex A, is image-analysis-based. Light is projected through a parallel grid (forming a striped pattern) on to a 250 mm × 250 mm area of the seam. The grid pattern appears warped on the surface, forming a topographical map. A CCD camera is then used to capture four images of the striped pattern on the fabric, each from slightly different positions. The images are then analysed in three dimensions. The software compares the analysis to the analysis of the five-grade seam puckering replicas used by human graders and produces a numerical rating for the seam's appearance.

Method 2, detailed in Annex B, uses spot laser sensing or line laser scanning. Once the topographical data are obtained, the software associates each point with a vector of five numbers between 0 and 1. These numbers represent the likelihood that the point could be considered a member of each of five different sets. Each line is sampled at 9 points and the series of vectors for points on a line forms a frequency distribution. These distributions are then input into a classic fuzzy neural network, which produces output patterns corresponding to AATCC pucker grades.

Table 1 — Comparison of the methods

	Method 1	**Method 2**
Software basis	Image processing/analysis	Artificial intelligence (neurofuzzy)
Input/image capture device	External CCD camera, parallel grid, light source, controller, PC Result is a 3-D data set	Spot laser sensing system or laser line scanner (with CCD camera), PC Result is a 3D data set
System output	Rating 1-9, which can be mapped to AATCC pucker grade	AATCC pucker grade
Sample measurement	Sampling distance is 0,5 mm, points in 250 mm × 250 mm image are sampled at approximately 1 mm intervals	Height resolution is 0,05 mm, points in the image area are sampled every 2,5 mm in the width and 1 mm in the length directions

Information on the Japanese system can be obtained from Dr. Ryohei Komatsubara, TechnoArts Laboratory Co. Ltd., 3-10-7 Kotobuku-cho, Fuchu-shi, Tokyo, Japan 1830056 (Tel: +81-42-362-9201; Fax: +81-42-362-9261; ryohei@talab.co.jp)

Information on the Korean system can be obtained from Dr. Chang Kyu Park, Department of Textile Engineering, KONKUK University, 1 Hwa-Yong, Kwang-Jin, Seoul 143-701, Korea. (Tel: +82-2-457-8895; Fax: +82-62-530-1779; cezar@konkuk.ac.kr)

Textiles — Three-dimensional measuring apparatus for fabric appearance

1 Scope

This Technical Report specifies a test method for the objective evaluation of fabric appearance with a three-dimensional measuring apparatus.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 139, *Textiles — Standard atmospheres for conditioning and testing*

ISO 6330, *Textiles — Domestic washing and drying procedures for textile testing*

ISO 7770, *Textiles — Method for assessing the appearance of seams in durable press products after domestic washing and drying*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
seam pucker
ridge, wrinkle or corrugation of the material or a number of small wrinkles running across and into one another, which appear on sewing together two pieces of fabric

4 Principle

4.1 Seamed fabric specimens are subjected to procedures simulating domestic laundering practices. One of the washing and drying procedures specified in ISO 6330 should be used, as agreed between the interested parties.

4.2 The seamed fabric specimens are instrumentally assessed using either Method 1 or Method 2.

4.3 These instrumental evaluation methods may not be suitable for all fabrics. Colours and patterns on fabrics may interfere with the accurate measurement of appearance. For information on whether a fabric is suitable for analysis, contact the manufacturer of the system.

4.4 For a detailed description of the theory behind the measurement apparatus and the assessment in Method 1, see Annex A. For a detailed description of the theory behind the measurement apparatus and the assessment in Method 2, see Annex B.

5 Apparatus

5.1 General

5.1.1 Washing and drying apparatus, as specified in ISO 6330.

5.1.2 Steam or dry iron, with appropriate fabric temperature settings.

5.1.3 Sewing machine, for fabric seaming.

5.2 Method 1

5.2.1 Lighting and evaluation area, as specified in ISO 7770 for measurement (see Figure 4).

5.2.2 Three-dimensional measuring apparatus, for evaluating seam appearance (single and double needle stitching) as shown in Figures 5 and 6. Its general principle and technological background are described in Annex A.

5.3 Method 2

5.3.1 3-dimensional measuring instrument, for fabric seam surface scanning.

5.3.1.1 Non-contact displacement meter, employing a spot laser sensor (or a CCD camera and a laser light source). It is not necessary that this be specified. See Figure 7 for examples. This instrument should have a resolution of the measured heights of 0,005 mm and in total 4 352 measuring points for each sample (17 lines with 2,5 mm intervals and 256 points with 1 mm intervals along each line) see Figure 3.

Dimensions in millimetres

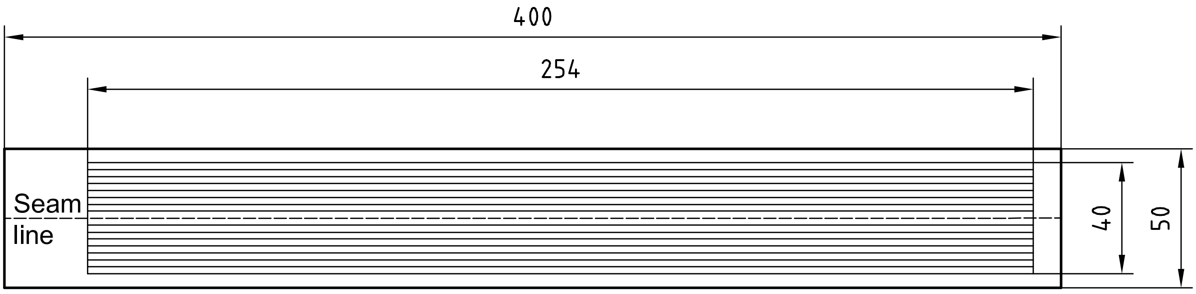


Figure 3 — Measuring area

5.3.1.2 One mounting frame and plate, for specimens (see Figure 8)

5.3.2 Objective five rating software, (see Annex B) capable of

a) calculation of: height data at the measuring points, frequency data between neighbouring measuring points, each average, each maximum and each variance along each measured line;

b) fuzzification of averages, maxima and variances of height and frequency along each measured line;

c) making the input patterns for the six neurofuzzy engines;

d) objectively rating by six neurofuzzy engines through defuzzification;

e) final objective rating from the average of the six rating results;

f) reporting the results;

g) utilities including 3-dimensional image viewing, data filtering, statistics, frequency analysis, etc.

5.3.3 Six artificial neurofuzzy engines, as described in Annex B. Six artificial neurofuzzy engines evaluate seam appearance of test specimens with different-angled points of view. The first, second and third neurofuzzy engines are based on height information of the seam appearance and use average, maximum, and variance of heights along each measured line respectively. The fourth, fifth and sixth neurofuzzy engines are based on frequency information of the seam appearance and use average, maximum and variance of height differences between neighbouring measured points along each measured line, respectively.

5.3.4 Personal computer, for data filtering, calculation, image viewing, fuzzification, neurofuzzy engines, objective evaluating and reporting.

6 Specimen preparation

Prepare three specimens. For Method 1, each sample should measure 38 cm × 38 cm. For Method 2, each sample should measure 50 mm wide by 500 mm long. For both methods, each should be prepared in an identical manner with a seam inserted through the middle. If the fabric is wrinkled, it may be smoothed by appropriate ironing prior to testing. Care should be taken to avoid altering the quality of the seam itself. If excessive fraying is anticipated, specimens shall be stitched loosely 1 cm from the edges, using dimensionally-stable thread.

7 Testing procedure

7.1 Washing and drying procedures

Wash and dry each specimen according to one of the procedures specified in ISO 6330, as agreed upon by the interested parties. If required, repeat the selected washing and drying cycle four times, for a total of five cycles.

7.2 Conditioning

The standard atmosphere for conditioning and testing textiles as defined in ISO 139 shall be used (a temperature of (20 ± 2) °C and a relative humidity of (65 ± 2) % with the exception of tests intended to study the effects of specific temperatures and/or relative humidities on the appearance of the seam.

7.3 Evaluation

7.3.1 Method 1

7.3.1.1 Mount the test specimen on the viewing board as illustrated in Figure 4, with the seam in the vertical direction.

The overhead fluorescent light shall be the only light source for the viewing board, and all other lights in the room shall be turned off. It is recommended that the side walls be painted black or that blackout curtains be mounted on either side of the viewing board to eliminate any reflective interference.

7.3.1.2 Adjust the position of the three-dimensional measuring apparatus so that photo images of an appropriate area (17 cm × 17 cm) of the seam can be taken.

7.3.1.3 Start taking the measurement by projecting a stripe pattern on the surface of the specimen and taking the image in the computer through a CCD camera and recording the rating indicated.

7.3.1.4 Each of the other two test specimens shall be processed in the same manner.

7.3.2 Method 2

7.3.2.1 Mount the specimen on the test plate.

7.3.2.2 Insert the plate with the test specimen into the 3-dimensional measuring instrument.

7.3.2.3 Measure the surface of the test specimen in a darkroom using the 3-dimensional measuring instrument described in 5.3.1

7.3.2.4 Rate the test specimens objectively from 1 (severe pucker) to 5 (light pucker) using the software described in 5.3.2 to 5.3.4.

7.3.2.5 Repeat the procedure for the remainder of the samples

7.4 Expression of results

7.4.1 Method 1

Average the ratings on the set of three specimens. Report the average to the nearest half a rating.

Table 2 — Seam appearance ratings

Class	Seam appearance
5	Equivalent to Standard 5 of 3-dimensional replicas
4.5	In-between appearance of Standard 5 and Standard 4
4	Equivalent to Standard 4 of 3-dimensional replicas
3.5	In-between appearance of Standard 4 and Standard 3
3	Equivalent to Standard 3 of 3-dimensional replicas
2.5	In-between appearance of Standard 3 and Standard 2
2	Equivalent to Standard 2 of 3-dimensional replicas
1.5	In-between appearance of Standard 2 and Standard 1
1	Equivalent to Standard 1 of 3-dimensional replicas

7.4.2 Method 2

Average the 18 evaluations made by the six neurofuzzy engines on the set of three test specimens. Report the defuzzification value and the final rating to the second decimal place.

8 Test report

The test report shall include the following information:

a) reference to the testing method;

b) details of the washing and drying procedures used as specified in ISO 6330;

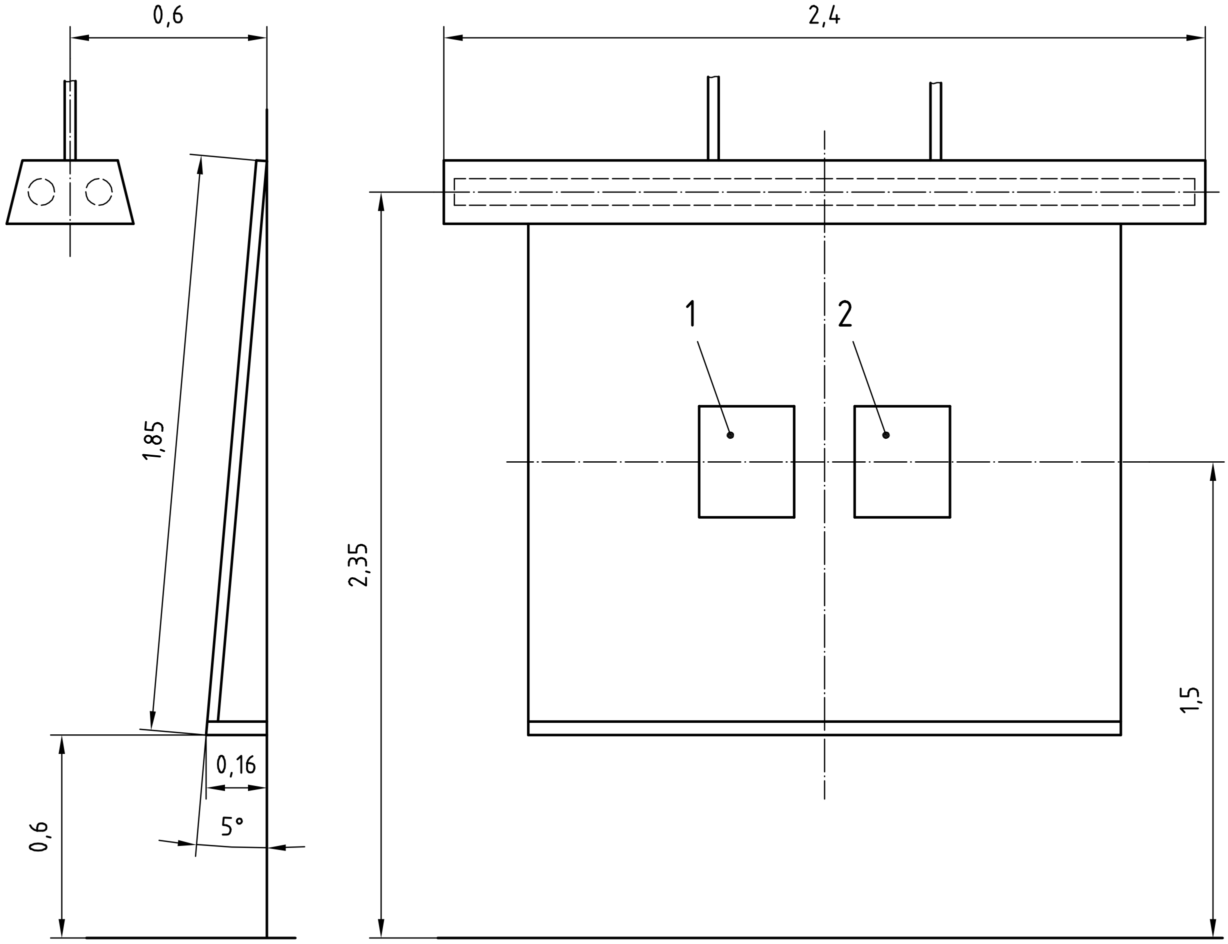
c) number of washing and drying cycles used;

d) sewing conditions (sewing thread used, stitch density, stitch type, needle used, etc.);

e) seam appearance rating as calculated above;

f) details of any deviation from the specified procedure.

Dimensions in metres



Key

1 standard

2 test Specimen

Figure 4 — Lighting equipment for viewing test specimens

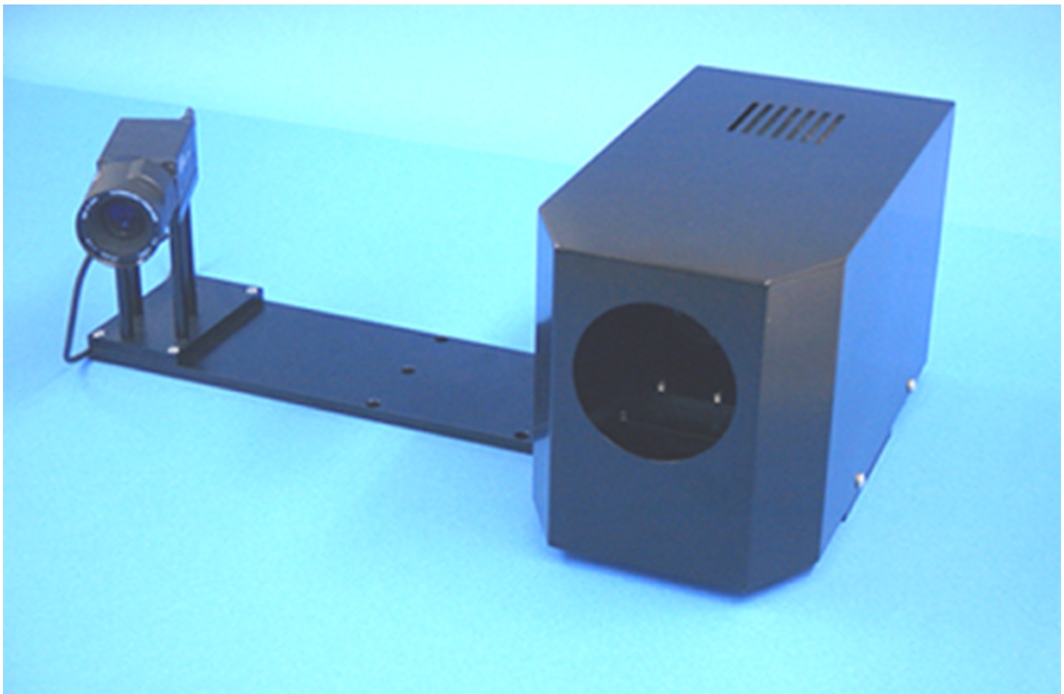
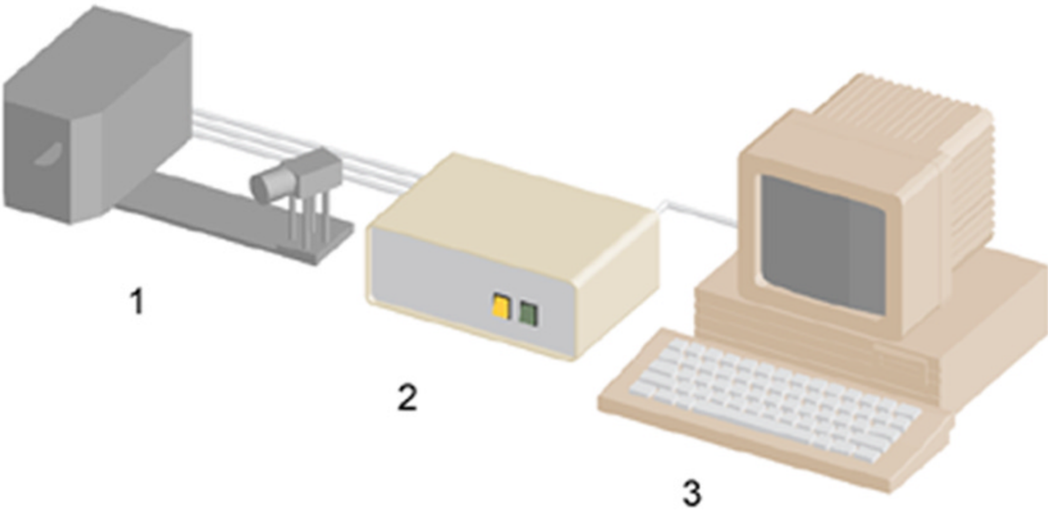


Figure 5 — Three-dimensional measuring apparatus



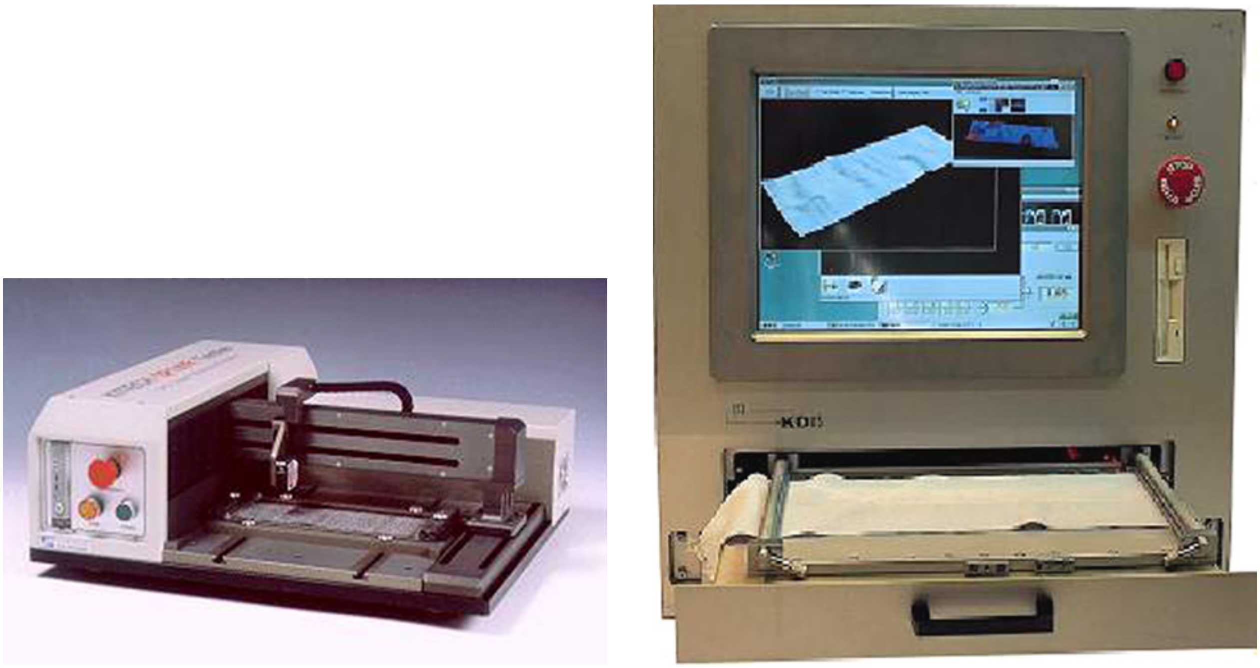
Key

1 sensor

2 controller

3 computer

Figure 6 — A set of measuring apparatus

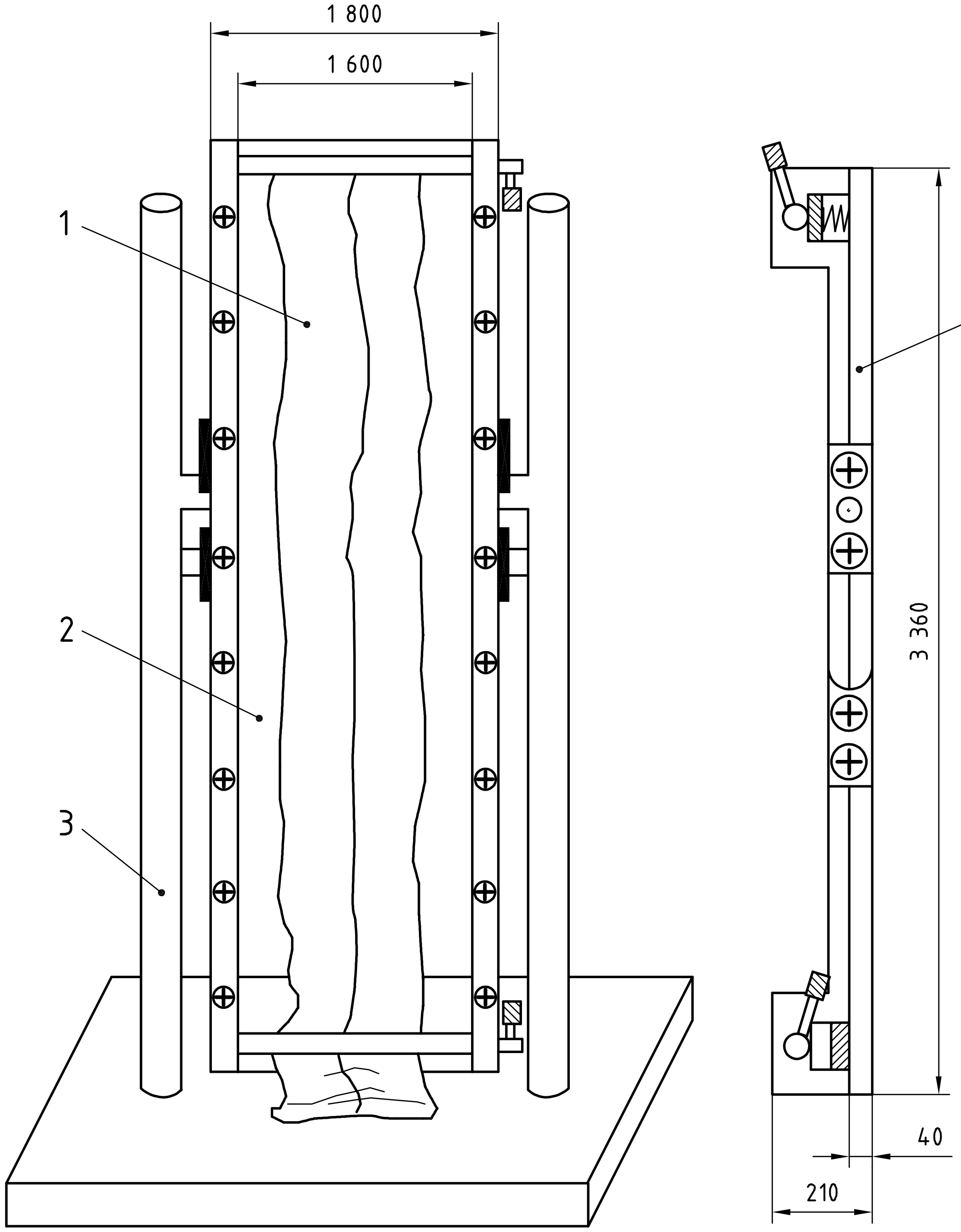


a) Spot laser sensing

b) Laser line scanning

Figure 7 — Two types of laser scanning systems

Dimensions in millimetres



Key

1 specimen
2 plate
3 frame
4 side of plate

Figure 8 — Mounting frame and plate for specimens

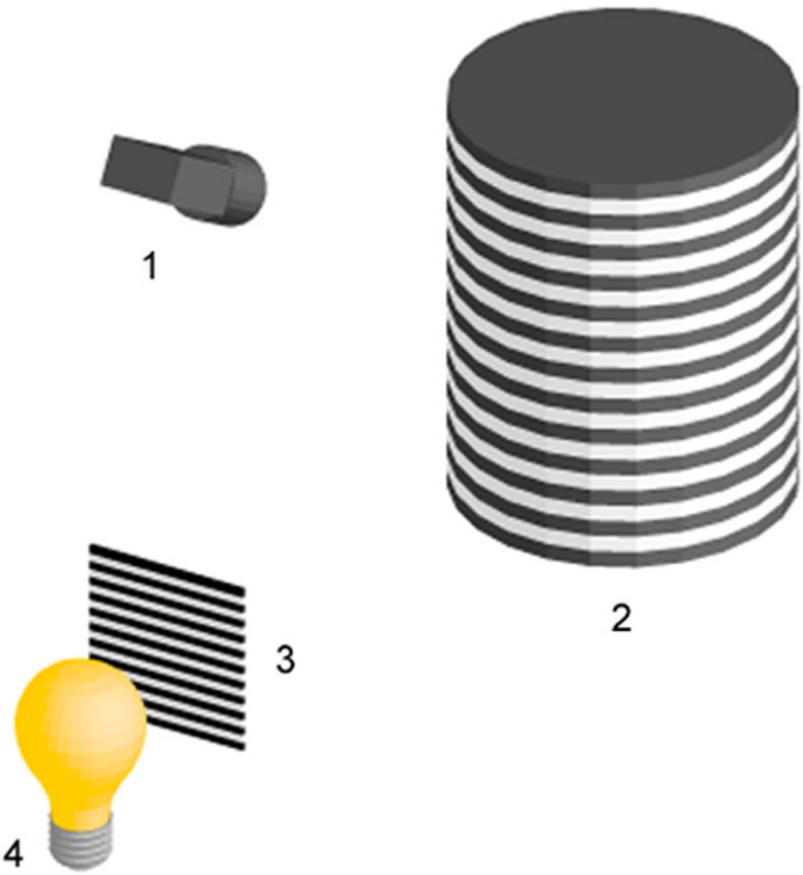
Annex A
(informative)

General principle and technological background of a three-dimensional measuring apparatus for assessing seam appearance — Method 1

A.1 Principle

The principle of seam appearance assessment using a three-dimensional measuring apparatus is based on an image analysis technique. As shown in Figure A.1, a stripe pattern is projected through a parallel grid on to the surface of a specimen by a white halogen light.

Four images (17 cm × 17 cm) of parallel grid on the surface of a specimen at slightly different positions are taken by a CCD camera and input to a computer.



Key

1 CCD camera
2 test specimen
3 stripe pattern
4 light

Figure A.1 — Schematic explanation of three-dimensional measurement

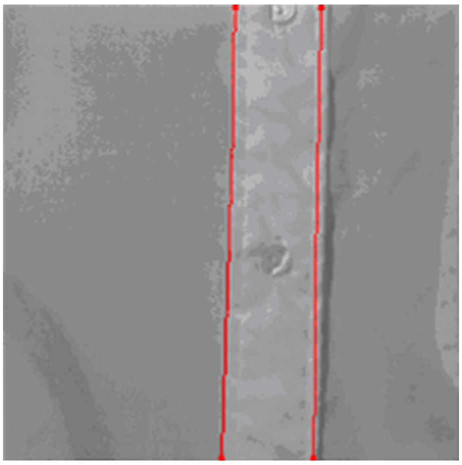
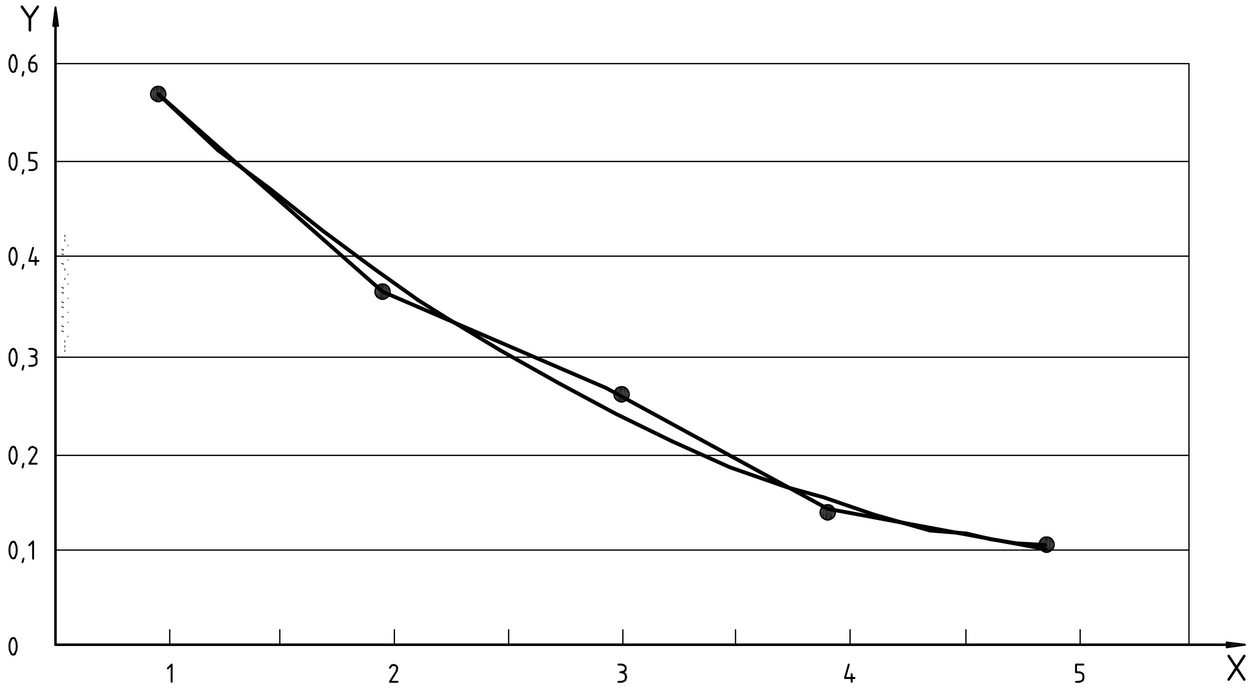


Figure A.2 — Photo image of seam appearance

The information from these four images is compared with that of Standard 3-D replicas, and processed with an applied method of a finite differences algorithm. The assessment results are indicated by a 0,5 unit of rating.



Key

X Rating of single seam appearance

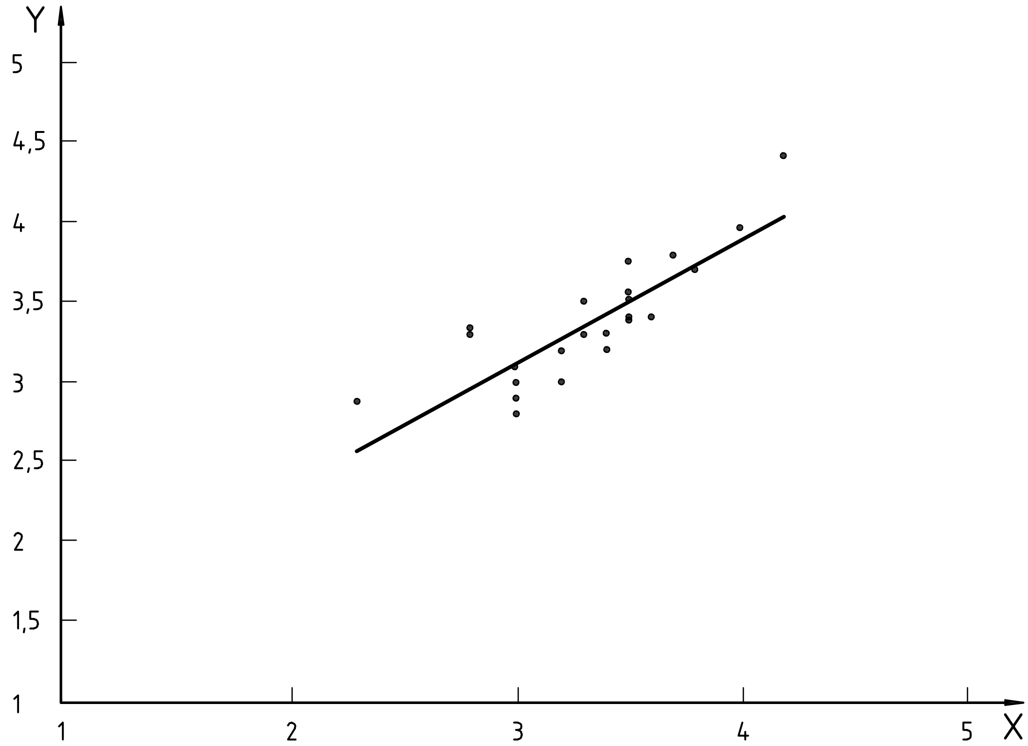
Y Average finite difference (mm)

Figure A.3 — Rating of standard 3-D replica vs seam pucker information of finite difference algorithm

A.2 Verification of the validity of the 3-D measurement

For the purpose of verifying the validity of the 3-D measurement, correlation between the 3-D measurement and visual rating method based on the procedure of 5.1 (1) described in JIS L 1905:1994 (—6.1 a) in the revised version of JIS L 1905:2000 was studied using 10 to 20 specimens of single and double seams in two textile inspection organizations.

The coefficient of correlation in single and double seams is shown in Figures A.4 and A.5 to be 0,840 and 0,948 respectively.

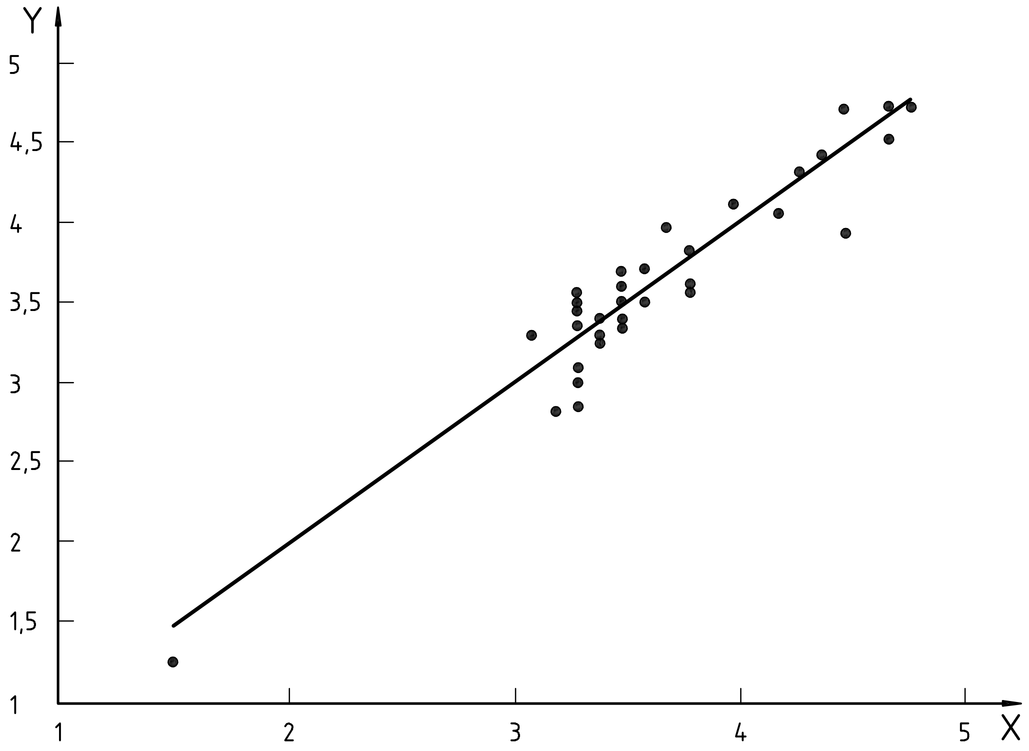


Key

X Visual rating

Y Rating by 3-D measurement

Figure A.4 — Correlation in single seam specimens



Key

X Visual rating

Y Rating by 3-D measurement

Figure A.5 — Correlation in double seam specimens

A.3 Specification of 3-D measuring apparatus

The specification of Japanese 3-D measuring apparatus used in this Technical Report is summarized in Table A1. The apparatus is available from Techno Arts Laboratory Co., Ltd., Fujimori Bldg. 302, 3-10-7, Kotobuki-cho, Fuchu-shi, Tokyo, 183-0056, Japan (TEL: +81-42-362-9201, FAX: +81-42-362-9261, HP: www.talab.co.jp)[1)]

1) Techno Arts Laboratory is the trade name of a supplier. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by ISO of the product mentioned. Equivalent products may be used if they can be shown to lead to the same results.

Table A.1 — Specification of 3-D measuring apparatus

Measuring area	250 mm (horizontal) × 200 mm (vertical)
Distance from the device to the specimen	500 mm
Horizontal and vertical resolution	512 × 480 pixels
Depth resolution	0,25 mm
Horizontal and vertical accuracy	0,5 mm
Depth accuracy	0,5 mm
Interface	PCI bus × 1, serial port × 1
Measuring time	1 s
Input device	1/3 in CCD (B/W)
Light	150 W halogen
Grating	0,5 mm pitch
Size	450 mm wide × 200 mm high × 300 mm deep
Weight	10 kg
Host computer	IBM PC/AT compatible
CPU	Intel Pentium 450 MHz or upper
Memory	128 MB or upper
Hard disk	10 GB or upper
OS	Microsoft Windows 95/98 Microsoft Windows NT 4.0 microsoft Windows 2000
Sampling points	256 (horizontal) × 240 (vertical)
Calculating time	5 s

Annex B
(informative)

General principle and technological background of a three-dimensional system for assessing seam appearance — Method 2

B.1 Artificial neural network

B.1.1 A simple neural network

An artificial neural network (or neuro-computing) is based on the mathematical modelling that simplifies biological neurons and their connections. The structures of biological and artificial neural networks are shown in Figure B.1. The main structure of a typical nerve cell includes dendrites for receiving signals, a single axon for sending signals and the cell body. Synapses connect the axons and the dendrites. The nerve signals are electric impulses that are transmitted across the synapse by means of a chemical process.

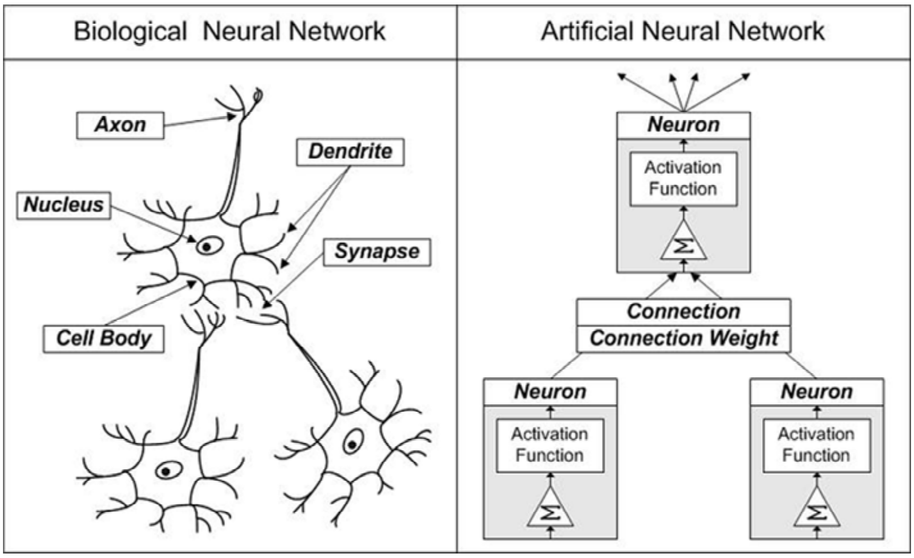


Figure B.1 — The structure of biological and artificial neural networks

In the artificial neural network shown in Figure B.1, the neurons play the roles of the dendrite and the axon. Neurons are connected to each other with directed communication links. A simple neural network is shown in Figure B.2. The input values to a neuron from connected neurons are multiplied by their connection weights. Then, all the input values are linearly summed (a weighted sum). The weighted sum is transformed by the activation function before it is transmitted to other neurons; i.e.,

$$Y_m = \sum_{j=0}^{n-1} X_j \times W_{j,m} \qquad \text{(B.1)}$$

$$X_m = f(Y_m) \qquad \text{(B.2)}$$

where

X_j (j = 0, 1, … , n–1)	is the input from the jth neuron (or the output of the jth neuron);
$W_{j,m}$	is the connection weight between the jth and mth neurons;
Y_m	is the weighted sum of the mth neuron;
X_m	is the output of the mth neuron;
f	is the activation function.

The procedure is called the feedforward action.

The activation function can be a threshold function, a linear function, a sigmoid function or a bipolar function. The sigmoid function is especially suitable for an error back propagation model because it is continuous, monotonically increasing and easily differentiable to save computation time. A typical activation function is the binary sigmoid function (shown in Figure B.2), which is defined in the range of (0, 1,0) as

$$f(x) = \frac{1}{1 + \exp(-x)} \text{ and}$$

$$f'(x) = f(x)[1 - f(x)]$$

A neural network is therefore characterized by the pattern of connections, the weights and the activation function.

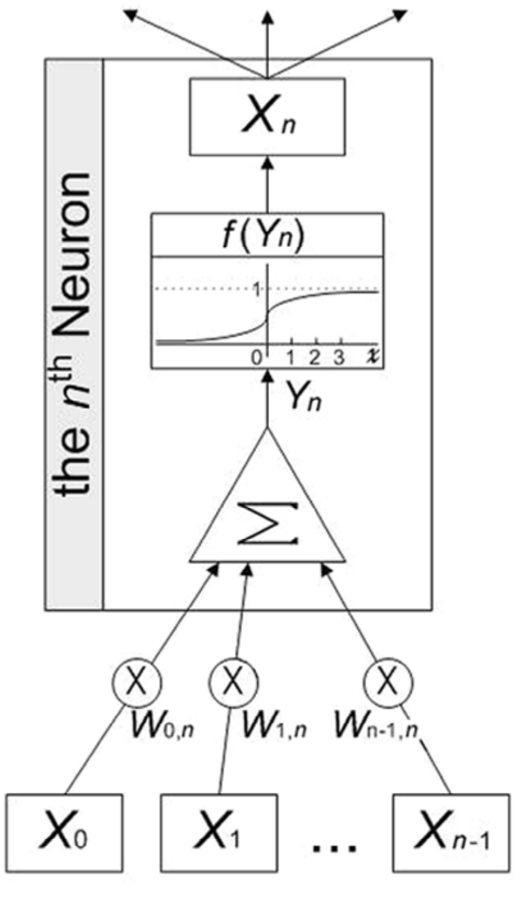


Figure B.2 — Simple neural network

B.1.2 Error backpropagation algorithm

In the artificial neural network, information is distributed throughout the network that has been properly taught through learning processes. Learning is an iterative process to specify the connection weights of a neural network. The error back propagation algorithm (or the generalized delta rule) developed by Rumelhart is one of the most popular learning rules in multi-layer networks (having input, hidden and output layers), based on the following principle: the error of a neuron (the difference between the target and output values) is attributed to all connection weights involved and the connection weights are iteratively corrected according to the size of error. The correction process is back propagated.

Figure B.3 illustrates the error back propagation algorithm. The error in the output layer is obtained from the difference between the target and output values as

$$E_j = T_j - X_j \tag{B.3}$$

where, E_j, T_j, and X_j are the error, target and output values of the jth neuron in the output layer, respectively.

Based on this error, the error factor of the output layer, δ_j, is computed as

$$\delta_j = f'(Y_j) \times E_j \tag{B.4}$$

where

$$f'(Y_j) = \frac{\partial f(Y_j)}{\partial Y_j}$$

$$= X_j \times (1 - X_j)$$

for the binary sigmoid function. The connection weights between the output and the hidden layer are corrected using δ_j, which will be explained later.

The procedure of the error backpropagation algorithm is the reverse of the feedforward action. As shown in Figure B.3, δ_j ($j = m, m+1, ..., p$) are multiplied by their connection weights and are transmitted into neurons in the hidden layer, where they are linearly summed. This summed value becomes the error of the nth neuron in the hidden layer, E_n.

$$E_n = \sum_{j=m}^{p} W_{n,j} \tag{B.5}$$

where, $W_{n,j}$ is the connection weight between the nth neuron in the hidden layer and the jth neuron in the output layer. Then, as was done in Equation (B.4), δ_n of the neurons in the hidden layer are obtained from Y_n and E_n.

$$\delta_n = f'(Y_n) \times E_n$$

Using the error factors obtained, the connection weights are corrected in the following manner

$$W(\text{new})_{i,j} = W(\text{old})_{i,j} + \alpha \times \delta_j \times X_i \quad \text{(B.6)}$$

where, α is the learning rate of the neural network ($0,0 < \alpha \leqslant 1,0$).

Note that the connection weights are corrected iteratively until the total sum of errors in the output layer reaches specified tolerance. The value of learning rate in Equation (B.6) controls the convergence rate. Once properly trained with converged weight values, the neural networks can recognize or classify characteristics of objects.

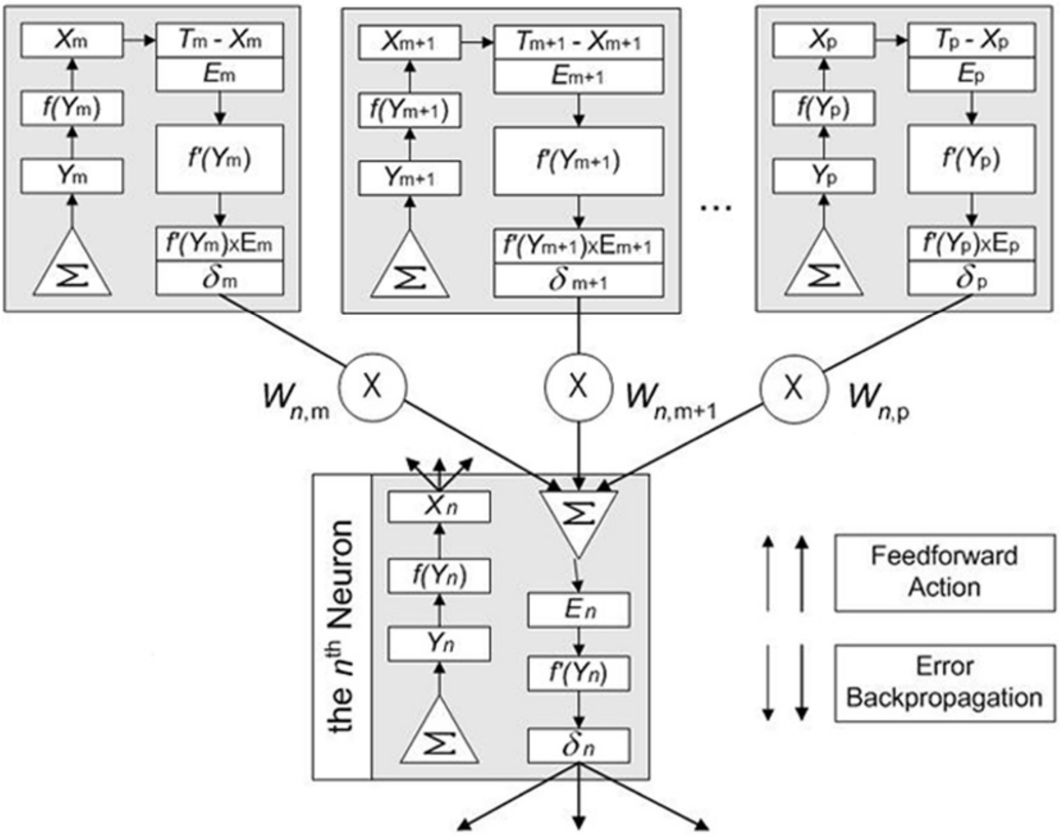


Figure B.3 — Error backpropagation algorithm

B.2 Fuzzy logic

B.2.1 Fuzzy sets and fuzzification

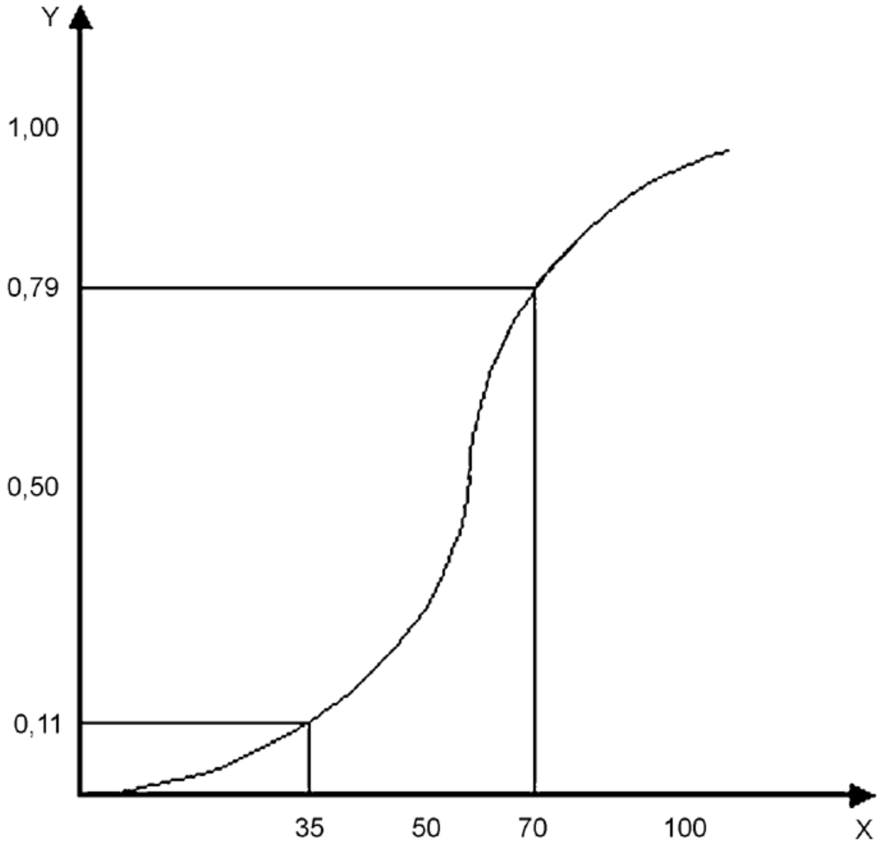
Since first proposed by Zadeh in 1965, the fuzzy logic has been expanded by many researchers and applied to a variety of areas including electronic products, stock markets and medical diagnostics.

An element of a fuzzy set, A, is the pair of a fuzzy variable, x, and a fuzzy number, $\mu_A(x)$. When "age" is the fuzzy variable and "the degree of old" is the fuzzy number as shown in Figure B.4, the fuzzy set is

Fuzzy Set, A $= \{[x, \mu_A(x)] | [x_1, \mu_A(x_1)], [x_2, \mu_A(x_2)], \ldots, [x_n, \mu_A(x_n)]\}$

= {(Age, The degree of old)|(35,0.11), (70,0.79)}

In this example, the degree of being old is quantified from the age using a membership function. The process to construct a fuzzy set is called "fuzzification". There are many types of membership functions and fuzzy numbers. In this study, the triangular and trapezoidal membership functions shown in Figure B.5 were used, which are defined as:



Key

X Fuzzy variable (age)

Y Membership function or fuzzy number (the degree of old)

Figure B.4 — A typical membership function for a fuzzy set

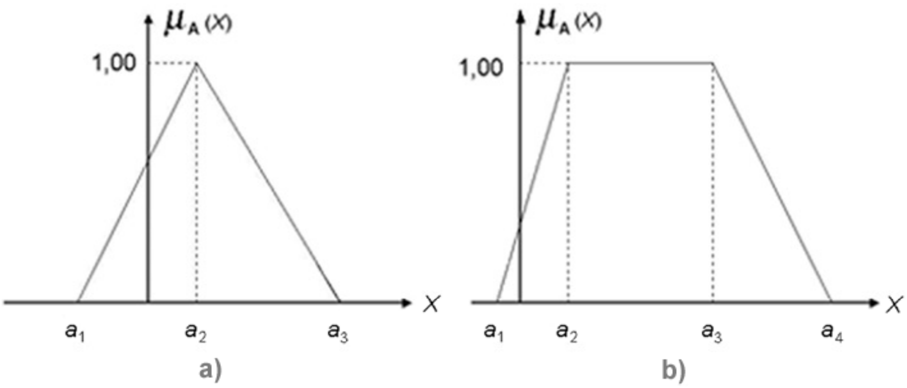


Figure B.5 — a) Triangular and b) Trapezoidal membership functions

a) Triangular membership function

$$
\begin{aligned}
\mu\text{A}(x) &= 0{,}0, & x &< a_1 \\
&= \frac{x - a_1}{a_2 - a_1}, & a_1 &\leqslant x \leqslant a_2 \\
&= \frac{a_3 - x}{a_3 - a_2}, & a_2 &\leqslant x \leqslant a_3 \\
&= 0{,}0, & x &> a_3
\end{aligned}
$$

b) Trapezoidal membership function

$$
\begin{aligned}
\mu\text{A}(x) &= 0{,}0, & x &< a_1 \\
&= \frac{x - a_1}{a_2 - a_1}, & a_1 &\leqslant x \leqslant a_2 \\
&= 1, & a_2 &\leqslant x \leqslant a_3 \\
&= \frac{a_3 - x}{a_3 - a_2}, & a3 &\leqslant x \leqslant a_4 \\
&= 0{,}0, & x &> a_4
\end{aligned}
$$

B.2.2 Defuzzification

Fuzzification includes the process for construction of the fuzzy set and fuzzy relation or matrix. “Defuzzification” is the process of obtaining the defuzzified values from fuzzy values. There are three methods of defuzzification: maximum criterion method, mean of maximum method, and centre of area (or gravity) method. Among them, centre of area (or gravity) method is currently the most frequently used and is shown in Figure B.6.

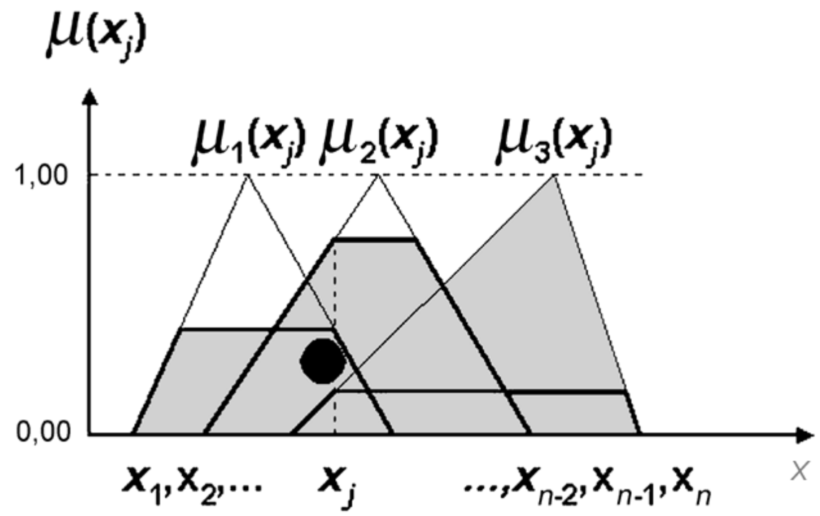


Figure B.6 — Centre of area method for defuzzification

The defuzzified x_0 can be calculated from the following equation expressed as fuzzy variables and fuzzy membership functions:

$$x_0 = \frac{\sum_{j=1}^{n} [x_j \times \mu_j(x_j)]}{\sum_{j=1}^{n} \mu_j(x_j)}$$

where x_j and $\mu_j(x_j)$ are domain values and known fuzzy numbers of the jth membership function, respectively. Hence, the fuzzified values through the various fuzzy operations can be easily transferred to the specific defuzzified values.

B.3 Neurofuzzy engine

B.3.1 Neurofuzzy algorithm

The structure of a neurofuzzy engine is shown in Figure B.7. The fuzzy engine described in Clause B.2 is the pre- or post-processor of the artificial neural network described in Clause B.1. In the pre-processor, fuzzy inputs for the neural network are obtained through the fuzzification process. Fuzzy neurons in the artificial neural network convert the fuzzy inputs into fuzzy outputs. The fuzzy neurons perform tasks using fuzzy values or fuzzy information. The final fuzzy outputs are transformed into numerical values through the defuzzification process.

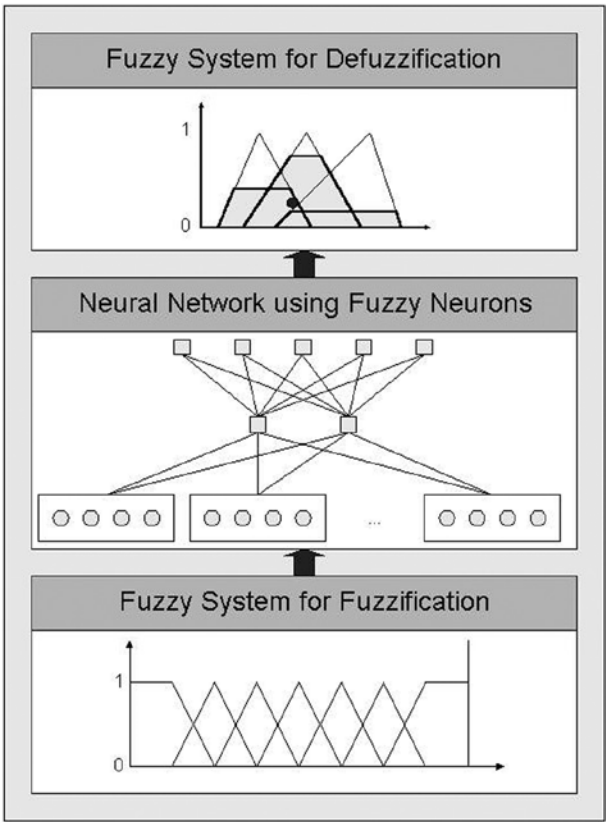


Figure B.7 — The structure of a neurofuzzy engine

The procedure of the new evaluation method is shown in Figure B.8. Using this method, puckered shapes are measured with a 3-dimensional measuring instrument and transformed into fuzzified values of height and frequency distributions. In order to rate seam appearance, the neurofuzzy engines are trained using the error back propagation algorithm described in Clause B.1 with the ISO (or AATCC) reference puckered shapes with ISO (or AATCC) standard grades, which were selected among many samples rated by human experts according to ISO (or AATCC) methods.

In Figure B.8, a real puckered seam is measured as numerical data in the 3-D coordinate system using a measurement system. The measured data are transformed into the fuzzy input patterns for neurofuzzy engines through the fuzzification process. The neurofuzzy engines produce the fuzzy output patterns of the objective ISO (or AATCC) pucker grade.

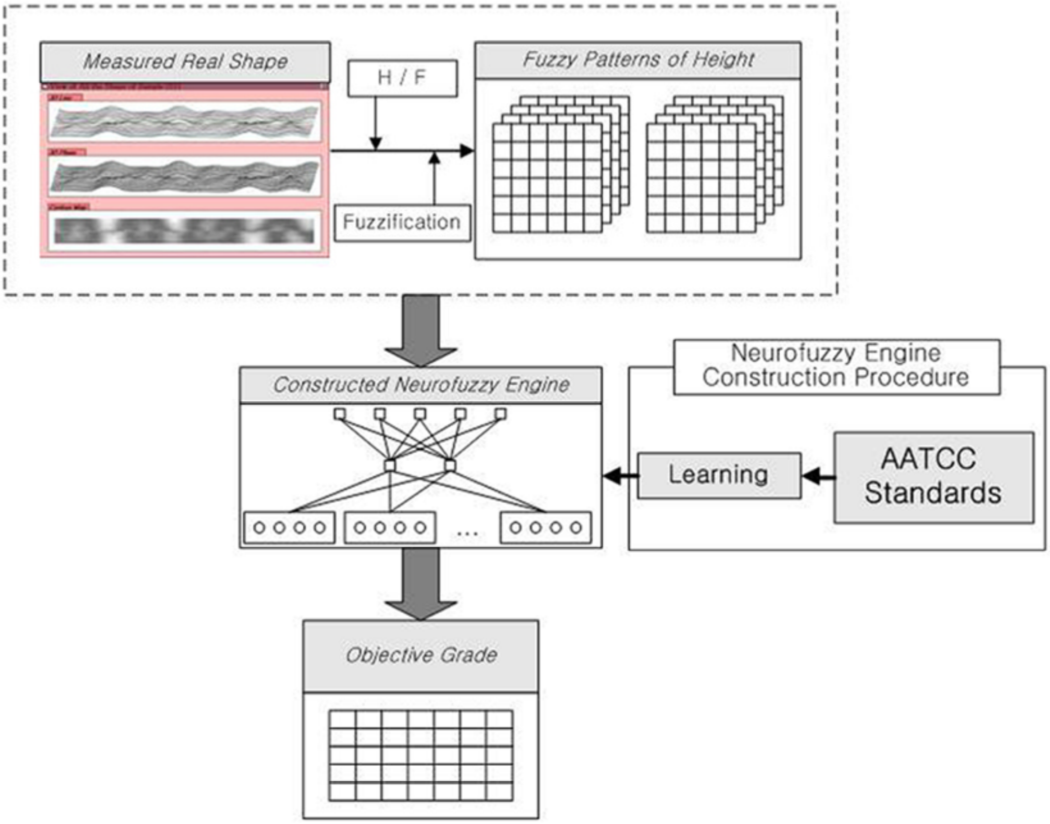


Figure B.8 — The procedure of the new evaluation method

For design of fuzzy patterns for neurofuzzy engines, the definition of fuzzy patterns is shown in Figure B.9. Five membership functions of a fuzzy variable are defined as triangular and trapezoidal functions as described. Also, those five membership functions are named as five intuitive linguistic values: small (S), quite small (QS), zero (ZE), quite large (QL) and large (L). Note that a_i ($i = 1, 2, \ldots, 5$) is a constant which determines the five membership functions.

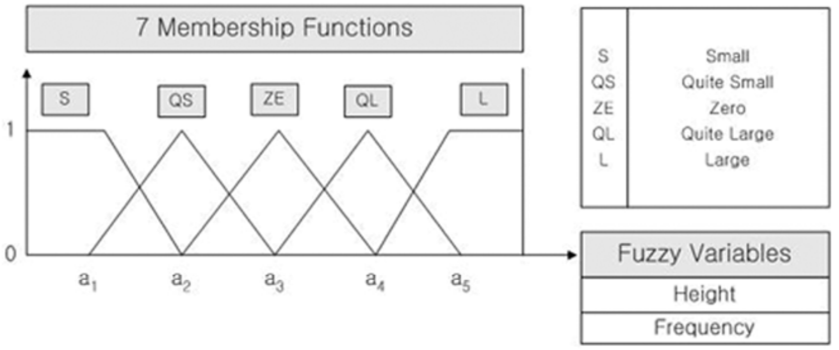
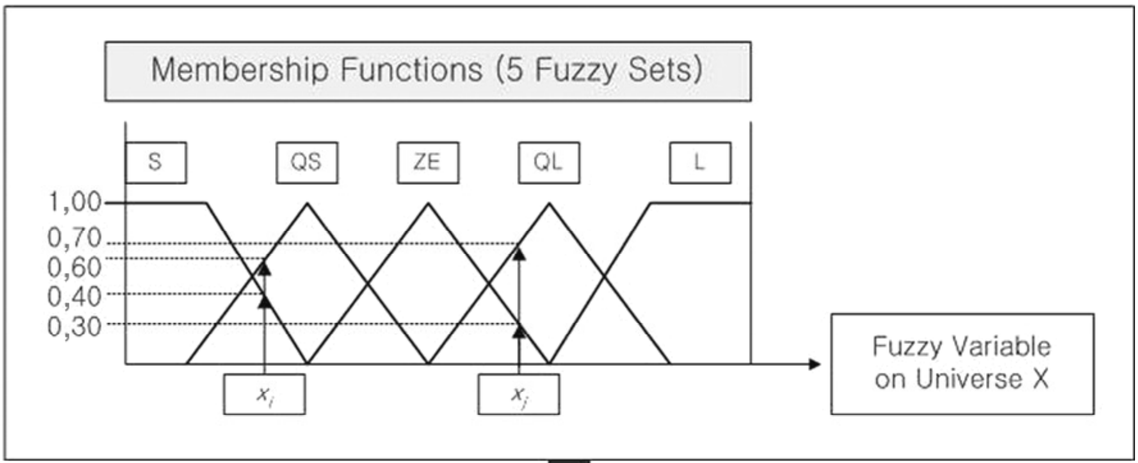


Figure B.9 — Fuzzy sets and membership functions

A general procedure to generate a fuzzy pattern is explained in Figure B.10. Here, five fuzzy sets are defined on universe X utilizing the five names of membership functions: S, QS, ZE, QL and L. For two variables x_i and x_j on the universe, each fuzzy set has elements as shown in the second table of Figure B.10. The fuzzy pattern is obtained from the five fuzzy sets as a 2 × 5 matrix in Figure B.10.



Fuzzy Sets of the Fuzzy Variables on Universe X	
S	{ (x_i,0,60) , (x_j,0,00) }
QS	{ (xi,0,40) , (xj,0,00) }
ZE	{ (xi,0,00) , (xj,0,30) }
QL	{ (xi,0,00) , (xj,0,70) }
L	{ (xi,0,00) , (xj,0,00) }

Fuzzy Pattern of the Fuzzy Variables on Universe X

X	S	QS	ZE	QL	L
x_i	0,60	0,40	0	0	0
x_j	0	0	0,30	0,70	0

Figure B.10 — Generation of a fuzzy pattern

The fuzzification procedure to obtain a fuzzy pattern from crisp[2)] values calculated using a crisp function. Note that one dimension is added to the dimension of the crisp variable in the fuzzification process and the final fuzzy pattern describes the distribution of crisp (or fuzzy) variables.

2) Here, "crisp" is used to describe values or functions, which are not "fuzzy".

B.3.2 Fuzzification of height and frequency distributions

The height and frequency distributions of the measured seam appearance image according to the specific position from the seam line are used for the objective ISO (or AATCC) rating. In view of height distribution, three parameters such as maximum, averages and variances of heights are used. For frequency distribution, three parameters such as the result of FFT (Fast Fourier Transformation) and averages and variances of height differences between neighbouring points measured are also used.

The six constant sets in Figure B.7, a_i ($i = 1, 2, \ldots, 5$), to determine the five membership functions of each parameter are obtained by considering experimental data and the resolution of the laser sensor. The fuzzy pattern of maximum height distributions is shown in Figure B.11.

For example, considering the 20,0 mm position at R1, the fuzzy values of maximum height at the 20,0 mm position are 0,4 of QS and 0,6 of ZE.

Position \ Range		S	QS	ZE	QL	L
at 20,0 mm from Seam Line	R1		0,4	0,6		
at 17,5 mm from Seam Line	R2		0,8	0,2		
at 15,0 mm from Seam Line	R3			0,5	0,5	
at 12,5 mm from Seam Line	R4		0,6	0,4		
at 10,0 mm from Seam Line	R5		0,2	0,8		
at 7,5 mm from Seam Line	R6			0,3	0,7	
at 5,0 mm from Seam Line	R7			0,1	0,9	
at 2,5 mm from Seam Line	R8			0,2	0,8	
Seam Line	R9		0,1	0,9		

Figure B.11 — Fuzzy patterns of nine neurofuzzy engines

B.3.3 Construction of neurofuzzy engines

For neurofuzzy engines, six types of input patterns and one type of target pattern are designed. In the objective ISO (or AATCC) rating system, the 17 sets composed of height measurements are regrouped into 9 sets by combining two sets obtained at the same distance from the seam line into one set. The input pattern is in a matrix form, where the row is the position (or the distance from the seam line) and the column is the fuzzy values of height and frequency distributions, respectively.

The value of its cell show in Figure B.11 is the fuzzy values described in B.3.1 and B.3.2. Each input pattern type is a 9 × 5 matrix as shown in Figure B.11. The target pattern is in a row matrix form with five components. The five target patterns representing the five ISO (or AATCC) standards are shown in Figure B.12.

AATCC Pucker Grade = 1	1	0	0	0	0
AATCC Pucker Grade = 2	0	1	0	0	0
AATCC Pucker Grade = 3	0	0	1	0	0
AATCC Pucker Grade = 4	0	0	0	1	0
AATCC Pucker Grade = 5	0	0	0	0	1

Figure B.12 — Five target patterns of the ISO (or AATCC) standards

The 15 reference samples are used to generate reference input patterns to train neural networks through the training process. The measured data are then transformed into the power spectra using the FFT. The six types of input patterns are obtained from the height and frequency distributions of the measured seam appearance image according to the specific position from the seam line. The 15 input patterns of each type (three input patterns for each pucker grade) can be used in the training processes to construct six neural networks for each type. The structure and configurations of the neural networks are shown in Figure B.13 and Table B.1 respectively.

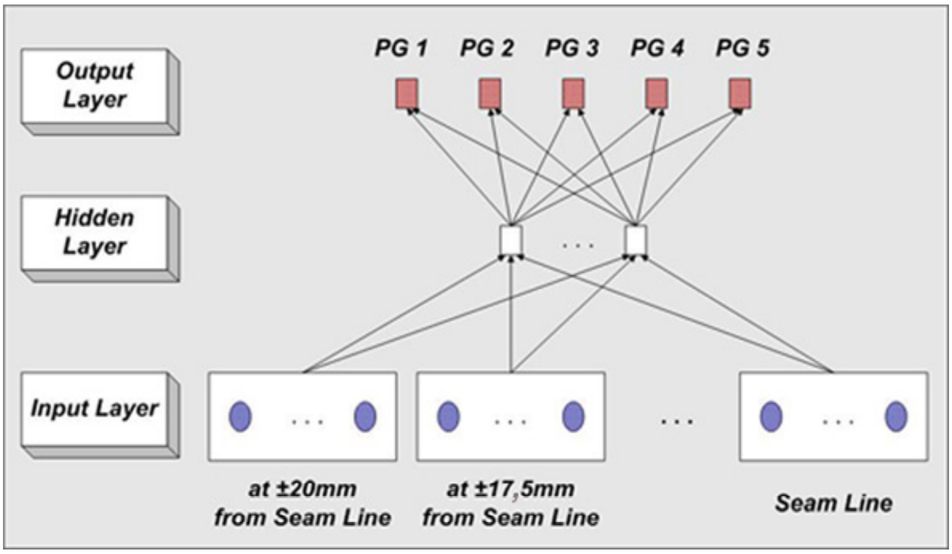


Figure B.13 — The structure of the constructed neurofuzzy engines

Table B.1 — Configurations of the neurofuzzy engines for objective ISO (or AATCC) rating method

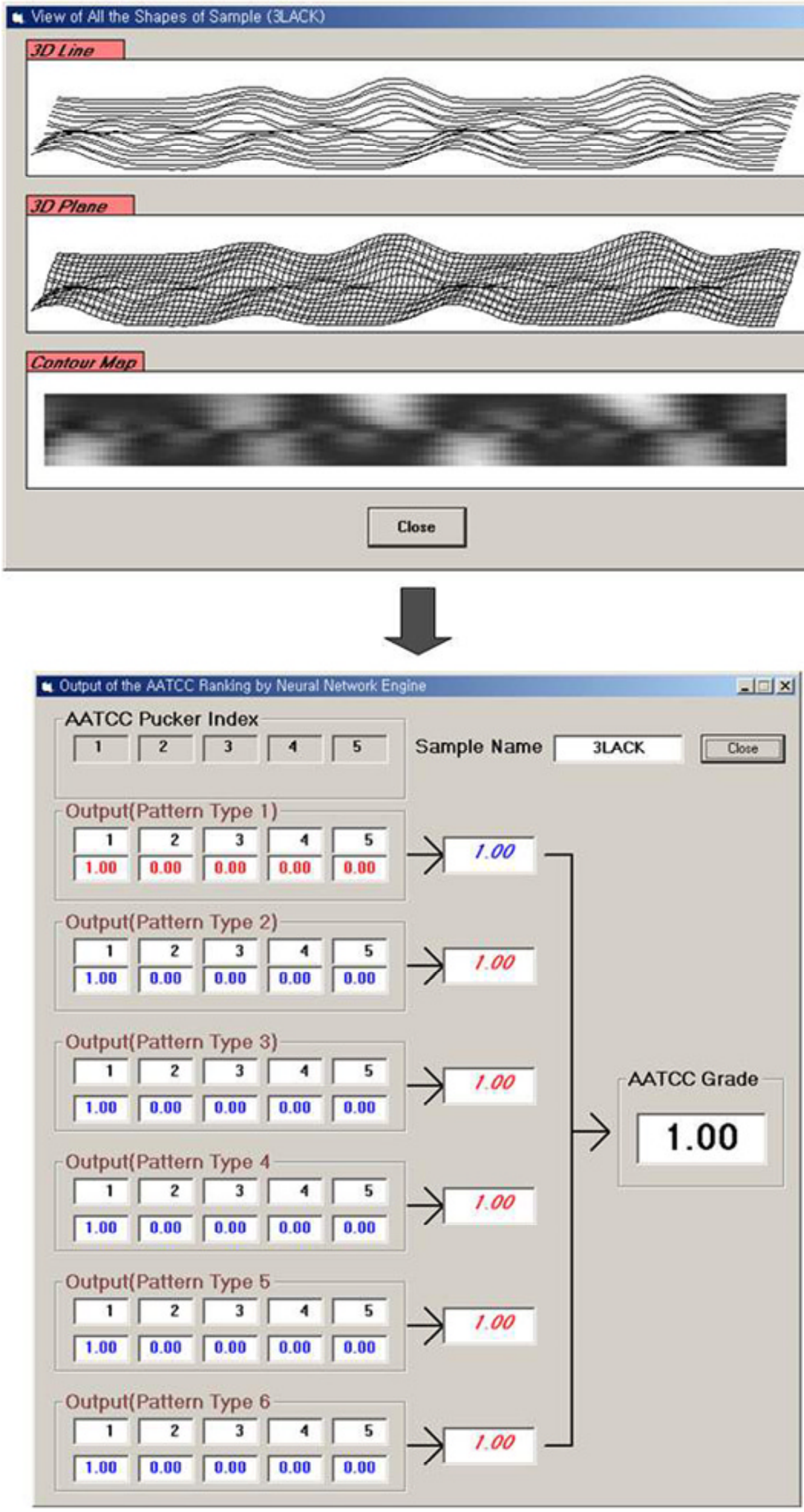
		Six neural networks
No. of input patterns for learning		15 (3 × 5)
No. of target patterns		5
No. of layers		3
No. of neurons		70
	Input layer	45 (5 × 9 matrix)
	Hidden layer	20
	Output layer	5 (row matrix)
No. of connections		1 000
Learning rate		0,5
Momentum		0,9

B.3.4 Defuzzification for final objective rating method

Using the constructed neurofuzzy engines, arbitrary sample fabrics are evaluated for the objective ISO (or AATCC) rating. The evaluation process is similar to the process used to train neural networks as shown in Figure B.14. At first, a sewn fabric with an unknown pucker grade is measured using the measurement system. Then, 3-D data are transformed into power spectra on the frequency domain using the FFT. The six input patterns are produced from the height and frequency distributions and output patterns are generated from the input patterns. The pucker grades, PG, were obtained from:

$$\mathrm{PG} = \frac{\sum_{i=1}^{5} (i \times X_i)}{\sum_{i=5}^{5} X_i}$$

where X_i is the output value of the ith neuron in the output layer and i (= 1~5) denotes the grade. The final ISO (or AATCC) grades are the average of the six pucker grades calculated from the six neural networks.


View of All the Shapes of Sample (3LACK)
3D Line
3D Plane
Contour Map
Close
Output of the AATCC Ranking by Neural Network Engine
AATCC Pucker Index
1
2
3
4
5
Sample Name
3LACK
Close
Output(Pattern Type 1)
1.00
0.00
Output(Pattern Type 2)
Output(Pattern Type 3)
Output(Pattern Type 4
Output(Pattern Type 5
Output(Pattern Type 6
AATCC Grade
1.00

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[1] AATCC Test Method 88B-2001, *Smoothness of Seams in Fabrics after Repeated Home Laundering*

[2] AATCC Test Method 88C-2001, *Retention of Creases in Fabrics after Repeated Home Laundering*

[3] AATCC Test Method 124-2001, *Appearance of Fabrics after Repeated Home Laundering*

[4] ISO 7768, *Textiles — Method for assessing the appearance of durable press fabrics after domestic washing and drying*

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