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# The Evaluation of Evenness of Nonwovens Using Image Analysis Method

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**Abstract:** Authors studied on the applicability of image analysis technique using a scanner with a CCD (charged coupled deviced) to the evaluation of evenness of nonwovens because it has distinctive features to considerably save time and labor in the analysis compared with other classical methods. As specimens for the experiment, two different types that are unpatterned and patterned ones were prepared. For the unpatterned specimen, webs were chemically bonded, while for the patterned specimen, webs being thermally calendered with engraved roller. Several webs having various areal densities were prepared and bonded. Coefficient of variation (CV%) was used as a parameter to evaluate the evenness. Scanning conditions could be suitably set up through comparing the total variance to the between-group variance and to the within-group variance, respectively, on the images scanned at the different conditions. The 2D convolution method with smoothing filter kernel was introduced to further filter the noises on the scanned images. After the filtering process, the increase of web areal densities gave an uniform decrease of the CV%. This showed that the scanned image analysis with proper filtering process could be successfully applicable to the evaluation of evenness in nonwovens.

**Keywords:** Evenness, Nonwovens, Image analysis, Filtering, CCD

## Introduction

Unevenness in nonwoven, which occurs mainly during the web forming and bonding process, has been known to damage the physical properties as well as the final product quality. Thus, the testing method should be developed to systematically analyze the evenness and set up an optimum process condition for obtaining the desired product qualities.

As for the measurement of evenness, testing methods could be mainly classified into two categories. One is to directly measure the thickness of the web using a thickness gage contacting itself with the web or to measure the weight of web with a balance in which a continuous measurement was impossible. The other is to indirectly measure them using a sensor without the contacting with the web. Since the former method causes to deform the web structure during the testing, the latter method is more desirable in the measurement and thus, most of recent researches have been carried out to develop this method[1-4].

In 1963, Barella *et al.*[2] developed a light transmition testing method to measure the evenness in nonwoven webs according to manufacturing conditions. However, the method had a limitation in its application to a heavy weight web because of its involving the difficulties in the light transmission. In 1991, Gupta and Pichardo[4] introduced a testing method of the electrical capacitance. This method has an advantage not only of the measurement in a relatively heavy web but also of characterizing the web structure by carrying out the measurements with rotating the specimen between two capacitance plates. However, it takes a time to fully measure the evenness through whole area of web because the width of plates in the existing testing apparatus is narrow and for the evaluation of overall evenness of nonwoven web, several specimen strips should be prepared and measured repeatedly. In 1991, Bullerwell *et al.*[3] introduced a light transmission testing method for the measurement while a testing specimen being moved. He found that the amount and intensity of light transmitted appeared different according to raw material used, and also found that the results came out constant regardless of the moving speed of specimen in the range between 22.9~635.8 m/s. In 1992, Aggarwal[1] developed a scanned-laser technique to analyze and monitor the evenness. The method could scan a wide width of the specimen and showed the possibility to measure up to the 70 $g/m^2$ of web density within the 2% of error.

With a fast development in computer technology, CCD (charged coupled deviced) camera has been widely used in various fields of the textiles such as pattern analysis, default detection, stain and quality analysis of dying, and so on. The method has an advantage of considerably saving time and labor for the analysis because a large part of the specimen areas can be scanned at a time and the data scanned be easily stored and analyzed on the computer.

In this research, authors studied on the applicability of image analysis technique with the CCD for the evaluation of the evenness in typically two different types of nonwovens such as unpatterned nonwovens and patterned nonwovens because most of nonwovens can be belonged to one of these categories. As a matter of convenience, the unpatterned nonwovens were prepared by bonding the web with chemical binders while the patterned nonwovens were prepared by thermally calendering with engraved roller. When nonwovens are subjected to lighting at the constant intensity, they reflect

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and scatter the light amount proportional to their web areal densities, which could provide a high potential in its application for evaluating the evenness of nonwovens. However, to further successfully apply CCD to the evaluation of the evenness, the most important things considered are how to transform and analyze the scanned image data according to the surface pattern types in specimens. As an example, in the patterned nonwovens, pattern images should be removed treating them as noises for a desirable analysis of the evenness. This study will explain the methods how to transform, analyze, monitor the image data, and show the possible application of the CCD to the evaluations of evenness in nonwovens.

## Experimental

### Materials

The applicability of image analysis technique for the evaluation of evenness in unpatterned and patterned specimen was investigated. For the unpatterned specimens, webs were chemically bonded while for the patterned specimens, webs being thermally bonded with engraved roller. In the manufacture, various web areal densities were prepared in the range from 28 to 100 g/m$^2$ for the unpatterned, and from 14.7 to 150.3 g/m$^2$ for the patterned. Web thickness after the bonding was in the range from 0.27 to 0.59 mm for the unpatterned and from 0.21 to 0.72 mm for the patterned. Colors of the specimens are all white.

### Image Processing

Figure 1 sketches image scanning system. UMAX S-12$^{(R)}$ scanner was used for scanning the specimens. The scanning conditions were controlled such that brightness, contrast, and sharpness were 0, gamma was 1, and highlight was 255. Specimen were cut to 7 cm $\times$ 7 cm. A black paper was placed on the backside of specimen to reduce the light reflections from the scanner cover.

For the evaluation of evenness, the variance of gray values

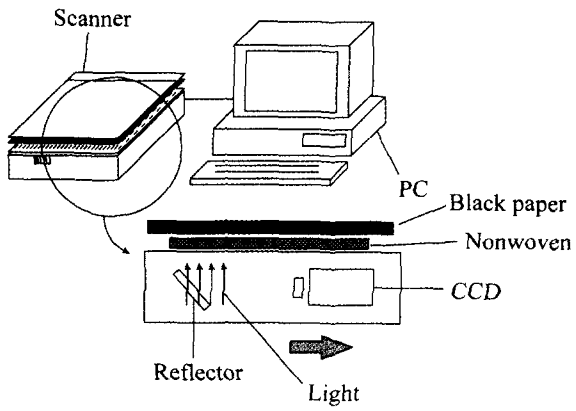



**Figure 1.** Image scanning system.

was calculated from the scanned images. For the calculation, first, the scanned image area was assumed to be divided into 16 equal-sized sub-areas with different gray values as follows.

| | | | |
|---|---|---|---|
| $x_1$ | $x_2$ | $x_5$ | $x_6$ |
| $x_3$ | $x_4$ | $x_7$ | $x_8$ |
| $x_9$ | $x_{10}$ | $x_{13}$ | $x_{14}$ |
| $x_{11}$ | $x_{12}$ | $x_{15}$ | $x_{16}$ |

And then, the sub-areas were finally rearranged into 4 groups as follows.

$$X_1 = \frac{1}{4}(x_1 + x_2 + x_3 + x_4)$$
$$X_2 = \frac{1}{4}(x_5 + x_6 + x_7 + x_8)$$
$$\vdots$$
$$X_j = \frac{1}{4}(x_{(4j-3)} + x_{(4j-2)} + x_{(4j-1)} + x_{(4j)})$$

| | |
|---|---|
| $X_1$ | $X_2$ |
| $X_3$ | $X_4$ |

From this, the variance was calculated as follows;

SST = SSW + SSB

SST: total variance $(\sum_i \sum_j (\chi_{ij} - \chi_{\cdot\cdot}))$

SSW: within - group variance $(\sum_i \sum_j (\chi_{ij} - \overline{X}_j))$

SSB: between - group variance $(\sum_i n_j (\overline{X}_j - \chi_{\cdot\cdot}))$

In the equation, total variance appears as the sum of the within-group variance and the between-group variance. The total variance represents the variance in $4 \times 4$ array, while the between-group variance represents the variance in $2 \times 2$ array. With the between-group variance being compared to the total variance, the effect of the resolution on the variance could be examined. On the other hand, with the within-group variance being compared to the total variance, the effect of the image size on the variance could be inspected. Thus, the most feasible scanning conditions could be properly chosen through comparing the total variance to the between-group variance and the within-group variance, respectively, on the images scanned at the several different conditions. The size of image and the resolution finally chosen were 196 $\times$ 196 pixels and 72 DPI, respectively at the gray scale of 256.

In patterned specimens such as the nonwovens calendered with engraved roller, it is needed to remove the pattern images, i.e. the bonding points because they be treated as noises in the analysis. For filtering the noises, the gray scale was recommended to be reduced to a proper value because it improves the filtering efficiency with simplifying the process of image analysis. From the experiment, the gray scale was reduced to 16 level for the filtering, that will be

| | | | | |
|---|---|---|---|---|
| $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ | $a_{15}$ |
| $a_{21}$ | $a_{22}$ | $a_{23}$ | $a_{24}$ | $a_{25}$ |
| $a_{31}$ | $a_{32}$ | $a_{33}$ | $a_{34}$ | $a_{35}$ |
| $a_{41}$ | $a_{42}$ | $a_{43}$ | $a_{44}$ | $a_{45}$ |
| $a_{51}$ | $a_{52}$ | $a_{53}$ | $a_{54}$ | $a_{55}$ |

$$\sum_{i=1}^{5}\sum_{j=1}^{5} a_{ij} = 1$$

$a_{ij}$: filter coefficient value

**Figure 2.** 5×5 filter kernel.

discussed later.

According to the gray scale being reduced, gray values at the reduced gray scale should be transformed as follows:

$$y = INT\left(\frac{x}{256/N}\right)$$

*INT*(*X*): the integer not greater than *X*
*x*: the gray values at 256 gray scale
*y*: the transformed gray values at a reduced gray scale
*N*: the reduced gray scale

After the transforming, pattern images were filtered using 2-D convolution method with filter kernel. Figure 2 sketches the 5 × 5 filter kernel. The coefficient values in the kernel are given differently according to filter types used. In this research, smoothing filter type was used[5]. Figure 3 sketches filtering process. Filtering process was made with moving the kernel step by step on the input image from the left to the right, and then, repeating it changing the row from the top to the bottom. At the position overlapped with the kernel on the input image, the filtered gray values were calculated by using the 2-D convolution method as follows:

$$x(i,j) \otimes a(i,j) = \sum_{n=0}^{N-1}\sum_{m=0}^{M-1} x(m,n)a(i-m,j-n)$$

where $x(i,j)$ represents the gray value of input image and $a(i,j)$ represents the filter coefficient at the $i$th row and $j$th column in the kernel, and $N$ and $M$ are the total number of rows and columns in the kernel, respectively.

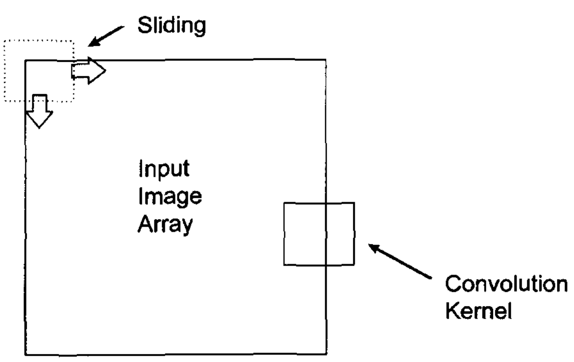



**Figure 3.** Illustration of filtering process with two-dimensional convolution method.

From the filtered gray values, the variance was calculated to finally provide a criteria to the evenness in the patterned specimens.

## Results and Discussion

### Relationship between CV% and Web Areal Density

Coefficient of variation (CV%) was introduced as a parameter in evaluating the evenness. The higher the CV%, the lower is the evenness. For judging a possible applicability of the scanning method to the evenness test, the relationship between CV% of gray value and web areal densities was investigated. Figure 4 shows the histograms of gray values at the different web areal densities in unpatterned specimen. As the areal density increased, the distribution of the histogram that refers to the CV% continued to decrease. Figure 5 shows the relationship between web areal densities and CV% of gray values calculated. In the case of unpatterned

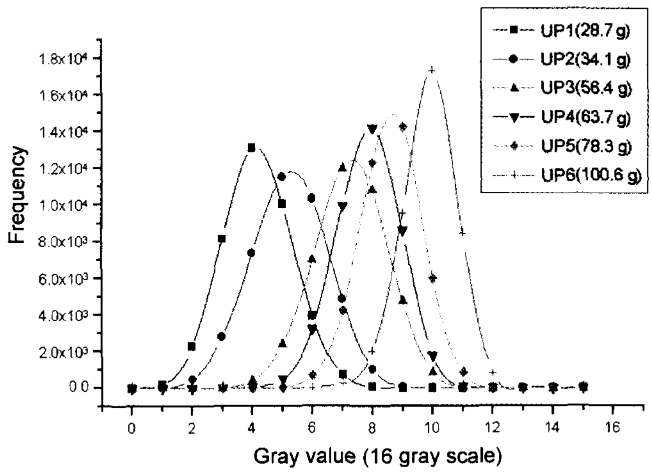



**Figure 4.** Histograms of gray value according to the different web densities in unpatterned specimens (UP=Unpatterned).

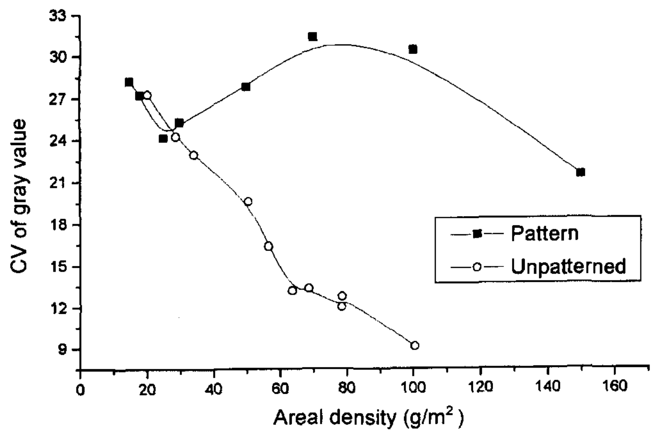



**Figure 5.** CV% against web density in patterned and unpatterned specimens.

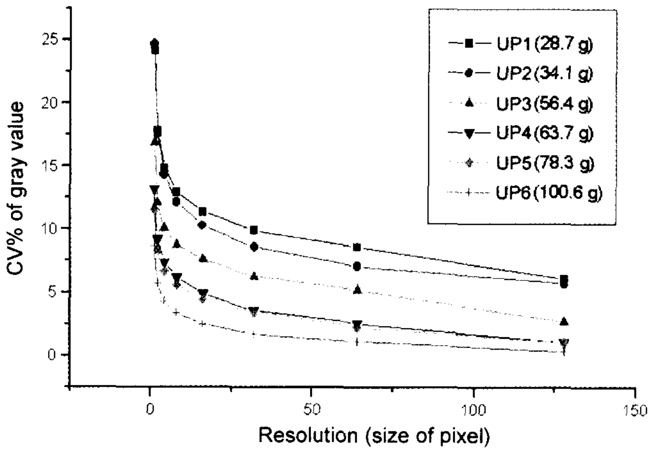



**Figure 6.** CV% of gray value against resolution in different web densities (UP=Unpatterned).

specimens, the increase of areal density led to an uniform decrease of the CV%. Since it has been already known that the increase of web areal density gives the increase of web uniformity in many literatures[1-3,6], the results proved that the scanning method could be applicable to the evaluation of the evenness in the unpatterned specimens.

On the other hand, in the patterened specimens, the relationship between web areal densities and the CV% appeared in irregular form as shown in Figure 5. In the case that the web areal density was very low, the pattern effect, i.e., the difference of the areal density between thermally bonded place and unbonded place was not significant, and thus, the relationship showed the similar tendency as in the unpatterned specimen. At the relatively high web densities, however, the pattern effect became great, which led to the significant difference of the light transmission between bonded and unbonded places resulting in the increase of

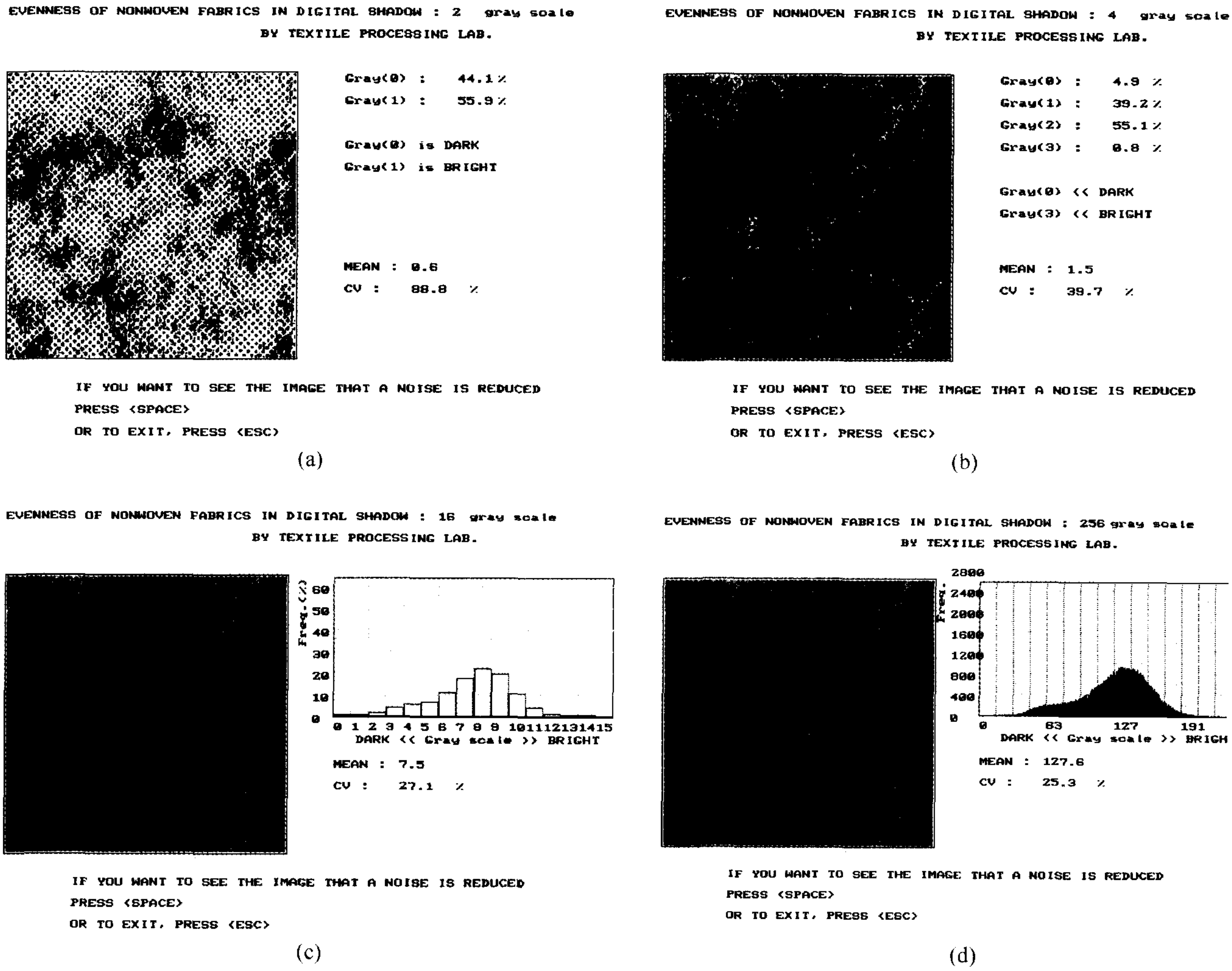



**Figure 7.** Reconstructed images and their CV% and histogram in patterned specimen. (a) 2 gray scales, (b) 4 gray scales, (c) 16 gray scales, (d) 256 gray scales.

CV% of gray value with the increase of the areal density. It informed that unlike in the unpatterned specimens, the pattern images in the patterned specimens should be filtered to properly evaluate the evenness of the original web before bonding.

## Effect of Image Resolution

Earlier researchers introduced the mean values as a parameter in evaluating the evenness[1,3]. However, even though it is an efficient method for evaluating the overall evenness, it could not give a detailed information. In this research, therefore, variance was measured in addition to the mean value.

For the measurement of variance, careful attention should be paid to determining the resolution condition, and thus, the effect of the resolution on the CV% of gray value was investigated. Figure 6 showed the change of the CV% against the resolution at the different web areal densities in unpatterned specimens. The decrease of resolution gave the decrease of CV% with the difference of CV% between web densities being lower. On the contrary, at the high resolution, i.e., the low value of the decrease of resolution in x-axis in Figure 6, the difference of CV% between web densities became greater. It indicated that the high resolution could provide a more detailed information to sufficiently characterize the evenness in unpatterned specimens.

However, in patterned nonwovens, it is desirable to reduce the gray scale as low as possible unless it significantly deforms the original image. This is because too high resolution, even though it gives an image very similar with the original one, decreases filtering efficiency. In this research, gray scales were reduced originally from 256 to 16, 4, 2 and then, the images at reduced gray scales were compared with the original one. Figure 7 shows the images at the different gray scales. The image of the 16 gray scale, being compared with the images of 2 and 4 gray scales, is most similar with the original one of the 256 gray scale. At 16 gray scale, the histogram and the value of CV% that is a key parameter for the evaluation of evenness, are almost same with the original ones, being compared to the others.

## Pattern Filtering

The thickness at places bonded with thermal engraved roller becomes thinner than that at other unbonded places, and thus, the light at the bonded places was more easily transmitted even though the local web areal density at the bonded place was same with or higher than original web density before calendering. Accordingly, when pattern specimens were scanned, as shown in the histograms in Figure 7, the dark portion positioned left from the mean value, which represents bonded places in calendered web, came out broader than the bright portion. For a correct evaluation of the web evenness in patterened specimens, thus, this dark portion should be filtered.

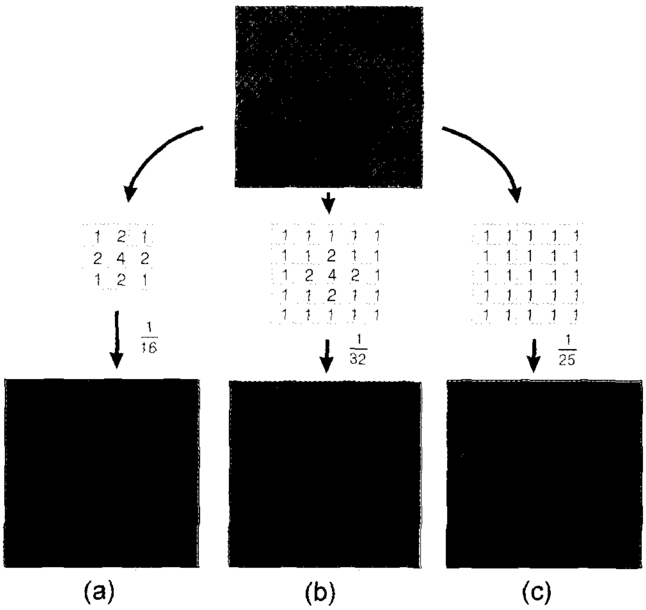
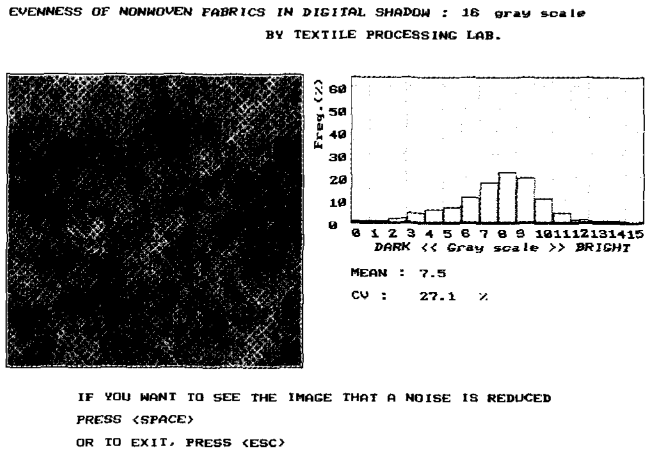
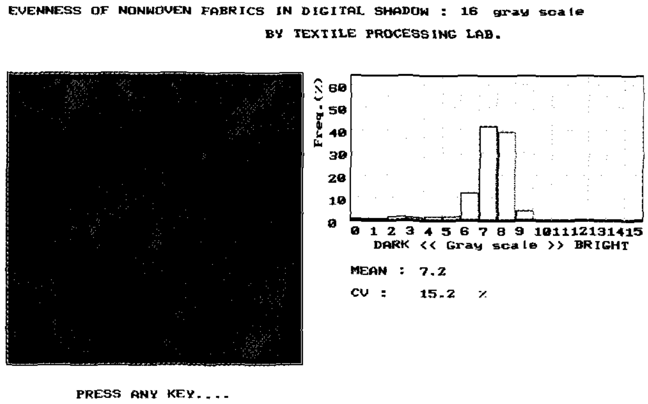



**Figure 8.** Smoothing filter kernel and the filtered images.




(a) Before filtering




(b) After filtering

**Figure 9.** Filtering effect on the image and histogram in patterned specimens.

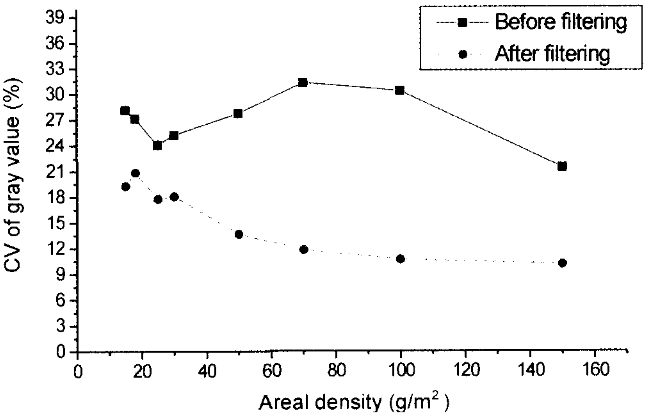



**Figure 10.** Filtering effect on CV% of gray value.

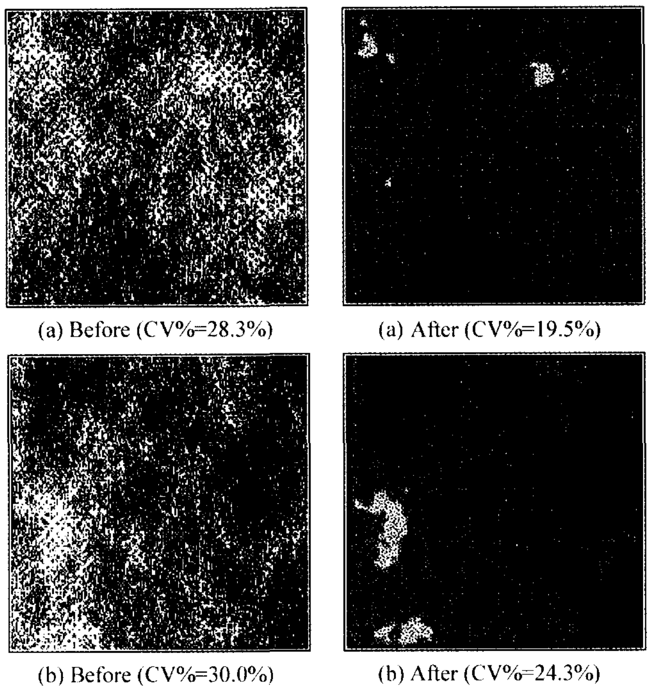



**Figure 11.** Filtering effect on the images and their CV% in patterned specimens.

For the filtering, 2-D convolution method with smoothing filter kernel was used. Filtering process was carried out with try and error method applying different kernel types and filtering coefficients. Figure 8 shows the filtered and unfiltered images at the 16 gray scale. Top figure shows the original image while bottom figures show the filtered images on the typically selected filtering conditions. It is shown that in the case of (C), the pattern images were well filtered while the image shape in unbonded places remains almost same with the original one. Therefore, type (C) filter was chosen for the filtering. Figure 9 shows the images and histograms of gray value before and after filtering. In the filtered images, over the wide range of dark portions, the frequency was remarkably reduced. It means that the bonded patterns were almost removed filtering with the type (C) filter.

Figure 10 shows the relationship between CV% and web areal density in filtered specimen. After filtering, the CV% decreased almost uniformly as the web density increased. Figure 11 compares the images visualized before and after filtering in the two patterned specimens (a) and (b) with remarkably different evenness but the same web density of 23.3 g/m$^2$. Before filtering, the values of CV% between two specimens came out to be almost same (28.3% and 30.0% in CV%), even though a significant difference in the evenness was visualized. After filtering, however, the values of CV% between two came out different enough to distinguish the evenness (19.5% and 24.3% in CV%), while the apparent images appeared a little different from the original ones due to the pattern removement. The results indicate that filtering process are of paramount importance for the evaluation of evenness in patterned nonwovens.

## Conclusions

The evaluation of evenness in nonwovens plays an important role in determining the physical properties and their application to a desired final product design for the end-uses. The applicability of the image analysis with CCD for the evaluation of the evenness in nonwovens was reviewed. Two different nonwoven types were prepared, that are unpatterned and patterned ones. Coefficient of variation (CV%) calculated on the scanned image was used as a parameter to evaluate the evenness. The most suitable scanning conditions could be chosen through comparing the total variance to the between-group variance and within-group variance, respectively. In unpatterned specimen, the increase of areal density gave an uniform decrease of the CV%, showing that the scanned image analysis method had a high potential in the evaluation of evenness. However, in the patterned specimen, pattern images remained as noises in the analysis, which resulted in the irregular relationship between the CV% and web areal density unlike in unpatterned specimens. And thus, for further successful application of the image analysis, the pattern images were filtered. 2D-convolution method with smoothing filter kernel was introduced. After the filtering, the relationship between the CV% and areal density appears in a regular fashion as in unpatterned specimens. In addition, it was confirmed that the values of the CV% after the filtering came out enough to distinguish the evenness in the patterned specimens typically prepared with remarkably visually different evenness but same web areal density. The results showed that with the filtering process being introduced properly, the scanned image analysis method could be successfully applicable to the evaluation of evenness in nonwovens.

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