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ORIGINAL ARTICLE

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A reference standard of defect compensation for leather transactions

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Abstract Defects exist on natural leather surfaces and they usually cannot be eliminated during processing. No international criterion specifies the compensatory counting for calf leather surface defects. So complicated negotiation causes additional cost and argument between suppliers and purchasers. The objective of this article is to establish a compensatory standard of leather defects for finished leather transactions. We start by collecting 170 samples of defective leather and classify the leather defects into seven types. By using digital image processing techniques, we can identify the defects and group nearby defects into a larger scrap area. The area of leather falling into disuse can be calculated. The compensatory standard corresponding to each type of leather defect is then defined. The established compensatory standard for finished leather transactions is evaluated for simulated practical leather transaction. Simulation results showed that the proposed approach is useful and beneficial for practical leather transactions.

Keywords Image processing · Leather surface defects · Leather transactions · Simulation

1 Introduction

The usage of leather has a long history. Although quite a few synthetic leather types are available today, natural leather still cannot be replaced by synthetic leather. At present, cattle leather is the largest in the shoe leather market. However, defects on cattle skin are more intensive than those of other animals [1]. So this article focuses on the surface defects of cattle leather.

The growth environment of cattle and raising methods affect leather Defects, which are related to scratch, pinhole, putrid spot, parasitic damage, brand mark, etc. Most tanneries in Taiwan and China try to improve their manufacturing processes to remove the defects from the surface of leather [2]. However, defects cannot be eliminated entirely by the current manufacturing technology.

No international standard has been developed to specify the compensatory measurement for finished leather surface defects. The major difficulty is the issue on the argument about deductible areas of leather defects in leather transactions. In order to satisfy the suppliers' and purchasers' rights in the leather supply chain, an acceptable standard for leather defect compensation is required.

2 Literature review

There are many types of surface defects on leather. The LeaVis system [3] was the first system to use a machine vision method to detect leather defects. The system aimed at processing and segmenting the defect images and the areas of different quality, which are usually marked manually.

Leather surface defects often look like some kind of textures. They are composed of random features immersed within a random environment. Limas-Serafim [4, 5] used multiresolution pyramids to construct an image model of leather surface texture. This methodology was implemented and applied for segmenting the small vein and scar defects in calf leather.

Lovergine et al. [6] used a leather patch as a unit to classify the input leather surface types based on gradient orientation and local coherence. Leather defects such as scars and folds can be detected by segmenting the oriented texture map of the leather surface.

Branca et al. [7, 8] found leather surface defects according to oriented structures by using human inspection. A neural-network approach was used to analyze the oriented texture. The resulting system is flexible and does not depend on dimensions, structure,

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or the color of the defects. Pölzleitner and Niel [9] proceeded in a hierarchical manner and detected seven features of wet blue leather.

In industry, because the size of a leather surface is quite large, it is difficult to detect all of the defects on a leather surface in a short time. The size of a leather cattle hide could be as large as 2 m × 3 m, but a defective area could be as small as 150 μm × 150 μm. The defects are generally hidden behind the irregular textured background of the leather surface. It is difficult for a human grader to detect all leather defects completely.

Traditionally, leather hides are graded according to the quarter rule. A transparent template of 10×10 square units with each unit equal to $\sqrt{10} \times \sqrt{10}\,\mathrm{cm}^2$, is used in measuring the defects [10]. The inspector counts the number of square units covered by the leather defects. Based on this approach, Hoang and et al. [11] proposed a machine vision system for automatic leather grading. Yeh and Der-Baau [12] proposed a semiautomatic machine vision method to measure the area of unusable surface defects in wet blue hides. A demerit count reference standard was proposed for classifying and grading the wet blue hides.

3 Leather hide defects classification

In leather hide manufacturing, a two-stage procedure is generally used. The first stage is hide tanning, which generates usable leather. Tannery processing affects the characteristics of the leather. The second stage controls the flexibility, scuffing, waterproof, folding endurance, abrasion resistance, and solvent resistance properties [13].

There are many types of defects on a leather hide. Defects are caused by the leather manufacturing process, the cattle's growth environment or by the slaughter, storage, or transportation processes. The defects generally can be classified according to the shapes on the leather surface or the leather manufacturing process that caused the defects.

In this research, we classified defects according to their shapes by which the inspectors can tell easily on a piece of finished leather. Approaches adopted by inspectors are so formalized that can be applied to the classification of leather defects. We therefore collect and analyze a set of defective leathers and categorize the defects into seven types as summarized in Table 1.

In Table 1, a clear definition of the appearance of each type of defect is given. Examples of the mark or scar of different types of leather defect are also listed. Defects that are underneath the skin and invisible on the leather surface are not included in this research.

Table 1. Seven types of leather defect

Type of defect	Defect appearance and definition	Mark or scar of leather defect
1. Thin spots	Spots like scars with a diameter of ≤1 mm	Hair root, over buffing, pinhole, putrid spot, dermatitis
2. Spots	Spots like scars with a diameter of >1 mm	Thorn scratch, nail mark, fish eye effect, chrome stain, salt stain, cure stain, putrefied
3. Lines	A line-type scar with a width of ≤1 mm	Vein, fat fold, crack, healed scratch, wring felt mark
4. Strips	A line-type scar with a width of >1 mm	Brush mark, score knife, neck wrinkle, iron mark
5. Holes	Hole damage	Dig damage, grub hole, bullet mark
6. Patterns	Animal breeding mark	Brand mark
7. Irregulars	No regular appearances as in any of the above types or several types of defects mixed together	Wart, foul (contamination, pipe grain, flay mark, putrefied, oil burnt), shade variation, water stream mottle, scratch, chafe mark, hook mark, gear mark, not uniform abrasion, parasitic speckled (tick, mange, insufficient), dung stain

4 Establishing a compensatory standard

To establish a compensatory standard for the defective area in finished leather transactions, we first identify the defects using the image processing method. Then the unusable regions caused by the defects on the leather surface are computed. Finally, the compensatory standard for each type of leather defect is constructed by using the flowchart shown in Fig. 1.

After acquiring the image of the defect, we check the grey value of the original pixels. The grey value distribution of a typical leather surface image can be considered as a combination of two approximations of independent normal distribution, as shown in Fig. 2.

Good leather in Fig. 2 forms the background of the image and defects form the foreground. Usually the defective regions are darker than the background of good leather. Therefore, the grey value of background pixels occupies the middle part of the histogram and that of defects occupy the two ends. If some pixels are found to have different grey values from the average grey value of the leather, then these pixels are categorized as defects. From the grey value histogram of the entire image, we can use Otsu's method [14] to select a threshold value automatically. A binarization operation is then applied. The pixels with grey values over the threshold are set as defective leather and others are set as non-defective leather. The area of each of the defects can be obtained by calculating the number of corresponding pixels in the image. From the viewpoint of leather footwear or handbag manufacturers, who use leather as their main raw material, the area between two nearby defects might practically be too small to be used. If the distance between two nearby defects is less than $\sqrt{10}\,\mathrm{cm}$ (about the width of three fingers), then the two nearby defects are grouped to form a larger unusable region. The algorithm, which can group the two nearby defects of wet blue leather, can be found in Yeh and Der-Baau [12]. This algorithm can also be used to group the two nearby defects of finished leather. Figure 3 illustrates seven clusters formed for seven defect patterns.

According to the defect data extracted from the collected 170 defective samples, the defective area and unusable area can be calculated, respectively, by the number of corresponding pix-

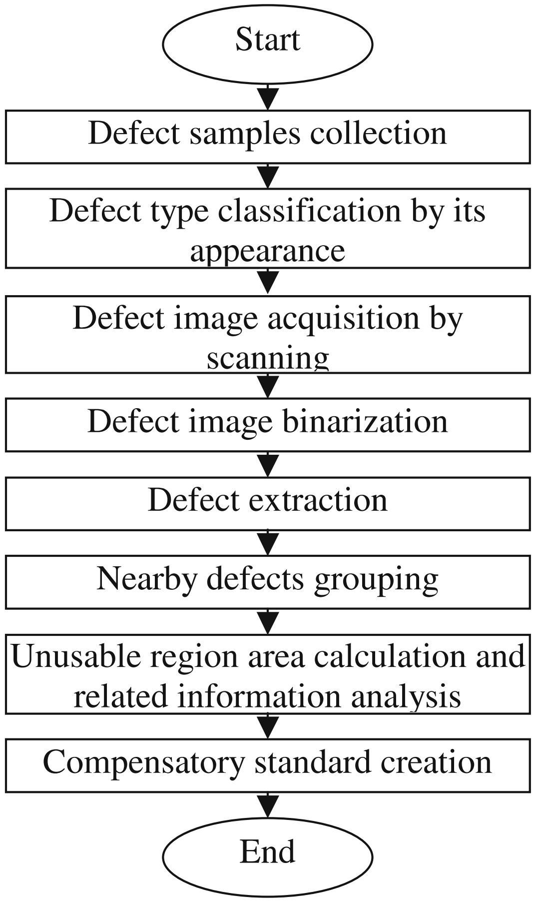

Fig. 1. A compensatory standard construction flowchart

els in the defective and unusable regions. Under a resolution of 150 dpi, each pixel is equivalent to 0.00029 cm^2. Based on the calculated defective area and unusable area, we can create a scat-

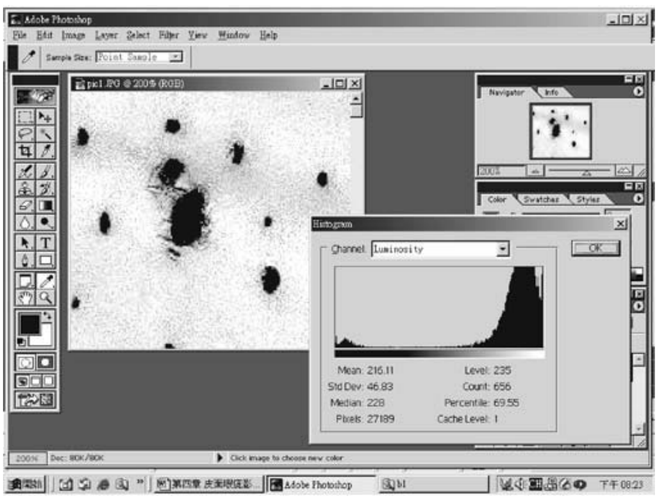

Fig. 2. Two approximations of normal distribution histogram (Bullet market defective image)

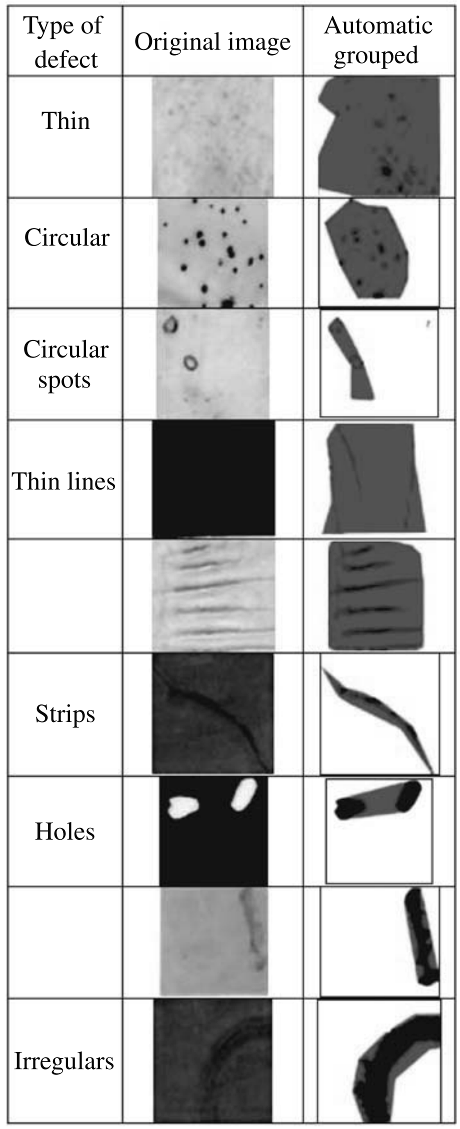

Fig. 3. Leather defects clustered into unusable regions

ter plot by using the corresponding seven types of defects (see Fig. 4).

In Fig. 4, the corresponding relationship of defective areas with unusable area for each type of defect is illustrated. There is no obvious straight-line relationship between defective area and unusable area for each type of defect. So we have to construct a compensatory standard for each type of defect by calculating the mean value of the unusable region area from the samples of each type of defect. Each compensatory unit is set to 10 cm^2 in accordance with the unit of conventional leather defects proposed by Hoang and Nachimuthu [10]. Table 2 lists the derived compensatory standard for the seven types of defects.

In Table 2, the mean value of the area of each type of defect is computed by averaging all of the defective areas for each type of the collected sample defective leather. The mean unusable area is calculated in the same way. The unit of compensatory standard

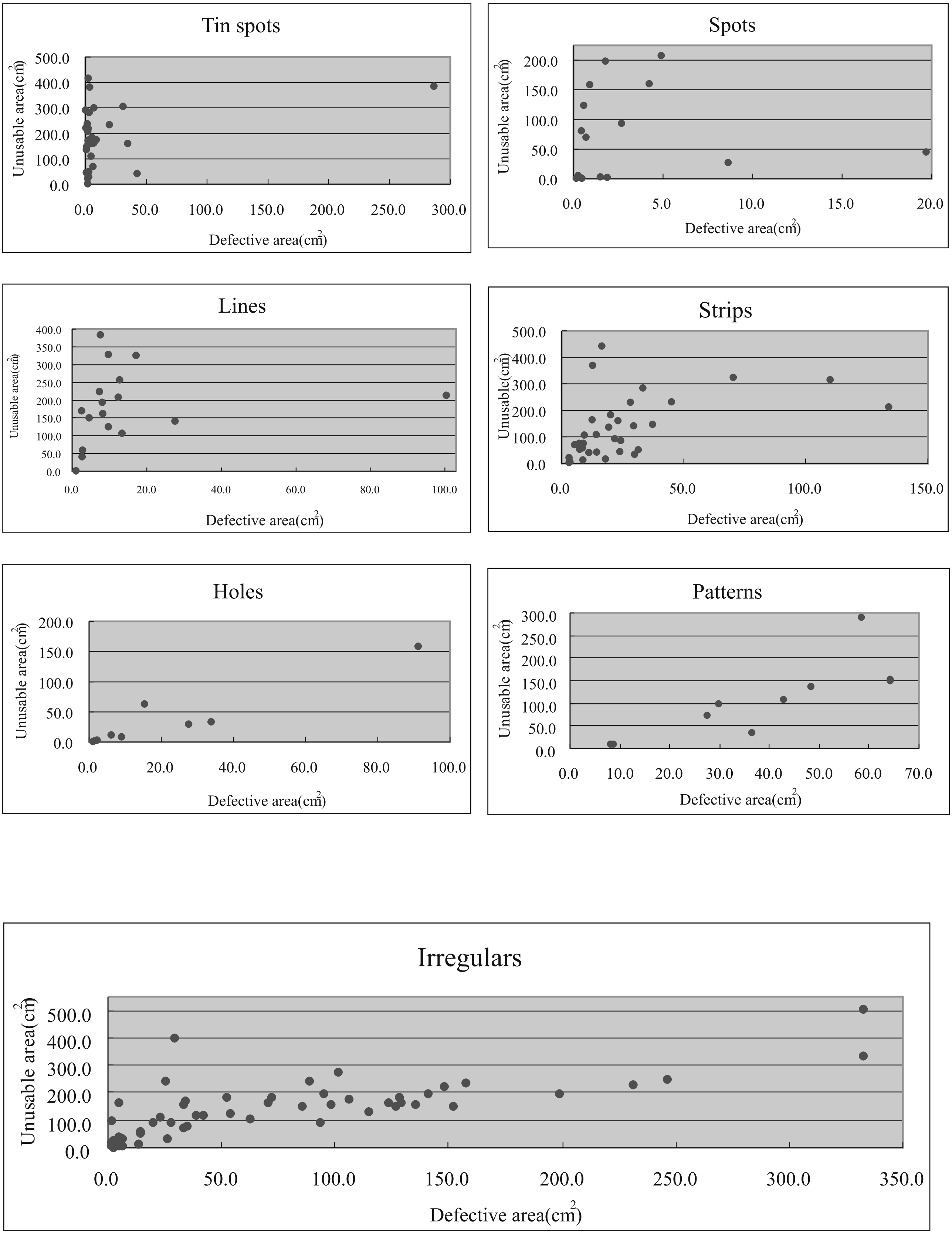

Fig. 4. Scatter plot for seven types of leather defect

Table 2. The calculated compensatory standard for each of the seven types of defect

Type of defects	Number of samples	Defective area (cm^2)		Unusable area (cm^2)		(2)/(1)	Compensatory standard (unit)	Remarks
		Mean (1)	Standard deviation	Mean (2)	Standard deviation			
Thin Spots	30	33.33	51.18	189.33	108.98	5.68	19	This research sets:
Spots	16	4	4.81	71.8	72.88	17.95	7	one compensatory unit
Lines	17	11.76	22.33	185.88	100.70	15.81	19	$= \sqrt{10}\,\text{cm} \times \sqrt{10}\,\text{cm}$
Strips	33	26.81	28.21	132.12	112.24	4.93	13	$= 10\,\text{cm}^2$
Holes	9	26.38	27.17	37.77	23.83	1.43	1	
Patterns	10	39	19.63	104	80.04	2.67	10	
Irregulars	55	78.63	79.21	128	100.81	1.63	13	

(UCS) for defect type i is set to be

$$\text{UCS}(i) = \text{Round}(\text{A}(i)/10\,\text{cm}^2), \quad (1)$$

where $\text{A}(i)$ is the mean value of the unusable area for type i defect (except holes). Round(x) is the function that will round the value x into its nearest integer.

As to holes, the UCS for holes can be computed by practical experience as follows:

$$\text{UCS(holes)} = \text{Round}\left\{\left[\overline{\text{A}}\text{u(hole)} - \overline{\text{A}}\text{d(hole)}\right]/10\,\text{cm}^2\right\}, \quad (2)$$

where $\overline{\text{A}}$u(hole) and $\overline{\text{A}}$d(hole) are, respectively, the mean unusable area and mean defective area of hole.

From Table 2, we can summarize some characteristics of defective leather for managers of leather manufacturing companies.

(a) The mean defective area for different types of defects can be ordered decreasingly as irregulars, patterns, thin spots, strips, holes, lines, and spots. The mean unusable area caused by different types of defect can be ordered decreasingly as thin spots, lines, strips, irregulars, patterns, spots, and holes. There is no close relationship of these two sequences. The defective areas of thin spots and lines usually have greater influence on the accompanying unusable area than do other types of defects.

(b) Different types of defects have different variances in both defective area and unusable area. The standard deviation for the area of each type of defect can be ordered decreasingly as irregulars, thin spots, strips, holes, lines, patterns, and spots, while the standard deviation for unusable areas caused by different types of defect can be ordered decreasingly as strips, thin spots, irregulars, lines, patterns, spots, and holes. There is no direct relationship between the size of defective area and unusable area for different types of defect. That is, the size of the unusable area does not change proportionally with the change of defective area.

The compensatory standard for different leather defects can be used for finished leather transactions. When the finished leather is spread out over a table to be graded for transaction, the inspector only needs to count the total number of compensatory units for different types of defects. The deductible areas for unusable regions of that finished leather can be obtained by multiplying the total number of compensatory units for different types of defect by $10\,\text{cm}^2$.

5 Compensatory standard evaluation by simulating leather transactions

In order to evaluate the validity of the established leather defect compensatory standard, we compare the difference between the actual unusable area and the deductible area determined by the compensatory standard for each defective sample.

The mean error rate and deviation rate were computed in the simulated transaction. The algorithm for verifying the validity of the established compensatory standard by simulated transactions of different lot sizes is given below.

Algorithm: Simulated leather transaction for verifying the validity of the established compensatory standard

(1) Symbol description:
T_n is the incremental unit of each simulated lot size of leather transaction;
T_s is the pieces of leather to be transacted each time;
D_s is the number of defects that may occur on a piece of leather. It could be any type of defect selected randomly from the 170 defective samples;
D_n is the number of total defects generated randomly on a piece of leather. It is assumed to be less than 30.

(2) Output:
Unusable area, deductible area, error rate, and deviation rate of each transaction.

(3) Method:

```
1. Set up the values of unusable area for each of the 170 defective samples and the value of compensatory standard for each of the seven types of defect.
2. for ( Tn = 50; Tn <= 1000; Tn = Tn + 50)
      {
3.    for (Ts = 0; Ts <=Tn; Ts = Ts +1)
         {
4.       Ds = 0;
5.       Generate a random number Dn;
6.       while (Dn <> 0)
            {
7.          for ( Ds= 0; Ds < = Dn; Ds = Ds +1)
               {
```

Table 3. Error rate of simulated leather transaction for different lot sizes

Lot size	50	100	150	200	250	300	350	400	450	500
Error rate	1.95E-02	1.45E-02	1.25E-02	1.43E-02	1.36E-02	1.12E-02	8.54E-03	1.17E-02	1.01E-02	1.19E-02
Lot size	550	600	650	700	750	800	850	900	950	1000
Error rate	1.14E-02	1.16E-02	9.13E-03	1.20E-02	9.91E-02	9.78E-03	0.011545	8.86E-02	1.04E-02	1.04E-02

8. Choose randomly the unusable area corresponding to the compensatory unit from one of the 170 defective samples in the database;
9. Calculate the unusable area and the deductible area for each of the randomly selected defect;
}
}
}
10. Compute the total unusable area, total deductible area, error rate, and deviation rate in the simulated leather transaction;
}
11. Output the unusable area, deductible area, error rate, and deviation rate of each transaction.

First, the values of unusable area of each of the 170 defective samples and the value of compensatory standard for each of the seven types of defect are set up. The lot-size increment for each simulated leather transaction is assumed to be 50. The number of total defects of any type that may appear on a piece of leather is generated randomly and is assumed to be no greater than 30. Once the simulation process is started, the unusable area of the randomly selected defect and the corresponding compensatory standard are computed by referring to the database of 170 defective samples. The deductible area for each randomly selected defect can be computed in the same way.

The lot size of each leather transaction is simulated from 50 to 1000 pieces. When the number of leather pieces in each transaction is reached, the total unusable area, total deductible area, error rate, and deviation rate can be computed accordingly.

5.1 Validity evaluation of the established compensatory standard

The error rate of simulated leather transaction for different lot sizes is shown in Table 3.

In Table 3, let A_{U} be the total area of the entire whole unusable leather defect computed directly by referring to the 170 sample defects. Let A_{D} be the total deductible area of all of the unusable defects derived by referring to the compensatory unit of corresponding leather transaction. The error rate can then be computed as

$$\text{Error rate} = (\mathrm{A_U} - \mathrm{A_D})/\mathrm{A_U}), \tag{3}$$

where $\mathrm{A}_U = \sum_{j=50}^{T_n} \sum_{i=1}^{D_n}$ (unusable area of defect (i) on leather piece (j)).

$\mathrm{A}_D = \sum_{j=50}^{T_n} \sum_{i=1}^{D_n}$ [compensatory unit for defect (i) on leather piece (j) $\times$ 10].

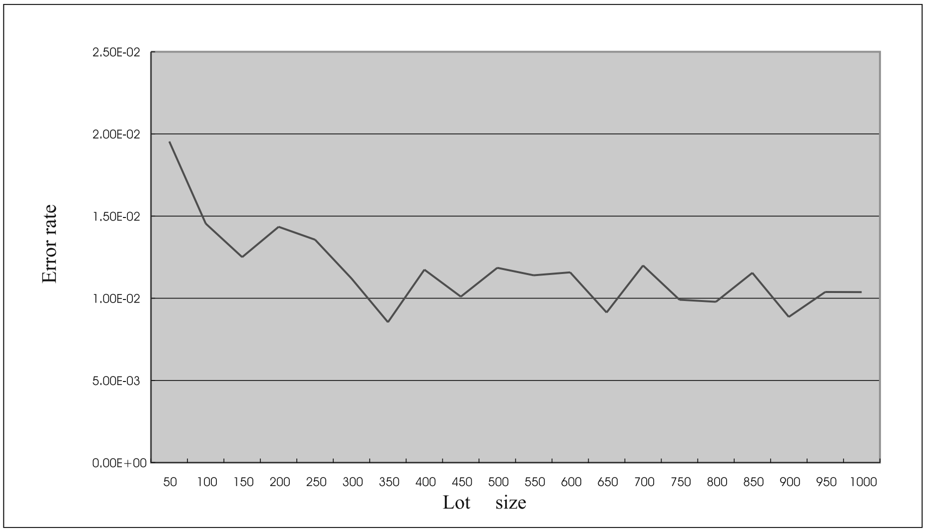

Fig. 5. Error rate curve corresponding to different lot sizes of simulated leather transaction

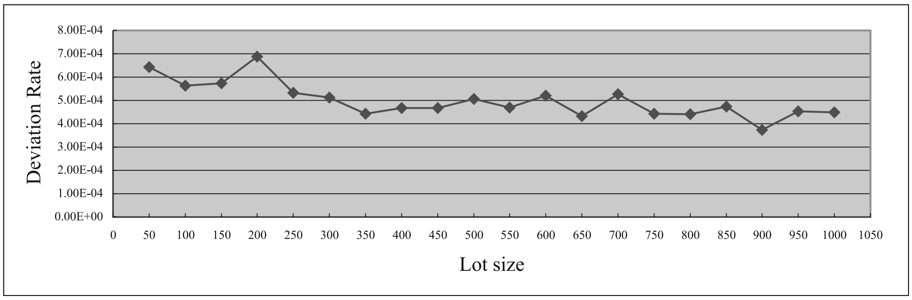

Fig. 6. Deviation rate for different lot sizes of simulated transaction

T_n, D_n is defined respectively as in the algorithm for simulated transaction.

The data in Table 3 is plotted in Fig. 5.

In Fig. 5, the error rate curve of simulated leather transaction has a decreasing tendency against lot sizes from 50 to 250 pieces. When the lot size is over 350 pieces, the error rate variance tends to be small and stable. The average error rate is 1.16% for the transacted lot size from 50 to 1000 pieces. This simulation provides a high confidence of established compensatory standard.

5.2 Identify the stability of established compensatory standard

To identify the stability of the established compensatory standard for variable lot sizes in leather transactions, we define a new indicator of deviation index rate based on the deviation area and the average area of a single side of finished leather. We assume that the average area for a piece of a single-side finished leather is 22 500 cm^2. The total area in each leather transaction can be defined as multiplying the transacted lot size by 22 500 cm^2. From the simulation described above, the deviation area of each lot size D_A can be computed as

$$\mathrm{D_A} = |\mathrm{A_U} - \mathrm{A_D}|. \quad (4)$$

The deviation rate can be written as

$$\text{Deviation rate} = \mathrm{D_A}/(\text{Transacted lot size} \times 22\,500\ \mathrm{cm}^2). \quad (5)$$

The deviation rate for different lot sizes of simulated transaction is given in Fig. 6.

From Fig. 6, we can see that the deviation rate for the transaction of different lot sizes is also small and stable. The mean deviation rate is 0.05%, which is practically acceptable by both leather manufacturing companies and leather goods manufacturers.

6 Conclusions and future directions

A reference compensatory standard, corresponding to each of the seven types of casual leather defects, for finished leather hide transactions has been established in this article. An algorithm for evaluating the validity and the stability of the established compensatory standard has also been presented by simulating the practical leather transaction manner. Simulation results show that the established compensatory standard is reliable and effective, not only for the suppliers, but purchasers can refer to the established compensatory standard to reduce arguments when in leather transactions; also the tanneries can use it to improve their manufacturing processes.

The established compensatory standard will have the following benefits:

(1) It provides a flexible and reliable standard to determine the unusable defective area of finished leather.
(2) It can be used to reduce the effort in training a leather classification expert.
(3) It can be used to develop a national compensatory standard for leather transactions.

Although we have established a compensatory standard for seven types of leather defects, the total number of compensatory units still have to be counted manually. Future research work will concentrate on the automatic detection of unusable defective areas and on the automatic classification of defect type for establishing a fully automatic compensation mechanism.

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