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Image Analysis of Luster Images of Woven Fabrics and Yarn Bundle Simulation in the Weave

- Cotton, Silk, and Velvet Fabrics -

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Abstract

The attractiveness of the textile fabrics are generally judged by visual or tactile evaluation methods. Since the surface of the textile materials are so diverse that the visual factors such as optical properties or luster of the fabrics are not easily measurable. While most of the cotton fabrics are not so much lustrous, calendering process could impart the cotton fabric better luster. Also, the general grade silk-like polyester fabrics resemble silk fabric with some limit in terms of luster properties. One of the interesting fabrics showing subdued luster is the velvet fabrics with dark shade. In this study, the luster related properties are examined using some image analysis methods. Yarn models based on the fabric weave types were developed to further investigate the effect of fabric crimp shapes due to weave on the optical properties or luster of the fabrics.

Key words: luster, reflectance, rendering, satin, woven fabrics

I. Introduction

In the past, one of the main research interests had been a search for new polymers that could possibly be made into textile fibers. Today, synthetic fibers are not an alternative to natural fibers, but are new materials of high functionality and high performance which play a key role in the technology sectors. In the 1960s, a lot of attention had been paid to the modification of cross-sectional shapes of the fibrous materials. Microscopic studies of the fibers revealed trilobal cross-sectional shapes of the silk. The outcomes of the studies were that the cross-sectional shapes of the silk filaments are highly related with the luster. The fabric structure or cross-section became an issue since 1960s. As in most cases of structural order, the third step of technological innovations concerns the structure of fabrics. As a result of the combination of existing high-technologies that have been developed in the past, new breeds of fabrics have emerged based on the fiber-forming synthetic polymers. These have further sophisticated by combining two or more separate technologies[1), 2)].

When light flux impinges upon a single round cross-sectional or a triobal filament, or a yarn bundle, it could be partially reflected, transmitted, or absorbed. This behavior determines the visual characteristic appearance of the fiber or yarn. On top of this, the optical properties of fibers are a source of information regarding the internal fine structure of the fibers. The polymeric molecular orientation could also be estimated from the refractive indices differences.

Liao and Adanur[3] developed a geometric model of woven, braided, knitted and other 3D performs using the computer aided geometric design technique. Their previous models mainly considered the perform in two dimensional planar form. Emphasis was put on representing the 3D net shapes of textile composite performs with complex external shapes. They used 3D trajectory to represent the yarn shape. They visually presented the texture and lighting of the yarn braided.

In textile industry, visual inspection of the fabric appearance is an important process for quality assurance of the product. Even if the incidence of serious weaving defects can be reduced using modern technology, fault detection in many manufacturing sites still incurs extra costs. To increase productivity, textile mills are adopting some automated visual inspection system which employs a video camera and related imaging routines based on a computer. Image acquisition and automatic evaluation may form the basis for a system that will ensure a high degree of fabric quality assurance. The main difficulty, however, in automatic fabric inspection in lieu of the manual and traditional quality inspection system is the great diversity of the textile types.[4]

Due to the complex nature of the textile fabric appearance, it is important to have fundamental understanding of the properties related to the fabric surface and the luster stemming from its constituent fibers, yarns thereof, the fabric weaves, and finishing effects.

II. Experimentals

The first two fabric specimens in the list are plain cotton fabric and chintz cotton fabric for comparing the luster property differences.(Table 1) Another set of fabric samples included in this study were silk satin fabric and PET satin fabric, through rather harsh, which gives the look of silk to some degree. Velvet was included to investigate the luster of fabrics having free vertical fiber ends protruding from the fabric surface. Firstly, each fabric specimen was prepared to form a circle of 10 cm diameter for taking image of 2,272×1,704 pixels. Specimen was placed on top of a plastic hemisphere of diameter of 12 cm for acquiring image using a digital camera. Secondly, in order to analyze the luster characteristics of the fabric specimens in detail, microscopic images were taken using a CCD camera coupled with an objective lens. In

<Table 1> List of fabric specimens

Fabric code	Material	weight, mg/cm^2	thickness, mm	fabric count threads/inch	weave type
C1	cotton	9.43	0.13	73 x 73	plain
C2	cotton	11.15	0.19	239x130	satin
S	silk	7.16	0.15	319x135	satin
P	PET	9.81	0.16	260x105	satin
V	PET	24.67	1.05	107x97	velvet

this case, each specimen was prepared to form a square of 5cm.

1. CCD camera

In order to register an image of the fabric specimen, one has to use a mean of detecting light waves that carry energy. If a point source emits a certain amount of energy, and if this is collected in an area D_1 at distance r_1, then the same amount of energy could be collected at the larger distance r_2, provided that the area, D_2, available at this larger distance was

$$D_2 = \left(\frac{r_2}{r_1}\right)^2 D_1 \qquad (1)$$

The intensity I, that is, the energy received per unit time and unit area, is thus inversely proportional to the square of the distance to the source:

$$I \propto r^{-2} \qquad (2)$$

As can be shown theoretically, the intensity of an electromagnetic wave is proportional to the square of the amplitude. The surface brightness possesses the property of being independent of the distance between light emitter and receiver. This derives from the fact that the intensity of light from each point source and, each small object area, decreases with distance according to the expression (2), but the reception solid angle for the object area decreases in exactly the same manner.

In a CCD camera, the traditional film strip in a camera is replaced with an integrated light detector, CCD(charge coupled device), that is, a microelectronic unit based on semiconductor technology. This chip may be regarded as a large number of individual light detectors arranged in a designated area. The individual detectors are called the pixels of the CCD, and a typical number might be 640×480 or higher - a spatial resolution[5].

In this study, 640×480 CCD, or 2,272×1,704 CCD was used to capture desired portion of the fabric specimens under specific illumination conditions. The images were stored in the computer for further image processing and analysis to determine the luster or optical properties of the fabric specimens.

2. 3-dimensional modeling and rendering

In order to interpret the luster properties of actual fabrics, 3-dimensioanl yarn models are constructed. Assuming the filaments composing the yarn are parallel to the yarn axis, and the cross-sectional shape of the filament is round, 3-dimensional filament yarn models are prepared. One of the representations of 3-dimensional objects is the wireframe model. In this model, the object is displayed as a set of lines that join vertices. The wireframe model could be shaded with removing hidden surfaces from the viewpoint.

In this 3-dimensional yarn modeling, a NURBS (Non-Uniform Rational B-Splines) based modeler, Rhinoceros(McNeel and Assoc., USA)[6] , was employed. NURBS are mathematical representations of 3-dimensional geometry that can accurately describe shapes from a simple 2-dimensional line, circle, arc, or curve to the complex organic free-form surface or solid. Each yarn model was comprised of 13 continuous filaments. Rendering was implemented with a rendering program, BMRT(Blue Moon Rendering Tool).

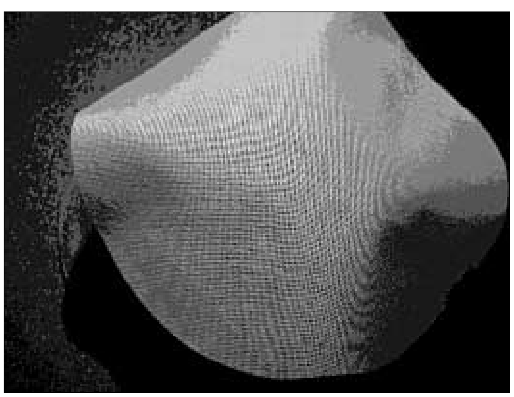
3. Image Analysis

Even if the commonly used term *information* has rather different meanings depending upon the context, it is possible to say that information may be represented and transmitted in some physical form. One of the most efficient media for representing idea or transmitting information is *images*. The difference between images and other types of signals-the quantities representing and transferring the information- is mainly the fact that an image constitutes a surface, a two-dimensional space, over which the signal values are allowed to vary. In contrast, our perception of sound is one-dimensional. Also, the electric field is a temporal and a one-dimensional signal, whereas the electric field is an example of a spatial one-dimensional signal.[7] We may want to process an image for qualitative reasons-that is, to improve fabric appearance and make it easier to examine visually. Most frequently, however, we want quantitative answers, such as the number, size and shape of the objects such as luster unit we are studying. The images were processed and analyzed using Global Lab Image/2(Data Translation, USA) and ImageJ(NIH, USA). Histogram values were exported to the MS Excel program to prepare proper charts.

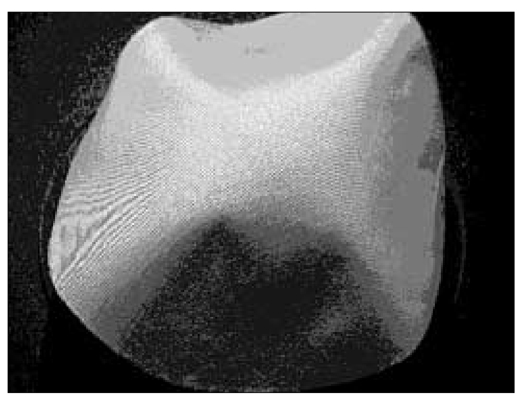
III. Results and Discussion

A number of finishes are applied to textile fabrics and garments in order to enhance their appearance and handle. Fabrics could be made to have deep gloss or soft sheen surfaces by finishing process. For example, Cire fabrics are those with a deep, glossy surface. The deep luster partially comes from the finish and special calendering process, which involves the use of roller whose surface is highly polished and heated. The deep gloss on this type of fabrics is therefore the results of the thermal treatment, the wax, the roller speed difference, and the pressure that is imposed on the fabric material to flatten the fabric surface. These altogether add to the uniformity of the light reflection.

Readily found cotton plain weave fabric(C1) is shown in Figure 1, which does not present lustrous look so much. As a comparison, in Figure 2, chintz cotton fabric(C2) is shown, which has more glamorous luster than the previous



<Fig. 1> Cotton plain fabric, C1



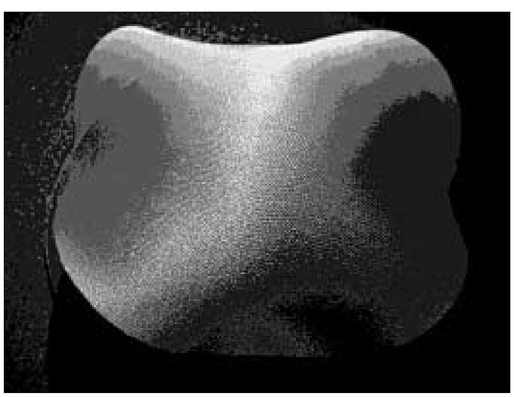
<Fig. 2> Cotton chintz fabric, C2

specimen. The surface finishing endowed on the chintz cotton fabric, together with the higher number of yarns of the specimen reflecting incoming light ray, could explain the lustrous look of the specimen.

Polished fabrics are usually cotton plain weave fabrics with either a surface layer of starch or wax in which case the finish is temporary, or a resin for a more durable finish effect. Polished cotton and chintz are commonly found glazed fabrics. To glaze or polish a fabric, it is first immersed in a chemical solution comprising the starch, wax, or resin and subsequently dried. The fabric is then passed through a calender.

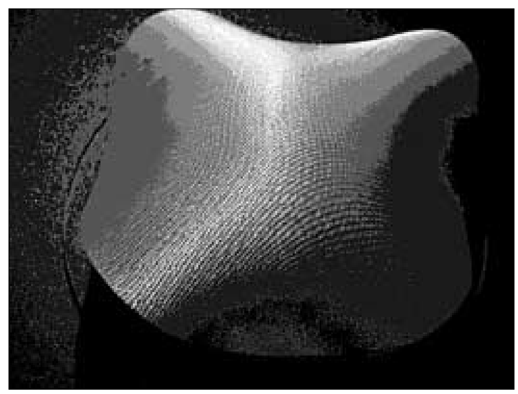
In Figure 3, silk satin fabric(S) is shown. For comparison, polyester silk-like fabric specimen(P) is shown in Figure 4a. The silk fabrics are known to have excellent luster, softness, and unique bulkiness. Cultivated silk fiber, from which the sericin or silk glue has been removed, is translucent and white with a soft subdued luster.

The luster of silk fibroin is higher than that of sericin-coated silk fiber. The luster of degummed or scoured silk fiber is subdued with somewhat occasional glittering. It stems from the fact the silk fibroin has relatively high crystallinity and its trilobal cross-sectional shape.

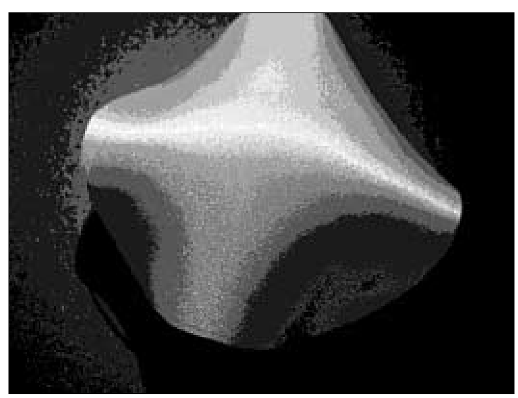


<Fig. 3> Silk fabric, S

Dried and mature cotton fiber appears as a flat and twisted ribbon. The fibrils comprising spiraling layers of the fine structure of the cotton fiber are composed of linear cellulose. The convolutions developed during drying of the mature cotton fiber are another factor that adds to the comfort of the fiber. The luster of cotton fiber is generally low. The convoluted fiber surface reflects light in a random and scattered pattern. The low luster of cotton fiber and the fuzziness of cotton yarns due to those protruding free fiber ends result in low luster cotton fabrics. Cotton

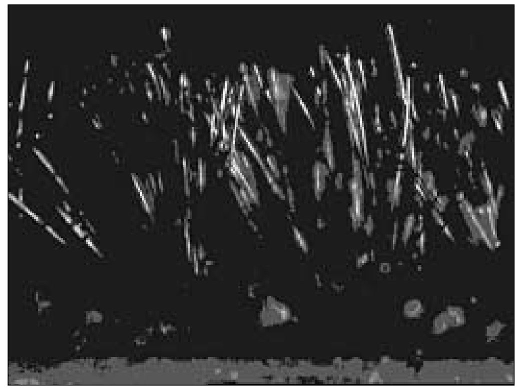


<Fig. 4a> Polyester fabric, P



<Fig. 4b> Polyester fabric, P. Warp direction parallel with the incident light

<Fig. 5a> Velvet fabric, V



<Fig. 5b> Enlarged view of the pile fibers on the velvet fabric specimen

fabrics have good bulk and cover. Therefore opacity requirements are generally met during general use.

In Figure 4b, the effect of specimen direction is demonstrated with comparison to the one in Figure 4a. When the specimen's warp direction is parallel to the plane of incident light direction and receiving direction, the luster intensity on the specimen, in general, becomes stronger than in the previous direction. Since the satin fabrics have long float of yarns[8], either warp direction or filling direction, the luster property has some dependency on the illumination or observing direction. When the direction of light source and the camera are parallel with the floating warp or filling yarns, reflection intensity becomes relatively stronger than in the other direction.

Velvet fabric is a good example of peculiar luster fabrics. The surface fibers on the velvet specimen, as in Figures 5a and 5b, in most cases do not reflect incoming light very much, since only the fiber tips are being observed. When the long surface fibers are exposed in such a case as some part of the velvet fabrics are bent sharply, large amount of incident light is reflected from that section.

Luster is one of the important aesthetic properties of textile fabrics. If a light ray falls upon a surface, it could be reflected along the angle of reflection in a specular manner, or diffuse. The overall appearance resulting from these reflection modes determines the material luster. In textile fabrics, fabric luster is easily observed subjectively. Objective characterization of the fabric luster, however, is highly complex due to the nature of fiber, yarn, and fabric structures.

In case of the plastic or the paint manufacturing, the visual appearance of the products could sometimes be described using some of the terms such as gloss, glitter and shade, or haze, glare out of numerous descriptors. Since the textile fabric surface or the matrix of fiber assemblies are somewhat complicated than flat plastic sheets or films in terms of the number of independent comprising objects, the luster descriptions are said to be quite diverse. In case of the traditional silk fabric alone, the satin weave gives the fabric more sparkling look when compared to some of the silk fabrics composed of spun silk yarns which imparts the fabric rather subtle and subdued

<Table 2> Image analysis result of fabric specimens

Specimen code	Fiber material	Average	Std. dev.	CV%
C1	cotton	60.42	11.27	18.7
C2	cotton	83.36	11.14	13.4
S	Silk	77.73	27.06	34.8
P	PET	94.60	39.90	42.2

luster.

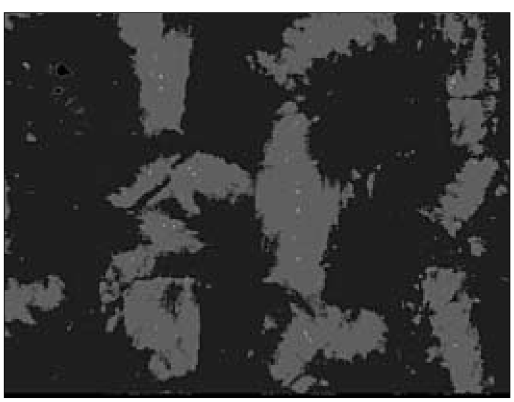
Due to numerous paths of the light reflection or transmission within the myriad of layers of filaments or fibers comprising the textile fabrics, each type of textile product has its own characteristic appearance or luster and optical properties. Therefore it would be quite difficult to clear-cut the appearance of the textile fabric or luster of the fabrics using some selected describing terms.

In order to have better understanding of the fabric luster in detail, microscopic images were analyzed using image analysis programs.

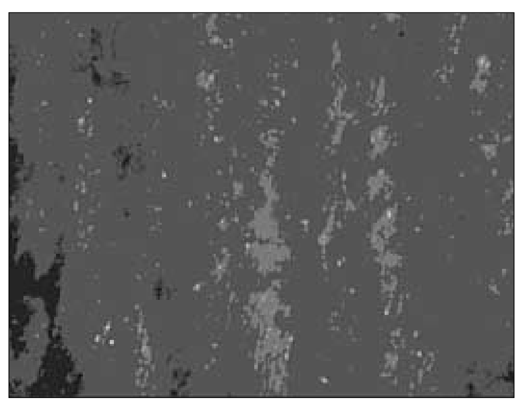
In Table 2, the image analysis results are shown for fabric specimens. As was discussed earlier, the amount of reflection, on an arbitrary scale of 0(black) to 255(white), from C1(cotton plain) is lower that that from C2(chintz), reading 60.42 versus 83.36 respectively. With silk(S) and PET silk-like fabric(P), the readings are 77.73 and 94.60. The polyester silk-like fabric presents much stronger luster.

Figures 6a and 6b are enlarged views of cotton(C1) and cotton chintz(C2). Figures 7a and 7b are histogram representation of the pixel values, for the selected ROI(region of interest) of 350,000 pixels, in the images. As is readily recognized, the C2 sample shows higher position of the histogram peak in the pixel value axis compared to C1. However, the cotton chintz(C2) has more yarns per unit length leading to more reflecting area under specific illumination condition. Therefore it would be reasonable to analyze the image on a yarn to yarn basis.

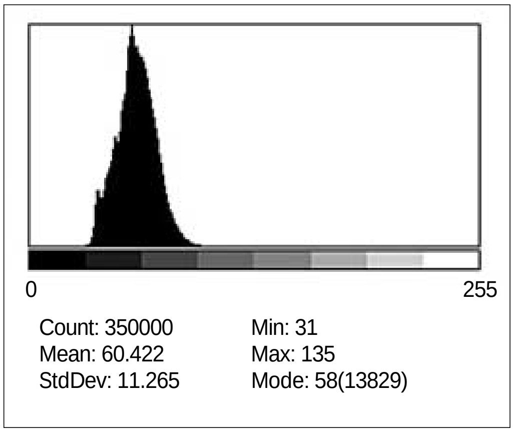
More detailed analysis of the images at a yarn scale was attempted to explain the luster quality of the two cotton fabrics. As shown in Figures 8a and 8b, the luster on a selected part of a single



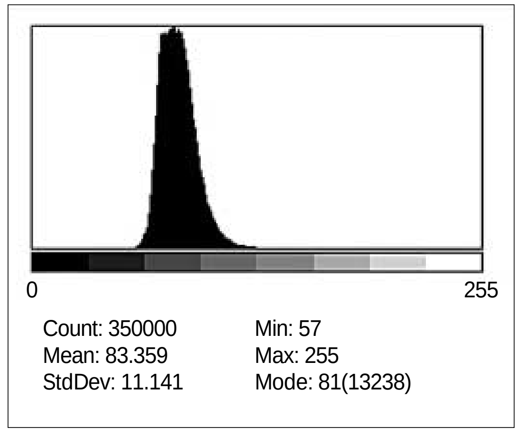
<Fig. 6a> Enlarged view of cotton, C1



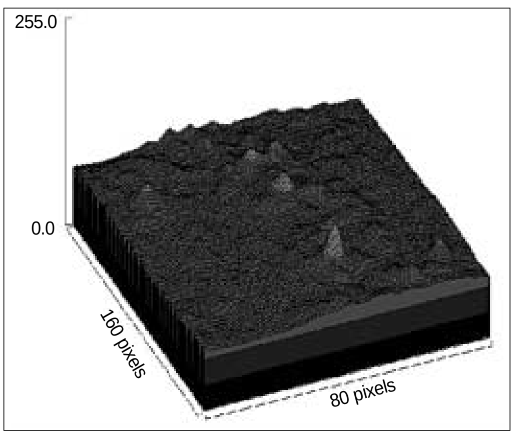
<Fig. 6b> Enlarged view of cotton, C2



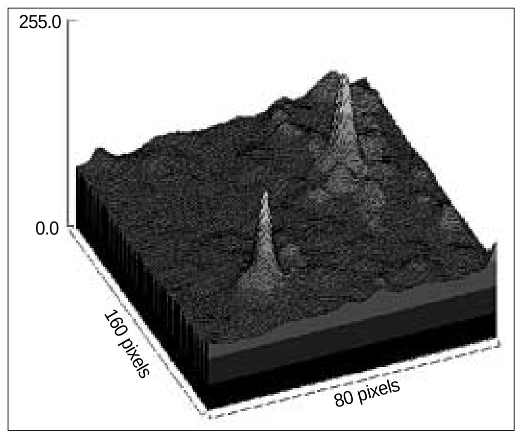
<Fig. 7a> Histogram of cotton fabric, C1



<Fig. 7b> Histogram of cotton fabric, C2



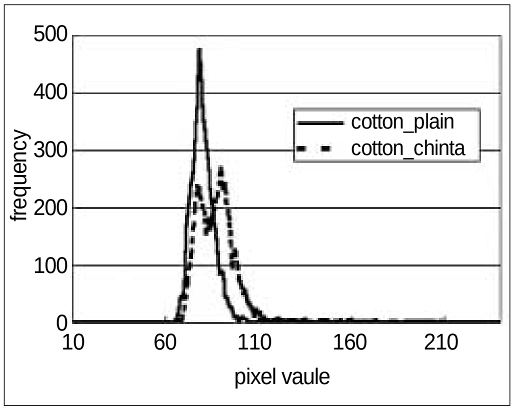
<Fig. 8a> 3-dimensional representation of a part of yarn on cotton fabric, C1



<Fig. 8b> 3-dimensional representation of a part of yarn on cotton fabric, C2

warp yarn comprising each fabric is represented as a 3-dimensional plot. Vertical axis of the plot represents the amount of reflection, on an arbitrary scale of 0(black) to 255(white) from the fabric surface. Evidently, the yarn comprising the chintz fabric specimen has more lustrous area than the plain cotton fabric(C1).

As shown in the Figure 9, the chintz gives off more luster than the plain cotton fabric does. Since the finishing process generally involves the use of calender, the cotton fabric is imparted lustrous appearance. The other factor on top of the finishing process is that the satin weave structure of the fabric specimen has long floating yarns than the plain fabric specimen which has short repeating sinusoidal waviness. If the cover factor values of the fabric specimens are the same, number of reflecting surfaces might be larger for the plain weave. In some specific case, however, such as the light source direction is in a specularly reflecting direction toward the CCD camera, the long floating yarns of the satin weave

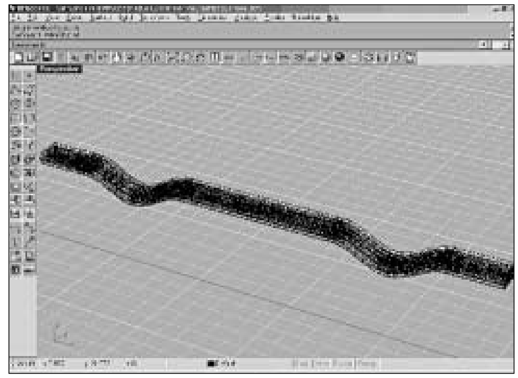


<Fig. 9> Histogram of cotton fabric specimens, plain and chintz

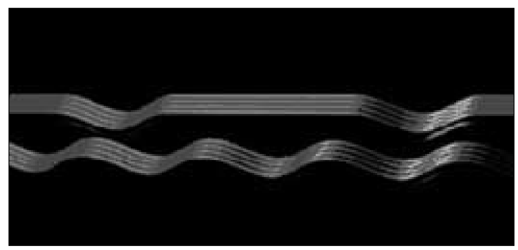
could provide the fabric more specularly reflecting surface area.

This effect could be explained using some model yarn constructed using three-dimensional modeling tool and ray tracing programs. With the lighting position change, one could easily analyze the luster behavior under some designated condition.(Figures 10a-10b) In Figure 10c, the reflection of the yarn model from a satin weave shows relatively continuous and flat pattern at a specific illumination condition, while that from a plain weave shows wavy pattern.

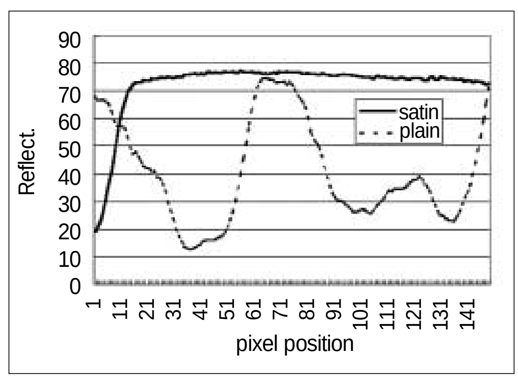
The silk and PET silk-like fabric has distinct luster properties. The subtle luster of silk fabrics has been one of the objectives of the silk-like fabric development originating from polyester material. In Figure 11, the histogram of the pixel values in the image of silk fabric is shown. While the pixel value range of most of the pixels are from 50 to 160, a small number of pixels corresponding to the highly lustrous portion of the image are located to the rightmost part of the x-axis around the values of 250~255. In the Figures 12a and 12b, the differences in the reflection from the specimens are readily recognizable. The



<Fig. 10a> 3-dimensional simulation of filament yarns in a satin weave (mesh and shaded)

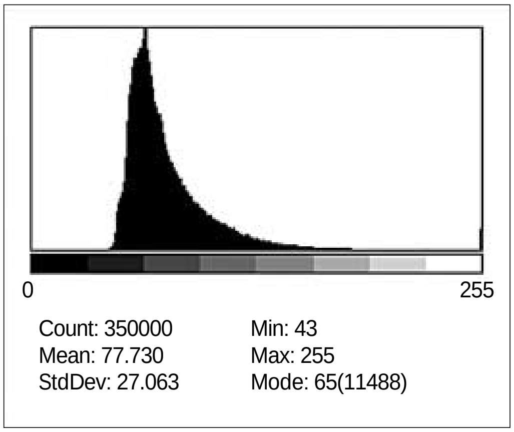


<Fig. 10b> Rendered image of 3-dimensional simulation of filament yarns in a plain(front) and satin(back) weave

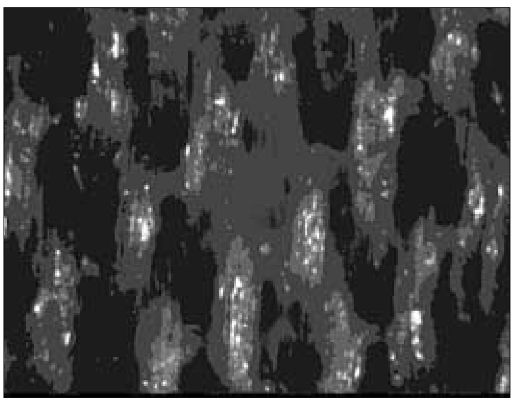


<Fig. 10c> Profile plot of yarn from satin and plain weave on the rendered image

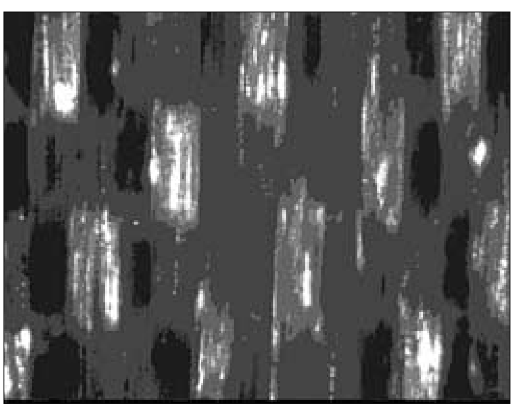
pattern from PET is rather strong and continuous throughout the floated portion of the filament yarn bundle, while that from silk is smaller and



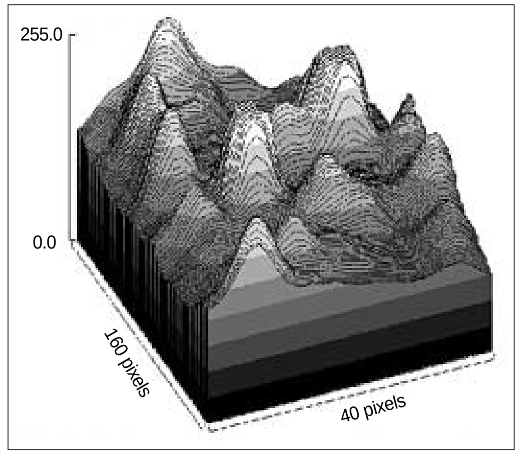
<Fig. 11> Histogram of the enlarged view of silk fabric, S



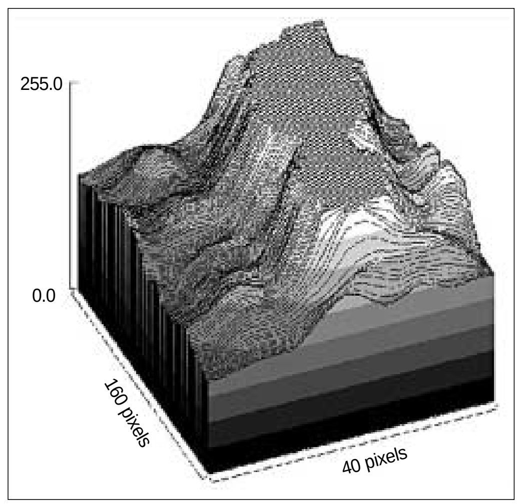
<Fig. 12a> Enlarged view of silk fabric, S



<Fig. 12b> Enlarged view of polyester filament fabric, P



<Fig. 13a> 3-dimensional plot of luminance distribution of silk yarn



<Fig.13b> 3-dimensional plot of luminance distribution of PET yarn

distributed in small units of gloss on the floated silk yarn. The difference is 3-dimensionally represented in Figures 13a and 13b. Vertical axis of the plot represents the amount of reflection, on an arbitrary scale of 0(black) to 255(white) from the fabric surface.

IV. Conclusions

Image analysis methods have been applied to delve into the luster characterization, subtle or strong, of several fabric specimens which have definable surface characters. Compared to the cotton plain weave fabric specimen, C1, which has low fabric count, satin weave chintz cotton fabric specimen, C2, shows more luster objects on its component yarn. If the cover factor values of the fabric specimens are the same, number of reflecting surfaces might be larger for the plain weave. In some specific case, however, such as the light source direction is in a specularly reflecting direction toward the CCD camera, the long floating yarns of the satin weave could provide the fabric more specularly reflecting surface area. The calendering process together with the weave structure and higher fabric count of the satin could have imparted the cotton fabric better luster. Also, the general grade silk-like polyester fabrics resemble silk fabric with some limit in terms of luster properties. The pattern from the silk-like polyester fabric is rather strong and continuous throughout the floated portion of the yarn bundle, while that of silk is smaller and distributed in smaller units of gloss on the floated silk yarn. With the three-dimensional modeling tool and ray tracing programs, yarn models having the crimp patterns within the fabrics. The reflection of the yarn model from a satin weave shows relatively continuous and flat pattern at a specific illumination condition, while that from a plain weave shows relatively wavy pattern. This could provide some explanation of the luster differences due to the fabric weave differences.

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