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Measuring thickness of translucent plastic by scanner

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ABSTRACT

Thickness measurement is important in various engineering fields. The several methods have been used to measure the thickness. This work explains a novel method for measuring the thickness of translucent plastic materials using scanner. The plastic samples were scanned against a white and a black background and the RGB parameters of obtained images were used to measure the opacity. Then, the thickness was calculated using relationship between thickness and opacity of samples. The best thickness prediction was obtained using a 3rd polynomial regression with the XYZ parameter.

1. Introduction

The measurement of thickness is the one of the most fundamental measuring fields and is important in physical investigations, industrial applications and in engineering such as mechanics, optics, photographical and chemical industries [1–3]. Recently, several approaches have been employed to measure the sample thickness that can be classified such as destructive and nondestructive [2,4].

The scattering of photon depends on the thickness of the layer that it passes through. When light passes through a transparent object such as a layer of water that includes absorbing materials, a part of the light is absorbed and the remainder is transmitted. The light absorption in these layers depends on their thickness. Translucency is obtained by inclusion of pigments in transparent materials such as plastic, rough sanding of a glass or plastic surface which some light passes through the object, whereas the remainder scatters on the surface or interior. In these materials, the light absorption depends on the concentration of colorant and their thickness [5]. Also, in these materials, the transmittance rapidly decreases with increasing thickness. So the reflectance increases with increasing thickness to approach the opaque layer value. In opaque colored objects, the light reflectance does not change with increasing thickness [6,7].

The color scanner usually has three rows of CCD sensor elements, which measure the amount of light. To make this grayscale photo into the three primary computer colors, these sensors covered with red, green and blue (RGB) filters [8,9]. The color of each image pixel is shown by three values in various color spaces. Therefore, a color image is represented by a vector field, that each direction and length of vector is related to the pixel's chromatic properties [10].

In this work, the thickness of plastics was determined by measuring the opacity factor by scanner. In this method, the RGB values of samples images were converted into several color spaces and then the opacity was evaluated in those color spaces. Several regression equations were used to make relation between the opacity and thickness.

2. Materials and methods

The performance of scanner for measuring the thickness of plastic was evaluated using 5 samples in various colors. Each sample was scanned over white and black paper as a background. The thicknesses of samples were measured by Digital thickness gauge M034A of SDL Corporation. The samples thicknesses are shown in Table 1.

The reflectance spectra and color parameters of samples were measured by XRite Color Eye 7000A spectrophotometer. The reflectance spectra were measured within the visible spectrum at 16 wavelengths at 20 nm intervals from 400 to 700 nm. The color and reflectance measurement was repeated 4 times. The average of color and reflectance was used to calculate the opacity. The reflectance spectra of samples over gray background are shown in

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Table 1
Thickness of samples.

Sample	Thickness (μm)
1	25
2	30
3	12.5
4	18
5	15

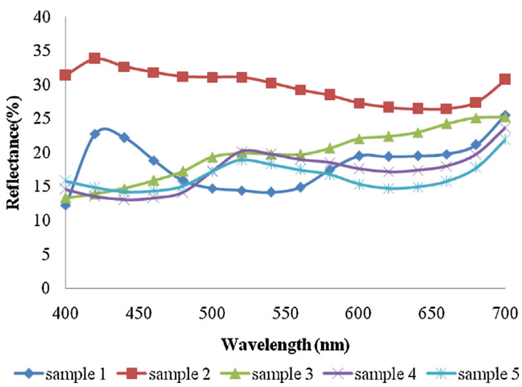

Fig. 1. The reflectance spectra of samples over gray substrate.

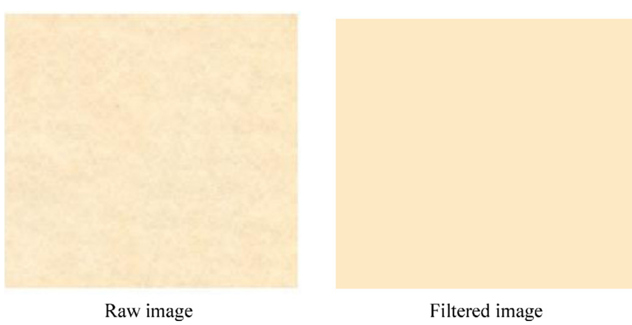

Fig. 2. The mean filtration of image.

Fig. 1. The color parameters were measured under 10° standard observer and D65 standard illuminant. The color parameters of samples are shown in Table 2.

The samples were scanned using HP Scanjet G3010 scanner at 200 ppi condition. The scanning was repeated for several layers of plastic. The obtained images were not smooth and the RGB values of pixels were changed in image. So, for obtain the color parameters (RGB), the average filter was used to remove unevenness of images. Fig. 2 shows the raw and filtered image. The RGB values of images were converted into various color systems. The color parameters of samples over white and black background were used to measure the opacity of samples. In order to measure the thickness, dataset divided in two set as training and testing dataset. The linear, exponential, power, 2nd, 3rd, 4th and 5th order polynomials regression were used to make relationship between opacity and thickness. The accuracy of thickness estimation was calculated using Eq. (1)

$$\text{Accuracy} = \frac{\left\lfloor \text{predicted thickness} - \text{actual thickness} \right\rfloor}{\text{actual thickness}} \times 100 \qquad (1)$$

3. Results and discussion

The RGB values were converted to other color spaces such as the CIELab (D65, 10°), Grayscale, sRGB, CMYK, hLab (Hunter Lab), XYZ and LSLM. Also, the XZ color space was given by the sRGB method. Then the opacity factor of samples was calculated in several color spaces by following equations:

$$\text{RGB : opacity value} = \frac{\text{Avg}(R, G, B)_{\text{black}}}{\text{Avg}(R, G, B)_{\text{white}}}$$

$$\text{CIELab : opacity value} = \frac{L^*_{\text{black}}}{L^*_{\text{white}}}$$

$$\text{Grayscale : opacity value} = \frac{(\text{value})_{\text{black}}}{(\text{value})_{\text{white}}}$$

$$\text{sRGB : opacity value} = \frac{\text{Avg}(R, G, B)_{\text{black}}}{\text{Avg}(R, G, B)_{\text{white}}}$$

$$\text{CMYK : opacity value} = \frac{(1 - K_{\text{black}})}{(1 - K_{\text{white}})}$$

$$\text{hLab : opacity value} = \frac{L_{\text{black}}}{L_{\text{white}}}$$

$$\text{XYZ : opacity value} = \frac{Y_{\text{black}}}{Y_{\text{white}}}$$

$$\text{LSLM : opacity value} = \frac{L_{\text{black}}}{L_{\text{white}}}$$

The opacity factors of samples 1–5 are shown in Tables 3–7, respectively. The opacity factor of each sample was evaluated at 1–12 layers. As shown in these tables, the opacity increases with increasing the number of layers.

The effect of samples opacity on relationship between opacity and number of layers are shown Fig. 3 As shown in this figure, the opacity (Grayscale system) of sample 2 is more than samples 1, 3, 4 and 5.

The samples with 1, 2, 4, 6, 8, 9, 11, 12 layers were used to obtain the relationship between thickness and opacity factor. The performance of thickness estimation method was evaluated using samples with 3, 5, 7, 10 layers. The total accuracy of thickness estimation using the RGB, CIELab, Grayscale and sRGB color spaces is shown in Table 8. As shown in Table 8, the best accuracy of thickness estimation in the RGB values is 3.69% which is obtained using a 3rd order polynomial regression. The best accuracy of thickness estimation in the CIELab color system is 3.37%

Table 2
Color specification of samples over gray substrate.

No. of sample	L^*	a^*	b^*	C^*	h	Opacity	
						$L^*_{\text{black}}/L^*_{\text{white}}$	$R_{\text{black}}/R_{\text{white}}$
1	47.23	11.15	−7.67	13.54	325.48	0.51	0.24
2	61.22	−2.38	4.01	4.66	239.24	0.63	0.33
3	51.93	0.40	9.49	9.50	87.56	0.47	0.21
4	49.87	−5.29	10.71	11.95	116.30	0.48	0.19
5	48.24	−6.02	5.40	8.09	138.13	0.46	0.18