Bezier-Exemplar Hybrid based Image Inpainting Method in Computerized Colorimetric Protein Estimation System

K. S. Sim, *Member, IAENG*, C. K. Toa, *Member, IAENG*, Z. Y. Lim, and L. C. Y. Kathy

***Abstract*—During the quality assurance process of latex gloves, the modified Lowry method is considered as one of the standard methods to determine the protein concentration for quality assurance. Nevertheless, this traditional method requires several tedious chemical processes, which results in time-consuming. To overcome this weakness, our previous work has implemented a new method based on image processing namely Computerized Colorimetric Protein Estimation Method (CCPE). This method provides fast and efficient in determining the protein concentration with an uncomplicated chemical test and the aid of computer vision technology. In the CCPE method, there will be a section where a scanner will be used to scan glove samples and convert samples into a digital image. Afterward, the digitalized glove sample image will go through computerized algorithms to estimate the protein concentration. However, during the scanning process, wrinkles on the image will affect the accuracy of the estimation results. Thus, this paper presents our implemented Bezier-exemplar Hybrid based Image Inpainting (BeHbII) method that is used to eliminate out the wrinkle of the image efficiently. The results shows that the inpainting method can restore the wrinkled image up to 99% similarity based on the unwrinkled original image of the same glove model and improve the accuracy of protein concentration detection up to 96%. This method does not limit to the latex glove imaging process but contributes to other imaging fields that face the wrinkles issue too.**

***Index Terms*—Latex Glove, Image Processing, Inpainting, Wrinkles**

I. Introduction

For just over a year of the COVID-19 pandemic, latex gloves have become one of the highly used personal protective equipment (PPE), not only for the healthcare worker but also for the civilian. Latex surgical gloves are made from natural rubber latex [1]. In the medical and healthcare environment, latex gloves are used in protecting patients and healthcare workers from exposure to bloodborne pathogens and other harmful substances through contact with bodily fluids [2], [3]. Even though latex gloves have been seen as a significant piece of PPE in the healthcare environment [4], it is also one of the possibilities of causing latex allergic reactions to the user [5], [6]. Thus, protein concentration detection is mandatory in assuring the quality of latex gloves to avoid causing allergy to the user [7], [8].

The Computerized Colorimetric Protein Estimation (CCPE) method is a simple and efficient method in determining protein estimation. In our previous work [9], we implemented the CCPE method to overcome the limitation of the Modified Lowry method, i.e., the need for numerous types of chemical reagents, high chemical cost, and time-consuming. Fig. 1 shows the process of the CCPE method in chemical test, image acquisition, and color difference calculation.

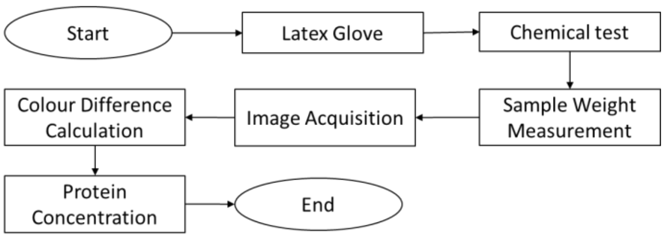

Fig. 1. The process flow of the Computerized Colorimetric Protein Estimation (CCPE) method.

The process of the CCPE method can be divided into several main parts. First is the chemical test where Bradford protein assay is used as a chemical reagent to detect the proteins located on the gloves. The color of the glove sample will turn into blue color with the presence of protein on the glove surface. Second, the weight of the glove samples will be measured using the analytical balance. These weight data will be used to help calculate protein values. Third, a flatbed scanner will be used to digitally convert the glove samples into a digital image through the scanning process. Fourth, a colorimetric analysis algorithm will be applied to the glove sample image to calculate the color difference values. Fifth, the weight and color difference data will be used to plot the graph to estimate the protein concentration [9].

However, during the image acquisition process, the wrinkles which appeared on the glove samples greatly affected the color difference calculation data. The wrinkled surface will negatively influence the color difference

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K. S. Sim (Corresponding Author) is a Professor of Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, , Malaysia. (e-mail: kssim@mmu.edu.my).

C. K. Toa is a PhD candidate of Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia. (e-mail: toacheankhim@yahoo.com)

Z. Y. Lim is a PhD candidate of Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia. (email: zhengyou_93@live.com)

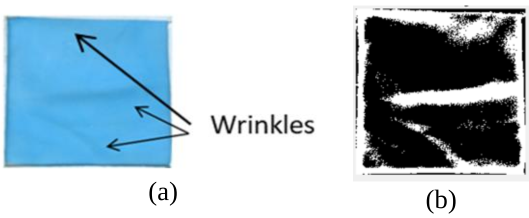
L. C. Y. Kathy is a graduate student of Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia. (email: ktlim817@gmail.com)

calculation in the image, thus, lead to incorrect estimation of protein concentration.

To solve the wrinkles issue, an image inpainting algorithm is proposed. The Bezier-exemplar Hybrid based Image Inpainting (BeHbII) method is the implemented algorithm to overcome the wrinkles issue efficiently. Exemplar-based techniques are effective in terms of processing cost and time in producing a patch according to the source image [10] [11]. The texture is constructed in the target region pixel by pixel using the produced patch [12]. However, this method only works efficiently for linear structure and most of the images including the wrinkled images are not in a linear structure. This method is further enhanced by employing Bezier curves to generate the target region [13]. In this way, it can eliminate the wrinkles from the image by preserving smooth contours and color values. The objective of this paper is to implement the effective image inpainting method in a computerized colorimetric protein estimation system for solving wrinkles issues.

II. Implementation Method

The exemplar-based technique is known as an effective inpainting technique in terms of processing cost and time in identifying the inpainting patches and generating a new texture [14], [15]. To provide smooth contours, the Bezier curve is proposed to refine the color value of the generated texture. Thus, this method is named as Bezier-Exemplar Hybrid based Image Inpainting (BeHbII) method. By integrating these two techniques, it provides an efficient approach that protects the information of structure and texture during image reconstruction. This approach is suitable to eliminate the wrinkles and brown stained marks which appeared at the latex gloves, where the targeted region is filled with the background information. Fig. 2a shows that the wrinkles represent the targeted region in latex gloves images. Fig. 2b represents the blue intensity mask of Fig. 2(a). The white region in Fig. 2(b) indicates the targeted region which is the wrinkled part by using the threshold function.



(a) (b)

Fig. 2. Scanned wrinkled glove sample. (a) Original image; (b) Threshold mask image.

In the BeHbII method, the inpainting region is the target region to be determined. Next, the confidence values are generated for all the pixels involved in this region. For the inpainting domain pixels, the confidence value is initialized to one, which indicates white color. Fig. 3 shows the procedure for filling the targeted region, and the steps are repeated until it is filled.

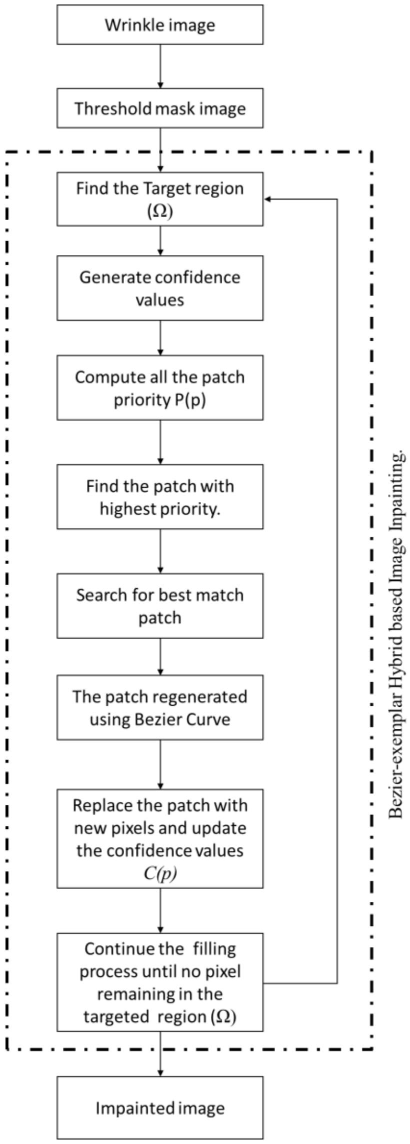


Fig. 3. The detail process flow using the Bezier-exemplar Hybrid based Image Inpainting (BeHbII) method.

The threshold mask is used to select the target region from the background. The mask is distributed to 3 color masks which are red, green, and blue masks. Next, to find the region with the wrinkle information, a source region (Φ) is calculated using Equation 1.

$$\Phi = \mathrm{I} - \Omega \qquad (1)$$

where I is the input wrinkle image and Ω is the target region selected using the threshold mask. In the target region, the confidence values will be generated for all the neighboring pixels and those pixels will then congregate together. The congregated pixels are known as the contour or boundary. Then, the contour points are used to generate a vector. A patch is generated by using the contour or boundary points.

The priority of the patch is determined by using the confidence term *C(p)* and the data term *D(p)*. *C(p)* determines the number of pixels filled up in the patch. *D(p)* stimulates the generation of the color values for the target region. The size of the mask which is also known as the window Ψ has the default setup of 9 x 9 pixels. However, this value can be adjusted larger if the element is greater in size.

The high-priority filling strategy is employed to reconstruct the targeted region. In this technique, the targeted patch is chosen according to its calculated priority value. Therefore, a patch is built with that pixel placed in the middle for each boundary pixel. The existence of confidence term and data term on the continuation of strong edges and more amount of filled pixels contained by confidence term and data term with known information are the criteria considered by patch priority. The patch priority *P(p)* is calculated for every patch in the targeted region. The patch priority *P(p)* for a patch, Ψ_p, is computed by using Equation (2).

$$P(p) = C(p) \times D(p) \qquad (2)$$

where *p* is the pixel, $p \in \delta\Omega$, *C(p)* is the confidence term and *D(p)* is the data term.

The calculation of confidence terms *C(p)* and *D(p)* is denoted at Equation (3) and Equation (4).

$$C(p) = \frac{\sum q \in \Psi p \cap (1 - \Omega) c(q)}{|\Psi p|} \qquad (3)$$

$$D(p) = \frac{|\nabla Ip \perp . n_p|}{\alpha} \qquad (4)$$

where α is the normalization factor, n_p is a unit vector orthogonal to the front in the point *p*. *C(p)* is the calculation of the number of color values relevant to the pixel. *D(p)* is a function used to generate texture information.

The color values and information for the target patch can be obtained from the source region, Φ. When all priorities have been computed, the highest priority of the patch can be found, which will then be filled with the data extracted from Φ as shown in Equation 5.

$$\psi_{\hat{p}} = \arg \max_{p \in \delta\Omega} P(p) \qquad (5)$$

where Ψ_p is the target patch and $\delta\Omega$ is the target contour.

In the reconstructed image, the blurring is apparent if the pixel value from the source region is disseminated through diffusion. The resultant texture of the inpainting image is determined by the information of the source patch. Thus, the patch from the source region is preferred with the highest similarity with the target patch. Equation (6) shows the calculation used to search for the best match patch by determining the patch in the source image that has the highest similarity to the highest priority target patch, Ψ_p.

$$\Psi q = \arg \min_{\Psi q} d(\Psi p, \Psi q) \qquad (6)$$

where Ψ_p is the target patch, Ψ_q source patch, and $d(\Psi_p, \Psi_q)$ is the distance between the source patch and target patch is determined using the sum of squared differences. When the Ψ_q is found, each pixel value is transferred from Ψ_q to the Ψ_p. Thus, the information of the color values is disseminated from the source region to the targeted region patch by patch based on the priority.

The color difference within the object surface or texture in the real world does not change linearly or drastically. Instead, the color difference is changing more like polynomial curves within the same surface. Thus, color values from the source patch will be regenerated using the Bezier Curve. The Bezier curve is used to design polynomial curves where the pattern of the curve can be designed in a relatively simple way. The pattern of the Bezier curve can be manipulated by the control points. The path of the Bezier curve will change according to different control points. Given the called control points $P_{cc} = \{P_0, P_1, P_i, \ldots, P_n$, $0 \le i \le n$ for the Bezier curve. In this approach, the quadratic Bezier curve is implemented, thus *n* = 3. This curve is a Bezier curve of degree 2 and is defined through 3 points which are P_0, P_1, and P_2. Thus, the color value is calculated using the formula of the Bezier curve, B(v) expressed in Equation (7).

$$B(v) = (1 - v)^2 P_0 + 2v(1 - v)P_1 + v^2 P_2 \qquad (7)$$

where *v* is the normalized value from 0 to 255 into 0 to 1, $v \in [0.1]$.

Later, the generated color values will construct the new pixels, which are then used to fill the highest priority target patch. Once the filling is completed for the patch, the confidence value of the patch is recalculated and updated, resulting in a lower value. Thus, the second-highest priority patch will be updated as the highest priority to continue the process. Equation (8) indicates the updated confidence, *C(p)* once the patch Ψp is filled with new pixel values.

$$C(p) = c(\acute{p}) \qquad (8)$$

The process continues with the next target patches with the highest priority. The filling process will only stop when no pixel remains in the targeted region. This indicates that the whole target region has been reconstructed and resulted in the inpainted image. Fig. 4 shows the simplified process flow of filtering the wrinkle on the latex glove image using the Bezier-exemplar Hybrid based Image Inpainting (BeHbII) algorithm.

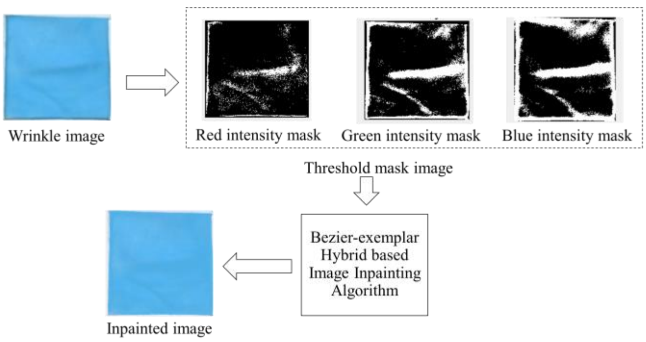


Fig. 4. The simplified process flow using Bezier-Exemplar Hybrid-Based Image Inpainting (BeHbII) method.

III. Experimental Results and Discussion

In this research, a total of 20 gloves were used for testing. For each glove, 7 samples, including 2 from palm, 1 from the thumb, 1 from the index finger. 1 from the middle finger, 1 from the ring finger, and 1 from the little finger are obtained. The sample images with wrinkles are applied with the implemented Bezier-Exemplar Hybrid-Based Image Inpainting (BeHbII) method and then compared visually with the wrinkled images. Table 1 shows 5 randomly selected samples of wrinkled images and the resultant inpainting images using the BeHbII method.

TABLE I
IMAGE INPAINTING ON WRINKLES SAMPLE IMAGES

Samples	Original Images	Inpainting image
Sample 1		
Sample 2		
Sample 3		
Sample 4		
Sample 5		

The visualization result shows that the wrinkled parts will produce a darker color intensity. After being applied with the BeHbII method, the wrinkles can be eliminated efficiently while preserving the smooth contours on the part of removed wrinkles.

Next, the calculation results are assessed by comparing the color difference, similarity percentage, percentage error, and accuracy values between the wrinkles and the inpainting. 10 samples are randomly selected with unwrinkled images and wrinkled images from the same glove model. The wrinkled images are applied with the BeHbII method and generate the inpainting image. Next, the color difference of all the samples based on color intensity is calculated using International Commission on Illumination Delta E (CIEDE) 2000 method [16], [17]. Fig. 5 shows the comparison of color difference for the wrinkled and the inpainting images based on the unwrinkled original image.

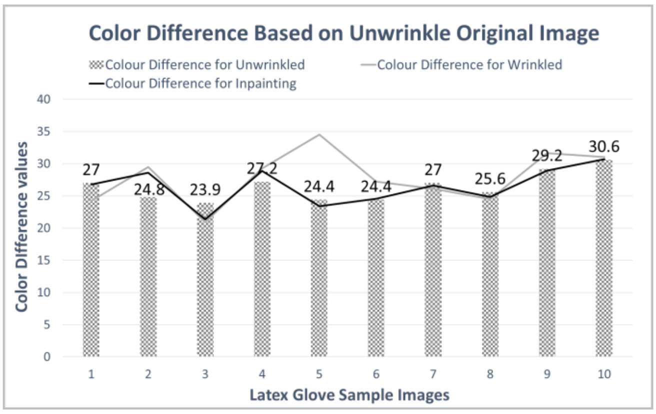


Fig. 5. The color difference of the wrinkled image and inpainting image will be compared with the unwrinkled original image.

The bar chart in Fig. 5 shows the color difference value of the unwrinkled original image, while the line chart is the color difference for both wrinkled and inpainting images. It seems that for sample 5, the wrinkled image has a color difference value of 34.547 which is 10.134 larger than the value of the unwrinkled image. For samples 1, 3, 4, 6, and 9, the wrinkled images also have a color difference value which is around 2.6 higher or lower than the value of unwrinkled images. As for the inpainting images, we can see that for samples 2 and 3, the color difference value is around 3.1 higher than the values of unwrinkled images. For the rest of the sample images, the color difference of inpainting images only has a value of around 1.08 higher than unwrinkled images. From these results, we can see that compared to the wrinkled images, the color difference values of most inpainting images are closer to those of unwrinkled images, indicating that the BeHbII method able to filter out the wrinkled and generate images that are closer to the unwrinkled images.

The performance of the BeHbII method was also further assessed by the similarity percentage based on the CIEDE 2000 value of the unwrinkled original image. Fig. 6 shows the visualized result for the similarity percentage.

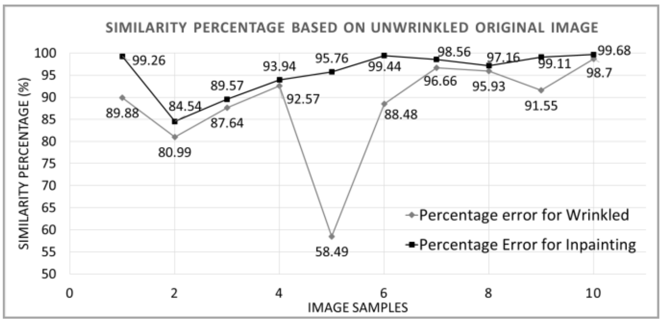


Fig. 6. Similarity percentage of wrinkled images and inpainting image based on the unwrinkled original image.

According to the results of Fig. 6, it indicates that wrinkled images have a similarity percentage from 58.49% to 98.7%, while the BeHbII method can generate inpainting images that had a similarity percentage from 84.54% to 99.68%. Some of the inpainting sample images can achieve 99% of the similarity percentage after being applied with the BeHbII method on the wrinkled image. This shows that the BeHbII method able to correct the color difference on most of the wrinkled images.

Moreover, with the further intention of validating the performance of the developed BeHbII method, the accuracy of protein estimation of wrinkled images and inpainted images are compared with the actual protein concentration. By using CIEDE 2000 values of the samples, the average protein concentration is calculated by using the Computerized Colorimetric Protein Estimation (CCPE) method [7]. The accuracy is benchmarked with the actual protein concentration results provided by the Malaysian Rubber Board by using the modified Lowry method. Fig. 7 illustrates the percentage error and Fig. 8 illustrates the accuracy results based on the actual protein.

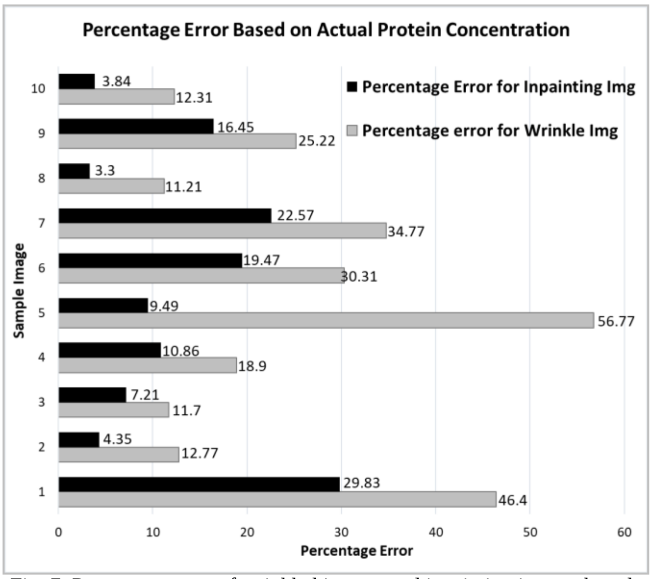


Fig. 7. Percentage error of wrinkled images and inpainting images based on actual protein concentration.

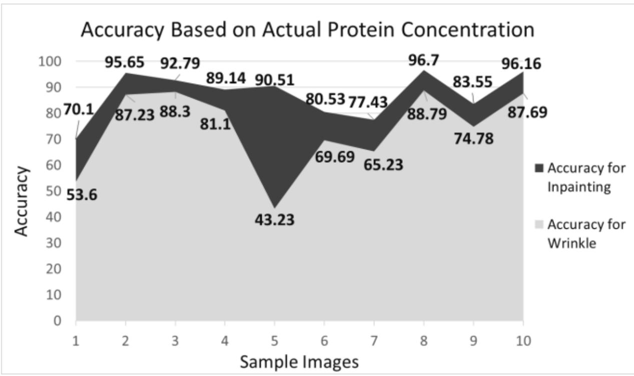


Fig. 8. Percentage accuracy of wrinkled images and inpainting images based on actual protein concentration.

Based on the results, it can be seen that the images applied with the developed BeHbII method yield a lower percentage error of about 3.3 to 29.83 and higher accuracy of about 70.17% to 96.7% in estimating the protein concentration of the latex glove samples. The method can reduce the error rate from 56.77% to 9.49% which eliminated 47.28% of error in total, as illustrated in the result for sample 5. Besides, as shown in Fig. 8, the BeHbII method was able to uplift the accuracy of protein concentration detection up to 96%, while the accuracy of wrinkle images was only 88%, which is an increment of 8%. This shows the efficiency and importance of this inpainting method in yielding better results.

IV. Conclusion

In conclusion, the Bezier-exemplar Hybrid-based Image Inpainting (BeHbII) technique is implemented to eliminate the wrinkles efficiently from the scanned glove sample images. The results indicate that this technique can remove wrinkles while preserving smooth contours on the surface. Besides, the efficiency and performance of the method are also verified by comparing the detection error and accuracy based on the actual result computed by the Malaysian Rubber Board. The results show that the inpainting method applied to the wrinkled image can correct the color difference and restore the wrinkled image up to 99% in terms of similarity of CIEDE value based on the unwrinkled original image of the same glove model. Besides, this method also uplifted the accuracy of protein concentration detection using the CCPE method up to 96%. Lastly, this technique is not only applicable in the application of latex glove samples but other imaging fields where the occurrence of wrinkles will cause a significant effect in their applications.

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