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Single Image Reconstruction of Human Heart Surface with Specular Reflection Remover

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***Abstract*—3D reconstruction with specular reflection remover is one of the vital and robust tools that provide aid in many fields, especially medical filed. This article presents a novel method for reconstruction a real human heart surface from a single view image with a remover specular reflection while keeping the image structure. Reconstruct a heart model from numbers of real images is difficult task and time consuming especially involve reflections, resulted from moisten of the human heart surface. In this paper, we propose a novel method for reconstruct a human heart from a single image while detecting and correcting the specular reflection. The process start with acquired the real heart image by a digital camera in cardiac surgery. Second, processed the image to extract the x, y, and z axes for each pixel and automatic detect the specularities using the difference of the maximum blue color channel and standard deviation of the RGB color channels. Later proceeded with the correction process by the L-shape inverse (Γ) to recover losing information saturated by lights in the operation theater. Finally, the reconstructed of the 3D model for the heart. Experimental results on the heart images show the efficiency of the proposed method comparing to the existing methods**

***Keywords*-Human heart surface, L-shape inverse; specular reflection; Surface reconstruction; Image base reconstruction;**

I. Introduction

In this paper, we proposed a new method to automatically reconstruct 3D surface model of the human heart from a single-view image taken by digital camera, automatic detecting and correcting a specular reflection. In this process, only image acquisition process is done by people and all other process is executed by computer automatically until 3D model is produced. The detection is based on the difference between the standard deviation of the RGB color values and blue color value at each pixel position, and the correction of the specular is done by the average of the L-shape inverse (Γ) neighbor pixels.

Recently, there has been a great deal of interest in extracting 3D information or forming new 3D images from a set of 2D images. This problem has appeared in many forms over the years, 3D reconstruction of the heart from multiple image sequences obtained from medical imaging technique; need a lot of effort and time consuming. Others who doing similar work are, Tankus, A. et al. [1] proposed a method based on the image irradiance equation on the assumption of perspective projection, where they improved reconstruction method based on the perspective formulation, with a modification of the Fast Marching method. Yefeng, Z. et al. [2], propose a 4-chamber surface mesh model for a heart using landmarks such as valves and cusp points on interventricular septum landmark to guide the automatic model fitting process. Devernay, F. et al. [3] propose a method to achieve coronary localization by augmented reality on a robotized stereoscopic endoscope. Devernay method proposed involves five steps: making a time-variant 3D model of the beating heart using coronarography and CT-scan or MRI, calibrating the stereoscopic endoscope, reconstructing the 3D operating field, registering the operating field surface with the 3D heart model, and adding information on the endoscopic images by augmented reality.

II. HEART RECONSTRUCTION METHODOLOGY

For the acquisition of the heart, collection images of human heart have been obtained by a digital camera during heart surgeries as shown in figure 1. From the observation that the size of the heart and the specularities effect is different for each patient, we can make an assumption that is no real 3D acquisition can be directly performed.

In most of Operation Theater, light sources are emitting a huge amount of light rays that reflect from the heart surface as it is a moist surface. There are big and bright regions

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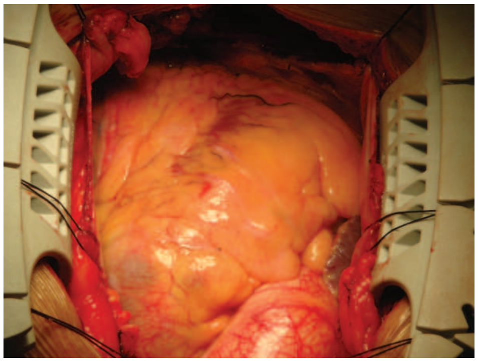


Figure 1: Human heart photo taken during the heart surgery with specularities.

Figure 2: Different operation theatre lighting source.

in different parts of the heart surface. Figure 2 shows the different lighting sources in the operation theatre emits huge lighting rays that reflected from the heart surface which caused losing of the original information in the specular regions.

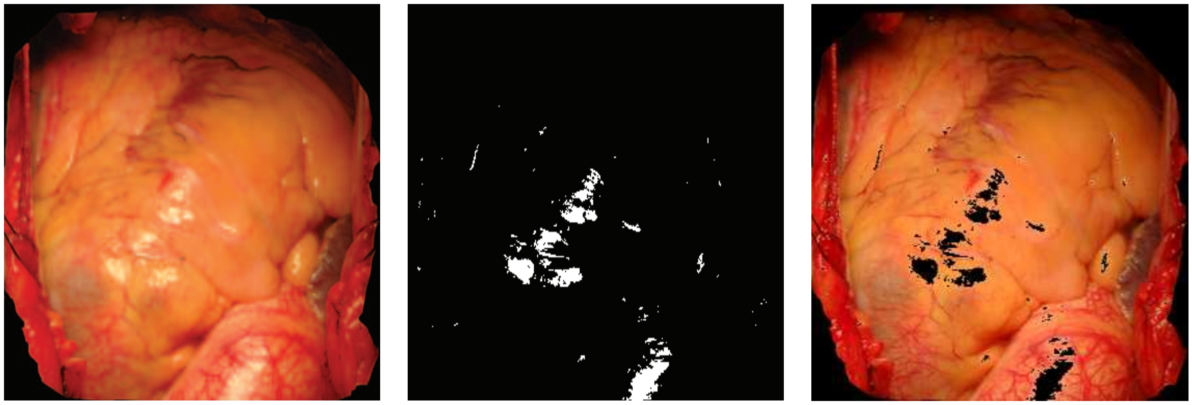
Numbers of research has been conducted to detect and eliminated these specularities, such as segmentation of the specular reflection by grayscale value introduced by Schirmibeck, E.U. et al. [4] or linear transformation of the RGB color space to another color space, introduced by Stehle, T. [5] using a YUV color space with low pass filters in esophagus and colon endoscopic images, and the work presented by Oh, J. et al. [6] which transformed RGB to HSV color space in order to detect the specularities. Even though their work proved an excellent visualization, however, their methods required high computational cost of the detection methods and the choice of the color space. Before proceeding to 3D reconstruction, the images need to pre-process by initially performed noise reduction using a median filter. Later, proceed to detecting the specularities. Our proposed method is simple and gives an efficient way to detect the specularities based on the grayscale value as in Arnold, M. et al. [7]. After visual review of the results from several experiments done on the human heart images, the threshold value has been automatically set, to the grayscale value of each pixel equation (1), the following condition will satisfy if the pixel is within the specular region:

$$gs(p) > maxB - SD \tag{1}$$

Where gs is the grayscale value of the pixel p, maxB is the maximum value of the blue color channel, and SD is the standard deviation of the RGB color channels value, if the grayscale value is greater than the different between the maximum value of blue color channel and standard deviation value, it identify the pixel within the specular reflection region. We carry out several experiments on the image RGB channel parameters with a large number of heart images taken by digital camera during open heart operation. As a result, we found that the threshold value depends on the blue color channel and standard deviation values to identify pixels if they are within the specular reflection region. As well, the intensity of red and green color channels is relatively larger than that of blue color. Especially at specular regions, red channel has very high intensity, and green channel has high intensity, while the blue one has very low intensity. The result of specular reflection detection of heart is shown in Figure 3.

Once detected, the next work is to correct those regions. To correct the losing regions, we can use information from reference frame in the image sequences, or filling from neighboring pixels by the inpainting algorithms. Using the reference frame information [5, 6, 8], a comparison and replacement for the specular pixel in the current frame with the pixel in the same position from the reference frame are performed. This method is simple and works well in the small specular regions (spots). However, these methods have the drawback of being computationally costly and lack in practicality and applicability.

In the filling method, the iterative process is used to replace the specular pixel with the information from the average of the non-specular neighbor pixels Greenspan, H. et al. [9]. This method also gets a good result in the small specular regions. However, in the heart surface, the specular regions are large. Furthermore, the reflections sometimes are found in two different regions. The replaced pixels will be blended together these two regions and the result will not be clear. An inpainting method used by Arnold, M. et al. [7] was deployed where this method needs to assign the distance and filter window sizes manually. Thus, the results of this method are good for small and uniform regions. Nevertheless, the result appears strongly blurred when it is applied to large regions. To overcome the disadvantage of the previous methods, we propose a novel method which is called L-inverse shape (Γ) method using only the nearest four neighbor pixels to the specular reflection pixel. Several experiments were done using different window sizes in the neighbor pixels such as 3 x 3, 5 x 5, 7 x 7, and 9 x 9. The



(a) (b) (c)

Figure 3: Specular reflection: (a) Original heart. (b) Detection of specularities. (c) Final detection of specularities (black).

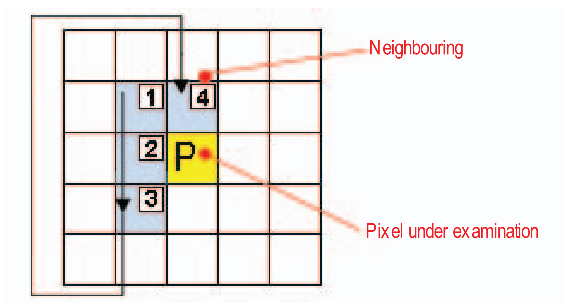


Figure 5: L-shape inverse (Γ).

results from these experiments are the replacement of the specular reflection with blurred regions. The time consuming increases as the size of the window increase. The results of the different mean filter windows are shown in figure 4.

In the proposed method, the four neighbor pixels as shown in figure 5 are used to correct the specular region of interest. The method starts pixel by pixel from the top-left corner pixel of the heart image and moves column-wise vertically up to the bottom. If it is a specular pixel, it will be corrected by the average of the Γ neighbor pixels.

The proposed method has the advantage of the simplicity and reduces the time because the processes are carried out with only four pixels and its non-iterative process. In addition to that, it requires no prior information on the conditions of illumination. Furthermore, it improves the efficiency of the correction process and the computational cost. The result of Γ method is shown in figure 6.

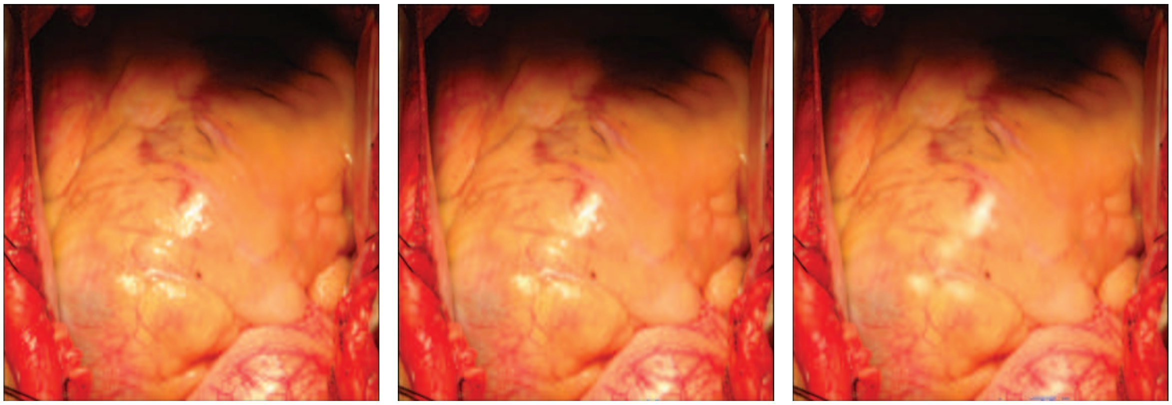
III. Result and Discussion

The proposed method was tested on around 20 images randomly chosen from a dataset contains hundreds images of different patients average age 56 years old of the human heart taken from the operation theatre in Universiti Kebangsaan Malaysia Medical Centre (UKMMC). The performance evaluation of the proposed method was done using a common measuring metrics such as specificity, accuracy, precision, and sensitivity Han, J. et al. [10]. The evaluation started with creating a set of ground truth by manually labeled and corrected a set of human heart images from different patients. Then comparing the performance of the proposed method with the inpainting algorithm proposed by Arnold, M. et al. [7], and 8 neighbor pixels method by Muthukumar, S. et al. [11], that we implemented. The results are reported in table 1. It can be seen that the accuracy of the proposed method has improved; furthermore, it can process the image faster due to the only 4 neighbor pixels in the correction process.

For each image, we optimize the parameter of Arnold, M. et al. [7] method and the method of Muthukumar, S. et al. [11], while the proposed method is automatically optimized. At the same time for the 3D reconstruction, we carried out similar experiments using several images of real human heart, the result are shown in figure 7. In figure 7, (a) original image of a real human heart, (b) and (c) are the 3D reconstruction results. All input photos are taken by a Sony cyber-shot DSC-T30 digital camera, with focal length between 6.33 - 19.0mm, resolution 7.2 megapixels, and 3x optical zoom with aperture range f3.5?10f. Results show robustness and efficiency of our proposed method.

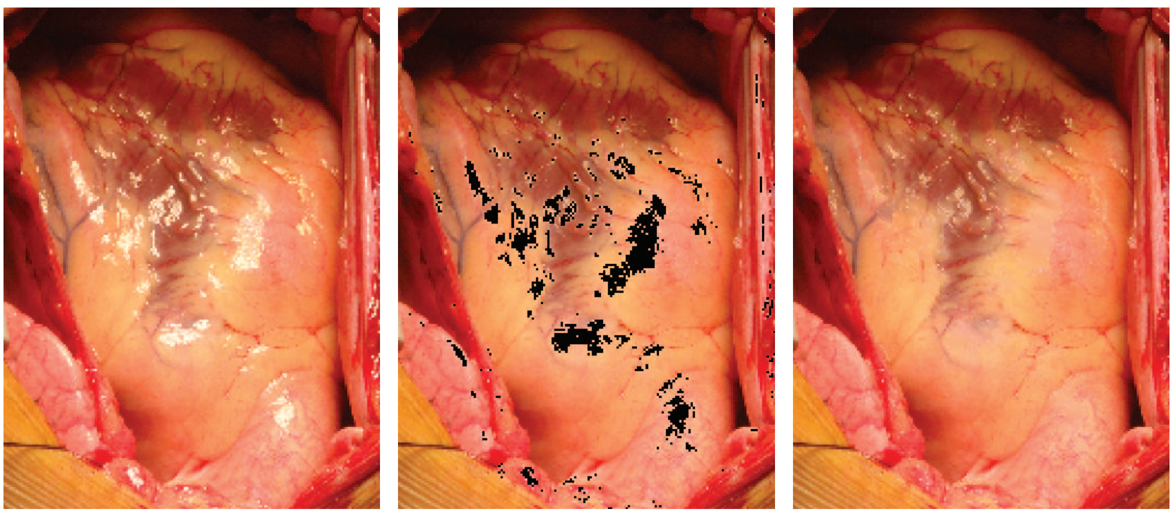
IV. Conclusion

In this paper, we have presented a simple and new method for reconstruction of human heart surface. The reconstruction of the heart surface method is sensitive to specular reflections. To overcome this problem, we developed a method based on a blue color channel and standard deviation, and a new specular reflection correction method. Using a single human heart image, the reflection correction process replaces the losing information by 4 local Γ surround pixels without



(a) Original image (b) 3 x 3 (c) 9 x 9

Figure 4: The result of the mean filter with different window sizes.



(a) (b) (c)

Figure 6: Detection and correction of specular reflection: (a) Original image. (b) Detection of specularities (black). (c) Correction image by Γ method.

Table I: Proposed method Compared to the method introduced by Arnold et. al., and to Muthukumar et. al. method.

Method	Specificity%	Accuracy%	Precision%	Sensitivity%
Proposed method	99.76	97.19	99.76	91.78
Arnold et al. method	99.52	64.37	99.77	54.26
Muthukumar et al. method	99.26	62.6	99.80	54.61

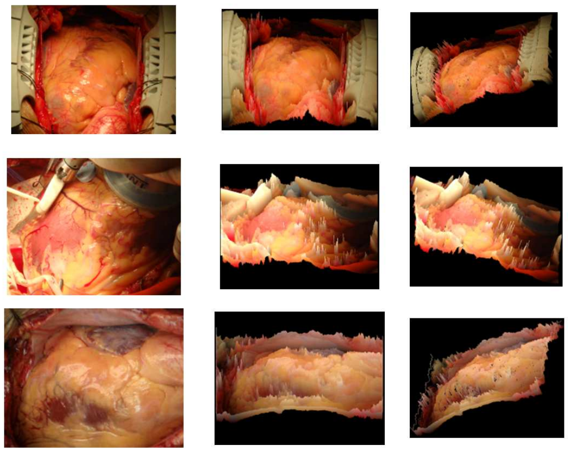


Figure 7: Images and 3D Models of Reconstruction.

any iteration process. The results obtained with the tested images show a significant improvement and robustness in the detection and correction process which have a better performance and high accuracy. It can also process high-resolution images and is able to deal with various types of human images of internal organs such as endoscopic images.

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