Pupil Size Measurement Under Illumination Variation Based on Machine Learning

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***Abstract*—In this study, we propose the use of the Hough transform, Kalman filter, and U-net convolutional neural network to measure the pupil size under varying illumination on eyes. First, the eye video captured under varying illumination conditions are used to detect the pupil region. The Hough transform is employed for detecting the pupil as a Hough circle. Then, the Kalman filter is applied to improve the results obtained from the Hough circle. The pupil size is subsequently measured. Next, we also utilize the U-net deep learning network to automatically segment the pupil region and then determine its size. The results from both methods show that the pupil size can be successfully determined and the U-net model achieves better performance than the first method.**

I. Introduction

Pupil detection and segmentation have received great attention for medical and clinical applications [1, 2]. In this paper, three methods for pupil size measurement are proposed. Given an eye image, we first use the Hough circle scheme to detect the rough pupil location and determine its size. Next, we employ the Kalman filtering on the detected pupil size for the consequential frames in a video. Finally, we apply the U-Net model to segment the pupil area of the image to further improve the accuracy of pupil size. The proposed methods can be integrated as a mobile APP so that the pupil size measurement can be much convenient and much easier than current medical instruments.

II. Methods

Figure 1(a) shows the system architecture diagram of the first method. By capturing pupil images under the varying illumination, the image is first converted to grayscale and then denoised through Gaussian filtering. The image is then sharpened to make the boundary between the pupil and iris more visible. After the boundary of the pupil is enhanced, the binarization and morphological operation are used to extract the pupil region in the image. Then the non-pupil part in the image is removed by region of interest (ROI) extraction. Only the pupil part is retained for subsequent detection. Based on the characteristics of polar coordinate space transformation in Hough circle detection and then updating Kalman filter's result, we can detect a pupil boundary that is close to the ground truth.

In the second method, we use the deep learning neural network to directly perform pupil segmentation. Figure 1(b) shows the block diagram for training and testing stages. We first create the labeled images by manually labeling the pupil region of the images. For the training purpose, data augmentation is performed. Here we utilize U-net model for pupil segmentation since its efficiency for iris segmentation has been proved [3]. In the test stage, we use the trained model to segment the pupil region in a test image. Finally, the size of segmented pupil region in each frame is measured and recorded.

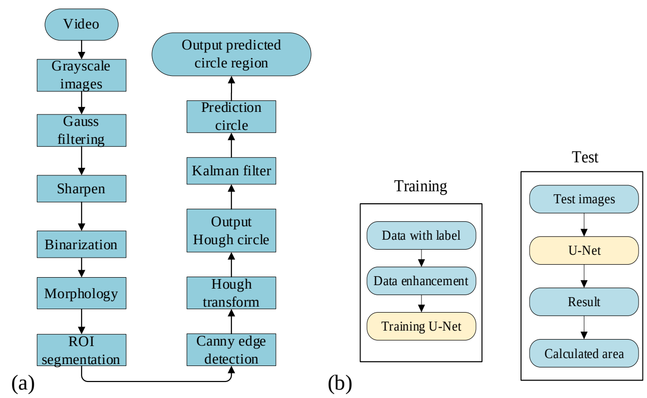

Fig. 1. The proposed methods based on: (a) Hough cicle with Kalman filter; (b) deep learning U-net

III. Experimental Results and Discussion

Figure 2 shows the pupil size (represented as a number of pixels within the detected pupil area) of each frame in a recorded video. Within the 71th and 111th frames of the video, the increase of incident illumination leads to the decrease of pupil sizes. It verifies that the proposed methods can efficiently determining the pupil size because the pupil sizes are close to the ground truth. For comparison, Tab. 1 shows the detection error (represented as the root mean squared error (RMSE) and mean absolute error (MAE)) between the detection results and ground truth. Obviously, the U-net model outperforms the traditional method.

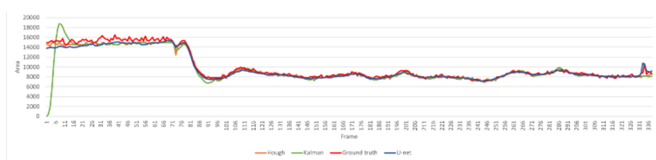

Fig. 2. Ground truth (shown in red) and detected pupil sizes at each frame

TABLE I. Detection error under the two proposed methods.

Method	*RMSE*	*MAE*
Hough circle +Kalman filter	1.55	0.66
U-net	**0.84**	**0.38**

References

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*Research supported by the "Intelligent Recognition Industry Service Center" from The Featured Areas Research Center Program within the framework of Higher Education Sprout Project by Ministry of Education (MOE) in Taiwan.

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