Iris Region Matching for Visible-Spectrum Gaze Trackers

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Abstract—The iris region matching would be the core of the visible-spectrum gaze tracker. The design challenge is much more difficult than the one of the traditional infra-ray gaze tracker due to the imperfection of the eye images. In practical application environments, the iris regions on the eye images may be influenced by the reflection light, and the matching process is also affected by the eyelids and wrinkles near the eyes. In this paper, we further improve the fitness function used for iris region matching. The experimental results show that the new one can effectively prevent the matching results from being dominated by the wrong textures near the eyes.

I. INTRODUCTION

The gaze tracker has become an attractive human-machine interface for consumer electronics, but commercial ones have a fundamental problem, that is, the poor user experiences caused by the infra-ray illumination of the eyes. The problem can be solved by developing the visible-spectrum gaze tracker by detecting the boundary of iris region instead of locating the pupil region to estimate the gaze direction [1]. Nevertheless, the design appears highly challenging due to several factors [2], [3]. In this paper, we thoroughly address the issues of iris region detection and propose a modified formula for the optimal matching of iris regions. The experimental results show the proposed the matching scheme as well as the formula can significantly improve the matching performance for the eye images affected by reflection light. Even if a large part of iris region is blocked by the eyelids, the matching accuracy still maintains.

II. PROBLEM STATEMENT OF IRIS REGION LOCALIZATION

The detection of the iris region on an eye image suffers from the following difficulties: (a) The iris region is generally determined by the edge detection on the boundary of the region. However, the contrast ratio of the pixels inside/outside the iris region depends on the human race and the illumination condition. (b) The intensity of pixels on the iris region boundary is not a sharp edge but a smooth gradient area. A simple edge detector fails to identify the boundary of iris region. (c) The eyelids usually form a sharp edge near the eyeball. A fake limbus circle which covers the eyelids may get a higher fitness value, if the fitness function is designed without considering this situation. (d) The shape of the iris region can be approximated by a circle, but it becomes an ellipse when it projects on the image plane. Several potential solutions may achieve higher matching score, but only one is the right one.

In our previous work, we propose a matching function for searching the iris region, which is also known as limbus circle. The eyeball model is shown in Fig. 1-(a) in which the iris region

\[
\begin{align*}
\text{Fig. 1. Eyeball model. (a) the shape of iris region depending on the yaw/roll (\theta, \varphi) angles, (b) some possible iris region models and a starburst line crossing on an point of the limbus circle.}
\end{align*}
\]

The function \( f(\theta, \varphi) \) projects on the image plan can be a circle or an ellipse according to the yaw/roll angels \((\theta, \varphi)\). Based on the model construction we proposed, the center location as well as the radius of the iris region as well as the radius of the eyeball can be estimated.

This paper aims at improving the performance of the remaining iris region matching process based on the eyeball model defined in Fig. 1-(a). In our previous work [3], the fitness function \( f \) of a given rotation \((\theta, \varphi)\) for the iris region matching is defined as

\[
\begin{align*}
f(\theta, \varphi) &= \prod_\alpha g_{\theta, \varphi}(\alpha) \quad (1) \\
g_{\theta, \varphi}(\alpha) &= \Delta p_{\theta, \varphi}(\alpha) = \tilde{p}_{\theta, \varphi}(\alpha) - \hat{p}_{\theta, \varphi}(\alpha) \quad (2)
\end{align*}
\]

The function \( g \) represents the match score of a pixel \((x_\alpha, y_\alpha)\) on a ray line with angle \(\alpha\) crossing the ellipse defined as shown in Fig. 1-(b). The symbols \( p_{\theta, \varphi}(\alpha) \) and \( \Delta p_{\theta, \varphi}(\alpha) \), represents the pixel intensity and the gradient, respectively. The intensity of the pixels outside and inside of the limbus circle and close to \( p_{\theta, \varphi}(\alpha) \) are denoted as \( \tilde{p}_{\theta, \varphi}(\alpha) \) and \( \hat{p}_{\theta, \varphi}(\alpha) \), respectively. For the pixel inside the iris region \( (\tilde{p}_{\theta, \varphi}(\alpha)) \) should be darker than the one outside the iris region \( (\hat{p}_{\theta, \varphi}(\alpha)) \).

The fitness function defined in (1) and (2) executes quite well for the matching of normal cases, but it may fail in certain extreme cases, in which the iris regions are influenced by the eyelids. Fig. 2 indicates an example of incorrect matching result based on the fitness function \( f \). The point \( \delta_1 \) locates on the eyelid, but it attains a higher score than the point \( \delta_2 \) on the correct model. The final estimated ellipse crosses the iris region on the point \( \delta_2 \). It is noticed that a minor mismatch result may lead to a large error in the final gaze estimation output. Thus,
this error needs to be cautiously handled in the iris region matching stage.

Fig. 2. An example of fail iris region matching. Left: the matching is affected by the eyelids; Right: the correct matching result.

III. PROPOSED MATCHING FUNCTION

In this paper, the modified fitness function has been presented. The gradient function \( g \) is redefined as a modified contrast function \( h \).

\[
f^*(\theta, \varphi) = \prod_{\alpha} h_{\theta,\varphi}(\alpha)
\]

\[
h_{\theta,\varphi}(\alpha) = \frac{\hat{g}_{\theta,\varphi}(\alpha)}{\hat{g}_{\theta,\varphi}(\alpha)} \cdot k(\hat{g}_{\theta,\varphi}(\alpha), p_C)
\]

\[
k(p_1, p_2) = \tanh \left( \rho \times (p_1 - p_2) \right) + 1
\]

where \( \rho \) and \( p_C \) denote an adjustable parameter and the intensity of the ellipse center pixel, respectively. The idea of the new function adopts the pixel contrast value instead of pixel gradient and combines the factor of the intensity difference between the center pixel and the outside pixel.

Also, the proposed compensation factor \( k \) can be explained in Fig. 3. The intensity of the center pixel \( p_C \) is assumed to be 50. If the outside pixel \( \hat{p} \) of a pixel \( p \) is darker or similar to \( p_C \), the pixel \( p \) may not be the correct pixel on the boundary of the iris region. Thus the function \( k \) for the pixel \( p \) gets a value lower than 1. On the contrast, the function \( k \) reaches a higher value but less than 2, if the \( \hat{p} \) value is higher than \( p_C \). Using the function \( \tanh \) to limit the output value between -1 and 1 helps to maintain the integrated fitness function evaluation. By examining the cases shown in Fig. 2, the pixel \( \delta_3 \) gets a higher score than the one on \( \delta_2 \). As well, this factor also removes the wrong case whose central pixel is not a darker one. If the \( p_C \) is too high, the model should be a wrong one. The function \( k \) gets a lower one and attenuates the function \( h \) for all pixels. Then, the fitness value of this model becomes lower than the ones of the other ones. Thus it prevents this wrong model from being selected.

IV. EXPERIMENTAL RESULTS

Fig. 4. The examples of the iris region matching results with two fitness functions. Left: the original fitness function; Right: the new fitness function.

Fig. 5. The fitness function planes for an example of the iris region matching with two fitness functions. Left: the original one; Right: the new one.

Fig. 4 provides examples of iris region matching results with the original [3] and the new fitness functions. The results show that the final limbus circles may be affected by the eyelids and the wrinkles near the eyes. A demonstration video for the comparison can be found in [4]. Fig. 5 shows the detailed data with the original/new fitness functions for a matching case. Two or more peaks may be found in the planes with the original fitness functions. This situation leads to the wrong judgement for the final limbus circle. With the new function we proposed, the problem can be solved.

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[4] The internet website at: https://www.youtube.com/playlist?list=PLJv4KXu0hpfxEFFdDIEQ81zjzgNap2Egd