ANNALS OF FACULTY ENGINEERING HUNEDOARA
- INTERNATIONAL JOURNAL OF ENGINEERING
Tome IX (Year 2011). Fascicule 1. (ISSN 1584 - 2665)

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DETECTION OF DETERMINED EYE FEATURES IN DIGITAL IMAGE

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ABSTRACT: This paper deals with problem of digital image processing, mainly with localisation of determined interest objects. As application area the eye localisation in a frame of video-sequence has been chosen with continuing in iris and pupil detection. The article contains a theoretical part, with preview of frequently used methods and reasoning of concrete methods selection. The next part presents the actual experiment realised via computing environment MATLAB. In paper conclusion the acquired results are summarised and commented.
KEYWORDS: Digital image processing, localisation of interest objects, features of human eye, iris, pupil, circular Hough transform, threshold, MATLAB, Image Processing toolbox

❖ INTRODUCTION

The localization of interest objects presents the important task of image analysis. At first, for eye image analysis it is necessary to detect the exact eye position, then its main parts and its parameters, e.g. the pupil, the iris, the eyelids, the border of the eyes. This information is used in different applications: monitoring of eye movement, iris extraction for biometrical identification purpose etc. According to the winking frequency it is possible to ascertain driver vigilance, too. In all listed cases several advisable methods of image processing are applied, which afford an opportunity to detect and to locate the interest areas in static image or video-sequence frame. For detection the typical features of eye and of its parts are used, which afford an opportunity to differentiate the particular objects. The resolution of input image is an important factor, which limits the choice of adequate methods. The resolution of eye image for its analysis has a fundamental influence on its precision. Some methods can not be used due to low image resolution because of insufficient details. Generally, image analysis deals with compromise between processing reliability and required processing time. The lower resolution is often used for acceleration of detection process, for working in real time with frames of video-sequence. In these cases the eye area is acquired from the face image cut-out. In the frames of face in resolution 640x480 cut-out of the eye can represent too small part of the frame.

❖ LOCALISATION OF HUMAN EYE AND DETECTION OF ITS PARTS. FEATURES OF HUMAN EYE

The most significant feature in the eye is the iris with a large variety of colours. The iris is the annular part between the pupil and the sclera. Iris and pupil can be taken approximately as non-concentric circles. Apart from these features, the eye has two additional features – the upper and lower eyelid. The ring of the iris might not be completely visible even if the eye is in its normal state, because its top and bottom part are often covered by eyelids and eyelashes. Pupil size varies depending on the light conditions and it is darker than the rest of the eye, even in brown or dark eyes. Sclera is the white visible portion of the eyeball. At a glance with unaided eye, it is the brightest part in the eye region, which directly surrounds the iris. The radius of iris can be defined by the anthropometric measures approximately as 1/6 of the length of the eye. The next constraint for iris detection is that the directions of the edge gradient and the normal to the annulus should not differ more than $\pi/6$. The iris is always darker than the sclera no matter what colour it is. In this way the edge of the iris is relatively easy to detect as the set of points that are disposed on a circle. In Fig. 1 are shown all main features in the human eye.

❖ METHODS FOR LOCALIZATION OF EYES

Eyes can be generally localized from face image in two ways. Either is first detected face or eyes are detected from whole image, with using active infrared (IR) based approaches or image-based passive approaches. Eye detection based on active remote IR illumination is a simple effective approach which relies on an active IR light source to produce the dark or bright pupil effects. This method is not widely used, because in many real applications the face images are not IR illuminated. This paper only focuses on the image-based passive methods, which do not affect the input image. In our application we are detecting position of eyes in two steps, the first is locating face to extract eye regions and the second is eye detection from eye window. The face detection problem has been faced up with different approaches: neural network, principal components, independent components, skin colour based methods etc.

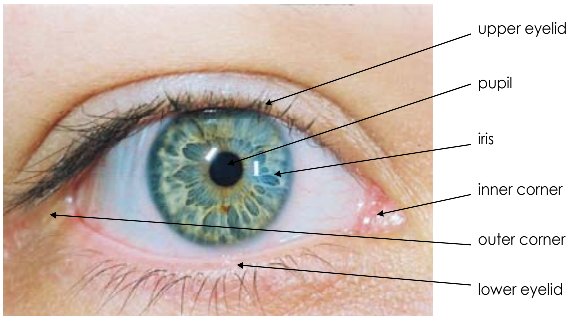


Figure 1. Eye features

We used the method Viola – Jones [1] where face is detected in image with using of AdaBoost classifiers. The image-based passive methods can be classified into three categories. First, template based method, secondly is feature based method and the third is the appearance based method [2]. In the template based method, a generic eye model, based on the eye shape, is designed first. Template matching is then used to search the image for the eyes. While this method can detect eyes accurately, it is normally time-consuming. The appearance based method detects eyes based on their photometric appearance. For this method is needed a large amount of data, representing the eyes of different subjects in different conditions for training classifiers (e. g. neural network or the support vector machine). Feature based methods use for detecting the characteristics of eyes such as contrast difference between iris, pupil and sclera and their edges. This method has a problem with low contrast images. In [3] circular Hough transform is used to detect the iris border where both centre and radius are estimated simultaneously. In some approaches, the iris radius is supposed to be known or limited to a set of expected values.

❖ DETECTING OF EYE FEATURES

The main objective of our work is to detect features such as iris and pupil boundary in eye region. Many distinct approaches have been proposed in this area. [4] Integrodifferential operator is introduced in [5] to find both the iris inner and outer borders. This operator is sensible to the specular spot reflection of non diffused artificial light. Wildes [6] uses for iris segmentation binary edge map followed by circular Hough transform. Liam et al. [7] have proposed a simple threshold method with function maximisation to obtain iris inner and outer borders. Another approach [16] is finding approximate pupil centre as minimum value of the summation of intensity along each row and each column. Then it is applying Canny edge detection and Hough transformation for detection of exact pupil centre. Also morphologic operators, Laplacian or Gaussian operator for edge detection with median filter can be applied to obtain iris borders [2].

In order to locate eye corners, one general approach is utilization of deformable templates [2] which requires a good initialization for correct work, and another common approach is projection functions [9]. Lastly, the proposed methods for eyelids can be classified under two groups: using deformable contour models or curve fitting [2].

In our work we focus on detecting iris and pupil as features of eye. From all approaches mentioned above, we chose circular Hough transform for detecting circles of iris. Hough transform is a very precise technique which can be used to isolate features of a particular shape within an image.

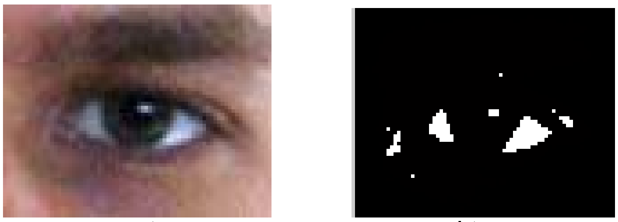
❖ APPLICATION OF SELECTED METHODS

In our application we acquire the eye areas proportionally from face dimension. Moreover, these larger areas contain the eye image background too. This background is necessary to be eliminated, than we can work only with the area, which responds to the eye. For distinguishing the objects from background and for the precise eye localisation we used combination of the image segmentation methods, thresholding and edge-based methods. Before using these methods, pre-processing is applied to image for improving the details and adjust the contrast differences. We use histogram equalization, Gamma correction to improve its contrast and brightness and median filter to eliminate the noise [10].

Thresholding is the transformation of an input image *f* to an output binary image *g* as follows:

$$g(i,j)=1 \quad for \quad f(i,j)\geq T,$$
$$=0 \quad for \quad f(i,j)<T, \tag{1}$$

where *T* is the threshold. Since the eye borders are markedly darker, applying adequate threshold allows dividing the background [11]. An example of thresholding method on eye region image is shown in Fig. 2. The result is a binary image with the brightest part of image, which is sclera.



a) b)

Figure 2: a) Original image, b) segmented image

The threshold is added with horizontal and vertical projection [9]. We used variance projection function (VPF) rather than integral (IPF) because variance projection better reflects the difference in image. It is defined with

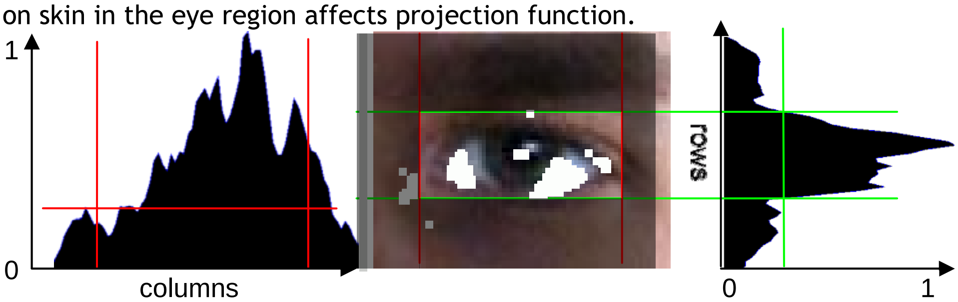
$$\sigma_H^2(y)=\frac{1}{w}\sum_{i=1\ldots w}\left[I(x_i,y)-H(y)\right]^2, \tag{2}$$

where *H*(*y*) is the mean value for the line *y*, calculated as:

$$H(y)=\frac{1}{w}\sum_{i=1\ldots w}I(x_i,y), \tag{3}$$

where *y* is the number of the line, *w* is the width of the image. With horizontal projection we can determine height of the eye opening. The vertical projection is realised likewise (2), but we don't observe the changes in the rows but in columns.

Thresholds in both normalized projections Fig. 3 a), c) are evaluated based on mean and standard deviation of each function. Green lines represent limitation from horizontal projection while the red ones the limitation from vertical projection. Result from region cropping is on Fig. 3 b). Disadvantage of this method is that the presence of any other significant objects such as glasses or some mark on skin in the eye region affects projection function.



a) b) c)

Figure 3: a) vertical projection, b) result from variance projection function, c) horizontal projection

For the purpose of eye and background segmentation, the Skin-Tone Segmentation method is often used. The skin-tone has specific colour-ranges that distinguish between the colours of the inner parts for eye. Human skin colours can be mapped into one of quadric plane on Cb-Cr chrominance space. But it is necessary to have a colour image in such case

❖ CIRCULAR HOUGH TRANSFORM FOR IRIS DETECTION

Having selected the more accurately the region of the eye, the next step is iris detection. For this purpose we used circular Hough transform (CHT), since the iris is nearly circular. The pupil of the eye is plotted as the circle centre and the circular shape of the iris is located and drawn as the circle parameter with its specific radius from the circle centre. As a first, Hough transform is applied to whole eye region, to detect iris. When both centre and radius of iris is detected, then the pupil circle inside iris is localized.

This technique detects imperfect instances of objects within a certain class of shapes by a voting procedure. This voting procedure is carried out in a parameter space, from which object candidates are obtained as local maxima in an accumulator space [3]. The result of Hough transform is an accumulation array in which the higher values represent areas with the occurrence of circles in image with specific radius.

In many cases an edge detector can be used as a pre-processing stage, to obtain image points or image pixels that are on the desired curve in the image space.

Our algorithm is based on the gradient field of the input gray-scale image. A thresholding on the gradient magnitude is performed before the voting process of the Circular Hough transform to remove the 'uniform intensity' image background from the voting process. Thus pixels with gradient magnitudes smaller than gradient threshold are not considered in the computation.

It is not possible to know the exact diameter of the iris, since people can have different iris dimensions and also the system has to manage variable distances between people and the camera. For this reason a range [minimum_radius, maximum_radius] is set to tackle different iris radius. These values are estimated from ratio of iris size to eye width (1/6) mentioned in 2.1. But larger range of radius results in more computational time and memory consumption.

The main advantage of the Hough transform technique is its tolerance to the gaps in feature boundary descriptions and that it is relatively unaffected by image noise.

The circular Hough transform is almost identical to the Hough transform for lines, but it uses the parametric form for a circle:

$$x = x_0 + r\cos\Theta, y = y_0 + r\sin\Theta, \tag{4}$$

where x_0 , y_0 is the coordinate of the circle centre, r is the radius of the circle. When the θ varies from 0 to 360°, a complete circle of radius r is generated.

❖ GRADIENT OF IMAGE

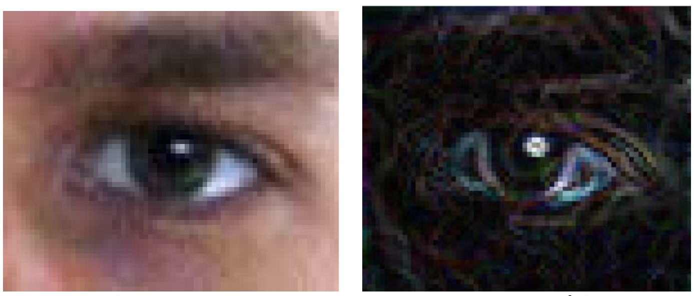
To build the accumulation array it is necessary to compute the gradient (5) and the gradient magnitude (6) of the selected eye region (Fig. 4). It is the first derivative of 2D image. The gradient follows the changes in gray level in direction *x* and *y* [12]. Gradient ∇*I*[m, n] of image in direction *x* and *y* is defined as:

$$\nabla I = \frac{\partial I}{\partial x}\vec{i}_x + \frac{\partial I}{\partial y}\vec{i}_y = (h_x \otimes I)\vec{i}_x + (h_y \otimes I)\vec{i}_y, \tag{5}$$

where $\vec{i}_x$ and $\vec{i}_y$ are unit vectors in the horizontal and vertical direction, h_x horizontal derivative and h_y vertical derivative.

Gradient magnitude:

$$|\nabla I| = \sqrt{(h_x \otimes I)^2 + (h_y \otimes I)^2}, \tag{6}$$



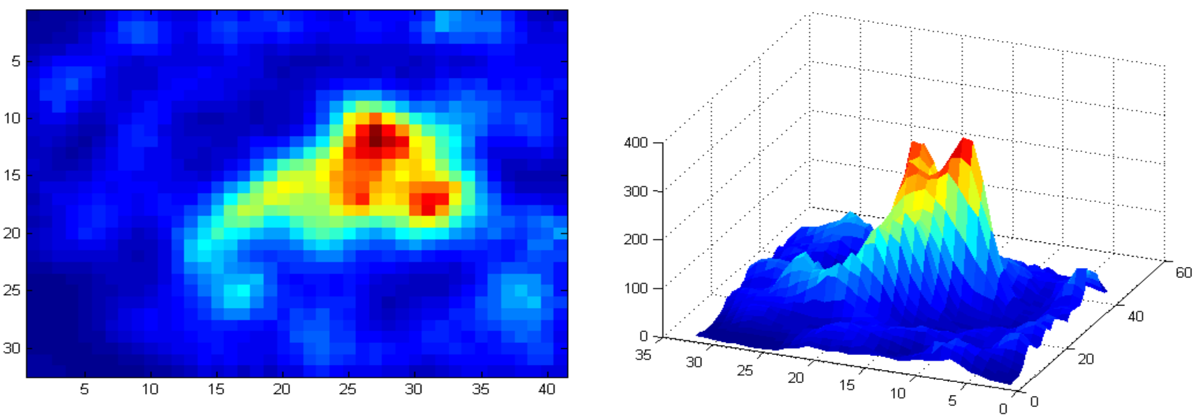
a) b)

Figure 4: a) Original image, b) gradient magnitude of image

For pixels whose gradient magnitudes are larger than the given threshold, the linear indices, as well as the subscripts are created. The accumulation array of the image consists of the gradient magnitude of the image and its linear indices as

A=accumarray(subs, val);

Accumarray is created by an A array, accumulating elements of the vector val (gradient magnitude) using the subscript in *subs* (linear indices). Each row of the m-by-n matrix subs defines an N-dimensional subscript into the output A. Each element of *val* has a corresponding row in subs. Finally the locating of local maxima in the accumulation array is executed (Fig. 5).



a) b)

Figure 5. Example of accumulator array: a) 2D representation, b) 3D representation

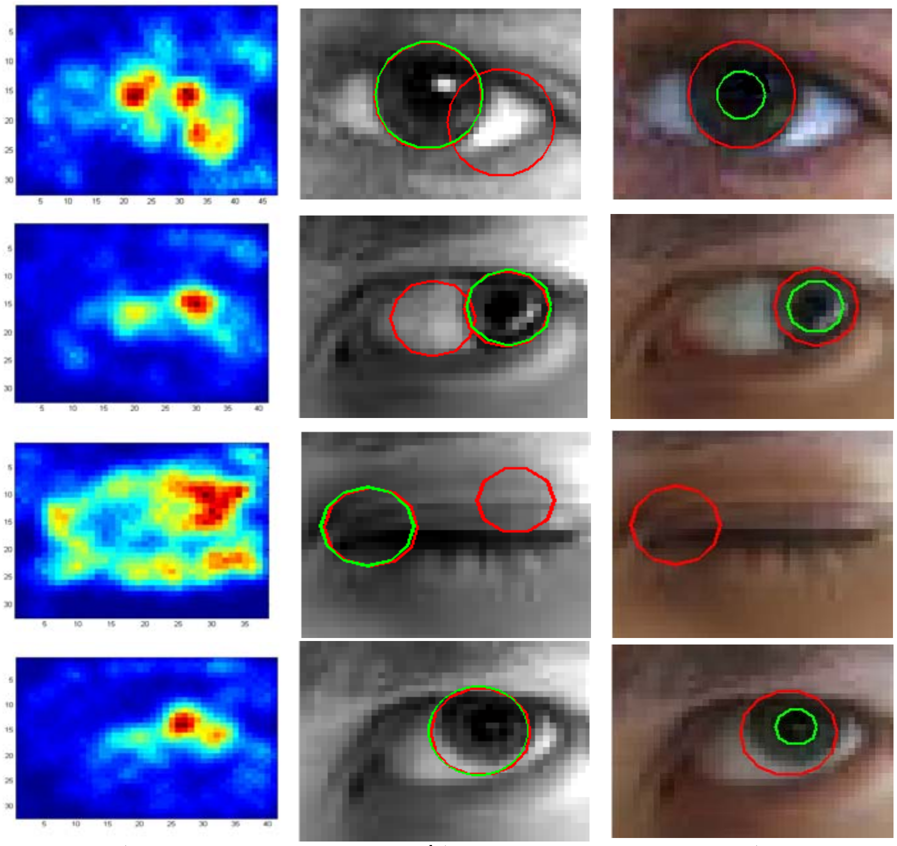
EXPERIMENTAL RESULTS

All methods and algorithms have been implemented in programming environment Matlab, using function from Signal and Image processing toolbox. Input images have been taken from video sequence with resolution 640x480 pixels captured with common web camera.

The set of tested images has contained approximately one hundred video frames from few different people. After face detection, the eye region was cropped for next analysis. One eye region had resolution about 80x80 pixels with some surroundings and the segmented real eye size is only about 50x25 pixels. For its correct function, the CHT Algorithm requires an input image sized 32x32 pixels as a minimum, thus it is necessary to adjust the segmented eye region to this dimension.

Experiments were carried out to test the accuracy of CHT algorithm in iris, using many variations of parameters and input images. For pupil detection, the algorithm is searching for the circle with the smallest average intensity inside localized iris.

Pupil detection requires elimination of reflections on eye; this is done with fill in the brightest parts inside localized iris boundary. In Fig. 6 are presented the examples of testing set of left eye images in many variations of eye gaze and states of eye opening.



a) b) c)

Figure 6: a) CHT accumulation array,
b) CHT candidates to iris, c) result of iris and pupil detection

CONCLUSION

The circular Hough transform (CHT) is very reliable and for a small browsing area it is a fast method for iris detection. This conclusion is valid for our concrete experiment, where the circular object with small resolution has been used. If the iris position changes in the direction towards the eye corner, its precision is slightly worse, due to the loss of circle configuration of the iris, compared with centre position. In this case it is necessary to expand the range of an expected radius. For evaluation and selection from more candidate circles, except local maximum criteria of accumulated area, the darkness criterion of candidate area has been added. This combination helps to eliminate the error detection in some cases. The detection failed only if the opening of eye was not sufficient. For closed eye the dark area in eye corner was detected as iris area. In this case it is necessary to use other methods to evaluate the iris colour.

❖ ACKNOWLEDGEMENT

This work has been supported by the Grant Agency VEGA of the Slovak Republic, grant No. 1/0023/08 "Theoretical apparatus for risk analysis and risk evaluation of transport telematic systems".

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