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Human eye localization using the modified Hough transform

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Abstract

The precise localization of parts of a human face such as mouth, nose or eyes is important for their image understanding and recognition. The developed successful computer method of eyes and eyelids localization using the modified Hough transform is presented in this paper. The efficiency of this method was tested on two publicly available face images databases and one private face images database with the location correctness better than 96% for a single eye or eyelid and 92% for eye and eyelid couples.

Keywords: Human eye localization; Modified Hough transform; Eye iris and eyelid shape determination

1. Introduction

Face exploration, description and recognition of a certain part of human face are important in many image understanding applications (e.g. [1,2]). For example, the static and dynamic face anomalies are studied in medical practice in order to describe the effects of some diseases and imperfections.

Many reliable devices for eye localization and eye tracking are based mostly on imaging in red and near infrared spectra [2–10] because for such radiation the reflection from an eye is more expressive than from its surroundings. Therefore, the eye area can be searched out more easily. Whereas the minimum of 100 pixels per iris radius was often required [6] the aim of our investigation was to localize much smaller irises of minimum radii equal to eight pixels.

For finding the sufficiently correct positions of eyes and eyelids, some relevant procedures were developed so far. For example, the dynamic training, lip tracking and movement of a subject can be used to localize eyes in video sequences [7]. Also the correlation procedures are profitable [11].

The aim of our investigation was the correct localization of human eyes in the image of a human face without special devices (such as the infrared arrangements). It means to find the positions of centres and sizes of radii of eye irises as well as of eyelids in visible face images. In our approach, we assumed the circle shape of the eye irises and eyelids. We did not accept any premises regarding to position of the face in the image (although it may be useful). The correctness of the obtained results was finally tested on two publicly available faces databases and one private faces database.

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In the beginning, the images were pre-processed in a standard manner, i.e., scaled and filtered. Then the relevant edges were found in every image using the Canny's edge detection [12,13]. The following modification of the Hough transform [14,15] was used in order to reduce the computational complexity and to select the image points (pixels) of the relevant edges that represent the outer circles belonging to eye irises or circle segments belonging to eyelids.

For our investigations, the following two types of images were exploited:

- the part of a human face including the eyes and nose;
- the whole human face (respective with a human body part).

The face images databases suitable for testing the correct localizations should fulfil the basic requirements:

- The image resolution must be sufficient to find enough details (i.e., the size of an eye image should be at least several pixels).
- The images should be shot "en face" and not in profile so that both eyes are quite visible.
- The image background can be acceptable only when we are aware of some unfit shapes similar to eyes.

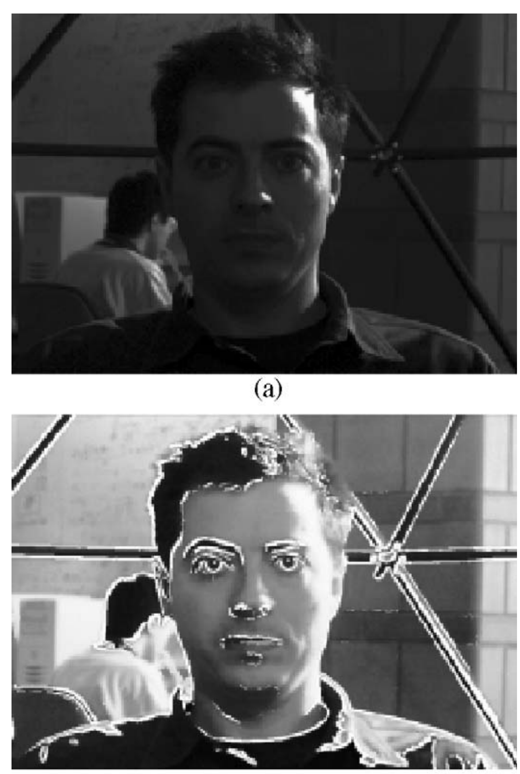
Generally, the following public face images databases were considered: AT&T Laboratories Cambridge [16], UMIST [17], BioID [18], Yale [19], AR [20] and CVL [21]. With regard to the fulfilment of the mentioned basic requirements, only two public faces databases were utilized for our testing, i.e., the AR database and the CVL database. These databases were completed by one private face database [22]. The private face database was obtained by collecting 341 images from the Internet. These images were intentionally of different size and resolution (i.e., a face with a part of the body, respective a face only) and different spectral composition type (i.e., greyscale or colour) to make the tests enough convincing and to test the robustness of the method. Other databases were not considered because of little details, too low resolution or extreme background disturbance. Because the aim was to find the correct localizations of eyes and eyelids, the person should not blink or close the eyes during the time when the image is produced. The recognition procedures of our method were implemented in C++ programming language. The method was evaluated by the PC using Pentium 4, 3 GHz.

2. Basic procedure of the developed localization method

Every primary (original) face image was pre-processed and then the modified Hough transform was applied. The basic recognition procedure consisted of the following steps:

- The face image was scaled to the proper size using the bilinear interpolation.
- The image histogram equalization was performed in dependence of the image quality.
- The Gaussian filtration was utilized in order to minimize a detection of false edges, noise and inappropriate details.
- The relevant curves (edges) were found using Canny's edge detection with hysteresis.
- The curves of eye and eyelid shapes were localized using the modified Hough transform.
- Such localizations were used to specify and verify the extracted positions of the investigated eyes and eyelids.

The pre-processing adaptive histogram equalization was performed on the dark face images (e.g. Fig. 1a) where the necessary details were hidden in dark areas and the intensity levels were within a small range. Their dynamic ranges should be large enough for the further correct image processing, especially for the edge detection. Then a suitable image filtration must be done by convolving the image with a Gaussian mask. The



(a)

(b)

Fig. 1. The original greyscale image (a) and the result (b) of the Canny's edge detection applied after a proper Gaussian filtration superimposed on the image.

optimum value of variance of the Gaussian mask, which was set experimentally, depends on the level of detail and noise in the image. Such value is to preserve only the significant edges after the edge detection which was applied in the next step. In our procedure, the convolution of an image with the Gaussian mask was performed separately in x and y directions for the sake of faster filtration.

An important task is to detect the edges from which the final shapes should be extracted. The Canny's edge detection with hysteresis was most suitable for such purpose. The input for the Canny's edge detection was a greyscale face image and the output was the corresponding binary (bi-level) form. Their symbol of denotation 1 represents an edge pixel; the symbol 0 relates to their background. When the Canny's edge detection was performed, the tangential directions of the edge points were also computed and stored for their further usage. Such directions are needful for the successive application of the modified Hough transform for circle detection of eye irises and eyelids. A result of the edge detection carried out on the properly filtered face image is shown in Fig. 1b.

3. Fundamental principle of the Hough transform

The outer boundary of an eye iris was supposed to form a circle, also it was assumed that the eyelids are circle segments. The considered Hough transform is a mathematical and computational manner which is often used to isolate lines of a given shape in an image. Every line must be specified in a parametric form. In the simplest case, the Hough transform is used to detect the straight lines in an image without a large computational complexity. Its principle consists in finding straight lines in the (x, y)-coordinate plane which satisfy the conventional linear equation of parametric form

$$y = ax + b \tag{1}$$

for the chosen values of the tangential slope a and linear intercept b (one example is shown in Fig. 2a). These parametric values form the (a, b)-parameter plane (Fig. 2b)

$$b = -xa + y. \tag{2}$$

Each point contained in one line in the (x, y)-coordinate plane is associated with the given constant slope–intercept couple (a, b). For example, it is the case of points (x_1, y_1), (x_2, y_2) and (x_3, y_3) in Fig. 1a. The corresponding graphical dependences (2) in the (a, b)-parameter plane for those points are shown in Fig. 2b. Their intersection relates to the common point $(a = a', b = b')$. Thereby, the number of straight lines going through the common point (a', b') in the (a, b)-parameter plane corresponds to the number of points lying in one straight line in the (x, y)-plane.

A practical insufficiency of the previous approach is that a slope a in Eq. (1) is infinite for every vertical line. Therefore, the so-called normal parametric representation

$$\rho = x \cos \varphi + y \sin \varphi \tag{3}$$

of a straight line in the (x, y)-coordinate plane is more suitable instead of representation (1) (see Figs. 2c and d). In such representation with the angular parameter φ and the perpendicular distance parameter ρ, a horizontal straight line has the angular position $\varphi = 90°$, while the angular position of a vertical straight line is $\varphi = 0°$. The computational attractiveness of the Hough transform under consideration arises from dividing the (φ, ρ)-parameter plane into the so-called accumulator cells $A[\varphi_i, \rho_j]$ that correspond to certain values of φ_i and ρ_j (Fig. 2e). The total numbers M and N of subdivisions $i = 1, 2, \ldots, M$and $j = 1, 2, \ldots, N$ in the (φ, ρ)-plane determine the accuracy (absolute errors) $\Delta\varphi/2$ and $\Delta\rho/2$ of the co-linearity of points forming a line, i.e., the relationships $\varphi_i \approx \varphi_i \pm (\Delta\varphi/2)$ and $\rho_j \approx \rho_j \pm (\Delta\rho/2)$ can be accepted. Minimum and maximum values $(\varphi_{\min}, \varphi_{\max})$ and $(\rho_{\min}, \rho_{\max})$ relate usually to the extents $-90 \leqslant \varphi \leqslant 90$ and $-D \leqslant \rho \leqslant D$, where D is the distance between two opposite corners of the explored image area. Then we solve the equation

$$\rho_j = x_k \cos \varphi_i + y_k \sin \varphi_i \tag{4}$$

for every considered non-background image point (x_k, y_k), $k = 1, 2, \ldots, K$, and the certain single values φ_i, $i = 1, 2, \ldots, M$. We obtain the relevant incremental points (φ_i, ρ_j) in the accumulator cells $A[\varphi_i, \rho_j]$ for each point (x_k, y_k). Finally, the total the number n_{ij} of points in each accumulator cell $A[\varphi_i, \rho_j]$ expresses how many non-background points lie on every line of Eq. (4) for given φ_i and ρ_j (in our example of Figs. 2c and d, $n_{ij} = 3$).

4. Interpretation of the developed modified Hough transform for the eye and eyelid localizations

The Hough transform can be generalized for a specific shape of a line that we wish to isolate. The description of the modified alternative of the Hough transform, which was specially developed by us for the computational determination of the proper centre positions and radii of the human eye irises outer boundaries as well as for the eyelid curves in their circle approach, is presented in the following text.

Just as a straight line can be defined parametrically, so can be also defined a circle or a general curve [14,15].

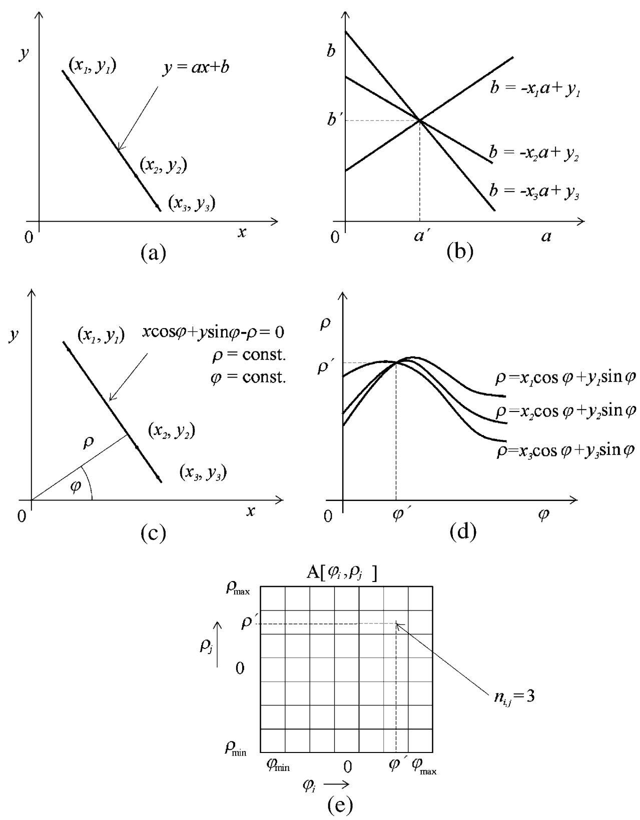


Fig. 2. Illustrations for explanation of the Hough transform fundamental principle for straight lines detection.

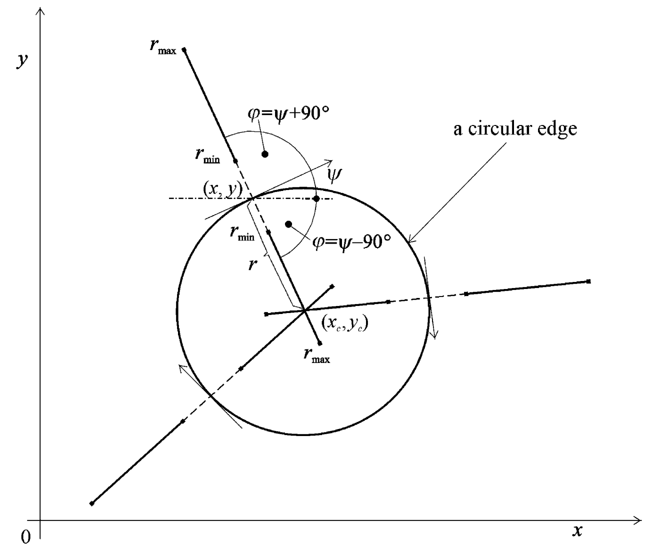


Fig. 3. Illustration for explanation of the developed modified Hough transform for eye circle centres determination.

The relevant equation in the (x, y)-coordinate plane for a considered circle (circular edge) of radius r can be of conventional parametric form

$$(x-a)^2 + (y-b)^2 = r^2. \tag{5}$$

Unfortunately, Eq. (5) contains three parameters (a, b, r) and then it is of higher computational complexity. In order to reduce this complexity, the following steps of the chosen modified Hough transform were utilized (see also Fig. 3):

Step 1: Finding the all relevant edges in the pre-processed human face image by the Canny's edge detection with hysteresis and determining and storing their angular directions ψ for all edge points (x, y).

Step 2: Computation of the all likely eye circle centres (x_c, y_c) that lie on a straight line with an angular direction

$$\varphi = \psi \pm 90^\circ \tag{6}$$

(perpendicular to the edge direction ψ) going to both sides from every edge point (x, y), which was found in the Step 1. The line on which a potential centre can lie was realized by the equations

$$x_c = x + r\cos\varphi, \quad y_c = y + r\sin\varphi, \tag{7}$$

where r can be within a range $r_{min} \leqslant r \leqslant r_{max}$ (see Fig. 3). For each position (x_c, y_c) of the computed centre, the corresponding accumulator value $A[x_c, y_c]$ was incremented. Then, when all of the edge points were processed, the highest values in the accumulator $A[x_c, y_c]$ indicate the most possible centres (x_c, y_c). Furthermore, their suitable limiting number was selected (150 in our case).

Step 3: Verification whether the computed (approximate) outer eye edge points form a circle for each computed centre position (x_c, y_c) from the Step 2 and for the possible radii $r \in \langle r_{min}, r_{max}\rangle$. Such verification was based on considerations about the relevant accumulator array $A[r]$. For each value $r \in \langle r_{min}, r_{max}\rangle$, the positions (x, y) of points lying on an approximate circle of the centre (x_c, y_c) were computed. To determine the number of points $n(r)$ coincident with the correct eye edge image, the Bresenham's algorithm for a circle approximation was used [23]. After normalization of the number of coincident points dividing them by the number of the approximate circle points and storing the obtained value to $A[r]$, the highest number in $A[r]$ for the considered values of r was found. Such number relates namely to the searched correct radius r for the given centre (x_c, y_c).

Step 4: Finding the eyelids positions by verification whether an eye circle of a centre (x_c, y_c) and a radius r determined in the Step 3 is coincident with the circle segment representing an eyelid. Such eyelid detection step is similar to the previous Step 3, except that the coincidence of circle segment of standard angular extent $\alpha \in \langle 220^\circ, 320^\circ\rangle$ was taken into consideration. Its radius was supposed to be between $2r$ and $3r$ with regard to the eye centre which was adequately translated by $2r$ or $3r$, respectively.

Table 1. The summary of some obtained results

Database	Sort of images	Numbers of tested face images	Correctness of eye iris couples localizations (%)	Correctness of single eye iris localizations (%)
AR	768×576 pixels, grey	279	94.98	98.21
CVL	640×480 pixels, colour	226	93.14	99.56
Private	Mixed—different size, grey or colour	341	92.52	96.19

Step 5: Additional testing the quality of the performed eyes and eyelids localizations by suitably chosen weighted quantities which relate to the actual localizations, and mutual positions of eyes and eyelids and also to the iris grey symmetry. Moreover, the usual assumption that the ratio of the distance between two eyes of a human face and the diameter of the outer iris circle is approximately 10 was respected with a given tolerance.

5. Presentation of the obtained results

Some results of human eye localizations obtained by the developed computer method are summarized in Table 1. This table includes the kinds of utilized face images databases, sort of the images, numbers of tested face images, and the corresponding correctness of localizations of the investigated eye iris couples and the single eye irises. We tried to have the similar testing conditions for each database considering their specific properties and structures. For example, only the image scan Sections 1, 2, 3, 5, 6, 7, 11, 12, 13 of the greyscale database AR and the image scan Sections 3, 6 of the colour database CVL were considered and tested. The other sections were unsuitable because of invisible eyes. Therefore, the total 279 images of the AR database and 226 images of the CVL database were profitable. Moreover, only the red light component of colour images (RGB) was exploited because we proved experimentally that this component gave considerably better results. The time of testing of a single image by the PC mentioned in Section 1 was from 0.4 to 0.6 s in dependence on the image area size. For a more objective understanding of the presented method, the graphical marking of a greyscale result of human eyes and eyelids localization based on the AR faces database is shown in Fig. 4.

(a)

(b)

Fig. 4. The original greyscale image (a) and a graphical marking of the obtained result (b) of human eyes and eyelids localization.

6. Conclusion

The present article is an extension and completion of investigations done so far in the field of exploration of the human eye irises and eyelids correct localization in a face image. Its main contribution consists in development, verification and exploitation of the new actual computer method for direct and fully automated determination of centres and radii of the outer irises boundaries and eyelids under the adequate circular conception. For such purpose, two public and one private face images databases were utilized. The suitably pre-processed images were submitted to the Canny's edge detection. Then the obtained relevant circular edges were localized using the specifically adjusted modification of the Hough transform.

The tests performed on more than one thousand face images proved high stability and robustness of the developed method. Also the correctness of computed results, compared with the expected results, is acceptable. It is better than 96% for the single eye or eyelid and 92% for the eye and eyelid couples. The best results approached to the correctness 99.56% for a single eye were obtained by the face images database CVL, while the maximum correctness of 94.98% relates to the AR face images database and the eye couples. The obtainable short times from 0.4 to 0.6 s for testing a single image belonging to the presented method are also advantageous. An unambiguous correct and direct comparison with other methods of eye localizations cannot be quite adequate because the conditions and procedures are often different.

The main future investigation planned will relate to the improvement of the fast image filtration manners because they influence significantly the effective eye and eyelid localizations. Such localizations are useful in many identification and tracking systems exploring the human face appearances.

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