Using Genetic Algorithm for Eye Detection and Tracking in Video Sequence

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ABSTRACT

We propose a high-speed size and orientation invariant eye tracking method, which can acquire numerical parameters to represent the size and orientation of the eye. In this paper, we discuss that high tolerance in human head movement and real-time processing that are needed for many applications, such as eye gaze tracking. The generality of the method is also important. We use template matching with genetic algorithm, in order to overcome these problems. A high speed and accuracy tracking scheme using Evolutionary Video Processing for eye detection and tracking is proposed. Usually, a genetic algorithm is unsuitable for a real-time processing, however, we achieved real-time processing. The generality of this proposed method is provided by the artificial iris template used. In our simulations, an eye tracking accuracy is 97.9% and, an average processing time of 28 milliseconds per frame.

Keywords: Image Understanding, Genetic Algorithm, Template Matching, Eye Detection, Eye Tracking, Human Interface

1. Introduction

The analysis of gaze direction has been considered from a cognitive and developmental perspective. Moreover, it is important to measure the eye movement in the field of medicine and human interface. For examples, as biomarker [1, 2, 3] for neurodegenerative disease, such as Parkinson's disease. According to some authors, the observation and interpretation of gaze may be a key factor in developing a "theory of mind"– the capacity to attribute mental states, such as intentions or beliefs, to other individuals [4, 5]. These functions of gaze are important for not only human to human communication but also human to machine communication. Therefore, eye gaze detection and estimation is useful interface that has no physical contact between the device and the human user.

It is important for the eye gaze detection and estimation to detect and track eye location. In this study we try to develop eye detection and tracking method as the human interface with eye in active scene, such as mobile robots and ubiquitous computing. Moreover, information of the eye is useful for many applications. Therefore, as part of the objectives, we try not only to detect and tracking but also to acquire numerical parameters to represent the eye. These parameters are location, scaling, and rotation angle of the iris. An axis of the rotation angle is the camera direction. In this paper, we proposed an eye detection and tracking method in real-time video processing.

To achieve the eye detection for the active scene, we use template matching with Genetic Algorithm (GA). In general, GA is not suitable for video processing, since a high computational effort is required even for one video frame in a video sequence. This problem is solved by Evolutionary Video Processing for eye detection and tracking. Moreover, considering a practical use, generality must be ensured. As a solution, we create and use an artificial iris template.

In our simulations, the effectiveness of the proposed method is verified by a comparison experiment. The detection accuracy is 97.9% and the average processing time per frame is 28 milliseconds.

Moreover, the information acquisition of the detected eye is shown. The information is useful for many applications, such as eye gaze detection or estimation in robot perception and mobile devices interfaces. Section 2 describes the related work in the eye tracking research. In next section, some problems which are addressed in this paper is described. Moreover, Evolutionary Video Processing for eye detection and tracking method is explained in section 4. Section 5 shows two simulations, for a single image processing and for video processing. These two simulations are compared to evaluate the effectiveness of the Evolutionary Video Processing for eye detection and tracking. Lastly, conclusion of this paper is described in section 6.

2. Related Works

A large number of researches have been carried out in eye gaze detection and eye tracking [6, 7, 8, 9, 10, 11, 12, 13]. Eye tracking method can be divided into two categories: contact and contact-free method. In contact type method, electrooculography (EOG) potential measurement technique is proposed in [6]. A reference electrode must be placed on the forehead. [7] presents electromagnetic tracking of coil inserted in eye. This method is invasive.

The major method of the contact-free type is using infrared illumination [8, 9]. These gaze-tracking systems consist of a single eye tracker box with an infrared light source to illuminate the eye. The method determines gaze position by calculating the changing relationship between the moving pupil and the essentially static reflection of the infrared light from the cornea, such as purkinje image. This method facilitates highly accurate and robust gaze tracking methods and is applied in many commercial products, however, an infrared emitter is necessary, and the camera position is not flexible. Moreover, Near-infrared illumination is particularly hazardous, because the eye does not respond with protective mechanisms, such as aversion, blinking, and pupil contraction [14]. In our proposed method, we use only one CCD camera for flexible use and safety.

Some methods are reported without the infrared light source [10, 11, 12, 13]. In [11], a color-based approach to track pupils in video sequences is proposed. A method using morphable models is used in [12]. Eye gaze estimation by template matching with limited eye template images which represent the gaze direction, is proposed in [13]. However, few techniques are proposed for the active scene. This could be because eye tracking is difficult in active scene. This reason being that human head and camera moves independently, and human eye is always moving by visual interest and the iris moves freely in all directions independently of the face. In this paper, our purposes are a size and rotation invariant eye detection for the head motion and eye motion.

Moreover, numerical parameters to represent the eye, for example, position, scaling, and rotation angle, are important for many applications. However, there are few techniques to acquire the numerical parameters at the same time as the eye detection and tracking, because it is difficult for real-time processing. Therefore, as part of the objectives, we also try to acquire the numerical parameters in real-time.

3. Research Problem

In this paper, we address four issues for eye detection and tracking:

1. Active scene by three dimensional free human head motion.
2. General interface.
3. Real-time processing.
4. Feature extraction—parameters of eye appearance.

In this study we try to develop eye detection and tracking method as the human interface with eye in active scene, such as mobile robots and ubiquitous computing. Therefore, not only the accuracy but the general interface and the real-time processing must be taken into account. Additionally, it is desirable to detect the eye and to acquire information of the eye simultaneously, for the real-time processing.

Generally, it is better to take an eye region as large as possible by a camera, in order to acquire the more detailed information from an image. For instance, the eye gaze estimation method with a target image of one eye is proposed in [15], and it is reported that the accuracy is better than a method, which uses both eyes. However, this causes the difficulty of eye detection and tracking, because a little motion of the object has a big effect on the input image. The active scene, which include motions such as head motion, is not considered in [15]. In the proposed system, the input a face image is used, which includes one eye (see Figure 1). The motion of head is addressed with our proposed method.

To solve these problems, our proposed system is based on a single template matching using GA. Generally, the GA is time consuming process, however, this problem was resolved by Evolutionary Video Processing for eye detection and tracking, as described below.

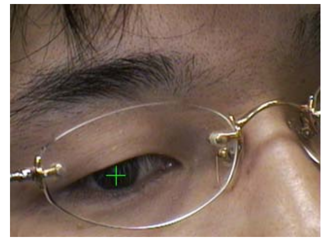


Figure 1. The iris template images

4. Evolutionary Video processing for Eye detection and Tracking

General Template

The iris which indicates the eye gaze direction, has some significant features. The first is contrast color between the iris and the sclera which is white area of the front of the eye and outer coat of the eyeball. The second is the appearance of the iris—a circle. Using these features is useful to achieving the purpose of this study. Therefore, to locate the iris by its color and shape information, we use template matching using the iris template.

The contrast color is used as a feature of the iris, therefore the input data is gray scale values. Moreover, considering general use of this system, a general template should be used. Therefore, an artificial template is created. Normally, the whole iris does not appear, because the iris is occluded by the eyelid. Then, the eyelid should be included in the template. Moreover, not only the white area but also the gray area should be prepared in the template as the sclera, in order to verify the importance of the contrast color, as mentioned above.

Considering these points, some iris templates are developed, such as illustrated in Figure 2. The black area is the iris. The white area in templates (a) and (b) and the light gray area in templates (c) and (d) represent the sclera. The dark gray areas are the eyelid. The upper and lower eyelid is illustrated in all templates.

The size of iris area is same in templates (a), (c), and (d), and it is small in template (b). The upper eyelid size is same in all templates. The lower eyelid of templates (d) is larger than others. The iris area has gray scale value of 0, and the eyelid it is 154. In the sclera it is 255 in templates (a) and (b), and 230 in (c) and (d). The size of all template images is 16×16 pixel.

In our previous report [16], we tried to chose a best iris template from some templates, such as shown in Figure 2. The simulation results indicate that the template (a) is a best template. Therefore, in this paper, the template (a) is used.

Structure of Chromosome

In the GA, a chromosome of an individual is a solution candidate to be optimized. In other words, chromosomes specify parame-

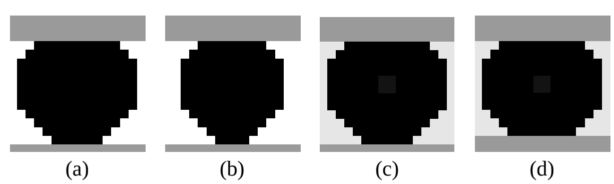


Figure 2. The iris template images

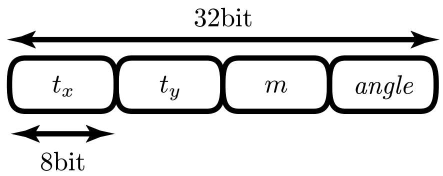


Figure 3. A structure of chromosome

ters which represent coordinates, scaling and rotation of an object to be explored on the target video frame. In Figure 3, t_x and t_y are coordinates after parallel translation, m is scaling rates, and $angle$ is rotation angle of the iris template.

In this paper, the chromosome is expressed as a binary string for simplicity. However, parameters except the coordinate to optimize are real value, then the real-valued genotypes should be used. In our future work, we compare the binary-GA and real-coded GA [17] in processing time and efficiency of exploration.

The parameters are coded in 8-bit by the following ranges.

$$\begin{aligned} 0 \leq t_x &\leq \text{width of target video frame} \\ 0 \leq t_y &\leq \text{heigh of target video frame} \\ 2.0 \leq m &\leq 4.0 \\ -15.0 \leq angle &\leq 15.0 \end{aligned}$$

These ranges are decided by a supposed motion in the general frame rate, 30 frames per second. The reason why the range of the scaling rate is $[1.0, 3.0]$ is that the template size is smaller than the eye on the target video frame. To overcome problems of the Hamming cliff when using the binary encoding, the gray encoding [18] is used.

A template image is transformed by parameters in the chromosome on the target image, then template matching is performed by a fitness function in GA. This transformation is shown in equation (1).

$$A^* = AMRT. \tag{1}$$

Let A be a point on the template image, and A^* is a point, which corresponds to a transformed point A on the target image.

$$A = [X, Y, 1], \tag{2}$$

$$A^* = [X^*, Y^*, 1]. \tag{3}$$

In equations (2) and (3), A and A^* are represented by homogeneous coordinates [19] to make it easy to compose multiple matrices, as shown by equation (1). The template image is transformed for geometric changes. As shown below, some matrices are specified by chromosome of the GA. M represents the scaling, R is the rotation on y-axis, which corresponds with a camera direction, and T is the parallel translation as shown in equations (4), (5), and (6).

$$M = \begin{bmatrix} m_x & 0 & 0 \\ 0 & m_y & 0 \\ 0 & 0 & 1 \end{bmatrix}, \tag{4}$$

$$R = \begin{bmatrix} \cos(angle) & \sin(angle) & 0 \\ -\sin(angle) & \cos(angle) & 0 \\ 0 & 0 & 1 \end{bmatrix}, \tag{5}$$

$$T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ t_x & t_y & 1 \end{bmatrix}. \tag{6}$$

The point A^* is given by the simple equation (1).

The pixel of the template image, which is transformed on the target image, is compared with the pixel on the target image in a fitness function.

Fitness Function

After the transformation of template by the chromosome, a pixel difference is calculated between the template and a video frame. Then, an objective function and a fitness function are calculated. The objective function is regarded as a minimization problem and the fitness function is regarded as a maximization problem.

Let O be an objective value, and w and h be width and height of the template image, then we may write an objective function as

$$O = \sum_{j=1}^{h} \sum_{i=1}^{w} \left| a^*_{ij} - a_{ij} \right|, \tag{7}$$

where, a is a pixel value of a point A on coordinate (i, j) in the template image, a^* is a pixel value of a point A^* in a target video frame, A is a point on the template image, and A^* is the point that corresponds to a transformed point A on the target video frame.

A fitness function can be defined using the objective function, equation (7) as follow.

$$\mathit{fitness} = 1.0 - \frac{O}{(w \times h)(A_{\max})}, \tag{8}$$

where $fitness$ is the fitness value, the template size is w and h, $A_{\max}$ is a maximum value of pixel, and O is a value of the objective function. In equation (8), the objective value is normalized, therefore, the closer to 1 the fitness value is, the better the template match is.

Evolutionary Video Processing

In template matching with GA for a single image processing, at first, individuals are initialized by random numbers. These individuals are evaluated by their fitness values, as described above. After this, the next generation is created by GA operators, such as selection, crossover, and mutation. By iteration of these GA operations, the eye region can be detected in a single image.

On the other hand, in this paper, we address the video processing. If this single image processing is simply applied to video processing, it is difficult to achieve the efficient and fast detection and tracking. The reason is that the population of the GA is initialized by random numbers every frame. To avoid this problem, in Evolutionary Video Processing, to continue evolution in whole video sequence, the genetic information is inherited to the next frame, as explained below.

Inheritance of genetic information: In case of video processing, it is very useful to use information between video frames. Generally, in order to detect a moving object, an inter-frame difference picture is used as the information between video frames. However, it is difficult to use the difference picture in our system, because a part of a face is used as a target video frame (see Figure 1), moreover human head moves intensively.

Therefore, we use genetic information as a relation between video frames. In fact, without making new population, eye detection for a next frame is proceeded with the population used in a last frame. Although the frame rate is 30 frames per second, it is unthinkable that prodigious changes come out with geometric parameters, such as location, scaling, and rotation angle all together, which consist the chromosome. In other words, the genetic information, which has evolved in a previous frame, is useful for a current frame. Therefore, this method can be expected to reduce the processing time and increase the accuracy.

System Flow

Flow charts of our system are illustrated in Figure 4. Figure 4(a) represents the main part of our system. In Figure 4(b), GA process is represented. New population is made in Figure 4(c). In Figure 4, $frame$ and $generation$ are variables, which count the number of frames in video sequence and the number of generations in GA.

Our approach consists of dual-loop; the outside loop is for video sequence (see Figure 4(a)), and the inside loop is for GA (see Figure 4(b)). At first only one artificial template is input (see Figure 2). Image data put into the system is gray scale image.

After an initial population is generated with random numbers, GA is started. The matching process is executed between the template image and a target frame in a fitness function. The generation is increased, till a termination condition of GA is satisfied. In this paper, GA is terminated if $generaion > 100$. If the termination criterion is not satisfied, a new population of the next generation is generated according to the fitness of each individual (Figure 4(c)).

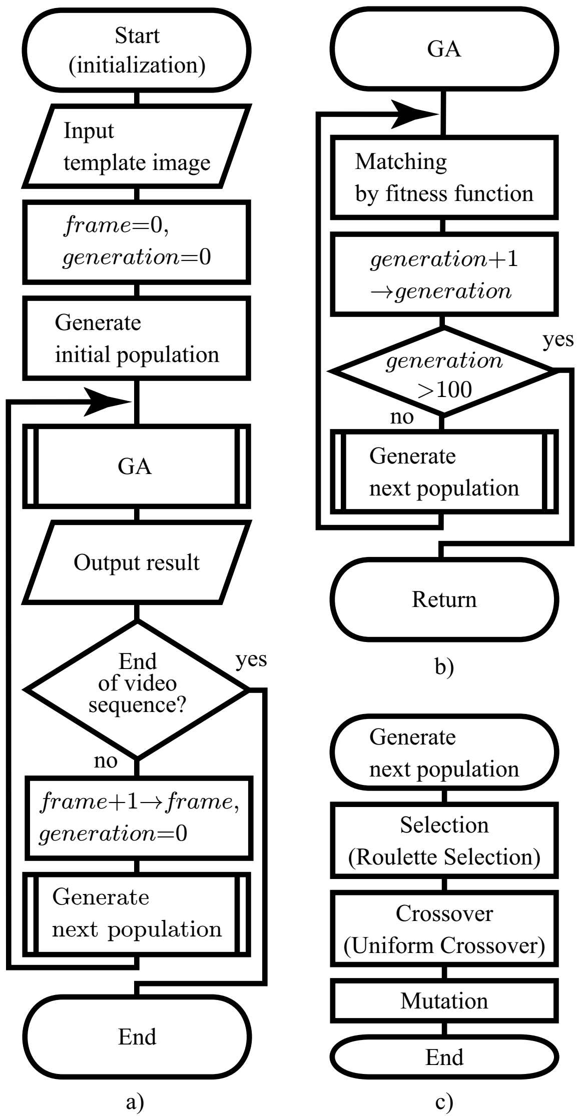


Figure 4. Flow charts: a) main process ; b) GA process ; c) generate a new population.

After GA process is completed, the results are obtained as image and numerical data. Then, new process begins for the next frame. In Figure 4(a), special attention should be paid to the initialization of the GA population only when $frame = 0$. At this time, some genetic information of the last GA are inherited to the new GA process. This method is described above. By the Evolutionary Video Processing, we can detect and track, moreover we can extract its geometric information with high accuracy in real-time.

The above process is continued to the end of the video sequence.

5. Computer Simulation

The proposed method, the Evolutionary Video Processing for eye detection and tracking is video processing. A feature of this method is the inheritance of genetic information, as mentioned Section 4. In order to verify the effectiveness, we compare the proposed method with another method, which does not inherit the genetic information. In other words, we compare detection accuracy between the single image processing and the video processing.

Moreover, information of detected eye is presented, which is acquired by the proposed method.

Input Images and Video Sequence

In this paper, Figure 2(a) is used as an artificial template, which is a best template in Figure 2 [16].

On the other hand, as far as we know, there is not data base which includes the active scene to have significant motion of human head with the eye movement by visual interest, as stated in Section 1 and 2. Therefore, we use the video sequence as explained below.

The equipment used in the simulations, is only a CCD camera. In simulations for a verification using the video sequence, the eye is tracked online with capturing the video sequence from the CCD camera. In simulations for a single still image, the video sequence is stored in a memory storage, then a image is cut and used. In what follows, the target image is explained by a single still image as example.

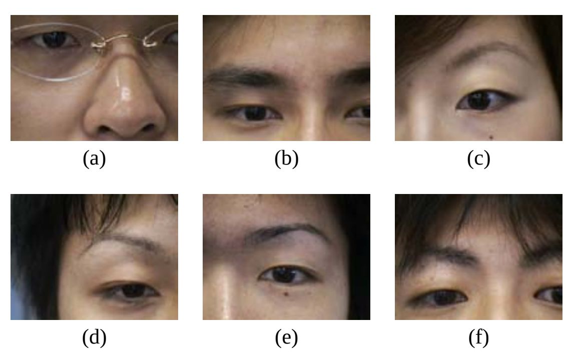


Figure 5. Examples of the target images

As mentioned in Section 4, generally, it is better to take an eye region as large as possible by a camera, in order to acquire the more detailed information from an image. The target image is a face image that includes at least one eye as shown in Figure 5. The number of subject is six, and five images are acquired per subject for simulations. Figure 5 shows some examples of the target images. The size of the target image is 320×240 pixels. The eye and head of the subject is free and can move.

GA Settings

Our GA is almost same with a simple GA (SGA) [20]. The parameters of GA are: population size is 10, probability of crossover is 0.7, probability of mutation is 0.05, and the type of crossover is uniform crossover. The population size is small, because this method will be applied for real-time processing in the future. The GA processing is terminated at 100 generations.

Simulation with a single image

In this part, the proposed method is verified as the single image processing. The method used in this simulation, is as shown in Figure 4(a) where the loop is terminated at first frame. This means that the genetic information is not inherited to the next frame. Results of this part is compared with the proposed method (video processing), which uses the inheritance of genetic information.

The target images consists of five images acquired per subject. There are six subjects in all. Moreover the system is simulated ten times per target image.

The average processing time is 28 milliseconds with a machine has 3.0 GHz CPU, because the termination criterion of the GA is $generation = 100$ and the population size is very small, 10 individuals.

The accuracy results are shown in Table 1. The accuracy is decided by a difference between the template position and the true iris position— the difference in $[-3, 3]$ pixel is regarded as a successful tracking. The most highest accuracy is 88.0%, however, the average is very low, 76.0%. The main reason is that the population size is small, therefore the diversity of the population is lost. If the population size is large, the processing time will increase, however, the accuracy should be better. This means that there is trade-off between the accuracy and processing time.

In order to avoid this trade-off, we propose the eye detection and tracking method using the Evolutionary Video Processing, as described in section 4. The evaluation of this is presented in next part.

Simulation with a video sequence

In this simulations for a verification using the video sequences, which are captured from the CCD camera, the eye is tracked online. The result video frames are stored in a memory storage to evaluate the result.

At first, effectiveness of Evolutionary Video Processing is described. Figure 6 presents an example of resulting video frames. The number at upper left in each frames is a frame number for

Table 1. Eye detection accuracy for a single still image (%)

subject (a)	(b)	(c)	(d)	(e)	(f)	total
60.0	74.0	82.0	80.0	88.0	72.0	76.0

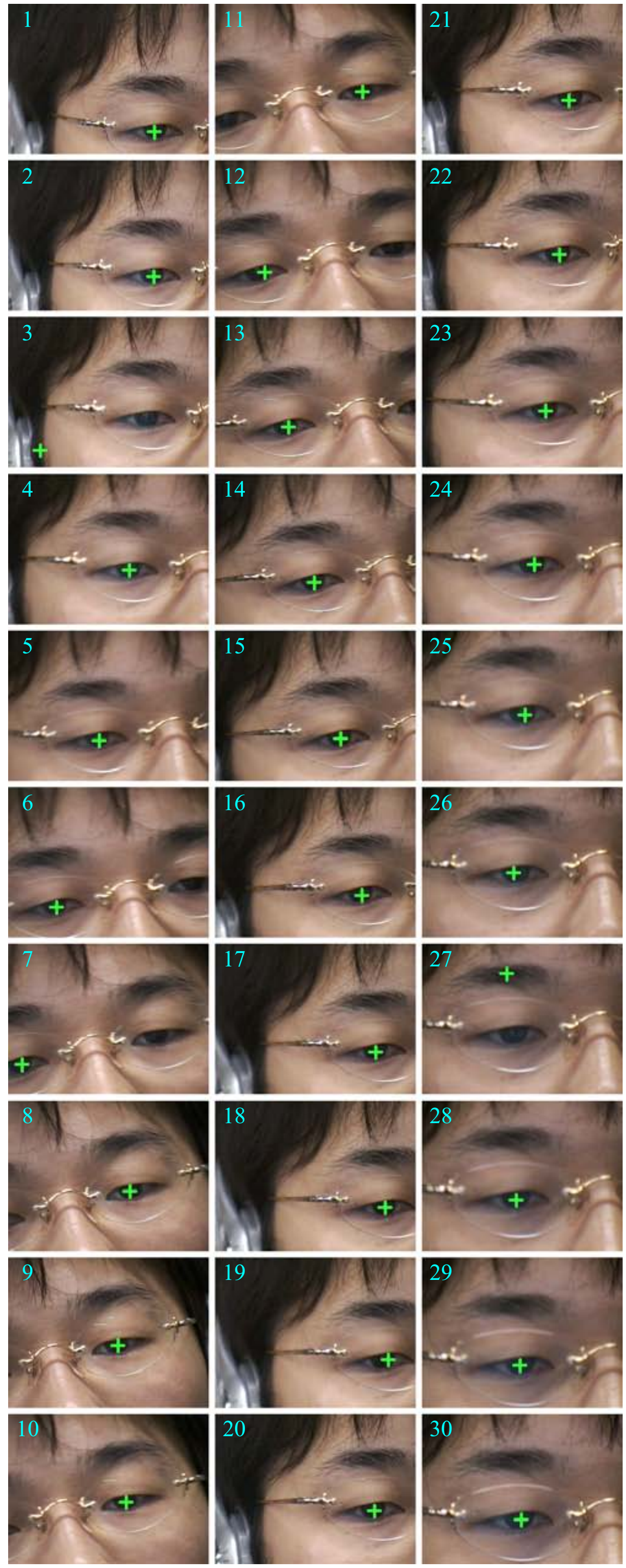


Figure 6. Example of result video frames (see from top left to bottom right): each row includes 10 frames. A cross point is tracked eye. This subject wears glasses and headphones.

follow descriptions. The cross represents tracked eye. In the seventh and eighth frame, the cross jumps from the right eye to the left eye. This reason is that the proposed method can track only one eye, and the GA decided that the solution is an individual which has the highest fitness value. The eye tracking fails to work in the third, twelfth, and twenty-seventh frame. In the third frame, a combination of grey scale value of headphones, skin, and sideburns is similar the sclera and iris combination in the template. Therefore, the proposed method fails. In the twenty-seventh frame, the eyebrow is tracked as the eye. This reason is same with above. However, after these failures, it has recovered in the next frame. This recovering function is achieved by the GA, because the diversity still remains, although the population size is very small.

In the twelfth frame, the both eyes appear in same one frame, then the population is divided into two local optimum. Therefore, the failure of the twelfth frame has a little misalignment between GA solution and true solution. The population is divided into two local optimum, because the both eyes appear in same one frame. The tracking of both eyes is our future work. Totally, good eye tracking is achieved in almost every frame.

Next we discuss the accuracy of the proposed method. The online simulation is carried out one time of every subject. The number of frames which are processed in simulations, are shown in Table 2. The average of processing time per one frame is about 28 milliseconds with a machine has 3.0 GHz CPU. The accuracy results are shown in Table 3. Over 90% accuracy is achieved in every subject. Compared with the single image processing, Evolutionary Video Processing greatly improves the tracking accuracy. This reason is that geometric parameters of eye does not prodigiously change, although the frame rate is 30 frames per second. Therefore, the genetic information as a relation between video frames is important. From these simulation results, it is clear that this method can reduce the processing time and increase the accuracy.

Information Acquisition

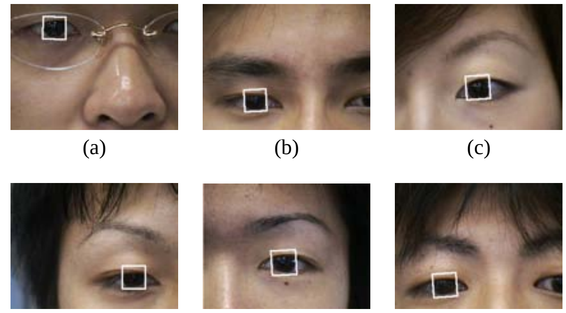
Lastly, information of the iris, which is acquired by this proposed system, is described. Examples of successful results are shown in Figure 7, where the filled rectangle region is detected region. Acquired information appears in Table 4. These values are parameters which are optimized by the GA and represent the position, size and orientation of the iris. We think this information is useful for many application which uses the eye movement interface.

Table 2. The number of frames in video sequences

subject						total
(a)	(b)	(c)	(d)	(e)	(f)	
108	109	113	213	135	114	657

Table 3. Eye detection accuracy for video sequences (%)

subject						total
(a)	(b)	(c)	(d)	(e)	(f)	
99.1	98.2	92.0	100.0	100.0	97.4	97.9



(a) (b) (c) (d) (e) (f)

Figure 7. Examples of best resulting image for Figure 5 images.

Table 4. Acquired information of the detected iris region in Figures 7

subject	location		scaling rate	rotation angle
	x	y		(deg)
(a)	85	47	2.91	1.27
(b)	102	185	2.80	-1.98
(c)	160	160	3.00	-4.14
(d)	237	181	2.95	-0.49
(e)	155	151	2.95	3.20
(f)	97	196	3.00	-4.45

6. Conclusion

We proposed a high-speed size and orientation invariant eye detection and tracking method, which can acquire numerical parameters to represent the size and orientation of the eye. In this paper, we discussed that a high tolerance for human head movement and real-time processing is needed for many applications, such as eye gaze tracking. An artificial template is used in this method for the method generality.

To solve these problem, we use template matching with genetic algorithm. A high speed and accuracy tracking scheme was achieved by Evolutionary Video Processing for eye detection and tracking. Furthermore, an artificial iris template was used for the generality of the method.

The effectiveness of our proposed method is verified in two simulations, the single image processing and the video processing. In the single image processing, the genetic information is not inherited. The detection accuracy of the single image processing is 76.0%, on the other hand, the video processing is better 97.9%. These results indicate that the proposed method is effective. The average processing time per frame is 28 milliseconds.

Moreover, the information acquisition of the detected eye is shown. The information is useful for eye gaze detection or estimation in robot perception and mobile devices interfaces.

In our future work, we evaluate whether the system has some influences by various illuminations, such as a dark place, and we must compare to the other work with same datasets. Moreover, we must try to not only track the eye but also detect the eye gaze.

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