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New Iris Tracking Method using a Generalized Particle Filter

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Abstract—Precise iris tracking is an important tool in assistive technology, and has many advanced applications such as in human-computer interactions and driver fatigue detection. Features such as shape, colour, and size of the iris enable specific position and centre of the iris to be tracked during its movement. The iris tracking system is divided into four stages: image acquisition, face detection, eye detection, and eye tracking. This study proposes a new method for iris tracking using a generalized particle filter. This approach utilizes a sample set of the tracked iris which is created at the beginning of the tracking process. The prior representation and position of the tracked iris are then predicted depending on the minimization of parameters of the proposed generalized probabilistic distribution. Results of the experiments show that the proposed method has high accuracy and can be used to efficiently track the at a shorter length of time.

Keywords- *Iris tracking; Particle filter; β-Distribution; Biometrics; Fatigue detection*

I. INTRODUCTION

The Iris is the round contractile membrane of the eye, which is suspended between the lens and cornea and perforated by the pupil (Figure 1 shows the anatomy of human eye). In the image acquisition stage, a camera is used to capture a video, and the image (data) is entered into the system. The outcome of image acquisition stage is RGB space image. Face detection is carried out after image acquisition. Face detection procedure is performed using a current technique called colour feature method. Light intensity, pixel colour and face brightness of the RGB representation differ between different people and atmospheres. RGB representation is thus not efficient for face colour identification, and can lead to misidentification. Following face detection, the eyes are located using eye colour, based on face anatomy. Vertical and horizontal projections techniques are used for eye detection. The last stage of the iris tracking system is the eye tracking stage, in which a particle filter is applied for eye tracking. The particle filter technique combines computational and numerical methods to attain conditional probability density function [1]. Eye tracking has many useful applications including iris recognition, diagnosis of different clinical conditions, and drowsiness detection. Eye tracking is a method of tracking the movement of eye or absolute POG (point of gaze), which refers to the gaze of the user relative to a visual scene. Iris tracking is useful in a wide range of areas including medical diagnostics, psychological research, usability studies and interactive and gaze-controlled applications [2]. The main objectives of this study were to track iris using generalized particle filter and to investigate new methods for improving the speed of eye tracking process. Generalized particle filter (GPF) reduces the fault rate and the level of computational in eye tracking. Iris tracking is mainly applied in computer vision and image processing, although this technique can also be applied in several other fields including medical diagnostics, biometrics, behavioural research, driver fatigue detection and human-computer interactions.

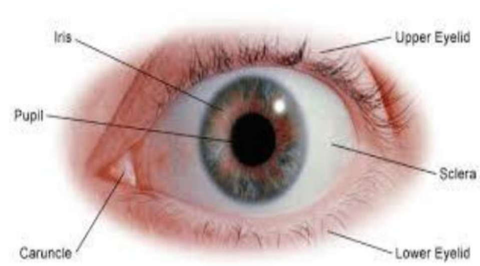

Figure 1. The anatomy of the human eye.

Many eye tracking methods have been proposed by investigators over the past years including the gaze tracking method [3], the Hough transform method [4], and template matching and classification method [5]. These techniques provide very reliable results with a low error rate; however, they are computationally demanding and are therefore not well-suited for implementation in real-time applications. Recently, new techniques, such as horizontal and vertical projections [6, 7], eye detection based on colour information, [8] and eye-tracking using grayscale prediction [9], have been proposed which aim to improve the speed of eye tracking algorithms, and are better suited for real time iris tracking . However, these techniques still have some limitations; they analyse image intensity inputs and are thus very sensitive to changes in lighting conditions and obstacles, which can result in mismatching. Iris tracking is an important part of the measurements of eye activity or movement. The analysis of iris tracking image or data with reference to the head and visual scene is called gaze tracking. Investigators who conduct studies in this field usually use the terms eye-gaze tracking, gaze-tracking and eye-tracking interchangeably in different investigations. The gaze tracking method may be utilized in all assistive technologies which involve eyes such as eye-typing for the physically disabled, cognitive and behavioural therapy, Psychology, marketing or advertising, neuroscience and visual search [2]. In Hough transform (HT) technique [10], following intensity gradient estimation, votes are casted by the presumed edge pixels for positions of the centres of the circle with radius r. Each edge pixel casts a vote in the gradient direction for a position at a distance, r, away from pixel. The centres of the circle are found at the local maxima of the vote count. The centres, radii and average length of gradient of the two irises are determined as follows: (a) first, an initial estimation of the position of two the eyes is computed; (b) given the initial estimates on the location of the eyes, the initial estimation of the radii of the iris is also computed; (c) and then fine tuning of the centre position & radii of the two irises. Each of these steps utilizes the Hough transform technique for the purpose of iris detection. The search is usually performed in three steps which helps to decrease the number of pixels that are permitted to cast votes and also to decrease the radii for which Hough transform is employed. The available methods for iris tracking can be classified into three categories: learning-based, motion estimation and knowledge-based methods. The learning-based methods may be further divided into three subcategories: support vector machines, AdaBoost classifiers and neural networks. The motion estimation techniques first estimate the position of object in the current frame, and then identify the exact position of the object using local search. In the knowledge-based techniques, the tracking algorithms are developed based on rules attained by various analyses of the face components. Thus, the knowledge-based techniques basically apply some rules in order to express the face features & their relations [1]. Iris tracking processing requires the coordinates of the centre of iris, and the extraction of this parameter depends on the following conditions:

First, in order to be suitable for real-time applications, the centre of iris should be determined both rapidly and frequently, meaning its location on each frame should be estimated. Secondly, the iris tracking model should be variable to allow tracking during occlusions caused by blinking. Thirdly, the iris tracking algorithm needs to be robust and unaffected by environmental conditions such as light. This paper proposes an iris tracking algorithm based on minimization of the parameters of generalized probabilistic distribution, in order to reduce the computational demands of the process. A new, rapid detection algorithm has been devised which utilizes the variance of the particle filter's weights i.e. A collection of Bayesian estimators. The method identifies saccades across a wide range of amplitudes. Saccades detection may or may not be intermixed with eye drifts or pursuit movements because the technique suppresses the baseline velocity, which eventually disrupts rapid detection. Particle filters are the most powerful tools of estimation in non-linear & non-Gaussian systems. The high speed eye movements are called saccades, and can be estimated using a particle filter. The subjects are tasked to track a moving target by using smooth pursuit eye movements. Finally, vengeance movements are performed where the eyes move in a disjunct, in order to set both irises parallel to the same task. Eye movement investigations need the capacity to find exactly which parts of the movements match the stable gaze or fixation, fast re-direction of LOS (line of sight) or saccades and tracking of the moving task or smooth pursuit. This is the main advantage of the rapid detection using particle filter [11]. In this study, we predicted the prior representation and position of the tracked iris, by minimizing the proposed generalized probabilistic distribution parameters. We used Generalized Particle Filter (GPF) technique to track iris movement, based on the generalized probabilistic distribution. The likelihood estimation of each particle being sampled from the distribution function was computed. Rest of the paper is organized as follows, Section II contain the related work, Section III describe the generalized particle filters, Section IV contain the experimental results and Section V is conclusion.

II. Related Work

Many algorithms for eye tracking have been proposed, and they can be used as the basis for developing an eye tracking system which achieves the highest accuracy and best performance at the lowest cost. Recently, there has also been a growing interest in head motion detection among researchers. Some of the proposed eye tracking systems, especially those with simplified algorithms, may be implemented using low computational hardware such as a microcontroller. Many different methods have been deduced for the implementation of eye detection and tracking systems [12]. Although many eye tracking methods have been proposed, investigations are still ongoing, aiming at finding robust eye detection and tracking methods that can be used in a wide range of applications. Hotrakoolet al., [13] proposed an eye tracking system based on gradient orientation pattern matching along with automatic template updates. In this method, the iris is detected based on low-level features and motion detection between subsequent video frames. The method is suitable for real-time eye tracking applications that require a high level of robustness against fluctuations in lighting conditions during operation. Moreover, by applying down-sampling on the video frames, the computational time can be greatly reduced. A high-performance eye tracking algorithm introduced by Fu and Yang [14] involves the manual extraction of two eye templates (one for each eye) from the first video frame for system calibration. Following the detection of the face region in a captured frame, a normalized 2-D cross-correlation is carried out which matches the template with the image. The direction of eye gaze is estimated by iris detection through both Edge and Hough circle detection. Although the researchers used their algorithm to implement a display control application, the calibration process is inflexible. Khairosfaizal and Nor'aini [15] developed a simplified eye tracking method based on a mathematical circular Hough transformation for eye detection, which can be applied to facial images. The first step of their procedure involves the detection of the face region which is carried out by an existing face detection method. Subsequently, the eye is searched based on the circular shape of the eye in a 2-D image. Another eye tracking system was introduced by Kuoet [16]. They used a particle filter which estimates a sequence of hidden parameters based on the data observed. In this method, , the process of eye tracking starts immediately after the detection of possible eye positions Selection of grey level histogram as the characteristics of the particle filter provides an effective and reliable eye tracking process. One advantage of this method is the use of low-level features in the image which increases the speed of the algorithm. The system has a high accuracy; however, its real-time performance has not been investigated. In another experiment, Tang &Zhang [17] used a combination of grey prediction and detection algorithm to develop an eye tracking system. Reducing the search area of the particle filter in an iris tracking system reduced the computational cost. Moreover, in order to achieve robust tracking, the outer inlier edges were eliminated by limiting the iris search area inside the eyelid. According to Toennies et al. [4], when the concluding result is calculated from many independent incomplete solutions, using templates in Hough transformation is beneficial. Thus, the Hough transform is compatible for the mixture of incomplete results with the prediction from the model. The Hough transform variant for circles has been verified to be effective & robust. Majaranta and Bulling [18] discussed the possible applications of video based infrared-pupil corneal reflection (IRPCR) and video-based tracking with remote visible light video cameras and electro-oculography (EOG), and they indicated that these video-based methods contain numerous useful features. Video-based eye tracking systems may be either utilized in a head mounted or remote configuration. Sadri et al. [19] indicated that the movements of eye during scene viewing expose helpful information regarding the relationship between eye and mind. Eye tracking may be utilized for psychological studies, driver fatigue detection, human & machine interface etc. The term eye tracking used in studies refers to the tracking of eye movement or gaze determination with respect to the head.. Boumbarov et al. [20] proposed an eye tracking with the help of pupil modeling by the standard ellipse. In pupil tracking using a particle filter, limited particles can be used to identify a suitable location of the pupil.

III. GENERALIZED PARTICLE FILTERS

Generalized particle filters (GPF) provide a more powerful estimation for non-linear & non-Gaussian system when compared with other estimators of non-linear systems such as the extended Kalman Filter. The main advantage of the GPF is that the particles do not depend on the linearization of estimated non-linear method. The paths followed by eye movements are not linear, notwithstanding, there is no set of dynamic equations that estimate the general path of eye movements. Generalized particle filters are able to estimate large non-linear dynamical systems set, hence, they are useful regardless of the cost of computation. GPF can be computed at low cost. Our algorithm is divided into two phases: In the first phase, we acquired a video using a camera. Video of specific regions, focusing on simple but powerful features of the eye, was saved in mp4 format. The colour of the iris is different from the rest of the eye and therefore confers an advantage. We divided the video into sequential frames; in our method 50 frames per second was used. In the second phase of our experiment, we located the iris in the eye region. Generalized Particle Filter (GPF) procedures were applied to track the iris movements based on the generalized probabilistic distribution, and the likelihood estimation of each generalized particle filter being sampled from the distribution function was computed. Generalized particle filters are a general approach for particle filters using a sequential Monte Carlo algorithm. The generalized gamma distribution given in Eq. 1 was been used for particle representation.

$$p_x(x \mid a,\beta,\gamma) = \frac{\gamma\beta^{-a\gamma}}{2\Gamma(a)}|x|^{a\gamma-1}\exp\left[-\left(\frac{|x|}{\beta}\right)^{\gamma}\right] \tag{1}$$

For tracking the iris, we stored the set of irises states as $x_0, x_1, \ldots, x_{t-1}$.$X_t$ is the state of the position of an iris at time $t = 1, \ldots, n,$ where *n* is the number of frames. The tracking of the iris was carried out in three phases:

Prediction: Tracking of iris, followed by observational measurements as Y_t: where

$y_0, y_1, \ldots, y_{t-1}$ Is a set of measurements of frame at time

t. This was used to define the following formula

$P(X_t | Y_0 = y_0, \dots, Y_{t-1} = y_{t-1})$.

Data association: we used the formula

$P(X_t | Y_0 = y_0, \dots, Y_{t-1} = y_{t-1})$

To determine some measurements obtained from frame t.

Correction: there are relevant measurements, so we computed the representation using the formula below:

$P(X_t | Y_0 = y_0, \dots, Y_t = y_t)$.

During iris tracking, we assume that $p(X_0)$ represents the probability of the first state in the Position of iris, with observation Y_0. Put together, we used the formula below:

$$P(X_t | Y_0 = y_0) = \frac{P(y_0 | X_0) P(X_0)}{P(y_0)} \quad (2)$$

We must initialize with a diffuse prior of a special form that is easily sampled

High-dimensional state vectors without difficulty. In order to compute the expected state of the iris given some information, we calculated the variance of the state, thus, the probability distribution is a device for accurately calculating expectation.

Sampling representation: The main function of the generalized particle filter method is sampling representation of the probability distribution. Sampling representation of the likelihood from a collection of

$$x_t | i = 1, \dots, N_s \quad (6)$$

samples (particles) at time t and an associated collection of weights wt, where x is the Numbers of samples for this state. These points are independent samples drawn from the probability distribution function $P(x_t | x_{t-1})$. The normalization of Weights is given by:

$$\sum_{t=1}^{Ns} w_t = 1 \quad (7)$$

The discrete weight is approximated to a posterior probability distribution function (pdf).

$$P(X_t | Y_0 = y_0, \dots, Y_{t-1}) = \int P(X_t, X_{t-1} | y_0, \dots, y_{t-1}) dX_{t-1} \quad (3)$$

$$P(X_t | Y_0 = y_0, \dots, Y_{t-1} = y_{t-1}) = \int P(X_t | X_{t-1}) P(X_{t-1} | y_0, \dots, y_{t-1}) dX_{t-1} \quad (4)$$

The correction involves obtaining the representation of $P(X_t | y_0, \dots, y_t)$

$P(X_t | y_t)$ can also be written as:

$$P(X_t | y_t) = \frac{P(y_t | X_t) P(X_t | y_0, \dots, y_{t-1})}{\int P(y_t | X_t) P(X_t | y_0, \dots, y_{t-1}) dX_t} \quad (5)$$

$P(Yt | Xt)$ represents the likelihood that will be computed by comparing predictions of the image with the actual image. As the likelihood must have many peaks, they must be monitored and recorded so that increased number of frames and particles can provide quality data for tracking. The generalized particle filter method is a sampling method for approximating the generalized distribution that makes use of its temporal structure, and can thus handle multiple peaks and

$$p(x(t) | y_{0:t}) = \sum_{t=1}^{Ns} w_t \delta(x(t) - x_t) \quad (8)$$

Where N_s (number of particles) must be large enough to converge on the true pdf. The sample x_t that is draw from the importance distribution function is given by $q(x_t | x_{0:t-1}, y_t)$, .The weights are then updated according to the following formula:

$$w_t \alpha \frac{p(y_t | x_t) p(x_t | x_{t-1})}{q(x_t | x_{0:t-1}, y_t)} \quad (9)$$

Generalized particle filters can operate as importance samplers for this distribution. The importance sampling technique is a method of generating samples with the importance density as the prior density. Thus, the weight can be updated according to this formula:

$$w_t \alpha w_{t-1} p(y_t | x_t) \quad (10)$$

Parameter estimation: We used the maximum likelihood technique to estimate the parameters of the proposed distribution.

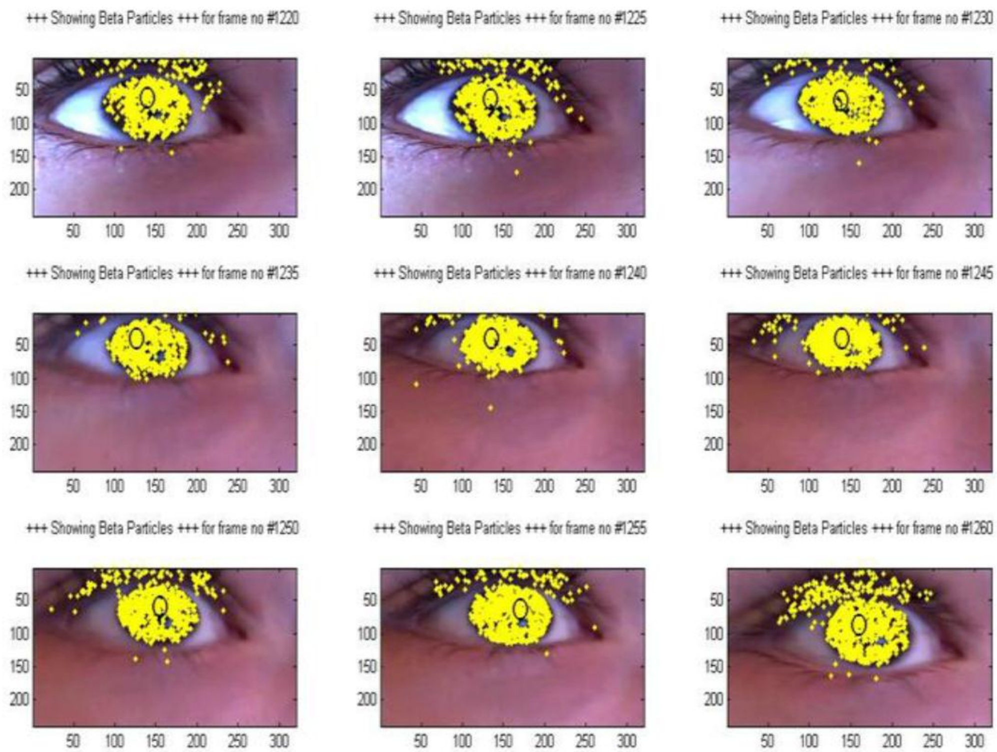

Figure 2. Graphic showing the particles drawn onto the iris using aβ-distribution function.

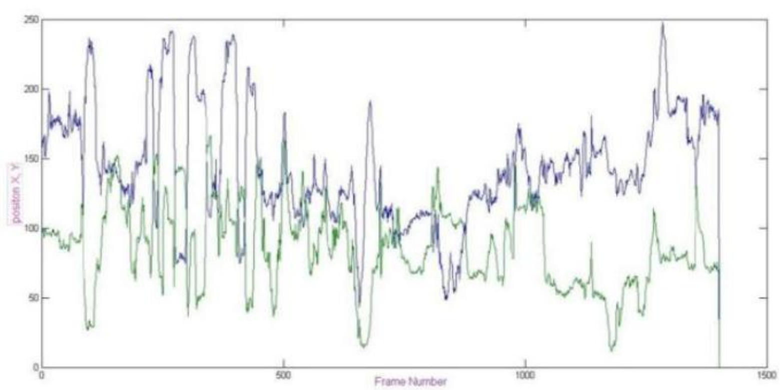

Figure 3. Chart showing the position of the centroid of the particles on each frame using β-distribution function (a = 1 and gamma = 3).

IV. EXPERIMENTS

We applied the proposed method for iris tracking using the generalized probability distribution algorithm, together with different parameters to achieve our results. Figure 2 shows iris tracking using the β-distribution function, with 2000 particles on some frames. Figure 3 shows the position of the centroid of the particles on each frame. Figure 4 shows the tracked iris using a Gaussian distribution function with 2000 particles on some frames. Figure 5 shows the position of the centroid of the particles on each frame.

We resampled the parameters that were computed from log likelihood by calculating the cumulative distribution, and then resampled the cumulative distribution that matched the cumulative distribution for the open and closed eye color histograms for frames 1–1447. Figure 6 shows the histogram for iris tracking through an open and closed eye.

Most of the existing iris tracking methods rarely investigate the required CPU time. However, real-time applications require investigation and optimization of performance requirements. In addition, most studies do not address the measurement of computation time. Using the proposed method, we were able to track the iris within a shorter length of time compared with the existing methods [13], and the computation time of the approach was also faster. Table 1 clearly shows that computation time is reduced to about 3.22ms with detection rate 100% among other old methods.

Table 1. Compares the existing iris tracking methods with our proposed method.

Method	Detection Accuracy %	CPU Time ms
[6]	100%	N/A
[16]	90%	N/A
[22]	N/A	N/A
[21]	94.1%	N/A
[15]	86%	N/A
[13]	100%	12.92
Proposed Method	100%	3.22

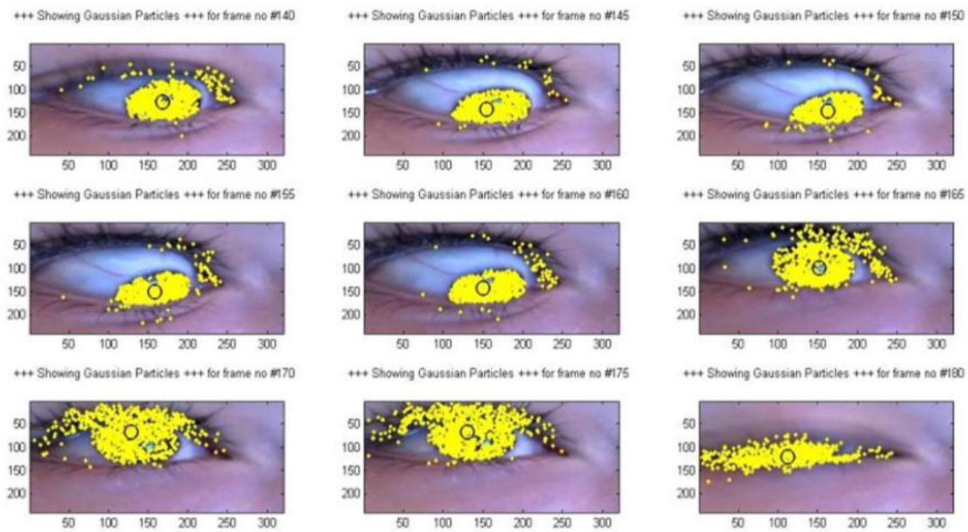

Figure 4. Graphic showing the particles drawn on iris using a Gaussian distribution function.

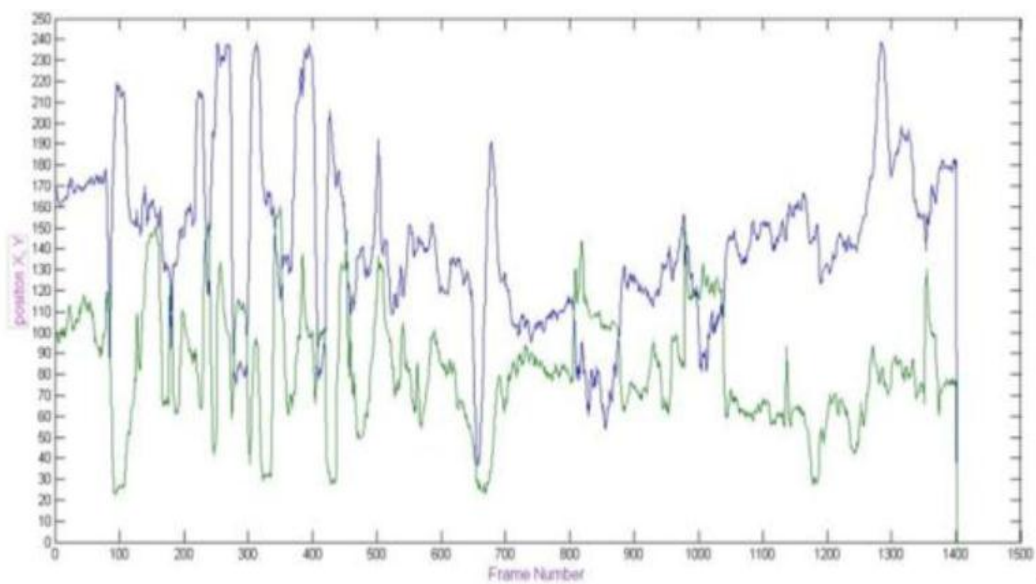

Figure 5. Chart showing the position of the particle centroid on each frame using a Gaussian distribution function (a=1 and gamma =0.5).

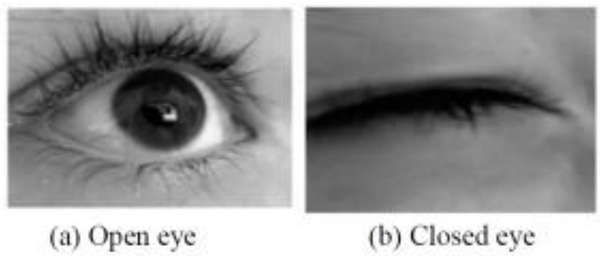

Figure 6 (a). Examples of closed and open eyes

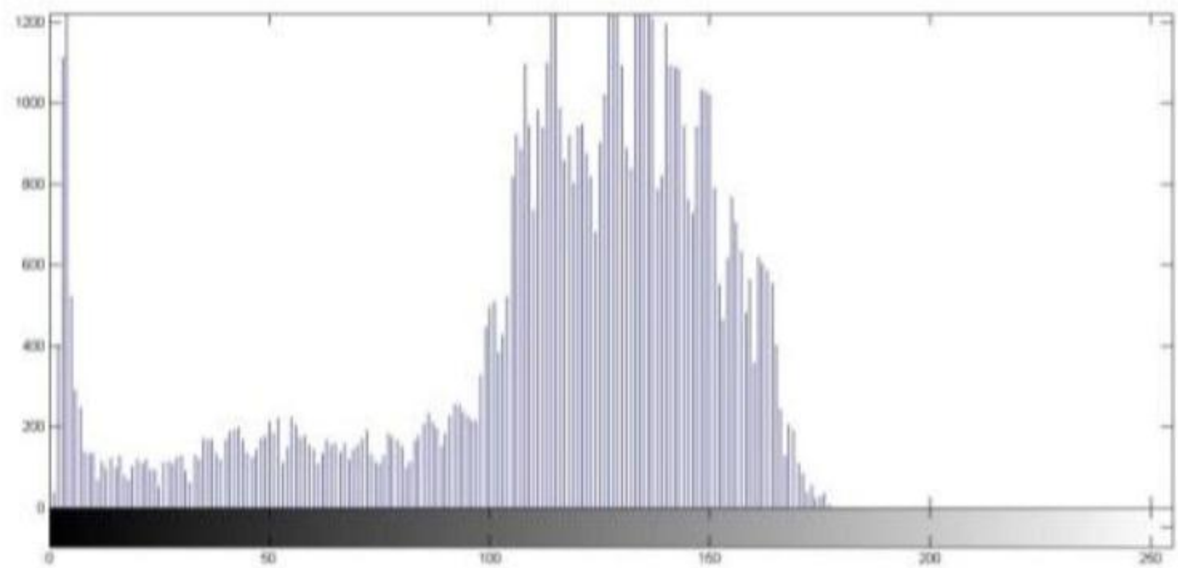

Figure 6 (b). Charts showing histograms for the closed eye in frames 1 to 1447.

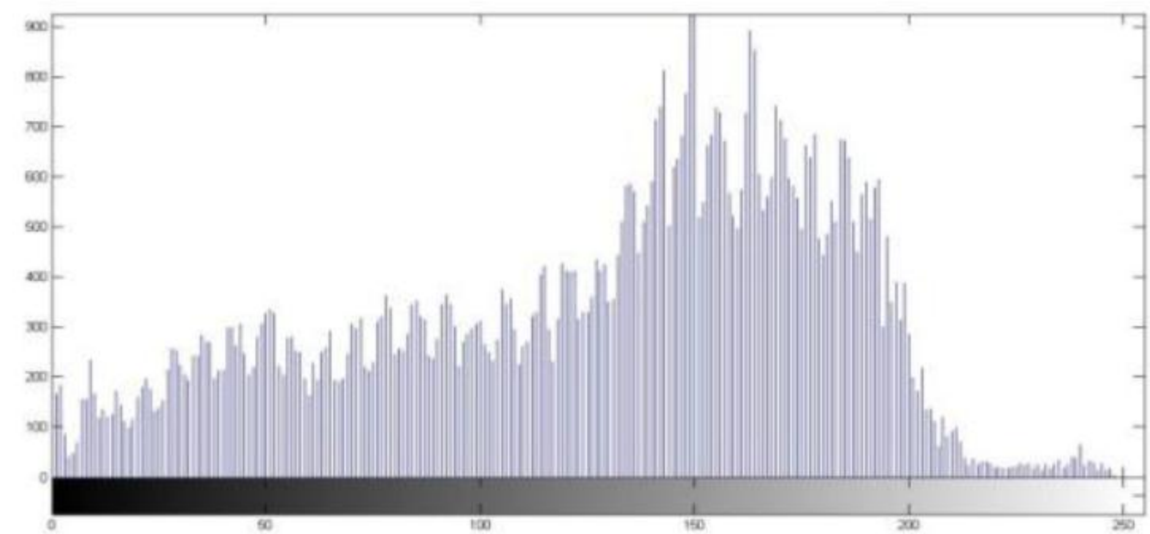

Figure 6 (c). Charts showing histogram for open eye in frames 1 to 1447.

V. CONCLUSIONS

In this paper, we proposed a new method for tracking the iris using generalized probabilistic particle filter algorithm. In this method, a sample set of the tracked iris is created at the beginning of the tracking process, and the prior representation and position of the tracked iris is then predicted depending on the minimization of parameters of the proposed generalized probabilistic distribution. The likelihood estimation of each generalized particle filter being sampled from the distribution function is then computed. Our approach provided reliable results with a low error rate a reduced computational burden. This technique aimed to improve the speed of the eye tracking algorithm which can improve the real-time application of eye tracking systems. The results show that the proposed method is robust with detection accuracy 100% and CPU time 3.22 ms, it works smoothly in real time. However, the proposed method was not tested under poor lighting condition. This issue requires some further research with more sensitive tracking algorithms. Therefore, in our future studies, we will work on generalizing the proposed framework to become robust against poor conditions.

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