Eye-Gaze Driven Display Power Management and Conservation System

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Abstract: Effective power management is among the most important challenges faced by the computing industry especially in wake of rapid shift of trends from desktop computing machines to battery operated portable machines. The prevailing operating system based advanced configuration and power interface (ACPI) technology are passive in nature depending solely on user physical inactivity from keyboard or mouse for specified interval before the system enter into power conservation mode. With the intent to improve the display power management controls in mind, a simple and smart PC display power management and conservation system (PMCS) is proposed that could improve power consumption efficiency based on actively monitoring user presence or PC bound attention via facial and eye gaze information. Facial and eye gaze are most important signs to reveal user presence and prevalent state of engagement with the computer. The system track user eyes gaze within near frontal facial positions and sustain power-up mode as long as the user eye gaze is focused on the computer screen. On failure to detect user presence or attention beyond some threshold interval the system enter into power down mode. The system employs a low-end webcam typically integrated in the laptops as a mean to obtain user facial and eye gaze information. The system will contribute toward improved PC power consumption.

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1.Introduction

Power consumption is attributed as a significant contributor to companies overall operating expenses. A general purpose personal computer (PC) consumes approximately 90 watts when in active mode, consisting of 50 watts for the central processing unit and 40 watts for the display, as compare to 3 to 4 watts when in sleep mode. In a typical modern office environment PCs accumulate 10% of the total electricity requirement (Mark Blackburn, 2009). With the ever increasing intervention of personal computer based solutions coupled with their associated costs, effective power management has become among critically important contributors to companies' sustainability. In addition, battery-operated portable system such as notebook and laptops are gradually replacing tradition desktop PCs. These portable devices also seek more efficient power management for sustained utilization between the power recharges. Most of the research made in this field so far is tied exclusively to power optimization through improved system architectural design with lesser emphasis on user related power losses associated with bad device usage. According to 1E the pc energy report one-sixth of the PC user community never turned off their machines at night or weekends translating into estimated 1.5 billion kWh of annual electricity loss and costing £ 115 million to economy and emission of 700,000 tonnes of CO2 (1E Report, 2009).

Even though technological innovation in computing devices has helped optimize power consumption, nevertheless further progress in this regard is limited due to their inherited limitation. Effective PC power management approaches needs to be holistic in manner that takes into consideration different components of the computing environment including the system and the system users. PC power consumption can be considerably improved by relating the PC I/O responses directly to users. It has become critically important to develop smart power management techniques that real-time monitor user engagement and response accordingly.

Here we present a smart solution for PC display power management that uses general purpose webcam typically embedded in laptops or can be mounted on the PC display as a sensor. The system constantly monitor user's presence or level of attentiveness by mean of captured images from the webcam and face, eye gaze determination algorithm. Face and eye gaze information are used as cues to determine user's presence and level of attentiveness respectively. The system enter into power down mode in situations where the user is either not observed within the camera field of view or observed inattentive beyond some threshold interval.

The outline of the paper is as under. Section 2 dicuss some high level details of current state of research in PC power management and eye gaze tracking technologies. Section 3 presents architectural design of the proposed system. Experimental setup details are elobrated in section 4. In section 5 we report some outputs of our prelimary study. Section 6 concludes the paper.

2.Existing Methods

The discussion on existing methods is divided into two sub sections. In the first section we present the technologies adapted industry wide to optimize PC power. In the later section we will highlight the most widely used approaches in eye gaze tracking.

2.1 PC Power Management

Realization of PC power management dates back to 1989 when Intel Corporation integrated power management technology within their processors allowing the system to swing between different modes such as CPU to slow down, enter into suspension or shut down modes to reduce the energy consumption. Since then several standards emerged as the subject attracted wider attention of both research community and the industry. Advanced Power Management (APM) was the initial standard for power management controlled at the BIOS level. APM changed power states or enter into power conservation mode when the system remain idle for pre-specified time with longer the idle time lesser the power consumption. Advanced Configuration and Power Interface (ACPI) is the most recent and widely adapted power management standard that was first released in 1996 by Compaq/Hewlett-Packard, Intel, Microsoft, Phoenix and Toshiba to address the limitation of early industry standard. ACPI allows power management control from within the operating system and maintain several distinct power conservation states such as standby, sustain between system ON and OFF states. Each power state represents different level of energy consumption. ACPI solely depends on inactivity intervals from the input devices to enter into power conservation state. The inactivity interval is defined at the OS level. The passive nature of the ACPI depending on predefined inactivity intervals make ACPI inefficient and troublesome in changing scenarios e.g. defining inactivity intervals quite short can result in frequent interrupts while defining inactivity intervals too long will decrease the effectiveness of the ACPI. To overcome such issues PC power management requires more robust and efficient user activity monitoring. The system need to robust enough to detect user presence or inattention to switch the system mode. Since ACPI monitor user inactivity through gap between physical interaction via mouse and key board it cannot determine the user presence or distinguish between user attentive or non attentiveness.

2.2 Eye Gaze Tracking

Eye gaze tracking is considered enabling technology having immense application domain including human computer interaction, marketing research, neurological and medical research, as assistive technology for disabled persons as an alternate mode of interaction as well in automobile industry for vigilance detection etc (Shahid et. al, 2013). Over the years there is a great deal of realization of the potential eye gaze can offer to the community in real world application. As a result eye gaze is attracting wider attention of research community to improve its accuracy, flexibility and efficiency. Earlier research in eye gaze tracking was quite intrusive in nature requiring specialized body attachments such as scleral coil, contact lenses and electrodes etc. to function. These techniques were only suited for experimental or laboratory arrangements with no or limited acceptability in daily usage. Rapid advancements in computing and imaging capabilities have given rise to new research direction involving nonintrusive vision based techniques for eye gaze tracking.

Vision based eye gaze tracking can be broadly classified into two classes; head mounted gaze tracking (HMGT) and remote gaze tracking (RGT) techniques. The former requires user to wear head mounted devices holding the camera at a fixed distance to eye. HMGT techniques mostly use pupil center corneal reflection vector for gaze estimation. HMGT allows maintaining constant head-to-camera displacement; however extended use of such systems results in discomfort or fatigue to users. RGT techniques provides a more natural and convenient way of interaction as the user need not to wear any devices. The camera used are either integrated or attached to LED. RGT techniques are broadly sub classified as shape-based, appearance-based and feature-based.

Shape-based techniques (Xie et. al., 1994)(Lam et. al., 1996) involve defining eye template based on the structural appearance of eye and then searching the template within the target image for maximum correlation. These techniques are although accurate but computationally quite expensive.

Appearance-based techniques (Huang et. al., 2000) adopt holistic approach based on photometric appearance as characterized by intensity distribution of eyes and their surrounding region. These techniques use classifiers such as support vector machine (Shih et. al., 2004) and neural networks (Rowley et. al., 1998) for eye detection. The classifiers are trained over a large dataset of eyes of different subjects under varied scale, orientation and lighting conditions.

Feature-based techniques (Feng et. al., 2001) take into consideration a set of features that are unique and mostly related to eye region such as dark/bright pupil, iris, eye corners and corneal reflections etc.

A typical eye-gaze detection process mostly involve three broad stages; face detection, eye sockets detections and gaze estimation as depicted in Figure 1.

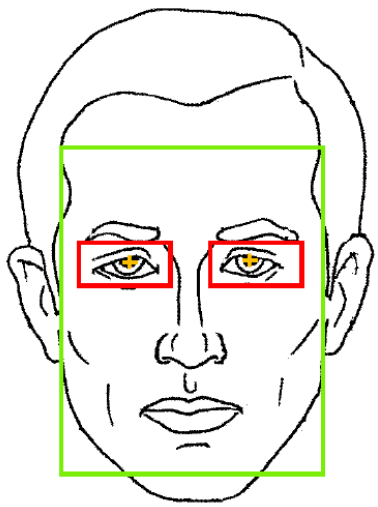

Figure 1. Face detection, eye socket detection and gaze estimation.

3.Material and Method

3.1 System Overview

Users do not operate PC constantly due to several distractions such as phone calls, engagement with colleagues and other office breaks etc. (Moshnyaga, 2012). During such disengagement, the PCs constantly remain in power up mode. The PC continues to consume energy and add to expenses which could have otherwise been saved. The situation is more critical in case of battery operated devices such as laptop and notebook where this mismanagement could add more problems.

The prime objective of this research work is to optimize PC energy consumption by mean of giving the PC necessary intelligence to actively monitor user presence as well as level of engagement and switch to power down mode as the user either step away from the PC or not attentive to computer screen. The key concept is very trivial. As long as PC continues to observe the user facing directly to the computer screen the system maintain power up state. If the PC fail to detect user or the user is distracted or not focused to the computer screen and the situation remain unchanged for some threshold period the system step in to power down state. The system finally switches to standby state if the user is continuously not observed or defocused from the computer screen for long time.

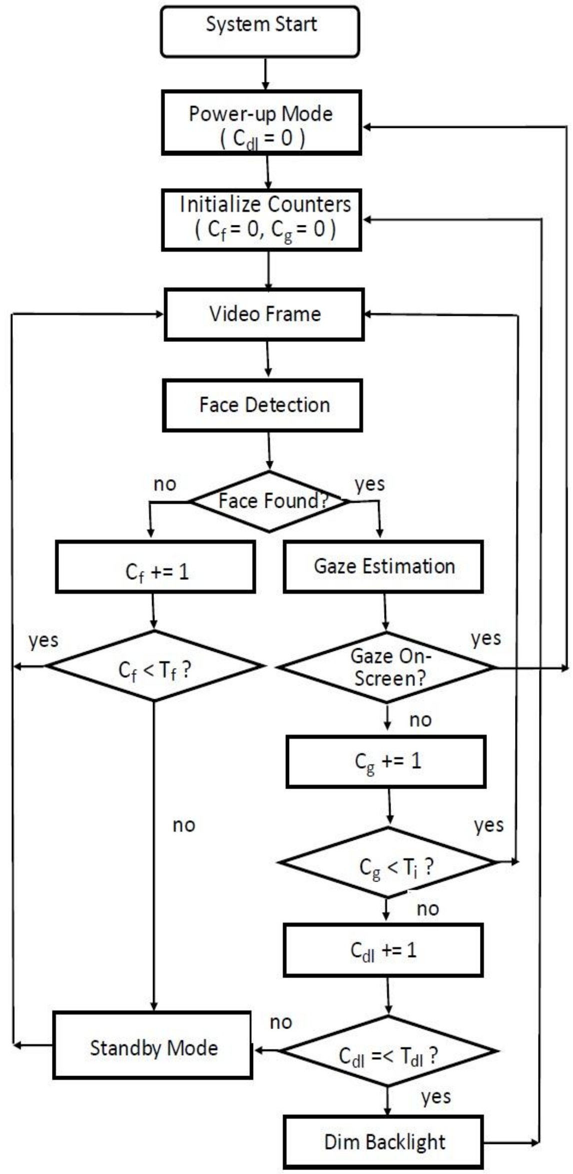

Figure 2. Flowchart of the proposed eye-gaze driven display power management and Conservation system.

Figure 2 outlines the design flowchart. The system initialize with powered up mode. The proposed system captures the video sequence V_s via CCD based sensor. Frames $F(x, y)$ are extracted from the input video sequence where (x, y)represents the spatial coordinates of the image plane. The system begins with user face detection within initial frame. Successful face detection is followed by eye socket detection within the sub region bounded by facial coordinate and gaze estimation. Failure to detect face or finding eye gaze off the computer screen beyond threshold interval put the system into power down mode. The threshold period is marked by number of successive frames. The power down mode consists of several stages each consisting of specific threshold interval defined as $T = \{t_1, t_2, t_3, \dots \dots \dots . . t_i\}$ before the system enter into standby mode. Every next stage depends on non-detection of user for the specific threshold interval in the preceding stage. During such stages if the system finds the user attention, the system instantly switch to the power up mode.

3.2 Frontal Face Detection

The objective of face detection is to determine user presence in front of PC. In events user face is not detected within the frame $F(x, y)$ signifies either none presence of user or substantial shift from normal PC position. The system initiates counter C_f and non-detection of face for successive frame beyond threshold T_i switch the PC to power down mode. Face detection step also helps localize face region from the frame $F(x, y)$ for use in the subsequent step for eye socket detection.

Faces bear considerable variation in appearance when capture on the CCD camera due to difference among individuals' skin tone, facial structure, illumination conditions as well as facial position and orientation vis-a-vis camera etc. Considering the requirement of the proposed application this paper adapted the frontal face detection method proposed in (Voila et. al, 2004) with some slight adjustments.

The method has several benefits compare to other contemporary face detection methods. The first and foremost is the use of special image representation known as integral image. Each specific location of integral image comprise sum of pixels values to the top and left of the corresponding location of the original image. This makes the calculation of rectangular shaped Haar-like features computationally efficient at different scale. The other benefit is a classifier found on the Adaboost learning algorithm by selecting a small number of critically important features from a large feature base. Finally, the method pool up more complex classifier in a cascade like structure to yield extremely potent classifier that significantly reduce the computational efforts by eliminating non potential background region and spending more effort on promising face-like regions. Considering the normal operating distance between the PC and the user, camera resolution and to improve system performance, a minimum detection size of 64 x 64 is considered for face region. To embody the detected face region, a bounding box is set around the detected region, as shown in Figure 3.

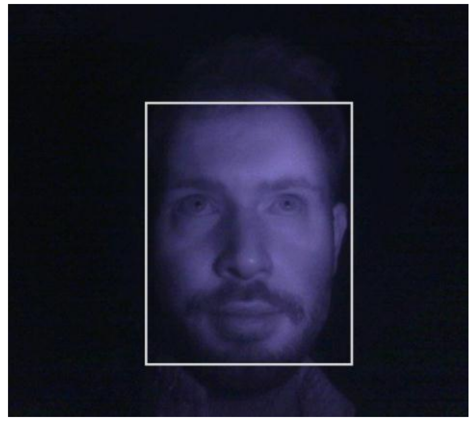

Figure 3. Face detection using Adaboost classifier.

3.3 Eye Sockets Detection

Eye detection is triggered subject to successful face detection in the preceding step. Eye socket detection aims to detect and register eyes in the bounded face region of the frame $F(x, y)$and is considered pre stage to gaze estimation. Failure to register eye sockets forces the system to move to next frame. At this stage it is assumed that face is already localized in the current frame. Geometric position of eyes within the face space along with detected eyes coordinates from the preceding frame is used to define reduced search space. Eye socket detection is performed using the approach mentioned in (Voila et. al, 2004). Figure 4 shows real time output of eye sockets detection.

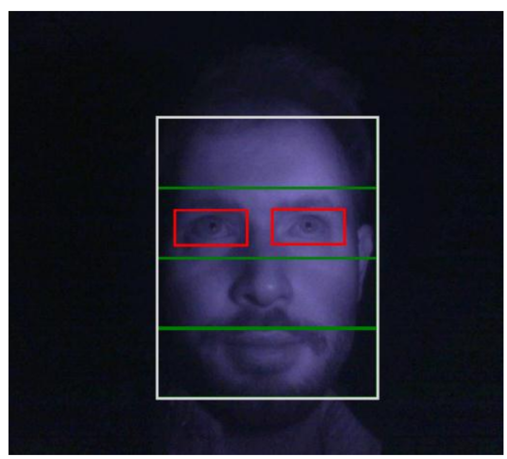

Figure 4. Eye sockets detection using Adaboost classifier.

3.4 Gaze Estimation

Although face and eye sockets detection approves user presence in front of PC but they don't guarantee PC bound focus of attention. Gaze direction provides a more direct and promising way to measure focus of attention. Gaze estimation involves mapping of image coordinates to the real world space as defined by

$$G_v = \varphi(E_v)$$

Where φ denotes gaze function that compute gaze vector G_v from the eye features vector E_v detected from the image frame. Features vector typically involves a variable positioning point and an accurate fixed reference or anchor point to measure the gaze vector. The proposed system adapts variable positioning pupil center and inner eye corner to estimate the gaze vector. Inner eye corner is considered a good option as reference point as it maintains stable state during eye gaze movements.

3.4.1 Pupil Detection

Pupil detection is performed using the method proposed in (Shahid et. al, 2010). This method considers using darkest region finding approach and requires high contract between the eye regions. Compare to visible spectrum, infrared illumination offer several advantages especially in case of indoor environment and is considered more appropriate for the given application based on the following grounds:

1. Under infrared illumination, pupil appears as very dark or bright region making it very easy to distinguish and detect with high accuracy.
2. By using filters to block non-infrared light, brightness and contrast remain constant and the subject is not affected by interference due to other uncontrolled light sources from the environment.
3. The images are free from reflection of other objects available in the scene.
4. Infrared light is invisible to human eye and therefore does not distract the subject or cause the pupil to contract.

The application uses dark pupil effect by placing the infrared light emitting diodes off the camera optical axis to produce the desired effect.

Pupil consists of lowest intensity value pixels within the eye sockets. Eye brows and eye lashes are other regions that qualify the criteria. The method detects pupil prospect point (PPP) by first selectively applying a search window centered on each of the lowest intensity value pixels within the eye region and then applies lowest average neighborhood intensity criteria. We assume that the PPP must satisfy the following criteria:

1. The PPP has the lowest average neighborhood intensity value.
2. The PPP lies within rectangular window centered at the midpoint of the eye sockets as shown by yellow boxes in Figure 5. The rectangular windows helps avoid false positive PPP lying on eye brows and eye lashes.

Outward horizontal projections from PPP are drawn within the labeled edge map of eye sockets. The projections intersecting the first edge on either side having identical label is considered pupil candidate. Pupil detection is validated based on the criteria that both the eyes move in parallel and resultantly the two pupil lies on the same horizontal lines. Pupil center coordinates are obtained by taking midpoint of longest horizontal and vertical lines within the detected pupil contour.

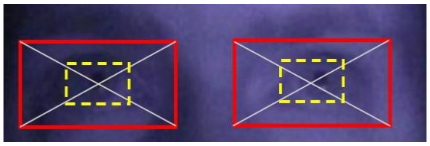

Figure 5. Rectangular window centered at midpoint of eye sockets.

3.4.2 Inner Eye Corner Detection

Eye corner detection is performed using modified Harris corner detector (Bengoechea et. al., 2013) (Harris et. al, 1988). Harris corner detector is considered good choice for eye corner approximation considering its strong invariance to scale, orientation, lighting condition and factors related to image noise. The Harris corner detector relies on local auto-correlation function of a signal where the function calculates the local changes of the signal with patches translated by small amount in different directions. The objective is to determine small areas of the image that provide relatively large response when moved around. For any given pixel and its neighborhood, a matrix M can be defined as under:

$$M = \begin{pmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{pmatrix}$$

where, I_x and I_y represents image derivatives along x and y directions respectively. We can calculate score R for each point as defined under:

$$R = \det(M) - k * trace(M)$$

where $\det(M) = \lambda_1\lambda_2$ and $trace(M) = \lambda_1+\lambda_2$ and λ_1 and λ_2 are the eigenvalues of matrix M.

Sub region are defined based on geometric location of the inner eye corners within the eye sockets i.e. eye portion adjacent to nose region. The method is applied separately to sub region of each eye socket. Harris corner detector is first applied to the original sub images and then to their smoothed versions with $k = 0.06$. The smoothing is done using a Gaussian filter. The following criteria are used to classify any detected point as prospective corner candidate:

1. For the original sub image all the local maxima of score R.
2. For the smoothed image 50% of the maximum value of R.

Harris corner detector detects all local maxima as prospective corner candidates which distribute intricately within the original sub image. The quantity of candidate points in original image makes it very difficult to decide for the exact inner corner point. However, in smoothed version only fewer corner candidates are obtained (maximum two). In case of two qualifying points, the one closer to nose is selected as best approximation of corner point in the smoothed sub image. The candidate points in the original sub image are compared to the candidate point of the smoothed image and the point closest to the smoothed image is approximated as eye corner point.

Few geometric criteria are applied to validate the approximated corner points. Considering typical upright forward facing position it is observed that two eye corner points lies nearly on the same horizontal line.

Eye sockets coordinates are saved. Subspace around eye sockets are used for eye detection in successive frame.

3.4.3 User Dependent Calibration

As an initial step, one point user dependent calibration is performed. The calibration is done only once and that at the time system is powered up. For this users are asked to gaze at calibration point displayed in center of computer screen. Vectors p_1c_1, p_2c_2 and p_1p_2 as shown in Figure 6 are measured based on the detected pupil centers and inner eye corners.

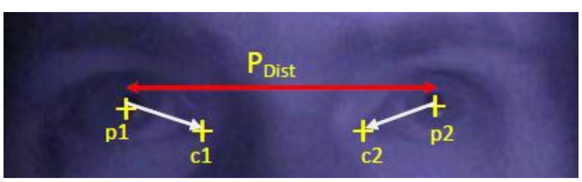

Figure 6. Eye feature vector determination.

For real time performance evaluation we assumed that eye gaze is on-screen if either of the following two criteria is satisfied:

1. Pupil center eye corner vectors are within the threshold limit of vectors detected during the calibration phase.

$$p1c1 = p1'c2'$$
$$p2c2 = p2'c2'$$

where p_1c_1, p_2c_2 vectors are from the calibration phase and $p1'c2', p2'c2'$ are vectors determined during the evaluation phase.

2. Distance between the two detected pupil centers are within the threshold limit of the distance measured during the calibration phase.

$$p1p2 = p1'p2'$$

where $p_1\ p_2$ vector is from the calibration phase and $p1'p2'$ is vector determined during the evaluation phase.

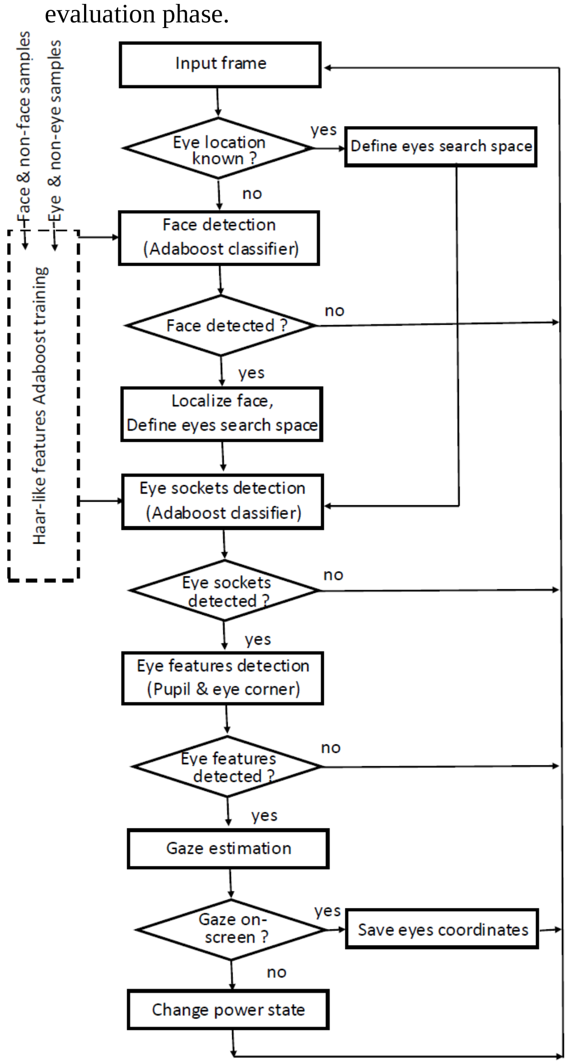

Figure 7. Eye Gaze Tracking Algorithm.

Figure 7 illustrates the proposed algorithm. The system first determine integral image for each input frame. If the eye socket coordinates are known from the preceding frame the system search only a small sub space i.e. + 10% around the eye sockets location from the preceding frame otherwise complete search is made first for near frontal face detection using Adaboost classifier. The addition of 10% search space is based on the assumption that there is fractional shift in face position considering the frame rate. Successful face detection is followed by the two eye sockets detection using Adaboost classifier within the area bounded by detected face region. Geometric position of eyes within the face region is employed to reduce the search space for eye sockets detection. Eye gaze is measured based on successful pupil centers and inner eye corners detection. On successful gaze estimation, eye sockets coordinate are updated for subsequent frame and the system continue normal mode of operation.

4.Experimental Setup

Experimental setup consists of Intel i7 Core™ CPU with display monitor. Modified Microsoft LifeCam VX-5000 for infrared imaging was used for real time video input. The camera was mounted on the center top of the monitor in neutral forward looking position. Infrared illumination source placed on the center bottom of the monitor was used to illuminate the subject face. The distance between the monitor/camera to user was within the range of 1.5 – 2.25 Feet (approximately 45 – 70 centimeters).

5. Experimental Results

To validate performance the proposed system was tested on two different users under real-time PC operating conditions. Certain constraints were considered during the evaluation such as the placement of the camera vis-à-vis user (in between distance), non-occlusion of the eyes and illumination conditions etc. The performance of the system was evaluated on two parameters:

1. User presence detection
2. Eye gaze estimation

User presence detection does not involve any complex analysis and the criterion used to decide was detection of user near frontal face. The proposed system efficiently detected user presence when the users were in neutral forward facing position. The proposed system detection accuracy for user presence detection was recorded 98.2%..

An initial one point user calibration was performed for evaluation of eye gaze estimation. For each session, users were asked to gaze at the center of the PC for predefined interval. Pupil center to eye corner and pupil center to pupil center vectors were recorded. The detected eye gaze vector were used as benchmark for evaluation of on- or off-screen focus of attention in subsequent frames. For realistic modeling of user eye gaze, most of the application considers head pose and orientation information to fine tune eye gaze vector. However, such information was considered redundant in view of the application specific requirements as well as the computational complexity of head pose and orientation which was not in consonance with the proposed system targeting improvement in energy efficiency of the PCs. The system assumes only shift in users' eyes position and not rotation. During the second phase, the users were allowed to freely gaze on and off-screen. If the system failed to detect both the eye sockets or eye gaze vector is not within the threshold limit of the vector detected during the calibration phase, the system assume non focus of attention. Accuracy of 92% was recorded for successful evaluation of user attention.

Figure 8 shows some sample output of our proposed system tracking user eye gaze. The detected pupil centers and inner eye corners are marked yellow.

Figure 8. Output from the proposed system depicting successful pupil centers and inner eye corners detection.

6. Conclusion

In this paper, we extended a new system for PC Power Management. The system has wide potential to be employed in general purpose PC operation to reduce the energy drainage due to bad device managment. Interactive Kiosk and Automated Teller Machine clients operate consistently without having any builtin intelligence for energy conservation. If the proposed system is integrated in those systems that switches the display power state based on user presence will help improve the energy efficiency. The proposed system is cost effective solution with very good accuracy. One of the unique aspect of the sytem is that it based on non invasive appraoch The system passively monitor users without any hind of user direct intervention, thus giving a comfortable feeling to the users.

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