Application of Head Flexion Detection for Enhancing Eye Gaze Direction Classification

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***Abstract*- Extensive research has been conducted on the tracking and detection of the eye gaze and head movement detection as these aspects of technology can be applied as alternative approaches for various interfacing devices. This paper proposes enhancements to the classification of the eye gaze direction. Viola Jones face detector is applied to first declare the region of the eye. Circular Hough Transform is then used to detect the iris location. Support Vector Machine (SVM) is applied to classify the eye gaze direction. Accuracy of the system is enhanced by calculating the flexion angle of the head through the utilization of a microcontroller and flex sensors. In case of rotated face images, the face can be rotated back to zero degrees through the flexion angle calculation. This is while Viola Jones face detector is limited to face images with very little or no rotation angle. Accuracy is initiated by enhancing the effectiveness of the system in the overall procedure of classifying the direction of the eye gaze. Therefore, the head direction is a main determinant in enhancing the control method. Different control signals are enhanced by the eye gaze direction classification and the head direction detection.**

***Index Terms*— Eye gaze direction classification, flex sensor, head flexion, Viola-Jones.**

I. INTRODUCTION

The eyes as well as their movements play a great role in expressing a person's needs, emotional states, and the perception of the visual world [1]. This leads to the need of robust eye detection and tracking algorithms which can be used in implementing and designing human-computer interaction systems, attentive user interfaces, assistive technology, and human affective state analysis systems.

Head movement is also a natural and effective method for interaction, communication and pointing to objects. Therefore, the field of head movement detection has been the subject of many researchers' attention. One of the several applications for head movement tracking is to provide a way to control many devices by mapping the head movement or position into control signals.

This paper presents an enhancement to an eye gaze direction classification system. The eye gaze direction classification system uses Viola-Jones face detector to detect the face and define the eye region. Circular Hough Transform is used to locate the eye iris. Color features are then computed and SVM is used to classify the eye gaze direction. The proposed enhancement suggests calculating the head flexion angle using flex sensors and a microcontroller where the angle can be used to rotate the face image back to 0° angle. This increases the system accuracy when applied to rotated faces. It also overcomes the limitation of Viola-Jones face detector as it is not effective in detecting rotated faces.

This paper is outlined as follows. Section II glances at prior related work. In Section III, a discussion is shown on the aspects of system implementation of the eye gaze direction. Section IV provides a discussion of the proposed enhancement. Section V summarizes the experimental results. Section VI concludes the overall paper.

II. RELATED WORK

There are various eye gaze direction classification systems. Such systems apply different methodologies in order to initiate effectiveness in the outcomes [2]. One methodology of such systems includes the electric potential that applies electrons for estimating the eye gaze through a system known as the Electrococulogram. The movement of the eye is incurred by the value changes of the Electrooculogram measurement that is analyzed in estimating the eye location. Computer vision systems have also been developed in the estimation of the eye gaze detection. These systems make use of camera to capture the movement of one or both eyes. The information obtained in is then used to approximate the direction of the eye gaze [3]. On the other hand, Lui *et al.* [4] developed a detection system that applied the template matching and the face detector capable of locating the eyes. The system developed included the Zemike Moments that extracted different characteristics of the eye rotation. Support Vector Machine was used in accordance to non-eye or eye categories.

With the overall view of different research in this area, this paper aims at concluding that the SVM is effective in detecting the head movement direction and estimating the eye gaze direction. Various methods were used; for instance the application of the Viola Jones [5] that initiated a disadvantage on head rotation, the Circular Hough Transform [6] that was noted as the most effective circular pattern detector enhancing the color features of the eye, and hence; applied in classification of the eye gaze. On the other hand, many researchers focused on head orientation and movement detection [7]. Siriteerakul *et al.* [8] proposed a system known as the Local Binary Pattern that applied detection of texture in determining the direction of the head. Comparison of different texture was carried out through the approximation of head rotation angles and the presented video frame. Additionally, accelerometer sensors and gyroscope sensors have been applied for detection of the head movement. Other researchers developed systems through the combination of the head movements and the eye tracking [9]. Kim *et al.* [10] proposed the epipolar approach that was combined with the feature point matching to enhance the estimation of the position and degree of head rotation.

III. System Overview

This section illustrates the classification system of the eye gaze direction. Viola Jones face detection is used in image capturing. According to the data retrieved on detection of the eye, the Circular Hough Transform is used to define the effective region of the eye for processing [11].

A. Viola Jones Face Detection

Three concepts are used within the Viola Jones technique that lead to enhanced face detection; the cascading classifier, AdaBoost classifier and the Integral Image. The integral image illustrates the image utilized for features evaluation. The value of the integral image at pixel x, y is defined as the sum of pixels to the left and above that specific location [5]:

$$ii(x, y) = \sum_{x' \leq x, y' \leq y} i(x', y') \qquad (1)$$

where $ii(x, y)$ represents the location point x, y within the integral image. The original image of the pixel is represented by the $i(x, y)$. For face detection, the three features that are applied include the two rectangle features, three rectangle features and the four rectangle features. The adaboost is used to select a small set of calculated features within the classifier.

B. Circular Hough Transform

Circular Hough Transform (CHT) is applied for detecting the iris by locating the circular curve candidates in the image [6].

C. Support Vector Machine

SVM is applied in tracking objects and applies learning algorithms significant to classification. A kernel function is applied for mapping the input data into an N dimension space [12].

D. HSI Color Space

HSI, which stands for hue, saturation, and intensity, is a color representation that uses conic-coordinates. HSI color representation rearranges the RGB color representation geometry, separating the luminance, i.e. the image intensity from the image chrominance, or the information about image color. This separation eliminates the effect of the changes in lighting conditions.

E. Algorithm Implementation

The first stage in the eye gaze direction classification system proposed in [11] is face detection. Viola-Jones is used to obtain data about the face region. This information is used for defining the eyes region and calculating the approximate eye radius range to be used with the Circular Hough Transform. The possible values for the eye radius range from 3% to 4.5% of the detected face height [11].

Another benefit for face detection is that the extracted face information can be used in defining the eye region which will be processed. This reduces the number of potential iris candidates detected due to the elimination of the noisy image background.

The coordinates of the iris center are found using the Circular Hough Transform. The Circular Hough Transform parameters are: radius, threshold, and delta. When it comes to radius, the Circular Hough Transform is flexible in defining the radii of the circles which will be detected. The Circular Hough Transform will detect the circular curves having radii within the range specified. As mentioned earlier, the detected face information is used to derive this range.

A binary edge map is created based on the threshold parameter. Pixel values are normalized prior to thresholding the image. This parameter is set to 0.15 [11].

The delta parameter represents the difference level between the detected circles for which these circles are considered to be the same circle. The possible values for the delta parameter were found to be larger than 30% of the height of the detected face. To reduce the possibility of errors, delta is set to 20% of the face height [11].

All circles with radii values within the given range will be detected. However, the image should contain only two irises. The two irises will have the highest count of edge points. From these 2 irises, the circle having the darkest color, because of the presence of a clear black pupil inside, is selected for further processing.

In order to determine the eye gaze direction, a sub-image is extracted from the original video frame after it is converted to HSI color space.

Two regions are defined in the extracted sub-image: right and left. These two regions have a height and a width equal to the iris diameter. One of the two regions will contain the white area of the eye according to the eye gaze direction while the skin area will be in the other region. In HSI color space, white and black have the maximum hue and the other colors have hue values that are below maximum. Therefore, the average of the hue in the two regions can be effectively used as good features for classifying the eye gaze since there is a noticeable difference between the hue of the skin area and the hue of the white area of the eye [11]. The average of the hue values in the regions is calculated as:

$$avg = \frac{1}{M} \sum_{k=1}^{M} X_k \qquad (2)$$

where M is the pixels count and X is the hue of the pixel.

IV. System Enhancements

As discussed earlier, the first step of the presented eye gaze direction classification system is face detection using Viola-Jones detector. Viola-Jones detector achieves high and accurate face detection. However, it does not successfully detect faces which are flexed in angles greater than 20°, both clockwise and counter clockwise. Figure 1 shows a face that has flexion angle 20° clockwise.

To overcome this limitation of face detection, this paper proposes rotating the face image back to the no-rotation position (face angle = 0°). This can be achieved by computing the angle of face rotation and then rotating the face with the computed angle but in the opposite direction. In order to compute the face rotation angle, four flex sensors that are connected to a PIC microcontroller (PIC18F4550) are used to measure the amount of bend in the neck.

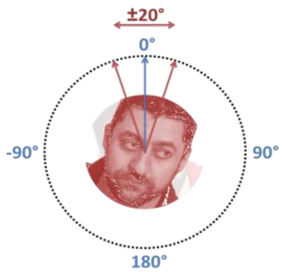

Figure 1. A face that has flexion angle 20° clockwise.

Flex sensors are a type of sensors which change resistance according to how much the sensors are bent. In these sensors, the change in bend amount is converted to electrical resistance. When the sensor is bent, it gives a resistance based on the radius of the bend. When the radius is smaller, the resistance value will be higher [13].

The sensors are placed around the neck as illustrated in Figure 2 which shows the location of the left and right flex sensors. Two more sensors are placed in the front and the back of the neck.

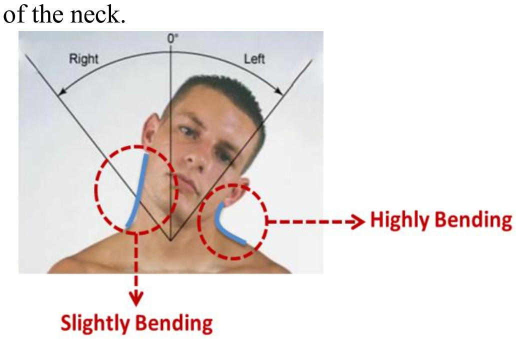

Figure 2. Right and left flex sensors placement.

Figure 3 shows the interfacing connections of the flex sensors and the PIC microcontroller. The flex sensors readings obtained by the PIC microcontroller are used for calculating the head flexion angle which will be used to rotate the face image before being processed by the eye gaze direction classification system. In Figure 4, the left sensor is bending more than the right sensor. The angle calculated for the most bending flex sensor will be considered for face flexion angle.

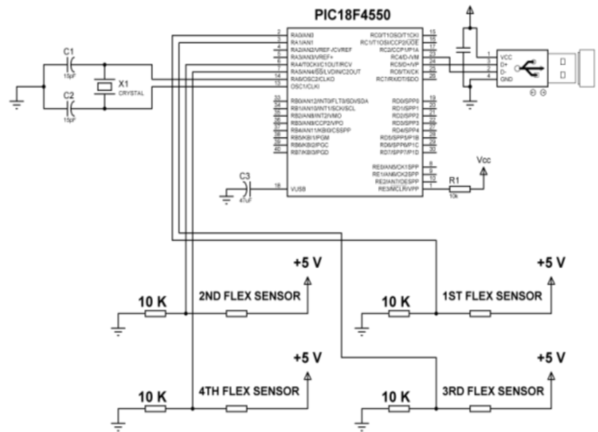

Figure 3. The microcontroller interfacing connections with the sensors.

This enhancement not only increases the accuracy of eye gaze direction classification (as will be seen in the next section), but also allows for the recognition of head positions. Head positions can be mapped into additional control signals. For example, the proposed system which combines eye gaze direction classification and head flexion detection can be applied to assistive technology applications with several commands, some of which are eye commands and the others are head movement commands. This increases the variety of functionalities that can be controlled using the proposed system.

V. Experiments and Results

This paper presents enhancements on an eye gaze direction classification system presented in [11]. The suggested enhancement includes calculating the face rotation angle and using it for rotating the face images back to 0° rotation. This enhancement allows accurately detecting faces and therefore, accurately detecting and classifying eye gaze direction. The experiments were carried out using MATLAB and a dataset containing 4000 face images for 40 individuals from different ages and genders [14]. The resistance of the flex sensor is used to find the flexion angle. The resistance can be computed by measuring the input voltage entering the PIC from the sensor. Figure 4 shows the PIC input voltage resulting from different flex sensor bending angles.

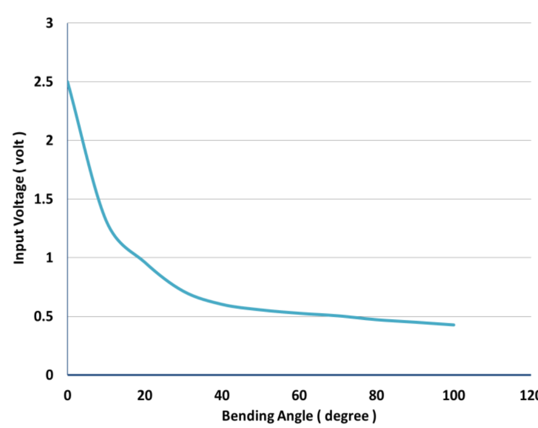

Figure 4. The input voltage for flex sensor bending angles.

Figure 5 shows the flex sensor bending angle and the corresponding resulting resistance.

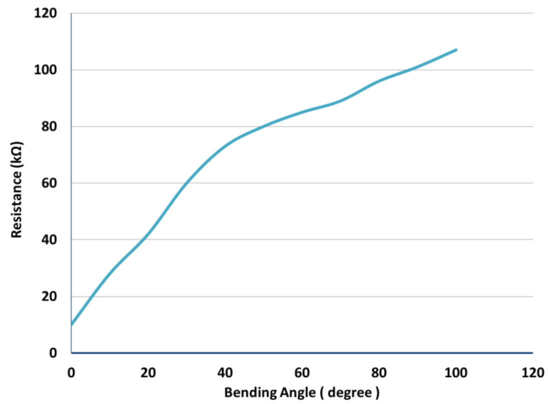

Figure 5. Flex sensor bending angle and the corresponding sensor resistance.

The accuracy of the eye gaze direction classification using face rotation is compared with the accuracy without using face rotation for several classifiers. Small face rotations, even if these rotations were in the range acceptable by Viola-Jones face detector, caused a large decrease in the accuracy before using the enhancement. Figure 6 shows that the accuracy of classifying eye gaze direction decreases for rotated face images when the rotation angle increases without the suggested enhancement. With the suggested enhancement, the accuracy for eye gaze classification is not affected by face rotation angles because the face images are rotated back to angle 0° and the accuracy became constant on the maximum accuracy value.

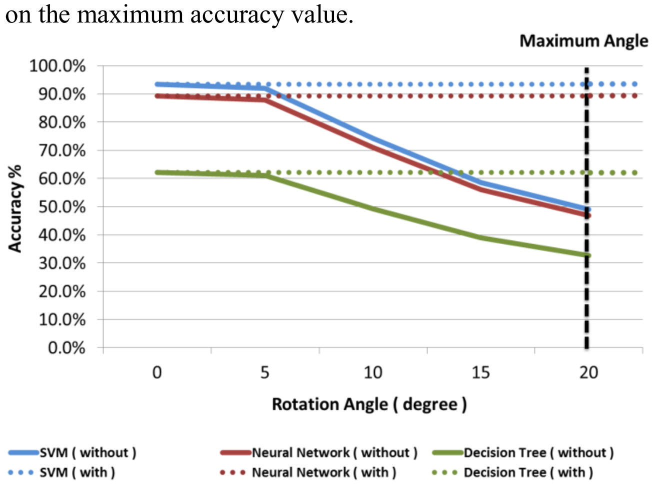

Figure 6. The accuracy of classifying eye gaze direction with and without the suggested enhancement.

VI. Conclusion

Much research has been conducted on the detection of the head movement and Eye tracking. The overall presentation of the paper provided the classification system of the eye gaze direction. The system applied the Viola Jones face detector that illustrated the first stage of the eye region and the face detection. In order to find the iris location, the Circular Hough Transform was applied [11]. For the classification of the eye gaze direction, SVM was utilized. Through the application of a PIC microcontroller and flex sensors, the effectiveness of the overall study was enhanced by calculating the flexion angle of the head. The flexion angle was used to rotate the face image back to 0 degrees. This type of application is more suitable than the Viola Jones face detector which is not effective for detecting rotated face images. The results illustrated that the face rotation does not affect the proposed systems accuracy. Therefore, the enhancement allows the application of the head angle as a method of control for various assistive technology applications.

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