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COMPUTER VISION AIDED MEASUREMENT OF MORPHOLOGICAL FEATURES IN MEDICAL OPTICS

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Abstract. This paper presents a computer vision aided method for non invasive interupupillary(IPD) distance measurement. IPD is a morphological feature requirement in any oftalmological frame prescription. A good frame prescription is highly dependent nowadays on accurate IPD estimation in order for the lenses to be eye strain free. The idea is to replace the ruler or the pupilometer with a more accurate method while keeping the patient eye free from any moving or gaze restrictions. The method proposed in this paper uses a video camera and a punctual light source in order to determine the IPD with under millimeter error. The results are compared against standard eye and object detection routines from literature.

1. Introduction

Research in this domain has a powerful motivation because of its significant contribution to the real world. It has a major importance to industry, community (helping the visually impaired) and, one of the most prominent application fields, medical computer vision or medical image processing [1].

Object Recognition raises many problems, the most important being that human visual recognition is not yet fully understood [1] and this makes it difficult to provide exact mathematical and algorithmic descriptions of the processes undertaken by the human brain. Human vision is invariant to the rotation, size or position of the objects and its attention is guided by an early processing of the image. These are problems that recognition systems, including the one presented in this paper, attempt to solve.

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Object Recognition is dependent on the process that captures the visual image as well as on the preprocessing of the input. A typical vision system is composed of several modules before the actual Object Recognition step [1, 2]: visual image capturing, noise reduction and enhancement of details and dividing the image into regions of interest (segmentation). The results of all the intermediary stages are essential to the correctness and robustness of the recognition algorithms. Post-processing algorithms can be afterwards used to obtain higher localization accuracy.

This paper proposes a non invasive method for precise measurement of the interpupillary distance (IPD). In order to achieve this, the system uses a camera, light reflexions in the center of the pupils and an auxiliary object containing markers for precise eye localization and pixel to millimeters conversion. The high accuracy of the detection as well as the low computational cost are essential to the project.

The recognition system described in this paper is divided into three main parts: the first handles capturing the video stream and the calibration of the camera(s); the second deals with the preprocessing of the frames in order to obtain the final image where the detection algorithm is applied, and the last part computes the ophthalmological measurements. The detection stage is divided into: precise circle center detection (for the markers) and precise pupil center detection.

2. Prerequisites

For pupil recognition the system uses a light source directed towards the face of the patient. This light is reflected in the center of each pupil (Figure 1) allowing precise localization.

Figure 1. Illuminated center of pupils

In order to convert between the pixel and the metric system we use an auxiliary object with markers. The object has three white circles with a black dot inside, as shown in Figure 2. The markers are well defined shapes with high contrast colors in order to simplify detection.

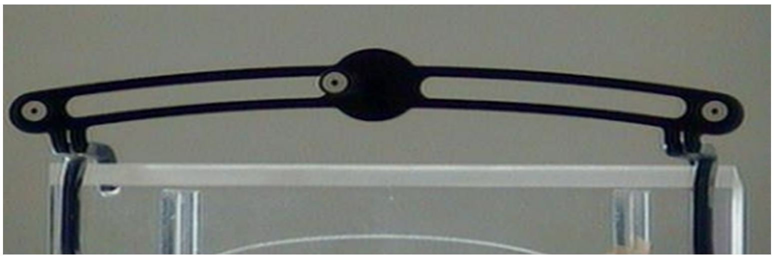

Figure 2. Auxiliary object with markers

In terms of illumination, the recognition system is designed to work under changeable visual illumination conditions. The problem of multiple light sources and multiple reflections around the eye zone is addressed as presented in Figure 3. The algorithm performs a selection of the pupil candidates. However, in some cases, these can interfere with the accuracy of the method.

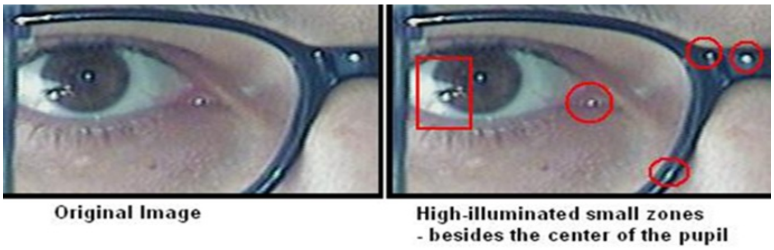

Figure 3. Multiple reflections issue

Another important hardware aspect is the capturing device. Higher resolutions can significantly increase the detection accuracy while smaller resolutions improve the speed of the process. The algorithm is designed to work on changeable resolution values.

3. Marker Detection (Circle Detection)

The detection of well defined shapes, such as circles and ellipses, can be achieved by using several standard algorithms. The following approaches have been researched in order to test for best accuracy and robustness: Hough Circle detection [1, 2, 4] and an Ellipse Fitting method [4, 8]. In both cases, the processing time was fitted for real time processing. However, under normal testing conditions, the number of omissions and false positives was high (around 25%-50%) and the precision of the localization was not satisfactory.

The results of the Hough Circles Detection algorithm massively differed with respect to the input parameters and image parameters. The Ellipse Fitting method has proven to be relatively more stable and was incorporated as part of the detection system. The preprocessing stage is composed of:

- Image enhancement algorithms: opening and closing - morphological filters used for eliminating the noise;
- Canny edge detection - the contours are given as input to the Ellipse Fitting method
- Image enhancement: closing filter - in order to create more connected contours (Figure 4)

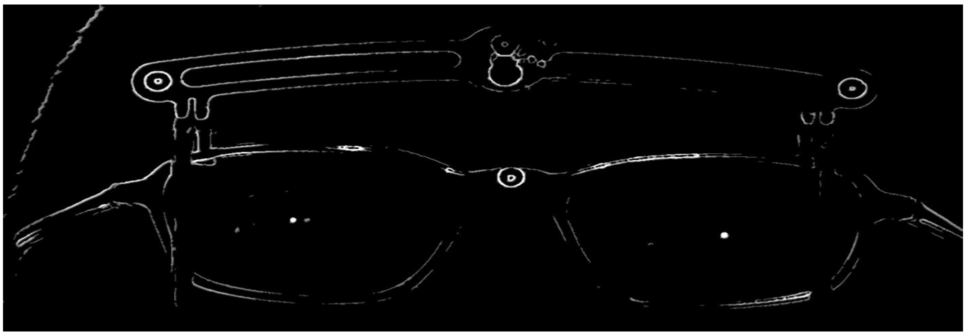

FIGURE 4. Final preprocessing step: Canny Edge Detection and Closing

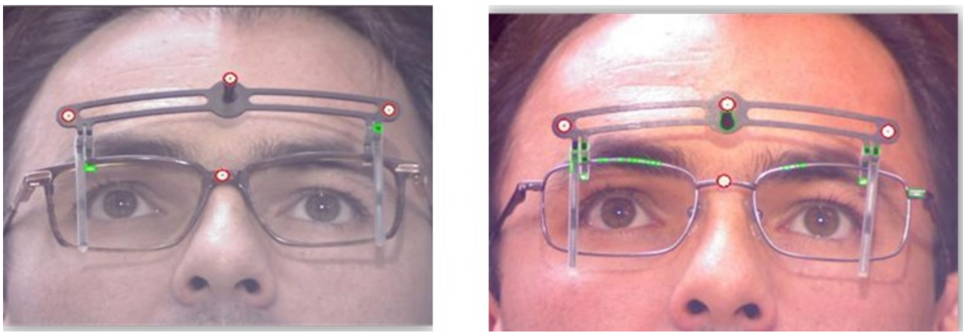

FIGURE 5. Ellipse Fitting results

After applying this technique we have the approximate location of some of the circles (it is not necessary that all markers are found) and certain false positives (Figure 5). Further analysis is needed in order to achieve better results. First, the false positives are eliminated by several methods:

- The preponderant values of the R, G and B channels inside the circles must be approximatively equal (shades of gray). An intensity threshold is not used so as not to impose any restraints on the luminosity of the scene.
- Color segmentation of the surrounding zone is performed in order to obtain the real object's dimensions. They must not highly differ from the candidate circle dimensions (in certain cases ellipsoid patters appear after the edge detection step).
- False positives are detected by comparing the circles' areas with the median area value.

In case at this point we have not selected three or more valid marker zones we apply a Fast Template Matching algorithm. The template image passed on to the method is chosen from the previously found markers in order to enhance localization. False positive elimination is performed after this step as well.

A final adjustment is necessary to increase precision, as illustrated in Figure 6. We position each of the found markers inside the center of the black dot:

- The marker image zone is binarized using and adaptive threshold
- Color segmentation is used to detect the black zone in the center of the white circle
- The enclosing square of the black circle is computed; the center of the circle is considered to be the center of the square; for higher precision, the result of this step is returned as a floating point number.

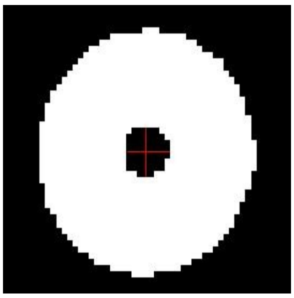

FIGURE 6. Center detection on binarized image of circle

Knowing the distance between the left and the right circle in pixels and dividing it to the real distance in millimeters (110mm in our case) gives us the ratio pixel to millimeters of the image.

4. Pupil Detection

There is much prior work on detecting and localizing facial features [1, 4], however most of these methods approach a general solution with approximative results while we are interested in extremely precise localization.

In this paper we present a fast and robust method for precise eye localization starting from the implementation of the Paul-Viola algorithm [10] for object detection using a boosted cascade of Haar-like features [2, 4]. The results of this method applied with an eye trained classifier are a sequence of rectangles representing the candidate eye zones. This includes many false positives and redundant information.

In terms of execution time, the algorithm performs well on low resolution images but it proved not to be suitable for a real time usage, especially when working with high resolution images. Figure 7 illustrates the results of the standard method compared to the final results.

Our detection system makes use of the Haar-like features in an efficient way that allows real-time processing. The source image is down sampled several times until we reach a minimum predefined resolution. The eye detection technique is applied starting from the smallest resolution image to the highest resolution image until two valid eye zones are selected. At each step the following selection methods are applied:

- Eye zones are separated into left and right eye candidates by taking as vertical axis the mean value of the centers of all detected rectangle zones. The vertical axis is dynamically chosen so as not to impose any restraints on the position of the face in the image.
- False positives are eliminated by comparing the eye zone areas with the median area value. We do not impose a predefined eye dimension.
- All eye pairs of the remaining candidates are computed and inadequate pairs are eliminated based on angle and distance measurements. The minimum angle and distance parameters are highly tolerant. However it is presumed that two eye zones cannot considerably overlap or have an angle larger than 60 degrees.

Generally the algorithm detects two valid eye zones after the first or the second iteration. The processed image is 4 times to 8 times smaller than the original which considerably reduces the execution time.

After choosing the left and right eye pair, further processing is needed in order to achieve high precision. The bright reflections in the pupils are searched inside the eye rectangles. The existence of multiple reflections in the eyes and eye glasses frames has a negative effect on the reflection candidates. This problem is addressed by taking into consideration all bright spots found in the surrounding zone and choosing the best fit pair.

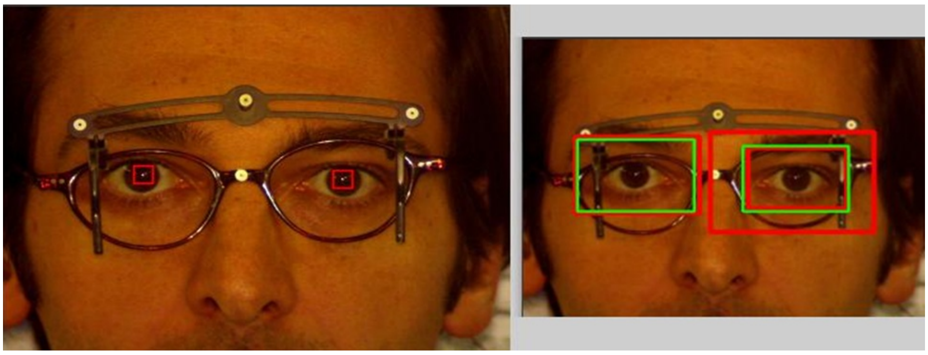

FIGURE 7. Left: Final post-processing results; Right: Initial result of detection;

The detection of the *bright pupil effect* has been used for eye detection and tracking [11, 12]. This effect takes place in near infrared illumination and the result is similar to the reflections in our images. This type of approach uses a set of two images with brightened respectively dark pupils. The difference image is used in order to obtain the reflections. Haro et al. [12] captured the two images for each frame using a system of two lightning sources. Zhao and Grigat [11] captured only one image per frame containing the brightened pupils and removed the bright spots by applying morphological opening operation [1], yet they applied another more complex algorithm for some special cases (where the pupils were not bright enough).

We use a similar technique for detecting the bright spots without the use of infrared lightning. By performing opening operation on the Red channel (where we observed that white light is less visible) we obtain the dark image. The difference between this image and one of the other color channels (where the white light is more visible) gives us the illuminated spots (Figure 8). Histogram equalization [1] is previously applied on both channels and allows us to correctly localize the reflection even when it is not clearly visible (as shown in Figure 8 and Figure 9).

Choosing the best pupil pair is done by heuristically selecting the brightest points closest to the center of the eye rectangle. Shape and intensity resemblance is also taken into consideration.

5. Experiments

In order to evaluate the presented detection system we collected two test sets, shown in Table 1. The images in the first set come from a normal usage and are obtained from different subjects under different conditions. The

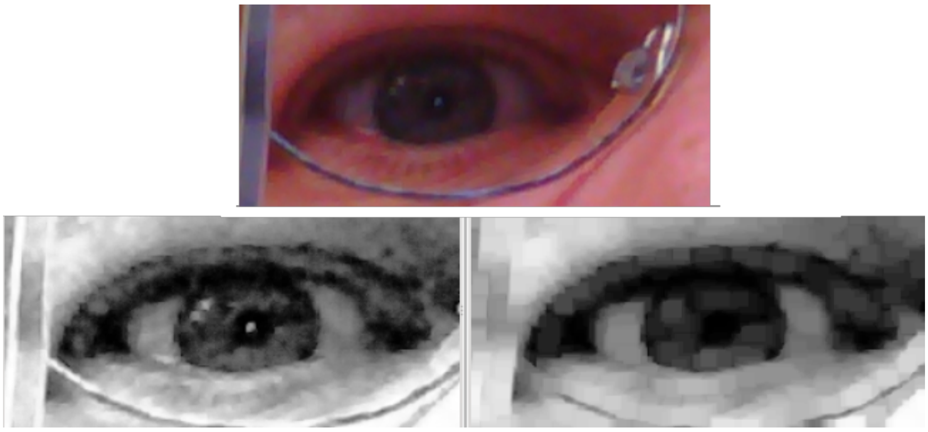

FIGURE 8. Original image with corresponding bright and darkened channels

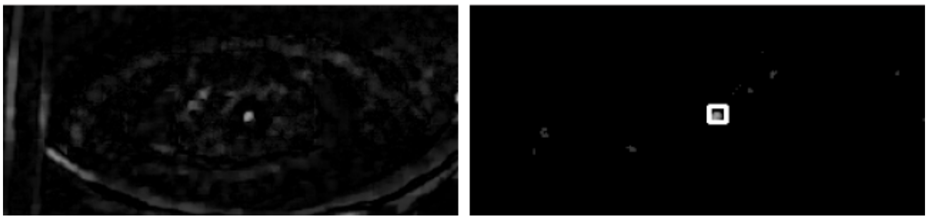

FIGURE 9. Left: Channels difference; Right: Final selection

Test Set	Size	Contents
Set 1	159	1600x1200 Images from normal usage
Set 2	30	Various Resolutions - special cases (low illumination, multiple light sources, etc.)

TABLE 1. Experimental data-photos taken on patients.

images were taken using a high resolution camera. The distance and the angle between the subjects and the camera differ slightly.

The second data set contains images specially captured in highly changing conditions. Multiple light sources were tested as well as low contrast images. The distance between the subjects and the cameras differ greatly as well as the angle of the camera and the rotation of the face.

Test Set	**MARKER Localization**	**Hit Rate (%)**	**Mean error (pixels)**
Set 1 (159 images)	Ellipse Fitting	74.2%	23.25
	EyeIPD	94%	6.2
Set 2 (30 images)	Ellipse Fitting	61.5%	32.4
	EyeIPD	94%	3.12

Table 2. Hit rate - markers detected and pixels mean error estimation.

Test Set	**EYE Localization**	**Hit Rate (%)**	**Mean error (pixels)**
Set 1 (159 images)	Haar Features	85%	24.4
	EyeIPD	94%	3
Set 2 (30 images)	Haar Features	93%	26.5
	EyeIPD	96%	2.8

Table 3. Hit rate - eyes detected and pixels mean error estimation.

We compared the results of the *ellipse fitting method*, *Haar detection* and the *detection algorithm (EyeIPD)* presented here with the manually chosen positions. For each image the manual locations of the eyes and markers were selected in a specially created application. These values were considered to have an accuracy of 100% (a 0 pixel error). Table 2 and 3 show the hit factor (percent of correctly detected markers/eyes) and the average measured error in pixels.

Considering that the average pixel to millimeter ratio is around 9 pixels/mm we get an 4-8mm error in computing the IPD using *Ellipse Fitting* and *Haar eye detection*. Using the *EyeIPD* method the maximum error is around 0.73mm. This yields an improvement in accuracy of four to eight times.

6. Conclusions

In this paper we propose a detection system that can be used for precise measurements in Medical Optics. The algorithm is designed and optimized in order to allow working on video capture and multiple resolution images. The method is flexible with respect to changes in illumination and contrast, camera angle, distance between the face and the camera and face rotations.

The recognition system developed does eye detection and localization: the position of the center of the eye is detected with an accuracy of more than

98% in more than 94% of the testing images. The location of the center of the eyes is then used for computing the exact interpupillary distance of the patient. For the support localization, the markers are circles that simplify detection and are attached to the eye-glasses for providing more information about the real distances. The three support circles centers were detected with an accuracy of over 99% in more than 90% of the images.

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