Automatic Measurement of Eye Features Using Image Processing

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Abstract. *This paper presents a camera based eye anthropometric measurement system that automatically computes the pupil size, the inter-pupillary distance, palpebral fissure (PF) and the marginal reflex distance (MRD). These values are in general manually obtained in ophthalmologic exams using a millimetric ruler or gauges, and therefore are subject to errors. Besides improving the accuracy and reliability of the measurements, the system uses near-infrared (NIR) light that allows its use in different lighting conditions. A single NIR non-calibrated camera is used to measure both eyes at the same time. The eye features are extracted using image processing algorithms, and metric values are computed using a known chessboard pattern as reference. Experimental results demonstrate the real-time performance, accuracy and robustness of the method.*

1. Introduction

Accurate extraction of anthropometric eye features provides means to assess facial shape and detect shape changes over time. This information is widely used to diagnose particular health conditions, including genetic and acquired malformations. It is also commonly used as a surgery planning and evaluation tool, documenting pre and post surgery conditions. Douglas [Douglas 2004] presents a recent review of image processing techniques for extraction of facial anthropometry and cephalometry. Such techniques have the potential to enhance anthropometric applications by reducing the time spent on examinations and improving the accuracy and reliability of the measurements.

This paper presents a camera based eye measurement system that automatically computes the pupil size (PS), the inter pupillary distance (PD), the upper and lower marginal reflex distance (uMRD and lMRD), and the palpebral fissure (PF). These measurements are used in many situations, such as prescribing the correct eye glasses and determining risk of refractive surgery to a person. Typically, these quantities are manually measured by a trained technician or ophthalmologist by means of a millimetric ruler or gauge. Sometimes, pictures are taken to be processed by a computer or human later. Boboridis [Bobridis et al. 2001] reports that the repeatability and reproducibility of these measurements are clinically acceptable when the assessment technique is standardized, but there is a learning curve associated with the experience of the examiner.

Our camera based system automates this process. The user is given a texture pattern of known dimensions that is placed on the face of the subject, leaving the eye features visible, as seen in Figure 4. This pattern serves as a ruler, that allows the computer to estimate the eye measurements from non calibrated images. The next section defines

the eye anthropometric features computed by our system. Section 3 introduces the image processing techniques that are used for the extraction of the metrics from the camera images. Experimental results from a real-time prototype implementation of the system is described in Section 4, and Section 5 concludes the paper.

2. Eye Anthropometrics

The common human eyeball has an approximately spherical shape, with an average radius of 12 mm. The external visible parts of the eye are the eyelids, the sclera, the iris, and the pupil. Next some common eye anthropometric features are described.

2.1. Pupil Size (PS)

Normal pupil size varies with age and gender. Men usually have smaller pupils than women of the same age, and pupils get smaller with age. According to Holladay [Holladay 2008], 67% of refractive surgery patients have between 5 and 7 mm pupils, 17% have pupils larger than 7 mm and approximately 2.5% have pupils greater than 8 mm.

Accurate measurement of pupil size (pupillometry) has become an essential part of the evaluation for refractive eye surgery such as LASIK, because people with large pupils are generally bad candidates for this kind of surgery due to possible problems with halos and glares after surgery.

Holladay [Holladay 2008] mentions the following three main commercial pupillometers:

- 1) objective infrared video camera with pupil detecting system: the Procyon P2000SA is a binocular pupillometer that calculates the average size of 10 pupil images captured in 2 seconds. The instrument is accurate to ±0.1 mm, and can measure at three user-adjustable light levels.
- 2) infrared tubes with a reticule or display: allows the observer to see the pupil using infrared light that does not affect the pupil size and a graduated reticule that overlays the pupil. This technique requires technician training but can be accurate to ± 0.5 mm. The Pupilscan II displays the pupil image and a digital readout of the pupil size to ± 0.1 mm.
- 3) gauges: cards with half or full pupil size patterns, as seen in Figure 1. These patterns are matched against the patient's pupil by a trained technician. Accurate measurements (± 1.0 mm) can be achieved with good illumination and practice.

Figure 1. Commercial ruler and pupil gauge from Medimeter.

Scotopic pupil measurement is required for eye surgery, so only the first two methods described above are recommended. The method described in this paper automatically

measures both pupils at the same time using a single near infra-red camera, allowing measurements at different light levels, scotopic and mesopic.

2.2. Inter pupillary distance (PD)

PD is defined as the distance between the center of one pupil to the center of the other pupil. It is an important measurement to manufacture prescription glasses as they determine the distance between the optical axis of the glasses' lenses. The higher the power of the lenses in the glasses prescription, the more important it is to use an accurate PD.

PD is measured either during the eye test or when prescription glasses are ordered. The examiner places a millimetric ruler close to right eye, aligns the origin of the ruler with the center of the right pupil, and measures the distance between the centers of the right and left pupils, as shown in Figure 2a. The PD of a person does not change once she becomes an adult, and typically the PD is about 62 mm.
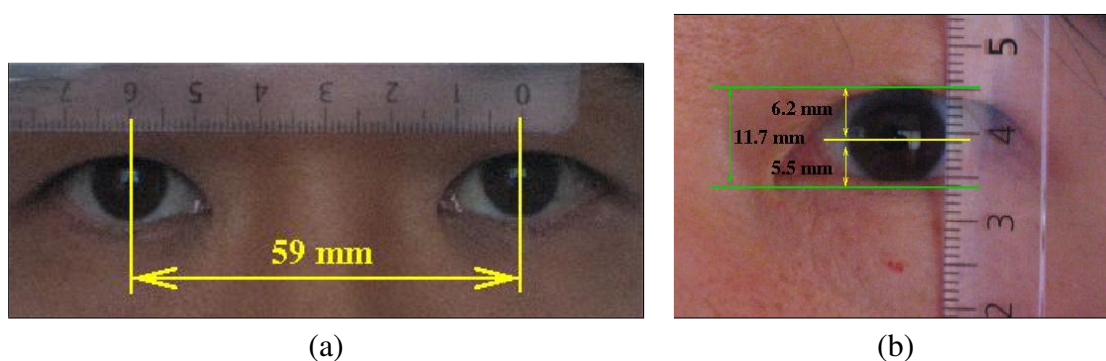

<center>(a)</center>

<center>(b)</center>

Figure 2. a) Inter pupillary distance, and b) Upper and lower marginal reflex distance (MRD) values are 6.2mm and 5.5mm respectively. The palpebral fissure (PF) is 11.7mm.

2.3. Palpebral evaluation

The palpebral evaluation consists of a thorough examination to collect data and measurements using a millimetric ruler. Boboridis *et al.* [Bobridis et al. 2001] studied the repeatability and reproducibility of upper eyelid measurements when following a standard protocol to measure three basic measurements: marginal reflex distance (MRD) for upper and lower lids, upper slid skin crease (SC), and levator function (LF). The procedures are as follows:

- MRD measurement: the patient is requested to look at a light source and distances from the corneal reflection to the upper and lower eyelids are recorded.
- SC measurement: the patient is asked to look down, the upper lid skin fold is gently raised if necessary, and the distance of the skin crease from the eyelid margin is recorded.
- LF measurement: the patient's eyebrow is first stabilized by pressure exerted with the examiner's thumb and then asked to look fully up, then fully down, while the excursion of the eyelid is measured against a ruler. This procedure is repeated three times and the average measurement is recorded.

For each measurement, the examiner must sit in front of the patient at the same level and both look in the primary position. Their results suggest that interobserver and

intraobserver variability in assessment of upper lid ptosis using this protocol was low and clinically acceptable. Figure 2b shows how the upper and lower MRD are measured.

Another commonly used measurement is the palpebral fissure (PF), which is defined as the region delimited by the upper and lower eyelids. The standard procedure to measure the distance between eyelids is to have the patient and the examiner looking in the primary position, while the measurement is taken along an imaginary vertical line crossing the pupil center using a millimetric ruler. Figure 2b shows how the PF is measured.

3. Image Processing

A recent survey paper about face detection techniques is presented by Yang *et al.* [Yang et al. 2002]. Several methods are based on detecting facial features such as the eyes. A particular computational efficient method for detecting eyes using a single camera is presented by Morimoto *et al.* [Morimoto et al. 2000]. They use two near infrared (NIR) light sources synchronized with the camera frame rate, so that only one light source is active while capturing one image frame. The first light source is placed close to the camera's optical axis to generate a bright pupil image, and the second light source is placed farther from the optical axis to generate a dark pupil image. The system presented in [Morimoto et al. 2000] uses a very narrow field of view camera to capture high resolution images of one eye. The high resolution images are required to increase the accuracy in estimating the eye gaze direction.

We have tried a similar approach with a wide field of view camera with good results. The advantage of this method is to capture images containing the whole face, as seen in Figure 3. The top row of Figure 3 shows the bright and dark pupil images. The bottom left image of Figure 3 shows the difference of the dark from the bright pupil images, with darker pixels corresponding to higher contrast regions. The highest contrast regions, detected using a constant threshold, correspond to the pupils as seen in the bottom right image of Figure 3. Observe that the system works well even for people with glasses, despite the reflections cause by the NIR light sources on the surfaces of the glasses' lens.

In order to compute metric information from a single camera, we propose the use of a chessboard pattern as seen in Figure 4. The size of each square is known to be 12.7 mm (or 0.5 in). Figure 4a shows the detected pupils on the dark pupil image, and Figure 4b shows detected corners of the chessboard pattern on each corner of the image. The pattern is placed in contact with the patient's forehead and parallel to the patient's face. Assuming orthographic projection, any detected corner connected to two orthogonal corner neighbors can be used as a basis to compute metric distance between image points. This hypothesis can be easily verified by checking if the remaining detected corners correspond to the expected corners of the chessboard pattern. In case the remaining corners demonstrate significant perspective distortion, the corners can be used to warp the image so that all transformed corners lie on their expected positions.

The quadrant with most corners is selected to define the basis of a coordinate system. Let n be the number of corners detected in that quadrant. The center of mass M is computed as

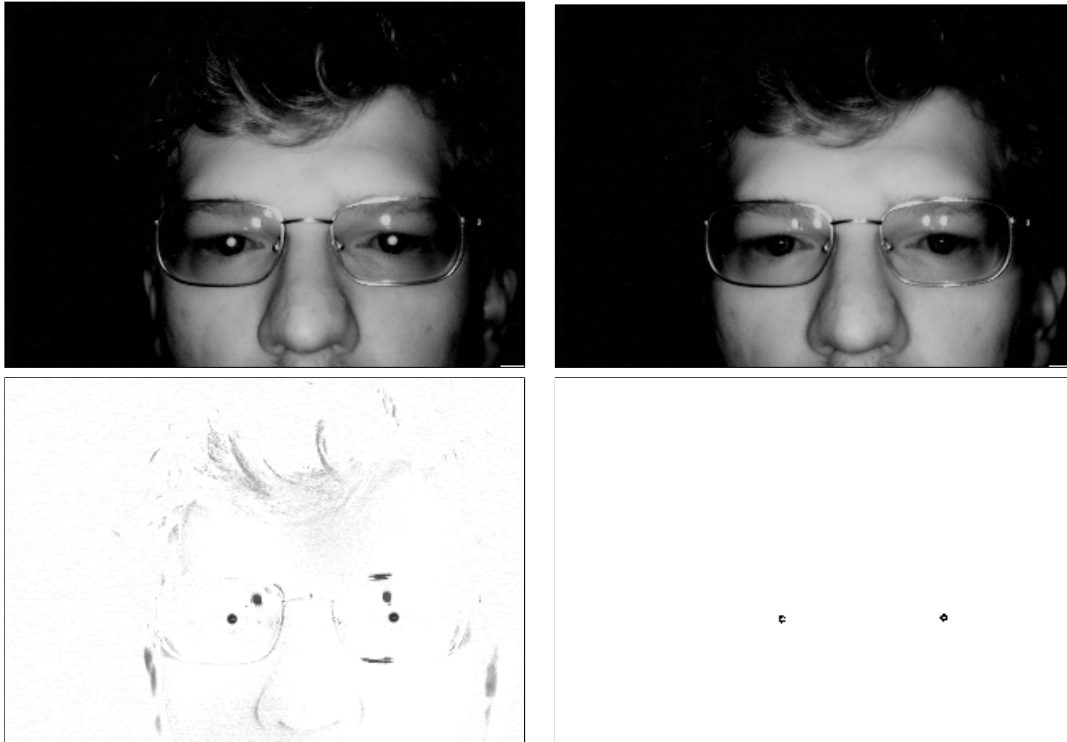$$M = \frac{\sum_{k=0}^{i} C_k}{n}.$$
(1)

Figure 3. Multiple pupil detection process. Top row shows the bright and dark pupil images obtained using two NIR light sources synchronized with the camera. The bottom row shows the high contrast regions (darker means higher contrast) and the segmented pupils computed using a threshold.

The following algorithm in pseudo language is used to find 3 orthogonal corners of a square:

- 1. Sort corners according to their distance to M, so that C_o is closest to M, and C_{n-1} is the farthest.
- 2. for (i = 0, found = false; i < n-4 AND !found; i++)
- 2.1. compute the set N with up to 4 corners C_j, $i \neq j$, that are closest to C_i;
- 2.2. for all pairs of corners (C_j, C_k) in N
- 2.2.1 if (C_i, C_j, C_k) form a basis
- 2.2.2 then found = true; break;

If a basis for a coordinate system is not found in a quadrant, the above algorithm can be used for the other quadrants. If a basis cannot be found in any quadrant, that in practice only happens when the pattern is not present in the image, eye measurements are not computed. Once the basis is computed, the norm of the basis vectors is assumed to be 12.7 mm. All measurements are computed using this coordinate system. Because this system is image based, the subject has some freedom to move his face without loss of accuracy.

3.1. Eye features computation

Once the image has been calibrated using the corners of the chessboard pattern (i.e., computation of the coordinate system), the first computed eye anthropometric feature is the size of both pupils. The contour of the bright pupils are extracted and used to fit a circle
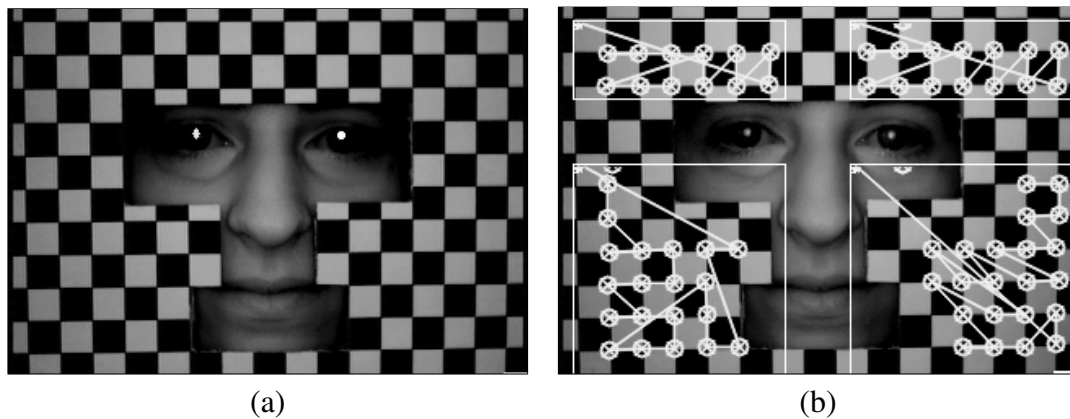
(a)   (b)

Figure 4. a) Dark pupil image showing the detected pupils around a chessboard pattern and b) bright pupil image showing detected pattern corners.

with subpixel accuracy using least squares. The diameter of each circle is used to measure the pupil size.

The subpixel distance between the centers of the pupils are used to compute the inter-pupil distance. The centers of the pupils also define the horizontal line. The MRDs and PF are measured along directions that are perpendicular to the horizontal line.

To compute the upper lid MRD of one eye, the pixel perpendicularly above the center of the pupil of that eye that is not part of the pupil is selected as a starting point. The gradient along the perpendicular direction is computed away from the pupil, within the expected eyelid region. The point with maximum gradient is selected as the top eyelid. A similar procedure is used for the lower eyelid. The PF is computed as the sum of the upper MRD and the lower MRD.

4. Experimental Results

A prototype of the system was developed using a microcomputer Athlon 1.5GHz with 1GB RAM, running Linux. The programs was developed in C++, using OpenCV for most of the computer vision routines. The prototype is able to capture 8 bit grey level images of 640×480 pixels of a NTSC video camera.

Four people have volunteered to test the prototype, 2 males and 2 females. Two of the subjects wear glasses, but all experiments were conducted without glasses. Each subject was asked to hold the chessboard pattern parallel to their faces, resting on their forehead. They were sit in front of the camera, with the lens about the same height of the eyes. The distance between the face and the camera was about 50 cm, and the subjects were asked to look straight at the camera lens while a brief video was recorded for later processing.

Figure 5 shows the results for PD, uMRD, and lMRD for one of the subjects. Observe that the center of the pupils are correctly located, and the gradient method detects the upper and lower eyelids at a perpendicular direction relative to the line that connects both pupils. The only parameter that has to be adjust at the moment is the threshold to segment the pupils. For 1 of the subjects, the threshold had to be lowered due to low contrast, but the system was still able to detect both pupils correctly.
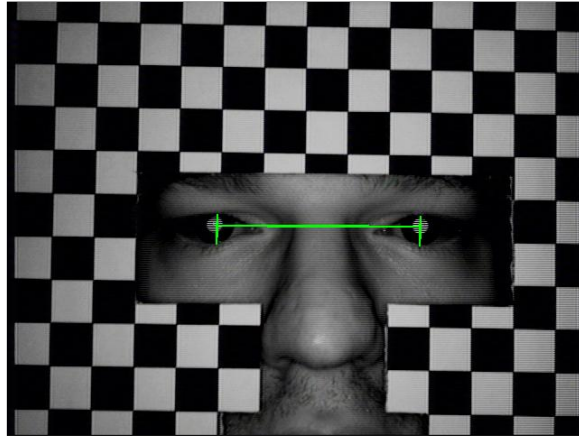
Figure 5. Inter pupillary distance and upper and lower MRD for both eyes.

Quantitative results for the 4 subjects are shown in Table 1. These quantities are computed from a single image. All distances are in millimeters. All eye features were also measured using a ruler using the traditional method. The error in millimeters is presented in brackets.

		P1	P2	P3	P4
Left	PS	5.2 [1]	5.5 [1]	5.2 [0]	6.2 [0]
eye	uMRD	2.9 [2]	3.6 [2]	3.6 [2]	4.3 [1]
	lMRF	8.3 [2]	8.3 [1]	8.7 [0]	10.1 [1]
Right	PS	5.3 [1]	5.5 [1]	5.0 [1]	6.2 [0]
eye	uMRD	3.2 [2]	3.8 [2]	3.4 [3]	3.8 [1]
	lMRD	8.6 [2]	8.7 [1]	8.9 [2]	9.4 [3]
PD		63.7 [1]	65.9 [2]	64.2 [0]	64.3 [1]

Table 1. Measurements of the eye anthropometric features for subjects P1 to P4 in mm. Error using a millimetric ruler is given in brackets.

Figure 6 shows the results from the tests for one of the subjects. Observe that the system is able to detect the pupil even when the eyelid is slightly covering the pupil. Eyelashes are the main cause of error in our experiments.

5. Conclusions

We have introduced a single camera eye anthropometric measurement system that automatically computes the pupil size, the inter-pupillary distance, the palpebral fissure and the marginal reflex distance. The system uses two independent near infrared light sources that are synchronized with the camera frame rate, to facilitate the detection of the pupils. The chessboard pattern is placed around the eyes region in order to compute metric information from the non-calibrated camera. A prototype was implemented and demonstrates the robustness of the eye measurement system to different lighting conditions. Experimental results show good accuracy, reliability, and easy of use. Average errors of less than 1mm compared to the traditional method were obtained using the prototype.
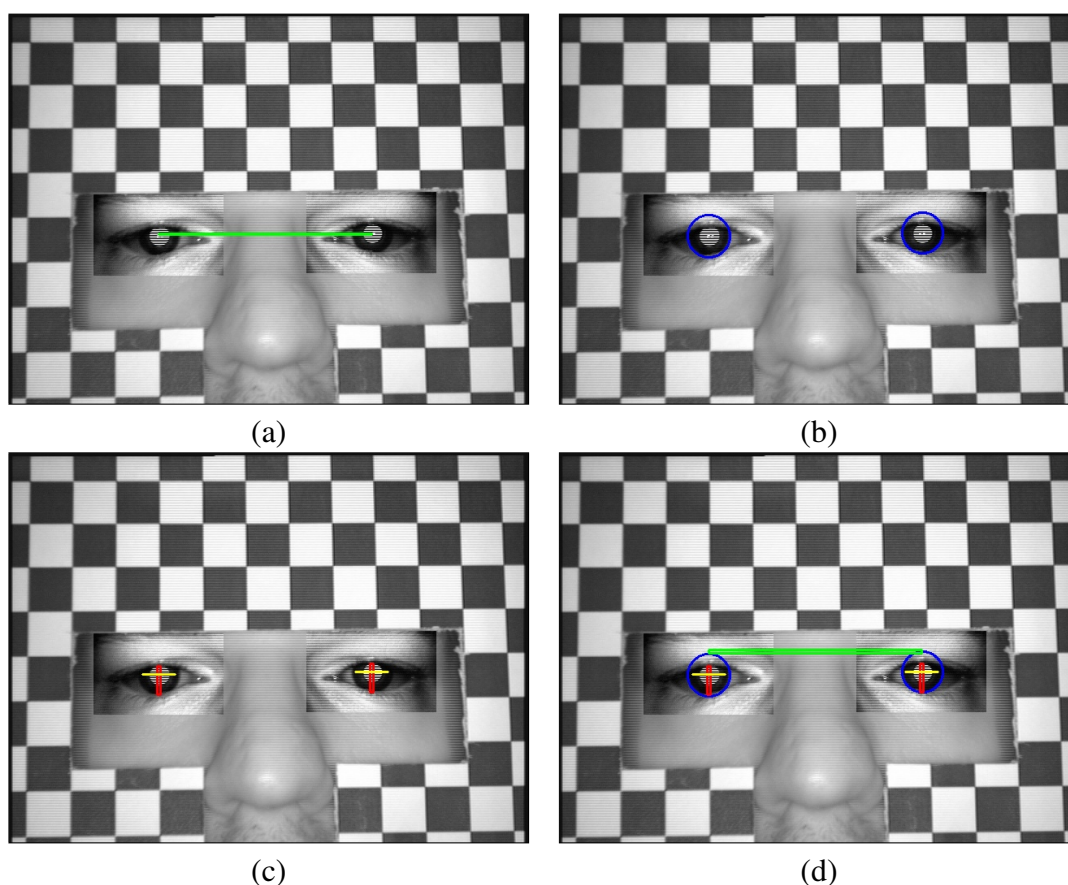
Figure 6. a) Pupilary distance; b) Detected irises; c) Upper and lower MRD; and d) All measures in the same image.

Acknowledgements

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