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Computational methodology for automatic detection of strabismus in digital images through Hirschberg test

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ABSTRACT

Strabismus is a pathology that affects about 4% of the population, causing aesthetic problems, reversible at any age; however, problems that can also cause irreversible muscular alterations, and alter the vision mechanism. The Hirschberg test is one of the exams used to detect this pathology. The application of high technology resources to help diagnose and treat ophthalmological conditions is, lamentably, not commonly found in the sub-specialty of strabismus. This work presents a methodology for automatic detection of strabismus in digital images through the Hirschberg test. For such, the work was organized into four stages: (1) finding the region of the eyes; (2) determining the precise location of the eyes; (3) locating the limbus and brightness; and (4) identifying strabismus. The methodology has produced results on the range of 100% sensibility, 91.3% specificity and 94% for the correct identification of strabismus, ensuring the efficiency of its geostatistical functions for the extraction of eye texture and for the calculation of the alignment between the eyes on digital images obtained from the Hirschberg test.

1. Introduction

Strabismus is an abnormal condition that makes the eyes lose their parallelism between. While an eye stares at a frontal point, the other turns aside, or even upwards and downwards. Because of this, the brain receives two images with different focuses, instead of two images that converge into a single spot. There are several types of strabismus: the affected eye can be yawed toward the nose (convergent strabismus); it can turn aside (divergent strabismus); or it turns upwards or downwards (vertical strabismus). There can be a combination of horizontal and vertical yaw in the same patient, as, for example, toward the nose and upwards.

In general, it can be said that the mechanical component of strabismus, in other words, the esthetic aspect of the yaw, can be treated at any age. On the other hand, the sensorial disturbances are more significant, and are only treatable at a certain period in one's life—the stage of plasticity of the visual system, which lingers on till the age of nine. Thus, as the main sensorial complication of a yaw is the strabismic amblyopya, its treatment must be initiated as soon as a strabismus condition with amblyogenic characteristics is detected [1,2].

To diagnose strabismus, the following exams are performed: visual acuity, eye background, external examination of the eyes (cornea, sclera, conjunctiva, iris, lens, etc.), and eye movement exam, obtained by means of the Cover test and the Hirschberg test. The Hirschberg test consists basically of sending a thin beam of light into the patient's eyes in order to verify if the reflection in each eye is located at the same place on both corneas. Besides these exams, there are the devices called electronic synoptophores, which measure strabismus via the projection of two separate and dissimilar images in the same position in space.

Despite the increasing use of cutting-edge resources to help with the diagnosis and the treatment of various ophthalmological conditions, the sub-specialty of strabismus has not been given the same importance. Considering the fact that it is not easy to find professionals with enough experience in this sub-area away from large urban centers – a fact that makes precocious diagnoses more difficult – these technologies have become essential in cities father away from those more advanced centers.

In 1998, the Brazilian government created the Unified Health System (SUS). This system provides health assistance – from simple ambulatory assistance to organ transplantations – ensuring integral, universal and cost-free health benefits for the entire population. Within this program, and in harmony with the principles and dictums of the SUS, the Health Program at Schools

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(PSE) was created in September, 2008, aiming at reinforcing health actions in the primary sphere, caring for the prevention and the promotion of better health assistance in Brazilian schools.

The PSE structure lies upon four platforms. Let us consider the first of these, from where there stems the main objectives of our work. This includes, among the ever so large numerous health issues, visual acuity tests. Consequently, the relevance of our work may be directed mainly toward the precocious diagnoses of strabismus and also toward the implementation of the ophthalmologic acuity test. This project can be further extended to the activities developed in the Family Health Program (PSF). Besides, this is a test that can be safely applied by non-specialized stuff, helping with patient triage, and contributing to the reduction of waiting queues and public expenses.

The field that involves the use of computational tools to support the diagnosis of strabismus has come under consideration recently. However, some tools have already been or will be developed so that health professionals can make reliable decisions concerning a number of sight pathologies.

In [3], the development of a device called *Trophorometer* is described. The Trophorometer is used to measure the position and the movement of the eye by employing computerized image processing to help diagnosing phorias and tropias. The moving window thinning technique was used to detect the edges of the pupil and limbus, and Hough's Transform was applied to locate the pupil.

In [4], it is proposed a method that uses telemedicine to treat strabismus in locations where a specialist is unavailable. For such, digital photographic cameras were employed to capture patients' images, and computers were used to send the images via e-mail to a strabismologist[1] so that the images could be analyzed.

Eye motion research laboratories use ocular trackers or magnetic devices to measure yaws and eye movements, but, despite the precision of these devices, these methods are expensive and hard to apply in a real situation [5].

There is also the report of the devices used to measure strabismus, or any other devices that use the same basis as that of a synoptophore. These devices basically work like a common optical synoptophore, but the fixing images are generated electronically on video, and the measurements are done by means of a computer [6]. Nevertheless, synoptophores are difficult to use for eye motion by non-specialized people. Also they are neither compact nor easy to transport. They can only be used on collaborative patients. Finally, such devices have not been used for the evaluation of the yaw in these past decades. This would require a very special universe of equipments, something like a laboratory, far from the patient's daily reality.

In order to develop a method capable of helping the specialist in the detection of strabismus, one would require initially to determine the position of the eyes. Many approaches have been developed to automatically detect the position of the eyes from digital images. In [7], a method to detect the eyes in facial images using Zernike's moments with support vector machines (SVM) is presented. Here, the eye and non-eye patterns are represented in terms of the magnitude of Zernike's moments, and are classified by means of the SVM. Zernike's moments are invariant to rotation, that is, they can detect the eyes, even if the face has been rotated. The orthogonal property of Zernike's polynomial allows each moment to be unique and independent as to the information provided by an image. This method has achieved matching rates of 94.6% for detection of eyes in the face images from the ORL base.

With similar goal in mind, the authors in [8] have proposed a method for the automatic detection of human faces' digital images by using the semivariogram, geostatistical function to represent the region of the eyes, and a support vector machine to classify eye candidates. The detection obtained matching rate of 88.45% for images from the ORL base.

Geostatistical functions have been applied to other works. In [9], a method to identify people through the analysis of iris texture by using semivariogram and correlogram functions was proposed. This method produced success rate of 98.14%, and it used an iris base called CASIA. In [10], the geostatistical functions were used to classify lung nodules, as either malignant or benign in computerized tomography images.

Differently from the equipment and methods presented in the introduction, and presently being used by ophthalmologists, this work proposes the development of an easy, fast and cheap way of automatically diagnosing someone with strabismus. For this reason, this is a method most useful for the average ophthalmologist. A digital camera and a computer – either portable or not – will be used with strabismus detection software installed, in compliance with the methodology proposed in the present work.

This work, based on a master's dissertation developed by the author [11], aims to evaluate the efficiency and effectiveness of the use of image processing and pattern recognition techniques to automatically diagnose strabismus based on digital images of human faces. The geostatistical measurement emivariogram, semimadogram, covariogram and correlogram have been used together with image processing techniques (Canny's Method and Hough's Transform), selection of features (stepwise Discriminant Analysis)and pattern recognition (Support Vector Machines) to verify and determine if a person is strabic, by using the Hirschberg test as reference.

The remaining of the present work was organized into four sections. Section 2 provides the theoretical basis, without which it would be difficult to understand our approach. Section 3 describes the four stages (detection of eye region, eyes location, location of limbus and brightness, and the identification of strabismus), which comprises the methodology used to detect strabismus from digital images based on the Hirschberg test. In Section 4, the results obtained by the proposed methodology are shown and discusses. Finally, Section 5 presents the work conclusions, analyzing the efficiency of the techniques used.

2. Theoretical basis

This section presents the theoretical basis necessary for the understanding of the proposed methodology.

2.1. Strabismus

Strabismus, one of the commonest ophthalmologic alternations in childhood, can be defined as an abnormal binocular interaction between the eyes, where the same image does not reach the fovea[2] of both eyes at the same time; consequently, the eyes do not fixate on the same image.

Once the position of each eye (center of the pupil) is determined, relative to a reference (either the observed point or the observation point), i.e. the directions of each axis (either the visual or the pupillary point), strabismus may be defined as the difference between the expected alignments, i.e. the angle between the ocular directions, corresponding to a disturbance of

[1] Physician specialized in the treatment of strabismus.

[2] The fovea is located in the optical axle of the eye, on which is projected the image of the focused object, and the image formed on it is very sharp [12].