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Automatic diagnosis of strabismus in digital videos through cover test

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ABSTRACT

Background and Objective: Medical image processing can contribute to the detection and diagnosis of human body anomalies, and it represents an important tool to assist in minimizing the degree of uncertainty of any diagnosis, while providing specialists with an additional source of diagnostic information. Strabismus is an anomaly that affects approximately 4% of the population. Strabismus modifies vision such that the eyes do not properly align, influencing binocular vision and depth perception. Additionally, it results in aesthetic problems, which can be reversed at any age. However, the use of low cost computational resources to assist in the diagnosis and treatment of strabismus is not yet widely available. This work presents a computational methodology to automatically diagnose strabismus through digital videos featuring a cover test using only a workstation computer to process these videos.

Methods: The method proposed was validated in patients with exotropia and consists of eight steps: (1) acquisition, (2) detection of the region surrounding the eyes, (3) identification of the location of the pupil, (4) identification of the location of the limbus, (5) eye movement tracking, (6) detection of the occluder, (7) identification of evidence of the presence of strabismus, and (8) diagnosis.

Results: To detect the presence of strabismus, the proposed method achieved a specificity value of 100%, and (2) a sensitivity value of 80%, with 93.33% accuracy in diagnosis of patients with extropia. This procedure was recognized to diagnose strabismus with an accuracy value of 87%, while acknowledging measures lower than 1Δ, and an average error in the deviation measure of 2.57Δ.

Conclusions: We demonstrated the feasibility of using computational resources based on image processing techniques to achieve success in diagnosing strabismus by using the cover test. Despite the promising results the proposed method must be validated in a greater volume of video including other types of strabismus.

1. Introduction

Strabismus is a condition in which the line of sight of one eye does not fixate on the object upon which both eyes are focused [1]. That is, while one of the eyes focuses on the object, the other eye focuses toward another direction, generating a misalignment of the ocular muscles in relation to the eye focus at the frontal point. This anomaly can be classified according to the focus direction in which the deviated eye points, which can be either manifest or latent. The former is identified by simply looking at the patient; the latter requires tests to obtain the diagnosis.

Studies show that 65% of people with strabismus developed this anomaly by the age of 3 years [2,3]. Several studies elaborate upon the importance of early treatment of strabismus in order to reduce undesirable social and emotional consequences to a person's life, such as depression, low self-esteem, bullying, and relationship issues [4–10]. Children usually express negative feelings towards the condition around the age of 6 years by expressing signs of hostility and dislike [8]. In [5], subsequent to strabismus surgery, 61% of children younger than 4 years exhibit increased visual contact, and 55% of children between 4 and 6 years exhibit improvement of their self-esteem. Research has also identified that strabismus has a negative impact on the quality of life of adult patients. These impacts can cause psychological issues and the inability to perform

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daily activities caused by binocular diplopia[1] related to strabismus [11].

Several tests are usually required to diagnose strabismus. Among these tests, the most common test is the cover test, qualified by a subtype: (a) the prism cover test (PCT) known as the 'golden standard' by specialists [12], (b) the unilateral cover test used to detect strabismus [13] and (c) the alternate cover test used to diagnose strabismus [14]. These tests are included within the category of ocular motility tests that are used for the detection and diagnosis of strabismus, either manifest or not. When performing the cover test, one of the eyes is occluded by an opaque object. Next, the occluder is shifted from one eye to the other, alternating back and forth, and the direction and estimated magnitude of eye movement are observed [15].

Currently, the number of strabismus specialists located in urban areas is relatively small, and it is difficult to find a strabismus specialist in a suburban area. The availability and use of high technology tools and resources to assist in ophthalmology diagnostics is limited within the subspecialty of strabismus, despite publication results of some studies in recent years.

Some of these studies are based entirely on manifest strabismus and are conducted by the use of tools that are difficult to obtain and utilize by non-specialized professionals in strabismus or professionals whose understanding of the requisite fully automated technology is limited. The purpose of this work is to propose an automated methodology that is based on the alternate cover test to solve the shortcomings of the aforementioned studies. The tests are conducted using computational resources and provide a second opinion to be analyzed by strabismus specialists.

In addition, this work contains additional sections that address the objective and results of the proposed methodology. In Section 2, we briefly present some studies related to strabismus diagnosis using computational resources. In Section 3, we describe the eight stages of the methodology, from the acquisition of videos to the diagnosis of strabismus. In Section 4 and Section 5, we present and discuss the results achieved by this methodology. Finally, in Section 6, we present the conclusions, contributions, and suggestions for future work.

2. Related work

Although the use of computational resources to aid ophthalmology specialists is relatively recent, studies that present both tools and methodologies already exist. This section introduces research, equipment, and related work that support the detection and diagnosis of strabismus.

Regarding the equipment used for the detection and diagnosis of eye pathologies, we cite Eye Tracking [16], which is used in ocular motility research labs to measure deviations and eye movement, and Electronic Synoptophore [17], used in the diagnostic investigation and orthoptic treatment of strabismus. However, in practical terms, both devices are difficult to operate by professionals that are not specialized in ocular motility. In addition, these devices are expensive.

Helveston et al. [18] proposed a method that uses telemedicine for the diagnosis and treatment of strabismus in geographical areas lacking specialists. In their work, images were captured cameras and sent via e-mail to strabismus experts, accompanied by patient information (age, gender, refraction, and medical record), so that the remote experts in strabismus can carry out an analysis and forward the results to the ophthalmologists.

Chandna et al. [19] used backpropagation neural networks to perform differential diagnosis[2] of strabismus using measures obtained by applying the cover test, in combination with prisms to measure deviation. Among 10 models, the average accuracy was 100%. This methodology, however, is limited to vertical strabismus and the network is restricted such that it requires manual input of the test data. We propose a methodology that is capable of diagnosing strabismus without the use of prisms and user intervention and is not limited by deviation direction.

Kim et al. [20] developed software to diagnose strabismus using image processing techniques, mathematical algorithms, and a 3D model of the human eye. To evaluate the software, they carried out an analysis of the statistical correlation of the proposed method results and the Krimsky test,[3] which was applied by two doctors to ten patients. The authors concluded that the correlation coefficients among the diagnoses obtained by the software and the coefficients provided by the specialists were 0.955 and 0.969, respectively. The correlation coefficient between the two specialists was 0.968.

The Yang et al. [21] methodology used a combination of an infrared camera to capture images, computer software, and the cover test, deploying an occluder that uses a filter supporting only infrared waves. To conduct the ophthalmologic exam, the researchers applied the Krimsky and the alternate cover test methods to 90 patients. Two specialists restricted their assessment to the horizontal strabismus: 30 with exotropia, 30 with esotropia, and 30 without strabismus. The objective was to compare the specialist's diagnoses, when applying the two exams, with the diagnoses obtained with their methodology. As a result, a correlation of 90% was achieved.

Seo et al. [22] proposed a methodology to diagnose strabismus from digital videos through a combination of the alternate cover test and the Hirschberg test,[4] using glasses with a liquid crystal shutter and an infrared camera. When the shutter closes, it blocks the visible light while the infrared is not absorbed. Subsequently, the degree and the deviation direction were calculated from the difference between the pupil center and the reflex created by the light in the eye. The authors reported successful identification of the type of strabismus, within a time period of approximately one minute.

Khumdat et al. [23] developed a methodology limited to detecting strabismus that uses images produced by the Hirschberg test applied to patients, and it is divided into three stages: (1) detection of the face region, (2) identification of the location of the eyes, and (3) detection of corneal light reflex. Images from 103 patients were captured, two images per patient, totaling 206 images. The methodology achieved an accuracy of 94.17%.

Almeida et al. [24] proposed a methodology divided into five stages to detect and diagnose strabismus using the Hirschberg test: (1) face segmentation, (2) detection of the eye region, (3) identification of the location of the eyes, (4) identification of the limbus location and brightness, and (5) strabismus detection and diagnosis. The researchers used 200 images of 40 patients, with and without strabismus and corrective lenses, obtained in five different gaze positions: (1) the primary position (PP), (2) the upward gaze (SUPRA), (3) the downward gaze (INFRA), (4) the left-side gaze (LEVO), and (5) the right-side gaze (DEXTRO). This work was

[1] Diplopia or double vision is a disorder in which two images of a single object are seen.

[2] Differential diagnosis is a method to distinguish two disorders with similar appearance.

[3] The Krimsy Test is an ophthalmological exam for strabismus diagnosis that consists in quantifying the corneal reflex dislocation using prisms in an appropriate position.

[4] The Hirschberg test is an ophthalmologic exam to diagnose strabismus that consists in analyzing the relative position of corneal reflex, through binocular simultaneous illumination.