Computers & Graphics xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Computers & Graphics

journal homepage: www.elsevier.com/locate/cag

Special Section on SIBGRAPI 2018

Mobile campimetry

Q1 Marcelo M. Oliveira[a,*], Luiza A. Hagemann[a], Airton L. Kronbauer[b], Manuel M. Oliveira[a]

[a] Instituto de Informática – UFRGS – Porto Alegre, Brazil
[b] Cenro de Olhos Rio Grande do Sul – CORS – Porto Alegre, Brazil

ARTICLE INFO

Article history:
Received 30 April 2018
Revised 26 August 2018
Accepted 8 September 2018
Available online xxx

Keywords:
Campimetry
Smartphone-based Campimeter
Visual acuity
Vision health

ABSTRACT

Campimetry is an important test to detect and monitor central and peripheral ocular dysfunctions, which might indicate the existence of serious conditions such as glaucoma, or the occurrence of strokes or brain tumors. Commercially-available campimeters are expensive and lack portability. We present a portable, low-cost, easy-to-manufacture smartphone-based campimeter. We evaluated our prototype in a user-study, which has shown that its results are consistent with the ones obtained with the Humphrey Field Analyzer - HFA II-i campimeter, with a Pearson correlation coefficient above 0.98 for all sampling positions on the visual field. Moreover, its reproducibility is also comparable to the Humprey campimeter. Given its portability and low cost, our mobile campimeter provides a promising alternative for patient screening in schools and community health centers, as well as for visual evaluation of patients with mobility restrictions, for keeping track of the visual field at home, and for use in communities with limited access to medical services.

1. Introduction

Campimetry, also known as *perimetry*, is an important test to detect and monitor central and peripheral ocular disfunctions. These might indicate the existence of serious conditions such as glaucoma, or the occurrence of strokes or brain tumors, which pose serious threats to one's health, and may dramatically affect the person's quality of life. Glaucoma, for instance, the leading cause of irreversible blindness, damages the optic nerve and often manifests itself as a silent disease. Without proper treatment, it may lend to blindness in just a few years [1]. Current estimates indicate that the worldwide prevalence of glaucoma in the population aged 40–80 years is approximately 3.54%, affecting over 64 million individuals, and should reach 76 million by 2020, and 111.8 million by 2040 [2]. Surprisingly, more than half of the patients suffering from glaucoma in developed countries are unaware of their condition. The situation is even more critical in underdeveloped countries.

Campimetry is a psychophysical test that checks the subject's perception of stimuli across the visual field. One eye at time, the patient should acknowledge each visual stimulus by pressing a button. The resulting maps reporting the minimum perceived intensities across the visual field are used by doctors along with other data (such as intraocular pressure or images of the optical nerve structure and the retina) for diagnosis.

The first concepts of computational campimetry appeared around 1970 [3] and provided the basis for current devices. Modern campimeters are still big and expensive, costing tens of thousands of dollars and found almost exclusively in ophthalmology clinics. Their lack of portability and high cost has prevented their widespread use as screening devices for ocular disfunctions. The availability of a portable, low-cost campimeter could change this situation, with the potential to significantly reduce the number of cases of avoidable blindness.

We present a smartphone-based campimeter designed to fulfill such needs. We have validated our prototype by performing a user study with 20 participants, who performed visual field evaluation both on our prototype and on a modern commercial campimeter (the Humprey Field Analyzer - HFA II-i). We compared the subjects' evaluations using statistical tools for perimetry examination [4], and show that the results produced by our prototype are consistent with the ones obtained with the HFA II-i campimeter, with a Pearson correlation coefficient above 0.98 for all sampling points on the visual field. Moreover, its reproducibility is also comparable to the one of the HFA II-i using the SITA Fast algorithm. Thus, our mobile campimeter provides a promising alternative for patient screening in schools, organizations, and communities with limited access to medical services, as well as for visual evaluation of patients with reduced mobility. Fig. 1 illustrates the use of our

* Corresponding author.
E-mail addresses: mmoliveira@inf.ufrgs.br, oliveira@inf.ufrgs.br (M.M. Oliveira), lahagemann@inf.ufrgs.br (L.A. Hagemann), alkronbauer@hotmail.com (A.L. Kronbauer).

https://doi.org/10.1016/j.cag.2018.09.007
0097-8493/© 2018 Elsevier Ltd. All rights reserved.

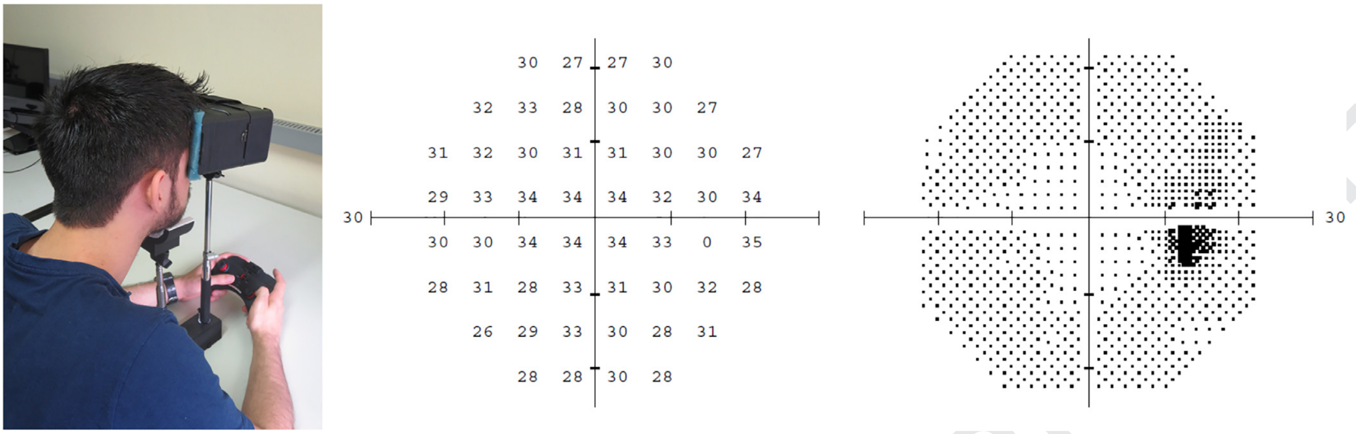

Fig. 1. Our mobile campimeter. (left) Prototype during a visual field evaluation. (center) Minimum perceived intensities (in dB) computed by our campimenter and (right) its graphical representation (blind spot shown as a dark spot). A complete report example is shown in Appendix B.

mobile campimeter prototype in one of its possible configurations, and shows examples of its reports.

The **contributions** of our work include:

- The design and demonstration of a portable, low-cost, smartphone-based campimeter (Section 3). Our prototype obtains results comparable to the ones obtained with commercial perimeters. Unlike these, ours does not require a controlled-lighting environment. The results of the exams can be sent to doctors and patients by instant messaging or making them available on-line;
- The design of optics and interactive software that allows a small programmable display at close proximity to the eye to be effectively used for visual-field evaluation (Section 3). Our solution is the first truly portable campimeter. Unlike commercially-available perimeters, ours contains no mechanically moving parts;
- A fast algorithm for visual field evaluation that obtains results comparable to the ones used in commercially-available campimeters, both in terms of quality and examination time (Section 3.3).

2. Background and related work

Some of the first methods used to evaluate the visual field were the Amsler Grid and the tangent screen [5,6]. The first perimeter using a cupola shape, as used by commercial devices today, was designed by Goldmann in 1945. Fankhauser developed the first prototype of an automated perimeter in 1972 [3]. Since then, more sophisticated and precise devices and algorithms have been developed.

A modern campimeter works by projecting a series of white light stimuli of various intensities (brightness) across a uniformly illuminated cupola (background) that covers the patient's field of view. Covering one eye at a time with an eye patch, the patient looks at a central fixation point and indicates (by pressing a button) whether each stimulus is perceived. The goal of the exam is to determine the minimum perceived intensities at a set of sampling positions across the visual field. The estimated values are presented in decibels (dB), computed relatively to the intensity of the uniformly illuminated background.

Commercial perimeters are very similar both in shape and functionality. Currently, some of the most popular campimeters in the market are the Humphrey Field Analyzer (HFA) II-i series, manufactured by Zeiss [7], and the Octopus 900, manufactured by Haag-Streit [8]. They consist of a computer together with a mechanical, an electronic, and an optical sub-systems, making them heavy, big, expensive machines. For instance, the HFA II-i weights 40 Kg, occupying a volume of $60 \times 58 \times 51$ cm^3 [9], and costing tens of thousands of dollars. Carvalho et al. [10] have developed an automated campimeter with features similar to the commercially-available campimeters. All these devices require a controlled-lighting environment for operation. In contrast, our mobile campimeter provides a truly portable, low-cost alternative for visual-field evaluation. Our co-design of optics and interactive software allows the use of a programmable display at close proximity, avoiding the need for controlled-lighting environment or mechanically moving parts.

Tafaj et al. [11] describe a PC-based solution inspired by a mechanical campimeter developed by Bruckmann et al. [12]. The evaluation of Tafaj et al.'s campimeter consisted in comparing its measurements of blind-spot sizes with the corresponding measurements obtained with an Octopus 101 perimeter. No evaluation of the minimum perceived intensities across the visual field has been provided [11].

In recent years, several works [13–16] have evaluated the use of tablets (iPads) and apps to perform perimetry. In all these experiments, the tablet was kept at approximately 33 centimeters from the subject. During the test, the distance and positioning of the subject with respect to the device are checked by the tester through visual inspection. The use of tablets required a controlled-lighting environment and the tests were restricted to up to eight intensity values. Except for [13], these experiments used fixation points at the tablet's border, restricting the portion of the visual field that could be tested at once.

2.1. Head-mounted-display-based solutions

Matsumoto et al. [17] and Dariusz et al. [18] developed customized head-mounted displays (HMDs) for evaluating the visual field. Both HMDs use high-definition LCD displays and include additional hardware to provide eye-tracking. The equipment described by Matsumoto et al. [17] includes a sophisticated optical system consisting of several components. In both devices, the field evaluation is controlled by external processing units. Matsumoto et al. use a tablet to control the test and collect the patient's responses. The equipment described by Dariusz et al. is connected by cable to a personal computer through some customized hardware interface. Unlike these devices, our mobile campimeter uses a smartphone to control the field evaluation and collect the patient's responses, providing a low-cost, autonomous, portable solution.

Please cite this article as: M.M. Oliveira et al., Mobile campimetry, Computers & Graphics (2018), https://doi.org/10.1016/j.cag.2018.09.007