An Automated Phoropter System for Objective, Accurate, and Rapid Assessment of the Visual Acuity

Erol Ozgur[1], Farhad Akhoundi[1,2], Craig Draper[1,2], Ram Voorakanam[2], Nicholas O'Brien[2], Jaclyn Wycoff[1,2], Pierre-Alexandre Blanche[1], Chen Liang[2], Gholam Peyman[1,2], and N. Peyghambarian[1,2]
[1]*James C. Wyant College of Optical Sciences, University of Arizona, Tucson, AZ, USA*
[2]*ICRX Inc., Tucson, AZ, USA*
erol@optics.arizona.edu

Abstract: We describe an automated phoropter employing fluidic lenses, measuring the visual acuity and correcting the vision without patient feedback within seconds. The <0.1 D measurement accuracy greatly surpasses the phoropters used in doctors' offices.
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1. Introduction

Worldwide, refractive errors such as myopia, hyperopia, and astigmatism are the most common types of visual impairment [1]. Refractive errors are found in all populations irrespective of age, sex, and ethnicity [2] with estimates of the number of people worldwide with refractive errors is at least 2.2 billion, of whom at least 1 billion have a vision impairment that could have been prevented or is yet to be addressed [3]. Particularly, the frequency of myopia has grown significantly over the past few decades, and it is estimated that 3.3 billion people will be affected by myopia within a decade [3]. If the refractive errors are not corrected or the correction is inadequate, the result can be ongoing low vision and even blindness [2]. The World Health Organization report indicates that uncorrected refractive errors can have impacts across society as a whole [2].

Since the early 1900s, ophthalmologists have used phoropters equipped with numerous solid spherical and cylindrical lenses to measure patients' visual acuity [4]. The lenses are flipped in front of the patient, who looks at an eye chart and tries to read the symbols and indicate if position A or position B provides a "better" image (Figure 1 (a)). Effective use of the phoropter is time-consuming, requires a skilled examiner, and needs the full cooperation of the patient to read the eye chart. A fully automated, inexpensive, and accurate system would reduce subjectivity and measurement time, permit point-of-care screening, and address difficulties encountered by the elderly, children, and mentally impaired patients with current testing techniques.

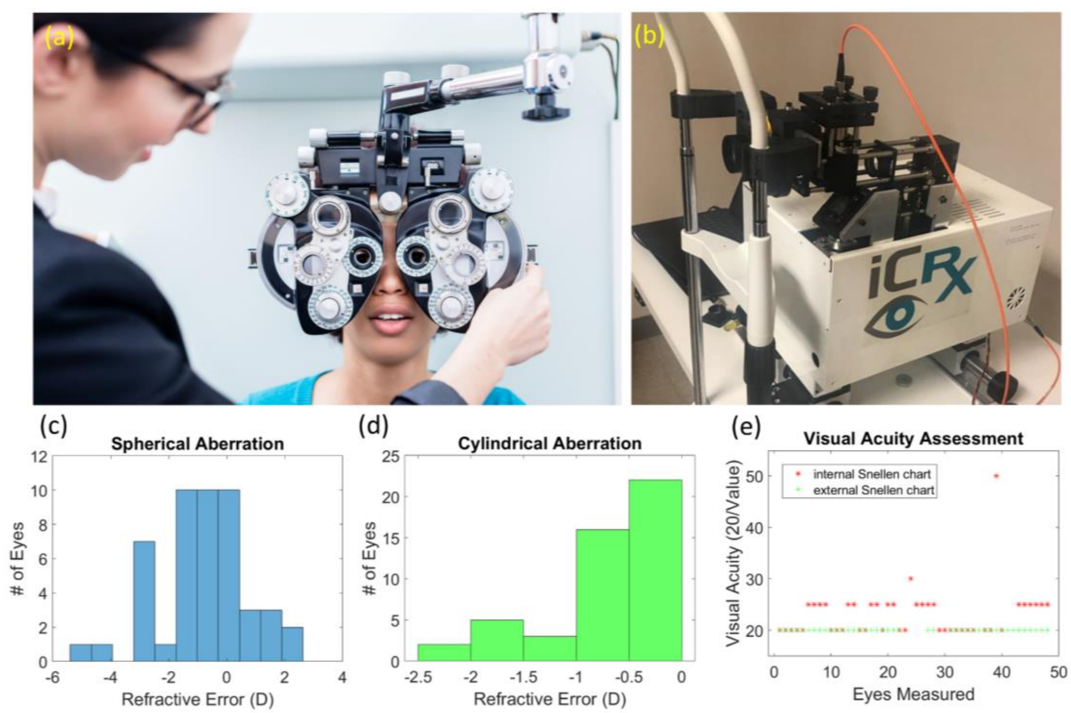

Figure 1 (a) Standard phoropter, (b) Automated phoropter prototype system, (c) The range of spherical aberrations measured by the system, (d) The range of cylindrical aberrations measured by the system, (e), The visual acuity obtained after the refractive error assessment and correction using the fluidic lenses and the internal Snellen chart (red), and ophthalmic trial lenses and an external Snellen chart (green).

The complexity of the ophthalmic measurement using phoropters could be significantly reduced using objective assessment of the wavefront error using wavefront sensors [5], and incorporation of focus tunable lenses instead of the conventional solid lenses [6]. Here, we demonstrate an automated phoropter system that accurately prescribe for refractive errors between ±5 D spherical and up to 3 D cylindrical aberrations with any axis orientation direction within a few seconds, without the need for an experienced operator. The automated phoropter system contains a wavefront sensor for measuring the refractive error and a fluidic lens system [7] that corrects for spherical and cylindrical refractive errors. The system allows subjects to view an integrated fixation target while the adaptive optics system determines both defocus and astigmatic aberrations over a wide range and performs the necessary corrections. Two integrated optical Snellen charts enable the verification of the visual acuity after the correction for far and near sights, sequentially. The device is compact and automated. Our approach significantly simplifies the eye prescription process, without compromising the measurement accuracy.

2. Results and Discussion

The automated phoropter system consists of several optical, mechanical, and electronic modules, which could be grouped as a fluidic lens system with three lenses (one spherical and two cylindrical), a wavefront sensor, an LED illumination system, a visible wavelength telescope, refractive optics to form the beam path, polarization and wavelength control elements, two eye charts for far and close distance, a fixation target, a pupil imaging system, and an electronics board. The most significant parts that make our system unique and more reliable than other instruments are the fluidic lenses and the wavelength sensor.

The fluidic lens system consists of three tunable fluidic lenses that correct for spherical and cylindrical aberrations, as well as the optical axis of the astigmatism. The lenses are fabricated using a transparent flexible elastomer, which is placed on an aluminum holder to securely mount the lens. For the spherical fluidic lens, the membrane is attached on one side of the clear aperture, while a circular glass with Anti-Reflective coating is used on the other side to form a concave or convex lens. For the cylindrical lens, two apertures were fabricated on opposite sides of the aluminum frame. The two cylindrical lenses have a 45° angle between them so they can reproduce any astigmatism axis. The lens compartment of each fluidic lens is connected through semi-flexible tubes to three independent liquid reservoirs. These reservoirs have a flexible diaphragm on one side on which stepper motors can either perform push or pull action. This action changes the volume of the liquid in the lens compartment and creates a change in the refractive properties of the fluidic lens.

A Shack-Hartmann wavefront sensor was built in-house using a low-light level sensitive CMOS sensor camera and microlens array. A custom-built software was developed to calculate the optical aberrations. The sensor was uniquely designed to measure the optical signal scattering back from the human eye. The fluidic lenses and the wavefront sensor could together measure and correct for the refractive errors, both spherical and cylindrical, with an accuracy better than 01. D. The measurement of both eyes usually takes less than one minute.

Human testing was conducted under an IRB from the University of Arizona. The prescriptions were verified using ophthalmic trial lenses. The measurement results demonstrate that the device is capable of rapidly measuring and correcting the refractive error of the human eye within a few seconds for a large diopter range. The visual acuity after the proposed prescription was at the 20/20 level for the vast majority of the subjects. These results show that our automated phoropter system provides major improvements in accuracy and time spent at the doctors' office. This device could revolutionize the way refractive assessment of the human eye is being done currently with important applications that require high throughput screening of the visual acuity of the people in numerous clinical and point-of-care settings.

3. References

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