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Nabeel A. Riza, M. Junaid Amin, Mehdi N. Riza, "Eye vision system using programmable micro-optics and micro-electronics," Proc. SPIE 8930, Ophthalmic Technologies XXIV, 89300C (28 February 2014); doi: 10.1117/12.2038334

Event: SPIE BiOS, 2014, San Francisco, California, United States

Eye Vision System using Programmable Micro-Optics and Micro-Electronics

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ABSTRACT

Proposed is a novel eye vision system that combines the use of advanced micro-optic and microelectronic technologies that includes programmable micro-optic devices, pico-projectors, Radio Frequency (RF) and optical wireless communication and control links, energy harvesting and storage devices and remote wireless energy transfer capabilities. This portable light weight system can measure eye refractive powers, optimize light conditions for the eye under test, conduct color-blindness tests, and implement eye strain relief and eye muscle exercises via time sequenced imaging. Described is the basic design of the proposed system and its first stage system experimental results for vision spherical lens refractive error correction.

Keywords: Vision Correction, Ophthalmic examination

1. INTRODUCTION

For many people living in Western societies today, regular medical check-ups are a common occurrence. Dental, physical, and ophthalmic evaluations, to name but a few, are done regularly in order to maintain the health and well-being of the general population. However, limited by technology, sometimes these evaluations are not carried out in an optimized or convenient manner. This paper focusses on ophthalmic tests where eye examinations of patients with vision defects are carried out in order that eyeglasses or contact lenses of the correct prescription may be issued to them [1-2]. Today, these examinations are carried out through the use of phoropters, bulky optical instruments which patients are asked to look through while the optometrist manually changes certain settings and combinations of lenses until the patient is able to see a perfectly clear image of an eye chart across the room. There are several minor problems with this kind of examination: one of these being that these tests, depending on the patient, can take a long time (possibly up to 15 minutes). Another issue is that patients often have trouble distinguishing between the effects of certain lenses in the phoropter, leading the optometrist to just pick one of them based on subjective instincts. Also, modern day eye evaluation methods are not very suitable for young children (aged 4 – 10 years). Not only do the test's subjectivity and the required patient participation make it harder for younger patients to get an accurate prescription, it could also be very difficult for a younger child to sit still for the duration of the examination. Because small children have limited patience and perseverance for these types of examinations, their parents may prefer to wait until they are older before taking them to the eye doctor. However, this means that existing vision defects will remain undiscovered and uncorrected for several years, possibly allowing them to grow in severity. Moreover, inaccessibility of widespread eyecare facilities in developing countries due to the high costs linked with the necessary technical expertise requirements to operate bulky modern eye test equipment leads to a further urgency to develop a portable and automated eye vision test system. For these reasons, a lightweight and electrically programmable eye vision evaluation system is proposed for replacing the classic mechanics-based phoropter so as to enable a more cost effective, time-efficient, easier to operate, and "child friendly" vision testing experience [3].

As mentioned, eye vision correction measurement is traditionally done using bulky opto-mechanical systems called phoropters that commonly have large moving parts and minimal handheld portability [4]. It would be highly desirable to have an eye vision (for prescription) test instrument that has minimal large moving parts and uses compact low power consumption optical and electronic devices. The desire to use electrically programmable optical lens devices to replace

Ophthalmic Technologies XXIV, edited by Fabrice Manns, Per G. Söderberg, Arthur Ho, Proc. of SPIE Vol. 8930, 89300C · © 2014 SPIE · CCC code: 1605-7422/14/$18 · doi: 10.1117/12.2038334

spectacles (contacts or glasses) for every-day use has been around since the 1970s [5]. Starting in the mid-1980s, the General Electric Corporate Research & Development Center (GE-CRD) fabricated novel electronically controlled Liquid Crystal (LC) lens devices, including for eye correction measurement applications [6-8]. Use of liquid-based lenses using mechanical pressure to change lens focal length has also been proposed for phoropters in 1995 and also more recently [9-10]. In addition, apart from using an electronic LC lens in a phoropter to get new eyewear refractive readings [7], two dimensional (2-D) optical spatial light modulator devices (via LC and micromachined or MEMS) devices have be proposed for color blindness tests as well as to provide the capability to perform eye strain relief and eye muscle exercises [11]. Today, both microelectronic and micro-optic device technologies have evolved to a very high degree, providing energy efficient, compact and light weight sub-systems. In particular, Radio Frequency (RF) wireless control is commonplace for many handheld systems and highly reliable liquid-based ECVFL micro-optic devices have entered the commercial arena such as using electro-wetting technology and electromagnetic actuation of elastic polymer membranes [12-13].

This paper proposes an eye vision system that combines the use of advanced micro-optic and microelectronic technologies to deliver a portable light weight system that can measure eye refractive powers, conduct color-blindness tests, and also implement eye strain relief and eye muscle exercises via time sequenced imaging. The paper starts with the basic design of the system and describes first stage system experimental results for vision spherical lens refractive error correction using commercial ECVFL devices.

2. PROPOSED EYE VISION SYSTEM USING MICRO-OPTICS AND MICROELECTRONICS

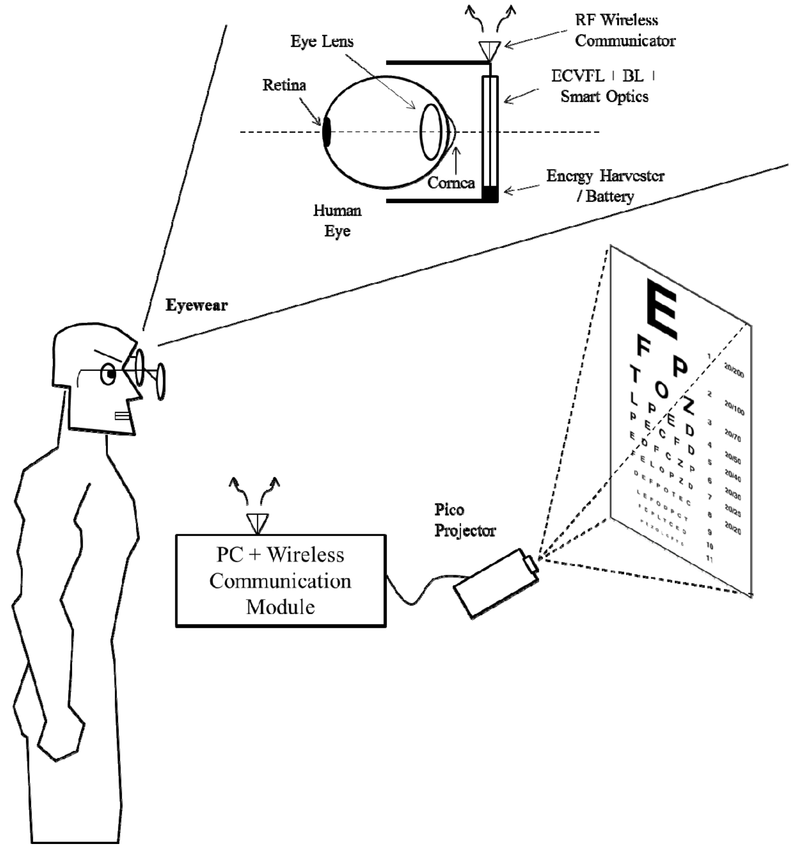


Figure 1. Basic Design of the Proposed novel Eye Vision System using micro-optics and microelectronics that encompasses the smart optics for light conditioning in the context of the specific human eye under test along with eyewear devices that enable wireless communication and control links, energy harvesting, energy storage and remote energy delivery.

Shown in Fig.1 is the basic design of the proposed eye vision system. The system eyewear includes an ECVFL, a Bias Lens (BL) and (not shown) novel frontend smart optics which can include an aperture control device, color control device, polarization control device, and optical throughput/attenuation control device. These smart optical devices can be stackable ultra-thin electrically controlled optical cells such as fabricated using a variety of LC materials, ultra-thin glass substrates and thin polarization optics. Multiple functionalities for light control can be within a single ultra-thin device. These devices can also be fabricated using other technologies such as liquids, MEMS, and liquid MEMS. The described eyewear combines with the eye's internal refractive optic (Eye Lens and Cornea) to project a clear image on the retina. RF/optical wireless communication between the eyewear and the Personal Computer (PC) controls the smart optics as well as the ECVFL focal length settings. The eyewear is also equipped with energy harvesting and storage devices to enable wireless remote power transfer to energy requiring components such as the ECVFL. The Pico Projector, which can use a micro MEMS chip (e.g., TI Digital Light Processing chip), a micro LC chip (e.g., Liquid Crystal on Silicon (LCoS)) or a laser scanner, displays the examination content on a screen. One can envision mounting a micro sized projector as part of the eyewear. The projector is connected to the PC which communicates with the eyewear optics via wireless communication. Depending on examination requirements and patient information, the projected display can either be static images/text, video or a hybrid data set to initiate appropriate patient response. Depending on patient feedback, the smart optics is adjusted via PC control according to pre-set instructions. The visual data sets are synchronized with both smart optics control and patient feedback such that it automatically converges to the eye's inherent refractive error accurately, enabling allocation of correct subscription eyeglasses. This means the proposed system does not necessarily need technically trained opticians to oversee eyesight diagnosis. Note that the PC can be replaced by modern-day handheld devices such as smartphones or tablets. Decreasing price of wireless technology and its wider availability means that this simple to use system is suitable for a majority of the populations of the developing countries that are deprived of even basic medical facilities. Absence of technical/medical expertise requirement enables the proposed eyewear system to have instant impact to large masses with regards to eyesight prescriptions in both the developing and the developed countries.

Micro-optics for lensing mounted on the proposed eyewear design comprises of an ECVFL along with fixed lens optics. Modern ECVFLs come in different sizes with specific power requirements and are based on different technologies including electrowetting [12], ultrasound [13], LCs, deformable mirror membrane, and others. For example, Optotune's EL-6-18 device [14] utilizes optical fluids and a polymer membrane to achieve variable focus action in less than 2 ms with a power consumption ranging between 0 to 350 mW depending on driver current which is governed by desired focal length requirements. The range of focal lengths mandatory in the earlier-mentioned demonstration requires roughly < 100 mW consumption at any time. For the proposed system using this particular Optotune ECVFL model, ECVFL operational power needs to be supplied from micro-electronic components mounted on the proposed eyewear. One option to provide this power is via a micro-sized battery, possibly via a rechargeable photo-cell. On the other hand, various wireless power transfer techniques are gaining popularity and can serve to be a viable option. Magnetic coupling technology [15-17] is able to wirelessly transfer up to 60 Watt over a 2 meter range, though the size of the receiver would need to be customized for the proposed eyewear application with its low power requirements. Solar cells for energy harvesting applications as well as micro-sized rechargeable batteries [18-21] can prove to be a relatively inexpensive option in the long run. Once power is established, communication via a wireless link needs to be established to convey information necessary for programmable micro-optics. This communication link can either be RF WiFi or via recently proposed optical energy efficient wireless indoor links [22-23] with an appropriate interface to the programmable optics. In addition, the wireless optical link can naturally be also used for remote energy transfer such as via the spatially controlled light from the LED or laser source. In summary, for a complete functioning system, the various components on the proposed eyewear and their interconnections need to be designed and optimized to keep the overall dimensions of the eyewear to a minimum weight and size while delivering the required performance for the eye vision system.

3. PRELIMINARY EXPERIMENT

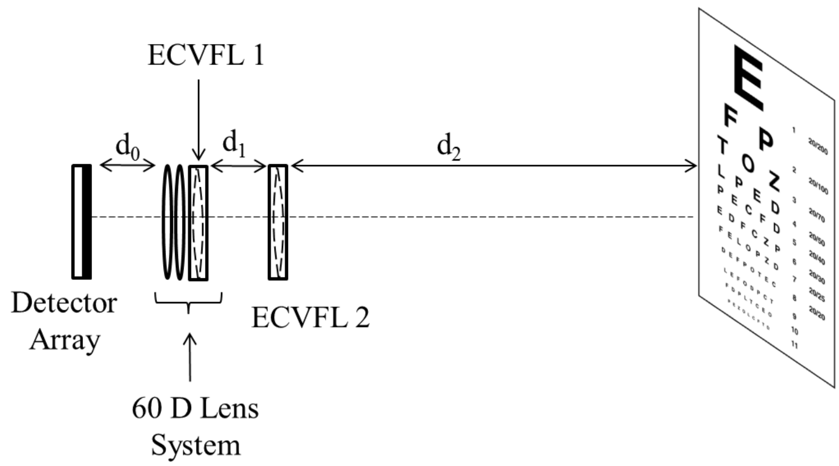


Figure 2. Preliminary Experimental Set-up of the Proposed basic system using commercial ECVFL devices.

To demonstrate the potential eyesight diagnosis capability of the proposed eyewear using a highly deployed commercial readily available ECVFL device, the experimental set up shown in Fig. 2 is implemented using Optotune ECVFL devices to simulate a human eye of different eye powers viewing a test image through an eye Dioptric power measuring ECVFL device. d_0 is 3.5 cm, d_1 is 2.5 cm and d_2 is 98 cm. The 60 D (Diopter) lens system replicates the average human eye's combined lens/cornea system. ECVFL 1 model deployed in the experiment is Optotune's EL-10-30, while Optotune's EL-6-18 is used as ECVFL 2 having focal length F_g. Initially, ECVFL 1 has its focal length altered to manually induce refractive error in the eye, simulating a patient's eye with varying degrees of Myopia. Myopia (nearsightedness) [24] is measured by the optical power (in Diopters) of the corrective lens which helps focus the image on the retina. Depending on the induced refractive error, subsequent control of ECVFL 2, which represents part of the programmable eyewear, allows correction to the induced error. Note that P Diopters represents the power of a lens of focal length of 1/P meters. Fig. 3 shows images of the 1 cm diameter model EL-10-30 ECVFL 1 and the 6 mm diameter model EL-6-18 ECVFL 2 used to introduce eye refractive error and dioptric power correction, respectively.

Figure 3. Images of Optotune models EL-10-30 (on left) and EL-6-18 ECVFLs used in the experiment.

Adjustment of ECVFL 1, which mimics the patient's eye, instigates a refractive error between 0 and -6.00 Diopters, in steps of 0.25 Diopters, representing a broad range of possible eye defects. ECVFL 2 is electronically tuned until a clear image forms on the detector when viewed through the eye. This procedure forms a calibration table, shown as Table 1, which connects the current value of ECVFL 2 needed to acquire clear images to the refractive error of the patient's eye.

Table 1: ECVFL Calibration Table.

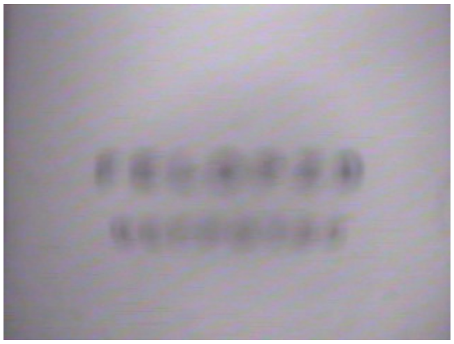
Induced Eye Refractive Error (Diopters)	**ECVFL 2 Driver Current required to correct for induced error (mA)**
0.0 (no refractive power)	59.0
-0.25	55.6
-0.50	54.2
-0.75	52.8
-1.00	51.4
-1.25	50.0
-1.50	48.6
-1.75	47.2
-2.00	45.8
-2.25	44.4
-2.50	43.0
-2.75	41.6
-3.00	40.2
-3.25	38.8
-3.50	37.4
-3.75	36.0
-4.00	34.6
-4.25	33.2
-4.50	31.8
-4.75	30.4
-5.00	29.0
-5.25	27.6
-5.50	26.2
-5.75	24.8
-6.00	23.4

This process, adjustment of a single knob, allows diagnosis of vision problems to within 0.25 Diopters, a resolution chosen for the experimental demonstration which is the same precision as that of a standard phoropter. The proof of concept experimental procedure is outlined as follows:

1) Current supplied to ECVFL 1 is set to 59 mA that corresponds to zero Diopters. The image on the display viewed through the simulated eye is clear, representing perfect vision.

2) To have imperfect vision in order to construct a calibration table, such as Table 1, a refractive error is introduced via changing the ECVFL 1 focal length setting. For an eye with -1.0 D refractive error, ECVFL 1 current is set to 51.4 mA. Fig. 4 shows snapshots of images viewed through the simulated eye taken for different refractive error settings. ECVFL 2 is electronically tuned until the viewed image becomes clear, giving the current value required by the proposed eyewear to achieve correction for a certain refractive error value.

During the experiment, ECVFL 2 is used to accommodate/correct for a wide array of focal lengths/ refractive errors, as can be seen Fig. 4 images. ECVFL 2 is equally capable of going into the positive range of powers (above 0.0 diopters) by increasing the current above 59 mA in accordance with the manufacturer's datasheet. These positive ECVFL 2 dioptric powers would be useful in testing far-sightedness/hyperopia in patients. Although, positive range of powers wasn't considered for this proof of concept experiment because hyperopia and related vision problems do not normally occur among younger patients, it is fully realizable using the proposed system. The demonstrated resolution of 0.25 D can be enhanced using smaller ECVFL drive current steps that will in-turn give smaller focal length change. With optimized ECVFL technologies suited for the desired range of focal lengths, the patient's eyes can be diagnosed with greater accuracy. In conjunction with the smart optics described in the previous section, the proposed eyewear system has potential in taking the eyesight diagnosis process to the next level of vision systems impact to human health.



(a) F_g = - 4.0 D

(b) F_g = - 3.0 D

(c) F_g = - 2.0 D

(d) F_g = - 1.0 D

(e) F_g = 0.0 D (Clear image)

Figure 4. The shown images recorded by the CCD that is acting as a retina indicate the varying degrees of simulated myopia (nearsightedness) in the human eye model under test. ECVFL 2 focal length values F_g correcting the induced refractive errors are (a) F_g = - 4.0 D , (b) F_g = - 3.0 D, (c) F_g = - 2.0 D, (d) F_g = - 1.0 D, and (e) F_g = 0.0 D.

4. CONCLUSION

Proposed is a unique eye vision system using programmable micro-optics and micro-electronics that features eyewear with remote RF/optical hybrid data communications as well as remote wireless energy harvesting and energy storage for ECVFL focus control as well as optical attenuation, aperture, and light polarization control. The system is particularly suited for child eye vision tests given child eye vision characteristics including child behavior and psychology. Our preliminary design and experimental results show that commercial ECVFLs and related micro-technologies can indeed be useful for vision testing and correction applications. Future work relates to the design and demonstration of the proposed eye vision system with its smart optics and optical and RF wireless capabilities, including energy harvesting and remote energy transfer, capture, and storage. It is expected that such a system can lead to a lightweight, energy efficient, user friendly, economical and reliable instrument for wide spread deployment around the world.

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