A method for enhancing digital information displayed to computer users with visual refractive errors via spatial and spectral based processing

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Abstract

The ability to interact effectively with computers through typical graphic user interfaces (GUIs) is greatly affected by any refractive errors present in an individual's visual system. These errors can be mathematically modeled (as the wavefront aberration function) and a system for overcoming these aberrations is proposed which has the potential to increase the effective human-computer interaction for these individuals. This paper introduces a dissertation research plan that seeks to:

1. further develop techniques realizing software pre-compensation
2. test this method using human subjects with each subject's unique wavefront aberration.

Introduction

Humans take advantage of their high visual acuity to perform their daily activities. Specifically, normal visual acuity is a pre-requisite for proper usage of most contemporary Graphic User Interfaces (GUIs). The common interface for humans to use computers is via visual information, presented on a digital display, such as a cathode ray tube (CRT) or a liquid crystal display (LCD). Consequently, the user's ability to interpret the information presented in the GUIs directly impacts his/her ability to use computers effectively.

Persons with limited visual acuity cannot interact properly with GUIs. The most common forms of visual acuity loss, myopia, hyperopia, and/or astigmatism, are considered "low-order" because of the order of the polynomials used to model them. There exist, however, more complex aberrations that cannot be easily remedied by current methods of vision correction such as contact lenses, glasses, or LASIK surgery. These common forms of compensation are not suited to deal with high-order aberrations such as keratoconus [7].

Optical aberrations can be modeled through what is known as the Point Spread Function (PSF) of the human eye. The PSF can be obtained indirectly through the wavefront aberration function of the human eye, currently assessable through wavefront analyzers. A mathematical representation of the PSF allows the simulation of how digital images are viewed by the person, and consequently a method for providing software based compensation can be formulated. An all digital pre-compensation approach is sought. In contrast with optical corrections, this approach is based on modifying the image at its source, i.e., applying image processing modifications on the image to be displayed onscreen before it is shown to the user, based on the knowledge of his/her own wavefront aberration function.

Research purpose

The aim this research is to modify the intended display image in a way that is opposite to the effect of the wavefront aberration of the eye. Once this is achieved, the result is displayed to the viewer so that the wavefront aberration in the viewer's eye will "cancel" the precompensation, resulting in the projection of an undistorted version of the intended image on the retina. Furthermore, the pre-compensation proposed here overcomes some of the limitations of the previous attempt at an all-digital, software solution.

Research problem

The Research Problem has two main facets:

1. To characterize a fixed and known optical system and provide the compensation for that optical to verify the conceptual integrity of the methods developed before the added complexity of testing with human subject is implemented.
2. In order to test the significance of the compensation, characterize several human eyes and provide a custom compensation for each eye, based on the PSF.

Significance of study

Since the proposed method of pre-compensation is entirely digital, i.e., the method is implemented completely in software, any Personal Computer (PC) capable of running a 32-bit operating system with an SVGA graphics card could theoretically be used to deliver the pre-compensation.

Additionally, an estimated 7 million people in the United States alone have some type of high-order refractive aberration in their eye(s) [6]. This research has the potential to benefit those people who suffer from these high-order aberrations, allowing them to potentially interact with any type of digital display more effectively.

Research questions

Question #1:

Will the proposed method for precompensation provide an improvement in visual acuity for an artificial eye if its wavefront aberration function is known a priori?

Question #2:

Will the proposed method for precompensation provide an improvement in visual acuity for human subjects if their customized wavefront aberration function is known a priori?

Preliminary results

Artificial CCD eEye

In order to verify the proposed processing, a method of verifying the results in a physical optical system is necessary. This eye will be used to provide several testing conditions allowing for variation of several parameters including pupil diameter, focal length, and various types of wavefront aberrations introduced via lenses as well as, allow for both objective measurement/characterization of the optical system (i.e. assessment of the wavefront aberration function of the system via the COAS wavefront analyzer) as well as the ability to 'see' through the optical system via the CCD, something that cannot be done with human eyes.

Simulation results

The mathematical portion of pre-compensation approach has been developed and, in simulation has yielding encouraging results. For a detailed explanation of the mathematical aspects, please refer to [1-3]. However, as the development of the original pre-compensation approach progressed, it was found that there are two sources for potential error in the method of processing due to the inherent nature of the measurement device as well as the fact that the human eye is a dynamic optical system.

1. The defocus term has a very high variability among different wavefront analyzers, making it difficult to predict the actual value for the defocus term in the wavefront aberration function [4].
2. The actual wavefront aberration function Zernike terms vary with pupil diameter for the same optical system [5]. This can lead to a Zernike term mismatch, degrading or altogether destroying the pre-compensation process. Fortunately, he provides a method for producing a new set of Zernike terms for a given change in pupil diameter. It is thus necessary to build into the testing system a way to account for these potential errors.

Scope of the proposed work

The dissertation work will occur in the following modules:

- Further Develop the Method of Pre-compensation to improve final projected retinal image
- Develop testing with a fixed and controllable optical system (artificial CCD eye)
- Subject recruitment and testing
    - Phase 1 and 2
    - Phase 3 and 4
- Subject testing data analysis

Subject recruitment and testing will occur in two main phases each with two sub-phases. For each main phase, 1 and 2, there will be a sub-phase for subject recruitment and wavefront analysis data collection, and a sub-phase for testing visual acuity with the proposed pre-compensation method.

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