Verification of Computer Display Pre-compensation for Visual Aberrations in an Artificial Eye

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ABSTRACT
The possibility of pre-compensating images in a computer display according to the visual aberrations previously assessed in an optical system (e.g., the computer user's eye) has been confirmed for a simple "artificial eye". This device has been constructed from optical components, which include a plano-convex lens, an adjustable aperture, and a Charged-Couple Device (CCD) array that mimics the retina of a real eye. While the CCD array allows for the inspection of the image as it would form on the retina of a real eye, its specular reflection does not allow the resulting "artificial eye" to be measured appropriately in a wavefront analyzer (a necessary pre-requisite for the image precompensation process). Therefore, an alternative, interchangeable CCD array covered with gray paint (i.e., disabled) was also created to provide the diffuse reflectivity that is presumed in the operation of the wavefront analyzer. Experiments with this system show that the visual aberrations in a properly characterized optical system can, in fact, be precompensated by the methods proposed by Alonso et al., [1]. These same experiments, however, reveal the need to adjust the precompensation method according to the effective pupil diameter in the system during viewing.

Categories and Subject Descriptors
I.4.9 [**Image Processing and Computer Vision**]: Applications

General Terms
Algorithms, Measurement, Performance, Design, Experimentation, Human Factors, Theory.

Keywords
Low Vision, Visual Aberration, Wavefront Aberration, Point Spread Function, Compensation, Deconvolution, Eye Model.

1. INTRODUCTION
Previously, Alonso et al. proposed that if the visual aberration of an optical system (e.g., the eye of a computer user) is known, images displayed on a computer screen could be pre-treated, in a manner that is inverse to the visual aberration known, to counter its effects and achieve an undistorted perception of the image by the viewer [1].

The ultimate goal of this custom precompensation is to facilitate computer access to users with significant visual impairments. So far, in addition to the mathematical simulation of the complete process of pre-compensation and aberration, the approach has been tested in actual examples that demonstrate effective pre-compensation when viewing display images through optical systems that have been characterized on the basis of their known optical prescription (e.g., -6 diopter lens) [2], or approximated by a generic aberration (e.g., approximating the aberration of a defocused digital camera as a "generic blur")[3]. These experiments are particularly interesting, considering that recently developed wavefront analyzers have been specifically designed to measure and report the wavefront aberration of human eyes. At this juncture, however, a necessary next step is the verification of the precompensation approach when viewing the computer images through an optical system empirically characterized with a wavefront analyzer. While, of course, the human eye can be characterized by the wavefront analyzer and offers to each individual the possibility of viewing computer images that have been correspondingly precompensated, it has two significant restrictions: a) The human eye is a highly dynamic system, and therefore some of its important operational characteristics (e.g., accommodation, pupil diameter, etc.) could change from characterization to viewing, or even as the viewing session takes place; b) the projection of the precompensated image on the eye's retina defines the subject's perception of the image, not allowing anyone but the viewer to assess the efficiency of the precompensation. With these restrictions in mind, it was deemed that the creation of a an "artificial eye" that could be first characterized by the wavefront analyzer and then used to "view" the precompensated computer images (making the "retinal" images available to the scrutiny of the complete design team), would be an important development to undertake towards the ultimate goal of custom precompensation of visual impairments in computer users.

2. MATERIALS AND METHODS

An "artificial eye" that can be used to study the process of computer image pre-compensation through deconvolution, must:

a) Be appropriate for characterization in a wavefront analyzer.

b) Provide adjustable values of key operational parameters. In particular, given the previous studies that point-out the variability of the wavefront aberration function with changes of pupil diameter [4][5], it is important to have an adjustable pupil diameter in this model.

c) Allow the visualization of the "retinal image" formed in the model, so that it can be assessed by all the researchers involved in the project, and not just by the actual experimental subject.

Unfortunately, the first and last requirements proved to be mutually exclusive, at least in principle. This is because any Charge-Coupled Device (CCD) array used to capture the "retinal" image will provide a segmented, specular reflection in the "retina" side of the model eye, which is very different from the diffuse reflection expected in the human retina. This, in turn, interferes with the operation of the wavefront analyzer, impeding an adequate characterization of the optical system. Ultimately, this problem was solved by using two identical, interchangeable end-caps for the physical model: One with a working CCD array, to be used during viewing, and a second one with a disabled CCD array, which had been spray-painted with a coat of flat gray paint. The rest of the model was built with standard optical components, which included a lever-controlled iris diaphragm to provide the ability to test under different, known pupil diameter conditions (1.2 – 11.2 mm). This is critical, since it will be used to verify the viability of the analytical method provided by Campbell [4] to adjust a wavefront aberration function originally measured (in the wavefront analyzer) with a given pupil diameter, to a situation in which the pupil diameter of the optical system has been reduced to a given percentage of its original size.

3. RESULTS

Initially, using the disabled, spray-painted CCD end-cap, and a pupil diameter of 6 mm, the artificial eye was characterized in the wavefront analyzer. This information was used to prepare the precompensation of computer images. Then, the working CCD array was placed in the artificial eye and used to capture Figure 1, which shows the blurring of a normal image. When a pre-compensated version of the image was displayed, the CCD array revealed the image shown in Figure 2, where the letters "A" and "E" are more distinguishable, as expected. Next, to illustrate the impact of pupil diameter in the precompensation, the pupil of the artificial eye was adjusted to (approximately) 4mm, which deteriorated the precompensation, as observed in Figure 3.

Lastly, the precompensation process was re-adjusted, accounting for the reduction in the physical size of the pupil, using Campbell's method [4]. The newly generated precompensated image was displayed and captured through the artificial eye with the pupil diameter still set at 4mm. The resulting "retinal" image regained its quality, as shown in Figure 4.

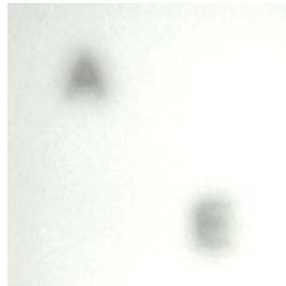

Fig .1. Normal Image, blurred by the artificial eye.

Fig. 2. Precompensated image, seen through the artificial eye.

Fig.3. Same as in Fig. 2, after changing the artificial eye diameter to 4 mm.

Fig. 4. A new precompensated image, adjusted for 4 mm, seen with the artificial eye at 4mm.

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