The Analysis and Visualization of Metamorphopsia through 3D Scene Regeneration

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Metamorphopsia is a vision defect caused by a distorted retina in one or both eyes. Affected patients perceive this condition as a dynamic distortion in the geometry of their environment. Metamorphopsia transforms the patient's world into a perpetual Escher-like environment. Mild horizontal distortions produce binocular depth perception errors as evident in the attached figure. More severe horizontal distortions as well as vertical distortions cause ghosting or frank double vision. The patient finds navigating stairs or non-uniform topologies a challenge. Sudden onset of the distortion causes the greatest difficulties, whereas if the distortion develops more slowly, there may be some adaptation to the sensory input such that the patient may not even realize that a visual defect exists.

A tool to document metamorphopsia has been developed as part of the Multi-Axis Vision Evaluation System (MAVES). With distortion data derived from testing a patient with MAVES, the 3D environment can be reconstructed from the patient's point of view. This process involves projection of the 3D dataset onto each binocular 2D retinal plane. The planar data are perturbed by the documented distortions, and two 3D datasets are reconstructed. Visualization of the reconstructed datasets allows a third party, such as the ophthalmologist or family member, to observe the perturbations the patient sees.

The MAVES testing apparatus consists of a 21-inch video monitor and PC, a chin-rest to fix the patient's head, an interaction control pad, and fixation monitoring via an infrared pupil tracker. The metamorphopsia analysis program presents 5x5 regular spline grid with random perturbations overlaid on a cross, which the patient fixates at its center. The display grid dims if the pupil tracker detects a fixation deviation. The patient is instructed to remove the distortions from the grid until all of the lines appear straight and uniform. This is accomplished by manipulating over the grid using buttons on the control pad and adjusting the deviation of the lines using a joystick. The resulting grid objectively documents the macular distortions.

The distortion data from the resultant grid may be applied to a flat, 2D image. The distortion maps the image from the world image space to the patient's image space. An image with the distortion applied will appear geometrically correct when presented to the patient. The inverse distortion maps the image from the patient's image space to the world image space. An image with the inverse distortion applied is representative of the patient's monocular vision aberration and has been extremely useful in demonstrating to the ophthalmologist or family the monocular distortion perceived by the patient. However, the 2D image fails to adequately express the real-world 3D distortion the patient perceives with binocular vision.

A CG 3D environment may be reconstructed to demonstrate what is perceived by the patient under binocular conditions. This process involves projecting the 3D point coordinates of the dataset onto each binocular 2D retinal plane through each eye's nodal point. The 2D planar points are perturbed by the documented distortion measured for each eye. Two vectors defined by the perturbed 2D points in each retinal plane and corresponding nodal point are projected back into the world space occupied by the original geometry to create two new 3D geometry datasets. The position where the two vectors are closest is analyzed. If the distance between the vectors (d) is smaller than a convergence error limit (k), then the center point of the line drawn between the two vectors defines the new 3D point for both geometry data sets. If $d>k$, then two new 3D points are defined by the point of closest approach for each vector.

The two 3D geometry sets are rendered to produce two images, one for each eye. A composite of both images is generated with 50-percent transparency to produce a single image representative of the patient's environment. As the patient moves, new geometry sets are calculated and rendered.

The warped 3D geometry appears to realistically represent the visual disturbances that these patients describe and for the first time has given clinicians an insight into this poorly understood and poorly appreciated aberration of vision.