REPPERGER RESEARCH INTERN PROGRAM

RESEARCH PROJECT #: AFRL-RHD-27-16

Beyond Standard Zernikes: Evaluating True Optical Quality Using the Gatinel-Malet Expansion

PROJECT DESCRIPTION: The United States Air Force (USAF) develops specialized protective eyewear to safeguard aircrew vision against directed energy threats. Ensuring the flawless optical integrity of these lenses is mission-critical. Manufacturing defects, such as molding or coating errors, can induce secondary wavefront aberrations—subtle distortions in how light passes through the lens. If left unaddressed, these induced aberrations directly compromise two foundational pillars of human visual performance: visual acuity and contrast sensitivity.

When viewed through imperfect eyewear, induced aberrations blur otherwise perfect imagery. This degrades a user's ability to resolve fine details (acuity) and detect targets against similar backgrounds (contrast sensitivity). To accurately quantify this visual degradation, this project utilizes a state-of-the-art clinical aberrometer. This advanced ray-trace technology captures precise physical measurements of optical distortion. The aberrometer mathematically decomposes the wavefront errors into specific aberration coefficients. Each coefficient represents a distinct deviation from ideal image formation, providing a highly detailed map of the induced distortions.

Standard Zernike polynomials are used to describe aberrations and are well-suited for mapping a patient's eye because they are mathematically orthogonal (meaning they do not overlap when calculating the total wavefront error). However, to make that mathematics applicable over a circular pupil, higher-order aberrations (HOAs) are forced to include lower-order components. When an aberrometer scan detects high spherical aberration, standard Zernike mathematics automatically generates a "fake" defocus value due to the mathematical coupling of higher- and lower-order terms. The outcome is to treat the eye as if it is severely out of focus and artificially blur the computed Point Spread Function (PSF). This, in turn, can cause the calculated Visual Strehl Ratio (VSOTF) score in the frequency domain to be highly degraded, failing to reflect the patient's actual visual performance.

This can be mitigated using a Gating-Malet (GM) expansion (also referred to as the Low-Degree/High-Degree decomposition framework) to mathematically untangle this coupling. The GM expansion extracts the hidden defocus terms and groups them entirely into the low-degree category, leaving a "paraxially flat" high-degree wavefront to compute a true, unpenalized VSOTF score. By using GM high-degree coefficients, the VSOTF calculation provides a robust measure of the true impact of irregular aberrations (such as coma or trefoil) without penalizing the score with mathematical artifacts.

LEARNING OBJECTIVES: Under the guidance of a mentor, you will gain hands-on experience to complement your education and support your academic and professional goals. Along the way, you will engage in activities and research in several areas, including but not limited to:

1. Gain skills in optical imaging and learn how to analyze high-resolution ray-trace aberrometry data from captured wavefront distortion profiles through specialized optical substrates.

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2. Learn how to implement the Gating-Malet expansion algorithm to eliminate mathematical defocus coupling inherent in ANSI Z80.28 standard Zernike decompositions.
3. Learn how to compute and validate objective image quality metrics (PSF, MTF, and VSOTF) from paraxially flattened high-degree wavefronts.
4. Quantify the operational impact of induced wavefront errors on human visual acuity and contrast sensitivity in high-stakes environments.
5. Learn how to apply an advanced mathematical framework used in ophthalmic wavefront aberrometry to reconstruct and analyze the optical aberrations of the human eye.
6. Learn how induced aberrations generated through defects in eyewear can influence visual performance.

ACADEMIC LEVEL: Undergraduate**;** Master's
DISCIPLINES NEEDED: Computer Science, Biophysics, Biomedical Engineering
RESEARCH LOCATION: JBSA Fort Sam Houston, Texas
RESEARCH MENTOR: Brenda Novar
Master's of Engineering Management, Drexel University, 2010

Ms. Novar holds a master's degree in engineering management and a bachelor's degree in electrical engineering. She has worked in industry at Motorola Corporation and as a contractor for Northrop Grumman. At present, she is a principal investigator at the 711 HPW/RHDO working on the development of models, conducting optical metrology measurements, and leading visual performance experiments that will inform a military standard. She is published in the peer-reviewed literature for her research work related to vision science and laser eye protection. During her employment at Northrop Grumman, she was awarded a United States Patent 7232240: Extended source laser illuminator, Kosnik, William D., Novar, Brenda J., Villavicencio, Victor I., 2007-06-19. She has also served as a research mentor through the Repperger Research Intern Program and actively promotes science and education as a participant in the Junior Academy of Science.

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