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13. ABSTRACT *(Maximum 200 words)*

The primary goal of the research was to investigate longitudinal and lateral resolving power of hybrid optical/digital imaging systems. Most loss of resolution is due to aberrations in the lens. The hybrid system modified the optics to be invariant to focus-related aberrations, yielding intermediate images with better lateral resolution. The post processing of the intermediate image resulted in a high-quality, high-resolution image. A matrix method was developed for analyzing imaging systems,. A means was found for overcoming the effects of lack of spatial stationarity on hybrid systems. Channel reduction techniques were developed to do more efficient processing of color images. This allows only one channel of a three-color image to be processed, and then the color added back to the image. A new technique was developed for measuring the axial depth of an image that had an error of less than 0.1% of the distance. This was demonstrated to be effective for passive ranging.

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HYBRID IMAGE ACQUISITION AND SIGNAL PROCESSING SYSTEMS FOR HIGH RESOLUTION

FINAL REPORT

W. Thomas Cathey, Gregory Johnson, Sara Tucker, and Hans B. Wach

31 July 2000

U.S. ARMY RESEARCH OFFICE

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1. BODY OF REPORT
A. STATEMENT OF THE PROBLEM

The problem to be solved involved limits on the performance of imaging systems when the optics, or image gathering portion, and the signal processing portion are designed separately. Recent work had demonstrated that by considering the optical and signal processing portions of an imaging system jointly, many different modalities of imaging can be obtained. For example, one modification of the optics can give the system a very large increase in the depth of field or focus. The image formed appears blurred because of the nonstandard point spread function. However, if done properly, the point spread function and the optical transfer function do not change over a very large region. Consequently, one digital filter can perform a deconvolution and provide a high quality final image. The problem is to maximize the resolution in the lateral direction and the depth or range resolution in the longitudinal direction.

B. SUMMARY OF IMPORTANT RESULTS

The primary goal of the research was to investigate longitudinal and lateral resolving power of hybrid optical/digital imaging systems. Most loss of resolution is due to aberrations in the lens. The hybrid system modified the optics to be invariant to focus-related aberrations such as chromatic aberration, spherical aberration, and curvature of field. This yielded intermediate images that are invariant to those aberrations. The post processing of the intermediate image resulted in a high-quality, high-resolution image. A matrix method was developed for analyzing imaging systems,. A means was found for overcoming the effects of lack of spatial stationarity on hybrid systems. Channel reduction techniques were developed to do more efficient processing of color images. This required only one channel of a three-color image to be processed, and then the color was added back to the image. A new technique was developed for measuring the axial depth of an image that had an error of less than 0.1% of the distance. This was demonstrated to be effective for passive ranging.

C. LIST OF PUBLICATIONS AND TECHNICAL REPORTS

Master's Thesis: "Experimental Procedures for Obtaining Extended-Depth-of-Focus Images Using Hybrid Optical/Digital Systems," Sara Cushman Bradburn, 1997, University of Colorado.

Ph.D. Dissertation: "Passive Ranging Systems Using Orthogonal Encoding," Gregory E. Johnson, 2000, University of Colorado.

Published papers

"Defocus Transfer Function for Circularly Symmetric Pupils," (with A. R. FitzGerrell and E. R. Dowski) Applied Optics, Vol. 36, pp. 5796 - 5804 (1997).

"Realizations of Focus Invariance in Optical-Digital Systems with Wave-Front Coding," Sara C. Bradburn, W. Thomas Cathey, and E. R. Dowski. Applied Optics, Vol. 36, pp. 9157 - 9166 (1997).

"Control of chromatic focal shift through wave-front coding," Hans Wach, E. R. Dowski, and W. Thomas Cathey, Applied Optics, Vol. 37, pp. 5359 - 5367 (1998).

"Extended depth of field and aberration control for inexpensive digital microscope systems," Sara C. Tucker, Edward R. Dowski and W. Thomas Cathey, Optics Express, Vol. 4, pp. 467 - 474 (1999). This is an electronic publication that is available at http://epubs.osa.org/oearchive/pdf/9522.pdf.

"Matrix description of near-field diffraction and the fractional Fourier transform," Sara Bradburn, J. Ojeda-Castaneda and W. Thomas Cathey, J. Optical Society of America A, Vol. 16, pp. 316 - 322 (1999).

"Channel reduction and applications to image processing," Hans B. Wach, W. Thomas Cathey and Edward R. Dowski), Applied Optics, Vol. 39, pp. 1794 – 1798 (2000).

"Passive Ranging Through Wave-Front Coding: Information and Application," Gregory E. Johnson, Edward R. Dowski, and W. Thomas Cathey, Applied Optics, Vol. 39, pp. 1700 - 1710 (2000).

Presentations

"Passive Ranging for Acquisition of Range Images: Application to Longitudinal Vehicle Control and Warning Systems" G. E. Johnson, E. R. Dowski, and W. Thomas Cathey, International Transportation Conference, Chicago, September 1997.

"Linear Transformation Operators for Spatially Discrete Fourier Optics," Sara Bradburn, W. Thomas Cathey, and E. R. Dowski) Optical Society of America 1997 Annual Meeting, Long Beach, California, 15 October 1997.

"Simplified lens design for digital imaging systems," E. R. Dowski and W. T. Cathey, Optical Society of America 1998 Annual meeting, Baltimore, Maryland, 5 Oct. 1998.

"Aberration control and extended depth of focus in microscopes containing the cubic phase mask," Sara C. Bradburn and W. T. Cathey, Optical Society of America 1998 Annual meeting, Baltimore, Maryland, 6 Oct. 1998.

"Antialiasing filter for digital photography," E. R. Dowski and W. T. Cathey, Optical Society of America 1998 Annual meeting, Baltimore, Maryland, 8 Oct. 1998.

"Channel reduction and applications to color image processing," Hans Wach, E. R. Dowski and W. T. Cathey, Optical Society of America 1998 Annual meeting, Baltimore, Maryland, 8 Oct. 1998.

"Modern Wavefront-Based Optical Anti-Aliasing Filter," E. R. Dowski and W. T. Cathey, 1998 International Optical Design Conference, Kailua-Kona, Hawaii, 12 June 1998.

"Applications of extended depth of focus technology to light microscope systems," Sara C. Bradburn and W. T. Cathey, 1998 Signal Recovery and Synthesis Topical Meeting, Kailua-Kona, Hawaii, 9 June 1998.

"Extended Depth of Field for Light Microscope Systems," Sara Bradburn, Edward Dowski, and W. Thomas Cathey, 11th International Conference on 3D Image Processing in Microscopy, Sydney, Australia, 14 - 17 April 1998.

"Channel reduction and applications to image processing," H. B. Wach, E. R. Dowski and W. Thomas Cathey, The Seventh Color Imaging Conference, 16 - 19 Nov. 1999.

"Matrix based tools for analysis of partially coherent imaging systems," Sara C. Tucker, Edward R. Dowski and W. Thomas Cathey, Optical Society of America 1999 Annual Meeting Conf. p. 105, San Jose, Calif. 27 - 30 September 1999.

"A novel 3D fluorescence microscope using wavefront coding optics," Carol J. Cogswell, M. R. Arnison, E. R. Dowski, Sara C. Tucker, and W. Thomas Cathey), Optical Society of America 1999 Annual Meeting Conf. p. 95, San Jose, Calif. 27 - 30 September 1999.

"A new generation, fast 3D fluorescence microscope using wavefront coding optics," Carol J. Cogswell, M. R. Arnison, E. R. Dowski, Sara C. Tucker and W. Thomas Cathey, Microscopical Society of America's Conf. on Microscopy and Microanalysis '99, Portland, Oregon, 1 - 5 August 1999.

"Optical and digital design considerations for extended depth of field microscopes," Sara Tucker and W. Thomas Cathey, Light for Life Conference, Cancun, Mexico, 29 July 1999.

"Why optics students should take digital signal processing courses and digital signal processing students should take optics courses," W. Thomas Cathey, Sixth International Topical Meeting on Education and Training in Optics and Photonics, Cancun, Mexico, 27 - 30 July 1999.

D. PARTICIPATING SCIENTIFIC PERSONNEL

Prof. W. Thomas Cathey
Dr. Edward R. Dowski, Research Associate
Sara Bradburn Tucker, M.S. degree in December 1997
Gregory E. Johnson, Ph.D. degree in June 2000
Hans B. Wach

2. REPORT OF INVENTIONS

U. S. Patent no. 5,870,179 (With Edward Dowski), "Apparatus and Method for Estimating Range," Feb. 9 1999

U. S. Patent no. 5,748,371 (With Edward Dowski), "Extended Depth of Field Optical Systems, " May 5, 1998.

"Increased Resolution, Antialiasing, and Color Performance for 3-CCD Digital Cameras and Color Scanners," W. Thomas Cathey and Hans B. Wach, patent application submitted.