Wearable Environmental and Physiological Sensing Unit

Safety of operations in hazardous environments could be enhanced.

Ames Research Center, Moffett Field, California

The wearable environmental and physiological sensing unit (WEPS) is a prototype of systems to be worn by emergency workers (e.g., firefighters and members of hazardous-material response teams) to increase their level of safety. The WEPS includes sensors that measure a few key physiological and environmental parameters, a microcontroller unit that processes the digitized outputs of the sensors, and a radio transmitter that sends the processed sensor signals to a computer in a mobile command center for monitoring by a supervisor. The monitored parameters serve as real-time indications of the wearer's physical condition and level of activity, and of the degree and type of danger posed by the wearer's environment. The supervisor could use these indications to determine, for example, whether the wearer should withdraw in the face of an increasing hazard or whether the wearer should be rescued.

The sensed parameters are the temperatures inside and outside the wearer's protective suit, the wearer's pulse rate and level of oxygen saturation of hemoglobin, acceleration, and concentration of combustible gas in the air. The wearer's pulse rate and level of oxygen are sensed by a commercially available pulse/oximeter that is clipped to the wearer's ear. The pulse/oximeter sends red and infrared light of several wavelengths into the wearer's tissues and measures the pattern and intensity of the light as scattered by the wearer's tissues. A companion signal-processing electronic circuit processes the analog output of the pulse/oximeter into a digital stream that is sent to the microcontroller unit.

The temperatures inside and outside the protective suit are measured by thermocouples. The analog outputs of the thermocouple circuits are fed to analog-to-digital converters (ADCs) within the microcontroller unit. The temperature readings are obviously of value in sensing overheating of the wearer and assessing the level of external hazard during firefighting.

The pulse reading can be used to determine the wearer's panic level and estimate the rate of consumption of air if the wearer is breathing from a tank. The presence or absence of a pulse can be used to determine whether the wearer is still alive when the wearer is unconscious or otherwise unable to respond by radio. The oxygen level is a good indicator of the wearer's overall health and can aid in identifying a respiratory deficiency that could lead to unconsciousness.

The wearer's acceleration is sensed by a commercially available two-axis accelerometer, the analog outputs of which are sent via buffer amplifiers to ADCs in the microcontroller unit. The accelerometer readings are taken as indications of the wearer's motion and, hence, level of physical activity.

The combustible-gas sensor is a commercially available unit that contains a catalytic bead heated to a temperature (≈500 °C) at which it can oxidize combustible gases. The role of this sensor is to provide a warning when the concentration of combustible gas in the wearer's vicinity approaches the lower explosive limit. The temperature of the bead, which varies with the atmospheric concentration of combustible gas, is transduced to a voltage that is buffered and sent to the microcontroller unit.

The microcontroller unit combines all the digitized sensor readings into a single digital stream at a maximum data rate of 10 kb/s. The stream is used to modulate the carrier signal in the radio transmitter, which operates at a frequency of 433.92 MHz. A receiver in the mobile command station recovers the data stream and sends it to the serial port of a laptop computer equipped with software that recognizes the data streams of the individual sensors in the combined stream and generates a visual display of the data coming from each sensor.

This work was done by Stevan Spremo of Ames Research Center and Jim Ahlman, Ed Stricker, and Elmer Santos of San Jose State University.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at (650) 604-2954. Refer to ARC-14770-1.

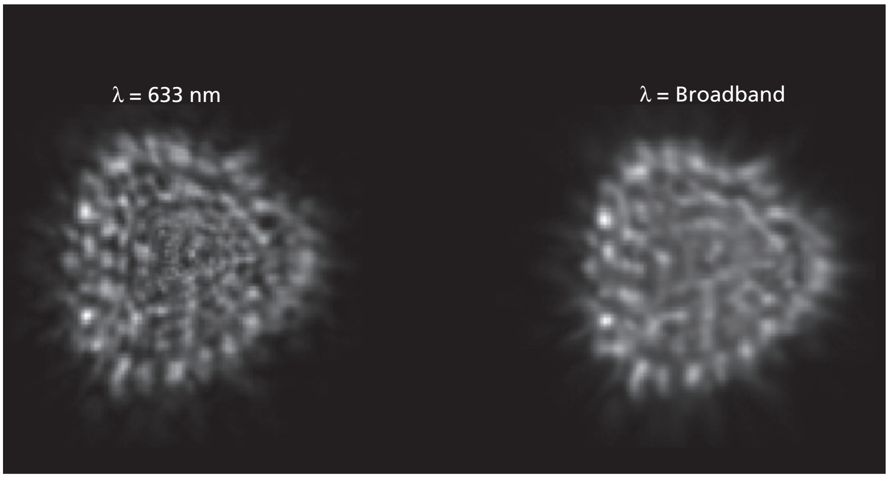
Broadband Phase Retrieval for Image-Based Wavefront Sensing

Broadband light can be approximated as monochromatic in phase-retrieval computations.

Goddard Space Flight Center, Greenbelt, Maryland

A focus-diverse phase-retrieval algorithm has been shown to perform adequately for the purpose of image-based wavefront sensing when (1) broadband light (typically spanning the visible spectrum) is used in forming the images by use of an optical system under test and (2) the assumption of monochromaticity is applied to the broadband image data. Heretofore, it had been assumed that in order to obtain adequate performance, it is necessary to use narrowband or monochromatic light.

Some background information, including definitions of terms and a brief description of pertinent aspects of image-based phase retrieval, is prerequisite to a meaningful summary of the present development. "Phase retrieval" is a general term used in optics to denote estimation of optical imperfections or "aberrations" of an optical system under test. The term "image-based wavefront sensing" refers to a general class of algo-



These **Point-Spread-Function Images** were obtained as the response of a test optical system (a deformable mirror) at the two noted wavelengths. The overall trefoil shape, representative of low-order aberrations, does not differ much between the two wavelengths. The "bumpy" higher-spatial-frequency image components of the two images differ noticeably, but these components represent higher-order aberrations that, typically, are smaller than the lower-order aberrations.

rithms that recover optical phase information, and phase-retrieval algorithms constitute a subset of this class.

In phase retrieval, one utilizes the measured response of the optical system under test to produce a phase estimate. The optical response of the system is defined as the image of a point-source object, which could be a star or a laboratory point source. The phase-retrieval problem is characterized as "image-based" in the sense that a charge-coupled-device camera, preferably of scientific imaging quality, is used to collect image data where the optical system would normally form an image. In a variant of phase retrieval, denoted phase-diverse phase retrieval [which can include focus-diverse phase retrieval (in which various defocus planes are used)], an additional known aberration (or an equivalent diversity function) is superimposed as an aid in estimating unknown aberrations by use of an image-based wavefront-sensing algorithm.

Image-based phase-retrieval differs from such other wavefront-sensing methods, such as interferometry, shearing interferometry, curvature wavefront sensing, and Shack-Hartmann sensing, all of which entail disadvantages in comparison with image-based methods. The main disadvantages of these non-image-based methods are complexity of test equipment and the need for a wavefront reference. This concludes the background information.

The present development began with a theoretical observation that the low-order aberration content of the point-spread-function of an optical system is not strongly affected by wavelength over the visible spectrum (see figure). As a result, variations in wavelength do not significantly affect what a phase-retrieval algorithm "sees" as input. This lack of variability of effective input is what makes it possible to assume monochromaticity when processing image data acquired while using broadband light.

The validity of the assumption of monochromaticity was demonstrated by comparing wavefront-sensing performances for broadband and monochromatic light in a known aberration test case. The significance of this development is that phase-retrieval algorithms can produce accurate phase estimates when test light is passed through filters having pass bands broader than were previously thought to be useable. Because more light is transmitted by broadband than by narrow-band filters, image-detector integration times can be significantly reduced and, therefore, time needed to perform wavefront sensing can be reduced. In some applications, filters can be eliminated entirely, thereby minimizing the complexity and cost of equipment for testing optical systems.

This work was done by Bruce H. Dean of Goddard Space Flight Center. Further information is contained in a TSP (see page 1).
GSC-14899-1

Filter Function for Wavefront Sensing Over a Field of View

Optical performance is more balanced when data from more field points are used.

Goddard Space Flight Center, Greenbelt, Maryland

A filter function has been derived as a means of optimally weighting the wavefront estimates obtained in image-based phase retrieval performed at multiple points distributed over the field of view of a telescope or other optical system. When the data obtained in wavefront sensing and, more specifically, image-based phase retrieval, are used for controlling the shape of a deformable mirror or other optic used to correct the wavefront, the control law obtained by use of the filter function gives a more balanced optical performance over the field of view than does a wavefront-control law obtained by use of a wavefront estimate obtained from a single point in the field of view. (The terms "wavefront sensing," "image-based," and "phase retrieval" are defined in the immediately preceding article.)

In a conventional approach to sensing and control of wavefronts, optical phase errors are estimated from the image of a single star or equivalent point source of light at a specific single location on a focal-plane image sensor. In effect, a wavefront control law is derived from a small area surrounding a single field point and is subsequently used to correct the performance of the optical system over the entire field of view. The disadvantage of this approach is that the performance of the system at other field points can suffer additional degradation because the wavefront information obtainable at those field points can differ from that obtained at the chosen field point.

A mathematically complete description of the filter function and its derivation would exceed the space available for this article; it must suffice to summarize. The derivation of the filter function