A Broad-Band Phase-Contrast Wave-Front Sensor
The intrinsic 90° phase shift of an ideal beam splitter would be exploited.

NASA’s Jet Propulsion Laboratory, Pasadena, California

A broadband phase-contrast wave-front sensor has been proposed as a real-time wave-front sensor in an adaptive-optics system. The proposed sensor would offer an alternative to the Shack-Hartmann wave-front sensors now used in high-order adaptive-optics systems of some astronomical telescopes. Broadband sensing gives higher sensitivity than does narrow-band sensing, and it appears that for a given bandwidth, the sensitivity of the proposed phase-contrast sensor could exceed that of a Shack-Hartmann sensor. Relative to a Shack-Hartmann sensor, the proposed sensor may be optically and mechanically simpler.

As described below, an important element of the principle of operation of a phase-contrast wave-front sensor is the imposition of a 90° phase shift between diffracted and undiffracted parts of the same light beam. In the proposed sensor, this phase shift would be obtained by utilizing the intrinsic 90° phase shift between the transmitted and reflected beams in an ideal (thin, symmetric) beam splitter. This phase shift can be characterized as achromatic or broadband because it is 90° at every wavelength over a broad wavelength range.

The phase-contrast approach was originally devised by Frits Zernike for microscopy as a means of obtaining intensity images from such phase objects as transparent biological samples. Figure 1 schematically illustrates an adaptation of the phase-contrast approach to real-time wave-front sensing for adaptive optics. The incident light from a guide star can be described in terms of a pupil field function $A \exp(i\phi)$, where $A$ is an aperture function that expresses the effect of the shape and size of the telescope pupil and $\phi$ is the difference between the actual instantaneous phase and the nominal (e.g., plane-wave) phase of the wave front at a given position within the pupil. If the pupil were simply re-imaged, the phase signal would not normally be observable. To make the phase signal observable, one reasons as follows:

Assuming a small-signal approximation ($\phi \ll 1$), the phase part of the pupil field function could be approximated as $1 + i\phi$. Hence, the phase-difference (diffracted) component would be 90° out of phase with the larger undiffracted component. To a first approximation, the undiffracted rays would be localized within the central $\approx \lambda/D$ portion of the telescope focal plane (where $\lambda$ is wavelength and $D$ is the diameter of the primary mirror or lens of the telescope), while the diffracted rays that contribute to the phase component would impinge on the telescope focal plane at off-axis positions. If a $\pm 90°$-phase-shift filter (e.g., a dielectric disk of suitable thickness) having approximately the diffraction-limited size $\lambda/D$ were placed at the focal point, then the undiffracted component would be shifted by $\pm 90°$ and would thereby be brought into phase (or phase opposition) with the diffracted component. As a result, the phase component would become observable as a small variation in

Figure 1. Phase-Contrast Imaging would use 90° phase shifting to generate phase feedback for adaptive optics.

Figure 2. A Broad-Band Phase-Contrast Wave-Front Sensor, shown here schematically, can be realized by using the intrinsic properties of a beam splitter to give an achromatic 90°-phase-shifting element.
Progress in Insect-Inspired Optical Navigation Sensors

Some details of implementation have become available.

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Progress has been made in continuing efforts to develop optical flight-control and navigation sensors for miniature robotic aircraft. The designs of these sensors are inspired by the designs and functions of the vision systems and brains of insects. Two types of sensors of particular interest are polarization compasses and ocellar horizon sensors.

The basic principle of polarization compasses was described (but without using the term “polarization compass”) in “Insect-Inspired Flight Control for Small Flying Robots” (NPO-30545), NASA Tech Briefs, Vol. 29, No. 1 (January 2005), page 61. To recapitulate: Bees use sky polarization patterns in ultraviolet (UV) light, caused by Rayleigh scattering of sunlight by atmospheric gas molecules, as direction references relative to the apparent position of the Sun. A robotic direction-finding technique based on this concept would be more robust in comparison with a technique based on the direction to the visible Sun because the UV polarization pattern is distributed across the entire sky and, hence, is redundant and can be extrapolated from a small region of clear sky in an elsewhere cloudy sky that hides the Sun.

Three different implementations of a polarization compass are under consideration. Each implementation offers distinct advantages and disadvantages relative to the others:

• In the lightest and least power-consuming implementation, the polarization signal in the sky is strongest in blue light. The basic principle of polarization compasses was described (but without using the term “polarization compass”) in “Insect-Inspired Flight Control for Small Flying Robots” (NPO-30545), NASA Tech Briefs, Vol. 29, No. 1 (January 2005), page 61. To recapitulate: Bees use sky polarization patterns in ultraviolet (UV) light, caused by Rayleigh scattering of sunlight by atmospheric gas molecules, as direction references relative to the apparent position of the Sun. A robotic direction-finding technique based on this concept would be more robust in comparison with a technique based on the direction to the visible Sun because the UV polarization pattern is distributed across the entire sky and, hence, is redundant and can be extrapolated from a small region of clear sky in an elsewhere cloudy sky that hides the Sun.

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