

ent behaviors as gyroscope drifts and thermomechanically induced alignment drifts. Because the polynomial coefficients are constant, this feature makes it possible to accommodate such behaviors while retaining the global re-linearization of the Kalman filter.

- A gyroscope-data pre-processing sub-algorithm makes it possible to compute and store gyroscope sensitivities in advance, thereby eliminating the need for repeated and time-consuming propagation of gyroscope sensitivities during each filter cycle.
- A parameter-masking capability offers the option of restricting estimation to an arbitrary subset of all the focal-plane parameters, thereby affording

flexibility to match calibration mathematical models of different levels of fidelity to different scientific instruments.

- A “multi-run” feature affords flexibility to estimate parameters by use of measurement data, which has been acquired during different observing sessions.
- An experiment design characterized by maneuvers illustrated in the figure provides for observability of all desired parameters and enables the use of the same Kalman filter for a variety of instruments.
- Measurements using observations of both visible and infrared sources can be included in the same set of calibration data.

- There is an option to process centroid information that is partial in the sense that it pertains only to position along a single axis of a photodetector array. Such information is obtained, for example, when calibrating the entrance aperture of spectrometer slit by first scanning a source across the narrow slit width, and then scanning the source along its length.
- The filter algorithm can be executed in one of several optional modes that offer compromises between accuracy and robustness.

*This work was done by Bryan Kang and David Bayard of Caltech for NASA’s Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-40798*

## Electronic Absolute Cartesian Autocollimator

Readout is not materially affected by drifts in analog circuitry.

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An electronic absolute Cartesian autocollimator performs the same basic optical function as does a conventional all-optical or a conventional electronic autocollimator but differs in the nature of its optical target and the manner in which the position of the image of the target is measured. The term “absolute” in the name of this apparatus reflects the nature of the position measurement, which, unlike in a conventional electronic autocollimator, is based absolutely on the position of the image rather than on an assumed proportionality between the position and the levels of processed analog electronic signals. The term “Cartesian” in the name of this apparatus reflects the nature of its optical target.

Figure 1 depicts the electronic functional blocks of an electronic absolute Cartesian autocollimator along with its basic optical layout, which is the same as that of a conventional autocollimator. Referring first to the optical layout and functions only, this or any autocollimator is used to measure the compound angular deviation of a flat datum mirror with respect to the optical axis of the autocollimator itself. The optical components include an illuminated target, a beam splitter, an objective or collimating lens, and a viewer or detector (described in more detail below) at a viewing plane. The target and the viewing planes are focal planes of the lens. Target light reflected by the datum mirror is imaged on the viewing plane at

unit magnification by the collimating lens.

If the normal to the datum mirror is parallel to the optical axis of the autocollimator, then the target image is centered on the viewing plane. Any angular deviation of the normal from the optical axis manifests itself as a lateral displacement of the target image from the center. The magnitude of the displacement is proportional to the focal length and to the magnitude (assumed to be small) of the angular deviation. The direction of the displacement is perpendicular to the axis about which the mirror is slightly tilted. Hence, one can determine the amount and direction of tilt from the coordinates of the target image on the viewing plane.

In a conventional all-optical autocollimator, the target is a first reticle, a technician observes the target image through an eyepiece, and a second reti-

cle affixed to the viewing plane is used to measure the coordinates of the displaced image of the first reticle. In a conventional electronic autocollimator (which could be characterized more accurately as a conventional optoelectronic autocollimator), the target is a pinhole and a position-sensitive photodetector is placed at the viewing plane. The location of the bright pinhole image is measured by use of the position-sensitive photodetector along with analog readout circuits. The net outputs of these circuits are two sets of voltage differences nominally proportional to the displacement of the pinhole image along two coordinate axes ( $x$  and  $y$ ) in the viewing plane. Like all analog devices and circuits, the position-sensitive photodetector and its readout circuits exhibit thermal and spontaneous drifts,

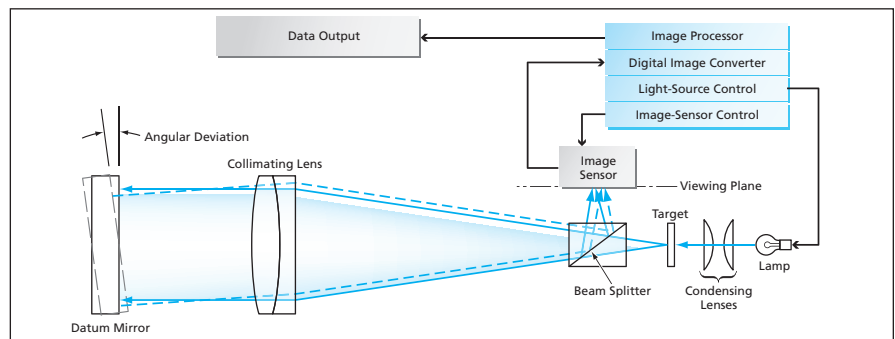


Figure 1. An **Electronic Absolute Cartesian Autocollimator** includes a conventional autocollimator optical system with a coded Cartesian-grid target, an image sensor, and a digital image-processing and control system.

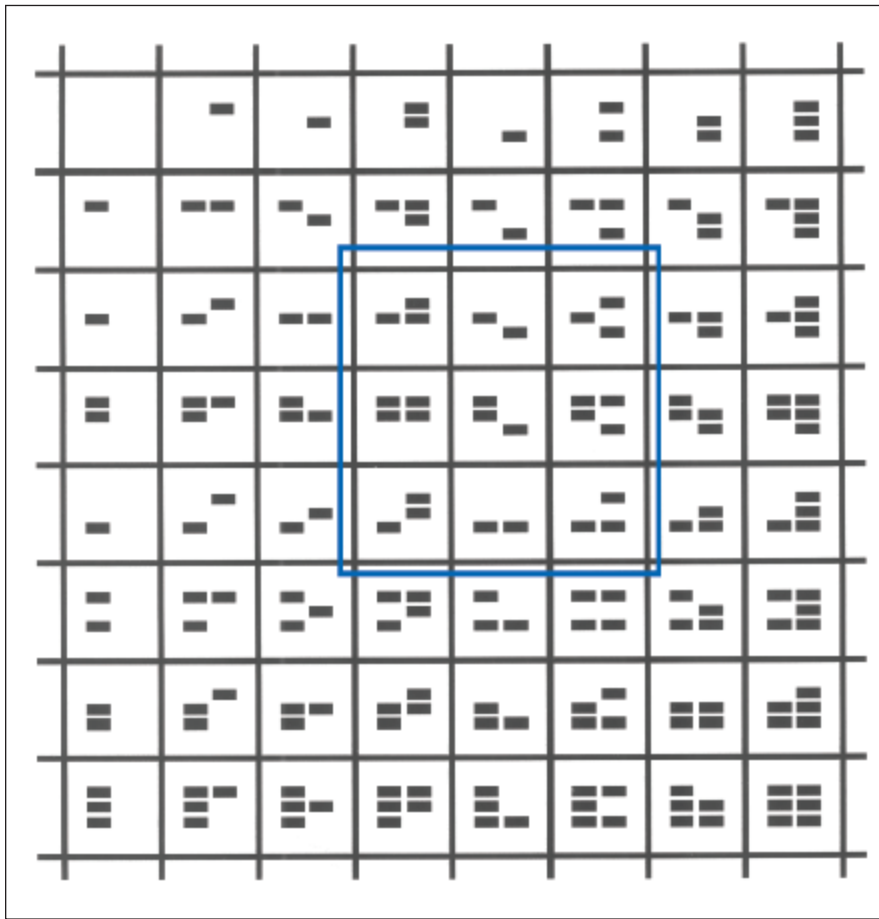


Figure 2. In the **Coded Cartesian Grid**, each grid cell contains a distinct binary image code that identifies that cell. The upper code bits in a cell identify the line at the bottom of the cell, while the lower bits identify the line at the left of the cell. In the instantaneous field of regard (square box), code bits identify vertical lines 2, 3, and 4, and horizontal lines 3, 4, and 5.

which contribute to errors and lack of stability in position measurements. Nonuniformity of the position-sensitive photodetector also contributes to readout nonlinearity.

In the electronic absolute Cartesian autocollimator, the target is a coded Cartesian grid (see Figure 2) and the viewing plane is occupied by an image

sensor. Vertical lines in the target image encode azimuthal deflections of the datum mirror from the optical axis, while horizontal lines encode elevational deflections. The planar array of pixels of the image sensor intrinsically constitutes a fixed high-resolution coordinate grid. The outputs from the pixels are digitized, and the resulting digital

data are processed to decipher the codes in the target image and to determine locations of centroids of grid lines, which provide angular measurement with a granularity nearly one thousand times finer than the angular extent of a single pixel. Each centroid produces an independent position measurement. Averaging measurements together naturally increases readout accuracy and sensitivity.

The combination of the intrinsic grid structure of the image sensor and the Cartesian grid of the target image ensures linearity of output and a high degree of immunity to any non-uniformity among responses of individual sensor pixels. The coding of the grid ensures unambiguous position readout.

Processing of the target image is not subject to drift as a result of weakness of signals on the image sensor. At worst, weakness of signals increases the proportion of noise. Therefore, the electronic absolute Cartesian autocollimator includes a servo loop that regulates the brightness of illumination to keep signal levels optimum. Finally, the electronic absolute Cartesian autocollimator offers one major additional advantage over a conventional electronic autocollimator: The cells of the Cartesian grid effectively constitute a multiplicity of targets that, collectively, makes the field of regard of this apparatus much larger than that of a conventional electronic autocollimator.

*This work was done by Douglas B. Leviton of Goddard Space Flight Center. Further information is contained in a TSP (see page 1).*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center, (301) 286-7351. Refer to GSC-14718-1.*

## Fiber-Optic Gratings for Lidar Measurements of Water Vapor

**These are highly selective, lightweight, tunable optical filters.**

*Langley Research Center, Hampton, Virginia*

Narrow-band filters in the form of phase-shifted Fabry-Perot Bragg gratings incorporated into optical fibers are being developed for differential-absorption lidar (DIAL) instruments used to measure concentrations of atmospheric water vapor. The basic idea is to measure the relative amounts of pulsed laser light scattered from the atmosphere at two nearly

equal wavelengths, one of which coincides with an absorption spectral peak of water molecules and the other corresponding to no water vapor absorption. As part of the DIAL measurement process, the scattered light is made to pass through a filter on the way to a photodetector. Omitting other details of DIAL for the sake of brevity, what is required of the

filter is to provide a stop band that:

- Surrounds the water-vapor spectral absorption peaks at a wavelength of  $\approx 946$  nm,
- Has a spectral width of at least a couple of nanometers,
- Contains a pass band preferably no wider than necessary to accommodate the 946.0003-nm-wavelength water-