Algorithm for Wavefront Sensing Using an Extended Scene

The restriction to a point source has been removed.

NASA's Jet Propulsion Laboratory, Pasadena, California

A recently conceived algorithm for processing image data acquired by a Shack-Hartmann (SH) wavefront sensor is not subject to the restriction, previously applicable in SH wavefront sensing, that the image be formed from a distant star or other equivalent of a point light source. That is to say, the image could be of an extended scene. (One still has the option of using a point source.) The algorithm can be implemented in commercially available software on ordinary computers.

The steps of the algorithm are the following:

1. Suppose that the image comprises M sub-images. Determine the x,y Cartesian coordinates of the centers of these sub-images and store them in a $2 \times M$ matrix.
2. Within each sub-image, choose an $N \times N$-pixel cell centered at the coordinates determined in step 1. For the ith sub-image, let this cell be denoted as $s_i(x,y)$. Let the cell of another sub-image (preferably near the center of the whole extended-scene image) be designated a reference cell, denoted $r(x,y)$.
3. Calculate the fast Fourier transforms of the sub-sub-images in the central $N' \times N'$ portions (where $N' < N$ and both are preferably powers of 2) of $r(x,y)$ and $s_i(x,y)$.
4. Multiply the two transforms to obtain a cross-correlation function $C_i(u,\nu)$, in the Fourier domain. Then let the phase of $C_i(u,\nu)$ constitute a phase function, $\varphi(u,\nu)$.
5. Fit u and ν slopes to $\varphi(u,\nu)$ over a small u,ν subdomain.
6. Compute the fast Fourier transform, $S_i(u,\nu)$ of the full $N \times N$ cell $s_i(x,y)$. Multiply this transform by the u and ν phase slopes obtained in step 4. Then compute the inverse fast Fourier transform of the product.
7. Repeat steps 4 through 6 in an iteration loop, cumulating the u and ν slopes, until a maximum iteration number is reached or the change in image shift becomes smaller than a predetermined tolerance.
8. Repeat steps 4 through 7 for the cells of all other sub-images.

This work was done by Erkin Sidick, Joseph Green, Catherine Ohara, and David Redding of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

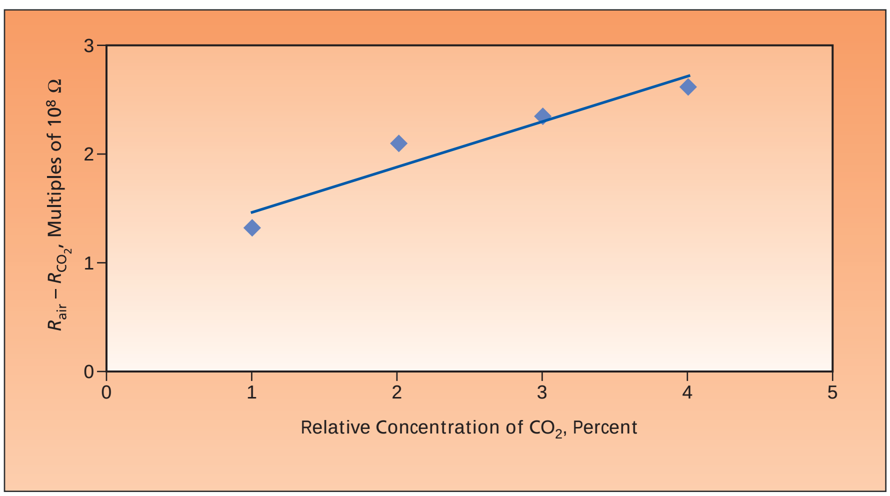
The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-44770.

CO_2 Sensors Based on Nanocrystalline SnO_2 Doped With CuO

Miniature CO_2 sensors could be mass-produced inexpensively.

John H. Glenn Research Center, Cleveland, Ohio

Nanocrystalline tin oxide (SnO_2) doped with copper oxide (CuO) has been found to be useful as an electrical-resistance sensory material for measuring the concentration of carbon dioxide in air. SnO_2 is an n-type semiconductor that has been widely used as a sensing material for detecting such reducing gases as carbon monoxide, some of the nitrogen oxides, and hydrocarbons. Without doping, SnO_2 usually does not respond to carbon dioxide and other stable gases. The discovery that the electrical resistance of CuO-doped SnO_2 varies significantly with the concentration of CO_2 creates opportunities for the development of relatively inexpensive CO_2 sensors for detecting fires and monitoring atmospheric conditions. This discovery could also lead to research that could alter fundamental knowledge of SnO_2 as a sensing material, perhaps leading to the development of SnO_2-based sensing materials for measuring concentrations of oxidizing gases.



The **Electrical Resistance** of a 1:8 CuO:SnO_2 film fabricated as described in the text was found to decrease as the concentration of CO_2 in air increased. R_{air} signifies the resistance of the film in pure air; R_{CO_2} signifies the resistance of the film at the indicated concentration of CO_2.

Prototype CO_2 sensors based on CuO-doped SnO_2 have been fabricated by means of semiconductor-microfabrication and sol-gel nanomaterial-synthesis batch processes that are amendable to inexpensive implementation in mass production. A fabrication process like that of the prototypes includes the following major steps:

1. Platinum interdigitated electrodes are

microfabricated on a quartz substrate.
2. Nanocrystalline SnO_2 is synthesized in a partial sol-gel process. CuO dopant is synthesized through a precipitation process. The dopant and the sol-gel are mixed in proportions chosen to obtain the desired composition of the final product. One composition found to be suitable is a molar ratio of 1:8 $CuO:SnO_2$.
3. The dopant and sol-gel mixture is deposited in drops on (and across the gaps between) the electrodes.
4. The workpiece is heated at a temperature of 700°C, converting the dopant and sol-gel mixture to a film of nanocrystalline CuO doped SnO_2.

In operation, a sensor of this type is heated to a temperature of 450°C while it is exposed to the CO_2 to be detected and the electrical resistance of the film between the electrodes is measured. Preliminary results of tests on a sensor containing a film of 1:8 $CuO:SnO_2$ showed an approximately linear response at CO_2 concentrations from 1 to 4 percent (see figure). In subsequent research and development efforts, it may be possible to increase sensitivities and / or reduce operating temperatures by combining CuO-doped SnO_2 with solid-electrolyte materials.

This work was done by Jennifer C. Xu and Gary W. Hunter of Glenn Research Center and Chung Chiun Liu and Benjamin J. Ward of Case Western Reserve University. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18247-1.

Improved Airborne System for Sensing Wildfires

Unlike prior such systems, this system could be operated in daylight.

Stennis Space Center, Mississippi

The Wildfire Airborne Sensing Program (WASP) is engaged in a continuing effort to develop an improved airborne instrumentation system for sensing wildfires. The system could also be used for other aerial-imaging applications, including mapping and military surveillance.

Unlike prior airborne fire-detection instrumentation systems, the WASP system would not be based on custom-made multispectral line scanners and associated custom-made complex optomechanical servomechanisms, sensors, readout circuitry, and packaging. Instead, the WASP system would be based on commercial off-the-shelf (COTS) equipment that would include (1) three or four electronic cameras (one for each of three or four wavelength bands) instead of a multispectral line scanner; (2) all associated drive and readout electronics; (3) a camera-pointing gimbal; (4) an inertial measurement unit (IMU) and a Global Positioning System (GPS) receiver for measuring the position, velocity, and orientation of the aircraft; and (5) a data-acquisition subsystem. It would be necessary to custom-develop an integrated sensor optical-bench assembly, a sensor-management subsystem, and software. The use of mostly COTS equipment is intended to reduce development time and cost, relative to those of prior systems.

The WASP system as envisioned (see figure) would include the three or four cameras, all aimed in the same direction, mounted in a camera subassembly. Three cameras would operate in the long-wavelength infrared (LWIR), medium-wavelength infrared (MWIR), and short-wavelength infrared (SWIR) wavelength bands, respectively. The fourth camera, if included, would operate in the visible or visible plus near infrared (VNIR) wavelength band.

The camera subassembly would be mounted on the camera-positioning gimbal, which would scan the camera line of sight through a cross-track angular range of 40°. Because the half cone angle of the fields of view of the cameras would be 20°, this scanning action would provide coverage of a cross-track swath of 60°. Precise knowledge of the direction of the line of sight would be obtained from the combination of information provided by the GPS receiver, the inertial sensor subsystem, and a precise angle encoder mounted on the gimbal drive axis. Image data from the cameras and position and line-of-sight information would be sent to an onboard data-storage-and-processing subsystem. The estimated total weight of the system is less than 220 lb (equivalent to a mass <100 kg); the estimated maximum operating power of the system is <550 W.

In a typical fire-detection mission using a multispectral line-scanning instrumentation system, a 10-km-wide swath is imaged from an aircraft at an altitude of 3 km. Typically, missions are conducted at night to reduce false alarms attributable to solar heating. The MWIR band is used as the primary-fire detection band, along with an LWIR band, which provides scene context. A hot spot detected in the MWIR band can be located with respect to ground features imaged in the LWIR band. The line scanner provides excellent band-to-band registration, but it is necessary to use a complex rate-controlled scanning mirror and significant post-processing to correct for variations between scan lines induced by variations in aircraft attitude and ground speed. The sensitive scanning mechanisms are also susceptible to failure and are difficult to service.

The WASP proposes to extend operation into the daytime and to improve operability. The extension into daytime would be enabled by the use of a SWIR camera in addition to the MWIR and LWIR cameras. (SWIR has been determined to be useful for discriminating fire targets in daylight and for detecting hot fires at night.) The fourth (visible or VNIR) camera, if included, would have very high resolution and would be used to provide detailed scene context during daylight operation.

In the WASP conceptual sequence of operation, the line of sight would be stepped across the swath between four discrete angular positions. The camera subassembly would be held steady at each angular position for a short time, during which the cameras would acquire image frames. The collection of frames would be assembled into a mosaic image spanning the cross-track swath. Because the frames would be acquired along momentarily steady lines of sight, there would be no need for complex rate-controlled servomechanisms. The motion of the aircraft would cause a small along-track offset between frames plus a small (typically, subpixel) smear during the image-integration (acquisition) time. Each of the four frames across the swath would be