Technology Focus: Sensors

Direct-Solve Image-Based Wavefront Sensing

This method saves time and effort in testing of optical systems.

Goddard Space Flight Center, Greenbelt, Maryland

A method of wavefront sensing (more precisely characterized as a method of determining the deviation of a wavefront from a nominal figure) has been invented as an improved means of assessing the performance of an optical system as affected by such imperfections as misalignments, design errors, and fabrication errors. Unlike some prior methods, this method does not require the use of an expensive, complex interferometric instrument for testing the optical system of interest: indeed, if the system under test includes an image sensor at its focal plane, then this method does not require any optical instrumentation other than the optical system under test. Unlike some other prior methods, this method does not involve processing of multiple defocused images by a nonlinear iterative phase-retrieval algorithm and interpretation of results by a human expert in phase retrieval. Instead, this method involves a single non-iterative algorithm that solves for the wavefront from a single in-focus image, without need for interpretation of results. Hence, the main advantages of this method over the prior methods are reduced computing time and reduced labor.

At the time of writing this article, only fragmentary information about the method is available. Beyond what has been stated above, what is known is the following:

- The method is implemented by software running on a single-processor computer that is connected, via a suitable interface, to the image sensor (typically, a charge-coupled device) in the system under test.
- The software collects a digitized single image from the image sensor.
- The image is displayed on a computer monitor.
- The software directly solves for the wavefront in a time interval of a fraction of a second.
- A picture of the wavefront is displayed.
- The solution process involves, among other things, fast Fourier transforms. It has been reported to the effect that some measure of the wavefront is decomposed into modes of the optical system under test, but it has not been reported whether this decomposition is postprocessing of the solution or part of the solution process.

This work was done by Richard G. Lyon of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15208-1

Use of UV Sources for Detection and Identification of Explosives

UV excitation is used to simultaneously detect Raman and fluorescence spectral information of explosive materials.

NASA's Jet Propulsion Laboratory, Pasadena, California

Measurement of Raman and native fluorescence emission using ultraviolet (UV) sources (<400 nm) on targeted materials is suitable for both sensitive detection and accurate identification of explosive materials. When the UV emission data are analyzed using a combination of Principal Component Analysis (PCA) and cluster analysis, chemicals and biological samples can be differentiated based on the geometric arrangement of molecules, the number of repeating aromatic rings, associated functional groups (nitrogen, sulfur, hydroxyl, and methyl), microbial life cycles (spores vs. vegetative cells), and the number of conjugated bonds. Explosive materials can be separated from one another as well as from a range of possible background materials, which includes microbes, car doors, motor oil, and fingerprints on car doors, etc. Many explosives are comprised of similar atomic constituents found in potential background samples such as fingerprint oils/skin, motor oil, and soil. This technique is sensitive to chemical bonds between the elements that lead to the discriminating separability between backgrounds and explosive materials.

The unique combination of the wavelength, optics, mechanical configurations, and chemometrics enables standoff (1 to 5 m) identification of trace amounts of explosive materials with rapid spatial scanning capability. Each data point, which can include both the native fluorescence and Raman signals, is automatically identified in <100 µs by the real-time analysis engine. The rapid acquisition and real-time analysis allows a user to scan the instrument over a large region such that the probability of false negatives resulting from a heterogeneous distribution of explosive material on a surface is dramatically reduced.

The hand-held or robot-mounted instrument has been tested using a number of experimental conditions. In one example, a car panel doped with RDX (an explosive nitroamine) was placed 1 m away from the instrument. The car panel segment was rotated as the instrument collected data to mimic scanning from a fixed distance. The composite traces from the detectors are used by the analysis to show a relatedness index (high values indicate a high match) of each data point as a function of time and spatial position. This sample was part of a blind test to determine whether it was possible to identify RDX on the car panel in the presence of Arizona dust (a standardized interferrant sample). As the sample is scanned, the RDX is found only in specific areas. In the other related experiments where the RDX samples were not so heterogeneous, the RDX relatedness index was consistently high. In other tests, a limit of detection less than 100 ng/cm^2 was demonstrated at a standoff distance of 1 meter using a 38 mm diameter collection aperture. Using a modestly larger aperture or at higher concentration amounts, the instrument can detect and identify explosives at longer standoff distances.

The developed sensor has an excitation wavelength of 248 nm from a transversely excited hollow cathode (TEHC) laser. An alternate excitation wavelength of interest is 224 nm, also from the TEHC laser. Although the optimum excitation wavelength is less than 250 nm at present, there is also an expectation that longer wavelengths up to about 400 nm may also be relevant for some applications.

This work was done by William Hug and Ray Reid of Photon Systems, Inc., and Rohit Bhartia and Arthur Lane of Caltech for NASA's Jet Propulsion Laboratory under an Army Phase I STTR contract (No. W81XWH-06-C-0395 CM: Dr. Gary Gilbert) with Photon Systems.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-45166, volume and number of this NASA Tech Briefs *issue, and the page number.*

Using Fluorescent Viruses for Detecting Bacteria in Water

Lyndon B. Johnson Space Center, Houston, Texas

A method of detecting water-borne pathogenic bacteria is based partly on established molecular-recognition and fluorescent-labeling concepts, according to which bacteria of a species of interest are labeled with fluorescent reporter molecules and the bacteria can then be detected by fluorescence spectroscopy. The novelty of the present method lies in the use of bacteriophages (viruses that infect bacteria) to deliver the fluorescent reporter molecules to the bacteria of the species of interest. Bacteriophages that selectively infect that species are selected, and fluorescently labeled virus probes (FLVPs) are prepared by staining these bacteriophages with a fluorescent dye. The FLVPs are immobilized on an optical substrate, which could be a window or a waveguide.

Bacteria/bacteriophage complexes are formed when the substrate is exposed to water containing the bacteria of interest. These complexes exhibit a characteristic fluorescence spectrum, which can be measured to determine the concentration of the complexes and, thus, of the bacteria of interest. Biosensors based on this method could, potentially, enable rapid, selective, and potentially very sensitive detection of bacteria in water. Such biosensors could be used alternatively or complementarily to immunodiagnostic or nucleic acid-based biosensors.

This work was done by Mary Beth Tabacco, Xiaohua Qian, and Jaimie A. Russo of Echo Technologies, Inc., for Johnson Space Center.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to MSC-23371-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Gradiometer Using Middle Loops as Sensing Elements in a Low-Field SQUID MRI System

Device could lead to an MRI diagnostic device for human diagnosis.

NASA's Jet Propulsion Laboratory, Pasadena, California

A new gradiometer scheme uses middle loops as sensing elements in low-field superconducting quantum interference device (SQUID) magnetic resonance imaging (MRI). This design of a second order gradiometer increases its sensitivity and makes it more uniform, compared to the conventional side loop sensing scheme with a comparable matching SQUID. The space between the two middle loops becomes the imaging volume with the enclosing cryostat built accordingly.

For optimal coupling to SQUID, the inductance of the gradiometer must be matched to that of the SQUID input coil. Previously, a second-order gradiometer was designed with optimized wire shape and split middle loops to increase the turn number for increased sensitivity, and/or the size for a larger field of view while keeping the inductance matched. This design was described in "Optimized Geometry for Superconducting Sensing Coils" (NPO-44629), *NASA Tech Briefs*, Vol. 32, No. 1 (January 2008), p. 26.

In a typical configuration of a SQUID MRI, the sensitivity of a gradiometer is a rapidly decreasing function of the distance from the sensing loops. This results in severe non-uniformity of sensitivity and signal-to-noise ratio (SNR) in the image. This problem can be solved by using two second-order gradiometers positioned at the opposite sides of the imaging volume, with two SQUIDs, one per gradiometer. This is not cost-effective since SNR improves only by a square root of two at the center of the imaging volume.

The new design, depicted in the figure, uses a single second-order gradiometer where the middle loops are used for sensing. Both the SNR and the uniformity of the gradiometer are greatly improved. In this scheme, the space between the middle loops be-