complex, and can be prone to errors. The errors can be compounded because of approximations in the model and inaccurate assumptions about the radiative coupling between the atmosphere and the terrain. The errors can increase the uncertainty of the TOA radiance estimates used to perform the radiometric calibration.

In comparison, the simplified approach does not use atmospheric radiative transfer models and involves fewer assumptions concerning the radiative transfer properties of the atmosphere. This new technique uses two neighboring uniform ground target areas having different reflectance values. The target areas can be natural or artificial and must be large enough to minimize adjacent-pixel contamination effects. The radiative coupling between the atmosphere and the terrain needs to be approximately the same for the two targets. This condition can be met for relatively uniform backgrounds when the distance between the targets is within a few hundred meters.

For each target area, the radiance leaving the ground in the direction of the satellite is measured with a radiometrically calibrated spectroradiometer. Using the radiance measurements from the two targets, atmospheric adjacency and atmospheric scattering effects can be subtracted, thereby eliminating many assumptions about the atmosphere and the radiative interaction between the atmosphere and the terrain. In addition, the radiometrically calibrated spectroradiometer can be used with a known reflectance target to estimate atmospheric transmission and diffuse-to-global ratios without the need for ancillary sun photometers.

Several comparisons between the simplified method and traditional techniques were found to agree within a few percent. Hence, the simplified method reduces the overall complexity of performing vicarious calibrations and can serve as a method for validating traditional radiative transfer models.

This work was done by Thomas Stanley of Stennis Space Center and Robert E. Ryan, Kara Holekamp, and Mary Pagnutti of Science Systems and Applications, Inc.

Inquiries concerning this technology should be addressed to the Intellectual Property Manager, Stennis Space Center, (228) 688-1929. Refer to SSC-00301-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Phase-Conjugate Receiver for Gaussian-State Quantum Illumination

Active optical sensors have application in military surveillance.

NASA's Jet Propulsion Laboratory, Pasadena, California

An active optical sensor probes a region of free space that is engulfed in bright thermal noise to determine the presence (or absence) of a weakly reflecting target. The returned light (which is just thermal noise if no target is present, and thermal noise plus a weak reflection of the probe beam if a target is present) is measured and processed by a receiver and a decision is made on whether a target is present.

It has been shown that generating an entangled pair of photons (which is a highly nonclassical state of light), using one photon as the probe beam and storing the other photon for comparison to the returned light, has superior performance to the traditional classical-light (coherent-state) target detection sensors. An entangled-photon transmitter and optimal receiver combination can yield up to a factor of 4 (i.e., 6 dB) gain in the error-probability exponent over a coherent state transmitter and optimal receiver combination, in a highly lossy and noisy scenario (when both sensors have the same number of transmitted photons). However, the receiver that achieves this advantage is not known. One structured receiver can close half of the 6-dB gap (i.e., a 3-dB improvement). It is based on phase-conjugating the returned light, then performing dual-balanced difference detection with the stored half of the entangled-photon pair.

Active optical sensors are of tremendous value to NASA's missions. Although this work focuses on target detection, it can be extended to imaging (2D, 3D, hyperspectral, etc.) scenarios as well, where the image quality can be better than that offered by traditional active sensors. Although the current work is theoretical, NASA's future missions could benefit significantly from developing and demonstrating this capability.

This is an optical receiver design whose components are, in principle, all implementable. However, the work is currently entirely theoretical. It is necessary to:

1. Demonstrate a bench-top proof of the theoretical principle,
2. Create an operational prototype off-the-bench, and
3. Build a practical sensor that can fly in a mission.

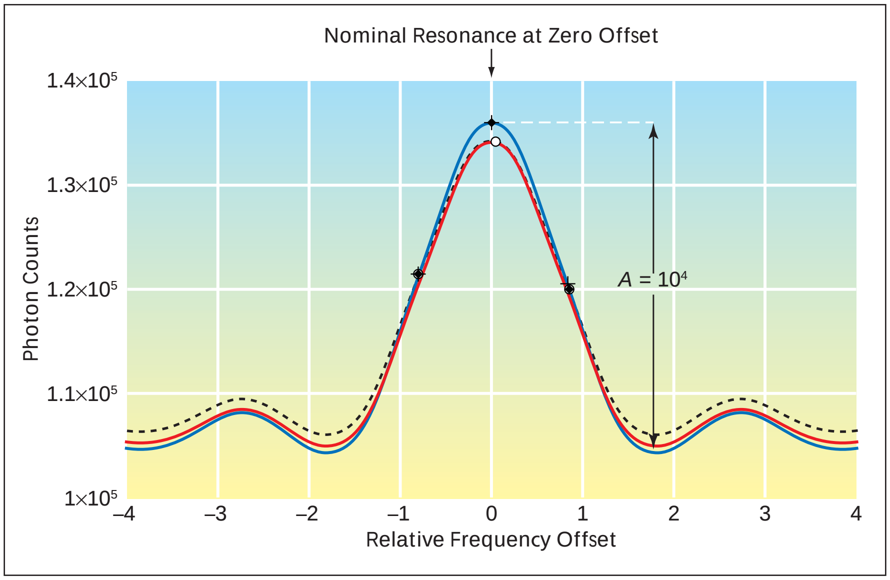
This work was done by Baris I. Erkmen of Caltech and Saikat Guha of BBN Technologies for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47152

Improved Tracking of an Atomic-Clock Resonance Transition

The resonance frequency is repeatedly estimated from sequences of three measurements.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved method of making an electronic oscillator track the frequency of an atomic-clock resonance transition is based on fitting a theoretical nonlinear curve to measurements at three oscillator frequencies within the operational frequency band of the transition (in other words, at three points within the resonance peak). In the measurement process, the frequency of a microwave oscillator is repeatedly set at various offsets from the nominal resonance



These Three Plots represent fits of the nonlinear curve to three sets of simulated measurements, each set comprising photon counts at relative frequency offsets (*y* values) of 0 and ±0.761. The parameters of the simulated measurements were B = 1.05 × 10^5 counts, A = 3 × 10^4 counts, and signal-to-noise ratio ≈30.

frequency, the oscillator signal is applied in a square pulse of the oscillator signal having a suitable duration (typically, of the order of a second), and, for each pulse at each frequency offset, fluorescence photons of the transition in question are counted. As described below, the counts are used to determine a new nominal resonance frequency. Thereafter, offsets are determined with respect to the new resonance frequency. The process as described thus far is repeated so as to repeatedly adjust the oscillator to track the most recent estimate of the nominal resonance frequency.

The theoretical nonlinear curve is that of the Rabi equation for the shape of the resonance peak

$$P(y) = \frac{\sin^2\left(\frac{\pi}{2}\sqrt{1+y^2}\right)}{1+y^2}$$

where the dimensionless variable y is related to the duration of the microwave pulse, T, and the frequency offset $\nu - \nu_0$ from the atomic absorption frequency, ν_0 , as follows: $y = 2T(\nu - \nu_0)$.

Assuming that the signal power has been optimized and that the photon count at a given measurement signal frequency includes a non-resonant background contribution plus a contribution attributable to the resonance, the basic measurement equation for the ith measurement is

$$C(i) = B + AP(y_1 - \varepsilon)$$

where $C(i)$ is the atomic fluorescence photon count, A is atomic fluorescence, and ε is an offset of the nominal resonance frequency from the actual resonance frequency. If measurements are made at three different oscillator frequency offsets (y_1, y_2, y_3), then one has

$$C(1) = B + AP(y_1 - \varepsilon)$$
$$C(2) = B + AP(y_2 - \varepsilon)$$
$$C(3) = B + AP(y_3 - \varepsilon)$$

Repeatedly, for the most recent such set of three measurements (see figure), this set of three equations is inverted to extract B, A, and ε from the measurement values $C(1)$, $C(2)$, and $C(3)$. Because the solution obtained through inversion of the three equations separates the influences of background light, signal strength, and the offset of the resonance from the nominal resonance frequency, unlike in a prior method, drift in the power of the lamp used to excite the clock atoms to the upper level of the transition does not seem to effect frequency pulling (that is, it does not seem to force a change in the estimate of the resonance frequency).

This work was done by John D. Prestage, Sang K. Chung, and Meirong Tu of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45958

Measurement of the Length of an Optical Trap

This technique aids in the assembly of MEMS devices.

John H. Glenn Research Center, Cleveland, Ohio

NASA Glenn has been involved in developing optical trapping and optical micromanipulation techniques in order to develop a tool that can be used to probe, characterize, and assemble nano and microscale materials to create microscale sensors for harsh flight environments. In order to be able to assemble a sensor or probe candidate sensor material, it is useful to know how far an optical trap can "reach"; that is, the distance beyond/below the stable trapping point through which an object will be drawn into the optical trap. Typically, to measure the distance over which an optical trap would influence matter in a horizontal (perpendicular to beam propagation) direction, it was common to hold an object in one optical trap, place a second optical trap a known distance away, turn off the first optical trap, and note if the object was moved into the second trap when it was turned on. The disadvantage of this technique is that it only gives information of trap influence distance in horizontal (x–y) directions. No information about the distance of the influence of the trap is gained in the direction of propagation of the beam (the z direction).

A method was developed to use a time-of-flight technique to determine the length along the propagation direction of an optical trap beam over which an object may be drawn into the optical trap. Test objects (polystyrene microspheres) were held in an optical trap in a water-filled sample chamber and raised to a pre-determined position near the top of the sample chamber. Next, the test objects were released by blocking the optical trap beam. The test objects were allowed to fall through the water for predetermined periods of time, at the end of which the trapping beam was unblocked. It was noted