Technology Focus: Test & Measurement

Optical Comb From a Whispering Gallery Mode Resonator for Spectroscopy and Astronomy Instruments Calibration

This technology can be used for surveillance of the Earth from space.

NASA's Jet Propulsion Laboratory, Pasadena, California

The most accurate astronomical data is available from space-based observations that are not impeded by the Earth's atmosphere. Such measurements may require spectral samples taken as long as decades apart, with the 1 cm/s velocity precision integrated over a broad wavelength range. This raises the requirements specifically for instruments used in astrophysics research missions — their stringent wavelength resolution and accuracy must be maintained over years and possibly decades. Therefore, a stable and broadband optical calibration technique compatible with spaceflights becomes essential. The space-based spectroscopic instruments need to be calibrated *in situ*, which puts forth specific requirements to the calibration sources, mainly concerned with their mass, power consumption, and reliability.

A high-precision, high-resolution reference wavelength comb source for astronomical and astrophysics spectroscopic observations has been developed that is deployable in space. The optical comb will be used for wavelength calibrations of spectrographs and will enable Doppler measurements to better than 10 cm/s precision, one hundred times better than the current state-of-the-art.

The concept leverages the progress of wide-span frequency comb generation in frequency standards and metrology. The source consists of a crystalline whispering gallery mode (WGM) microresonator, a near-IR tunable single-frequency CW (continuous wave) laser, an FM (frequency modulated) spectroscopy unit, and control and stabilization electronics. The coupling in and out of the resonator is fiber-based through the evanescent waves. This approach is based on an external laser coupled to the Kerr-media WGM resonator.

This novel precision comb provides a new generation of super-stable, evenly spaced, and wideband wavelength calibration sources. In addition, this source does not age as the lamps do. Presently, this approach allows users to achieve an absolute accuracy of better than 10^{-12} per day when referenced to a suitable atomic transition.

The improved Doppler measurement accuracy and resolution will significantly enhance the current astronomy observation capability in exoplanet search and the study of cosmology dynamics.

This work was done by Dmitry V. Strekalov, Nan Yu, and Robert J. Thompson of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48135

Real-Time Flight Envelope Monitoring System

The system uses a combination of three separate detection algorithms to provide a warning at a preset number of degrees prior to stall.

Dryden Flight Research Center, Edwards, California

The objective of this effort was to show that real-time aircraft control-surface hinge-moment information could be used to provide a robust and reliable prediction of vehicle performance and control authority degradation. For a given airfoil section with a control surface — be it a wing with an aileron, rudder, or elevator — the control-surface hinge moment is sensitive to the aerodynamic characteristics of the section. As a result, changes in the aerodynamics of the section due to angle-of-attack or environmental effects such as icing, heavy rain, surface contaminants, bird strikes, or battle damage will affect the control surface hinge moment. These changes include both the magnitude of the hinge moment and its sign in a time-averaged sense, and the variation of the hinge moment with time. The current program attempts to take the real-time hinge moment information from the aircraft control surfaces and develop a system to predict aircraft envelope boundaries across a range of conditions, alerting the flight crew to reductions in aircraft controllability and flight boundaries.

The concept was tested across a wide range of conditions and observed in-flight contamination, and a system and methodology of using the hinge-moment information to predict sectional airfoil stall in the presence of these contaminants was developed. An experimental test program was designed to provide the broadest test of the hinge moment monitoring concept. A NACA 3415 airfoil section with a 25-percent chord flap was tested with a series of simulated aerodynamic contaminants. These contaminants were designed to provide a range of simulated environmental and structural hazards, which would produce varying degrees of performance degradation, primarily in the form of premature stall and loss of maximum lift. These simulated cases included both leading-edge glaze and rime ice, both moderate and severe leading-edge roughness, and both a simulated 3D leading-edge and a simulated upper surface damage case.

Data from the experimental tests were used to develop a stall prediction methodology and detection algorithm

based on the unsteady hinge moment results. The stall detection algorithm provided a warning of stall several degrees prior to actual stall. In this way, the envelope monitoring system can alert the flight crew to the current aircraft envelope boundaries for both longitudinal and lateral control.

The system uses a combination of three separate detection algorithms based on the unsteady hinge moment signal to provide a warning at a preset number of degrees prior to stall. Results from the three algorithms are averaged to provide a single warning prediction. The averaging of the three separate algorithms provides a level of redundancy in the calculation and can also be used as a measure of the confidence of the stall boundary warning prediction. For the majority of the cases, the detection algorithm produced a warning within ±0.7° of the set boundary value. There appears to be sufficient signal to provide a stall warning boundary out to approximately 4° prior to stall. Output from the detector function for the range of shown contaminations collapses onto a single curve, as a function of the angle-of-attack prior to stall. By collapsing onto a single curve, the developed detector function-based system can use a simple threshold approach to set a variable warning boundary, up to several degrees prior to stall.

Nemesis Autonomous Test System

NASA's Jet Propulsion Laboratory, Pasadena, California

A generalized framework has been developed for systems validation that can be applied to both traditional and autonomous systems. The framework consists of an automated test case generation and execution system called Nemesis that rapidly and thoroughly identifies flaws or vulnerabilities within a system. By applying genetic optimization and goal-seeking algorithms on the test equipment side, a "war game" is conducted between a system and its complementary nemesis. The end result of the war games is a collection of scenarios that reveals any undesirable behaviors of the system under test.

The software provides a reusable framework to evolve test scenarios using genetic algorithms using an operation model of the system under test. It can automatically generate and execute test cases that reveal flaws in behaviorally complex systems. Genetic algorithms focus the exploration of tests on the set of test cases that most effectively reveals the flaws and vulnerabilities of the system under test. It leverages advances in state- and model-based engineering, which are essential in defining the behavior of autonomous systems. It also uses goal networks to describe test scenarios.

Mirror Metrology Using Nano-Probe Supports

Any application requiring precise measurement of a flexible object could benefit from this invention.

Goddard Space Flight Center, Greenbelt, Maryland

Thin, lightweight mirrors are needed for future x-ray space telescopes in order to increase x-ray collecting area while maintaining a reduced mass and volume capable of being launched on existing rockets. However, it is very difficult to determine the undistorted shape of such thin mirrors because the mounting of the mirror during measurement causes distortion. Traditional kinematic mounts have insufficient supports to control the distortion to measurable levels and prevent the mirror from vibrating during measurement. Over-constrained mounts (non-kinematic) result in an unknown force state causing mirror distortion that cannot be determined or analytically removed. In order to measure flexible mirrors, it is necessary to over-constrain the mirror. Over-constraint causes unknown distortions to be applied to the mirror. Even if a kinematic constraint system can be used, necessary imperfections in the kinematic assumption can lead to an unknown force state capable of distorting the mirror. Previously, thicker, stiffer, and heavier mirrors were used to achieve low optical figure distortion. These mirrors could be measured to an acceptable level of precision using traditional kinematic mounts. As lighter weight precision optics have developed, systems such as the whiffle tree or hydraulic supports have been used to provide additional mounting supports while maintaining the kinematic assumption.

The purpose of this invention is to over-constrain a mirror for optical measurement without causing unacceptable or unknown distortions. The invention uses force gauges capable of measuring 1/10,000 of a Newton attached to nano-actuators to support a thin x-ray optic with known and controlled forces to allow for figure measurement and knowledge of the undeformed mirror figure. The mirror is hung from strings such that it is minimally distorted and in a known force state. However, the hanging mirror cannot be measured because it is both swinging and vibrating. In order to stabilize the mirror for measurement, nano-probes support the mirror, causing the mirror to be over-constrained.