



## Technology Focus: Sensors

### Cryogenic Flow Sensor

*Marshall Space Flight Center, Alabama*

An acousto-optic cryogenic flow sensor (CFS) determines mass flow of cryogens for spacecraft propellant management. The CFS operates unobtrusively in a high-pressure, high-flow-rate cryogenic environment to provide measurements for fluid quality as well as mass flow rate. Experimental hardware uses an optical “plane-of-light” (POL) to detect the onset of two-phase flow, and the presence of particles in the flow of water.

Acousto-optic devices are used in laser equipment for electronic control of the intensity and position of the laser beam. Acousto-optic interaction occurs in all optical media when an acoustic

wave and a laser beam are present. When an acoustic wave is launched into the optical medium, it generates a refractive index wave that behaves like a sinusoidal grating. An incident laser beam passing through this grating will diffract the laser beam into several orders. Its angular position is linearly proportional to the acoustic frequency, so that the higher the frequency, the larger the diffracted angle.

If the acoustic wave is traveling in a moving fluid, the fluid velocity will affect the frequency of the traveling wave, relative to a stationary sensor. This frequency shift changes the angle of diffraction, hence, fluid velocity can be de-

termined from the diffraction angle. The CFS acoustic Bragg grating data test indicates that it is capable of accurately determining flow from 0 to 10 meters per second. The same sensor can be used in flow velocities exceeding 100 m/s. The POL module has successfully determined the onset of two-phase flow, and can distinguish vapor bubbles from debris.

*This work was done by John Justak of Advanced Technologies Group, Inc. for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at [sammy.a.nabors@nasa.gov](mailto:sammy.a.nabors@nasa.gov). Refer to MFS-32730-1.*

### Multi-Sensor Mud Detection

**This technology is also applicable to terrain hazard assessment in terrestrial or planetary situations.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Robust mud detection is a critical perception requirement for Unmanned Ground Vehicle (UGV) autonomous off-road navigation. A military UGV stuck in a



A General Dynamics Robotic Systems (GDRS) experimental unmanned vehicle (XUV) navigates through a muddy grass field during a data collection for the **Daytime Mud Detection System**.

mud body during a mission may have to be sacrificed or rescued, both of which are unattractive options. There are several characteristics of mud that may be detectable with appropriate UGV-mounted sensors. For example, mud only occurs on the ground surface, is cooler than surrounding dry soil during the daytime under nominal weather conditions, is generally darker than surrounding dry soil in visible imagery, and is highly polarized. However, none of these cues are definitive on their own. Dry soil also occurs on the ground surface, shadows, snow, ice, and water can also be cooler than surrounding dry soil, shadows are also darker than surrounding dry soil in visible imagery, and cars, water, and some vegetation are also highly polarized. Shadows, snow, ice, water, cars, and vegetation can all be disambiguated from mud by using a suite of sensors that span multiple bands in the electromagnetic spectrum. Because there are military operations when it is imperative for UGV's to operate without emitting strong, de-

tectable electromagnetic signals, passive sensors are desirable.

JPL has developed a daytime mud detection capability using multiple passive imaging sensors. Cues for mud from multiple passive imaging sensors are fused into a single mud detection image using a rule base, and the resultant mud detection is localized in a terrain map using range data generated from a stereo pair of color cameras. Thus far at the time of this reporting, JPL has:

1. Performed daytime data collections, on wet and dry soil, with several candidate passive imaging sensors, including multi-spectral (blue, green, red, and near-infrared bands), short-wave infrared, mid-wave infrared, long-wave infrared, polarization, and a stereo pair of color cameras.
2. Characterized the advantages and disadvantages of each passive imaging sensor to provide cues for mud.
3. Implemented a first-generation mud detector that uses a stereo pair of color

cameras and a polarization camera. For each set of input images, the innovators calculate degree of linear polarization (DOLP), back-project polarization pixels that have high DOLP into the left color image, generate a stereo range image (which is registered with the left color image), and insert detected mud into a world map using the stereo range data. As it is only expected for mud to occur on the ground surface, stereo range data are used to isolate ground surface pixels from the other pixels corresponding to ground clutter. Ground

clutter pixels with high DOLP (such as vegetation) are ignored.

Techniques to estimate soil moisture content have been studied for decades for agricultural applications; however, mud detection for UGV autonomous navigation is a relatively new research area. Ground vehicle methods of soil moisture estimation have used passive microwave sensors, but the antennas tend to be bulky and have been mounted directly downwards. This requires a UGV to drive on potentially hazardous terrain in order to characterize it. This work involves de-

tecting mud hazards from a UGV without having to drive on the hazard first.

Mud detection is a terrestrial application; however, the intermediate image processing steps and world modeling techniques performed for this task are valuable to terrain hazard assessment in general, terrestrial, or planetary situations.

*This work was done by Arturo L. Rankin and Larry H. Matthies of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact [iaoffice@jpl.nasa.gov](mailto:iaoffice@jpl.nasa.gov). NPO-46624*

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## Gas Flow Detection System

**Commercial applications include flow measurement systems.**

*John F. Kennedy Space Center, Florida*

This system provides a portable means to detect gas flow through a thin-walled tube without breaking into the tubing system. The flow detection system was specifically designed to detect flow through two parallel branches of a manifold with only one inlet and outlet, and is a means for verifying a space shuttle program requirement that saves time and reduces the risk of flight hardware damage compared to the current means of requirement verification.

The prototype Purge Vent and Drain Window Cavity Conditioning System (PVD WCCS) Flow Detection System consists of a heater and a temperature-sensing thermistor attached to a piece of Velcro to be attached to each branch of a WCCS manifold for the duration of the requirement verification test. The heaters and thermistors are connected to a shielded cable and then to an electronics enclosure, which contains the power supplies, relays, and circuit board to provide power, signal conditioning, and control. The electronics enclosure is then connected to a commercial data acquisition box to provide analog to

digital conversion as well as digital control. This data acquisition box is then connected to a commercial laptop running a custom application created using National Instruments' LabVIEW.

The operation of the PVD WCCS Flow Detection System consists of first attaching a heater/thermistor assembly to each of the two branches of one manifold while there is no flow through the manifold. Next, the software application running on the laptop is used to turn on the heaters and to monitor the manifold branch temperatures. When the system has reached thermal equilibrium, the software application's graphical user interface (GUI) will indicate that the branch temperatures are stable. The operator can then physically open the flow control valve to initiate the test flow of gaseous nitrogen (GN<sub>2</sub>) through the manifold. Next, the software user interface will be monitored for stable temperature indications when the system is again at thermal equilibrium with the test flow of GN<sub>2</sub>. The temperature drop of each branch from its "no flow" stable

temperature peak to its stable "with flow" temperature will allow the operator to determine whether a minimum level of flow exists.

An alternative operation has the operator turning on the software only long enough to record the ambient temperature of the tubing before turning on the heaters and initiating GN<sub>2</sub> flow. The stable temperature of the heated tubing with GN<sub>2</sub> flow is then compared with the ambient tubing temperature to determine if flow is present in each branch. To help quantify the level of flow in the manifolds, each branch will be bench calibrated to establish its thermal properties using the flow detection system and different flow rates. These calibration values can then be incorporated into the software application to provide more detailed flow rate information.

*This work was done by Thomas Moss, Curtis Ihlefeld, and Barry Slack of Kennedy Space Center. For further information, contact the Kennedy Applied Physics Laboratory at (321) 867-7513. KSC-13174*

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## Mapping Capacitive Coupling Among Pixels in a Sensor Array

**Cross-talk calibration of all pixels can be performed efficiently.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

An improved method of mapping the capacitive contribution to cross-talk among pixels in an imaging array of sensors (typically, an imaging photodetector array) has been devised for use in calibrating and/or

characterizing such an array. The method is applicable to almost all image detectors in modern electronic cameras for diverse applications, ranging from consumer cellular-telephone cameras at one extreme to

high-performance imaging scientific instruments at the other extreme. In comparison with prior methods of quantifying the capacitive coupling among pixels, this method is a more efficient means of ob-