Team designs a prototype fuel gauge for orbit

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Many satellites perform highly important and lucrative tasks, but some may be decommissioned with fuel still in the tank due to the current methods of measuring fuel quantity. Fuel gauges with higher accuracy could help ensure that satellites stay operational for longer and more is made of their time in orbit. Credit: NASA Jet Propulsion Laboratory

Liquids aren't as well behaved in space as they are on Earth. Inside a spacecraft, microgravity allows liquids to freely slosh and float about.

This behavior has made fuel quantity in satellites difficult to pin down, but a new prototype fuel gauge engineered at the National Institute of Standards and Technology (NIST) could offer an ideal solution. The gauge, described in the *Journal of Spacecraft and Rockets*, can digitally recreate a fluid's 3-D shape based on its electrical properties. The design could potentially provide satellite operators with reliable measurements that would help prevent satellites from colliding and keep them operational for longer.

"Every day that a satellite stays in orbit amounts to probably millions of dollars of revenue," said Nick Dagalakis, a NIST mechanical engineer and co-author of the study. "The operators want to utilize every drop of fuel, but not so much that they empty the tank."

Letting a satellite's tank run dry could leave it stranded in its original orbit with no fuel to avoid smashing into other satellites and producing dangerous debris clouds.

To reduce the probability of collision, operators save the last few drops of fuel to eject satellites into a graveyard orbit, hundreds of kilometers away from functioning spacecraft. They may be wasting fuel in the process, however.

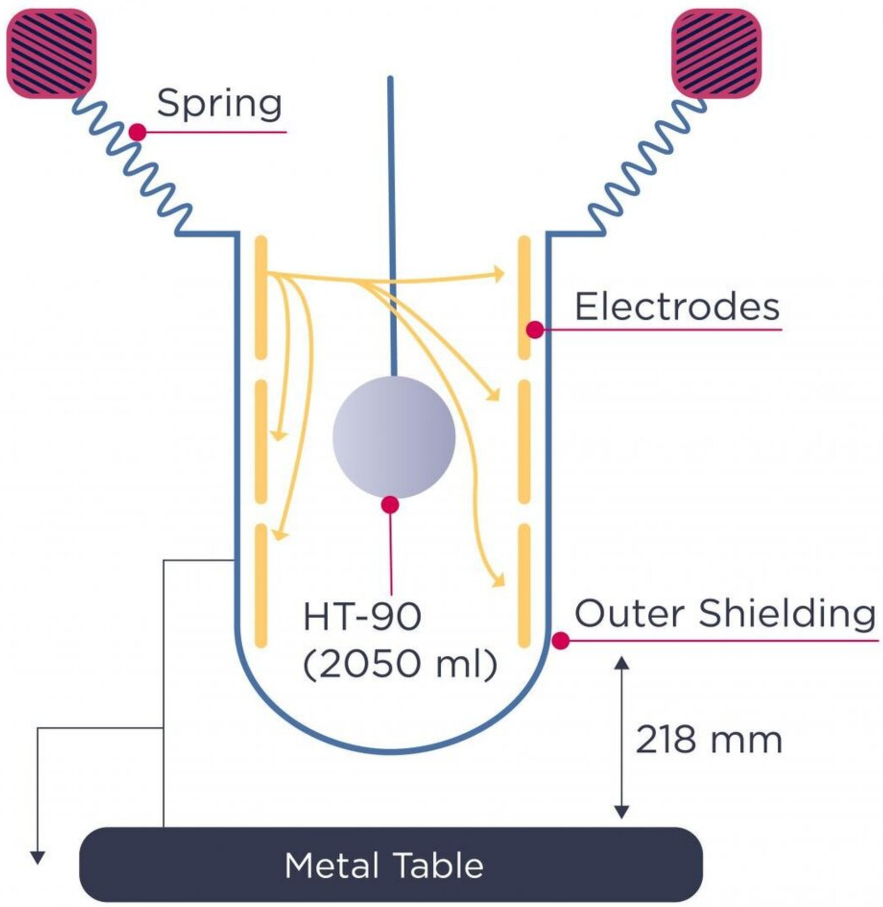
For decades, gauging fuel in space has not been an exact science. One of the most frequently relied upon methods entails estimating how much fuel is being burned with each thrust and subtracting that amount from the volume of fuel in the tank. This method is quite accurate at the start when a tank is close to full, but the error of each estimate carries on to the next, compounding with every thrust. By the time a tank is low, the estimates become more like rough guesses and can miss the mark by as much as 10%.

Without reliable measurements, operators may be sending satellites with fuel still in the tank into an early retirement, potentially leaving a considerable amount of money on the table.

The concept of the new gauge—originally devised by Manohar Deshpande, a technology transfer manager at NASA Goddard Space Flight Center—makes use of a low-cost 3-D imaging technique known as electrical capacitance volume tomography (ECVT).

Like a CT scanner, ECVT can approximate an object's shape by taking measurements at different angles. But instead of shooting X-rays, electrodes emit electric fields and measure the object's ability to store electric charge, or capacitance.

Deshpande sought the expertise of Dagalakis and his colleagues at NIST—who had previous experience fabricating capacitance-based sensors—to help make his designs a reality.



The interior of the prototype fuel tank is lined with flexible electrodes, each capable of emitting electric fields (yellow arrows) which weaken as they pass through the heat transfer fluid (HT-90) filled balloon. The electrodes pick up on the fields generated by the others, weakened or at full strength. By combining the measurements of every electrode pair, the gauge can estimate the location and volume of the balloon. Credit: NIST/N. Hanacek

In the NanoFab clean room at NIST's Center for Nanoscale Science and Technology, the researchers produced sensor electrodes using a process called soft lithography, in which they printed patterns of ink over copper sheets with a flexible plastic backing. Then, a corrosive chemical carved out the exposed copper, leaving behind the desired strips of metal, Dagalakis said.

The team lined the interior of an egg-shaped container modeled after one of NASA's fuel tanks with the flexible sensors. Throughout the inside of the tank, electric fields emitted by each sensor can be received by the others. But how much of these fields end up being transmitted depends on the capacitance of whatever material is inside the tank.

"If you have no fuel, you have the highest transmission, and if you have fuel, you're going to have a lower reading, because the fuel absorbs the electromagnetic wave," Dagalakis said. "We measure the difference in transmission for every possible sensor pair, and by combining all these measurements, you can know where there is and isn't fuel and create a 3-D image."

To test out what the new system's fuel gauging capabilities might look like in space, the researchers suspended a fluid-filled balloon in the tank, mimicking a liquid blob in microgravity.

Many liquids commonly used to propel satellites and spacecraft, such as liquid hydrogen and hydrazine, are highly flammable in Earth's oxygen-rich atmosphere, so the researchers opted to test something more stable, Dagalakis said.

At Deshpande's recommendation, they filled the balloons with a heat transfer fluid—normally used for storing or dissipating thermal energy in industrial processes—because it closely mimicked the electrical properties of space fuel.

The researchers activated the system and fed the capacitance data to a computer, which produced a series of 2-D images mapping the location of fluid throughout the length of the tank. When compiled, the images gave rise to a 3-D rendition of the balloon with a diameter that was less than 6% different than the actual balloon's diameter.

"This is just an experimental prototype, but that is a good starting point," Dagalakis said.

If further developed, the ECVT system could help engineers and researchers overcome several other challenges presented by liquid's behavior in space.

"The technology could be used to continuously monitor fluid flow in the many pipes aboard the International Space Station and to study how the small forces of sloshing fluids can alter the trajectory of spacecraft and satellites," Deshpande said.

More information: Seung Ho Yang et al, Flexible Assemblies of Electrocapacitive Volume Tomographic Sensors for Gauging Fuel of Spacecraft, *Journal of Spacecraft and Rockets* (2020). DOI: 10.2514/1.A34747

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