

Improved Calibration Shows Images' True Colors

NASA Technology

In satellite images, the waters of the Pearl River, which winds around NASA's Stennis Space Center, are about the same brownish green typical of waterways the world over. It's easy to tell, for example, that the water in the center's small, round reservoir is much darker. Odds are, though, that these images do not capture the precise, true color of either body of water, or anything else they depict.

Radiometric calibration, which improves the color accuracy of an image and enables it to be used to solve remote sensing problems, has always been a costly endeavor. A cooperative effort between Stennis and Innovative Imaging and Research Corporation (I2R), a small business located on the center's campus in southern Mississippi, is changing that.

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Research (SBIR) and Small Business Technology Transfer (STTR) programs at Stennis.

This is because I2R has built a better—and more efficient, and cheaper—integrating sphere.


An integrating sphere is a hollow globe whose internal surface is coated with a highly reflective white coating that diffuses light equally in all directions. The result is a

uniform glow with no discernable features, which, Stanley says, “gives you a disorienting feeling looking into it.”

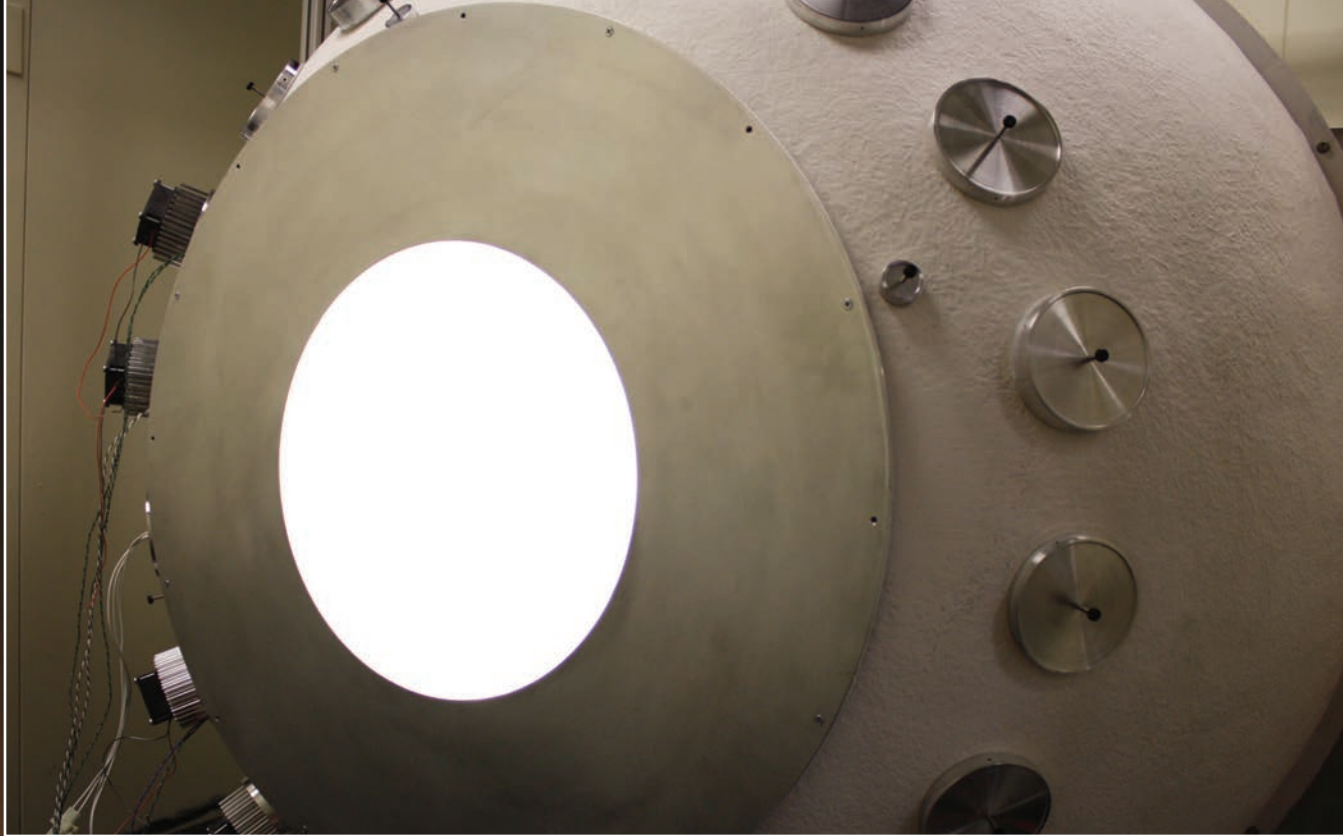
It's this blank uniformity that allows the operator to know that when a camera looks into the sphere, precisely the same wavelengths of light are hitting every pixel in the camera's focal plane with equal intensity. Then, the sensitivity of each of the individual photodetectors in the camera is adjusted until the resulting image reproduces the constant field of light in the integrating sphere.

Integrating spheres have normally been lit using tungsten halogen lamps, often paired with plasma arc lamps to simulate solar illumination, which is important for accurate radiometric calibration. The problem is that lighting a large sphere with this approach requires an inordinate amount of energy and large, expensive power supplies.

The construction of the spheres has also been costly, Stanley says. “The big spheres are tens of thousands of



One of NASA's applications for radiometrically calibrated cameras is “plume diagnostics”—using imaging to monitor propulsion tests, such as this test firing of Aerojet's AJ26 engine No. 8 at Stennis Space Center.



Large integrating spheres, used to calibrate entire arrays of cameras at once, have historically been almost prohibitively expensive to build and power. Innovative Imaging and Research Corporation (I2R) was able to affordably create and illuminate this massive, one-and-a-half-meter sphere by using LEDs instead of tungsten halogen and plasma arc lamps, making it from fiberglass instead of spun-cast aluminum, and making their own reflective paint.

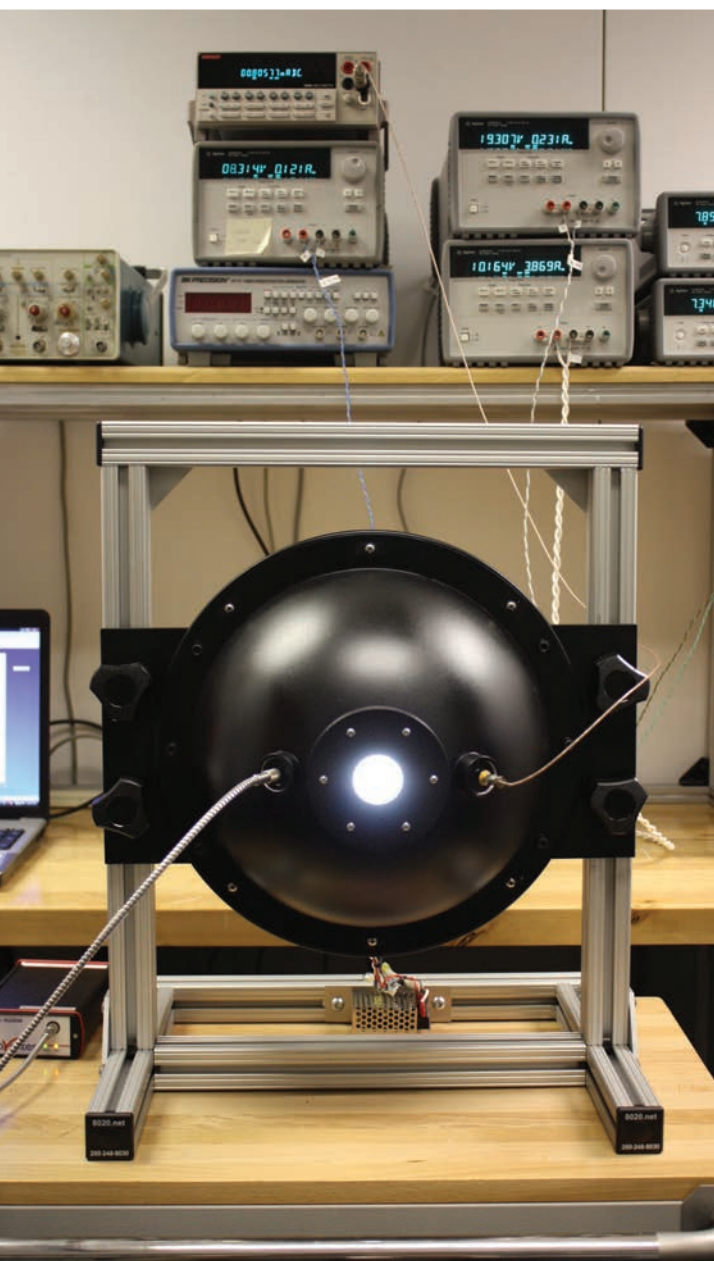
dollars, and a sphere that's a meter or more in diameter can cost more than \$100,000."

However, having a large integrating sphere can pay off when calibrating complex camera arrangements, such as those used for aerial mapping. These can have multiple camera modules, each providing different colors or increasing the coverage area. To calibrate them all at once, the sphere might need a port 400 millimeters (about 16 inches) across or larger for the camera assembly to look through. But the bigger the port, the larger the sphere has to be, or the light inside will lose its uniformity.

One option is to take the camera arrangement apart, calibrate one camera module at a time, and then reassemble it. However, Stanley says, this is time-consuming and requires a follow-up geometric calibration to make sure the reassembled lenses all line up correctly. "You save yourself a whole bunch of money on the back end by not having to disassemble and reassemble and recalibrate," he says.

Another complication with traditional integrating spheres is that tungsten halogen and plasma arc lamps degrade relatively quickly over time, which becomes a





I2R built this small integrating sphere, used to calibrate cameras, for sale to a commercial company. Using LEDs, the company was able to accurately and affordably reproduce the wavelengths of solar light for proper calibration.

bigger problem when the bulb can't be replaced because it's orbiting Earth on a satellite. And plasma arc lamps produce occasional spikes in their spectral output, which become more pronounced with time.

Technology Transfer

Mary Pagnutti, president and owner of I2R, was a support contractor at NASA when Stennis experimented with light-emitting diodes (LEDs) to illuminate an integrating sphere in 2007. Because they lose far less energy through heat than most other lighting sources, LEDs are much more energy-efficient. They are also more stable and longer-lived than the competition, with a lifespan of about 100,000 hours—more than 10 times that of traditional lamps—when operated at normal currents. However, the project lay dormant until Pagnutti and her business partner, Robert Ryan, approached the center in 2012 with a proposal to build a low-cost integrating sphere.

The use of LEDs also had another advantage, besides lower cost.

"We investigated using high-power LEDs and put them in such an arrangement that we could simulate the solar spectrum," Pagnutti says.

"They can essentially create whatever color they want within the sphere," Stanley confirms.

Being able to simulate sunlight is important for accurate radiometric calibration. The light from a "white" LED, for example, actually has a high output in the blue spectral region and low outputs of green and yellow wavelengths. A camera calibrated with these white-light LEDs would not properly reproduce the colors found outdoors under natural sunlight.

Recognizing NASA's interest in affordable, high-fidelity calibration for everything from satellite imaging of Earth to astronomical observations and even "plume diagnostics"—using imaging to monitor propulsion tests—Stennis entered into a dual-use agreement with I2R, under which each party paid half the cost to develop the product.

Because color LEDs emit light in specific wavelengths within a narrow bandwidth, Pagnutti and Ryan were able to combine diodes of different colors and, by adjusting

the current input for each one, imitate sunlight or just about any other type of light. They developed a computer algorithm that automatically determines the current powering the different-colored LEDs based on their individual "spectral shapes" and that of the sunlight they should imitate as a whole. The program compares the actual output with the desired output and keeps readjusting until it gets it right.

Before summer of 2014, Pagnutti and Ryan had a functional integrating sphere a meter and a half in diameter, which operated on about one-fourth the energy that would be required to run a standard tungsten halogen-lit sphere of that size.

Pagnutti says this wouldn't have been possible just a few years ago. "People just couldn't do it before LEDs became bright enough and powerful enough."

By this time, I2R also had already sold a smaller solar-simulated calibration sphere to a Silicon Valley satellite start-up company for use in its constellation of small satellites and was in negotiation with a large aerial camera manufacturer to calibrate its cameras at the I2R facility.


I2R cut expenses in other ways, too. Rather than build their sphere of the usual spun-cast aluminum, they contracted a globe manufacturer to make it out of fiberglass. And instead of buying the specialized reflective paint off the shelf, which Pagnutti says is "wildly expensive," they made their own paint, seeding it with particulate matter to make it diffusely reflective. LEDs also cost considerably less than plasma arc lamps. In the end, she says, "I believe we can probably build it for around 25 percent of what they go for today—certainly less than half."

This savings in building the sphere was more a question of will than technological advance, she says. "Some of this has to do with a mentality, thinking this is the way people have always done it, so that's the way they continue to do it."

Benefits

It's the savings in cost and energy that Stanley says is the most significant benefit of this new model for radiometric calibration.

"I think it's going to start putting a whole lot more fidelity in some of these commercial camera systems being



developed from off-the-shelf products,” he says. “It’s an industry-enabling technology.”

Now, he says, even many companies in the business of aerial imaging don’t calibrate properly. “Many don’t understand it, and it’s expensive, so they don’t do it.”

But proper radiometric calibration turns a camera into a scientific tool, Pagnutti says, explaining that in a calibrated camera, the digital number (DN) in each pixel can be assigned a reliable radiance value for each image. It becomes a measuring device. “You want more than a pretty picture. You want to know that DN value depicts a certain amount of radiance.”

When using digital satellite imagery to assess crop health or water resource management, for example, Stanley says, proper radiometry is essential. The same is true when using handheld units to determine the health of plants or human tissue. With the cost of calibration technology reduced, he says he foresees a day when cell phone cameras can become scientific instruments.

Indeed, NASA and I2R are already using the company’s integrating spheres to calibrate cell phone-grade imaging technology for use in monitoring indoor lighting under an STTR contract. This technology might be used on the International Space Station (ISS) one day. As the ISS has changed its lighting to LEDs, astronauts have found they have a harder time sleeping. Under the STTR, I2R will work to moderate lighting to either be conducive to sleep, or to induce focus or creative thinking—task-specific lighting, Stanley calls it—possibly to develop a lighting system for the space station.

He notes that three groups at Johnson Space Center were already keeping track of this LED lighting project before Pagnutti had even written her final report on the integrating sphere.

“One contract award doesn’t generally lead to a successful product,” he says, noting that I2R’s work seems to be an exception. ❖

Proper radiometric calibration is essential for satellite cameras used to monitor crop health, among other applications.

