Electro-optical sensor payloads for small UAVs - Excellent Overview

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Sensor designers are pushing into uncharted technological territory as they consider extreme design tradeoffs to improve sensor performance while reducing size, weight, and power consumption.

By John Keller

Military unmanned vehicles of today and tomorrow rely heavily on electro-optical sensor payloads to perform their missions. These are the sensors that detect light in many different spectra, and enable unmanned vehicles to see. Electro-optical payloads are the sensors that enable unmanned vehicles to see and avoid obstacles, detect movement, navigate accurately, find the enemy, and warn of the potential for buried improvised explosive devices (IEDs).

Yet designers of electro-optical sensor payloads for unmanned vehicles are under intense pressure to evolve their technologies to keep pace with fast-moving trends in the unmanned vehicles industry. Perhaps in no other market are needs for ever-smaller, lighter, and less expensive payloads as urgent as they are in the unmanned vehicles business. Small size, weight, and power consumption-known by its ubiquitous acronym SWaP-is a paramount concern.

Unmanned systems, especially the airborne variety, are proliferating at an explosive rate, and demand is extending beyond the military to more cost-sensitive industries such as law enforcement, agriculture, commercial remote sensing, traffic monitoring, and sporting events. Put simply, a growing number of people need unmanned vehicles that are small, inexpensive, and reliable, and they need electro-optical sensor payloads to match.

Not only is there demand for ever-smaller, lighter, and less expensive electro-optical payloads, but demand for capability also is increasing. As electro-optical and electronic component technology becomes smaller, lighter, and more affordable, payload designers sometimes have the option of choosing between smaller size and weight, or more capability. Sometimes they strive to do both, and this presents some interesting possibilities in design tradeoffs.


ALIRT imagery of the Grand Canyon obtained during a single flight using ladar sensing from Princeton Lightwave. Colors represent heights over a 1000-meter range. The inset displays a visible-camera image of a similar view of the canyon.

Unmanned aircraft

Unmanned aerial vehicles (UAVs) are at the forefront of unmanned vehicle research, development, and procurement. Although no less important than unmanned ground vehicles (UGVs) and unmanned marine vehicles, it is the UAV that is setting the agenda for unmanned electro-optical sensor payloads.

At the top of that UAV agenda is a broad trend toward large and growing numbers of relatively small UAVs that can provide local-area and short-duration surveillance-the kinds of UAVs that can provide squad leaders a view over the next hill.

Size and weight are crucial, because in these small UAVs one gram of payload weight translates into 10 minutes worth of fuel to operate, points out Chris Johnston, vice president of business development at HoodTech Corp. Vision Inc. in Hood River, Ore. HoodTech Vision provides sensor payloads for the ScanEagle catapult-launched UAV from Insitu Inc. in Bingen, Wash.

It is precisely this demand to reduce size and weight in unmanned vehicle payloads that is driving technology innovation like never before. It's a radical departure from the relatively early days of UAVs when the unmanned aircraft themselves were large, and U.S. Department of Defense (DOD) budgets were such that affordability took a back seat to state-of-the-art capability.

New paradigm

"In the not-too-distant past there was a big push on developing sensor technology, and size and weight didn't matter because DOD had large aircraft like Global Hawk and Predator, as well as manned aircraft," says David Bannon, CEO of unmanned electro-optical sensor specialist Headwall Photonics Inc. in Fitchburg, Mass.

Headwall specializes in hyperspectral imaging sensors that are small and rugged enough to fit on relatively small UAVs. Hyperspectral imaging is a sophisticated discipline that samples a wide variety of bandwidths in the light spectrum to provide a rich data set and detect objects of interest not visible to single-bandwidth imaging sensors.

"Our customer base has a dramatic push to add hyperspectral imaging as a standard element in an electro-optical and infrared (EO/IR) sensor suite," Bannon says. Given the shrinking size of today's and tomorrow's UAVs, that presents a difficult engineering challenge.

"We really need to maintain a level of performance that the industry and spectral imaging community has become accustomed to," Bannon says. "We needed to slim down the size of the offering so it can fit as an element of that sensor suite."

Headwall engineers started with a very small gimbal, and added high-definition visible-light video along with hyperspectral sensor payload. "We have to develop much smaller new products that weigh less, and it has caused us to look at a lot of new material sets that haven't been used before, and use those materials to design a sensor that is strong and lightweight," Bannon says.

The imperative for small size and light weight has forced Headwall to a common material set able to withstand harsh environmental conditions such as the stress placed on UAV takeoffs and landings. "The tarmac in the Middle East can be 120 degrees, and the payload must go to thousands of feet a few minutes later where it is much colder," Bannon says.

As electro-optical payloads for unmanned vehicles must continue to shrink in size, the engineering challenges become heavier and force engineers to make some custom designs where years ago they would have considered only off-the-shelf solutions.
In the days before such a proliferation of small UAVs, for example, Bannon says Headwall engineers could buy commercial camera cores off the shelf for their electro-optical payloads and spend most of their efforts on the hyperspectral payload. Today they no longer have that luxury.

"We have been working on the electro-mechanical aspect of the sensor, and we look at novel electronics," Bannon says. "It's not that we can go out and buy a camera core anymore. To make these sensors as small and efficient and affordable as possible we custom-designed the electronic components. Years ago we never had to do that."

Many thermal cameras and shortwave infrared (SWIR) cameras available off the shelf are not made to withstand the physical rigors of small UAV. Bannon says. As a result, "we've been forced to evaluate the size of electro-mechanical elements of these sensors, and invest in new detector technology for our electro-mechanical components."

Custom design like this does not come cheaply, but electro-optical payload designers are seeking cost savings elsewhere.

This hyperspectral image of European croplands was taken from a UAV and a Micro-Hyperspec sensor from Headwall Photonics.

Cooled vs. uncooled IR

Conventional wisdom holds that using high-quality cooled infrared sensors means compromising SWaP; cooled infrared sensors always are larger, heavier, more power-hungry, and more expensive than their uncooled counterparts—nearly always, that is.

Electro-optical payload designers at HoodTech Vision are making design tradeoffs beyond the sensor's components to include the glass optics necessary for different applications. They are finding, moreover, that conventional wisdom on cooled vs. uncooled IR doesn't always apply.

In years of experience designing electro-optical payloads for the Insitu ScanEagle since 2004, company engineers found that substituting cooled IR sensors for heavy optics can make the payload a winner in the SWaP competition.

The key circumstances that revealed this unconventional design tradeoff did not involve sensor technology so much as it involved a perceived need in the U.S. Army to fly UAVs at higher altitudes than manned helicopters to keep pilots safe from collisions, says HoodTech Vision's Johnston.

HoodTech Vision shipped thousands of electro-optical payloads for ScanEagle and other small UAVs between 2004 and 2008. They involved uncooled infrared sensors, weighed between 800 and 1,000 grams, and fit in a gimbal about seven inches around, Johnston says.

"In 2008, somehow, the military got more disciplined and rigorous, and said we shouldn't be flying UAVs at the same altitude as helicopters, so UAVs like us had to fly at 3,000 feet or more above ground level," Johnston says. Although those altitudes lend stealth to a UAV, "the optical issue becomes much more difficult to assess human activity from those altitudes."

The problem is the amount of glass necessary to achieve the magnification and field of view that sensors flying at 3,000 feet need. "To get a narrow field of view from 3,000 feet would require us to fly an uncooled optic that would crash the airplane," Johnston says.

As a result, payload weight budgets had to change. For the sake of performance, the weight of electro-optical payloads increased on the ScanEagle from about 1,200 grams to about 3,500 grams. It required some redesign of the aircraft and its center of gravity, but the changes were worth the performance increase.

ALIRT http://www.militaryaerospace.com/content/dam/mae/print-articles/volume-24/issue-10/1310MAE_TF_ladardebrisPrinc.jpg

In Haiti, ALIRT's direct and precise measurement of height and slope helped inform which type of vehicles may navigate obstructions after a serious hurricane.

At the same time, Johnston and his engineers realized that a weight budget of 3,500 grams meant they could try cooled infrared sensors. "To get the magnification you need, there is a crossing point where cooled becomes much more effective than uncooled in terms of mass," Johnston says.

The tradeoff has its downsides, however. HoodTech Vision designers use midwave infrared sensors, which compared with longwave infrared do not have comparable range of sensitivity to relatively cool objects. Longwave infrared cameras, for the time being at least, still are too large for small UAVs. Shortwave infrared sensors, on the other hand, offer inadequate sensitivity and resolution during nighttime operations, Johnston says.

Midwave IR, however, has big advantages in the small-UAV arena. "The midwave allows us to work with high F numbers, and with short integration times for excellent sensitivity," Johnston explains. The shorter the integration time, the less the influence that vibration from the aircraft has on the imagery.

An obvious approach to attacking the size-and-weight problem is to combine several different electro-optical sensors into one integrated payload. Many of today's electro-optical payloads combine daylight video camera, laser rangefinder, and one or more kinds of infrared or multispectral imaging sensors.

HoodTech, for example, has been able to combine midwave IR sensor, daylight video camera, and laser rangefinder into one payload that weighs about 1,200 grams. A separate multi-sensor payload from HoodTech involves a superpowered daylight video camera with camera and telescope spotter for extreme magnification and narrow field of view.

Stabilization technology

One of the most crucial, yet unsung requirements for electro-optical payloads in small UAVs is the ability to keep the sensor stable enough while in flight to provide useful video and images. The smaller the UAV, the more influence that even the smallest gust of wind can have on the sensor's ability to focus on areas of interest.

Historically, stabilization technology has been one of those things like cooling: heavy, expensive, and power-hungry. Yet despite its perceived drawbacks for use on small UAVs, sensor payload designers are zeroing in on stabilization technology not only to improve performance, but also to attack size and weight. The HoodTech superpowered video camera would be useless were it not for innovative stabilization while in flight, Johnston points out.

http://www.militaryaerospace.com/content/dam/mae/print-articles/volume-24/issue-10/1310MAE_TF_Iowa_image_compo.jpg
These three-band images in wavelengths from 740 to 720 nanometers come from the Headwall Photonics VNIR sensor running at a 60-Hz sampling rate at 8,000 above ground level flying at 120 knots. (Photo courtesy of the University of Iowa.)

The company has devised a four-axis stabilization system for its 3,500-gram payloads that involves gyros and drive motors against the gyro offsets, Johnston says. While many sensor payload designers for small UAVs use two-axis stabilization, that approach would be difficult, if not impossible, with the high-magnification video camera.

"In four-axis we have an inertial inner stage, and an outer stage that acts as a pan-and-tilt unit," Johnston explains. "It keeps the inner stage properly pointed out the window." Small atmospheric disturbances are addressed by the inertial inner stage. Buffeting winds or other forces on the UAV, however, would overwhelm inertial technology alone.

"Limited amplitude we can address with the inner stage, but if the aircraft gets bumped and shifts by 45 degrees in a second, that is difficult to address. For most disturbances we can effectively keep the camera pointed very accurately at the ground, and reject both the low frequency and the high frequency of the motor vibration."

Insitu ScanEagle UAV [http://www.militaryaerospace.com/content/dam/mae/print-articles/volume-24/issue-10/1310MAE_TF_scaneagle_1.jpg]

This photo shows the relatively small size of the Insitu ScanEagle UAV.

HoodTech designers rejected two-axis stabilization for more reasons than performance, Johnston says. "Everyone else in our class plays games with two-axis stabilization, but you can't get that very precise stabilization that you can with four-axis and it takes a lot more power to do two-axis than a four-axis stabilization system. It is the magic of the four-axis stabilization that allows us to perform so well," and to keep the size and weight of the payloads down, he says.

Applications

One of the most promising applications of relatively small UAVs is the ability to record precision 3D mapping data from high altitudes. Designers at Princeton Lightwave Inc. in Cranbury, N.J., are devising avalanche photo diodes to use as photon-activated switches in high-resolution laser radar (ladar) imaging sensors.

Imaging sensors on the ScanEagle small UAV [http://www.militaryaerospace.com/content/dam/mae/print-articles/volume-24/issue-10/1310MAE_TF_ScanEagle-imager.jpg]

Imaging sensors on the ScanEagle small UAV can combine as many as three different sensors packaged by HoodTech Vision.

"Where this technology really seems to be unparalleled is in very wide area mapping from altitudes where you cover enormous areas," says Mark Itzler, CEO and chief technology officer at Princeton Lightwave. This ability is a product of how fast the detectors can run, and how sensitive they are that enables electro-optical sensor payloads to fly at high altitudes on fast-moving aircraft.

While much of this technology still is in the experimental stage, Itzler says he sees potential future applications for it in UAV mapping and targeting pods. "We have single-photon sensitivity and very high frame rates of 100 Khz," Itzler explains. "We get less information per frame, but get it back in running 1,000 times faster."

Itzler also sees this technology applicable to helicopter sensors designed to detect obstacles in low visibility, such as high-tension power lines and ground features in brownout conditions when helicopters land in dusty areas. The technology also could lend itself to real-time autonomous navigation on unmanned ground vehicles.

Once that happens, several kinds of commercial applications could open up—specifically obstacle avoidance in high-end passenger cars, and eventually for future generations of driverless cars. In addition, this technology also might be applied to unmanned underwater vehicles for navigation, obstacle avoidance, and mine detection by changing the emitter's wavelength, Itzler says.