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A Powerful Security Solution

Commercial long-Range EO/IR sensors provide monitoring for borders, harbors and high-value asset protection sites like airports and nuclear facilities

- Infrared sensor suites
- Security and surveillance
- Near, long-range and thermal IR
- Pan/tilt

One of the more interesting areas in the field of security and surveillance is long-range imaging systems. These systems are used for border security and coastal and harbor monitoring. They are also used for high-value asset protection at sites such as airports or nuclear power facilities. A series of towers with long-range cameras can be more effective in many ways than a physical fence for

Figure 1: A multisensor system with DLTV camera, midwave IR camera and laser rangefinder. (Images courtesy FLIR)

border security. For coastal monitoring, long-range imaging systems can augment radar surveillance for tracking and identification of items of interest.

Systems such as this are described by the acronym EO/IR, which stands for electro-optical/infrared. Long range EO/IR systems consist of sensor suites or multisensors operating in multiple bands of the EM spectrum: the visible and the thermal infrared. These multisensors consist of a precision pan/tilt unit (PTU) that carries a daylight TV (DLTV) camera, and a thermal infrared (IR) camera. The two sensors are equipped with long focal length lenses which enable the operator to image distant targets.

The two sensors are boresighted by the use of adjustable mounts so that their fields of view are well matched. The lenses are typically of the zoom type with large zoom ratios which enables the operator to go from a wide field (search mode) to a very narrow field for long-range targets (track mode). While zoom lenses for color visible light cameras are commonplace, thermal IR optics have traditionally been designed to have just two or three selectable fields of view. Within the last few years, commercial continuous-zoom IR optics became available. This means that the EO and the IR channels often can be slaved, so that the fields of view match over a wide range of zoom settings.

Security and surveillance around high-value assets require continuous coverage in time. For daytime operation, a color visible-light sensor is the standard. A thermal infrared sensor enables nighttime imaging, and also penetrates through haze and turbulence much better than visible-light sensors. The typical system is designed so that the operator has simultaneous views of both the DLTV and IR images on two adjacent video monitors, and the two sensors are left on at all times. The DLTV sensor almost always contains a color CCD or CMOS camera, both because security personnel are used to seeing color imagery and because the images often contain important information like the color of a particular vehicle.

Figure 2a: A midwave IR image of a man and two cars at 10km range. The red arrow points to the man.

Figure 2b: a midwave IR image of man and two cars at 10km range with 2X digital zoom. The red arrow points to the man.

It is important to note that the typical color CCD camera is less sensitive than a comparable monochrome sensor (by about a factor of 10 in some cases) because of losses in the color mosaic filters and NIR cut filter. It also should be noted that in long-range situations, the color of targets tends to get washed out, especially when imaged through turbulent atmosphere or in low-light conditions.

LONG-RANGE INFRARED CAMERAS

The IR sensors used in long-range multisensor systems typically operate in the midwave IR band, which is 3-5 microns in wavelength. This band corresponds to an atmospheric window in between water absorption bands. Midwave cameras tend to give decent performance even in very humid environments such as tropical harbors. Cooled longwave IR cameras are used less often in commercial long-range surveillance applications because the longwave IR absorption coefficient due to

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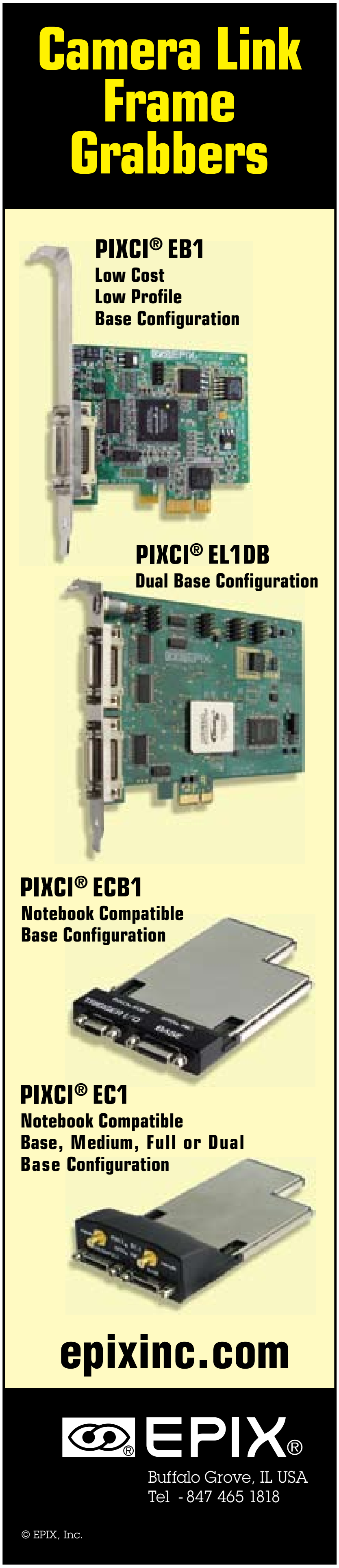

Figure 3a: A FLIR CVS radar trailer.

water vapor absorption tends to be higher, which degrades the image more strongly than in the midwave band at long ranges.

Though there are several commercial IR detector technologies that operate in the midwave IR band, the most popular is indium antimonide or InSb. This detector material must be cooled to around 77K, which is accomplished with Stirling-cycle cryocoolers, little refrigerator units with a typical operating life of around 10,000 hours. After continuous operation for 12-14 months, the cryocoolers in cameras will typically need to be recharged at the factory, a not-insignificant expense in time and money which is often mitigated by the purchase of extended warranty packages with advanced replacement.

A cooled camera is expensive relative to an uncooled microbolometer camera, both because of the detector and the cryocooler itself. But a cooled thermal camera is required for long-range thermal imaging. The reason for this has to do with the practicality of manufacturing long focal length lenses that have low f/numbers. In order to achieve the very narrow field of view required for imaging of man-sized targets at approximately 10km standoff distance, the IR camera's lens has to have a focal length between 750 and 1000mm.

To also realize the sensitivity needed to see a man-sized target with just a few degrees Celsius of temperature contrast, the f/number of the optics for a typical InSb sensor should be around f/4 or faster if possible. But even a 1000mm, f/4 infrared lens assembly needs a 250mm diameter objective, which is quite expensive to build. Uncooled cameras are designed with f/2 or faster optics just to achieve sensitivity values comparable to cooled cameras. But an f/2 lens assembly at these long focal lengths is quite impractical, because the germanium lens blank is extremely expensive and hard to fabricate.

A typical long-range system is designed to image a man-sized target at ranges out to 10km in optimal conditions. It is useful to estimate the sensor field of view required to perform this task. A man-sized target is typically modeled as being 1.8 meters tall by 0.5 meters wide. At a range of 10km, the height of a man therefore corresponds to an angle of 0.18 milliradians as seen by the camera. In order for the man-sized target to be apparent and recognizable on a viewing monitor, the man's image should be at least 1 percent of the height of the scene image. This is called "percentage of monitor" in the security industry. So a rough geometry-only calculation suggests that both the DLTV and IR cameras should have a vertical field of view angle that is no greater than 100 times 0.18 milliradians or 18mrad. This is an angle of a little over 1 degree or about twice the angular subtense of the full moon. In actual practice, the modulation transfer function (MTF) of the optical system and atmospheric turbulence will degrade the resolution of the system. The ability of the camera to see a warm target also depends on the sensitivity of the camera as well as the air path.

Cooled IR cameras for surveillance work are typically sold as an integrated package that includes a zoom or multiple FOV optic, a camera and an environmental housing. The housings are typically rated at IP66 or IP67, and the entire assembly is typically designed to be compliant with MIL-STD-810F, a military test standard that deals with shock, vibration, dust penetration and a host of other environmental conditions.

The FLIR Ranger 3 XR+ camera is an example of a fully integrated InSb camera with a long focal length lens. The HRC-U has a maximum focal length of 750mm, which, for its sensors size results in a field of view of 13mrad by 10mrad. This satisfies the notional requirement of a vertical field of view of 18mrad or less. Figure 2a shows a man of typical height imaged from 10km away in good atmospheric conditions by a Ranger 3 XR+ camera. The man is about 12 pixels tall, which is 2.5 percent of the image height in pixels. Figure 2b shows the same image with a two-times digital zoom. It is quite easy for a system operator to identify this as a man when he moves across the road.

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LONG-RANGE DLTV CAMERAS

Long-range DLTV camera systems consist of a long focal length zoom lens and a CCD camera core, typically ½-inch or 1/3-inch format. A half-inch format CCD has a sensor that is 6.4 by 4.8mm in size. For a half-inch format CCD-based system, achieving a 20mrad vertical field of view means that the lens has to have a focal length such that 4.8mm/(focal length) = 0.02. This is 240mm.

There are many optics vendors that offer zoom lenses with focal lengths that easily exceed this. The Fujinon D60x12.5R2D-ZP1 goes from 12.5mm focal length to 1500mm. The Pentax H55AME-F lens has similar specifications. The camera core is typically a color CCD camera with a 1 lux or lower sensitivity rating that outputs NTSC video. These sensitivity specs on the camera core can be misleading to the systems engineer, since the lux values are typically measured at a lens speed of f/1.4 or f/1.6 which is much faster than a commercial long-range zoom lens at maximum zoom.

A lens like the Fujinon mentioned above is f/7.1 at 750mm focal length. When it is combined with a camera core that is 1 lux at f/1.4, the system sensitivity is degraded to 26 lux. This level of sensitivity is quite adequate for daytime imaging, where illumination levels are thousands of lux. The lenses mentioned above have auto-iris control inputs from the camera core itself, which offers a way for the camera assembly to automatically adjust its sensitivity by many orders of magnitude over the course of a day. But at twilight, when ambient visible light levels fall to approximately 10 lux or below, the response of the DLTV camera core itself become important. One can buy more expensive camera cores that have responses of 0.1 lux or lower at f/1.4, which increases the operational envelope of the DLTV. When night falls, and the DLTV image finally degrades into noise, the system operator will turn his or her attention completely to the IR channel.

PAN/TILT UNITS

The pan/tilt units used for long-range multisensor systems are quite specialized. They must be able to handle payloads that can exceed 30kg in mass and withstand harsh conditions while maintaining their environmental sealing and performance for long periods of time. They typically have stepper motors, shaft encoders and sliprings inside, along with power and command interfaces for the sensors. A typical PTU rated for this application has a pointing accuracy of 1 milliradian in both the pan and tilt axes. For a system with a ~20mrad vertical field of view, a 1 milliradian pointing accuracy is acceptable. The accuracy is not usually critically important anyway, unless the system is set to scan from one preset position to the next or track a target.

What is more important is the minimum increment of motion for a long-range PTU, which should be able to allow an operator to jog the PTU into the perfect position to

Figure 3b: The interior of a FLIR CVS radar trailer showing the monitors.

watch something happen. This increment can be as low as 0.1 milliradians and is set by the shaft encoder resolution or the stepper motor step size and gear ratio. A 0.1 mrad increment allows for minute adjustments in the FOV position when imaging a long-range target. For example, at 10km range, the field of view could be moved by as small as 1 meter increments in the pan and tilt axes. This is a very fine adjustment for a camera like the Ranger 3 XR+ with its 13 by 10 mrad field of view, since the horizontal field of view is 128 meters at 10km range.

RADAR SLEW-TO-CUE

One of the difficulties that users of long-range security systems encounter is where to point the camera at any given time. When the system is set so that the DLTV and IR sensors have fields of view that are a degree or less, then the images appear as though looking through a soda straw. It is very fatiguing to the operators to scan a narrow-FOV imaging system in search mode. At wider FOV settings, the search process is easier on the operator, but the detection range is then limited by the size of the target. For example, if a small boat is so far away that it subtends just a few pixels on the monitor, it is very easy to miss.

An excellent solution to this problem is the use of commercial radar systems to provide target cues for the multisensor. For example, the FLIR CVS Integration Team has integrated marine radar systems with multisensors in such a way that small boats can be detected and tracked automatically. The radar system generates a target bearing which is turned into a pan and tilt position for the PTU. The bearing information is constantly updated so that the PTU automatically tracks the target by adjusting its pan position. Multiple targets can be monitored in this way, since the control software can be set to track a target for some interval of time, and then move to the next tracked target in a set. Guard zones can also be set up in the radar interface so that when a target crosses into a restricted area, it will become recognized

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and added to a list of tracked targets.

The Integration Team has constructed a radar surveillance trailer that can be towed to a coastal position. A Furuno X-band radar array is mounted on a telescoping mast, as is a FLIR multisensor system. Multiple video monitors inside and PCs are used to display DLTV, IR and radar video to the operator. The marine navigation software package MAXSEA is used to overlay radar returns onto NOAA nautical charts to make it easy to reference the position of targets relative to landmarks. The trailer is intended for demonstrations when powered by a generator, but can also be used for actual harbor or port security. Figure 3a shows a view of the trailer with the radar and multisensor systems deployed and Figure 3b shows the interior of the trailer.

ADDITIONAL MULTISENSOR DEVICES

Multisensor systems also can be equipped with various accessories, including laser rangefinders, digital magnetic compasses, GPS receivers and laser illuminators. The compass and GPS options are reserved for mobile applications, where the system needs to be georeferenced whenever it is moved to a new location.

Laser rangefinders used in this application typically are designed to range out to 20km with an accuracy of plus/minus 5 meters. The beam divergence is typically about 1 milliradian, although narrower divergence angles are commercially available. The laser beams are in the 1500-1600nm range which makes them “eye-safe,” with a nominal ocular hazard distance of zero meters, meaning that in principal, one could stare right into the aperture while the laser is firing and not suffer eye damage. The LRF is boresighted to the other cameras. Aiming crosshairs in the centers of the two images are required to accurately point the LRF at the target.

Laser illuminators or designators are usually near-infrared lasers with a tightly collimated beam. They are used to point at a particular target and light it up partially or fully so that security personnel with night vision goggles can see what the multisensor is looking at. This is very useful in cases where field personnel are being directed to a particular geographic location by the multisensor operators. The laser illuminators generally are safe only beyond a certain distance range and various safety mechanisms must be in place to ensure the safety of people down range. This includes limiting the power of the beam, and limiting the motion of the PTU so that no one on the ground can be illuminated until they are at a safe range. The lasers operate in the 800-900nm range, which makes them visible to standard night vision goggles but not to the naked eye. This poses an additional concern, since the eye does not blink in response to this light.

CONCLUSION

Long-range EO/IR sensor systems offer a powerful solution for security situations that require the monitoring of a large open area, such as a harbor, an airport or a desert border zone. Even though the cost of a single system is relatively high, it can replace a number of smaller short-range EO/IR sensors, or in some cases, physical fences that are many kilometers in length. When one adds in the cost of the infrastructure needed to support a number of short-range sensors, the case becomes even stronger in many scenarios. Radar systems can add a great deal of utility when combined with these EO/IR systems systems by acquiring targets across a very wide field of view even in bad weather conditions. Radar is low resolution—the targets appear as blobs, but all the radar needs to do is give a bearing to the PTU. Once targets are being tracked, they can be examined in detail using the EO/IR system, subject to range, size of target and atmospheric conditions. ***AI***

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