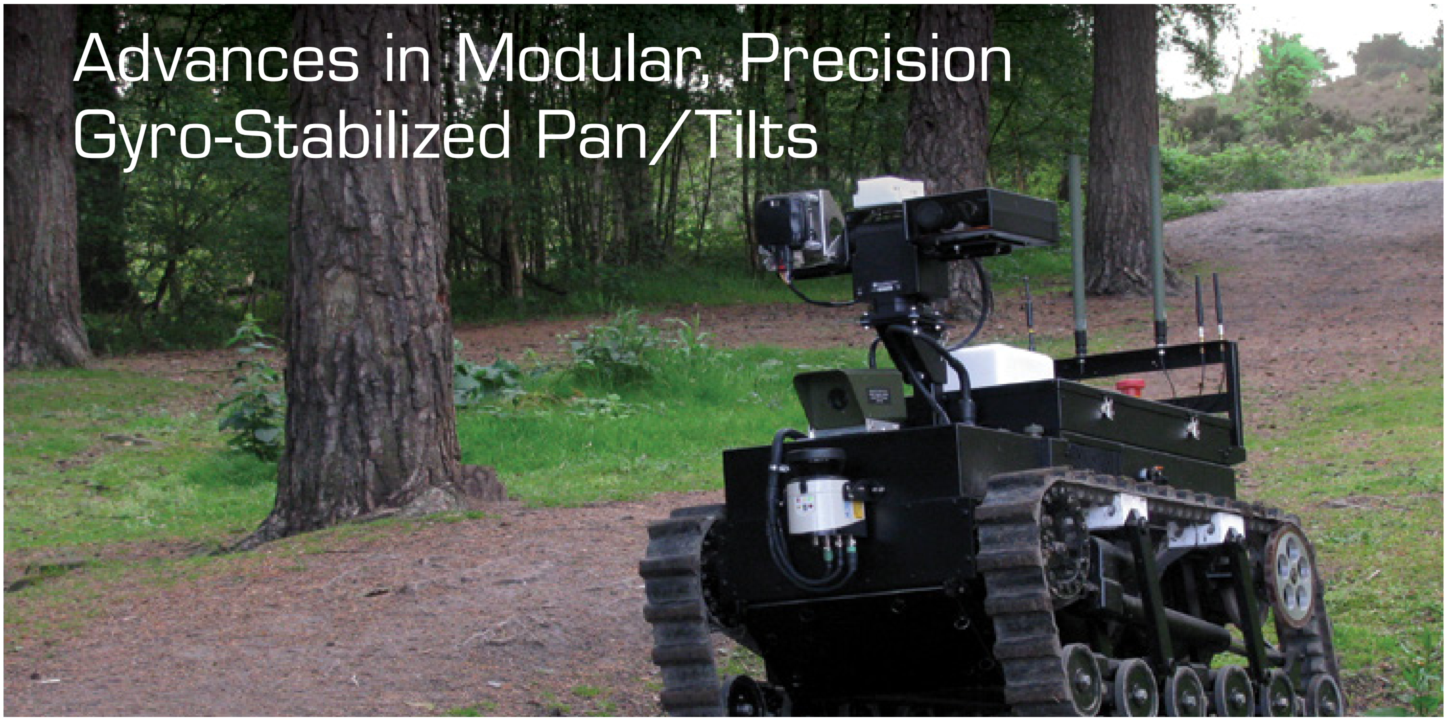
Application Note



Advances in Modular, Precision Gyro-Stabilized Pan/Tilts

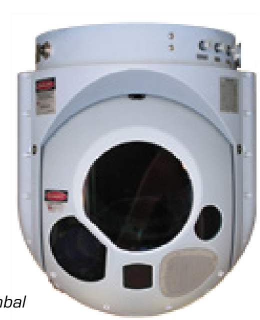
Electro-optic systems and sensor designers today are often asked to take their system “on the road” (or on the sea or in the air) as customers increasingly look for on-the-move operation. Adapting a camera or other sensing system from “fixed” mounted use to mobile use is a daunting task that requires addressing a number of considerations, including vibration tolerance, power supply issues, and stabilization.

On-the-move operation requires any directional sensor, such as a camera, to remain pointed in the desired direction while the vehicle is moving. This stabilization function has typically been provided by “gimbals,” which integrate a sensor suite into a highly engineered system that provides stabilized pointing, usually along with other functions like video tracking, targeting, etc.

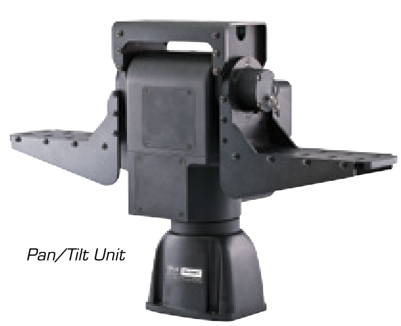
Another Option

Designers now have another option. Advances in lower-cost MEMs-based gyros, microprocessors, and high-performance pan/tilts have resulted in stabilized pan/tilt robotic platforms that provide a modular, low-cost, stabilized pointing capability for a wide range of on-the-move sensing applications.

Stabilized camera control from moving platforms such as aircraft, boats, and ground vehicles, has in the past typically been provided by “gimbals.” Gimbals are highly integrated camera systems that provide stabilized pointing and control as well as advanced features such as video tracking, targeting, radar slew-to-cue and more. Gimbals offer unparalleled performance and highly integrated feature sets. However, this performance comes at a cost both in terms of money, as well as in terms of flexibility. Pan/tilt systems provide designers with an alternative for lower cost/lower performance systems that are more adaptable to different sensor configurations and applications.



Gimbal



Pan/Tilt Unit

Types of Stabilization

There are various types of stabilization that can be brought to bear on the problem of improving imagery/sensing from a mobile platform. These can be broken down broadly into the following approaches

Optical Image Stabilization

In this approach, the optical path (from lens to image sensor) is altered to compensate for motion or vibration. This technique can be found in consumer cameras, telescope systems, and videography equipment. It is often built into the lens system.

One of the advantages of optical image stabilization is that it does not degrade the image in either space or time. It also operates independently of the image sensor resolution (within the limits of the optics).

A disadvantage of the optical approach is that it can compensate for a limited range of motion. Therefore it is well-suited to remove “shake” or vibration, but not well-suited to compensate for the larger motion of a boat or aircraft.

Optical techniques are applicable only to systems with appropriate optics, such as traditional cameras. Other types of sensors, or antennas, cannot use this approach for stabilization.

Digital Image Stabilization

Digital image stabilization techniques involve processing each frame of the video and "shifting" the pixels in X, Y, and sometimes roll, to offset the motion.

This approach has become more popular as microprocessor capabilities have improved to provide "real-time" image processing. However, at the same time, sensor resolutions are increasing, placing an ever-growing processing burden on electronic image stabilization techniques.

A disadvantage of this technique is that pixels are "lost." When the image is shifted to compensate for the motion, some pixels "fall off the edge." The resulting stable image is a subset of the original image. Some camera system makers compensate for this by using an image larger than the desired output image to feed into the image stabilization system.

Like optical approaches, digital image stabilization can only compensate for a limited range of motion. Both loss of pixels, and degradation of typical algorithms in the face of too much motion, limit the applicability of using digital image stabilization alone for mobile applications.

Mechanical Stabilization

Mechanical stabilization approaches involve physically moving the entire camera system to counteract the motion. There are two general categories of mechanical stabilization:

- Passive – using counterweights or large gyroscope to physically counteract the motion.

- Active – using sensors plus a drive system to measure the motion, and actuate the system to compensate.

Passive systems have an advantage of being fairly simple, but are limited in the response capabilities of the system by the overall inertia and gravity. Active systems have the advantage of being able to utilize actuators/drive system that can outperform gravity, and compensate for a wider range of motion disturbances, both in range of motion and in speeds and accelerations.

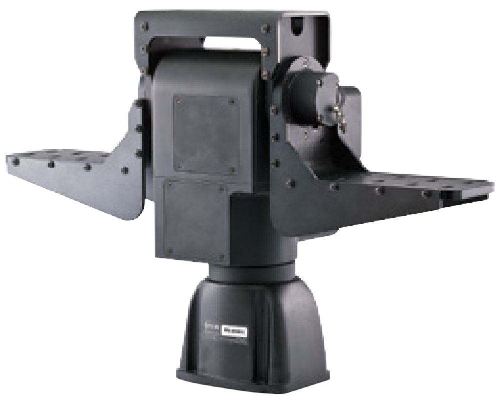
Combinations

State-of-the-art gimbal systems typically utilize active mechanical stabilization in addition to digital image stabilization. These systems are complementary in terms of the disturbance profiles they can address and can perform in a wide range of conditions and applications.

Advances in low-cost gyroscopes and embedded microprocessors have made active mechanical stabilization more attractive in terms of cost and performance. For camera systems where the objective is to provide stable images out of the system, a combination of active mechanical stabilization along with digital image stabilization can provide outstanding results.

Stabilized Pan/Tilts

Pan/tilt systems first started seeing widespread use in CCTV systems for providing automatic "tours" and for providing operators the ability to periodically reposition cameras. These CCTV pan/tilts are simple, low-cost devices designed for occasional use and simple human control



FLIR PTU-D300 Pan/Tilt Unit

Today's high-performance pan/tilts are a different beast. They are designed for high duty cycles, and reliable operations in extremely harsh environments. They offer sophisticated computer control as well as advanced features like stabilization, geo-pointing, and automated tracking.

Stabilized pan/tilts are computer controlled pan/tilt devices that include a capability to automatically, and actively stabilize a pointing angle based on a commanded inertial set point.

Theory of Operation

An actively stabilized pan/tilt system typically uses a microprocessor along with gyros to measure system position and its motion state. The microprocessor implements an automatic control algorithm that adjusts pan/tilt position, based on sensor readings, to hold the desired pointing angle.

As an example, consider a stabilized pan/tilt mounted on a ground vehicle. The operator has a joystick to control the position of the pan/tilt to aim at targets of interest. With stabilization engaged, when the operator lets go of the joystick, the pan/tilt will remain aimed in the direction of the target of interest. The gyros mounted in the pan/tilt continuously sense the movement of the vehicle and command the pan/tilt in an opposite direction to compensate for the motion. External user commands, like the joystick commands, are changes to the set point of the stabilization algorithm.

Two primary architectures for active gyro-stabilized pointing systems:

Payload Mounted

In this architecture, sometimes called "gimbaled mounting," the gyro is mounted with the payload. Readings from the gyro, along with position information, are used to estimate payload motion. The gimbal then controls the platform to counter the motion and maintain the specified inertial pointing angle.

Payload mounted systems offer some advantages in reduced computing requirement, and simpler individual gyros (for each axis). Disadvantages include a more complex mechanical design and integration of gyros with each axis.

Platform Mounted

Platform mounted, or "strapdown" systems mount the gyro on the moving platform (e.g., vehicle, aircraft, or boat) or non-moving part of the pan/tilt or gimbal. The platform motion is then mathematically transformed into the payload coordinate system, and the pan/tilt or gimbal is controlled to counteract the measured platform motion and maintain the commanded pointing angle.

Platform-mounted systems offer an advantage if being able to mount the gyros anywhere on the body – like the base of the pan/tilt, or elsewhere on the vehicle – and a simpler mechanical design. Platform-mounted systems may include additional error due to the mechanical inaccuracies of the system between the base and the payload.

When stabilization is disabled, a pan/tilt mounted on a vehicle or other moving platform will maintain the same pointing angle relative to the pan/tilt; however, the line of sight will change. When stabilization is enabled, the line of sight will be maintained as the PTU pans and tilts to compensate for pan/tilt mounting platform motion.

Measuring Stabilized Pointing Performance

In most applications, the figure of merit for a stabilized pointing system is the movement, or residual error, that is not compensated for by the system.

In camera systems the specific figure of merit is generally the amount of pixel movement remaining in the stabilized imagery. This can be specified as an angular movement expressed as a number or fraction of pixels. In stabilized systems that specify stabilization performance as an angular error, systems designers must translate this angular error to an expected pixel error using camera parameters including field-of-view and camera resolutions.

The performance of a stabilized system will depend on several factors including:

- Performance of gyroscope used to measure motion
- Pointing accuracy of pan/tilt device
- Computing power of the pan/tilt/controller device
- Speed and acceleration capabilities of pan/tilt device (which may depend on payloads)
- Input disturbances – the motion of the platform (boat, aircraft, ground vehicle)

Stabilized pan/tilts and gimbals are generally designed for a class of applications. More general-purpose solutions may need to be tuned to optimize performance for a given set of input disturbances and payloads.

Specifications of stabilized pointing performance can be approached in a couple ways. One is to specify a given angular residual error that will never be exceeded. Another is to specify a residual error that that is met some percentage of time or under some percentage of conditions. For example, a system specified as having a 1 milliradian error (RMS, 1 sigma) means that the error will be within 1 milliradian 65% of the time, as measured with the square root of the average of the squared positional errors.

Stabilization performance also can vary with input disturbance in terms of frequency and amplitude. Stabilized pan/tilt systems will sometimes specify the system performance as a function of different input frequencies. This can help system designers determine appropriateness for a given application.

Stabilized Pan/Tilts vs. Gimbals

Tightly-integrated gimbal systems provide the highest performance available for long-range stabilized camera systems. These systems integrate multi-axis active mechanical stabilization along with digital image stabilization to provide superior results over a wide range of operating conditions. To provide this level of performance, gimbals are designed around a specific set of payloads. If a gimbal is available with the desired payloads, which is often the best solution to provide stabilized pointing. High performance gimbals can provide stabilization performance on the order of a few microradians of jitter.

Stabilized pan/tilts provide another option for system designers. Pan/tilts offer a more modular approach that allows system designers to integrate various sensor/camera devices onto the platform. Pan/tilts typically offer lower performance than gimbal systems, however that performance is improving with advances in gyro and microprocessor technologies. Pan/tilts require additional integration by the system developer. Payload mounting and wiring, along with some tuning of the system, is required to develop a complete integrated solution. Typical stabilized pan/tilt systems offer stabilization errors of 1 to less than 0.1 degrees.

The other big difference between gimbals and pan/tilt solutions is cost. Gimbals (including integrated sensors) range from $50,000 to over $1 million, while stabilized pan/tilt units (without sensors) are available now for less than $10,000.

Requirements for a high-performance stabilized pan/tilt system

There are several important aspects of a high-performance pan/tilt platform that system designers should keep in mind. These include:

Open platform

To allow the most flexible integration options, the platform should be open providing multiple control interface options, flexible wiring and mounting architecture, and open command protocol.

High-duty cycle pan/tilt

Stabilization applications demand a lot of a pan/tilt in terms of continuous motion. Pan/tilts that are not designed for high duty cycle operation will not perform well over time. Designers should look for pan/tilts that are designed for high duty cycle operation in order to provide reliable stabilized performance.

Real-time control interface

Many stabilized applications require pointing to be controlled by a user (joystick) or application (e.g., video tracking, radar slew-to-cue) while being stabilized. This requires a robust real-time interface that will allow the pan/tilt to be commanded at a high rate during stabilization. Key capabilities include high command rates, low latency, and low timing-jitter.

Ease of use – fully integrated design

Pan/tilt platforms offer flexibility to integrate various payloads. However, this comes at a cost of integration complexity. Well-designed pan/tilt platforms offer features to simplify this integration including:

- Software development kits – to simplify integration of your control application
- Flexible payload mounting system
- Multiple wiring/slip-ring options to support various payload configurations
- Multiple control interfaces (serial, Ethernet, etc.)
- Support for additional capabilities including video tracking and geo-pointing.

Integrating other capabilities

Best-of-breed stabilized pan/tilt platforms offer additional options to approach full gimbal capabilities. These include:

Multi-camera integration – ability to support multiple cameras, lasers, or other sensors on a single stabilized platform.

Digital Image Stabilization – ability to integrate digital image stabilization to complement the mechanical stabilization.

Video Trackers – support for real-time control by video trackers. This allows object tracking, scene tracking, and other capabilities.

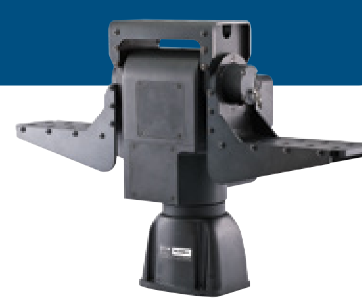
Geo-Pointing – Geo-pointing allows a pan/tilt to respond to commands to aim at a given geo-coordinate (latitude, longitude, altitude). This capability complements inertial angle stabilization, and allows pointing at a specific real-world location.

Gimbal vs. Pan/tilt

A gimbal is a pointing device that centers the payload(s) at the axes of rotation. It may provide two or three axes of rotation. Some high-performance gimbals may have five axes, providing a sort of gimbal within a gimbal, with one set of axes providing general pointing/motion capabilities, and the other focused on stabilization.

A pan/tilt turns the gimbal "inside out" placing the mechanism at the center, and the payload(s) on the top and/or sides. Variations of the pan/tilt may offset one axis from another allowing the payload to sit at the centers of rotation, and thus blurring the distinction between gimbal and pan/tilt.

Gimbals offer a big advantage in terms of pure performance since carefully centering the payload center of gravity at the centers of rotation, minimizes the torque required (and therefore weight of the system) and allows the highest speeds and accelerations to be achieved. This comes at cost of complexity and of the mechanism, as well as a more limited ability to adapt different size payloads without significant redesign. Pan/tilts are lower cost, and more flexible in terms of payload geometries, but are typically heavier and lower in performance in terms of speeds and accelerations.



Stabilized Pan/Tilts in the Real World

High-performance stabilized pan/tilt systems are being deployed today in a wide range of innovative applications across the world. This section outlines some of these applications.

Stabilized Ground Vehicle Surveillance System
(Thales Optronique)

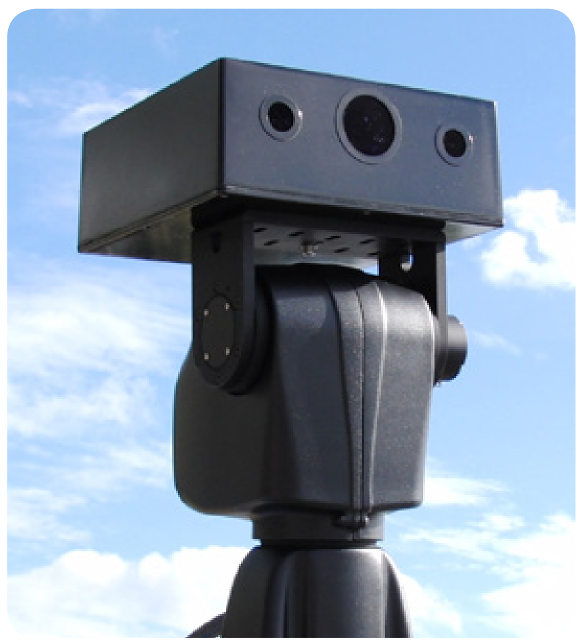
Thales Optronique has developed the MARGOT system. The MARGOT system is an integrated optronic system for border and coastal surveillance, law enforcement, and counter-terrorism. The system incorporates thermal and daylight cameras, laser range finder, as well as target geo-location capabilities, on a retractable mast system.

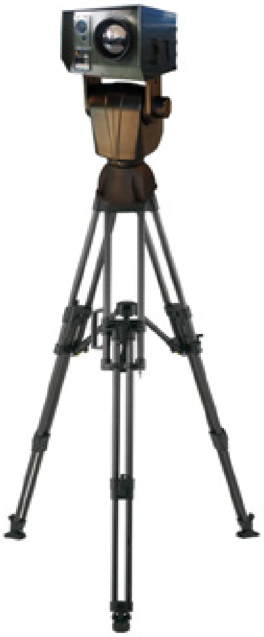
UAV Ground Control Station
(AAI/Textron)

AAI Unmanned Aircraft Systems is a leading manufacturer of unmanned aerial systems (UASs). Their Expeditionary Ground Control Station (EGCS) includes a computer-controlled tracking antenna that stays aimed at the aircraft to provide a real-time video link. The EGCS is designed for stationary and mobile applications, utilizing the FLIR MCS PTU-D300-ISM. This stabilization capability allows the system to operate reliably on the move.

Maritime Anti-Piracy System
(LaserSec)

SeaLase II is a multifunctional electro-optical system designed to detect, identify, and deter the approach of potential threats. The payload consists of a high power non-lethal laser device and a long range daylight/lowlight camera. The non-lethal laser is used to temporarily impair the vision of hostile contacts. Targeting the laser beam requires exceptional performance from the pan/tilt platform. The laser beam divergence is typically less than 0.3 degrees and, as such, the positioning is more demanding than for all but the longest range camera systems. Lasersec chose the FLIR PTU-D100E-ISM based on its outstanding specifications for accuracy and precision, simplicity of integration with tracking hardware, optional integrated gyro stabilization, and it's tolerance to nearly any environmental conditions. Extensive field testing in locations ranging from Finland during the winter to the deserts in the Middle East have confirmed the performance.

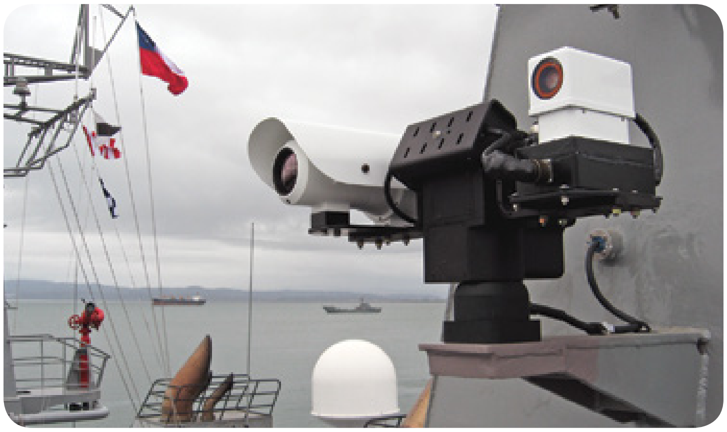




Border Surveillance
(ProOptica)

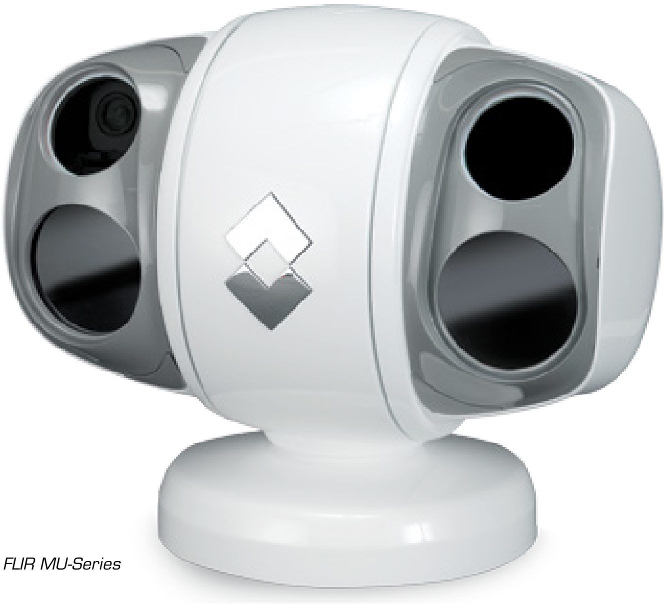
ProOptica is a leading defense and security products company in Romania. They have developed a range of systems designed for ISTAR (Intelligence, Surveillance, Target Acquisition, and Reconnaissance) applications.

Their system includes an integrated muli-sensor suite with thermal, daylight, and other sensors, that utilizes a stabilized pan/tilt for portable and mobile applications.



Shipboard Situational Awareness
(DESA)

The Chilean Navy asked leading electronics integrator DESA to develop a multi-sensor optical tracker for ship-board situational awareness. The requirement called for daylight and thermal cameras, and the ability to operate in the harsh deck environment of a navy vessel to operate a light gun in Maritime Police duties. The DESA team utilized the FLIR MCS PTU-D300-ISM to provide robust, stabilized positioning solution for the harsh maritime environment. The system is deployed on the "Iquique" fast missile boat of the Chilean Navy.



FLIR MU-Series

Maritime Thermal Night Vision Camera
(FLIR Systems)

FLIR Systems ATS division has developed high-performance thermal night vision multi-sensor camera system designed for a wide range of maritime security applications. The system utilizes a FLIR Motion Control Systems PTU-D100E-ISM stabilized pan/tilt to provide stable imagery, slew-to-cue, video target tracking and user joystick control.

Summary and Future Trends

The advances made in high-performance stabilized pan/tilt systems are poised to continue. There are several trends that are expected to expand the use of stabilized pan/tilt systems in the future including:

- Demand for more on-the-move applications
- Use of longer range cameras requiring stabilization for effective operation
- Improved MEMs gyro technology to lower cost and improve performance
- Lower cost and higher performance pan/tilt systems

System designers should learn about stabilized pan/tilt systems as a new tool in their arsenal for developing low-cost stabilized sensing systems. There are a growing list of suppliers offering compelling solutions that open up new applications, markets, and possibilities!

FLIR®