Stabilization, Steering, and Gimbal Technology as it relates to Cinematography

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ABSTRACT

Stabilization has become the new buzzword in remote heads. It has many of the head manufactures and distributors scrambling to get in on the latest craze. And why not? After all, by some accounts stabilization will fix every problem on set, right down to the taste of the coffee. While it is true that stabilization can appear to magically steady the camera in some of the shakiest environments it can't change the laws of physics.

The purpose of this paper is to help the reader understand stabilization, steering, and gimbal technology as it relates to cinematography. A classification system will be defined for stabilization systems and their components. Their attributes and weaknesses will be discussed. Issues such as isolation, steering, performance and mounting considerations will be looked at. Armed with this basic understanding you should be able to select appropriate equipment with the confidence that it will meet your needs on set.

Items that appear in *italics* are defined at the end of this paper.

INTRODUCTION

To understand stabilization as it relates to the cinematographer, a brief historical look at the development processes for aerial vs. ground based camera equipment is in order.

Aerial Cinematography

Aerial cinematography began with hard mounted and hand held cameras on fixed and rotary wing aircraft. The inherent vibration and difficulty in steadying the camera led to the development of the fixed gyro (the Kenyon gyro module) and the Tyler Mount. Combined, they offered a degree of vibration isolation and gyro stabilization. The next major improvement for the aerial cinematographer was the development of the WESCAM gyro stabilized remote camera system.

It should be noted that this aerial cinematography development cycle was primarily driven by the need to isolate the camera from the inherent vibration and angular disturbances of the aircraft.

Cinematography on the Ground

On the ground, the simple pan and tilt mechanisms atop the early tripods represent the first use of *gimbals* to constrain the motion of a camera. Fluid and geared heads were developed to refine the steering qualities of the camera. A host of other tools including dollies and cranes were developed to control the motion of the camera. Remote heads allowed further freedom in camera movement and steering.

By contrast to aerial cinematography, the ground based development cycle was focused on quality of steering and smoothness of camera motion. Stability was dealt with by the use of solid construction techniques to tie the camera to the earth.

The Clash:

With the desire to achieve more stable images from moving platforms on the ground came the need to apply gyro stabilization to the ground based cameras. When aerial stabilization systems were first applied to ground vehicles the clash in development approaches became a significant obstacle. Stabilized camera systems stabilize and steer relative to *inertial space*. Ground camera equipment steers relative to whatever it is mounted to. Aerial systems use a joystick to steer the camera. Subtly changing forces on the joystick are used to hold a subject in frame as the aircraft maneuvers. Ground based camera operators found the aerial equipment difficult to operate. The steering response was sluggish and mushy compared to a geared head. Even with wheels for steering, gyro drift would require a constant rotation rate of the wheels just to stand still. In most cases aerial camera operators were needed when aerial equipment was used on the ground. This caused undesirable disruptions in the normal workflow of ground shooting.

Stabilization goes to the ground:

Early ground based products offering stabilization dealt with this clash by allowing the operator to choose between quality steering vs. stabilization at the flip of a switch. This truly made the gap between the two worlds obvious, and new products were developed to bridge this gap.

What Stabilization is and isn't:

Stabilization systems remove unwanted angular motion from the camera and lens. They do not remove unwanted linear motion. *Passive isolation* systems can help to reduce this linear vibration but some linear motion or *parallax* as it is referred to will always remain.

Stabilization and steering are very different things. The qualities of one often come at the expense of the other. A camera floating in space free of the influence of the earth's atmosphere and gravity is perfectly stable (there are no outside forces to act upon it). However without some outside contact it is impossible to steer. If we brought this same camera back down to earth we could support it on a gimbal system balanced about its center of gravity (it may help to imagine a single axis gimbal). Now if the camera were perfectly balanced on the gimbal, the bearings had no friction, and the atmosphere were not considered the camera's inertia would cause it to stay pointing in the same direction regardless of the motion of the supporting base. There would be no force to rotate the camera. Again, perfect stability.

Down here in the real world the camera will not be "perfectly" balanced and the bearings do have friction, and the atmosphere must be considered. However, the inertia of the camera will still try to fight these disturbances. Imperfect balance will cause disturbing forces when the base is accelerated linearly (Try holding your pencil lightly between your thumb and one finger off to one side of center and then shaking it vertically). The bearing friction along with the forces from any cables that cross the gimbal will cause coupling forces (forces that tend to make the camera follow the base motion). The atmosphere will cause aerodynamic forces as the camera is moved through it (wind).

It is the task of the stabilization system to overcome these disturbing forces to stabilize the camera. It should be obvious enough that minimizing the imbalance, coupling forces and wind load will directly reduce how hard the stabilization system must work. It is less obvious, however, that even the best stabilization system is only able to remove most (a percentage) of the input motion. Regardless of how strong the actuators are, good balance will always directly reduce the image jitter in any system. Also, the effects of imbalance can be minimized by reducing the accelerations that the system is exposed to through passive vibration isolation. For any given stabilization system, good mounting choices with an eye to *passive isolation*, and good static balance are the lowest hanging fruit that you can find. Improvements here show up directly in the resulting image.

CLASSIFICATION SYSTEM:

To understand and categorize stabilization and gimbal technology it is helpful to begin with a look at the development cycle that it has gone through inside and outside of the film industry.

Gen-1: The WESCAM Stabilized Remote Camera System

This was the first commercially available gyro stabilized remote camera system. Originally developed by Westinghouse Canada (later Istec Ltd. which became Wescam Inc. and is now Pictorvision Inc.), it represented the state of the art when it was introduced in the 1960's. The basic technology has undergone many refinements over the decades by Wescam and SpaceCam. This stabilization technology relies on the angular momentum generated in three, *orthogonal*, large mechanical rate gyroscopes (gimbaled fly wheels) to augment the natural inertia of the camera platform. This artificial mass or *synthetic inertia* is used passively to maintain a stable platform that the camera is steered relative to. A servo system uses the angular rates measured by the *precession* of the gyros to cancel any disturbances. A dome enclosure keeps the wind and weather out and an internal passive vibration isolation system minimizes the vibration input to the system. The line of sight stability (<5 micro radians RMS jitter) of the original WESCAM type systems is still unsurpassed in the industry today.

Gen-2: The Classical Active Gimbal System

While this technology predates the Gen-1 gimbal technology in military use, it was not used commercially in this industry until after Gen-1. In its commercial introduction this under-performed the established Gen-1 technology on the grounds of stability. It was however, simpler, lighter, less expensive and exhibited better steering performance than the Gen-1 technology. These systems close rate loops directly about each gimbal axis. Rate sensors such as small mechanical sensing gyros are used to sense angular rates relative to inertial space. These rates are summed with the steering commands to stabilize and steer each axis.

The *actuator* can be either a direct-drive or a geared motor. The use of a geared actuator will increase coupling forces substantially and limit the *bandwidth* of the system by an order of magnitude.

The structure between each successive gimbal axis is subjected to the high frequency torques of the *actuator*. Compliance in this constraint structure will directly limit the bandwidth of the control system. For this reason Gen-2 gimbals are incapable of high bandwidth performance with the large cameras used in the motion picture industry.

Gen-3: The Active Follow-up Gimbal System

This technology takes a limited travel, high performance inner gimbal and mounts it on an outer follow-up gimbal. The inner gimbal provides the high bandwidth stabilization and fine steering performance, while the outer gimbal provides the coarse steering over a large field of regard. The inner gimbal uses high performance, direct drive actuators and the outer gimbal uses geared actuators. The high frequency torques is still applied through the inner gimbals' constraining structure. With the large cameras of the film industry the compliance of this structure limits the bandwidth of the stabilization system.

With the use of Fiber Optic Gyros (FOG's) the stabilization performance of this type of gimbal approaches that of the Gen-1. It is, however, still simpler, lighter, and less expensive than the Gen-1 with better stability and steering than the Gen-2.

Gen-4: The Unconstrained Actuator Active Follow- up Gimbal System

The Pictorvision XR avoids the bandwidth limitation of the Gen-3 gimbal system by using a patented process of torquing across the constraining structure instead of through it. The high frequency torques is applied directly from the outer gimbal to the camera base plate. Combined with a high performance FOG based Inertial Measurement Unit (IMU), this stabilization system raised the bandwidth so high that the structural compliances of the camera system became the limiting factor. To raise the stabilization bandwidth even higher the XR makes use of a "camera sled" to stiffen the camera, lens and magazine.

The Pictorvision XR (formerly Wescam) represents the current state of the art with geared head like steering and the ability to stabilize and steer the industry's longest lenses (beyond 2000mm on HD).

With the most advanced stabilization technology, Pictorvision is focused on steering quality and offers a variety of new steering modes and steering resolvers to "raise the bar" in the art of camera steering.

Sub-classifications:

Attitude:

Some gimbal systems can be mounted in any orientation. They are said to be *all-attitude*. Others may be restricted to mounting in one or two orientations such as *hanging* or *sitting* (inverted).

Isolation:

The purpose of the vibration isolator is to minimize the linear accelerations that the stabilization system must cope with. It is not intended to deal with *parallax*.

Isolation systems can be external (between the outermost gimbal axis and the mount interface) or internal (between the inner and outer gimbal). On Gen-3 and Gen-4 systems the inner gimbal and isolation are often mounted inside of a dome enclosure to reduce wind loading and provide some environmental protection.

Gimbal Number/Order:

We typically think of moving a camera in 3 linear and 3 rotational axes of motion. However, the number of degrees of freedom that a gimbal system has does not tell the whole story. Stabilization systems can be constructed with various numbers of gimbals in various orders.

A typical 3-axis gimbal (Pan/Tilt/Roll) is able to position the *line of sight* (LOS) in any direction in space with the camera at any roll angle. But, as the tilt angle approaches ±90° the system experiences *gimbal lock*. The pan and roll axes are parallel. The LOS cannot be fully stabilized or controlled as there are now only gimbal axes in tilt and roll. If the system were mounted on a moving vehicle a vertical LOS could not be maintained.

Another 3-axis gimbal configured in the order of Pan/Roll/Tilt is able to maintain a vertical LOS on a moving vehicle. This system would experience *gimbal lock* at a roll angle of ±90°. Pan and tilt would be parallel. Any conventional 3-axis gimbal system will experience gimbal lock at some point. The trick is to place the gimbal lock where you don't need to operate.

Additional gimbal axes are required in order to avoid gimbal lock. The control law for these additional axes gets complicated and is often unstable in some orientations.

The Gen-3 and Gen-4 gimbal systems have separate, limited travel, stabilized inner gimbals mounted on coarser, large travel, outer gimbals. Both the inner and outer gimbals vary in number and order of gimbals as well as actuator type. The order of gimbaling on limited travel inner gimbals is usually insignificant because of the limited travel (<±15º).

Sensor Type and Location:

There are 4 basic types of angular rate sensors available for use in LOS stabilization systems: mechanical rate gyros, Coriolis rate sensors, Fiber Optic Gyros (FOGs), and Ring Laser Gyros (RLGs). They are listed in order of current performance capability. While RLG based gyros exhibit the highest performance levels they suffer from a periodic loss of rate data availability during internal frequency changes that make them difficult to use for LOS stabilization applications (they would need a back-up rate sensor).

Within each type the performance levels vary dramatically. The main figure of merit for rate sensors is the *drift rate stability* (measured in º/hour over the operating temperature range). The difference between low and high performance rate sensors used in LOS stabilization systems can vary by several orders of magnitude. High drift rates require regular mulling with "drift pots".

These rate sensors can be single axis devices or combined with accelerometers into a 3-axis Inertial Measurement Unit (IMU). Individual sensors can be mounted directly on each gimbal axis or mounted at right angles to each other on the LOS. Integrated IMUs are mounted directly to the LOS.

Mounting the sensors directly on the LOS yields the highest bandwidth but requires the measured rates to be resolved back to each of the actuators axes. This complicates the control software.

Classification Example:

As an example the Pictorvision XR is a Gen-4, *all-attitude* gimbal system with a 3-axis direct drive (high *bandwidth*) inner gimbal. It uses external isolation and has an outer gimbal that can be configured in Pan/Tilt, Pan/Tilt/Roll, or Pan/Roll/Tilt gimbal order. It uses a high performance (low drift) IMU mounted directly on the LOS.

STEERING:

With the current state of Pictorvision's stabilization technology our emphasis has shifted from stabilization to steering. As such, we are developing a suite of new steering tools to aid the cinematographer in achieving his or her creative vision.

Frames of reference:

In order to discuss steering we must first discuss some established, standard, frames of reference. A frame of reference is the co-ordinate system used to describe the position or motion of the LOS. There are an infinite number of frames of reference but the following 5 are used commonly in LOS stabilization systems.

Line Of Sight (LOS):

The line of sight is the primary reference. This is the camera's point of view. This is also the frame of reference of the sensor if it is mounted on the LOS. The absence of a steering *resolver* will default to this frame of reference (provided that the sensors are mounted on the LOS). The roll axis is the LOS; the pan axis is perpendicular to roll and vertical with respect to (WRT) the camera. The tilt axis is perpendicular to the LOS and horizontal WRT the camera. Pan right is positive, tilt up is positive, roll right (CW) is positive.

Earth-Local Vertical:

This is the secondary POV and will be referred to as EARTH. This is the normal frame of reference that traditional Wescam (Gen-1) steering is resolved to. The Pan axis is the local vertical WRT the earth, the Tilt axis is perpendicular to Pan and is level to the horizon. The Roll axis is still the LOS, Pan right is positive, Tilt up is positive, Roll right (CW) is positive. When tilt is +/- 90° the pan and roll axes are parallel.

Mount:

The mount's frame of reference is with respect to the mounting surface of the first gimbal axis. The pan axis is the pan gimbals rotational axis; the tilt axis is perpendicular to pan. The roll axis is still the LOS, Pan right is positive, tilt up is positive, roll right (CW) is positive. When tilt is +/- 90° the pan and roll axes are parallel.

Gimbal:

This frame of reference refers to the independent axes of the gimbal system. The absence of a steering resolver will default to this frame of reference (provided that the sensors are mounted on the individual gimbal axes). In this the pan axis is the axis of the pan gimbal. Similarly, the tilt and roll axes are those of the tilt and the roll gimbals respectively.

Inertial Space:

Inertial space is independent of the earth's frame of reference. The earth rotates and orbits in inertial space. It is referenced to the star system.

Steering Resolvers:

Steering *resolvers* are tools that allow the steering controls to be *resolved* to any of the above frames of reference. The control system calculates the components of each of the steering inputs required for each new axis in the desired frame of reference. They allow the steering to be independent of gimbal order. Steering resolvers can be quite significant in dynamic environments or in steering moves that include roll steering.

The following are some examples of where each steering resolver can be useful. The Pictorvision XR supports each of them.

NONE (LOS):

This *resolver* is particularly useful for overhead shots where it allows the operator full steering control even at vertical. With the camera roughly positioned overhead the operator can still steer the camera across the frame. With the desired point in the center of the frame the LOS can now be rolled about its axis with the roll steering control.

EARTH (Local Vertical):

This is the most commonly used resolver. It steers like a Pan/Tilt/Roll gimbal mounted on a pitch and roll leveling head.

MOUNT:

This is useful when you are shooting a scene on the same vehicle that you are mounted on. A tilt steering input will follow the vertical WRT the outermost axis regardless of roll angle.

GIMBAL:

I haven't personally been able to think of a good use for this resolver. We include it because it is the one that most Gen-2 gimbals use if they don't resolve their steering commands.

Steering Modes:

Steering modes are separate and independent from resolvers. While resolvers are applied to all axes at once the steering modes can be applied to independent axes.

RATE:

The most common steering mode used in all remote heads is rate mode. In rate mode the rate of rotation of the hand wheel (or force on the joystick) is proportional to the rate of rotation of the LOS. Stabilization in rate steering uses inertial space as its frame of reference. In the absence of steering inputs, the LOS will remain in the same angular position in space as the vehicle moves around. This is typical for all stabilized gimbal systems.

RATE AID:

Rate Aid steering makes the rate or rotation of the hand wheel (or force on the joystick) proportional to an acceleration of the LOS. This is useful when constant steering rates are required such as when orbiting a subject. The stabilization in rate aid steering also uses inertial space as its frame of reference. In the absence of steering inputs, the LOS will remain at the same angular rate in space.

POSITION:

The position steering mode is a special case of rate steering that uses the MOUNT as its frame of reference. In the absence of steering inputs, the LOS will remain in the same angular position WRT the mounting surface of the first gimbal axis. This can allow the operator to steer relative to the vehicle that the system is mounted on.

LEVEL HORIZON:

Level horizon is a steering mode that locks the roll axis to the measured local vertical. The quality, type, and how the sensor is used will dictate the performance of this steering mode. There are three basic types of sensors available to sense the local vertical: inclinometers (pendulous or bubble), accelerometer arrays, and vertical reference gyros. All of these sensors are subjected to the accelerations of the vehicle as well as the earth. They all tend to topple under sustained accelerations (like an orbit of long linear acceleration).

The only way to create a "bulletproof" vertical reference on dynamically moving vehicles is to use an Inertial Navigation System (INS). A typical INS uses an IMU and a GPS or other position reference to constantly compute its position and attitude relative to the earth.

The INS has other advantages too. If you recall we said that stabilization systems stabilize the lens relative to inertial space. The earth is rotating at 15º/hour in inertial space. The INS can compensate for the earth's rotation and allow the system to stabilize and steer in the EARTH frame of reference. This is the frame of reference that cinematographers are accustomed to working in.

GEO Tools:

GEOgraphic tools are a set of steering modes and special functions that make use of the INS.

GEO:

GEO steering is the most commonly used GEO tool. It is similar to the RATE steering mode except that it uses the EARTH as the frame of reference for the stabilization. In the absence of steering inputs, the LOS will continue to point at the same spot on the earth's surface, even as the vehicle moves past. The steering inputs simply steer this point around on the earth's surface. When shooting stationary or near stationary scenes from dynamically moving vehicles (such as helicopters) this mode eliminates or minimizes the steering inputs required to control the framing.

GEO AID:

GEO AID steering is similar to the RATE AID steering mode except that it uses the EARTH as the frame of reference for the stabilization. In the absence of steering inputs, the LOS will remain at the same angular rate on the surface of the earth. This is useful for targets moving at near constant speeds. The steering inputs required to hold the target in frame will be minimized.

GEO CUE:

This is a special function that allows the operator to mark a target position on the earth. When the target is in the frame a reticule appears on the video overlay to highlight the target. When the target is outside of the frame an arrow appears on the video overlay screen to show the operator the direction to the target. This is particularly useful for *blind reveals* giving the operator complete control of how the target enters the frame.

GEO TRACK:

This is a steering mode that is like GEO steering except that it steers relative to a target point that is being continuously updated. The target data can come from a GPS unit mounted on the target or any similar source. This is particularly useful when shooting from one moving vehicle to another. The operator is able to control the framing with much smaller steering inputs.

GEO FOCUS:

This special function makes use of the calculated distance between the target and the camera to command focus. It is particularly useful with the GEO TRACK steering mode.

The accuracy and usability of these GEO Tools is limited only by the quality and accuracy of the sensors and algorithms used in the INS. The Pictorvision XR currently includes the GEO and GEO AID modes. GEO CUE, GEO TRACK, and GEO FOCUS are currently under development.

MOUNTING CONSIDERATIONS:

When considering the problem of mounting stabilized gimbal systems, like any other problem, we should start by defining the problem: What are the requirements of the shot? What field of regard or travel in each axis do we need? How stable do we want the shot to be and at what focal length? How close will the subject be and will this cause focus or parallax issues? What are the required steering rates and accelerations? What environment is the shot to take place in? Is the vehicle rough or smooth? What about wind loading at speed? Wet or dry? These are some of the questions that need to be considered when choosing and mounting a stabilized gimbal system.

Configuration:

Generally the Pan/Roll/Tilt gimbal order is more suitable for mounting on vehicles because of its look down steering capabilities. However, look out level roll angles are limited to less than $\pm 90^{o}_{MOUNT}$ due to *gimbal lock*. At ± tilt angles $>20^{o}_{MOUNT}$ the LOS may be rolled continuously.

The Pan/Tilt/Roll configuration can allow for continuous roll but experiences gimbal lock at tilt angles of $\pm 90^{o}_{MOUNT}$. They are un-usable for looking down from moving vehicles and require a leveling head to look down in non-vehicle mounted applications.

If roll steering is not required and the combined roll angles of the vehicle and isolator are expected to be less than the available travel of the inner roll axis, then a Pan/Tilt outer gimbal may be acceptable. Gen-2 gimbals always require 3 axes on moving vehicles if a level horizon is to be maintained.

Leveling Heads:

All attitude systems can be mounted in any orientation and typically don't require a leveling head. This means that a *Cube Mount* can be used in place of the servo driven leveling head on telescopic cranes. This not only saves weight but also can shift the gimbal lock point, due to the crane elevation angle, to a more or less favorable location. A *Cube Mount* can mount the system from any of three faces (hanging, sitting, or on axis).

Isolation:

If the system requires external isolation, every effort should be made to use the hanging orientation. This places the center of gravity (Cg) below the spring center (Cs) like a pendulum. This means that gravity will help the system recover from lateral accelerations. In the sitting orientation the Cg is almost always well above the Cs and is less stable. The isolator array is much smaller and lighter for a hanging attitude and will usually out-perform a sitting isolator. An *ideal* or *decoupled* isolator would place the Cg at the Cs. External isolators are not usually all attitude.

You can find isolation in some of the most unexpected places if you know how to look for it. You want an appropriately low resonant frequency. With the system mounted you can usually spot this buy thumping or shaking the mount interface point. Next you need enough friction to damp out the resonance quickly (so the vibration doesn't carry on for more than a couple of cycles after you stop shaking it). Additional safety structure should be provided to limit the deflection of the "Isolator" (stops).

For example: a dolly lashed down to the front porch of a camera car can make a great external isolator. The long overhang of the structure of the front porch, friction and movement in its mounting, friction and movement in the dolly tires and lashing straps can all combine to make a well damped, low frequency isolator. And you get it for free. A piece of scaff tube running a few inches under the Mitchell offset plate can be used to limit the down travel as a safety.

The deflection of the isolator can cause focus and Parallax issues when shooting a subject that is close to the camera. Low frequency (<2Hz) isolators cause more parallax and focus issues but isolate better than high frequency (>10 Hz) isolators.

Isolation systems aren't usually instrumented. This represents an un-measured angular displacement in conventional encoder based CGI data outputs. INS based CGI outputs are referenced to the EARTH and are thus unaffected by isolator and structural deflections.

Environment:

Extremely rough environments may require the rigging of special isolators for the specific shot. I have rigged several such isolators from scaff tube and bungee cord for shots at over 1000mm focal length (on 2/3 inch video) while mounted on a flat bed truck crossing railway tracks.

If the vehicle speed is high a dome or some other method of shielding the stabilized gimbal from wind may be required. Similarly, water may require the use of a dome, cover, or other form of shielding to protect the system and camera. High wind speeds may affect the function of external isolators.

CONCLUSIONS:

There are a growing number of stabilized gimbal products available to today's cinematographer. Each represents a different set of design tradeoffs and compromises. As with automobiles, you would not expect one design to meet the needs of all automotive applications. So it is with gimbals too. For some Formula 1 represents the pinnacle of automotive excellence. However, they are hardly practical for carting the family around town.

Each product represents its designer's beliefs in what makes a product "ideal" for its intended application. To determine which product is best suited for your application you first need to understand the basic technology. This understanding should allow you to spot the tradeoffs and match them to your application.

Once a product is selected you begin the process of configuring it with all of its accessories and options. What you are really doing is tailoring it to your specific requirements. For many applications the "stock" configuration will work fine. But, as you push the performance envelope the systems will become more tailored to the specific requirements of the shot.

High performance stabilized gimbals tend to be more configurable and have more modes of operation in order to meet a diverse set of demanding applications. Conversely, lower performance units tend to be simpler but have narrowly defined applications where they excel.

A final note for those who fear the cost and complexity of the high performance systems. The many modes and options that make them more complex not only enable shots that were not previously possible, but also reduce the number of takes required to get the more routine shots in the can. But then, you can be the judge of that.

Pictorvision is committed to establishing a partnership with the motion picture industry. By establishing a dialog we hope to get input from the community on what types of tools it would like to have available in the form of new products.

DEFINITIONS:

Actuator: A servo motor. It may be direct-drive or geared. Direct-drive actuators are capable of higher bandwidth and produce high frequency forces on the constraining structure.

All-attitude: Can be mounted in any orientation.

Bandwidth: The bandwidth of the stabilization system is the frequency range over which the system is considered to be effective (i.e. 0 to X Hz).

CGI: Computer Graphics Interface: This refers to the data that is captured and used either in real time or in post production for key framing animated effects.

Drift rate stability: The time rate of output deviation from the desired output. It consists of random and systematic components and is expressed as an equivalent angular displacement per unit time *WRT inertial space*

Gimbal: In its simplest form a gimbal is just a mechanical contrivance to constrain the motion of an object about a single rotational axis. Combined together, several gimbals can constrain the motion of an object about each successive axis (i.e. Pan, Tilt, and Roll). *Gimbal* is often used to refer to a stabilized gimbal system.

Gimbal lock: A phenomenon, where 2 or more of the gimbal axes align, thus reducing the effective number of gimbal axes. Control systems often can't cope with this condition.

Hanging: The orientation where the LOS and center of gravity are below the mounting surface.

FOG: Fiber Optic Gyro: An angular rate sensor using a laser diode and a spool of optical fiber.

IMU: Inertial Measurement Unit: An sensor unit containing an array of 3 gyros and 3 accelerometers.

INS: Inertial Navigation System: A typical INS uses an IMU and a GPS or other position reference to constantly compute its position and attitude relative to the earth.

Inertial space: Is independent of the earth's frame of reference. It is referenced to the star system.

LOS: Line of Sight: The optical axis of the lens.

Orthogonal: At right angles to each other.

Parallax: Generally unwanted vertical and horizontal motion of the camera/lens (leftover linear vibration).

Passive isolation: Isolation that is not actively controlled with a servo system.

Precession: The rotational motion that results when a spinning wheel or gyro is rotated about an input axis perpendicular to the spin axis of the wheel. The precession will be about an axis perpendicular to both the spin axis and the input axis. In a rate gyro the precession angle is proportional to the input rate.

Resolve: To break down into its component angles.

Synthetic Inertia: The angular momentum of a spinning wheel appears to have greater rotational inertia in axes other than its spin axis. An array of 3 orthogonal gyros will create this effect in all 3 rotational axes.

Sitting: The orientation where the LOS and center of gravity are above the mounting surface.

WRT: With Respect To.

REFERENCES:

Gen-1 Patents:

1972	CA904616	Leavitt et al Original WESCAM	
1972	US3638502	Leavitt et al Original WESCAM	
1989	US4821043	Leavitt Vertically Slaved Window	
1991	US4989466	Goodman	SpaceCam

Gen-4 Patents:

1999	US5897223	Tritchew et al Wescam MX 20
2001	US6263160	Lewis Pictorvision XR

BIOGRAPHY:

Mike Lewis is the director of technology for PV Labs Inc. (formerly Wescam) with over 23 years of experience in stabilized gimbal technology. He holds a Bachelor of Technology degree in Mechanical Engineering and an Aerospace Engineering Technology diploma from Ryerson Polytechnical Institute in Toronto.
Patents:
US 5897223, GB 2334333, JP 11-223528
US 6263160, GB 2350897, JP 2001-41395, CA2275015

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