Image Stabilization Technology Overview

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Abstract

As Digital Still Cameras (DSC) become smaller, cheaper and higher in resolution, photographs are increasingly prone to blurring from shaky hands. Optical image stabilization (OIS) is an effective solution that addresses the quality of images, and is an idea that has been around for at least 30 years. It has only recently made its way into the low-cost consumer camera market, and will soon be migrating to the higher end camera phones. This paper provides an overview of common design practices and considerations for optical image stabilization and how silicon-based MEMS dual-axis gyroscopes with their size, cost and performance advantages are enabling this vital function for image capturing devices.

Introduction

Image stabilization first hit the consumer market in 1995, with the introduction of a stabilized zoom lens by Canon. Canon had published this idea in the United States as early as 1976 in a patent entitled “Image stabilizing optical system having a variable prism”. Since this introduction, image stabilization has appeared in an increasing number of products including digital single lens reflex cameras (DSLR), video cameras and binoculars. However, optical image stabilization in the mass market “point-and-shoot” camera is only a recent phenomenon, with Panasonic releasing the first of these cameras in 2004. Since this introduction, integration of image stabilization has been brisk, with several cameras launched in 2005 and marketing promotions ranging from prime-time television commercials to exclusive sections in big-box electronics stores devoted to displaying cameras with this feature. Now every DSC maker either has several models with IS already in the market, or is planning to have fairly soon.

Market

Optical image stabilization (OIS) is quickly on its way to becoming a standard feature. The Gartner Group estimates that 96 million digital cameras will be sold worldwide in 2006. InvenSense predicts that 30 percent of these will have OIS. By 2009, the expected penetration will be close to 90 percent of the 100 million unit plus digital camera market. In the high resolution camera phone market (3 megapixels and greater), there is an even greater need for optical image stabilization. Adoption is already underway, and the number of cameraphones will quickly surpass the total number of digital cameras over the next several years. InfoTrends anticipates that nearly 45 million handsets with 3 megapixel cameras and higher will be shipped in 2006 and over 330 million handsets by 2009. Initially, less than 5 percent will have image stabilization, but as the size and cost for key components of the optical image stabilization system decreases, experts believe that the penetration will rapidly rise to over 50% of the market.

Needed Solution

As DSC's shrink in size and weight, migrate to higher megapixel sensors, and incorporate 3x- and -4x optical zooms, engineers struggle to provide better quality images in lower lighting conditions without a color-distorting flash. Virtually all trends in photography have pushed cameras toward longer exposure times and higher resolutions which have largely resulted in image quality problems from shaky hands.

Figure 1. Anti-Shake demonstration by Konica Minolta

The human body is always in motion. No photographer is capable of holding a camera with outstretched hands without moving it to some degree; this movement is a biological phenomenon that cannot be easily defeated by training. Human hands shake with a frequency of 10 to 20 Hz and, when outstretched, will also drift at lower frequencies. In photography, this jittering produces an effect often referred to as "camera shake", and can cause blurring in photographs. Modern consumer cameras tend to amplify this effect by being small and lightweight, and by replacing the traditional viewfinder with an LCD screen, encourages users to hold their cameras with extended arms. In digital photography, in which image sensors are arrays of pixels, this effect can be ignored if it produces a blur over one pixel or less. The amount of blur that will be produced by hand jitter for a certain picture depends on the exposure time and the angular field-of-view corresponding to one pixel. If an image sensor is exposed to light only for a short amount of time, the camera may not move enough to blur the image; however, zoom, higher pixel densities and smaller movements will produce significant blur.

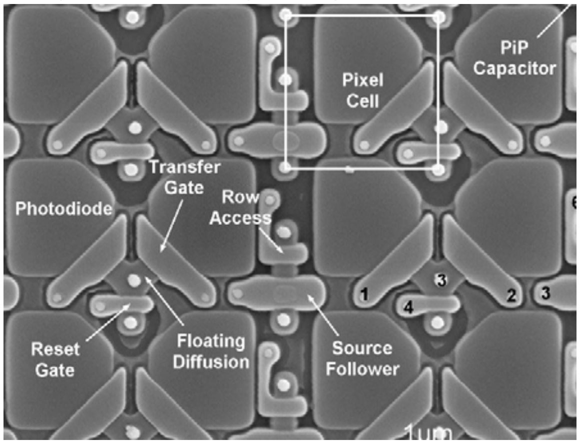


Figure 2. Micron's CMOS pixel array

The exposure time required for enough light to be absorbed in an image sensor depends on the amount of light present during the exposure, the aperture through which the light must travel, and the design of the sensor itself. A camera system designed for an action shot will have film that exposes very quickly, and a wide aperture for letting in as much light as possible, allowing the shutter to be open for as little as 1ms. In contrast, a 3 megapixel camera module designed for a cell phone will have a small aperture, as the phone itself must be small. Sensors with higher pixel densities must have smaller pixels, which will absorb light more slowly for a given aperture. In addition, most of these sensors are based on CMOS technology, in which transistors are integrated in the sensor along side the pixel; the part of the pixel that absorbs light is even smaller, to make room for this additional circuitry. This is usually expressed with a “fill factor”, the ratio of the actual light-absorbing area to the area occupied by the entire pixel. In Figure 2, only the photodiodes actually absorb light. Ultimately, when such a system is used in an indoor location with a typical lighting condition, the exposure time can easily be over 100ms.

Figure 3 shows two seconds of hand jitter as recorded by an IDG-1000, InvenSense’s dual-axis gyroscope. It also shows 100ms of this data that has been isolated and integrated, giving a typical angular path of a camera during an exposure.

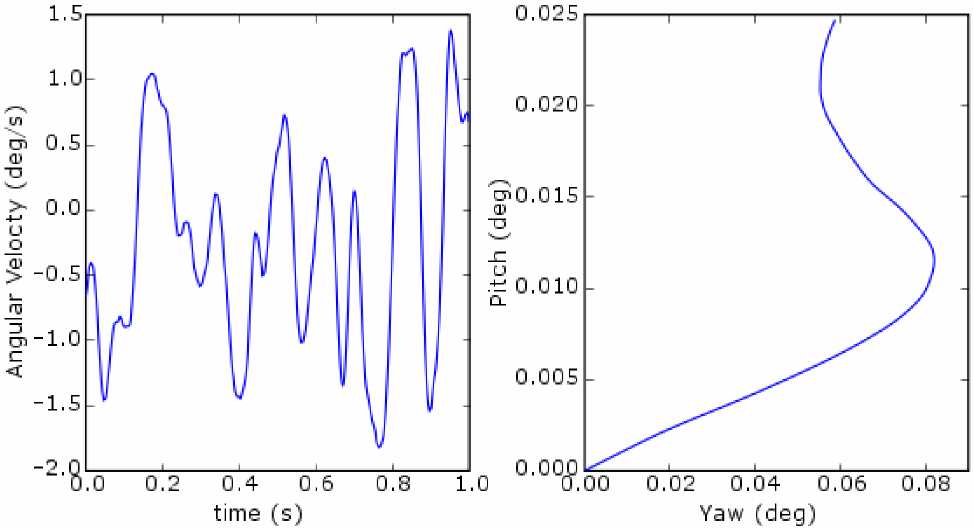


Figure 3. Left: Yaw Hand Jitter data, 1s. Right: Pitch and Yaw integrated data, 100ms.

Typical low-cost camera systems have a field of view of 35º to 45º along the horizontal. For a 640x480 VGA camera with a field of view of 45º, each pixel corresponds to a horizontal angle of 0.07º. The derived camera path shown in Figure 3 has a total horizontal drift of 0.08º, producing a negligible blur of 1.1 pixels in such a VGA image.

However, as an example, if the pixel density is increased to 2 megapixels (1600x1200), the horizontal blur becomes 2.9 pixels. Such a blur will begin to be noticeable, though the impact it has on a viewer can, to some degree, be reduced by artificial image sharpening algorithms. Pixel densities of 3 and 6 megapixels simply allow greater resolution of this blur, revealing it to 3.6 and 5 pixels respectively. In fact, it is clear that, for such slow shutter speeds, increasing resolution beyond 2 megapixels accomplishes nothing more than enlarging the blur caused by hand jitter. Note that these numbers were derived without any optical zoom, which would amplify the movement of the camera, and produce even more blurring. Photography in conditions with low lighting would extend the necessary exposure time, introducing additional blur.

Optical image stabilization reduces any hand jitter that is within a given range, usually ±1°, certainly enough to defeat the hand movement shown in Figure 3. Figure 4 shows an experiment involving several images that were acquired with and without image stabilization. The improvement in image quality is impressive.

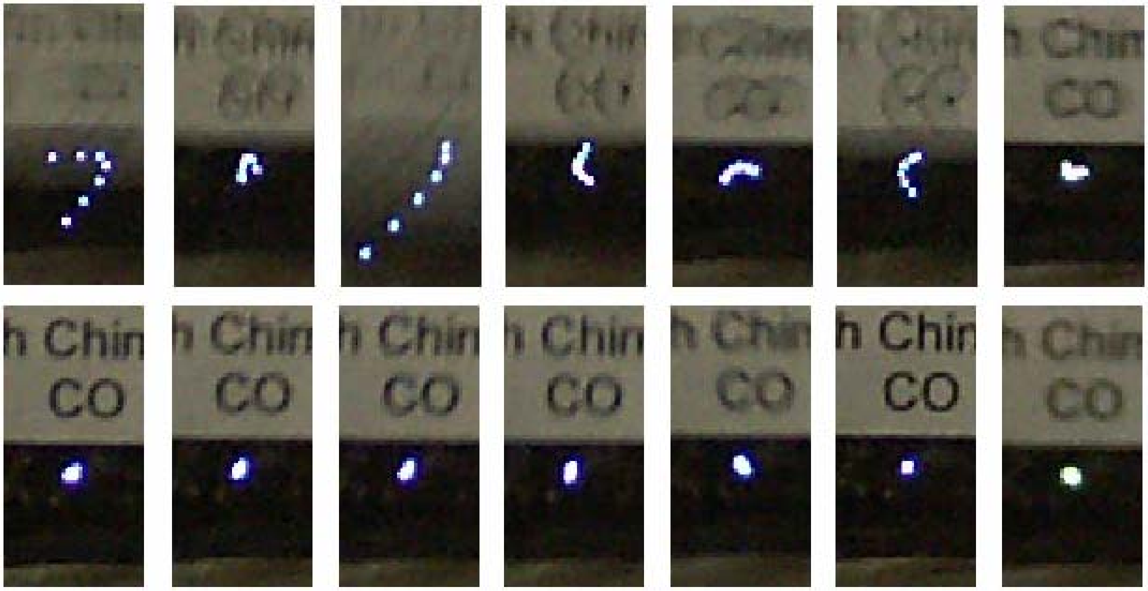


Figure 4. Minolta A1, 51mm lens, 1/15th second shutter speed. Top: OIS off. Bottom: OIS On.

As consumers demand higher resolution cameras with optical zoom, packed into smaller and lighter DSC's and cell phones, the blurring due to hand jitter will become even more noticeable and stabilization systems will become standard features.

Photography Terminology

Aperture	Shutter Speed	Film Speed
f-32	1/8	ISO-25
f-22	1/15	ISO-50
f-16	1/30	ISO-100
f-11	1/60	ISO-200
f-8	1/125	ISO-400
f-5.6	1/250	ISO-800
f-4	1/500	ISO-1600
f-2.8	1/1000	ISO-3200

Table 1. Stops in photography.

Aperture sizes are measured in "f-numbers", which refer to the ratio of the lens focal length to the diameter of the hole, as both influence the amount of light per area that will be incident on the film or image sensor. The film speed is measured using a scale known as "ISO", defined by the International Organization for Standardization, though the application of this metric to digital sensors is sometimes vague. Since the blur generated depends on a multitude of factors, a metric called a "stop" is often cited in photography to refer to changes in aperture, shutter speed, or film speed. For example, increasing the shutter speed from 1/30th of a second to 1/60th of a second is referred to as increasing it "one stop", and will reduce the final exposure of the image; but decreasing the aperture size from f-11 to f-16 will allow half as much light in, having a similar effect, and is described as reducing the aperture one stop. If the film used has a speed of ISO-200, the film speed can be reduced by one stop by replacing it with a slower film with a speed of ISO-100. Some commonly used stops are shown in Table 1.

Evaluating Blur

With this metric, a simple evaluation of an OIS system can be done that takes into account alterations of any of these parameters, and differences between cameras. A good OIS system is usually said to enable 2 to 3 stops of exposure. This means that if the exposure time is increased until blur starts to appear, and then an OIS system is activated, the blur will disappear; and the exposure time can now be increased an additional 2 to 3 times before blur stars to reappear. This is a relative measurement, as the actual allowed exposure time will depend on the other parameters.

Optical Image Stabilization

Blur due to hand jitter is reduced by mechanically stabilizing the camera. A two axis gyroscope is used to measure the movement of the camera, and a microcontroller directs that signal to small linear motors that move the image sensor, compensating for the camera motion. Other designs move a lens somewhere in the optical chain within the camera. A typical high-level block diagram is shown in Figure 5.

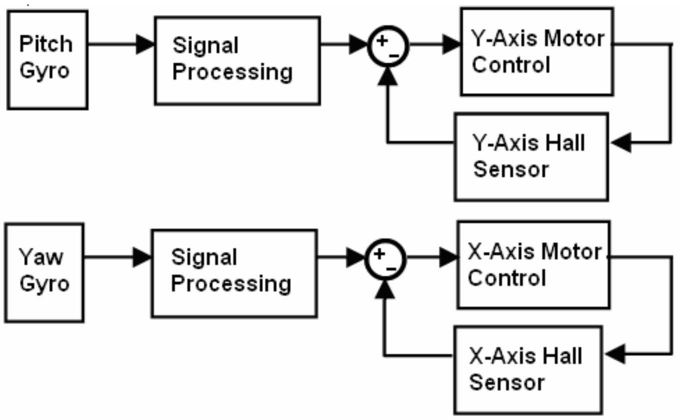


Figure 5. OIS High level block diagram.

With either method, the result is that the body of the camera may shake, but light strikes the pixels of the image sensor as though the camera were not shaking.

Sensor Requirements

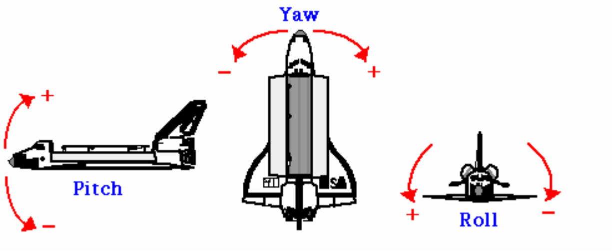


Figure 6. Roll, Pitch, and Yaw, from NASA.

For an OIS system to function properly, the sensors, actuators, and electronics must be carefully chosen. A newcomer to this field may immediately wonder why gyroscopes are used in image stabilization, rather than other sensors, such as accelerometers. A gyroscope measures the rotation about an axis, where rotations about X, Y, and Z axes for a given object are referred to as roll, pitch, and yaw, depicted in Figure 6. Gyroscopes are perfect for the job because they measure rotation, which dominates linear movement in its effect on picture taking, at relatively fast rates, ~100 to 150 Hz,

A camera creates an angular representation of the world, mapping everything within its angular field of view onto an image sensor. In such optical systems, the linear motion becomes negligible for far away objects, but rotation must always be taken into account. The diminishing effect of translation on the angular field of view of a scene can be visualized with the diagram in Figure 7.

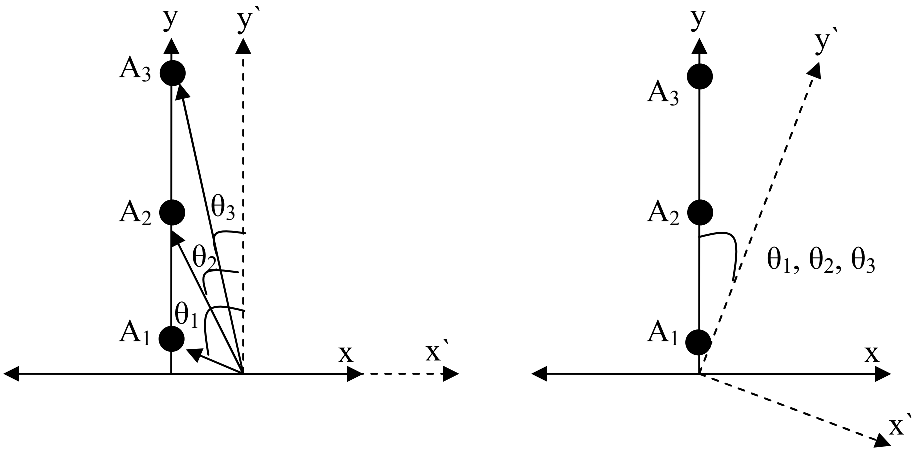


Figure 7. Left: Impact of Translation on FOV. Right: Impact of Rotation on FOV.

Note that when the camera's frame of reference moves linearly, as in the diagram on the left, objects at A1, A2, and A3 find themselves at different angles within the camera's field of view. This effect is known as parallax. Objects that are further away will appear to move less within the angular field of view of the camera. In the diagram on the right, in which the camera has rotated, all three objects have the same angular displacement regardless of their distance from the camera. The impact of linear movement decreases, but the impact of rotation does not. As an example, a 0.08º rotation of the camera will cause objects in its field of view to be displaced by 0.08º. To achieve this same displacement of an object 10 meters away with a translation of the camera, the camera would have to move 10m•tan(0.08º), or about 1.4cm. This would require an unnaturally excessive hand jitter.

Linear jitter is only damaging in the field of macrophotography, which involves close-up photographs, typically of insects and plants; here, the objects may not be far away relative to the magnitude of the linear jitter. Effects due to translation can be reduced when using lenses designed for macrophotography, which have large magnification factors that allow the photographer to be further from the object being captured. Note that in practice, there are no consumer cameras that compensate for any motion other than pitch and yaw. Blurring due to roll and linear movements is small enough that it can be ignored.

While accelerometers can sometimes be used to measure rotation by detecting the acceleration due to gravity, the resulting output is noisy and coupled with linear movement in ways that are impossible to separate without gyroscopes. In addition, accelerometers would not be able to sense yaw. For these reason, the gyroscope has always been fundamental to image stabilization systems.

Gyroscopes

Gyroscopes are employed in IS systems to sense pitch and yaw with low noise and high sensitivity in order to resolve the small movements associated with hand jitter. Typically, these systems require a full-scale range of +/-30 degrees per second, with at least 10-bit resolution.

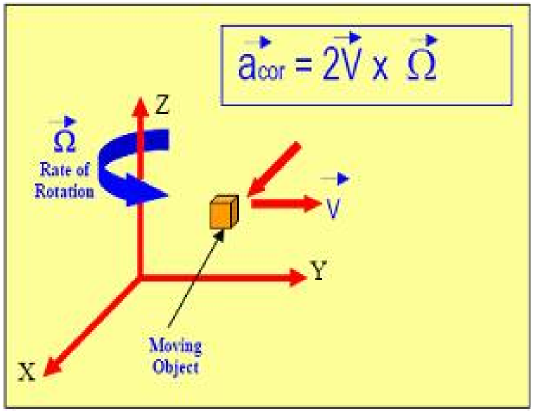


Figure 8. Coriolis Acceleration

Almost all reported micromachined gyroscopes use vibrating mechanical elements (proof-mass) to sense rotation. They have no rotating parts that require bearings, and hence they can be easily miniaturized and batch fabricated using micromachining techniques. All vibratory gyroscopes are based on the transfer of energy between two vibration modes of a structure caused by Coriolis acceleration. Coriolis acceleration, named after the French scientist and engineer G. G. de Coriolis (1792–1843), is an apparent acceleration that arises in a rotating reference frame and is proportional to the rate of rotation, Fig. 8.

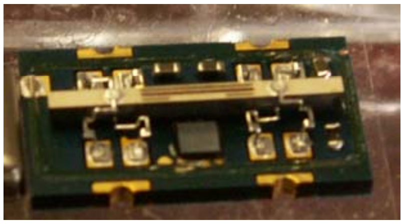


Figure 9. Older gyroscope technology

Vibratory gyroscopes were demonstrated in the early 1980's. An example of this type of devices is the quartz tuning fork like the Quartz Rate Sensor by Systron Donner. Although quartz vibratory gyroscopes can yield very high quality factors at atmospheric pressure with improved level of performance, due to use of quartz as the primary material, their batch processing is not compatible with IC fabrication technology. In the late 1980's, after successful demonstration of batch-fabricated silicon accelerometers, some efforts were initiated to replace quartz with silicon in micromachined vibratory gyroscopes. Charles Stark Draper Laboratory demonstrated one of the first batch fabricated silicon micromachined rate gyroscopes in 1991.

In older image stabilization systems, two single axis piezoelectric or quartz gyroscopes were used with many external components to amplify and filter the signals to achieve the desired full-scale range. In order for image stabilization to become a standard feature in digital cameras and camera phones, it will be necessary for gyroscopes to be smaller and less costly, measure pitch and yaw simultaneously, meet more stringent shock and vibration standards as well as achieve a lower overall system cost with more integrated features.

Although many companies have attempted to commercialize MEMS gyroscopes, only a few, namely Bosch and ADI, have succeeded in bringing single axis solutions to market. These gyroscopes serve high-end automotive applications, such as vehicle stability control and roll-over protection.

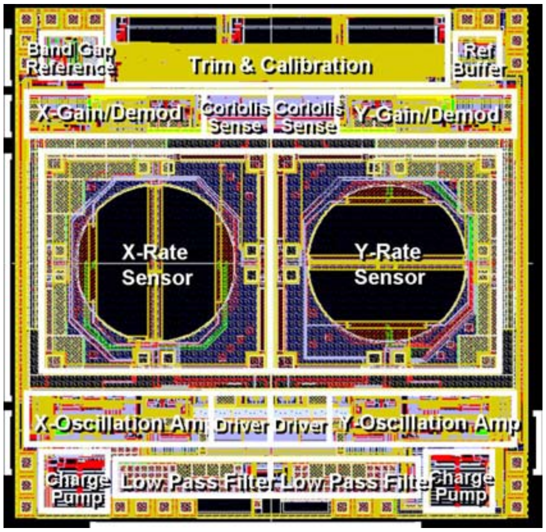


Figure 10. InvenSense gyroscope circuitry

InvenSense is the first and only company to bring to market an integrated dual-axis gyroscope using advanced MEMS technology. InvenSense's gyroscope is also the first solution that provides integrated amplifiers with programmable gain settings and integrated reset switches that are convenient for IS applications.

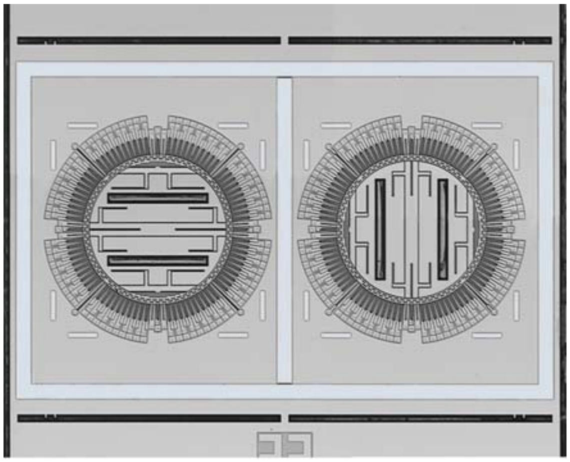
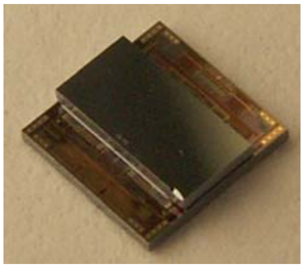


Figure 11. InvenSense resonating structure

One of the key advantages of InvenSense's solution is its patented out-of-plane, resonating structures that enable in-plane sensing and the integration two axes as shown in Figure 9. Another key advantage is its ability to achieve low cost. Patented wafer-level packaging technology allows for fully functional device testing at the wafer level. This is done by combining MEMS and ASIC wafers using a proprietary and patented wafer bonding technology. The wafer bonding process provides electrical connections between the CMOS and MEMS wafers, which also creates a hermetic seal between the two wafers. Integrating the finished MEMS structures with a standard off-the-shelf CMOS ASIC avoids many of the pitfalls associated with trying to integrate the MEMS and CMOS processes, as with a surface micromachining approach.

InvenSense's IDG-1000 is the first and only integrated MEMS dual-axis gyroscope currently in high volume production. Most other gyro manufacturers addressing IS use Piezoelectric quartz or ceramic technologies that are discrete solutions with package-level integration of the sensor and electronics. These solutions tend to be bigger in size, more costly to assemble and require vacuum-sealed ceramic packaging. MEMS technology is a very mature technology used in numerous sensors and other high volume consumer applications, such as accelerometers and inkjet printers.



InvenSense's gyroscope
Figure 12

Actuator Requirements

Actuators for OIS systems must be small, low-power, and accurate for tiny movements. The range of movement required by an OIS actuator depends on the optics of the system, but the desired outcome is an ability to compensate for ±1° of rotation. The most common actuator is the voice coil, an electromagnetic linear motor, used to drive the lens in Figure 13. In combination with strong permanent magnets, two coils are used to drive a platform both vertically and horizontally. As this system inherently creates a strong magnetic field, Hall effect sensors can be used to track the position of the platform by measuring this field. Motors and position sensors can be tightly integrated in a small package, and work together to precisely control the position of the platform.

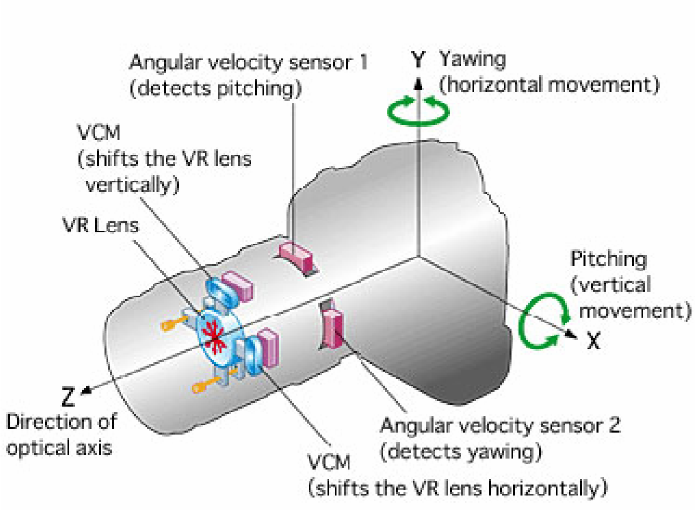


Figure 13. Nikon, shifting a lens.

Figure 14. Konica Minolta, shifting the image sensor.

Another implementation is shown in Figure 14, using piezoelectric actuators to shift the image sensor. These actuators are relatively new to this field, but can be used with lower power, and at lower frequencies than voice coils. Newer systems are including other types of composite shape-changing materials.

In either case, the actuators should

be designed to be as linear as possible, with as little cross-axis correlation as possible. This means that the displacement resulting from a signal delivered to the X-axis actuator should be proportional to that signal, and should not depend on the state of the Y-axis actuator. This design often requires two stacked platforms, an X-axis platform, and a Y-axis platform riding on the X-axis platform. This ensures that the axes can truly be controlled separately.

Hall Sensors

When using feedback with Hall sensors, it is important to place them carefully to prevent cross-axis errors, so that the X-axis Hall sensor only measures movement along that axis. Ideally, the entire system should also be designed so that the magnetic field changes in a linear fashion in the vicinity of these sensors, as this will simplify the design of the feedback control system. However, a small cross-axis error may be calibrated out and accounted for in software. As Hall sensors tend to vary greatly over temperature, the required signal conditioning and circuitry must be flexible. Figure 15 shows an example taken from an OIS patent (U.S. 6,631,042):

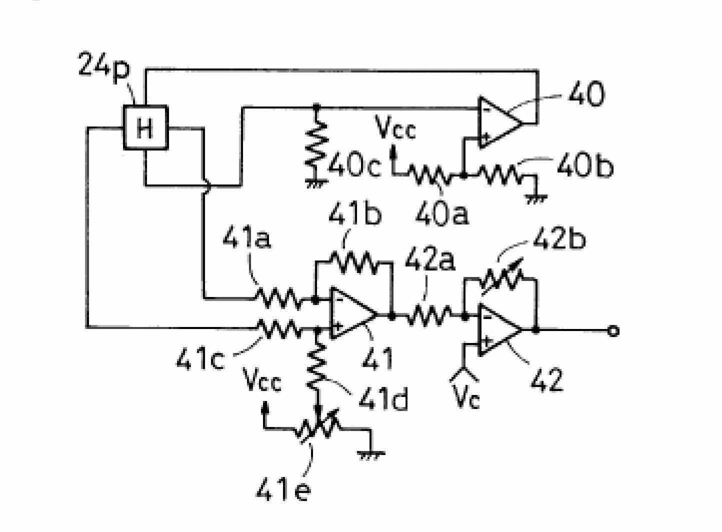


Figure 15. Canon, Hall sensor conditioning.

These sensors require two contacts for generating a known current, and two more contacts for measuring the deflection of that current due to a magnetic field. Note that a current source is used to minimize the temperature dependency, and the sensor is sampled using circuitry with a controllable amplification and offset, allowing calibration to be done on the fly. For example, by periodically driving the actuators to their mechanical limits and measuring the respective Hall sensor outputs, the four corners of the OIS system can be found, and these can be used as calibration factors. An alternative method is to use two complementary Halls sensors per axis, one on each side of the system, such that one always has a decreasing value when the other has an increasing value. The sum, which should be constant for a given temperature, can be used for temperature compensation, while the difference is used to compute the position of the actuator. Finally, using integrated Hall sensors with internal amplification greatly simplifies this design. In practice, however, most OIS systems use raw Hall sensors with more complex external circuitry.

Control Algorithm Requirements

Gyroscopes output angular velocity, which must be integrated in order to provide the absolute angle through which a camera rotates during an exposure. It must also be scaled in order to convert the measured angular camera movement into a directed linear movement of an image sensor or lens that will cancel (stabilize) the effect of the hand jitter effect on the image. This scale factor will depend on the fixed optical properties of the individual camera, but it must also be updated to account for different zoom factors. A zoom of 2X amplifies any movement of the camera, and the final instructions sent to the motors must similarly be amplified.

However, it is first necessary to filter out intentional hand movements from this integration, which is typically accomplished with a high-pass filter. For example, if a photographer begins framing a shot, and the gyroscope begin integrating from zero, and then the photographer proceeds to rotate the camera 90º in order to frame a different shot, the integrated data will track this 90º rotation, and a system without a high-pass filter would attempt to drive the optics of the camera to compensate, pointing at the original shot. This would be mechanically impossible, as well as undesirable. Pre-filtering the gyroscope data allows the OIS system to focus on removing the unintentional high-frequency hand jitter, without interfering with the photographer's ability to pan and frame shots.

A simple implementation of this system is shown in Figure 16.

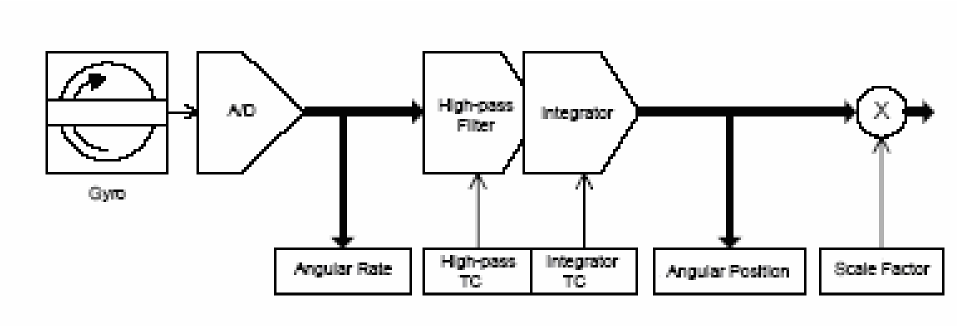


Figure 16. Gyroscope signal processing.

Note that each block has a coefficient that may be updated in real-time by a microcontroller. The scale factor may only need to be updated while the photographer is altering the zoom, but the other factors might be changed continuously, depending on the calculated exposure time and the movements of the camera.

The time constants used in the filter depend on the context of the shot. During a long exposure time, lower frequency arm movements become more prominent, and a short time constant intended to isolate a 10-20Hz vibration may not be sufficient. A time constant around 10s will allow the OIS system to compensate for any movements made during a period of a few seconds, without the data being distorted by artifacts produced by the filter. However, a long time constant interferes with the photographer's intentional movements. For example, when attempting to take a picture of a moving car, in which the car is to be sharply displayed against a blurry background, a photographer must rotate the camera to follow the car. An OIS system with a long time constant will inappropriately attempt to compensate for this movement. For such pictures taken with panning, a short time constant on the order of 0.1s to 1s is preferable. A panning shot may be set as a mode within the camera menu system, but should ideally be detected from the gyro data itself, giving a user greater freedom to move the camera and shoot at will.

Long time constants can become particularly annoying if the OIS system is designed to be active before the shot is taken. While low-power implementations will avoid using the OIS system until the moment the shutter opens, it may be desirable to use the OIS during the framing of a shot, to prevent the jitter from distracting the photographer. In addition, while some autofocus systems use ultrasonic ranging to measure distances to objects, others depend on the images acquired by the image sensor, incrementally adjusting the focus until the image acquired is sharp enough, as measured by an image processing algorithm. Such systems will not function with the OIS deactivated, as none of the images will be sharp, especially under 3X zoom or higher conditions.

The Feedback Control Loop

When using Hall sensors as feedback to position the actuator, a feedback loop must be designed. This is usually done in firmware in camera systems, but has been implemented as an analog circuit in some binocular systems. The classic PID control algorithm can be used, in which the actuator is driven by the Hall sensor signal by summing proportional, derivative, and integral components.

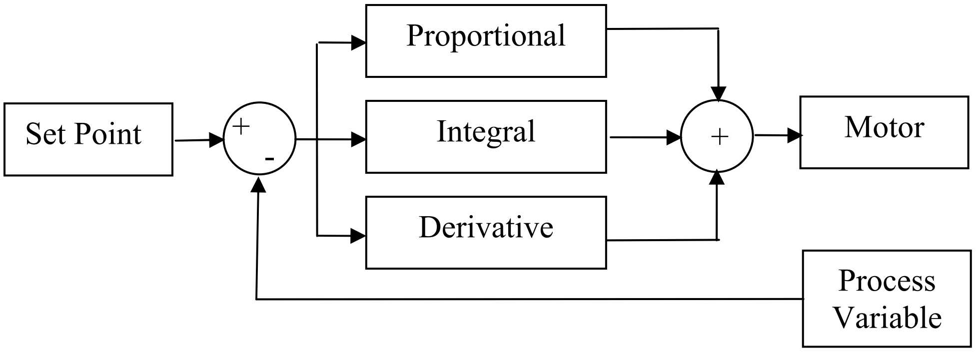


Figure 17. PID Block Diagram

In Figure 17, a set-point is derived from the gyroscope data as in Figure 16, and compared to a measured process variable obtained from the Hall sensors. The difference between them is passed through three blocks independently, a proportional block, an integral block, and a derivative block. The values are summed, and used to drive the motor.

The proportional term is the meat of the system, driving the actuator until the set-point and the process variable are equal. The derivative term is important for stability with systems that don't have high levels of internal friction, such as the voice coils. In contrast, the piezo-electric actuators have a certain amount of friction built in for aiding with low frequency compensation; control algorithms for the piezo systems will be quite different. The integral term is usually important for systems in which the accuracy of the final position is important. OIS designers may decide to omit it, as stabilization systems only require accuracy in relative positioning. That is, if there is a small, constant offset in desired position of the motor and the true position of the motor, this will not influence the blur in the final image. However, due to lens aberrations, there may be image quality compromises in some OIS systems that can be reduced if the motors stay as close as possible to the centers of their ranges. In such systems, it may be desirable to remove such small offsets, and an integral term should be used. These offsets from the center will also decrease the range of movement in some direction, and may reduce the cameras ability to stabilize when movement is required in that direction.

As the hand jitter being detected is around 10-20Hz, OIS systems must iterate at least ten times faster in order to resolve this. However, it may be necessary to run the actuator control loop even faster in order to make up for non-linearities in the actuators or Hall sensors, as non-linear systems can be treated as linear if they are driven at a high enough rate. In practice, the control loop will usually be run from 500Hz to 4kHz, though the gyroscope need not be sampled as often.

Note that not all designers use a PID system. In some systems a lead-compensation control algorithm is used, and in others a PDD system is used, using differences in position, velocity, and acceleration.

Microcontroller Requirements

In some systems, the OIS system is implemented as part of an interrupt service routine on the main processor; in others, the system is given its own microcontroller. This controller need not be excessively fancy, but must be able to run a feedback control algorithm somewhere in the 500Hz to 4kHz range. The math used can be 16-bit fixed point, and can be implemented on an 8-bit or 16-bit processor relatively easily. When using filters with long time constants, some 32-bit math may be necessary to handle the large numbers that will accumulate.

Note that the just as the gyroscope must be accurate, the measurement of time in this system must also be accurate, due to the integration step in the signal processing. For example, the integration of the gyroscope data can be implemented in software as:

$$\alpha' = \alpha + \omega \Delta t$$

The new calculated position is α', α is the previous position, ω is the gyroscope angular velocity output, and Δt is the time since the last update. Any error in the gyroscope data will be contained in ω, but any error in the measurement of time will be contained in Δt.

Either way, the product of ωΔt will contain an error that will propagate. For this reason, it is important that the chosen microcontroller either have an external clock signal or crystal to provide precision timing, or have an internal oscillator that is at least as accurate per unit time as the gyroscope is per unit angular velocity. Ideally, it should be accurate enough such that any errors in time have a negligible effect on ωΔt when compared with the noise in the gyroscope.

Driver Requirements

Piezo and voice coil actuators require different driving signals. Piezo systems are typically low current but high voltage, and must be driven with high voltage transistors or opto-isolators, which allow low voltage inputs to control high voltage outputs. Voice coils, in contrast, require low voltages but high currents, and will need a driver with an H-bridge output stage. Low power can be obtained by using a PWM driver, as the inductance of the coils prevents excessive current from flowing when the driving signal is oscillating at a high frequency. This frequency should be well above 100kHz, ideally closer to 1MHz.

Electronic Image Stabilization

In video systems, two problems arise due to hand jitter. As each frame is recorded by an image sensor, just as it would be in a digital camera, the individual frames may be blurry; this makes high resolution video problematic. For video cameras with high pixel densities, optical image stabilization is required for achieving the target resolution. However, video cameras of any resolution also face a slightly different problem. Even if the individual frames are not blurred from the hand movement, this shaking will manifest itself as a frame-to-frame jitter over time. This effect is familiar to anyone who has attempted to sit through a home video made on a handheld camcorder without a stabilization system. As the problem is not the blur within the individual frames, but the shift from one frame to the next, it may not be necessary to adjust the optics of the system to solve the problem.

Instead, a system can be used that is known as electronic image stabilization (EIS). Gyroscopes are still used to detect the hand jitter, but instead of altering the direction of the light as it approaches the image sensor, the image is simply shifted in software by a certain number of pixels.

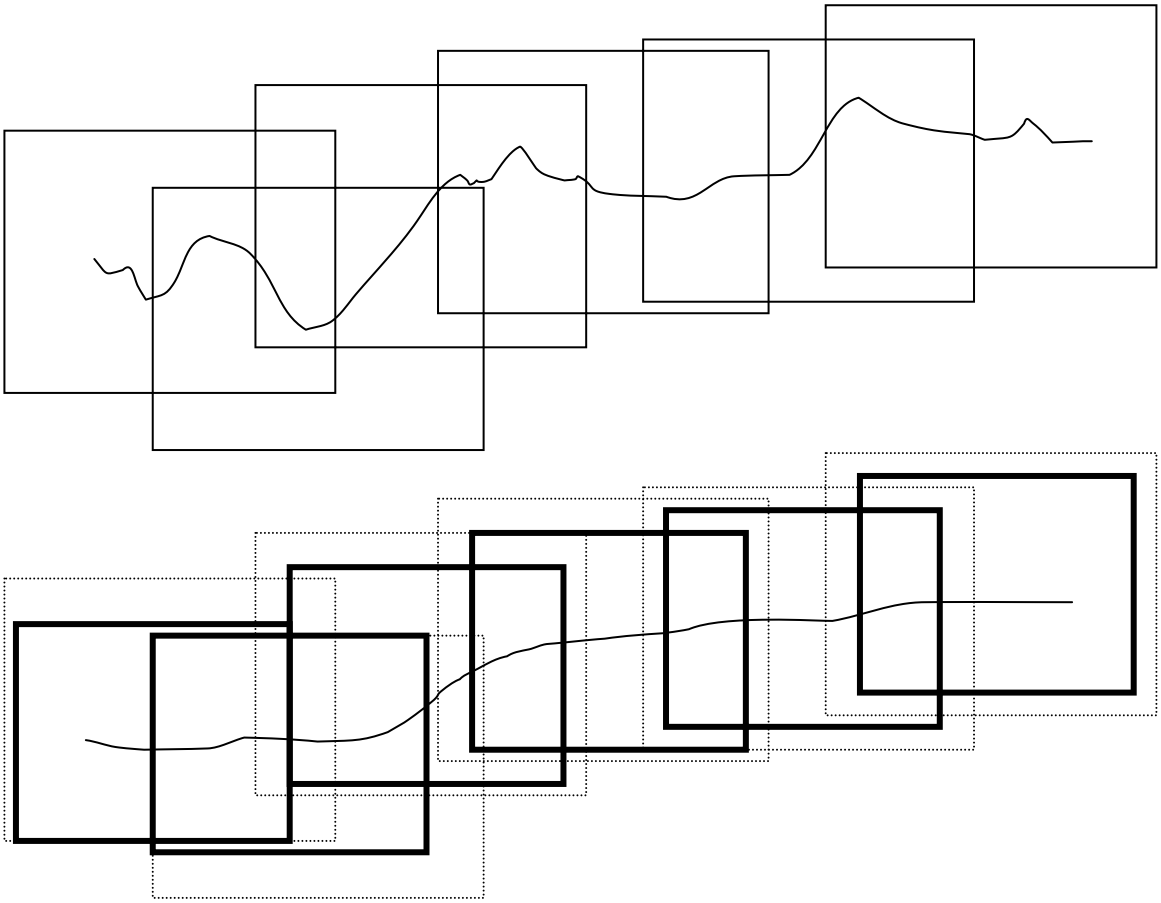


Figure 18. Above: jittery path of an object in video. Below: smoothed path with EIS.

In Figure 18, the top image shows a series of jittery frames, and the path of an object within those frames. The bottom image shows the output of an EIS system in which the frames have been shifted and cropped, and the resulting smoothed path of an object in the video. This has an advantage over optical image stabilization in that there are no moving parts, and the power dissipation can be much lower. However, if the resolution of the camera or hand jitter becomes high enough to cause a noticeable blur within each frame, simply shifting the frames in software will not solve the problem; optical image stabilization must be used. In practice, some video cameras use a hybrid system combining optical image stabilization and electronic image stabilization, allowing intelligent compromises to be made on the fly, based on resolution, zoom, and the amount of hand jitter present.

Note that EIS serves to line up a set of frames, and does not prevent a single frame from being blurred. It is a system for video, and is not helpful in preventing blurry photographs from being taken. However, as digital still cameras increasing support video, designers may find it useful. For example, EIS can be used to stabilize the video presented on the LCD screen, as a user frames a shot. Upon taking a picture, the camera can briefly activate the OIS system for acquiring a high quality image.

Conclusion

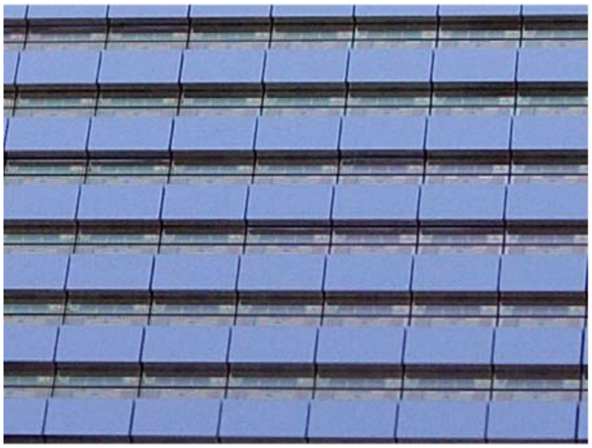


Figure 19. InvenSense gyroscope wafer

Gyroscope-based optical and electronic image stabilization systems are mature and proven technologies that address the quality of images. OIS has been penetrating the DSC market rapidly, and as camera resolutions continue to increase, optical image stabilization is expected to become as standard a function as autofocus on every DSC. As engineers struggle to pack advanced technologies into the scarce and premium real estates of handsets, small size and low cost are at the top of their lists. With the fast pace of increased CMOS sensors pixel densities and feature offerings, such as auto focus and optical zoom, OIS is expected to enter into the camera phone market very shortly. Many system designers are faced with the challenges of introducing image stabilization into already crowded broad spaces. Until recently, there have been no viable options that meet the demanding size and cost requirements. Thanks to InvenSense's innovative MEMS dual-axis solution, the barrier to the implementation of OIS into a new generation of high performance camera phones has been lifted, and solutions as early as spring o 2007 are expected.

About the Authors

David Sachs is a Systems Application Engineer at InvenSense. He has designed many gyroscope-based systems at InvenSense and MIT's Media Lab. His work ranges from low-level algorithmic development and multi-sensor fusion of gyroscopes, accelerometers, and magnetic field sensors, to complete motion-sensing systems including image stabilization systems, user interfaces, and gaming devices. He has a MS from MIT, and a BA from Oberlin College.

Steve Nasiri is the Founder, President and CEO of InvenSense Inc. and a 26 years veteran in the MEMS industry with expertise in fabrication and packaging of several MEMS products. His extensive knowledge of MEMS fabrication and high-volume packaging was instrumental in conceiving a novel mirror design for Transparent Networks, where Mr. Nasiri served as the Vice President of Operations and MEMS Development and where he derived the idea for the dual-axis gyroscope from optical device designs. He has co-founded several successful Silicon Valley MEMS startup companies including Sensym, NovaSensor, Integrated Sensor Solutions (ISS), ISS Nagano GmbH, Intelligent MicroSensor Technology, and most recently Transparent Networks. He has an MBA from Santa Clara University, and an MSME from San Jose State University, and BSME from University of California Berkeley. He has 28 issued patents.

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References

Nasiri, Steven. "A Critical Review of MEMS Gyroscopes Technology and Commercialization Status".

Nasiri, Steven and Seeger, Joseph, May 17, 2005. U.S. Patent #6,892,575, "X-Y axis dual-mass tuning fork gyroscope with vertically integrated electronics and wafer-scale hermetic packaging."

Nasiri, Steven and Flannery Jr., Anthony, September 6, 2005. U.S. Patent #6,939,473, "Method of making an X-Y axis dual-mass tuning fork gyroscope with vertically integrated electronics and wafer-scale hermetic packaging."

Furukawa, Hiroshi et al. March 9, 1976. U.S. Patent #3,942,862, "Image stabilizing optical system having a variable prism".

Hara, Yoshihiro et al. October 4, 2001. U.S. Patent Application #20010025477, "Control mechanism with actuator employing shape memory alloy and method for adjusting servo control of the control mechanism".

Kakiuchi; Shinichi. January 12, 2006. U.S. Patent Application #20060008263, "Camera provided with camera-shake compensation functionality".

Kawahara, Hideo et. al. November 8, 2005, U.S. Patent #6,963,361, "Image sensing method and apparatus capable of performing vibration correction when sensing a moving image".

Kitazawa, Tomofumi et. al, September 6, 2005. U.S. Patent #6,940,542, "Imaging apparatus, and method and device for shake correction in imaging apparatus".

Konica Minolta Photo Imaging, 2004. "Digital SLR Camera with World's First Body-Integral Anti-Shake Technology".

London, Barbara and Lipton, John. *Photography, 8th Edition*. Prentice Hall, 2004.

Masuda, Kazunori. January 9, 2003. U.S. Patent Application #20030007075, "Camera system, camera, and lens apparatus".

Micron Technology, Inc., 2006. "Lens Selection and Suppliers".

Nikon Corp, 2005. "Precise camera-shake compensation at every angle".

Noguchi, Kazuhiro. October 7, 2003. U.S. Patent #6,631,042, "Lens barrel having image shake correcting function and optical device having same".

Semiconductor Insights, September 20, 2005. "Micron MT9D011 CMOS Image Sensor awarded Most Innovative Image Sensor".

Toba, Akira. June 15, 1997. U.S. Patent #5,648,815, "Video camera with electronic picture stabilizer".

Washisu, Koichi. June 29, 2004. U.S. Patent #6,757,488, "Control apparatus for image blur correction".

Stavely, Donald J., Image Stabilization Technology Presentation, September 6, 2005.