IMU-Driven Optical Image Stabilization

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1 INTRODUCTION

Optical Image Stabilization (OIS) is a key technology in modern cameras and imaging systems. It counters unwanted motion and vibration during image capture — especially important for long exposure (low-light) photography and long-range imaging (telephoto).

OIS physically shifts an optical element (a lens group) or the entire camera module (lens + image sensor) to keep the projected image steady on the image sensor, minimizing blur from hand shake, vibration, or rapid motion.

Due to its maturity, cost-effectiveness, and reliability, lens-shift OIS currently dominates the consumer market, particularly in mid-range and high-end smartphones.

Both lens-shift and module-move approaches rely on motion sensors to sense camera movement and compute compensating motion. This article explains the OIS principle using TDK-InvenSense ICM-53621 IMU (Inertial Measurement Unit), with examples focused on the lens-shift method.

This article while using ICM-53621 as an example, also can be applied to TDK IMUs ICM-56622, ICM-45631, ICM-45621, ICM-45634, ICM-42631.

2 HAND TREMOR AND PICTURE QUALITY

Human hand tremor while holding a camera is typically below 1° around ~10 Hz. That angular motion produces a lateral shift of the image on the sensor, causing blur. The perceived blur depends on the sensor's pixel pitch and the number of pixels shifted: more pixels of shift → more blur.

As an example, a 1° tremor can produce 100+ pixels of image shift on a 48 MP smartphone sensor (actual pixel displacement depends on focal length and pixel pitch).

Figure *1* illustrates how pixel shift affects image blur across a horizontal pixel span (e.g., 3264 pixels).

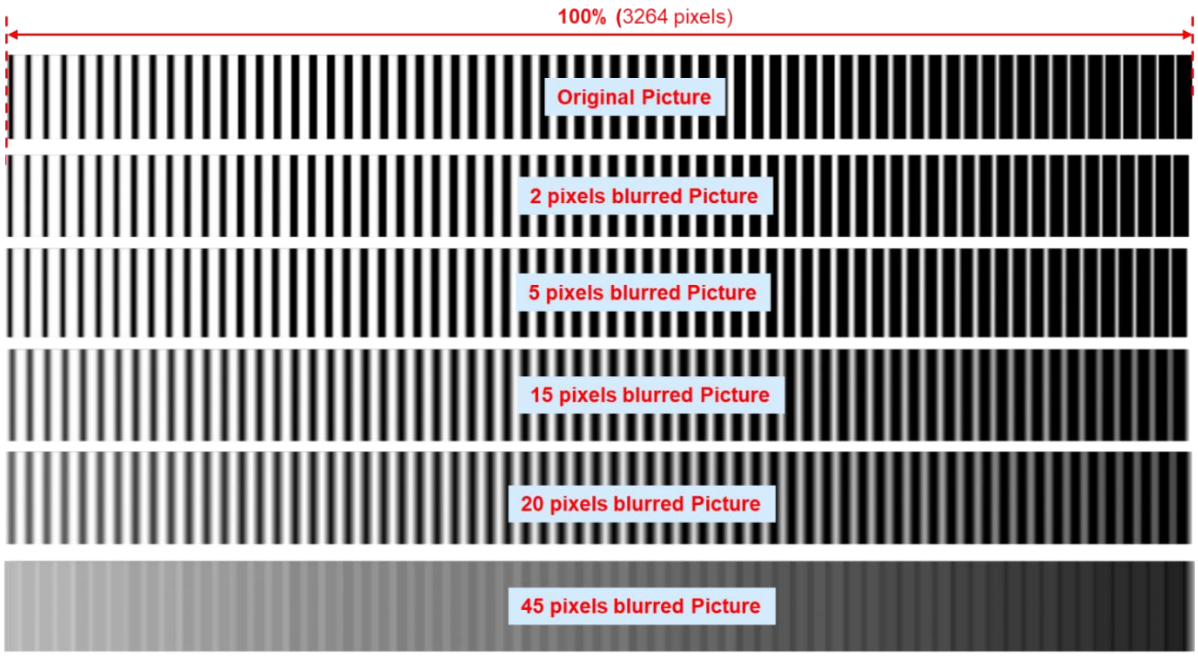

Figure 1. Image pixel shift vs blur

OIS systems are engineered to compensate for hand tremors, producing sharper, clearer images.

3 OIS BASIC PRINCIPLE

An OIS system combines motion sensors, compensation calculation, and an electronic control loop to counteract unwanted camera motion precisely.

The **Figure *2*** shows a typical OIS camera assembly: the lens element is mounted on a movable stage inside the actuator housing — a voice-coil actuator (VCM) in this example.

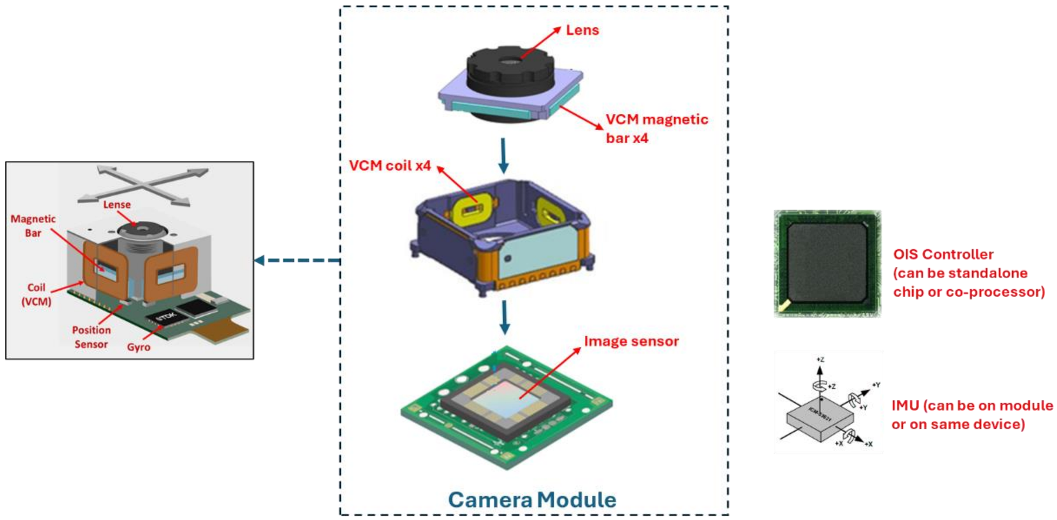

Figure 2 Device with OIS camera

Figure *3* shows a simplified OIS control loop. The gyroscope measures angular motion caused by hand tremors. Integrating the gyro rate over time gives the body rotation angle θ(t). Using the small-angle approximation (for $\theta \ll 1$ rad, $\tan\theta \approx \theta$), the required lateral displacement at the image plane can be computed and converted into physical actuator travel (µm). The controller compares this setpoint with the measured lens position (from the position sensor) and drives the lens actuator to minimize the position error (Err). The lens is moved opposite to the detected camera motion, effectively stabilizing the image.

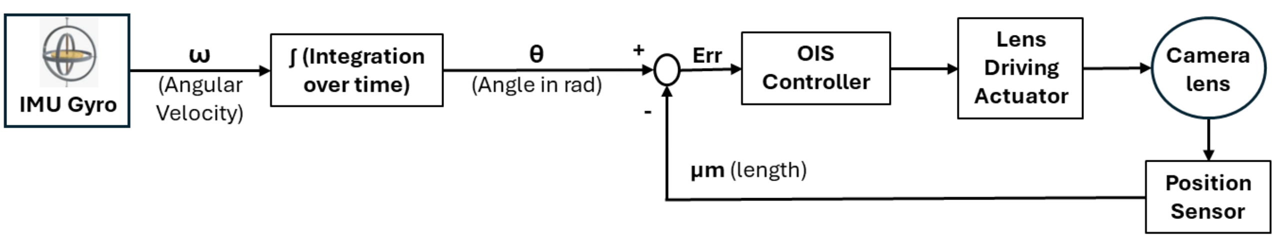

Figure 3. OIS Control Loop

4 IMU FOR OIS SYSTEM

The **Figure *4*** shows hand tremor in sine wave. Same hand tremor with same shutter time can create very clear or very blurry picture depending on when the shuttering falls in tremor waveform. The worst case happens when shuttering falls in black dash line period. During this time the tremor has highest angular velocity ɯ. The best case happens when shuttering falls in green dash line period. There is almost no pixel shift.

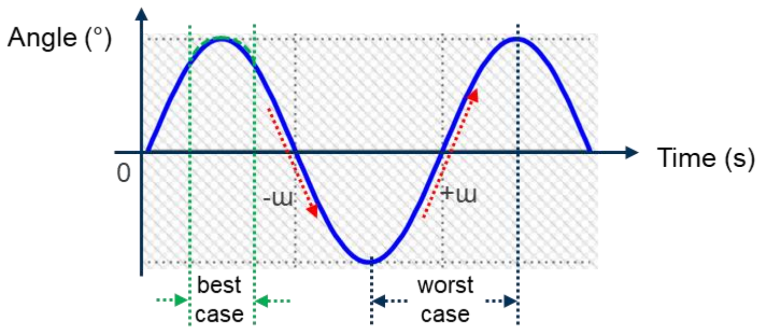

Figure 4. Hand Tremor

Hand tremor can be modeled as a sinusoidal angular motion.

- Moving angle θ(t) = A*sin(2*π*f*t)
- Moving angular velocity ɯ = d(θ)/d(t) = A*2*π*f*cos(2*π*f*t). Peak ɯ = A*2*π*f
- For 1° 10Hz tremor, the peak ɯ = 1*2*3.14*10 = 62.8 dps (°/s)

This indicates that the gyro full-scale range should comfortably exceed ~63°/s to capture typical hand tremor without clipping.

IMU gyro requirements for OIS include:

- High ODR (output data rate) and low latency (continuous, fast response)
- Full scale range above expected tremor (e.g., > 62.8°/s) with low noise
- High sensitivity accuracy, low cross-talk between axes, and low scale/sensitivity error
- Low thermal drift in offset and scale factors
- Low power consumption, and small package size
- Standard digital interfaces for easy integration

The TDK-InvenSense ICM-53621 is designed for motion and OIS applications. It provides dual digital interfaces that can output sensor data simultaneously on separate signal paths, allowing independent configurations (full-scale range, filter bandwidth, and interface protocol) per path. Its AUX interface supports an ODR up to 6.4 kHz and a gyro latency on the order of ~1 ms; gyro noise is around 5 mdps/√Hz, offset drift 0.015°/s/°C, and scale-factor drift 0.005%/°C. These characteristics make the ICM-53621 well suited for OIS loops. The **Figure *5*** shows its applications. Using the ICM-53621 customers can combine general motion IMU and OIS IMU in a single device, thus lowering bill-of-materials costs.

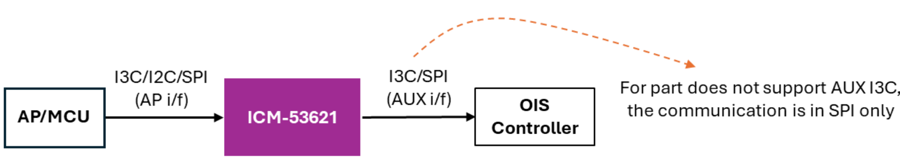

Figure 5. ICM-53621 Application

To reject a 20 Hz hand tremor effectively, designers typically target an OIS servo loop running between 2.5KHz to 5KHz depending on actuator technology. For OIS Motion SW, the controller commonly samples gyro data between 500Hz to 2 kHz to meet latency and stability requirements, where the ICM-53621 updates sensor data at 6.4KHz internally to minimize jitter.

5 OIS CONTROLLER

An OIS controller (hardware + firmware) reads motion sensors and lens position data, computes the corrective motion, and drives the actuator. Its typical functions are:

- Sensor fusion and feedforward: integrate gyro rates to generate a rapid displacement setpoint.
- Feedback control: close the loop on the position sensor (PID, PI, or state-space controller) to correct residual errors and drift.
- Drive circuitry: generate current/voltage commands for the actuator power stage (H-bridge, current driver, PWM/linear driver).
- Calibration, safety limits, diagnostics, and higher-level motion handling (panning/tilting algorithms).

Implementation options are:

- Standalone OIS controller IC (dedicated MCU/DSP + driver)
    - Pros: lowest latency and tremor, deterministic real-time loop, easier certification for safety/automotive, best bandwidth and residual motion performance.
    - Cons: higher BOM cost, additional area, and independent firmware/toolchain requirements.

- Sensor hub / SoC integrated controller (runs on shared MCU or camera SoC)
    - Pros: lower component count and material cost, shared memory/resources, easier data sharing with ISP and other subsystems.
    - Cons: possible higher latency and scheduling tremor (OS task contention), less deterministic timing under heavy host load — which can limit achievable OIS bandwidth.

Market note: dedicated OIS controller ICs are available from vendors such as ROHM. Many cost-sensitive designs implement OIS control on the sensor hub MCU when the performance requirements allow.

6 TDK OIS SOFTWARE

OIS Motion Software, developed and provided by **TDK**, is a next-generation motion control solution engineered to deliver flexibility and performance for optical stabilization and advanced motion applications.
Designed with a fully **agnostic approach**, OIS Motion seamlessly adapts to your ecosystem:

- **Actuator agnostic** – compatible with a wide range of actuator technologies
- **Target agnostic** – optimized for multiple use cases and product platforms
- **Architecture agnostic** – easily integrates across different system designs

Powered by advanced intelligence, the platform supports **EIS fusion**, enabling superior stabilization through combined electronic and optical motion processing.
OIS Motion also pushes performance further by:

- **Increasing stroke capability** for wider motion correction
- **Eliminating drift** to ensure long-term stability and accuracy
- Accelerating development with a **fast time-to-market advantage**

Backed by TDK's expertise in motion and sensing technologies, OIS Motion Software provides a scalable, future-proof solution that reduces complexity, enhances stability quality, and brings innovative products to market faster than ever.

7 LENS DRIVING ACTUATOR AND POSITION SENSOR

The lens driving actuator provides the controlled motion that cancels shaking. It must meet stroke, bandwidth, precision, size, power, and thermal requirements. Voice coil motors (VCM), shape memory alloys (SMA) and piezo-electric motors are used in OIS lens driving commonly.

- As shown in Figure 2, VCM is composed of permanent magnet and copper (or aluminum) coil. The magnetic bars are mounted on lens moving module. Coils are assembled stationery on camera base housing. Hall-effect sensor measures module position for feedback loop control. VCM produces fast-acting linear motion based on the Lorenz force principle. Its stroke range, high bandwidth and smooth linear motion are very suitable for OIS system. It is the most employed driving component in OIS systems.

- SMA wire length contract and extend with temperature change. The SMA actuator is made from SMA wires. The **Figure *6*** demos how the contract and extend moves object. It is very compact and simple for linear or rotary motion (wire springs, actuators) with low part count and cheap materials. To reduce BOM cost further, some vendors, such as CML, provide 8 wires SMA to manage AF (auto focus) and OIS with same actuator. The SMA actuator started being used in OIS system in recent years.

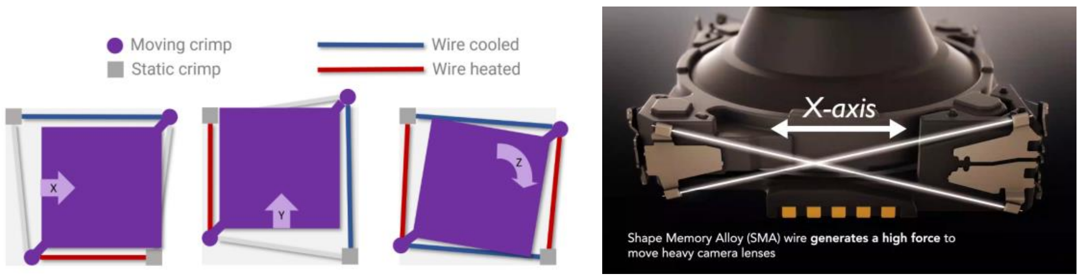

Figure 6. SMA wires contracting and extending when heated and cooled

- Piezoelectric actuator is based on the well-known piezoelectric effect, piezoelectric materials deform when a voltage is applied, producing precise, fast motion with sub-µm resolution. Native stroke is small and often requires mechanical amplification; they need high-voltage drivers and compensation for hysteresis, so they are used mainly in high-end OIS modules.

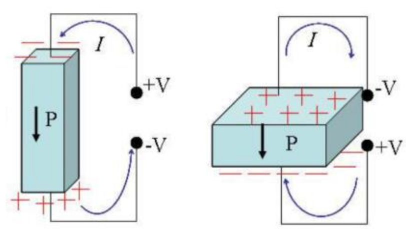

Figure 7. Piezoelectric

Position sensing commonly used in OIS are:

- Hall-effect sensors (most common in mobile OIS)
- Magnetoresistive sensors (AMR / GMR / TMR) for higher sensitivity
- Capacitive displacement sensors for very high resolution (used where packaging and contamination can be controlled)

8 OIS PERFORMANCE MEASUREMENT

OIS performance is commonly quantified by suppression or rejection of image motion. One practical metric is the suppression ratio (SR), often expressed in dB, which compares the amount of image damage (blurred/damaged pixels) with OIS enabled versus OIS disabled. A higher SR indicates better stabilization.

The **Figure *8*** illustrates how SR is measured and computed using controlled test motions and image analysis (for example, comparing the number of damaged pixels with OIS ON vs OFF).

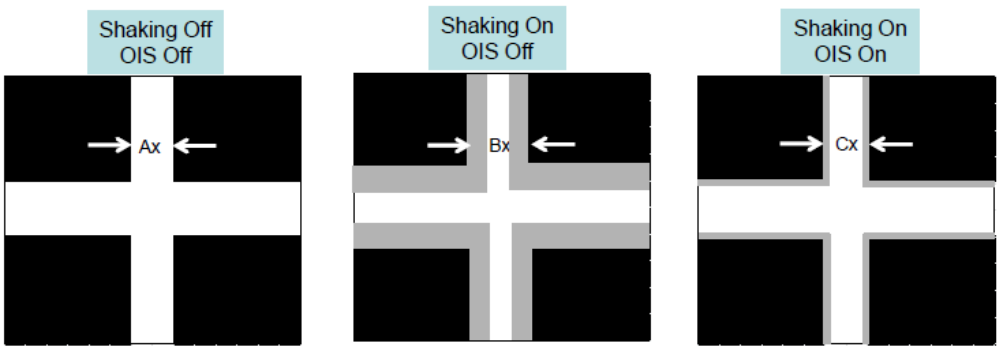

Figure 8. OIS suppression ratio

Common OIS test methods are:

- Mount OIS camera on a shaker, swept-sine with <1° at <10Hz.
- Capture 3 images
  - When shaker off and OIS off
  - When shaker on and OIS off
  - When shaker on and OIS on
- On computer, analysis the three images to count Ax, Bx and Cx in number of pixels.
- Use the formular to calculate suppression ration. **Suppression ratio (dB) = 20 Log** $(Cx - Ax)/(Bx - Ax)$

9 CONCLUSION

OIS systems integrate fast, low-drift low noise IMU, precise position sensing, responsive actuators, and deterministic controllers to minimize image blur from hand tremor.

Decisions about IMU selection, actuator type, position sensor, and controller implementation (standalone or integrated) must be balanced among performance, cost, power consumption, and physical size.

Low noise low thermal drift IMU (for example, the ICM-53621), proper calibration, thorough validation, and careful control-loop design are essential to achieving reliable and perceptible stabilization benefits.