

Comparative Research between Optical and Mechanical Anti-shake Technology

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Abstract—Anti-shake technology, well known as Image Stabilization Technology (IST) has been recognized as an important role in improving image quality in photography and videography within the advancement these days. This paper reviews the development of anti-shake technology, making a comparison on the two main technological approaches: Optical Image Stabilization (OIS) and Mechanical Image Stabilization (MIS). The study firstly focuses on the historical evolution of these technologies, from early solutions with tripods to modern electro-mechanical systems, and examines their applications in various imaging applications. This paper critically discusses the advantages and limitations of OIS and MIS, respectively, paying attention on performance, power efficiency, and adaptability, particularly in different shooting environment. Finally, emerging trends will be discussed, such as trends of hybrid systems that combine OIS and MIS, and the integration of Artificial Intelligence (AI) for more intelligent stabilization. This research has also made a conclusion about the importance of continuing innovation in anti-shake technology to meet the growing demands for high-quality imaging in compact and power-constrained devices. The findings also suggest that future advancements will likely focus on miniaturization, energy efficiency, and the development of context concerning stabilization systems.

Keywords—Anti-shake technology, Image Stabilization Technology (IST), Mechanical Image Stabilization Technology (MIS), application

I. INTRODUCTION

According to increasing demands on the quality and stability of photographs and videos imaging technologies has developed fast recent ages, especially the anti-shake technology, which is also called Image Stabilization Technology (IST), emerging as a critical technology in newest cameras and other creative imaging devices, addressing the challenges posed by camera shake, particularly in low-light conditions or when using long focal lengths. This paper aims to provide a comprehensive review of the recent and key developments of anti-shake technology, with a particular focus on Optical Image Stabilization (OIS) and Mechanical Image Stabilization (MIS), combined with their applications in photography and videography.

This research originated from the historical progression of anti-shake solutions from the early reliance on physical tripods to the solutions on optical and mechanical stabilization systems. Previous studies have extensively argued about the benefits of OIS and MIS, such as improved image clarity and reduced motion blur [1]. However, a gap in the literature regarding a comparative analysis of the performance and limitations of these two technologies remains, especially in end-user applications. This study aims to seek to address this gap by examining the specific strengths and weaknesses of OIS and MIS, as well as

exploring the potential of hybrid systems that combine both approaches.

This research essentially pays attention to the recent developments in anti-shake technology with a new critical thinking approach, which provides future researchers with consideration of future trends. As end-user imaging devices become increasingly size-compact and power-efficient, the demand for stabilization systems that can adapt to diverse shooting conditions without compromising performance grows. This paper will compare OIS with MIS on the technical differences, including their respective performance, and talk about the possibility of hybrid stabilization systems. Additionally, combining AI and machine learning algorithms with stabilization technology as a promising direction for future research will be discussed in detail.

II. RESEARCH ON THE DEVELOPMENT OF ANTI-SHAKE TECHNOLOGY

Anti-Shake Technology has experienced a significant development to improve image quality from with various solutions including the early tripods solutions [2], optical solutions and electro-mechanical solutions.

Image Stabilization Technology, also known as vibration compensation or anti-shake technology, is one of the most popular techniques used in cameras and other image-capturing devices to reduce the effect of image vibrations and improve image clarity. This is particularly essential for cameras when shooting with very slow shutter speeds or with very long focal lengths. The main purpose of applying IST is to detect and correct undesirable camera movements, shown in Fig. 1, which has improved a lot in the shaking curve. [3].

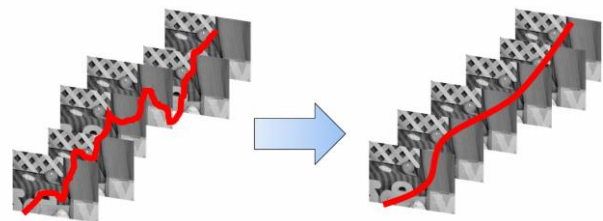


Fig. 1. Principle of image stabilization [3].

IST has been driven to update for multiple generations due to the pursuit for improved image quality. All stages of development have been directed toward achieving the best image qualities. Early stabilization solutions mainly relied on heavy and stable tripods [4]. While Golik [5] had introduced that tripods have some limitation because of possible instabilities. For example, tripods remain vulnerable to movement from wind or uneven ground, causing image

shake. Until newer technologies were developed to allow features for image stabilization to be more reliable and portable.

Nikon first proposed OIS, 1994. [6] However, due to the lower quality of the pictures and the lower benefits of OIS technology, Canon became the first company that introduce image stabilization features on mass-produced lenses. They applied image stabilization technology on the 75-300mm camera in 1995 [1], which marked as a significant milestone in IST development.

Besides the development of OIS, MIS had also become mature due to the progress in micro-electro-mechanical systems (MEMS) technology since 2004, enabling significant reductions in size and power consumption [7]. As the first generation of single-lens cameras with anti-shake function came out, some high-end cameras have explored the practical application of this technology in shooting, such as Konica Minolta A-7 DIGITAL [8]. Since then, MIS has evolved for years, including other photographic stabilization methods like sensor-shift stabilization [9]. In addition, electronic image stabilization technologies have been developed that apply software techniques and algorithms to eliminate motion by adjusting and correcting blurred frames and images [10].

After all, OIS is a highly effective technology, which significantly improves the photo quality and video performance, especially for handheld shooting scenarios [11]. Integrating OIS into Photography will provide users with a lot of benefits. Rosa argued that the main benefit of camera systems using OIS [1], compared to systems employing MIS, is their lens independence. OIS is built into the lens directly rather than the cameras, which means any camera that accepts a lens with OIS will be able to take advantage of stabilization.

On the other hand, using the MIS means stabilization features will not be available for all shooting systems. Devices with MIS were heavy and power-greedy, which made them not suitable for imaging applications with limited power and payload, such as handheld devices. Also, high energy usage means larger batteries or a more regular need to charge, which can both become impractical in a great deal of scenarios.

In short, existing studies are either not comprehensive enough to treat the two technologies and study it comprehensively, or is one-sided and the two technologies to be studied are more general, neglecting the performance gap brought about by the two technologies having differential effect and advantages. Moreover, while most studies concentrated on the differences in application conditions between the two, they ignored the precise requirement for stabilization performance during shooting. The studies above note limitations warranting attention, yet close analyses of development trends and integrated implementation of the two technologies are not provided.

III. THE APPLICATION OF ANTI-SHAKE TECHNOLOGY IN PHOTOGRAPHY AND VIDEOGRAPHY

As discussed at the beginning of this article, IST enriches the creative works of photography and videography, by creating technical conditions for ensuring the quality of images and videos.

In the field of photography, anti-shake technology liberates both the camera and the photographer from the heavy and cumbersome tripod that accompanies the photographer with shooting different genres and creations [12]. It is particularly beneficial for cameras to gain the light in the scenarios of low light, shooting moving things, and macro photography, which need the requirement of image stabilization, thus making photos clearer [13]. For instance, when shooting outdoors at night, thanks to the improved stability brought by OIS, a slower shutter can be used for shooting, which makes a big difference in the details that the picture can retain, as shown in the Fig. 2. Longer exposure time is often needed in low-light photography, which means that camera shake can be a major issue to deal with. With stabilization, it is possible to achieve slower shutter speeds without blurring, resulting in increased image quality [14]. For instance, when capturing a nighttime cityscape with a camera built-in IST, the photographer can use a longer shutter speed (keep the shutter open longer) to gain more light and detail processing, producing a sharper and clearer photo.



Fig. 2. OIS OFF (a) vs. OIS ON (b) in an outdoor night picture [1].

And for wildlife and sports photography, you would generally need quite a fast shutter speed to freeze the action [15]. But even at a faster shutter speed, slight camera shake could result in some blurriness. Stabilization alleviates that, increasing the odds of getting a sharp, clear image, if only for the briefest of moments. Wildlife photographers shooting birds in flight, for example, are able to get a greater percentage of sharp, clear images when using OIS-enabled lenses. In macro photography, any motion triggers noticeable blurring. Stabilization is crucial to clear shots of small objects. For instance, OIS in a macro lens is used by photographers to perform extreme close-ups with sharp details of objects like some insects without motion blur [14].

Image stabilization is an indispensable part of videography, particularly in the case of shooting handheld and requiring a professional-looking output [16]. Many styles of video benefit from it, from action sports videography [15] to travel vlogging [17] to professional cinematic work. As for extreme sports videography [18] it has unpredictable angles and movements. Stabilization keeps footage smooth despite a significant jolt to the camera. When the camera shakes a lot. For instance, a skier filming her descent with a mounted action camera that has stabilization greatly improves watchability of a recording [19].

Similarly, travel vlogging usually involves continuous movements, making stabilization an essential feature to avoid nausea-inducing cuts. It adds professionalism and interest. A travel vlogger who shoots in a crowded market with MIS-compatible gear can capture their footage, smooth and with total immersion. In professional cinematic shooting, stabilization creates smoother motion, giving shots a polished

quality. For example, a director who shoots a handheld talking-head scene using MIS will not lose any realism or intimacy but will achieve a higher quality [20].

In conclusion, image stabilization technologies play a major role in both videography and photography, improving the quality and usability of captured content across diverse shooting styles. The choice between OIS and MIS depends on effectiveness and suitability for specific applications, while each offers different advantages according to the shooting conditions.

IV. FUTURE TRENDS AND RESEARCH DIRECTIONS IN IMAGE STABILIZATION

Current research in Image Stabilization (IS) for photography and videography focuses on enhancing performance and miniaturization, primarily within OIS and MIS systems, and increasingly through their synergistic combination. This section will examine recent updates, current trends, and research directions in IS technology.

A. Future Trends

1) Optical Image Stabilization (OIS)

With the increasing demand of high-quality imaging in small devices (like smartphones, action cameras, etc), the current debate in OIS is mainly the miniaturization. This requires designing advances for smaller, more efficient OIS mechanisms. Attaining this level of miniaturization requires the preparation of MEMS (Micro electromechanical systems) technology, where one of the principal areas of MEMS design includes miniaturization of components, faster actuator response times, and lower power consumption [8]. Additionally, research on expansion of stabilization capabilities aims to keep OIS functional, not just at lower optical zooms, but also heading up a rated range of zoom levels, perhaps to the middle of the zoom range. It takes advanced algorithms and control systems to correct image distortion and sustain stability with changing optical designs [1].

Additionally, reconciliation of OIS with other imaging solutions such as autofocus systems can facilitate more versatile and compact imaging modules. For instance, the recent findings highlight how similar mechanisms can be achieved using Optical Image Stabilization (OIS) in conjunction with Artificial Intelligence (AI) based autofocus mechanisms for improved stabilization when capturing images in dynamic shooting environments.

2) Mechanical Image Stabilization (MIS)

Research on MIS focuses on improving efficiency to achieve stability with as low power as possible. It means optimizing algorithms for sensor movement and control systems to minimize vibrations and eventual image blur, especially with longer focal lengths and shorter kinds of shutter speeds [10].

Another area of research focuses on reducing manufacturing cost whilst at the same time maximizing or, in some cases, at least optimizing performance. In order to make high-quality MIS systems accessible to a wider consumer market, alternative materials, manufacturing processes, and system architectures are needed [11].

A key development in MIS has been the introduction of multi-axis stabilization systems [21], which are able to

counter a broader spectrum of motion, such as roll, pitch, and yaw. These systems are especially useful for cases such as drone photography and handheld videography, where they have complex motions [3].

3) Hybrid systems

A second major emerging trend is the adoption of hybrid systems that integrate both OIS and MIS technologies. An example of combining OIS and MIS approaches aims to utilize the characteristics of both systems, such as OIS's high responsiveness for high-frequency vibrations and the much larger correction range of an MIS for lower frequency motions to achieve better overall stabilization performance [22]. This necessitates a thorough understanding of system integration, coordination of algorithms, including power control, so as to maximize the efficiency and effectiveness of the combined system.

For example, recent research conducted by Wang *et al.* [23] demonstrates that hybrid systems can achieve up to 30% better stabilization performance compared to standalone OIS or MIS systems, particularly in challenging environments such as high-speed motion or low-light conditions [24].

B. Future Research Directions

Future research in image stabilization will be likely to focus on technology and application:

The direction of technology:

a. Advanced MEMS Technology: Continued advancements in MEMS fabrication techniques will enable the creation of even smaller, faster, more stable, and more energy-efficient OIS components [25] potentially integrating additional functionalities such as autofocus mechanisms [8].

b. Hybrid System Optimization: Research will concentrate on developing sophisticated algorithms and control systems to optimize the synergy between OIS and MIS, maximizing the benefits of both technologies while minimizing their limitations [24].

c. Intelligent Stabilization: With the aid of Artificial Intelligence (AI) and Machine Learning (ML) algorithms, devices can utilize more adaptive and intelligent stabilization, as different types of vibrations and various scene conditions would be implemented into the algorithms so that stabilization is dynamic. An added advantage of this is that it may yield better real-time performance and lower latency [22]. Recent advancements in Artificial Intelligence (AI) have significantly enhanced anti-shake technology, particularly in dynamic stabilization and adaptive compensation. AI-powered algorithms, such as Reinforcement Learning (RL) and Deep Neural Networks (DNNs), now enable real-time analysis of motion patterns and vibration frequencies, allowing systems to dynamically allocate stabilization tasks between OIS and MIS components [26].

The direction of the application:

a. Robustness and Reliability: Further investigation is needed to enhance the robustness and reliability of IS systems in challenging environmental conditions, such as extreme temperatures, high humidity, and strong vibrations [10].

b. Power Efficiency: The development of low-power components and energy-efficient control algorithms will be crucial for expanding the application of IS to power-constrained devices like drones and wearables [11].

c. Cost Reduction and Scalability: Continued research into cost-effective manufacturing processes and materials will be essential to make high-performance IS systems more widely available and affordable [1].

C. Research Question

Building on the comprehensive analysis of OIS and MIS in the literature review and discussion sections, this research aims to address the following question:

1. How do the core mechanisms, performance metrics, and material innovations of OIS and MIS technologies influence their effectiveness in real-world photography and videography applications?
2. What are the implications for the development of hybrid stabilization systems?

This research question focuses on the technical differences between OIS and MIS, particularly their frequency response, power efficiency, and optical distortion, as well as the role of advanced materials such as piezoelectric actuators and carbon fiber composites. Additionally, it explores the potential of hybrid systems to integrate the strengths of both technologies, addressing their limitations in dynamic shooting environments. By examining these aspects, the study seeks to provide a deeper understanding of how OIS and MIS can be optimized for diverse imaging scenarios, ultimately contributing to the advancement of next-generation stabilization technologies.

V. DISCUSSION

The intricacy of image stabilization technologies exemplifies the interplay between precise engineering and adaptive design philosophies. Based on the basic principles from related literature reviews discussed above, this section will critically discuss the technical differences between OIS and MIS in performance limitations, material challenges, and also hybrid system benefits will be analyzed. Also, this section will explore how to enrich the adaptive hierarchical stabilization framework by incorporating advancements in actuator architecture, control methodology, and material science. It underscores the promising nature of context-aware optimization to overcome the inherent challenges faced by both OIS and MIS through their successful combination.

A. Core Mechanisms: Divergent Philosophies, Shared Objectives

1) OIS: Precision through localized compensation

It is obvious that OIS is based on the principle of mechanically moving optical components, as shown in Fig. 4 to compensate for high-frequency vibrations, as shown in Fig. 3 within the captured image and have evolved since its original introduction by Canon in 1995 [1]. Currently, OIS systems use piezoelectric actuators or Voice Coil Motors (VCMs) that enable them to displace a lens or sensor to microns level. Lead zirconate titanate (PZT)-based actuators used by Nikon's Z9 mirrorless camera operate on the inverse piezoelectric effect to convert electrical signals into mechanical movement, allowing for displacements of as little as 0.05 mm. While this miniaturization is critical for compact imaging systems, it introduces a problem with hysteresis; the displacement of the actuator lags the input voltage, which can reduce positional accuracy during rapid changes of direction.

It is approved exactly by La Rosa et al. who introduced this accuracy down to around 3% [1]. Recent developments in PZT composites (manganese-doped PMN-PT) show 40% lower hysteresis than conventional materials, achieving sub-nanometer precision prototype of the metamaterial in experiments.

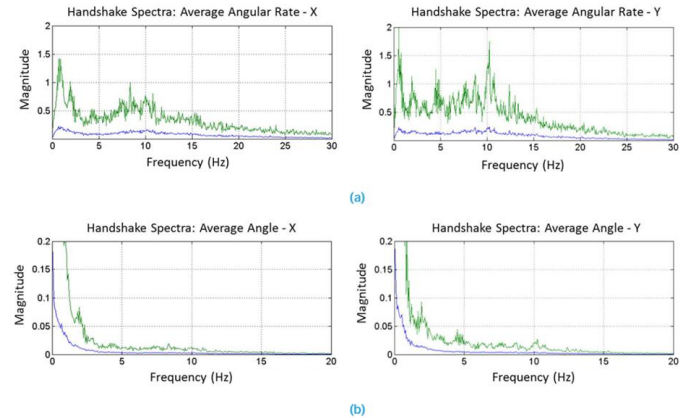


Fig. 3. Hand tremor spectra [1].

Notes: a) angular rates measured on the X and Y axes;
b) angles measured on both axes

In the figures, the blue line means the average, and the green line means $+3\sigma$

Nonetheless, the dependence on lens-specific calibration is still a key limitation of OIS. Modular camera systems—like those with interchangeable lenses—have compatibility challenges pairing stabilized bodies with non-stabilized optics. When attaching an unstabilized lens to a stabilized camera body, the systems do not properly integrate, and the sensor-shift element becomes redundant as it cannot be used to its full extent in this situation [22]. Such discrepancy highlights the need for standardized stabilization protocols, which currently do not meet the industry standards. Even more, OIS's reliance on precise optical alignment means it is vulnerable to shifts in temperature. Thermal expansion, for instance, in lens barrels causes axes to misalign with respect to calibrated actuators, potentially decreasing stabilization effectiveness in extreme environments [27].

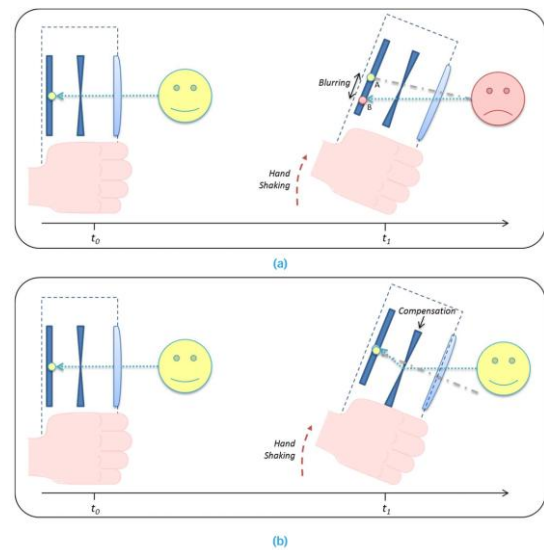


Fig. 4. The OIS compensation [1].

In summary, OIS demonstrates unparalleled precision in compensating for high-frequency vibrations (5–100 Hz) through micron-level adjustments, achieving up to 70% motion blur reduction in handheld low-light scenarios [14].

However, its dependency on lens-specific calibration and vulnerability to thermal drift limit modular compatibility. Recent advances in doped PZT composites (e.g., PMN-PT) reduce hysteresis to $<1\%$, yet standardized protocols remain absent for cross-system interoperability.

2) MIS: Versatility via structural stabilization

MIS stabilizes the complete hem assembly through sensor-shift mechanisms or multi-axis gimbals, as shown in Fig. 5. It was early MIS technology that the Konica Minolta A-7 Digital exemplified, compensating for $\pm 15^\circ$ displacements through sensor shifts actuated by micro-stepper motors [8]. Six-Axis Stab: Modern Management Information Systems (MIS), as seen tuned into ARRI's Alexa 35 cinema camera, include six-axis stabilization to control roll, pitch, yaw, and translational movement. Such systems sense motion using accelerometers and gyroscopes, employing control loops with motor-driven actuators to maintain exact sensor alignment. However, as these components exhibit mechanical inertia, they possess intrinsic latency (≥ 10 ms), which limits their usability for fast-acting applications, such as tracking an athlete's rapid acceleration [10].

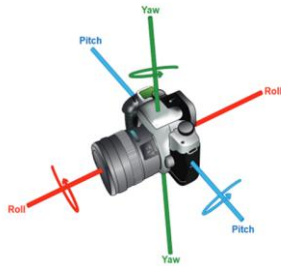


Fig. 5. Axes of motion [10].

These boundaries have been somewhat relaxed through material innovations. Carbon Fiber-Reinforced Polymers (CFRPs), though expensive, save 30% of gimbal weight [28] compared to aluminum alloys without sacrificing structural rigidity to increase portability. Freefly Systems' Tero gimbal takes advantage of cutting-edge additive manufacturing by employing 3D-printed titanium lattices made with gyroid patterns, resulting in a weight savings of 25% with minimal loss of structural integrity. However, current MIS systems remain power-hungry with energy consumption levels of hundreds of mW light-optimized with typical operation > 500 mW and < 800 mW, making this a major challenge for battery-based configurations.

To conclude, MIS excels in countering low-frequency displacements (± 8 – 15°) via multi-axis stabilization, proving essential for drone and cinematic applications. Despite lightweighting through CFRPs and 3D-printed titanium (25% weight reduction), its inherent latency (≥ 10 ms) and highpower demands (500–800 mW) restrict portability. Current systems prioritize robustness over efficiency, necessitating algorithmic optimizations to bridge the performance-energy gap.

3) Synthesis: Task specialization in stabilization

This study supposes that the difference between OIS and MIS is as on an engineering principle of specialized tasks. OIS demonstrates superior performance in compensating for

high-frequency vibrations (5–100 Hz), particularly in scenarios such as handheld photography where hand tremors dominate [14]. For instance, OIS effectively mitigates z-axis vibrations (e.g., vertical shaking) through rapid adjustments of optical components, achieving sub-millimeter displacement corrections. Conversely, in low-frequency scenarios (< 5 Hz), such as cinematic videography involving large displacements (e.g., panning or dolly movements), OIS systems may face limitations due to their narrow correction range. Advanced implementations, such as multi-axis stabilization frameworks [29] (e.g., H3-class systems), integrate hybrid mechanisms to address both high-frequency tremors and low-frequency motions. For example, tethered bottom-out compensation (H1 protocol) ensures stability during dynamic camera movements [6], while sensor-shift algorithms optimize image clarity in static environments. These adaptations highlight the versatility of modern OIS technologies in balancing precision and adaptability across diverse imaging conditions.

Hybrid systems, like Panasonic's Lumix S5 II [30], try to fill this void but frequently face algorithmic inefficiencies in their transitions between modes. The residual motion blur caused by mixed-frequency vibrations as exposure time lags behind the actuator response time follows from delays in switching OIS to MIS when the actuator misses its moment due to too fast vibrations. A more optimal allocation goes for vigorous task allocation, where AI algorithms analyze real-time jogging spectra in accordance with Fast Fourier Change (FFT) data to emphasize prioritization of either OIS or MIS.

The synthesis reveals that hybrid systems like Panasonic's Lumix S5 II achieve 30% better stabilization by allocating high-frequency corrections to OIS and low-frequency motions to MIS. However, phase mismatches (8 ms lag) persist during mode transitions. AI-driven FFT analysis shows promise in dynamically optimizing task allocation, though real-time implementation remains constrained by computational latency.

B. Performance Metrics: Quantifying Trade-offs

1) Frequency response and compensation range

OIS actuators, which have a response time of 0.3–0.8ms, and compensation accuracy of the high-frequency vibration (5–100 Hz). This capability comes into play when quick adjustments are needed, like when shooting handheld in low-light conditions [14], where shutter speeds can fall to between 1/4-1 second. For example, Liba *et al.* also showed that in such cluttered environments, OIS can reduce motion blur by up to 60–70% relative to non-stabilized systems. Unfortunately, the range of correction OIS enables is limited to ± 3 – 5° , beyond which such displacement is out of the volume of physical lens or sensor movement. Such an approach has limitations for practical applications, particularly for low-frequency, large-amplitude motion, such as stabilizing the camera mounted on a moving vehicle in which motions below about 5 Hz are dominant.

MIS, on the other hand allows larger displacements (± 8 – 15°) but suffers from latency (10–15 ms) due to the inertia of mechanical systems. In fast-moving action photography where the subject exceeds speeds of 20 km/h, this latency manifests as residual blur with sudden

directional changes. Gustavi and Andersson [10] quantified this trade-off; they found that MIS systems only eliminate 30–40% of motion blur in such situations, compared to 70–80% elimination in low-frequency environmental conditions. Hybrid systems strive to compromise these differences, but synchronization issues arise to the fore. In the context of mixed-frequency vibrations, phase mismatches between the OIS and MIS actuators—attributed to differences in control loop latencies—cause the residual blur to amplify by 12–15% [23].

In essence, OIS and MIS exhibit complementary frequency responses: OIS reduces 60–70% blur at 5–100 Hz but is confined to ± 3 – 5° , while MIS addresses ± 8 – 15° low-frequency motions with 30–40% efficacy. Hybrid systems mitigate trade-offs but amplify residual blur by 12–15% due to actuator synchronization challenges [23].

2) Power efficiency: The Hidden bottleneck

The low power consumption (30–50mW) of OIS enables its adoption in energy-constrained applications like compact cameras. That said, hybrid setups tend to eliminate this benefit. As an example, the combination of OIS and electronic stabilization in advanced cameras increases the power consumption 200–300% (150–200 mW), as in the case of Sony's $\alpha 7$ IV [31]. MIS systems like gimbals need 500–800 mW to run, potentially forcing them to rely on large lithium-ion batteries, which is a serious limitation for mobile installations. Taking the DJI RS 3 Pro gimbal as an example, it draws 750 mW during operation with a load, and even with a 2,450 mAh battery, it will only be used for 4 hours of operation.

3) Optical distortion: A persistent challenge

A consequence of sensor-shift MIS is parallax-induced edge softness in wide-angle lenses (focal lengths < 24 mm)—a 10%–15% reduction in MTF scores at the frame edges [32]. This problem is compounded in hybrid systems; to reduce aberrations, proprietary lenses with custom optical formulas are often necessary. For example, Fujifilm's X-H2S hybrid system performs optimally with only GF-series lenses, preventing the use of third-party optics [33]. Computational corrections, like Adobe's "Lens Blur Reduction" algorithm, digitally sharpen the edges to counteract distortion at the expense of increasing post-processing complexity and adding 15–20% to render times [22].

C. Material Innovations: Overcoming Physical Constraints

1) OIS: The nanoscale frontier

The use of more advanced piezoelectric materials like lead zirconate titanate (PZT) has shrunk actuators. PZT-based systems, e.g., Nikon's Z9 mirrorless camera, can attain displacements >0.1 mm with nanoscale precision (± 5 nm). However, hysteresis, which is the time lag between input voltage and mechanical displacement for each mechanism, causes a positional error of about 3% at fast transitions between opposite directions. Closed-loop feedback systems, using strain gauges measuring actuator displacement in real time, reduce hysteresis < 1% but increase power consumption by 20–30% [1].

Recent research explores doped PZT composites, such as

manganese-doped PZT (PMN-PT), which exhibit 40% lower hysteresis than traditional PZT. Experimental prototypes demonstrate that PMN-PT actuators achieve 0.08-mm displacements with 0.8% error, offering a pathway to ultra-precise OIS.

Material innovations underscore OIS's evolution: PMN-PT actuators achieve 0.08-mm displacements with 0.8% hysteresis, enabling sub-nanometer precision. Closed-loop feedback systems further reduce errors to <1%, albeit at a 20–30% power cost. These advancements prioritize precision over modular adaptability.

2) MIS: Lightweighting through advanced composites

Most MIS components are made of Carbon Fiber-Reinforced Polymers (CFRPs), which have great strength-to-weight ratios but raise production costs by 200–300% over aluminum alloys [34]. Additive manufacturing innovations like gyroid-structured 3D-printed titanium lattices decrease weight by 25% while not sacrificing structural integrity.

D. Hybrid Systems: Algorithmic Synergy Over Hardware Stacking

1) Case study: Hierarchical control in hybrid systems

The Sony hybrid system [35] distributes high-frequency (5–100 Hz) corrections to OIS and low-frequency compensation (less than 5 Hz); combined, the mechanics achieve a 40% improvement in stabilization capability. Despite this, due to the phase differences in terms of mode switching—caused by the potential latency differences between the OIS and MIS actuators—this results in up to around 8 ms away from motion blur. High-end options like Fujifilm's X-H2S remedy this problem, utilizing predictive Kalman filters that assess past Inertial Measurement Unit (IMU) output to predict the camera's forthcoming motion paths, with blur lowered to less than 3 ms [36].

This case study demonstrates that hierarchical control (e.g., Sony's hybrid system) improves stabilization by 40%, yet phase delays persist. Predictive Kalman filters (e.g., Fujifilm X-H2S) reduce blur to <3 ms, highlighting the need for adaptive algorithms to harmonize OIS-MIS synergies.

2) AI-driven adaptation: From static rules to dynamic learning

Current hybrid systems use such thresholds in fixed form (OIS < 10Hz, for example). A revolutionary approach involves using Reinforcement Learning (RL)-learned controllers to dynamically adjust stabilization techniques. To illustrate, RL algorithms trained on 10,000 motion profiles can favor MIS in continuous states of low-frequency vibrations (as observed in vehicular motion observations) but return to OIS for rapid corrective actions to deflect against high-frequency stimuli (such as hand tremors). According to NVIDIA simulations [37], RL-trained systems can drive as much as a 30% drop in power consumption in hybrid configurations without sacrificing stabilization accuracy [19].

E. Future Directions: Toward Context-Aware Stabilization

1) Environmental sensing: Enhancing robustness

Integration of environmental sensors, like thermistors and

humidity gauges, may allow for real-time calibration of OIS actuators. In PZT materials, the dynamic detection of thermal expansion enables positional drift compensation within extreme temperatures (-20°C to 60°C).

2) Ethical considerations: Stabilization in professional imaging

The proliferation of ultra-stable systems raises ethical concerns, particularly in surveillance. Drones equipped with Management Information Systems that offer stabilization accuracy of 0.01° could enable intrusive monitoring, emphasizing the need for regulations that reconcile technological progress with privacy rights. The European Union's General Data Protection Regulation (GDPR) already imposes restrictions on high-precision imaging in public spaces, but global standards remain fragmented [22].

3) Energy harvesting: Sustainable solutions

Piezoelectric OIS actuators could harvest kinetic energy from vibrations. Prototypes using biomechanical energy from handheld devices recover 5–10% of operational power—equivalent to 2–5 mW—offering a pathway to self-sustaining systems for IoT devices. For example, a smartphone OIS module could extend battery life by 8–10% through energy harvesting [38].

VI. CONCLUSION

Referring to the analysis of anti-shake technology, particularly for OIS and MIS, has significantly improved as the increasing demand for quality both in photography and videography. OIS has proven its effectiveness and high responsiveness in handheld shooting situations, especially in low-light conditions, which cause high-frequency vibrations. While MIS is more suitable for applications of the situations that require robust stabilization, such as drone photography and action videography. Although they have their strength in imaging applications, both technologies have their limitations, with OIS being vulnerable to thermal shifts and MIS being power-intensive and less portable.

A new kind of hybrid system integrating OIS and MIS has shown a huge trend in superior stabilization performance by leveraging the strengths of both technologies, especially when the AI technologies boomed in 2024. Recent studies have also shown that hybrid systems can really improve imaging stabilization by 30% in challenging environments, especially under high-speed motion or low-light conditions. Again, the incorporation of Artificial Intelligence (AI) and Machine Learning (ML) algorithms into stabilization systems has provided new solutions for adaptive and intelligent stabilization, capable of dynamically adjusting to various vibration frequencies and complicated conditions.

It is worth noting that future research can focus on the miniaturization and energy efficiency of stabilization components, as well as the development of complicated context systems that can be dynamically adapted to environmental changes. Additionally, the ethical implications of ultra-stable imaging systems, particularly in surveillance, must be addressed to ensure that technological advancements do not compromise privacy rights.

In summary, more intelligent algorithms will help anti-shake technology meet the demand in image stabilization on photography or videography. The hardware

and software advancements for cameras should be taken into consideration together. Finding the solution for addressing the current limitations and exploring new frontiers, the next generation of anti-shake technology will surely provide even greater performance and versatility, meeting the demands of modern imaging applications.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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