



Performance Analysis of a Low-Pass Filter for Stabilizing the Rotation of a Gyroscope-Based Virtual Camera

Dila Dahlia¹, Tito Pinandita², Sigit Sugiyanto³, Elindra Ambar Pambudi⁴

^{1,4}Department of Informatics Engineering, Universitas Muhammadiyah Purwokerto, Indonesia, 53174

dahliadila2314@gmail.com

<https://doi.org/10.37339/e-komtek.v10i1.3001>

Published by Politeknik Piksi Ganesha Indonesia

Abstract

Artikel Info

Submitted:

13-01-2026

Revised:

14-06-2026

Accepted:

14-06-2026

Online first :

19-06-2026

The use of mobile device cameras often suffers from rotational instability caused by jitter and sudden orientation changes, reducing visual quality and user experience in virtual camera applications. This study evaluates the effectiveness of a low-pass filter in stabilizing gyroscope-based virtual camera rotation. Experiments were conducted using an iPhone 12 under six movement scenarios: slow rotation, fast rotation, random movement, walking, stair climbing, and motorcycle riding. Euler angle and inter-frame jitter data were analyzed before and after filter implementation. The results show that the low-pass filter significantly reduces rotational jitter in five of the six scenarios. The greatest improvement was observed during walking, with an 86.55% reduction, followed by fast rotation (72.21%) and random movement (68.87%). These findings confirm that the low-pass filter effectively suppresses high-frequency rotational disturbances, enhancing virtual camera stability and providing a practical foundation for developing more reliable gyroscope-based rotation stabilization systems on mobile devices.

Keywords: Gyroscope; Jitter; Mobile Device; Camera Rotation; Low-Pass Filter

Abstrak

Penggunaan kamera perangkat seluler sering kali mengalami ketidakstabilan rotasi yang disebabkan oleh getaran dan perubahan orientasi mendadak, sehingga mengurangi kualitas visual dan pengalaman pengguna dalam aplikasi kamera virtual. Penelitian ini mengevaluasi keefektifan filter low-pass dalam menstabilkan rotasi kamera virtual berbasis giroskop. Eksperimen dilakukan menggunakan iPhone 12 dalam enam skenario gerakan: rotasi lambat, rotasi cepat, gerakan acak, berjalan, menaiki tangga, dan mengendarai sepeda motor. Data sudut Euler dan jitter antar-bingkai dianalisis sebelum dan sesudah penerapan filter. Hasilnya menunjukkan bahwa filter low-pass secara signifikan mengurangi jitter rotasi pada lima dari enam skenario tersebut. Peningkatan terbesar teramati saat berjalan, dengan pengurangan sebesar 86,55%, diikuti oleh rotasi cepat (72,21%) dan gerakan acak (68,87%). Temuan ini menegaskan bahwa filter low-pass secara efektif menekan gangguan rotasi frekuensi tinggi, meningkatkan stabilitas kamera virtual, dan memberikan landasan praktis untuk mengembangkan sistem stabilisasi rotasi berbasis giroskop yang lebih andal pada perangkat seluler.



This work is licensed under a [Creative Commons Attribution-NonCommercial 4.0 International License](https://creativecommons.org/licenses/by-nc/4.0/).

1. Introduction

The development of mobile device technology has rapidly advanced, especially in camera features. Mobile cameras are not only used for documentation but also for digital content creation, video streaming, visual-based learning, and applications involving visual reality. Camera rotation stability has become a crucial aspect because uncontrolled vibrations and orientation changes can reduce visual quality and disturb user experience. The use of smartphone cameras in real-time applications also shows that capture quality and image stability are strongly influenced by device and environmental conditions, particularly when the device is moved dynamically, such as by hand shaking or rapid positional changes [1].

Although modern mobile devices are equipped with Optical Image Stabilization (OIS) and Electronic Image Stabilization (EIS), these technologies are designed for physical camera hardware and cannot be directly applied to virtual cameras implemented in development environments such as Unity. As a result, virtual camera systems require alternative stabilization approaches that rely on internal sensor data rather than hardware-based mechanisms. Unity provides access to gyroscope sensors on iOS devices, enabling real-time acquisition of device orientation data that can be utilized for virtual camera rotation stabilization.

Some technical terms used in this study need to be clarified for readers. A gyroscope sensor is an inertial sensor that measures angular velocity and changes in device orientation along the pitch, roll, and yaw axes [2] Jitter is defined as rapid and undesired fluctuations in inter-frame rotation angles, causing virtual camera rotation to appear shaky and unstable [1] These rotation fluctuations are influenced by sensor noise and dynamic user movements. Jitter damping is achieved using a low-pass filter, a signal processing method that suppresses high-frequency components to produce smoother and more stable rotation signals [3], [4]

Previous studies have shown that gyroscopes play an important role in maintaining device orientation stability. Han et al. (2021) and Karpenko et al. (2011) emphasized that integrating gyroscopes can reduce jitter and improve movement accuracy in video stabilization processes. Hadi et al. (2019) and Asnada & Sulistyono, (2020) reported that stable gyroscopes are used in determining device orientation. Li et al. (2023) demonstrated that using gyroscopes can improve motion estimation reliability under unstable conditions. Research by Ren et al. (2024), Milanović et al. (2021), and a local study by Teguh Santoso et al. (2021) further confirm that gyroscopes are effective in maintaining orientation stability across various systems.

However, most existing research focuses on physical camera stabilization or post-processing of recorded video, while real-time stabilization of virtual camera rotation using gyroscope data in Unity-based mobile applications remains relatively unexplored. In addition, many studies emphasize qualitative improvements without providing a detailed quantitative analysis of inter-frame jitter reduction under diverse motion scenarios. This study addresses this gap by applying a low-pass filter algorithm directly to gyroscope-based virtual camera rotation in a real-time mobile environment and evaluating its performance quantitatively using jitter and angular deviation metrics across multiple realistic motion conditions.

Therefore, this study aims to analyze the performance of a low-pass filter algorithm in stabilizing virtual camera rotation using gyroscope sensor data on iOS devices. The evaluation is conducted by comparing angular deviation and jitter values before and after applying the algorithm under several motion scenarios. The results are expected to provide an objective and quantitative assessment of the effectiveness of the proposed method in improving virtual camera orientation stability under dynamic usage conditions.

2. Method

This study employs a quantitative approach to analyze the effectiveness of a low-pass filter algorithm in stabilizing virtual camera rotation using gyroscope data on a Unity application for iOS devices. A quantitative approach was chosen because camera rotation stability can be numerically represented through angular rotation changes (Euler angles) and inter-frame jitter values. The test device used in this study was an iPhone 12. The research stages are illustrated in [Figure 1](#).

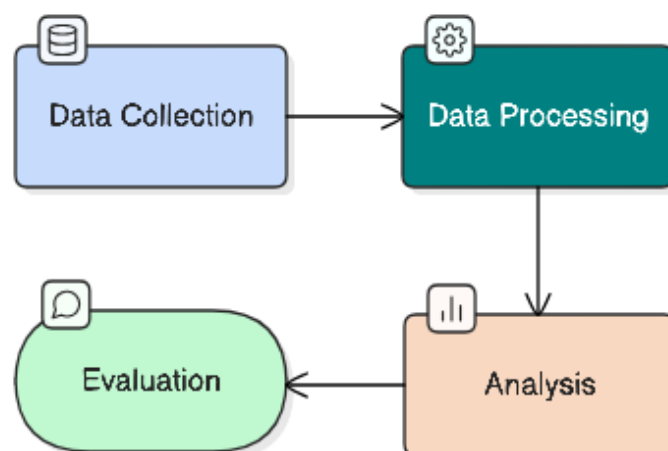


Figure 1. Research Stages

Figure 1 presents the research stages, which include collecting orientation data from the gyroscope sensor, processing the data using the low-pass filter algorithm, analyzing the stabilization results based on angular deviation and jitter values, and evaluating the effectiveness of the virtual camera rotation stabilization method.

2.1 Data Collection

Orientation data was collected using the gyroscope sensor on the iPhone 12 via the Input.gyro module in Unity. The obtained data consisted of device orientation along three axes: pitch, roll, and yaw, recorded at every frame of the application. Data collection was performed under two conditions: before and after applying the low-pass filter algorithm. A summary of the testing scenarios is presented in **Table 1**.

Table 1. Motion Scenarios

Scenario	Description	Data Recorded
Slow rotation	Device rotated slowly along pitch, roll, and yaw axes	Euler angles, jitter, rotation graphs, stability indicators
Fast rotation	Device rotated quickly to test stabilization response to large changes	Euler angles, jitter, rotation graphs, stability indicators
Random movement	Device moved without a specific pattern	Euler angles, jitter, rotation graphs, stability indicators
Walking	User walks while holding the device	Euler angles, jitter, rotation graphs, stability indicators
Stair climbing	Intense vertical vibrations from walking up and down stairs	Euler angles, jitter, rotation graphs, stability indicators
Motorcycle riding	Complex vibrations from motorcycle movement on road surfaces	Euler angles, jitter, rotation graphs, stability indicators

Each motion scenario was performed for 10 seconds at approximately 60 frames per second (fps), resulting in around 600 orientation data points per scenario. The duration of 10 seconds was selected to ensure sufficient temporal coverage for capturing both short-term fluctuations and repetitive motion patterns, while maintaining consistent user movement and avoiding excessive fatigue that could introduce unintended motion bias. At a frame rate of 60 fps, this duration provides an adequate dataset for calculating reliable inter-frame jitter statistics and observing stabilization trends across different motion scenarios.

The device was held in portrait orientation without additional stabilization tools to reflect realistic mobile usage conditions. The same data collection procedure was applied across all scenarios to maintain consistency and comparability of the recorded orientation data. The acquired rotation data were stored for subsequent processing and jitter analysis.

2.2 Data Processing

The orientation data obtained from the gyroscope sensor were processed to calculate angular deviation and inter-frame jitter. Virtual camera rotation stabilization was applied using a low-pass filter algorithm, which is commonly used to suppress high-frequency noise caused by sudden vibrations and rapid orientation changes. The low-pass filter was applied independently to each rotation axis (pitch, roll, and yaw) to ensure that stabilization was performed without coupling errors between axes and to preserve the natural rotational characteristics of the device motion.

In this study, the low-pass filter smoothing parameter α was set to 0.1. The sensitivity of the α parameter was considered based on its effect on the trade-off between rotation smoothness and system responsiveness. Smaller α values provide stronger noise suppression and smoother rotation but may introduce noticeable latency and delayed response to rapid orientation changes. Conversely, larger α values allow faster system response but reduce the effectiveness of jitter suppression. The selected value of $\alpha = 0.1$ was empirically determined as a balanced setting that sufficiently reduces high-frequency rotational fluctuations while maintaining acceptable responsiveness for real-time virtual camera applications.

Jitter, defined as rapid and undesired fluctuations in inter-frame rotation angles, was calculated as the absolute difference in rotation angles between consecutive frames using Equation (1):

$$\Delta\theta = |\theta_n - \theta_{n-1}| \quad (1)$$

Notation:

θ_n : angular orientation at the current frame

θ_{n-1} : angular orientation at the previous frame

This equation measures the angular change ($\Delta\theta$) between two consecutive frames. A larger $\Delta\theta$ indicates greater rotation instability.

Average jitter was calculated using Equation (2):

$$Jitter = \frac{1}{N-1} \sum_{i=2}^{N-1} \Delta\theta_i \quad (2)$$

Notation:

N: total number of frames

$\Delta\theta_i$: angular change between frame i and the previous frame

This equation calculates the average jitter across all frames. Jitter serves as an indicator of the rotation instability level.

The percentage of jitter reduction was determined using Equation (3):

$$\begin{aligned} & \text{Penurunan Jitter}(\%) \\ &= \frac{J_{\text{sebelum}} - J_{\text{sesudah}}}{J_{\text{sebelum}}} \times 100\% \end{aligned} \quad (3)$$

Notation:

J_before: jitter value before stabilization

J_after: jitter value after stabilization

A higher percentage indicates a more effective stabilization performance of the applied low-pass filter.

2.3 Data Analysis

Data analysis focused on comparing virtual camera jitter values before and after applying the low-pass filter algorithm for each test scenario. Jitter served as the primary indicator of rotation fluctuations. Descriptive analysis was conducted to assess the algorithm's ability to improve camera rotation stability under various usage conditions.

2.4 Evaluation

The evaluation assessed the effectiveness of the low-pass filter algorithm in stabilizing virtual camera rotation using the gyroscope sensor on the iPhone 12. The evaluation included analysis of average jitter values, percentage of jitter reduction, and visual observation of the application through rotation graphs, stability bar indicators, and text status. The evaluation results were used as the basis for drawing conclusions about the algorithm's performance.

3. Results and Discussion

This study aims to analyze the performance of a low-pass filter algorithm in stabilizing virtual camera rotation based on gyroscope sensor data in a mobile application. Testing was conducted using an iPhone 12. The results are presented based on six motion scenarios to compare conditions before and after applying the low-pass filter algorithm [6]. In this study, jitter is quantitatively expressed in degrees per frame (°/frame), which represents the absolute angular change between two consecutive frames. Lower jitter values indicate smoother and more stable virtual camera rotation, while higher values reflect greater inter-frame rotational instability.

3.1 Data Collection

Data collection was performed using the gyroscope sensor on the iPhone 12. The collected data consisted of device orientation in the form of Euler angles (pitch, roll, and yaw) for six motion scenarios: slow rotation, fast rotation, random movement, walking, stair climbing, and motorcycle riding. Each scenario was conducted for 10 seconds at approximately 60 frames per second, resulting in around 600 rotation data points. Data were recorded under two conditions: before and after applying the low-pass filter. These data served as input for the subsequent processing and analysis stages.

3.2 Data Processing

Data processing was carried out by applying the low-pass filter algorithm to the orientation signal from the gyroscope sensor. This process produced virtual camera rotation data with reduced angular fluctuations. The processed results were visualized using rotation graphs and stability indicators within the application.

3.2.1 Slow Rotation Scenario

The slow rotation scenario evaluated the system's response to gradual changes in angles. Before applying the low-pass filter, rotation fluctuations were observed due to sensor noise (Kok et al., 2017). After applying the low-pass filter, the angular changes became smoother as high-frequency components were suppressed [2].

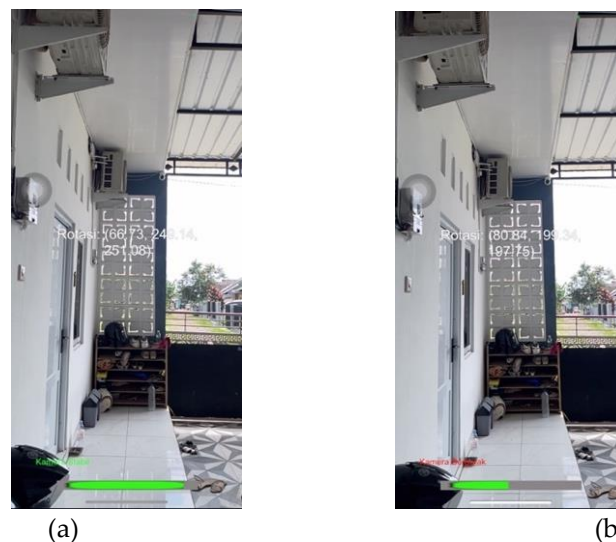


Figure 2 .Application View In The Slow Rotation Scenario: (A) Before Applying The Low-Pass Filter Algorithm (B) After Applying The Low-Pass Filter Algorithm

Figure 2 shows the condition before and after applying the low-pass filter. The left view illustrates fluctuations in pitch, roll, and yaw. The right view demonstrates smoother rotation after filtering.

3.2.2 Fast Rotation Scenario

The fast rotation scenario tested the system's response to rapid orientation changes. Before filtering, sharp angular spikes occurred due to high angular acceleration [12]. After applying the low-pass filter, the rotation movement was significantly damped.

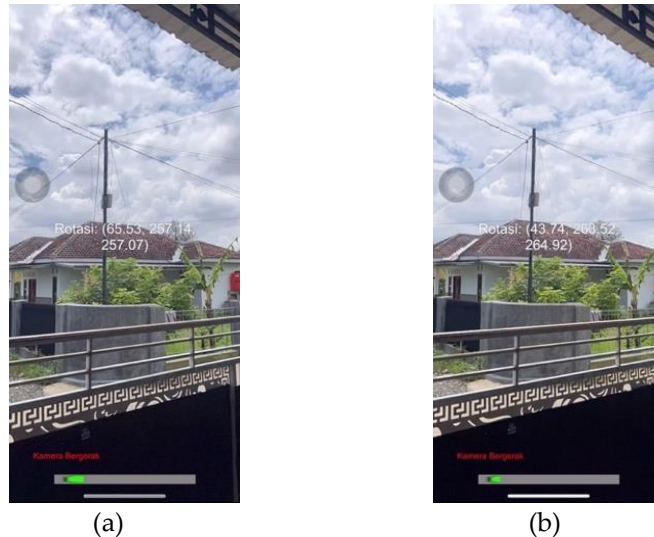


Figure 3. Application View In The Fast Rotation Scenario: (A) Before Applying The Low-Pass Filter Algorithm (B) After Applying The Low-Pass Filter Algorithm

Figure 3 illustrates the left view before applying the low-pass filter with sharp rotation spikes. The right view shows the result after applying the filter, with damped rotation according to the jitter reduction.

3.2.3 Random Movement Scenario

The random movement scenario represented usage without a specific pattern. Before filtering, irregular orientation fluctuations were caused by sensor disturbances [Click or tap here to enter text.](#)[12]. After applying the low-pass filter, the amplitude of angular fluctuations decreased, producing smoother and more consistent rotation.

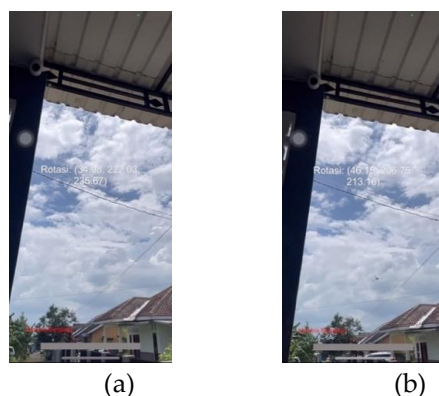


Figure 4 Application View In The Random Movement Scenario: (A) Before Applying The Low-Pass Filter Algorithm (B) After Applying The Low-Pass Filter Algorithm

Figure 4 shows the left view before filtering with irregular rotation changes. The right view shows smoother rotation after applying the low-pass filter.

3.2.4 Walking Scenario

The walking scenario simulated daily usage with periodic vibrations caused by footsteps. Before filtering, repeated rotation fluctuations were observed. After applying the low-pass filter, jitter was reduced, resulting in more stable virtual camera rotation [3].

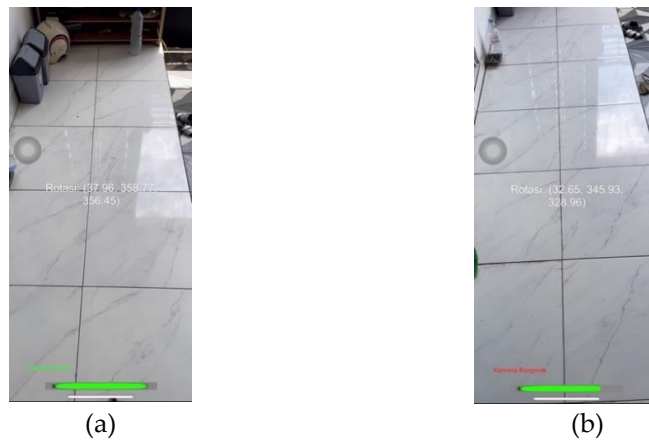


Figure 5. Application View in the Walking Scenario: (A) Before Applying the Low-Pass Filter Algorithm (B) After Applying The Low-Pass Filter Algorithm.

Figure 5 illustrates the left view before filtering with repeated vibration patterns. The right view shows more stable rotation after applying the low-pass filter.

3.2.5 Stair Climbing Scenario

The stair climbing scenario tested system response to high-amplitude vertical disturbances. Before filtering, large orientation spikes occurred. After applying the low-pass filter, some fluctuations remained because the filter was limited in damping intense vertical disturbances [3]

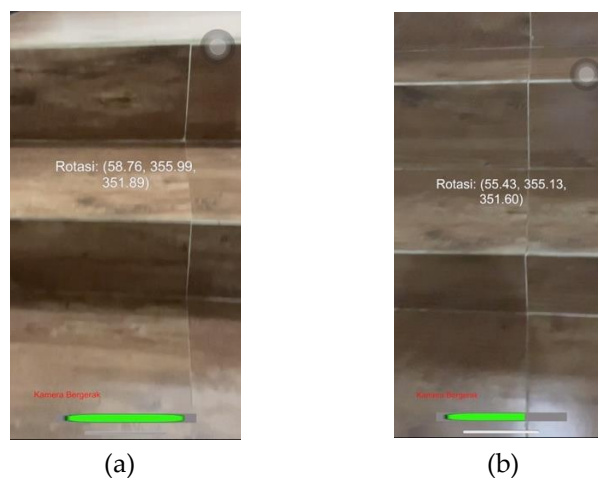


Figure 6 Application View In The Stair Climbing Scenario: (A) Before Applying The Low-Pass Filter Algorithm (B) After Applying The Low-Pass Filter Algorithm.

Figure 6 shows the left view before filtering with large orientation spikes. The right view demonstrates the result after filtering, although high-amplitude spikes are still visible.

3.2.6 Motorcycle Riding Scenario

The motorcycle riding scenario represented complex disturbances due to engine vibrations and road surface irregularities. Before filtering, orientation changes were rapid and irregular. After filtering, fluctuations were significantly reduced, although some vibrations persisted [3]

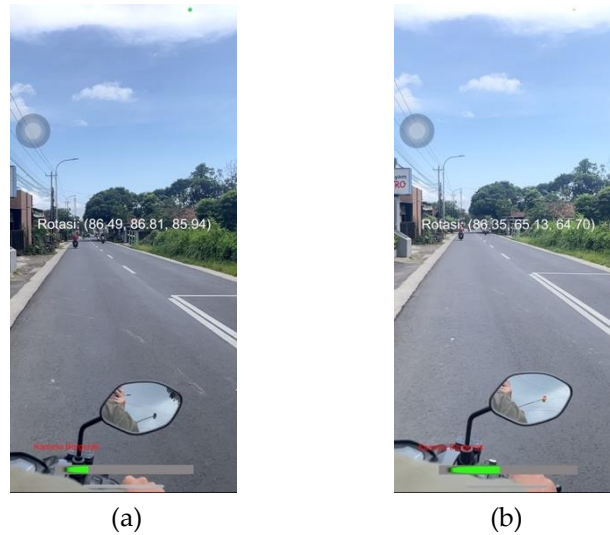


Figure 7. Application View In The Motorcycle Riding Scenario: (A) Before Applying The Low-Pass Filter Algorithm (B) After Applying The Low-Pass Filter Algorithm.

Figure 7 shows the left view before filtering with intense orientation disturbances. The right view illustrates smoother and more stable rotation after applying the low-pass filter.

3.3 Analysis of Results

The analysis was conducted based on jitter values before and after applying the low-pass filter for each motion scenario using the iPhone 12. Jitter was used as the primary indicator of virtual camera rotation instability. The reduction in jitter indicated improved rotation stability. The results are summarized in Table 2.

Table 2. Analysis of Results

Scenario	Before (°/frame)	After (°/frame)	Reduction (%)
Slow rotation	159.12	87.82	44.81
Fast rotation	287.27	79.84	72.21
Random movement	284.62	88.61	68.87
Walking	161.51	21.72	86.55
Stair climbing	168.85	255.55	-51.34
Motorcycle riding	176.28	59.77	66.09

3.3.1 Slow Rotation Scenario

This scenario evaluates the system response to gradually changing angles. The jitter value decreased from 159.12°/frame to 87.82°/frame, with a reduction of 44.81%. This result shows that the low-pass filter algorithm can damp small fluctuations caused by sensor noise. The virtual camera rotation becomes smoother after filtering.

3.3.2 Fast Rotation Scenario

This scenario tests the system response to large orientation changes in a short period. The jitter value decreased from 287.27°/frame to 79.84°/frame, with a reduction of 72.21%. The significant decrease indicates that the algorithm effectively suppresses high-frequency components caused by rapid rotation, resulting in a more stable virtual camera rotation.

3.3.3 Random Movement Scenario

This scenario represents usage conditions without a specific movement pattern. The jitter value decreased from 284.62°/frame to 88.61°/frame, with a reduction of 68.87%. The low-pass filter algorithm effectively reduces irregular fluctuations caused by random sensor disturbances, making the virtual camera rotation more consistent.

3.3.4 Walking Scenario

This scenario simulates everyday use with periodic vibrations from walking. The jitter value decreased from 161.51°/frame to 21.72°/frame, achieving the highest reduction of 86.55%. This demonstrates that the algorithm is very effective at damping periodic vibrations, resulting in a much more stable virtual camera rotation.

3.3.5 Stair Climbing Scenario

This scenario evaluates the system response to vertical disturbances with high amplitude. The jitter value increased from 168.85°/frame to 255.55°/frame, with a negative reduction of -51.34%. This indicates the limitation of the low-pass filter algorithm in damping intense vertical disturbances. Sharp orientation changes due to vertical acceleration are not fully filtered.

3.3.6 Motorcycle Riding Scenario

This scenario represents complex disturbances caused by engine vibrations and road surface irregularities. The jitter value decreased from 176.28°/frame to 59.77°/frame, with a reduction of 66.09%. The low-pass filter algorithm can damp most fluctuations caused by road vibrations, resulting in more stable virtual camera rotation, although some disturbances remain.

Based on the scenario-specific results, the low-pass filter algorithm effectively reduced jitter in five out of six testing scenarios. The highest effectiveness was observed in the walking,

fast rotation, and random movement scenarios. The limitation of the algorithm is evident in the stair climbing scenario, which involves high-amplitude vertical disturbances.

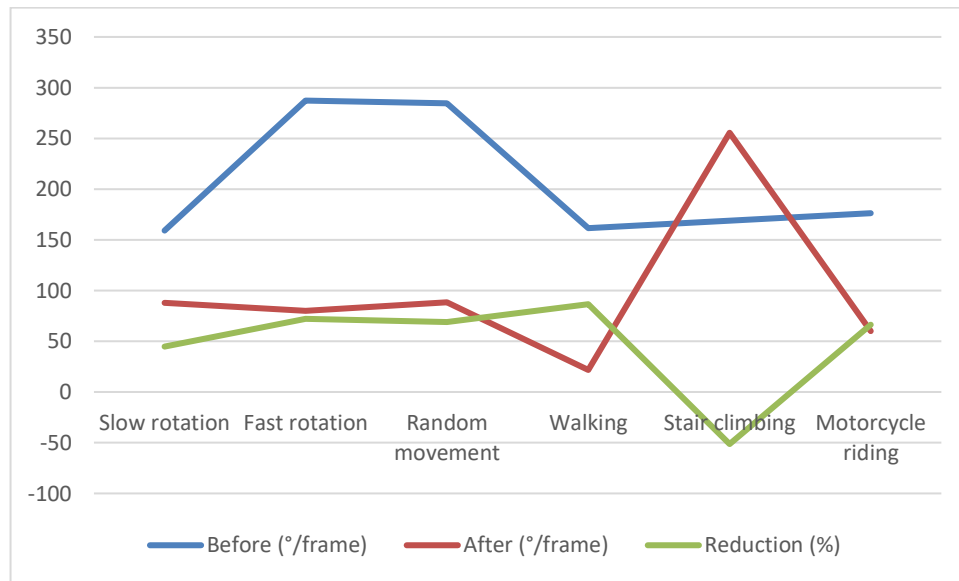


Figure 8. Comparison of Jitter Values Before and After Applying the Low-Pass Filter Algorithm

Figure 8 shows the comparison of jitter values before and after applying the low-pass filter across all scenarios. The graph confirms that the algorithm can damp rotation fluctuations in most scenarios, except during intense vertical disturbances.

3.4 Evaluation and Discussion

Evaluation of the low-pass filter algorithm demonstrates its effectiveness in stabilizing virtual camera rotation on the iPhone 12. The highest effectiveness was observed in walking, fast rotation, and random movement scenarios. The algorithm was less effective in the stair climbing scenario due to high-amplitude vertical disturbances. These findings indicate that the low-pass filter significantly improves virtual camera rotation stability under typical usage conditions.

The results align with previous studies indicating that gyroscope-based stabilization can reduce jitter and improve orientation consistency (Han et al., 2021; Karpenko et al., 2011; Hadi et al., 2019; Zheng et al., 2020). The study highlights that while low-pass filtering is effective in most dynamic conditions, additional techniques may be required to manage intense vertical motion, suggesting potential directions for future research.

3.5 Limitations and Robustness of the Method

The experimental results indicate that the proposed low-pass filter-based stabilization method is effective in reducing virtual camera rotation jitter under most motion conditions. However, several limitations should be acknowledged. The method shows reduced effectiveness in scenarios involving high-amplitude vertical disturbances, such as stair climbing, where

sudden acceleration changes introduce low-frequency components that are not fully suppressed by a single-parameter low-pass filter. This limitation is reflected in the increased jitter value observed in the stair climbing scenario.

Despite this limitation, the proposed method demonstrates robust performance across common mobile usage scenarios, including walking, fast rotation, random movement, and motorcycle riding. In these scenarios, the jitter reduction reached up to 86.55%, indicating strong robustness against sensor noise, periodic vibrations, and irregular motion patterns typically encountered in real-world mobile applications. In addition, the simplicity and low computational cost of the low-pass filter make it suitable for real-time implementation. Future work may explore adaptive or hybrid filtering approaches to further improve robustness under extreme motion conditions.

4. Conclusion

The results of this study indicate that the low-pass filter algorithm effectively enhances the stability of virtual camera rotation in most motion scenarios. Significant reductions in jitter were observed in fast rotation, random movement, and walking scenarios, demonstrating the algorithm's ability to suppress fluctuations caused by sensor noise and periodic vibrations. The stair climbing scenario showed an increase in jitter, highlighting the algorithm's limitation in handling high-amplitude vertical disturbances.

Comparison with previous studies shows similar findings, where the use of low-pass filters reduced jitter and improved rotational smoothness in mobile applications [4]. The main advantage of this algorithm is its simplicity and suitability for real-time implementation. Its limitation arises under extreme disturbances or rapid vertical accelerations, which may require additional stabilization techniques or a combination of filtering methods.

The novelty of this research lies in the quantitative evaluation of real-time gyroscope-based low-pass filter stabilization applied directly to virtual camera rotation in a Unity-based mobile environment, using inter-frame jitter ($^{\circ}$ /frame) as an objective performance metric across multiple realistic motion scenarios.

The low-pass filter algorithm can be applied as a simple and computationally efficient solution for stabilizing virtual camera rotation, improving user experience in virtual camera-based applications. Its implementation should consider conditions involving intense

disturbances or fast vertical movements, and future research may explore hybrid filtering approaches to further enhance stability under extreme scenarios.

References

- [1] F. Han, L. Xie, Y. Yin, H. Zhang, G. Chen, and S. Lu, "Video Stabilization for Camera Shoot in Mobile Devices via Inertial-Visual State Tracking," *IEEE Trans Mob Comput*, vol. 20, no. 4, pp. 1714–1729, Apr. 2021, doi: 10.1109/TMC.2019.2961313.
- [2] M. Kok, J. D. Hol, and T. B. Schön, "Using inertial sensors for position and orientation estimation," 2017, *Now Publishers Inc.* doi: 10.1561/20000000094.
- [3] E. M. Day, R. S. Alcantara, M. A. McGeehan, A. M. Grabowski, and M. E. Hahn, "Low-pass filter cutoff frequency affects sacral-mounted inertial measurement unit estimations of peak vertical ground reaction force and contact time during treadmill running," *J Biomech*, vol. 119, p. 110323, 2021, doi: <https://doi.org/10.1016/j.jbiomech.2021.110323>.
- [4] H. Li, K. Luo, and S. Liu, "GyroFlow: Gyroscope-Guided Unsupervised Optical Flow Learning." [Online]. Available: <https://github.com/megvii-research/GyroFlow>.
- [5] A. Karpenko, D. Jacobs, J. Baek, and M. Levoy, "Digital Video Stabilization and Rolling Shutter Correction using Gyroscopes."
- [6] M. Hadi *et al.*, "Sistem stabilisator kamera menggunakan sensor gyroscope dan kontroler PID," 2019. [Online]. Available: <http://journal2.um.ac.id/index.php/tekno>
- [7] R. T. , Asnada and Sulistyono, "Pengaruh Inertial Measurement Unit (IMU) MPU-6050 3-Axis Gyro dan 3-Axis Accelerometer pada Sistem Penstabil Kamera (Gimbal) Untuk Aplikasi Videografi," *Januari*, vol. 11, no. 1, p. 48, 2020.
- [8] Z. Ren, M. Zou, L. Bi, and M. Fang, "An unsupervised video stabilization algorithm based on gyroscope image fusion," *Comput. Graph.*, vol. 126, p. 104154, 2024, doi: 10.1016/j.cag.2024.104154.
- [9] P. D. Milanović, I. V. Popadić, and B. D. Kovačević, "Gyroscope-based video stabilization for electro-optical long-range surveillance systems," *Sensors*, vol. 21, no. 18, Sep. 2021, doi: 10.3390/s21186219.
- [10] D. Teguh Santoso, R. Puspa Sari, F. Fadlillaahi Mudzakir, and J. H. Ronggowaluyo Telukjambe Timur, "Rancang Bangun Gyroscope Stabilizer untuk Stabilisasi Perahu," 2021. [Online]. Available: <https://jurnal.polines.ac.id/index.php/rekayasa>
- [11] C. Li, L. Song, S. Chen, R. Xie, and W. Zhang, "Deep Online Video Stabilization Using IMU Sensors," *IEEE Trans Multimedia*, vol. 25, pp. 2047–2060, 2023, doi: 10.1109/tmm.2022.3142429.
- [12] L. Zheng, X. Zhan, and X. Zhang, "Nonlinear complementary filter for attitude estimation by fusing inertial sensors and a camera," *Sensors (Switzerland)*, vol. 20, no. 23, pp. 1–19, Nov. 2020, doi: 10.3390/s20236752.