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Analysis of Smartphone Camera Stabilization Based on Gyroscope Using Exponential Smoothing in Mobile Applications

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Abstract

Camera usage on mobile devices under dynamic conditions frequently induces vibration (jitter) and unstable orientation changes. This study aims to analyze the effectiveness of the Exponential Smoothing method in reducing rotational fluctuations of a gyroscope-based smartphone camera in a mobile application. An experimental approach was employed across six movement scenarios, namely stationary conditions, slow movement, fast movement, walking, stair climbing, and vehicle riding, by measuring rotation angle values and jitter values before and after stabilization. The results indicate a significant reduction in jitter following the application of Exponential Smoothing across all testing scenarios. The gyroscope-based stabilization system utilizing this method is proven effective in improving smartphone camera rotation stability in mobile applications.

Keywords: *Gyroscope, Camera Stabilization, Jitter, Camera Rotation, Exponential Smoothing*

Abstrak

Penggunaan kamera pada perangkat mobile dalam kondisi dinamis sering menimbulkan getaran (jitter) dan perubahan orientasi yang tidak stabil. Penelitian ini bertujuan untuk menganalisis kemampuan metode Exponential Smoothing dalam menurunkan fluktuasi rotasi kamera smartphone berbasis gyroscope pada aplikasi mobile. Pengujian dilakukan menggunakan pendekatan eksperimental pada enam skenario gerakan, yaitu kondisi diam, gerakan lambat, gerakan cepat, berjalan, naik-turun tangga, dan berkendara, dengan mengukur nilai sudut rotasi dan nilai jitter sebelum dan sesudah penerapan stabilisasi. Hasil penelitian menunjukkan adanya penurunan signifikan pada nilai jitter setelah penerapan metode Exponential Smoothing pada seluruh skenario pengujian. Sistem stabilisasi berbasis gyroscope dengan metode ini terbukti efektif dalam meningkatkan kestabilan rotasi kamera smartphone pada aplikasi mobile.

Kata-kata kunci: *Gyroscope, Stabilisasi Kamera, Jitter, Rotasi Kamera, Exponential Smoothing*

1. Introduction

The use of cameras in mobile devices has expanded significantly, particularly in real-time applications such as augmented reality, which relies on interaction between virtual objects and real environments [1]. Under dynamic usage conditions, such as hand movement during recording, cameras frequently experience jitter and unstable orientation changes that degrade the quality of visual output [2]. Gyroscope sensors in mobile devices are capable of detecting orientation changes in real-time with high precision [3]. However, gyroscope sensor output data in practice still contains noise that causes rotational fluctuations, resulting in unsmooth camera movement and susceptibility to jitter [4]. This issue presents a significant challenge in developing mobile applications that require high visual stability.

Various filtering approaches have been applied to reduce noise in motion sensor data, including Kalman filters, low-pass filters, and smoothing techniques to improve sensor reading stability in IMU-based systems [5], [6]. The Exponential Smoothing method is recognized as a simple and computationally lightweight technique that effectively reduces data fluctuations by assigning weighted values to previous data [7]. Several studies have demonstrated that smoothing techniques can improve the stability of sensor-based systems and reduce jitter effects in real-time applications [4], [8].

Despite the widespread use of various filtering methods, the application of Exponential Smoothing for gyroscope-based camera rotation stabilization in mobile applications has not been extensively analyzed under real usage conditions across diverse user movement variations. Previous studies have focused primarily on sensor noise reduction in general IMU systems rather than specifically evaluating rotational stabilization performance across multiple real-world movement scenarios.

This study focuses on analyzing the effectiveness of the Exponential Smoothing method in reducing jitter in gyroscope-based smartphone camera rotation. The analysis was conducted using a fixed parameter value of α = 0,1 across all testing scenarios. This study does not address parameter optimization or comparison of multiple α values, but rather focuses on evaluating the capability of the Exponential Smoothing method to improve camera rotation stability through jitter reduction. The testing was performed across six movement scenarios, namely stationary conditions, slow movement, fast movement, walking, stair climbing, and motorcycle riding, by measuring rotation angle and jitter values before and after stabilization. This study is expected to contribute a simple, computationally lightweight, and effective smoothing approach for improving gyroscope-based camera stability in sensor-based mobile applications.

2. Method

This study employs a quantitative approach to analyze the effectiveness of gyroscope-based smartphone camera rotation stabilization in a Unity-based mobile application for Android devices. This approach is selected because camera rotation stability can be quantitatively represented through changes in Euler angles and inter-frame jitter values **[9]**. The experimental device used in this study is a Vivo Y17s Android smartphone. The overall workflow of the Exponential Smoothing implementation is illustrated in **Figure 1**.

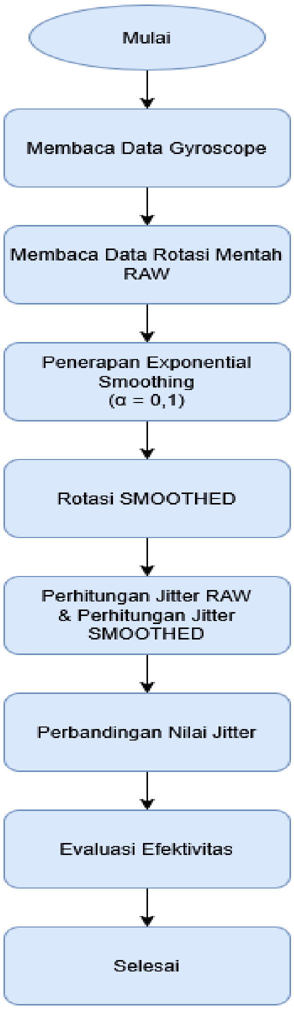

Figure 1. Workflow of Exponential Smoothing Implementation.

Figure 1 presents the research procedure consisting of four main stages, namely acquisition of orientation data using the gyroscope sensor, processing the data using the Exponential Smoothing method, comparison analysis of jitter values before and after stabilization, and evaluation of the stabilization system performance.

2.1 Data Collection

Orientation data were collected using the gyroscope sensor on an Android device through Unity's Input.gyro module. The acquired data consist of device orientation values along three axes (pitch, roll, and yaw), represented as Euler angles and recorded on a per-frame basis. Data collection was conducted under two conditions: before and after the application of the stabilization method. A summary of the testing scenarios is presented in **Table 1.**

Table 1. Motion Scenarios

Scenario	Description	Data Recorded
Stationary	Device remains static without movement	Euler angles, jitter, stability indicators
Slow Movement	Slow motion across all axes	Euler angles, jitter, stability indicators
Fast Movement	Rapid motion to test responsiveness	Euler angles, jitter, stability indicators
Walking	User walks while holding the device	Euler angles, jitter, stability indicators
Stair Climbing	Strong vertical vibration from stair movement	Euler angles, jitter, stability indicators
Motorcycle Riding	Complex vibrations from motorcycle motion	Euler angles, jitter, stability indicators

Each scenario was conducted for 10 seconds. Orientation data were recorded at approximately 60 frames per second (fps) using Unity, resulting in approximately 600 data samples per scenario. During all experiments, the device was held manually in portrait orientation without any external stabilization tools to simulate real-world usage conditions. The same data acquisition procedure was consistently applied across all scenarios to ensure experimental reliability.

2.2 Data Processing

The collected orientation data were processed using the Exponential Smoothing method to reduce fluctuations (jitter) in virtual camera rotation. This method applies a weighted combination between the current sensor reading and previous smoothed values, resulting in smoother and more stable motion output **[13].** In this study, the smoothing parameter $\boldsymbol{\alpha}$ was fixed at 0,1 and consistently applied across all testing scenarios. This fixed parameter setting ensures experimental consistency, allowing the analysis to focus on the effectiveness of the

Exponential Smoothing method in reducing jitter rather than parameter optimization.

The Exponential Smoothing model is defined as shown in Equation (1):

$$S_t = \alpha X_t + (1 - \alpha) S_{t-1} \qquad (1)$$

Where $\boldsymbol{S_t}$ is the smoothed value at time $\boldsymbol{t}$, $\boldsymbol{X_t}$ is the raw gyroscope data at time $\boldsymbol{t}$, $\boldsymbol{S_{t-1}}$ is the previous smoothed value, and $\boldsymbol{\alpha}$ is the smoothing coefficient within the range $0 < \boldsymbol{\alpha} \leq 1$. A smaller $\boldsymbol{\alpha}$ produces smoother output but results in slower response to motion changes. The implementation is further performed using Unity's Quaternion.Slerp function, which interpolates rotations in three-dimensional space as shown in Equation (2):

$$S_t = Slerp(S_{t-1}, X_t, \alpha) \qquad (2)$$

In Equation (2), $\boldsymbol{S_t}$ represents the smoothed rotation at time $\boldsymbol{t}$, $\boldsymbol{S_{t-1}}$ is the previous rotation state, $\boldsymbol{X_t}$ is the current gyroscope-based rotation input, and $\boldsymbol{\alpha}$ is the interpolation factor controlling smoothness. Spherical Linear Interpolation (Slerp) is used to ensure smooth rotational transitions in 3D space. Lower α values result in smoother motion but slower response to changes.

2.3 Jitter Calculation

Jitter is used as an indicator of camera rotation instability. The angular change between consecutive frames is computed using Equation (3):

$$\Delta\theta = |\, \theta_n - \theta_{n-1} \,| \qquad (3)$$

Where $\boldsymbol{\Delta\theta}$ represents the angular difference between frames, $\boldsymbol{\theta_n}$ is the rotation angle at frame $\boldsymbol{n}$, and $\boldsymbol{\theta_{n-1}}$ is the rotation angle at the previous frame. A higher $\boldsymbol{\Delta\theta}$ indicates greater rotational fluctuation. The average jitter value is calculated using Equation (4):

$$J = \frac{1}{N-1} \sum_{i=1}^{N-1} \Delta\theta_i \qquad (4)$$

Where $\boldsymbol{J}$ is the average jitter, $\boldsymbol{N}$ is the total number of frames, and $\boldsymbol{\Delta\theta_i}$ represents the angular difference between consecutive frames. Lower $\boldsymbol{J}$ values indicate more stable camera motion. The percentage of jitter reduction is calculated using Equation (5):

$$\text{Penurunan Jitter } (\%) = \frac{Jraw - Jsmooth}{Jraw} \times 100\% \qquad (5)$$

Where $\boldsymbol{J_{raw}}$ is the average jitter before stabilization and $\boldsymbol{J_{smooth}}$ is the average jitter after applying Exponential Smoothing. Higher values indicate better stabilization performance.

2.4 Data Analysis

Data analysis focuses on comparing rotation and jitter values before and after the application of Exponential Smoothing. Raw and smoothed data are displayed simultaneously in real time to ensure comparison under identical conditions. Analysis is performed across all motion scenarios to evaluate the effectiveness of the method in reducing rotational instability. A descriptive analytical approach is used to assess improvements in camera stability under real-world usage conditions.

3. Results and Discussion

This study evaluates the effectiveness of the Exponential Smoothing method in stabilizing gyroscope-based virtual camera rotation in an Android application. Experiments were conducted using two smartphones with different gyroscope characteristics, namely Vivo Y17s and Vivo V15 Pro. The system was tested under six motion scenarios: stationary, slow movement, fast movement, walking, stair climbing, and motorcycle riding. The obtained gyroscope data were processed into Euler angles (pitch, roll, and yaw) and analyzed based on jitter values before and after the application of the smoothing method.

The following section presents the experimental results and their interpretation based on each testing scenario.

3.1. Results

This section presents the experimental findings obtained from the implementation of Exponential Smoothing for gyroscope-based camera stabilization. The results are organized according to the predefined motion scenarios and presented using application outputs, numerical jitter values, and comparative analysis between raw and smoothed data. The parameter α = 0,1 was used consistently across all experiments to ensure balanced smoothing and responsiveness. The application visualizes two real-time camera rotation outputs, namely raw (unstabilized) and smoothed (stabilized) data. The comparison between both outputs is used to evaluate the effectiveness of jitter reduction in each scenario.

3.1.1 Application Interface

The developed application displays two virtual camera rotation conditions in real time, namely the rotation before stabilization (raw) and the rotation after stabilization (smoothed). The raw display represents orientation changes obtained directly from the gyroscope sensor, whereas the smoothed display represents rotation data processed using the Exponential Smoothing method.

In this study, the smoothing parameter was fixed at $\alpha = 0.1$ and applied consistently across all testing scenarios. This parameter value was selected to maintain a balance between rotational smoothness and system responsiveness during real-time operation. The raw and smoothed rotation values, along with the corresponding jitter measurements, are displayed simultaneously to facilitate direct comparison of stabilization performance.

3.1.2 Stationary Scenario

The stationary scenario was used to evaluate the inherent noise of the gyroscope sensor when the smartphone remained in a static position. Under the unstabilized condition, the virtual camera rotation still exhibited small fluctuations caused by internal sensor noise. This observation is consistent with the characteristics of inertial sensors, which are not completely free from random angular variations even when the device is stationary [10]. After applying the exponential smoothing method, these fluctuations were reduced, resulting in smoother virtual camera rotation on both test devices.

Figure 2. Application Interface on Vivo Y17s in the Stationary Scenario

Figure 2 illustrates the application interface on the Vivo Y17s during the stationary scenario. The raw display shows visible rotational fluctuations, while the smoothed display presents more stable rotation with lower jitter values after applying exponential smoothing.

Figure 3. Application Interface on Vivo V15 Pro in the Stationary Scenario

Figure 3 shows the application interface on the Vivo V15 Pro during the stationary scenario. The raw display still contains minor rotational fluctuations, whereas the smoothed display demonstrates more consistent and stable rotation. Compared with the Vivo Y17s, the Vivo V15 Pro exhibited relatively lower rotational fluctuations, indicating differences in gyroscope sensor characteristics between the two devices.

3.1.3 Slow Movement Scenario

The slow movement scenario was conducted to evaluate the response of the exponential smoothing method when the smartphone was moved gradually along the pitch, roll, and yaw axes. Before stabilization, the rotation signal still contained fluctuations caused by gyroscope sensor noise despite the relatively slow orientation changes **[10]**. After applying exponential smoothing, the virtual camera rotation became smoother because the weighting mechanism effectively reduced unwanted angular variations **[13]**.

Figure 4. Application Interface on Vivo Y17s in the Slow Movement Scenario

Figure 4 presents the application interface on the Vivo Y17s during the slow movement scenario. The raw data produced higher jitter values than the smoothed data, indicating that the exponential smoothing method successfully reduced rotational fluctuations caused by gradual device movement.

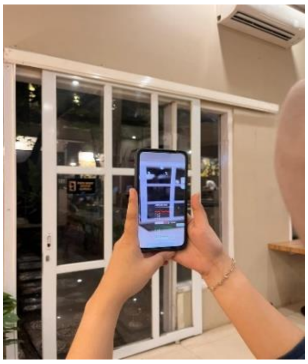

Figure 5. Application Interface on Vivo V15 Pro in the Slow Movement Scenario

Figure 5 shows the application interface on the Vivo V15 Pro during the slow movement scenario. The smoothed data exhibited a larger reduction in jitter compared with the Vivo Y17s, reflecting higher stabilization effectiveness for slow movements on the Vivo V15 Pro.

3.1.4 Fast Movement Scenario

The fast movement scenario was used to evaluate the performance of the exponential smoothing method under rapid orientation changes. Without stabilization, the gyroscope sensor generated high jitter values due to its sensitivity to large angular accelerations [14]. After stabilization was applied, the fluctuation spikes were significantly reduced, resulting in more controlled virtual camera rotation on both devices.

Figure 6. Application Interface on Vivo Y17s in the Fast Movement Scenario

Figure 6 illustrates the application interface on the Vivo Y17s during the fast movement scenario. The raw data exhibited substantial jitter spikes caused by rapid orientation changes, whereas the smoothed data effectively reduced these spikes, resulting in a significant decrease in jitter values.

Figure 7. Application Interface on Vivo V15 Pro in the Fast Movement Scenario

Figure 7 presents the application interface on the Vivo V15 Pro during the fast movement scenario. The raw data showed higher jitter spikes than those observed on the Vivo Y17s. However, the smoothed data successfully reduced the fluctuations with a comparable level of jitter reduction, demonstrating the effectiveness of exponential smoothing under rapid movement conditions.

3.1.5 Walking Scenario

The walking scenario was designed to simulate everyday usage conditions in which the smartphone experiences periodic vibrations generated by the user's footsteps. Without stabilization, the rhythmic vibrations produced repetitive rotational fluctuations in the gyroscope sensor data **[11]**. The application of the exponential smoothing method successfully reduced these periodic vibration patterns, resulting in more stable virtual camera rotation on both test devices.

Figure 8. Application Interface on Vivo Y17s in the Walking Scenario

Figure 8 shows the application interface on the Vivo Y17s during the walking scenario. The raw data exhibits periodic jitter fluctuations caused by footsteps, whereas the smoothed data demonstrates a significant reduction in jitter values, resulting in more controlled virtual camera rotation.

Figure 9. Application Interface on Vivo V15 Pro in the Walking Scenario

Figure 9 presents the application interface on the Vivo V15 Pro during the walking scenario. The raw jitter values were higher than those observed on the Vivo Y17s. However, the exponential smoothing method effectively reduced these periodic fluctuations, demonstrating stabilization effectiveness under rhythmic vibrations generated by human body movement.

3.1.6 Stair-Climbing Scenario

The stair-climbing scenario was conducted to evaluate the response of the exponential smoothing method to intense vertical disturbances generated during stair ascent and descent. Without stabilization, each step produced substantial orientation spikes in the gyroscope sensor data due to repeated vertical acceleration [15]. After applying exponential smoothing, these vertical disturbances were significantly reduced, resulting in more stable virtual camera rotation on both test devices.

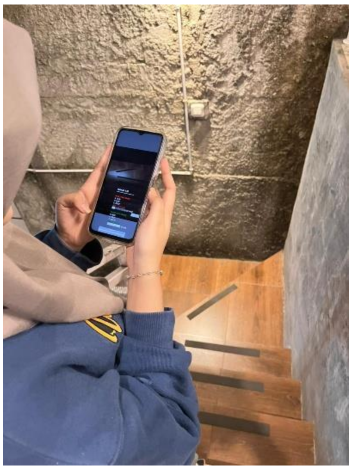

Figure 10. Application Interface on Vivo Y17s in the Stair-Climbing Scenario

Figure 10 illustrates the application interface on the Vivo Y17s during the stair-climbing scenario. The raw data exhibits pronounced jitter spikes caused by intense vertical disturbances, whereas the smoothed data shows a substantial reduction in jitter values, resulting in improved rotational stability.

Figure 11. Application Interface on Vivo V15 Pro in the Stair-Climbing Scenario

Figure 11 presents the application interface on the Vivo V15 Pro during the stair-climbing scenario. The raw data shows higher jitter spikes than those observed on the Vivo Y17s. Nevertheless, the smoothed data effectively reduced these vertical disturbances, producing a very significant decrease in jitter values on both devices.

3.1.7 Motorcycle Riding Scenario

The motorcycle riding scenario represents the most complex disturbance condition in this study due to the combination of engine vibrations and road surface irregularities, which generate multidirectional orientation fluctuations simultaneously. Without stabilization, the raw gyroscope sensor data exhibited rapid and irregular orientation changes [11]. The application of the exponential smoothing method significantly reduced these fluctuations, resulting in more controlled virtual camera rotation on both test devices.

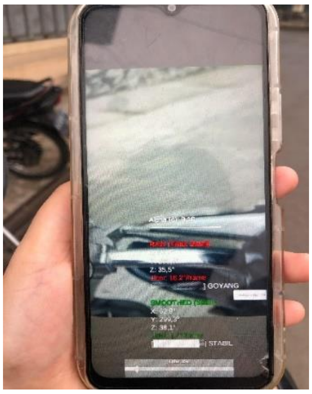

Figure 12. Application Interface on Vivo Y17s in the Motorcycle Riding Scenario

Figure 12 shows the application interface on the Vivo Y17s during the motorcycle riding scenario. The raw data exhibits the highest jitter values among all testing scenarios, whereas the smoothed data successfully reduces these complex fluctuations, resulting in a substantial decrease in jitter values.

Figure 13. Application Interface on Vivo V15 Pro in the Motorcycle Riding Scenario

Figure 13 illustrates the application interface on the Vivo V15 Pro during the motorcycle riding scenario. The raw data shows complex orientation fluctuations caused by vehicle vibrations, while the smoothed data demonstrates smoother virtual camera rotation. Although the raw jitter values on the Vivo V15 Pro were lower than those observed on the Vivo Y17s in this scenario, both devices exhibited consistent stabilization effectiveness after applying the exponential smoothing method.

3.1.8 Jitter Value Comparison Results

Jitter values were calculated from the angular difference between consecutive frames and used as an indicator of virtual camera rotation stability. Lower jitter values indicate smoother and more stable camera movement. The comparison of jitter values before and after applying exponential smoothing was performed for all testing scenarios on both devices.

Table 2. Jitter Value Comparison Results on Vivo Y17s

Scenario	Before (°/*frame)*	After (°/frame)	Reduction (%)
Stationary	1,3	0,3	76,9
Slow Movement	2,7	1,2	55,6
Fast Movement	12,0	0,9	92,5
Walking	2,3	0,2	91,3
Stair Climbing	7,8	0,3	96,2
Motorcycle riding	16,2	1,4	91,4

Table 2 shows that jitter values decreased in all testing scenarios on the Vivo Y17s after applying the exponential smoothing method. The highest reduction was observed in the stair-climbing scenario (96.2%), while the lowest reduction occurred in the slow movement scenario (55.6%).

Table 3. Jitter Value Comparison Results on Vivo V15 Pro

Scenario	Before (°/*frame)*	After (°/frame)	Reduction (%)
Stationary	1,2	0,5	58,3
Slow Movement	3,7	0,1	97,3
Fast Movement	14,6	1,2	91,8
Walking	8,0	1,3	83,8
Stair Climbing	11,7	0,2	98,3
Motorcycle riding	13,8	1,7	87,7

Table 3 shows that jitter values decreased in all testing scenarios on the Vivo V15 Pro after applying the exponential smoothing method. The highest reduction was observed in the stair-climbing scenario (98.3%), while the lowest reduction occurred in the stationary scenario (58.3%).

Table 4. Comparison of Jitter Reduction Values Between Devices

Scenario	Vivo Y17s (%)	Vivo V15 Pro (%)
Stationary	76,9	58,3
Slow Movement	55,6	97,3
Fast Movement	92,5	91,8
Walking	91,3	83,8
Stair Climbing	96,2	98,3
Motorcycle riding	91,4	87,7

Table 4 summarizes the percentage reduction in jitter obtained by both devices across all testing scenarios. The results indicate that the Vivo Y17s achieved greater jitter reduction in the stationary (76.9%), walking (91.3%), fast movement (92.5%), and motorcycle riding (91.4%) scenarios. In contrast, the Vivo V15 Pro produced higher reductions in the slow movement (97.3%) and stair-climbing (98.3%) scenarios. Both devices demonstrated consistently high jitter reduction during fast movement and motorcycle riding, suggesting that exponential smoothing is effective in mitigating rotational fluctuations under dynamic operating conditions. Variations in performance between the two devices are likely related to differences in gyroscope sensor characteristics, sensitivity, and measurement quality, which affect the stabilization process and the resulting rotation accuracy **[12].**

3.1.9 Jitter Comparison Graphs

Figures 14–16 present graphical comparisons of jitter values before and after applying the exponential smoothing method on both test devices. The graphs were generated based on the average jitter values obtained from all testing scenarios and were used to visualize the stabilization performance of the proposed method.

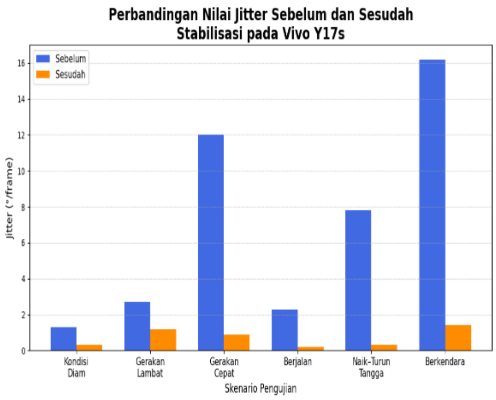

Figure 14. Comparison of Jitter Values on Vivo Y17s

Figure 14 shows the comparison between raw and smoothed jitter values across all testing scenarios on the Vivo Y17s. The results indicate that the exponential smoothing method reduced jitter values in every scenario. The most noticeable reductions were observed in the stair-climbing, fast movement, and motorcycle riding scenarios. These results demonstrate an improvement in virtual camera rotation stability after stabilization was applied.

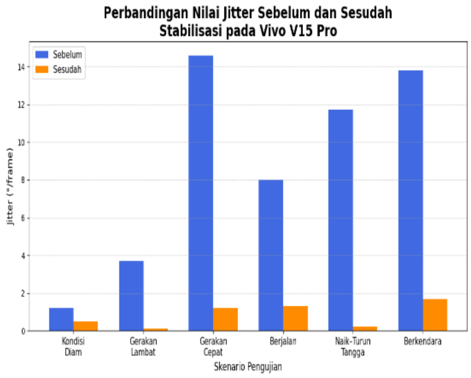

Figure 15. Comparison of Jitter Values on Vivo V15 Pro

Figure 15 presents the comparison between raw and smoothed jitter values across all testing scenarios on the Vivo V15 Pro. Lower jitter values were obtained after stabilization in every scenario. The largest reductions were observed in the stair-climbing and slow movement scenarios. Overall, the results indicate that the exponential smoothing method consistently reduced rotational fluctuations on the Vivo V15 Pro device.

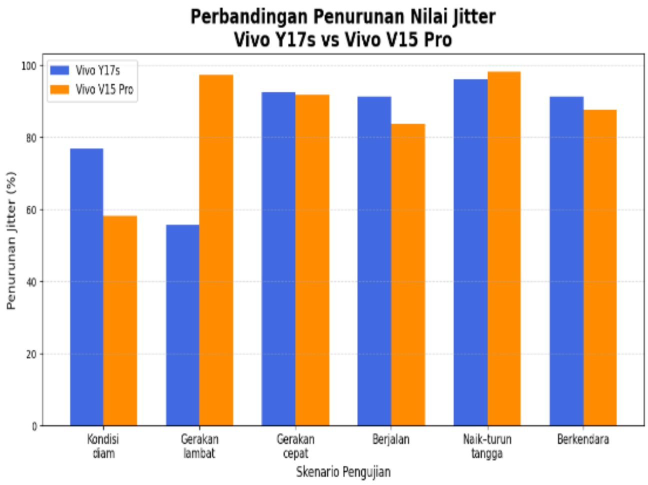

Figure 16. Comparison of Jitter Reduction Percentages Between Devices

Figure 16 illustrates the percentage reduction in jitter achieved by the exponential smoothing method on both devices for all testing scenarios. Overall, both devices experienced substantial jitter reduction after stabilization. The Vivo Y17s achieved higher reductions in several dynamic movement scenarios, whereas the Vivo V15 Pro showed greater reductions in the slow movement and stair-climbing scenarios. The graph highlights differences in stabilization performance between the two devices across the tested conditions.

3.2. Discussion

The results demonstrate that the Exponential Smoothing method effectively reduced virtual camera rotation jitter across all testing scenarios on both Android devices. The decrease in jitter values indicates that the method successfully suppressed rotational fluctuations generated by gyroscope sensor noise and device movement. These findings support the objective of this study, which was to improve virtual camera stability in mobile applications using a lightweight filtering approach.

Differences in stabilization performance were observed between the two devices. The Vivo V15 Pro achieved greater jitter reduction in the slow movement and stair-climbing scenarios, whereas the Vivo Y17s produced higher reductions in the stationary, walking, fast movement, and motorcycle riding scenarios. These differences are likely related to variations in gyroscope sensor sensitivity and calibration. Similar observations were reported by **[12]**. who found that stabilization performance can vary depending on sensor characteristics.

The obtained results are consistent with previous studies on gyroscope-based stabilization and signal smoothing **[13]**. explained that Exponential Smoothing can reduce short-term fluctuations by incorporating information from previous observations. Likewise, **[10]**. reported that inertial sensors inherently contain noise even under static conditions, while **[14]**. highlighted the sensitivity of gyroscopes to rapid angular motion. The significant jitter reductions observed in dynamic scenarios, such as fast movement, stair climbing, and motorcycle riding, further support these findings. Similar effects of motion-induced vibration on orientation stability have also been discussed by **[11]**.

This study contributes to the evaluation of Exponential Smoothing for gyroscope-based virtual camera stabilization under six real-world movement scenarios using two Android devices with different sensor characteristics. The findings indicate that a simple and computationally efficient filtering technique can significantly improve camera rotation stability without requiring complex algorithms.

However, this study has several limitations. The experiments were conducted using only two smartphone models and a fixed smoothing parameter (α = 0.1). Future research may investigate adaptive smoothing parameters, compare Exponential Smoothing with other filtering methods such as Kalman Filter, and evaluate performance on a wider range of mobile devices.

4. Conclusion

This study analyzed the effectiveness of the Exponential Smoothing method for stabilizing gyroscope-based virtual camera rotation in a mobile application. The experimental results demonstrated that the method successfully reduced jitter values across all testing scenarios on both the Vivo Y17s and Vivo V15 Pro devices. The reduction in jitter indicates that Exponential Smoothing effectively suppresses rotational fluctuations caused by gyroscope sensor noise and user movement, resulting in improved virtual camera stability during real-time operation.

The findings also show that stabilization performance varies between devices, suggesting that gyroscope sensor characteristics and sensitivity influence the effectiveness of the smoothing process. Nevertheless, both devices exhibited substantial improvements in rotation stability under stationary and dynamic movement conditions. These results support the use of Exponential Smoothing as a simple and computationally efficient approach for gyroscope-based camera stabilization in mobile applications.

This study contributes an experimental evaluation of Exponential Smoothing under six real-world movement scenarios using smartphones with different sensor characteristics. Future research may investigate adaptive smoothing parameters, evaluate a broader range of mobile devices, and compare Exponential Smoothing with other filtering techniques, such as Kalman Filter and complementary filtering methods, to further improve stabilization performance under more diverse motion conditions

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