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Standard-Compliant Framework for Acceleration Safety Analysis of Amusement Rides under ISO 17842-1

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Abstract

This study presents a standards-compliant framework for evaluating passenger acceleration exposure on amusement rides in accordance with ISO 17842-1 [1]. Building upon the standard's single-axis g-limit versus exposure-time diagrams, the framework introduces a threshold segmentation method that partitions acceleration time series into segments bounded by the standard's limit levels and zero crossings. This procedure produces segments that are uniform with respect to permissible g-ranges, enabling precise alignment between measured accelerations and standard-defined exposure thresholds. Segment safety is then evaluated using the duration criteria specified in the standard for each axis and polarity (positive or negative), while instantaneous spikes—samples exceeding any admissible magnitude—are detected without interrupting segment continuity. The framework also implements the ISO combined-axis safety inequality for axis pairs (x–y, x–z, and y–z), employing an operational definition of admissible acceleration per axis derived from the threshold in which the instantaneous sample resides. The data processing workflow includes robust inertial measurement unit (IMU) data ingestion, accurate time reconstruction, and a four-pole, single-pass Butterworth low-pass filter, with optional axis sign inversion to accommodate varying mounting conventions. To facilitate practical application, an interactive Streamlit tool has been developed. The tool enables users to upload IMU datasets, visualize filtered acceleration signals, assess shaded unsafe segments, and identify spike markers. Combined unsafe points are highlighted through vertical annotations, and summary tables are automatically produced for unsafe segments, individual spikes, and combined-axis violations. An optional comprehensive segmentation table is also generated to support validation and traceability processes. The approach is validated using both synthetic datasets, specifically designed to induce known limit-crossing events and combined-axis exceedances, and real ride measurement data. Results demonstrate that the threshold segmentation provides stable and interpretable segment boundaries along with highly consistent compliance labeling. The combined-axis checker effectively identifies instances where simultaneous multi-axis exposure exceeds safety thresholds, despite individual axis compliance. The proposed framework is suitable for use in ride commissioning, diagnostic evaluation, and academic research contexts. Sensitivity factors, including filter cutoff frequency, bin-edge conventions, and sampling rates, are examined to support reproducibility and performance tuning.

Keywords: amusement devices; vibrations; medical safety tolerances; IMU.

1. Introduction

The evaluation of human tolerance to vibrations has received significant attention within medical research, particularly concerning exposure duration and magnitude. ISO 2631 [2-6] standard assesses human response to vibration based on the frequency of exposure and duration. However, in the context of amusement rides, the duration of applied vibrational acceleration on the body is typically short, which is specifically addressed by ISO 17842-1. This standard delineates axis-aligned acceleration limits along the *x, y*, and *z* axes and specifies maximum permissible durations for each *g*-band. It also includes combined-axis admissibility formulas that account for co-occurring loads during ride operation.

To facilitate the analysis of acceleration data from amusement rides, the authors propose a practical pipeline that complies with these ISO standards. This pipeline encompasses several essential steps: (i) segmenting signals based on threshold bins defined by the ISO limit levels and zero; (ii) applying duration checks to classify single-axis segments as safe or unsafe; (iii) detecting instantaneous spikes that exceed permissible magnitudes without fragmenting the segments; and (iv) enforcing combined-axis inequalities at the sample level. The proposed pipeline is implemented through a Streamlit web application, designed to provide ride engineers and researchers with an accessible and effective tool for analyzing IMU (Inertial Measurement Unit) data. The contributions of this research include: (1) a segmentation scheme that aligns with the ISO threshold structure and incorporates polarity considerations; (2) a combined-axis checker that utilizes admissible values derived from the threshold bins; and (3) an interactive visualization and reporting tool offering insights into datasets, spike detections, combined violations, and segment audits.

By presenting this assessment framework in a user-friendly format, the proposed system facilitates more precise inspections of amusement ride designs, thereby supporting standard governing bodies in their oversight of safety. Technological advancements have led to the development of tools that establish a graphical interface for correlating inputs and outputs. This paper introduces such a platform specifically for assessing vibrations encountered by riders on amusement attractions. Moreover, this platform is beneficial for designers of modern and innovative rides, enabling them to evaluate their designs from health and safety perspectives, consider necessary revisions, and ensure compliance with relevant standards.

This paper is structured as follows: Section 2 outlines the methods for evaluating vibrations experienced on amusement rides, addressing both uniaxial and biaxial modes. Section 3 discusses the user interfaces that have been developed. Section 4 presents the synthetic data used for model evaluation, along with experimental data collected from the Alpine Coaster and the Lightning Ride. Section 5 analyzes the results obtained within the developed framework. Finally, the paper concludes with a summary, conclusions, and insights into future research directions.

2. Method of Vibration Evaluation

This section presents the methodology and formula for assessing the vibrational acceleration measurement on the amusement device, based on ISO 17842-1 international standard in compliance with the Iranian national version of INSO 8987-1 [7]. Fig. 1 shows how the X, Y, and Z axes are oriented relative to the human body while seated in the amusement vehicle.

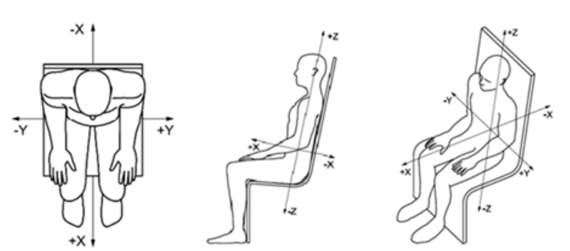


Figure 1. Body- fixed coordinate system in acceleration evaluation (ISO 17842-1, INSO 8987-1) [1]

2.1 Uniaxial Vibration Evaluation

In alignment with ISO 17842-1, this paper establishes positive and negative g-limit bands for each axis, as well as the corresponding maximum exposure durations. These thresholds, which are critical for safety assessments, are adapted according to specified constraints where applicable. Notably, the negative limits are differentiated based on the type of restraint system employed, such as the base case compared to over-the-shoulder restraints. The thresholds utilized for this analysis are systematically derived from figures presented in Annex I of the ISO 17842-1 standard, with the following steps:

a. Threshold-Bin Segmentation and Spikes

The analysis involves the creation of bin edges derived from the union of the established ISO positive and negative limit values, along with the inclusion of 0 g. Each sample is categorized into a closed-open interval, $[L_i, L_{i+1})$, where L_i represents the threshold boundary. Segment boundaries are defined only when there is a change in the bin category, ensuring that segments remain homogeneous concerning the ISO-defined bands and do not straddle the zero-acceleration point. Spikes are identified as individual samples where the absolute value of acceleration, $|g|$ exceeds the permissible magnitudes corresponding to the current polarity. While these spikes are recorded for reference, they do not serve to disrupt the segmentation process.

b. Segment Safety Assessment

For each identified segment, the duration and extreme values of acceleration (both $g_{\min}$ and g_{max}) are computed. A segment is classified as safe based on the following criteria:

- Positive Polarity: A segment is deemed safe if there exists a positive g-limit band ($g<=L$) that encompasses the segment's observed extremes and maintains a duration <= $T_{max.}$
- Negative Polarity: Conversely, a segment is considered safe if there exists a negative g-limit band ($g>=L$) that similarly covers the extremes of the segment with a duration <= $T_{max.}$

Segments that do not meet these specified criteria are labeled as unsafe, thereby warranting further analysis and intervention as necessary to ensure rider safety.

2.2 Biaxial Vibration Evaluation

According to ISO 17842:1, Section I.2.6, when acceleration occurs in multiple directions, it is necessary to verify the combination of these accelerations. The combination must be assessed for each pair of accelerations in the two distinct directions [1]:

$$xy\ pair: \quad \left(\frac{a_x}{a_{x,adm}}\right)^2 + \left(\frac{a_y}{a_{y,adm}}\right)^2 \le 1 \tag{1}$$

$$xz\ pair: \quad \left(\frac{a_x}{a_{x,adm}}\right)^2 + \left(\frac{a_z}{a_{z,adm}}\right)^2 \le 1 \tag{2}$$

$$yz\ pair: \quad \left(\frac{a_z}{a_{z,adm}}\right)^2 + \left(\frac{a_y}{a_{y,adm}}\right)^2 \le 1 \tag{3}$$

Admissible values $a_{x,adm}$, $a_{y,adm}$, and $a_{z,adm}$ are derived per sample by locating the threshold bin for each axis' instantaneous a_x, a_y, and a_z and selecting the corresponding limit edge of that bin. A point is combined-unsafe if any of the three inequalities is violated [1].

3. User Interface

An interactive Streamlit app has been developed to assist with the acceleration safety analysis of amusement rides. This app features a user-friendly design and offers real-time feedback through a variety of functionalities:

a. CSV/TXT Upload and Data Preview: Users can upload their IMU data files in CSV or TXT format, allowing them to preview the data in a table format to ensure it has been correctly ingested (signal processing model of the framework: Fig. 2a).

b. Filtered Signal Plots: The app generates plots of the filtered acceleration signals for each axis (*X*, *Y*, *Z*), enabling users to visually inspect the smoothed data.

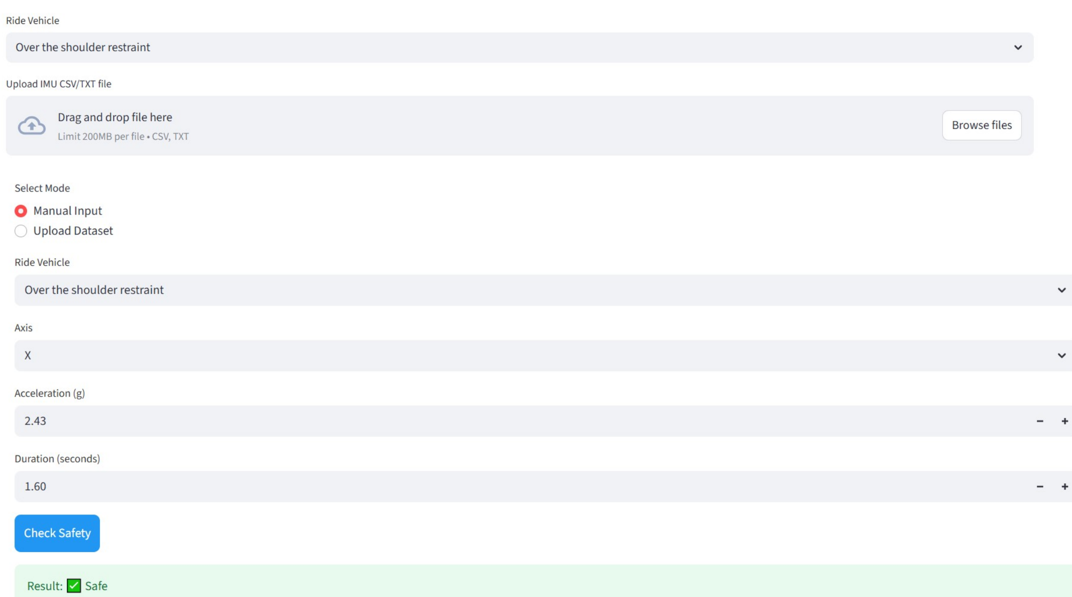
c. *Shaded Unsafe Segments*: Segments identified as unsafe, based on the threshold limits outlined in ISO 17842-1, are visually highlighted in the plots with shaded areas. This feature facilitates the easy identification of periods where the accelerations are deemed unsafe.

d. Spike Markers and Vertical Lines: In the plots, spikes where acceleration exceeds permissible limits are marked, and vertical lines are drawn at instances when combined-unsafe conditions occur, as determined by the combined-axis safety checks.

e. Tables for Unsafe Segments, Spikes, and Combined-Uunsafe Points: The app provides tables containing detailed information about unsafe segments, detected spikes, and instances of combined-unsafe conditions. An optional table is also available, offering all segment data for a more in-depth analysis.

f. Axis Inversion Toggles: Users have the ability to toggle the inversion of acceleration axes (for instance, multiplying the X and Z axes by -1) to align with the specific mounting configuration of the sensors.

g. Manual Mode: Alongside the primary features for dataset uploads and safety analysis, the app includes a manual mode (Fig. 2b). This mode enables users to practice analysing synthetic or controlled datasets, providing an intuitive interface for checking safety limits on simulated signals and helping users familiarize themselves with the tool's capabilities.



a)

b)

Figure 2. User Interface of the developed standard-compliant framework for acceleration safety check when using amusement rides: a) signal processing mode b) manual mode

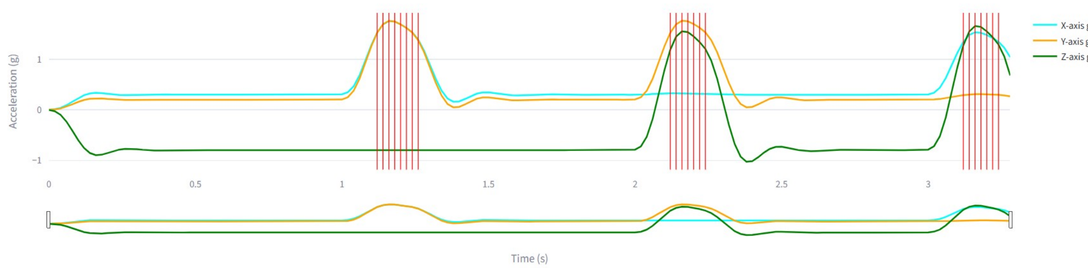
4. Synthetic and Experimental Site Data Collection

To validate the implemented framework, a synthetic dataset is generated. Then, the model is analysed on two real datasets collected in an amusement park complex by installing an accelerometer sensor on the device. The synthetic datasets are constructed focusing on key testing scenarios:

- Threshold Edges: Simulated long plateaus near acceleration limits to test duration logic.
- Spike Detection: Datasets with single-sample spikes to verify the spike detection mechanism.

To verify combined inequalities, it is required to assess medium acceleration values along all axes while testing for combined inequality violations, ensuring that individual limits are not exceeded. Fig. 3 illustrates the generated signal in the developed framework.

a)



b)

Figure 3. Synthetic datasets shown the developed framework: a) for uniaxial vibration evaluation b) triaxial vibration for biaxial vibration evaluation

In addition to synthetic datasets, real-world data is gathered from actual amusement ride vehicles at Tochal Entertainment Complex. The experiments utilized IMU sensors to measure accelerations from two different rides, each featuring distinct restraint systems: an Alpine coaster with a base case restraint and a Lightning ride that uses an over-the-shoulder restraint. The evaluation of the ISO standard varies for these two types of restraints, with the acceptable acceleration for the over-the-shoulder restraint being higher. Fig. 4 depicts the IMU sensors attached to both rides. The acceleration signals have been captured during multiple tests runs at a sampling rate of 50 Hz.

The recorded data have been processed and analysed using the developed app to identify unsafe segments, spike events, and instances of combined-unsafe accelerations. The results are displayed with shaded unsafe segments, spike markers, and vertical lines indicating combined-unsafe times. Both datasets were thoroughly tested for consistency and accuracy in accordance with ISO 17842-1 standards. Next section presents sample results, including visualizations of the filtered acceleration signals, shaded unsafe segments, and tables of detected unsafe points.

a)  b) 

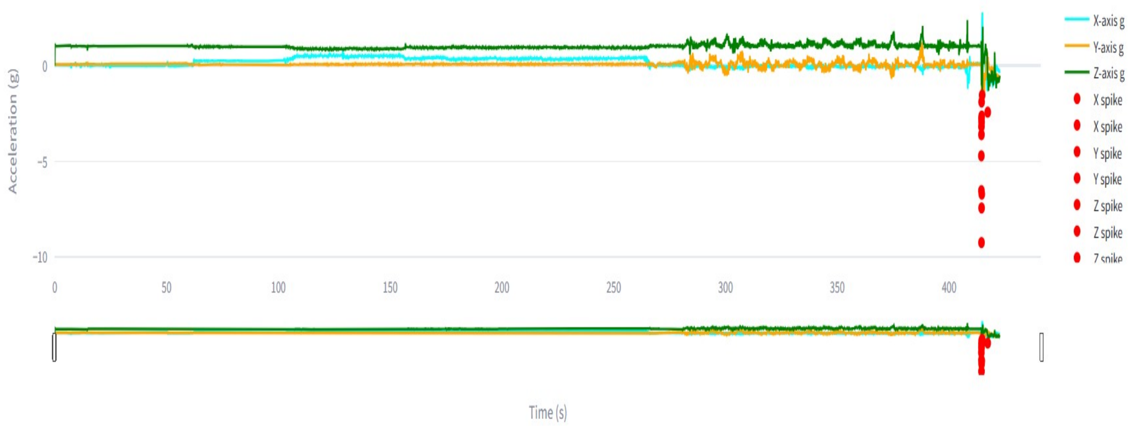
Figure 4. IMU Sensor attached to the rides in data collection process: a) Alpine Coaster b) Lightning ride

5. Results and Discussion

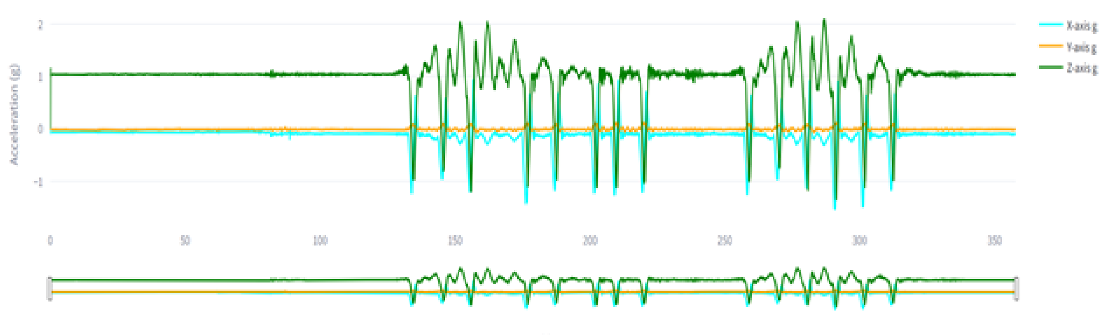
Following the presentation of the signal evaluation results based on ISO standard time duration limits in three directions, utilizing both uniaxial and biaxial evaluation techniques, a general assessment of the results is provided, along with a discussion of the developed framework.

5.1 Uniaxial Acceleration Safety Check

Fig. 5 presents result of applying the standard time duration limits to the gathered acceleration signals in three directions, respectively for the Alpine coaster and Lightning ride. As observed in the developed framework, developed tool highlights the unsafe segments in the signal, with regions where the accelerations exceed the predefined safety thresholds. Each axis is analyzed separately to identify areas where the ride's accelerations may exceed the acceptable limits for passenger safety. As visible as it is, there are no unsafe regions in the signal but there are spikes in the end of the track, related to the data gathering system.



a)



b)

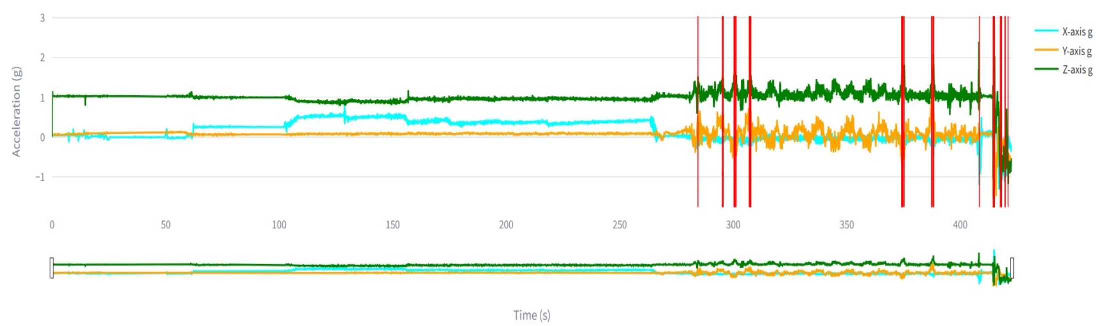
Figure 5. Time duration limits applied to uniaxial acceleration evaluation in three directions for: a) Alpine coaster b) Lightning ride

5.2 Biaxial Acceleration Safety Check

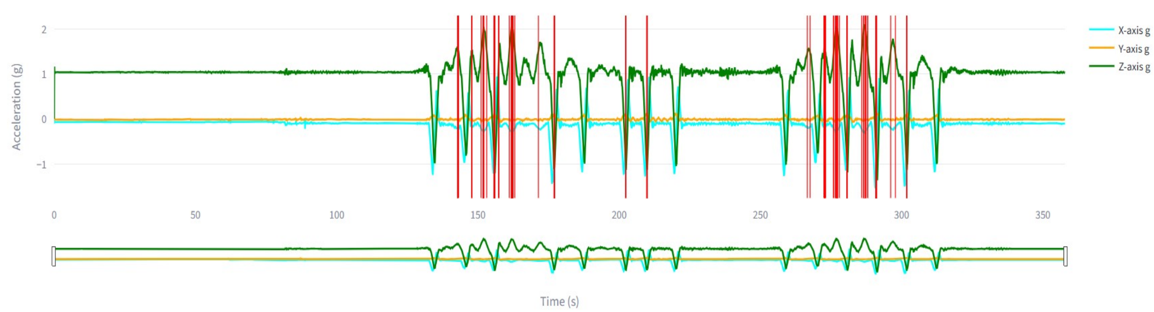
In this section, the results of the combined-axis safety analysis are presented, taking into account the interaction between accelerations across multiple axes. The combined-axis safety analysis is based on the inequalities outlined in the ISO 17842-1 standard, which evaluates safety by considering multiple axes simultaneously (e.g., XY, XZ, and YZ pairs).

The tool calculates and visualizes these combined safety checks to identify any instances where the ride's accelerations exceed the combined safety limits, potentially indicating unsafe conditions for passengers. This combined safety analysis enables the identification of complex safety violations that may not be evident when assessing individual axes in isolation.

Fig. 6 illustrates the results of the combined-axis safety analysis for both ride vehicles, highlighting the unsafe regions where the combined accelerations exceed the ISO limits. Vertical lines indicate the times when the combined-axis limits are violated. In both figures, red vertical lines represent the detected combined unsafe points.



a)

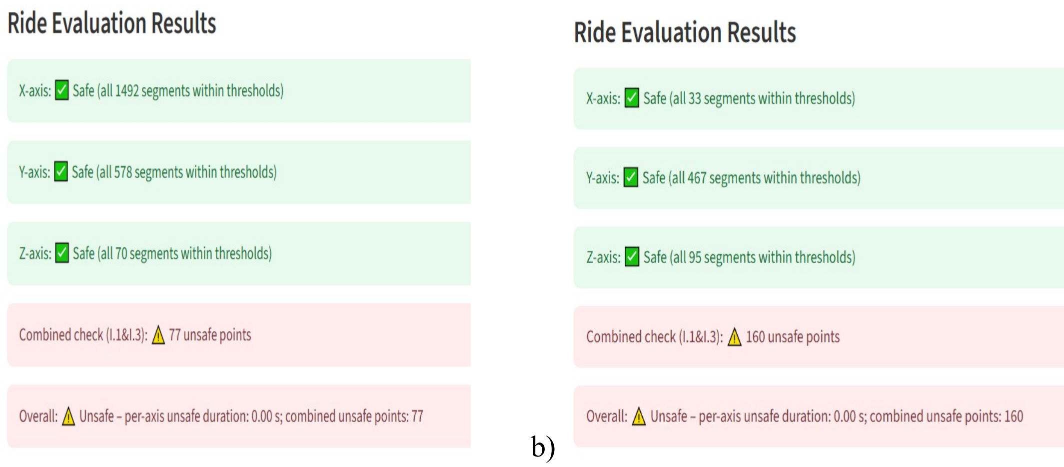


b)

Figure 6. Time duration limits applied to biaxial acceleration evaluation in three directions for: a) Alpine coaster b) Lightning ride

5.3 Evaluation of Results

The tool's interactive nature enables users to load and process real-world IMU data, facilitating the rapid visualization of safety checks for both individual and combined axes. The real-time feedback mechanism enhances usability by marking unsafe segments, spikes, and combined-unsafe points, which can be adjusted based on different ride types and constraints. Fig. 7 present the evaluation of the results discussed in the previous subsection. Based on these results, no unsafe regions are identified in the sled ride's signal; however, the analysis of the combined axes reveals 77 individual points in the dataset. Similarly, the results for the lightning ride show no unsafe zones in the signal, but, like the sled ride, this ride contains 160 combined unsafe points.



a) b)

Figure 7. Overall ride evaluation results in the developed framework for: a) Alpine coaster b) Lightning ride

One of the innovative presentation techniques employed in this paper is the use of a two-dimensional non-dimensional diagram (as described in Eqs. 1-3) to effectively and user-friendly visualize the results. Fig. 8 illustrates the number of out-of-boundary points for the two amusement devices.

a)

b)

Figure 8. Acceleration in newly developed illustration in this research, vibration amplitude in context of allowable combined magnitudes of X, Y and Z acceleration: a) Alpine coaster b) Lightning ride

5.4 Final Discussion

The results of the safety analysis demonstrate the developed framework's capability to identify both individual axis safety violations and combined-axis safety violations in accordance with ISO 17842-

1 standards. By utilizing real-time IMU data from actual amusement ride vehicles, the analysis assessed the performance of the safety system under various conditions, including rides equipped with different types of restraints: base case and over-the-shoulder restraints.

The interactive application developed serves as a valuable tool for evaluating ride safety, featuring the ability to process and visualize real-time IMU data. By allowing users to upload ride data, view filtered acceleration signals, and automatically detect unsafe segments, the application provides a user-friendly interface that can assist engineers, designers, and safety officers in ensuring the safety of amusement rides.

However, the system has certain limitations. Specifically, the application's safety analysis is constrained to the predefined thresholds outlined in ISO 17842-1 and does not account for potential ride-specific dynamics that could influence safety margins. Additionally, the accuracy of the safety analysis relies heavily on the quality and resolution of the IMU data.

6. Summary/ Conclusion

In this study, we developed a standards-compliant framework for the safety analysis of amusement rides, integrating ISO 17842-1 acceleration thresholds with an interactive tool built in Streamlit. The framework is capable of detecting unsafe acceleration events both on individual axes and across combined axes, offering a comprehensive safety assessment. Through experiments with real-world data from the Tochal amusement park, we demonstrated the app's ability to process and visualize IMU data, identify unsafe segments, and highlight areas where ride safety may be compromised. The interactive nature of the app provides a valuable tool for engineers, operators, and safety officers to perform real-time safety assessments. While the framework shows great potential, future work could focus on incorporating more advanced features, such as machine learning for anomaly detection, as well as integrating real-time feedback mechanisms for immediate safety interventions. Additionally, further research could explore the inclusion of other ride dynamics and sensors to improve the overall safety evaluation. Future iterations of this framework could include the integration of machine learning techniques to improve the analysis of acceleration data. For example, machine learning algorithms could be trained to detect patterns in the data that indicate potential safety risks, even in cases where the predefined thresholds are not violated. Furthermore, incorporating additional ride dynamics, such as rotational forces and vibration measurements, could provide a more comprehensive safety evaluation. Additionally, real-time integration with ride control systems could allow for immediate safety interventions when critical safety limits are reached, providing a proactive approach to ride safety.

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