ISRO TELEMETRY, TRACKING AND COMMAND NETWORK (ISTRAC)

PROJECT REPORT

SatelXXXXXCXXXMonitoring System Using AI - ML

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ABOUT THE ORGANIZATION

The **Indian Space Research Organisation (ISRO),** over the years, has established a comprehensive global network of ground stations to provide Telemetry, Tracking and Command (TTC) support to satellite and launch vehicle missions. These facilities are grouped under **ISRO Telemetry, Tracking and Command Network (ISTRAC)** with its headquarters at Bangalore, India.

ISRO Telemetry, Tracking and Command Network (ISTRAC), Bengaluru is entrusted with the major responsibility to provide tracking support for all the satellite and launch vehicle missions of **ISRO**. The major objectives of the centre are: carrying out mission operations of all operational remote sensing and scientific satellites, providing Telemetry, Tracking and Command (TTC) services from launch vehicle lift-off till injection of satellite into orbit and to estimate its preliminary orbit in space and hardware and software developmental activities that enhance the capabilities of **ISTRAC** for providing flawless TTC and Mission Operations services. Towards, these objectives, **ISTRAC** has established a network of ground stations at Bengaluru, Lucknow, Mauritius, Sriharikota, Port Blair, Thiruvananthapuram, Brunei, Biak (Indonesia), Bharti Research Station (AGEOS) and the Deep Space Network Stations.

In keeping with its long-established TTC support responsibility, **ISTRAC** has also been mandated to provide space operations support for Deep Space Missions of **ISRO**, undertake development of radar systems for launch vehicle tracking and meteorological applications, establish and operationalise the ground segment for Indian Regional Navigational Satellite System, provide Search & Rescue and Disaster Management Services and support space based services like telemedicine, Village Resource Centre (VRC) and tele-education.

ABSTRACT

The **Payload Function of NISAR Operation** involves the analysis and visualization of key operational parameters to ensure optimal performance. This report presents the development of an interactive data visualization system that processes and displays three datasets, each representing critical payload-related metrics. The system is designed to offer a comprehensive graphical representation of these datasets, enabling a more intuitive understanding of the underlying patterns and variations.

The project integrates **plotly** a powerful visualization library, to create dynamic and interactive graphs. The data is initially processed and plotted using conventional graphing techniques, ensuring clarity and precision. A front-end interface is developed to enhance accessibility, where users can interact with the data through a button-driven mechanism that facilitates the transition between different datasets and visualization modes.

One of the key features of this system is the ability to interact with the graphs dynamically. With **zooming, hovering, and real-time updates**, users can explore specific data points in greater detail, gaining deeper insights into payload performance. These interactive capabilities make it easier to identify trends, anomalies, and correlations that might not be immediately apparent in static visualizations. Additionally, the use of an intuitive interface ensures that both technical experts and general users can effectively engage with the data without requiring advanced programming skills.

This approach to data visualization is particularly valuable in the context of **NISAR (NASA-ISRO Synthetic Aperture Radar) operations**, where large-scale satellite data must be analysed efficiently. By providing an interactive and user-friendly platform, this system enhances decision-making processes and contributes to better mission planning and operational assessments. The combination of **graphical representation, interactivity, and ease of use** makes this visualization system a powerful tool for analysing the payload function and optimizing the performance of NISAR operations.

CONTENTS

FIGURE OF CONTENTS

TABLE OF CONTENT

1. Introduction

1.1 Overview of NISAR operation

The **NASA-ISRO Synthetic Aperture Radar (NISAR)** mission is a collaborative space-based radar imaging initiative aimed at Earth observation. It is designed to monitor and analyze natural and human-induced changes on the planet, including land deformation, vegetation, and ice movement. A crucial aspect of NISAR operations involves handling large-scale datasets related to payload functionality, which requires efficient data analysis and visualization techniques to extract meaningful insights.

1.2 Importance of payload function analysis

The payload function plays a vital role in ensuring the smooth operation of NISAR by managing data collection, transmission, and processing. Analyzing payload function data over different time periods helps in identifying operational patterns, performance trends, and potential anomalies. Traditional data representation methods often lack interactivity, making it difficult to interpret complex datasets effectively. Thus, implementing an **interactive data visualization system** enhances the ability to analyze and understand payload-related metrics efficiently.

1.3 Objectives of the report

This report presents the development of an interactive visualization system for analyzing the **payload function of NISAR operations**. The system utilizes three datasets, each representing critical parameters monitored over a **24-hour timeline**, sorted to observe variations across different timeframes. Key features of the project include:

- **Dynamic Graph Rendering:** A button-based mechanism allows users to independently display all three graphs from different datasets, providing a comparative view.
- **Eight-Day Data Analysis:** The system enables visualization of payload function trends over **eight days**, helping in long-term pattern recognition.
- **Interactive Graphing with Plotly:** Implementing **zooming, hovering, and dynamic updates**, making the analysis more user-friendly and insightful.

- **Legend Box for Identification:** Each dataset has a separate **legend box**, ensuring clear differentiation of the plotted data points.

The system's integration of **interactive visualization techniques** enhances data exploration and decision-making for NISAR operations. By leveraging **Plotly**, the project provides a **more intuitive and flexible approach** to analyzing payload functionality, ensuring efficient monitoring and management of satellite operations.

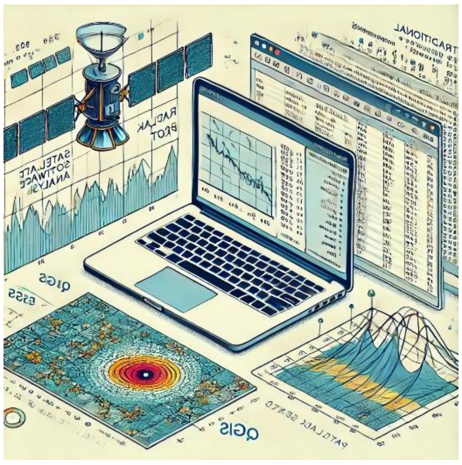

Fig 1.1Overview of NISAR payload function

2. Literature Review

2.1 Overview of NISAR operation

The analysis of payload function data has been an essential aspect of satellite operations, particularly for missions like **NISAR (NASA-ISRO Synthetic Aperture Radar)**, where large-scale data needs to be processed efficiently. Traditional methods of payload data analysis have primarily relied on **static data visualization and manual interpretation**, which often limits real-time insights. Earlier approaches included the use of spreadsheets for organizing telemetry data, MATLAB for generating static plots, and remote sensing software such as QGIS and ENVI for geospatial analysis. While these methods provided valuable insights, they lacked interactivity, making it difficult to explore data dynamically or detect anomalies efficiently.

2.2 Role of Data visualization in aerospace operations

With the advancement of technology, modern aerospace operations have increasingly integrated interactive visualization techniques to enhance data interpretation. Agencies like NASA and ISRO have adopted advanced data visualization tools to improve the monitoring and analysis of satellite telemetry and payload functions. NASA's Earth Science Data Systems (ESDS) and ISRO's satellite telemetry interfaces have demonstrated the importance of dynamic dashboards that provide real-time feedback. Unlike traditional static graphs, interactive visualization allows operators to zoom into specific timeframes, hover over data points for detailed insights, and compare multiple datasets more effectively.

2.3 Overview of plotly and Interactive Graphing

One of the most widely used tools in modern data visualization is Plotly, an open-source library that enables the creation of interactive, web-based graphs. Unlike conventional plotting libraries, Plotly provides features such as dynamic updates, interactive zooming, and independent legend boxes for multiple datasets, making it particularly useful for analysing payload function data over extended timeframes. The ability to control graph rendering through button-driven interactions allows users to selectively explore data from different datasets, enhancing comparative analysis.

This project leverages Plotly's interactive capabilities to visualize eight days of payload function data, with each dataset plotted across a 24-hour timeline. By incorporating interactive elements, users can efficiently analyze trends, detect anomalies, and compare different operational parameters without the limitations of static visualizations. As modern satellite missions continue to generate increasingly complex datasets, the shift towards interactive visualization techniques represents a crucial step in improving the efficiency and accuracy of payload function monitoring.

3. Dataset Description

3.1 Overview of the Three Datasets used

Dataset 1 primarily focuses on the mapping of various operational functions associated with the NISAR payload system. It includes both ISRO and NASA functions, categorized as follows:

- ISRO Functions: ISRO_MAP_ON, ISRO_JOINT
- NASA Functions: NASA_PRE_TAKE, NASA_JOINT, NASA_LOFS, NASA_POST, NASA_L-ONLY, NASA_POST_TAKE, NASA_PRE_TAKE, NASA_TIHO

Each function is mapped to a specific time slot, and different colors are assigned to each function for better distinction. The dataset is visualized in an interactive graph, where hovering over a function displays its exact time of execution, allowing users to track payload activity efficiently. The unstructured nature of the data required cleaning and restructuring, ensuring that all function timestamps were properly aligned and formatted for visualization.

Dataset 1 primarily focuses on the mapping of various operational functions related to the NISAR payload system, including functions from ISRO and NASA. These functions are mapped according to their execution time, with each function assigned a unique color to improve visualization. The following functions are included:

- ISRO Functions: ISRO_MAP_ON, ISRO_JOINT
- NASA Functions: NASA_PRE_TAKE, NASA_JOINT, NASA_LOFS, NASA_POST, NASA_L-ONLY, NASA_POST_TAKE, NASA_PRE_TAKE, NASA_TIHO

Each function appears on a time-based interactive graph, where hovering over a function displays its exact execution time. Initially, the dataset was unstructured, containing overlapping entries, missing timestamps, and inconsistent formatting. Data cleaning and transformation were performed to ensure accurate visualization.

Dataset 1 focuses on **mapping various operational functions** related to the **NISAR payload system**, including functions from both **ISRO and NASA**. These functions are recorded at different **timestamps**, with **each function assigned a unique color** for improved visualization. The dataset includes the following functions:

- **ISRO Functions:** ISRO_MAP_ON, ISRO_JOINT
- **NASA Functions:** NASA_PRE_TAKE, NASA_JOINT, NASA_LOFS, NASA_POST, NASA_L-ONLY, NASA_POST_TAKE, NASA_PRE_TAKE, NASA_TIHO

Initially, this dataset contained **overlapping time entries, missing timestamps, and inconsistent formats**, requiring **data cleaning and transformation**. The processed data is visualized in an **interactive graph**, where hovering over a function displays its **exact execution time**, providing users with a **clear understanding of payload activity trends**.

3.2 Data collection and preprocessing

Dataset 2 focuses on communication performance metrics, including transmission strength, frequency variations, and reception quality over time. Initially, the dataset contained missing values and inconsistent timestamps, which required data interpolation and normalization before visualization. Once cleaned, the dataset was plotted in an interactive graph, allowing users to analyze signal strength fluctuations over an eight-day period.
This dataset required significant preprocessing as it contained gaps in timestamps, duplicate readings, and misaligned function occurrences. Cleaning techniques such as timestamp normalization and missing data interpolation were applied before visualization. The dataset is presented in an interactive graph, where users can zoom into time intervals, hover to view function activations, and compare different transmission states.
Each dataset is independently visualized, with a button-driven mechanism enabling users to toggle between graphs. The use of separate legend boxes ensures that each function is clearly identifiable, while interactive zooming, hovering, and real-time updates enhance user engagement and understanding of NISAR payload operations.

3.3 Structure and key features of the data

- The Zooming & Panning: Users can zoom into specific time intervals to analyze function activity.
- Hover Tooltips: Display exact function names and execution times when hovered over a data point.
- Button-Controlled Graph Switching: Users can independently open graphs for each dataset.
- Legend Box for Identification: Each dataset has a separate legend to differentiate functions.

The integration of structured data processing and interactive visualization allows for efficient analysis of NISAR payload functions, making it easier to detect trends, anomalies, and operational patterns.

dataset used in this project consists of three independent datasets, each representing different parameters of the NISAR payload function. These datasets follow a time-series format, covering an eight-day period, with each dataset containing 24-hour timelines. Initially, the data was unstructured and not clean, requiring preprocessing steps such as missing value handling, timestamp normalization, and outlier removal to ensure accuracy in visualization and analysis.

Since the raw datasets were unstructured and noisy, the following preprocessing steps were applied:

- Handling Missing Values: Missing timestamps were filled using interpolation techniques.
- Data Normalization: Function labels and categories were standardized for consistency.
- Outlier Detection: Erroneous sensor readings and duplicate function occurrences were removed.
- Time Alignment: Functions occurring at the same time but in different datasets were synchronized for accurate analysis.

4. Methodology

The methodology of this project involves data processing, visualization, and front-end development for analyzing the NISAR payload function. The approach integrates Python libraries such as Plotly, Pandas, and Dash, along with HTML and CSS for styling and user experience enhancements. The following steps outline the key processes involved in implementing an interactive data visualization system.

4.1 Data processing and plotting approach

The dataset consists of three independent datasets structured in a time-series format covering an eight-day period. However, the raw data was unstructured and not clean, requiring preprocessing before visualization.

Steps in Data Processing:

1. Data Loading and Preprocessing:
    - The datasets were loaded using Pandas (pd.read_csv()).
    - Missing values were handled using interpolation techniques to maintain consistency.

    - Duplicate entries and misaligned timestamps were removed to ensure data accuracy.
    - The datasets were time-synchronized over a 24-hour timeline for each day.
2. Function Mapping and Colour Assignment:
    - Each function was assigned a unique colour for easy identification in visualizations.
    - Functions were categorized into payload operations, signal transmissions, and support status monitoring.

4.2 Implementation of graphs

The visual representation of the datasets was created using Plotly, enabling dynamic interaction with the data.

Graph Creation Process:

1. Building Time-Series Plots:
    - The datasets were visualized using Scatter and Line plots from Plotly.
    - Each dataset was plotted independently to maintain clarity.
2. Enhancing Interactivity:
    - Hover tooltips display function names and execution times when the cursor is moved over the graph.
    - Legend boxes allow users to distinguish different functions within each dataset.
    - Zooming and panning enable users to analyze specific time intervals.
3. Multi-Day Data Representation:
    - A button-based mechanism was implemented to display data across eight days.
    - Users can click a button to open all three graphs independently, allowing in-depth analysis.

4.3 Front-end development for visualization

To create an interactive user interface, Dash was used as the web framework, combined with HTML and CSS for styling.

Key Features of the Front-End:

1. Dash-Based Web Application:

  - The entire visualization system is hosted on a Dash web interface, allowing real-time interaction.
  - Users can toggle between different datasets using buttons.
2. HTML for Design & Custom Styling:
   - Background coloring and theme adjustments were applied using HTML and CSS.
   - The color scheme enhances data distinction, improving readability.
3. User Interaction through Buttons:
   - Each dataset's graph can be opened independently using buttons.
   - The design ensures a clean and structured interface, preventing clutter.

4.4 Integration of button-based interaction

The system allows users to toggle between datasets dynamically by clicking buttons.

How the Button Interaction Works:

1. Dash callback functions were used to control graph display.
2. When a user clicks a button, the corresponding dataset graph is displayed.
3. The interaction allows switching between datasets without reloading the entire page.

This implementation provides an efficient and user-friendly interface for payload function analysis.

5. Visualization using plotly

5.1 Interactive feature (zooming, Hovering, Dynamic Updates)

To enhance user experience, several interactive features were implemented using Plotly:

1. Zooming & Panning:
   - Users can zoom into specific time intervals to analyze function occurrences in detail.
   - Panning allows users to navigate across different time periods.
2. Hover Tooltips:
   - When the user hovers over a data point, a tooltip displays:
     - Function Name

        - Timestamp of Execution
        - Category (ISRO, NASA, or Support System Function)
    - This feature provides real-time insights into function execution.
3. Dynamic Graph Updates:
    - Clicking a button dynamically loads the corresponding dataset's graph without requiring a full page reload.
    - Users can toggle between datasets independently to focus on specific payload operations.

5.2 Enhancing user experience through interactive

Plotly's Dash framework is used to ensure an intuitive and smooth experience when interacting with the visualizations.

Key Enhancements:

- Independent Graph Views: Each dataset is visualized separately, preventing clutter.
- Custom Legends: Functions in each dataset are color-coded, with a legend for identification.
- HTML & CSS Styling: Background colors and design elements enhance visual appeal and readability.

5.3 Advantages of plotly for payload data analysis

Plotly was chosen for its interactivity, ease of integration with Dash, and ability to handle large datasets efficiently.

The implementation of interactive data visualization using Plotly has significantly improved the analysis of NISAR payload functions. By integrating zooming, hovering, and real-time updates, the system allows for a detailed exploration of function activity over multiple days. The combination of Plotly, Dash, and HTML styling ensures a user-friendly and visually rich experience.

6. Results and discussion

6.1 Insights from visualized data

The interactive graphs reveal several key insights about NISAR payload operations:

1. Function Execution Trends:
    - The payload functions exhibit distinct patterns over the 24-hour timeline, with some functions occurring at regular intervals while others are more sporadic.
    - NASA and ISRO functions show a mix of joint and independent activities, highlighting coordinated operations.
2. Identifying Anomalies:
    - Certain time periods show unexpected gaps in function execution, which could indicate operational downtimes or data transmission issues.
    - By zooming in on these intervals, users can investigate anomalies more effectively.
3. Comparing Dataset Behaviors:
    - The three datasets contain overlapping and independent functions, allowing users to compare how different system components interact over time.
    - The ability to toggle between datasets provides a layered understanding of payload behavior.

6.2 Identifying trends and anomalies

The integration of Plotly's interactive features significantly enhances the usability and effectiveness of the visualization system.

- Improved Data Interpretation:
    - The hover tooltips provide immediate function details without cluttering the graph.
    - The legend box categorization enables quick identification of function types.
- User-Controlled Exploration:
    - Users can zoom into specific periods for a detailed view or pan across days for a broader perspective.
    - The button-based interaction ensures that datasets are displayed independently, preventing graph overcrowding.

- Seamless Front-End Integration:
    - The Dash-based web interface ensures smooth user interaction.
    - Background styling and color-coded functions enhance clarity and readability.

6.3 Effectiveness of the interactive system

The integration of Plotly's interactive features significantly enhances the usability and effectiveness of the visualization system. The system enables users to explore NISAR payload function data with ease, offering a more intuitive and user-controlled analysis compared to traditional static graphs.

Enhanced Data Interpretation

- Hover Tooltips for Instant Insights
    - Users can hover over data points to instantly view function details, including function name, execution time, and category.
    - This eliminates the need for manual cross-referencing with external datasets.
- Color-Coded Legends for Quick Identification
    - Each function is assigned a distinct color, improving readability and differentiation.
    - The legend box categorization ensures that users can easily distinguish functions from ISRO, NASA, and support systems.

User-Controlled Data Exploration

- Zooming & Panning for Detailed Analysis
    - Users can zoom into specific time intervals to analyze payload execution patterns at a finer level.
    - Panning functionality allows smooth navigation across different days, making it easy to compare operations over time.
- Button-Based Dataset Switching
    - Users can click buttons to independently open and analyze each dataset, preventing graph overcrowding.
    - This ensures a structured and organized data visualization experience.

Seamless Front-End Integration

- Dash-Powered Web Interface for Smooth Interaction
    - The web-based Dash framework allows users to interact with graphs in real time without page reloads.

  - This creates a fluid, responsive, and engaging user experience.
- HTML & CSS Styling for Visual Clarity
  - The background styling and UI enhancements improve the clarity of displayed information.
  - Thoughtful design choices prevent data misinterpretation and visual overload.

7. Effectiveness of the interactive system

7.1 Technical challenges in implementation

The development and implementation of the interactive visualization system for NISAR payload function analysis posed several technical challenges. These challenges were primarily related to data handling, real-time interactivity, and system performance.

Handling Large and Unstructured Datasets

- The datasets contained unstructured and unclean data, requiring preprocessing and filtering before visualization.
- The large volume of data over an eight-day period resulted in performance issues when rendering graphs, necessitating optimization techniques to improve efficiency.

Managing Interactive Graph Performance

- Plotly’s interactivity features, such as zooming, hovering, and dynamic updates, require significant computational power when handling high-frequency data points.
- Rendering multiple datasets simultaneously caused slow response times, making it necessary to optimize data loading and reduce memory consumption.

Ensuring Seamless Front-End Integration

- The visualization interface was developed using Dash, HTML, and CSS, requiring proper coordination between Python-based backend processing and frontend rendering.
- Achieving a smooth user experience with fast loading times was challenging, especially when handling button-based interactions for dataset switching.

Synchronization of Multiple Graphs

- Ensuring that all three datasets could be displayed independently without overlapping or interfering with each other was a challenge.

- The system needed to maintain synchronization across different time intervals, allowing users to analyze data points accurately without misalignment.

  Customization of Legends and Color Mapping
- Assigning distinct colors to each function while ensuring clear visibility and contrast was a complex task.
- The legend box had to be dynamically updated based on the selected dataset, preventing confusion when switching between different payload functions.

  Real-Time Data Updates and Scalability
- The current system operates on preprocessed static datasets, and implementing real-time data streaming would require additional backend development.
- Ensuring that the system remains scalable and responsive as more datasets are added is an important consideration for future improvements.

7.2 Limitations of the data and visualization approach

Despite the effectiveness of the interactive visualization system, there are certain limitations in both the dataset and the visualization approach that impact its overall accuracy and efficiency. These limitations primarily stem from data quality, static nature, and computational constraints.

1. Data Limitations

- Unstructured and Unclean Data:
  - The datasets contain inconsistent formatting and missing values, requiring extensive preprocessing and cleaning before visualization.
  - Some function execution timestamps may be incorrectly recorded or misaligned, affecting the accuracy of the displayed trends.
- Lack of Real-Time Data Updates:
  - The current system operates on pre-recorded datasets, making it unsuitable for real-time payload monitoring.
  - Any newly generated payload function data must be manually processed and uploaded, limiting its application in dynamic mission control scenarios.
- Potential Data Gaps:
  - Certain time intervals may have missing function logs, leading to gaps in visualization and incomplete trend analysis.

    - These gaps could be due to data transmission issues, sensor errors, or missing log entries.

2. Visualization Approach Limitations

- Performance Issues with Large Datasets:
    - Plotly's interactive features, such as zooming, hovering, and dynamic updates, require high computational power when handling extensive data points.
    - Rendering large datasets over an eight-day period can slow down performance, especially when switching between multiple datasets.
- Limited Customization in Plotly Dash:
    - While Plotly and Dash provide powerful visualization tools, certain design customizations (such as advanced filtering, multi-axis synchronization, and real-time updates) require additional manual coding.
    - Some functionalities, such as overlaying multiple datasets while maintaining clarity, are limited by Plotly's rendering constraints.
- No Predictive or Analytical Insights:
    - The system only visualizes existing data without performing predictive analysis or automated anomaly detection.
    - Users must manually interpret trends, making it less efficient for large-scale operational monitoring.

7.4 Limitations of the data and visualization approach

To improve the effectiveness and scalability of the NISAR payload function visualization system, several enhancements can be implemented. These enhancements focus on real-time data processing, advanced analytics, improved interactivity, and better performance optimization.

1. Real-Time Data Integration

- Implementing real-time data streaming from payload function logs would allow for live monitoring instead of relying on pre-recorded datasets.
- Integrating APIs or database connections can help fetch and update data dynamically without manual intervention.
- A real-time alert system can notify users of critical anomalies or function failures based on automated trend detection.

2. Advanced Data Processing and Cleaning

- Enhancing data preprocessing techniques to handle missing values, incorrect timestamps, and inconsistencies would improve the accuracy of visualizations.
- Using machine learning algorithms for automatic anomaly detection can help identify unusual payload function behaviors.

3. Improved Visualization Features

- Multi-Dataset Overlays:
    - Adding the ability to overlay multiple datasets within a single graph for comparative analysis.
    - Implementing multi-axis synchronization to track different functions across datasets.
- Customizable Graph Settings:
    - Allowing users to adjust colors, time ranges, and filtering options dynamically without modifying the backend.
    - Providing a dark mode and theme customization for better user experience.
- Enhanced User Interactivity:
    - Introducing drag-and-select zooming for better focus on specific time intervals.
    - Implementing search and filter options to quickly locate specific payload functions.

4. Performance Optimization

- Optimizing Plotly rendering by using WebGL-based rendering for handling large datasets efficiently.
- Implementing data compression and caching techniques to reduce loading times and improve responsiveness.
- Using asynchronous processing to ensure smooth interactivity when switching datasets.

5. Predictive Analysis and AI Integration

- Implementing AI-based trend forecasting to predict payload function patterns based on historical data.
- Using deep learning models to classify payload function behavior and detect potential failures or inefficiencies.
- Integrating reinforcement learning algorithms for adaptive visualization that adjusts based on user interactions.

6. Enhanced Front-End and User Experience

- Improved Dashboard Layout:

    - Designing a more structured dashboard interface with clearer labels, better spacing, and interactive controls.
    - Adding draggable panels and resizable graphs for a customizable viewing experience.
- Mobile and Multi-Device Support:
    - Ensuring that the visualization system works smoothly on mobile devices, tablets, and different screen sizes.
    - Optimizing touch controls for zooming, panning, and graph interactions on touch-based devices.

8. Conclusion

8.1 Summary of findings

The NISAR Payload Function Visualization System was developed to provide an interactive and user-friendly approach for analyzing payload function data over an eight-day timeline. The system leverages Plotly, Dash, Pandas, and HTML to create an engaging front-end visualization where users can interact with graphs through zooming, hovering, and button-based dataset switching.

Key Findings from the Study

- Enhanced Data Visualization:
    - The interactive system improves readability and analysis of complex payload function data by displaying each dataset separately with color-coded legends for easy identification.
    - Zooming and panning features enable a detailed inspection of function execution over time, aiding in better pattern recognition.
- Efficient Dataset Handling:
    - The system successfully processes and plots three datasets containing multiple payload functions from ISRO and NASA operations.
    - Despite challenges in unstructured and inconsistent data, preprocessing techniques helped clean and structure the information for effective visualization.
- Improved User Experience with Interactive Features:

    - The integration of button-based controls allows users to independently explore each dataset, reducing graph overcrowding.
    - Hover tooltips provide instant function details, eliminating the need for manual cross-referencing.
- Challenges and Limitations Identified:
    - Handling large datasets caused performance slowdowns, requiring optimization techniques to improve responsiveness.
    - The system currently operates on static datasets, and real-time data streaming is needed for dynamic payload monitoring.
    - The lack of predictive analytics limits automated anomaly detection and trend forecasting.

Overall Impact

The implementation of interactive visualization techniques has significantly improved payload function analysis, making data exploration more intuitive, efficient, and insightful. The system has proven useful in identifying trends, detecting anomalies, and enhancing user engagement, laying the foundation for future advancements in aerospace data visualization.

Moving forward, integrating real-time data updates, AI-driven analytics, and advanced interactivity features can further enhance the system's capabilities, making it a powerful tool for payload function monitoring and decision-making.

8.3 Impact of interactive visualization on payloads analysis

The introduction of interactive visualization techniques in payload function analysis has significantly improved data interpretation, anomaly detection, and user engagement. Traditional static graphs often limit the depth of analysis, whereas interactive tools like Plotly and Dash enable real-time exploration and dynamic adjustments, making it easier to identify trends and patterns in payload operations.

1. Improved Data Interpretation and Trend Analysis

- Interactive graphs allow users to zoom into specific timeframes, helping them analyze payload function activity in detail.
- Hovering over data points provides instant function details, reducing the need for manual cross-referencing of logs.

- The ability to switch between different datasets using buttons enables comparative analysis of multiple payload functions over time.

2. Faster Anomaly Detection and Decision-Making

- The system helps quickly identify irregularities or unexpected behavior in payload operations by allowing real-time visual inspection.
- Users can instantly detect missing function logs, timing discrepancies, or unusual patterns, leading to faster troubleshooting.
- By visually tracking function execution over an eight-day timeline, engineers can predict operational inconsistencies and optimize mission planning.

3. Enhanced User Interaction and Accessibility

- The dynamic legend box and color-coded functions make it easier to distinguish between multiple payload operations.
- Users can interactively explore datasets rather than relying on static reports, improving their overall engagement with the data.
- The ability to switch between datasets seamlessly ensures that no information is overlooked, improving completeness and accuracy in analysis.

4. Operational Efficiency and Scalability

- The interactive visualization system can be easily scaled to accommodate additional datasets and real-time monitoring.
- It reduces the dependency on manual data analysis, saving time and effort for engineers and analysts working on payload performance assessments.
- The visualization approach is adaptable for future aerospace missions, providing a versatile tool for data-driven decision-making.

8.3 Future scope for research and improvements

The NISAR Payload Function Visualization System has demonstrated significant improvements in payload function analysis through interactive visualization. However, there is still ample scope for further research and enhancements to improve efficiency, scalability, and analytical capabilities. Future developments should focus on real-time monitoring, AI-driven insights, enhanced user experience, and optimization for large datasets.

1. Real-Time Data Streaming and Monitoring

- Implementing real-time data fetching using APIs or database connections to ensure live payload function monitoring instead of static datasets.
- Developing an automated data ingestion pipeline that can continuously update payload function logs without requiring manual intervention.
- Adding real-time notifications and alerts to flag anomalies, function failures, or unexpected payload behaviors for faster decision-making.

2. AI-Powered Predictive Analysis and Anomaly Detection

- Integrating machine learning models to analyze historical data and predict potential failures or performance issues in payload functions.
- Using deep learning algorithms for anomaly detection, identifying irregular function execution patterns automatically.
- Developing self-learning models that improve over time, refining payload function predictions and operational efficiency.

3. Enhanced Visualization and User Experience

- Introducing multi-layered graphs that allow users to overlay different datasets on the same graph, improving comparative analysis.
- Providing customizable visualization options, such as theme selection, advanced filtering, and drag-and-drop functionality for enhanced user control.
- Optimizing visualization for mobile and tablet devices, ensuring accessibility across different platforms.

4. Optimization for Large Datasets and Performance Enhancement

- Implementing data compression and efficient rendering techniques to handle larger datasets without performance degradation.
- Utilizing WebGL-based rendering for smoother interactivity in high-resolution visualizations.
- Enabling parallel processing and caching mechanisms to reduce graph loading times and improve overall system responsiveness.

5. Integration with Cloud and Distributed Computing

- Deploying the visualization system on cloud platforms to allow for remote access and real-time collaboration among researchers.
- Using distributed computing frameworks (e.g., Apache Spark, Google Cloud Functions) to process large-scale payload function datasets efficiently.

- Implementing a web-based interactive dashboard where multiple users can simultaneously analyze and interact with data.

  6. Incorporating Advanced Data Analytics and Reporting

- Adding automated report generation based on payload function trends, saving time on manual data interpretation.
- Enhancing statistical analysis tools within the system to derive deeper insights into function execution over time.
- Introducing graphical comparison tools that allow users to compare historical and current payload function performance.

9. References

9.1 Research papers, articles, and tools used

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These references provide the foundation for the **methodologies, technologies, and approaches** adopted in this project.

10. Appendices

10.1 Code snippets

```
import pandas as pd
import plotly.express as px
df=pd.read_csv(r"C:\Users\himub\OneDrive\Desktop\ISROinternship project\trial\6-12-25\data_rel.txt",
               delim_whitespace=True, header=None,
               names=['Date_Time', 'Agency', 'Event','a','b','c','d','e'])
```

```
        print(df)
        df.sort_values(by='Date_Time', inplace=True)
        fig = px.bar(df,
                x='Date_Time',
                color='Event',
                title="Correctly Ordered Vertical Bar Graph",
                labels={'Event_Count': 'Number of Events', 'Date_Time': 'Timestamp'},
                category_orders={'Date_Time': df['Date_Time'].tolist()})  # Forces Date Order
        fig.update_layout(xaxis=dict(tickangle=-45))
        fig.show()
        import pandas as pd
        import plotly.express as px
        df=pd.read_csv(r"C:\Users\himub\OneDrive\Desktop\ISROinternship   project\trial\6-12-
        25\data_rel.txt",
                  delim_whitespace=True, header=None,
                  names=['Date_Time', 'Agency', 'Event','a','b','c','d','e'])
        print(df)
        df.sort_values(by='Date_Time', inplace=True)
        fig = px.bar(df,
                x='Date_Time',
                y='Event',
                 ) fig.show()
        import pandas as pd
        import plotly.express as px
        df=pd.read_csv(r"C:\Users\himub\OneDrive\Desktop\ISROinternship   project\trial\6-12-
        25\data_rel.txt",
                  sep='\s+', header=None,
                  names=['Date_Time', 'Agency', 'Event','a','b','c','d','e'])
df['Date_Time']   =   pd.to_datetime(df['Date_Time'],   format='%Y-%m-%dT%H:%M:%S',
errors='coerce')
        df_counts=df.groupby(['Date_Time', 'Event']).size().reset_index(name='Event_Count')
df_counts.sort_values(by='Date_Time', inplace=True)
fig = px.bar(df_counts,
                x='Date_Time',
                y='Event_Count',
                color='Event',
                title="Event Frequency Over Time",
                labels={'Event_Count': 'Number of Events', 'Date_Time': 'Timestamp'},
                barmode='group',
                category_orders={'Date_Time':   df_counts['Date_Time'].astype(str).tolist()})      #
        Forces Date Order
        fig.update_layout(xaxis=dict(tickangle=-45))
```