Geo-tagged video visualisation using open-source Web-GIS Techniques for Road Surface Monitoring

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Abstract: The practice of identifying deterioration on paved or unpaved surfaces for roads is known as road surface monitoring (RSM). Road surface abnormalities, such as potholes, cracks, and bumps, which have an impact on driving comfort and on-road safety, must be found in order to effectively monitor the state of the road surface. The Road Surface Monitoring system is a web-based application designed to assist transportation authorities, maintenance crews, and engineers in assessing the condition of roads. The system utilizes GPS track data in GPX format and associated videos to provide a visual representation of road surface conditions. By synchronizing the GPS data with video playback, users can monitor and analyze road conditions with visual and geospatial information. The system's main features include the selection of GPX files representing road segments, visualization of road paths on an interactive map, and playback of associated videos. The system enables users to navigate and explore road segments, enlarge or reduce, and switch between different map views. As the video playback progresses, the system updates the displayed GPS track data, allowing users to monitor road conditions with current locations and identify specific surface issues like roughness, cracks, or potholes. With its user-friendly interface and real-time monitoring capabilities, the Road Surface Monitoring system offers several benefits. Users can access road conditions accurately, make informed decisions regarding maintenance and repairs, and prioritize resources effectively. The system also facilitates data-driven analysis and reporting, enabling authorities to optimize road maintenance strategies and enhance overall transportation infrastructure. Overall, the Road Surface Monitoring system provides a valuable Web-GIS tool for road surface assessment and monitoring, enhancing the efficiency and effectiveness of road maintenance efforts.

Key words: GIS, GPS, Road surface monitoring, Web-GIS, Visualisation

1. Introduction

Road infrastructure plays a crucial role in facilitating transportation and economic development. Maintaining high-quality road surfaces is essential to ensure safe and comfortable travel for motorists. Road surface abnormalities, such as potholes, cracks, and bumps, can significantly impact driving comfort, vehicle maintenance costs, and on-road safety. Identifying and monitoring these surface defects is essential for effective road maintenance and resource allocation. The significance of distress data in evaluating the condition of pavements has been acknowledged by pavement engineers for a considerable period. This data serves various purposes, such as recording the current state of the pavement, documenting its past performance, and forecasting its future performance (Mustaffar et al., 2008).

Road Surface Monitoring (RSM) is a practice that involves the systematic assessment and tracking of road surface conditions. The main objective of this procedure is to identify any signs of deterioration, such as cracks on the road surface, at an early stage to enable timely maintenance. Detecting road surface cracks early on helps facilitate maintenance before the expenses for repairs escalate excessively. With advancements in technology and the availability of geospatial data, there is an opportunity to employ innovative approaches to road surface monitoring. The advancement and integration of Mobile, GIS and GPS have been used to improve the monitoring practices of various natural and manmade resources, fast transmission of data between field and centralized database server (Sambyal et.al, 2020; Sharma et.al. 2022). The Web-GIS is a powerful tool and technique to distribute spatial data or information on web with quality, authenticity and advantages along with interactive representation (Patel et al, 2021). The Open Source community now offers a complete set of tools or software that are able to build up a complete web GIS system for various applications (Patel et al, 2023; Ajwaliya et al. 2017; and Patel et.al 2021).

The study by (Mustaffar et al., 2008) demonstrates that by utilizing a combination of the photogrammetric approach and APIP, the developed algorithms have the ability to accurately determine the type and severity level of cracking in pavements with approximately 90% accuracy, in comparison to the conventional method. This indicates that the integration of the photogrammetric approach and APIP forms a practical system for assessing pavements.
The Road Surface Monitoring system is a web-based application designed to revolutionize the way road surface conditions are assessed and monitored. It leverages the power of GPS track data and associated videos to provide a visual representation of road conditions in real-time. By synchronizing the GPS data with video playback, the

project offers a comprehensive and accurate assessment of road surface conditions. The primary objective of the Road Surface Monitoring system is to assist transportation authorities, maintenance crews, and engineers in evaluating the condition of roads more efficiently and effectively. By integrating GPS track data, users can visualize road paths on an interactive map and playback associated videos, enabling them to monitor road conditions in a dynamic and informative manner.

(Neitzel and Klonowski, 2011)'s contribution primarily focuses on the creation of 3D point clouds from digital images. It introduces web services and free software solutions that can automatically generate 3D point clouds from various image setups. The article also discusses the georeferencing capabilities and the accuracy achieved through these methods. The presented workflow is then applied to obtain 3D geodata, with a specific case study on a landfill survey demonstrating the generation of valuable products using an affordable UAV. This research paper aims to provide an in-depth analysis of the Road Surface Monitoring system, its features, and its potential benefits. The paper will explore the technical aspects of the system; including the integration of GPS track data, video synchronization, and interactive mapping. It will also delve into the user interface and functionalities that allow users to navigate road segments, zoom in or out, and switch between different map views. A desktop approach has been adopted for the geo-tagged video and GPS data synchronization using open source Video UAV tracker of QGIS plug-in (Mathur et al. 2022).

Kim J, 1998 conceptualised to create an affordable automated system for capturing video images of road surface. A research by C. Zhang and A. Elaksher, 2012, indicates that the system has the ability to accurately detect and assess surface distresses on roads by providing 3D information. The results of the experiments are highly promising, showcasing the system's capability to deliver reliable and precise outcomes. When evaluated using 2D and 3D models with known sizes, the system consistently achieves a measurement accuracy of less than a centimetre. Comparing the systems derived 3D information with manual measurements taken on-site; there is a variance of only 0.50 cm, which highlights the system's potential for future practical applications.

The Road Surface Monitoring system serves as a valuable tool for transportation professionals involved in road maintenance and management. By harnessing the power of geospatial data and video visualization, the system streamlines the road surface monitoring process, providing a comprehensive solution for assessing and monitoring road conditions. Through this research paper, we aim to shed light on the potential impact and benefits of the Road Surface Monitoring system in improving road maintenance practices and ultimately enhancing the quality and safety of road networks.

Various techniques have been employed for road surface monitoring. Traditional methods involve manual inspections conducted by trained personnel. These inspections often rely on visual observations and subjective assessments. However, these methods can be time-consuming, costly, and prone to human error. To overcome these limitations, researchers have explored the use of advanced technologies for road surface monitoring. Furthermore, the research paper will examine the advantages offered by the Road Surface Monitoring system. Accurate road condition assessment enables authorities to make informed decisions regarding maintenance and repairs, ensuring the optimal allocation of resources. The system's data-driven analysis and reporting capabilities empower authorities to optimize road maintenance strategies and enhance overall transportation infrastructure.

2. Study Area

Ludhiana city has been selected for the pilot study and to prove the technical implementation of the approach. Ludhiana city is the most populous and the largest city of Punjab state, India.

3. Materials and Methods

Data Collection

The first step involves collecting the necessary data for road surface monitoring. This includes obtaining GPS track data in GPX format, which contains coordinates and timestamps for road segments. Additionally, videos capturing the road surface conditions are collected and associated with the corresponding GPS track data.

Data Processing and Integration

The secondary objective is to devise methods for analyzing the collected video footage. Two systems were developed: one for collecting video images on-site and another for processing them in an office setting. A test was conducted by recording videos along a selected route, which included different types of pavements and various factors. The results of the test indicated that seven consecutive loop tests produced satisfactory outcomes for image analysis. By utilizing a video camera with a fast shutter speed, it was determined that the survey vehicle could travel at a high speed while maintaining good picture quality.

The collected data is processed and integrated to enable effective visualization and analysis. The GPX data is parsed and converted into a format compatible with the system. The videos are synchronized with the GPS track data timestamps, establishing a connection between the geographic locations and the corresponding road surface conditions.

Web Application Development

The system involves developing a web-based application that serves as the interface for road surface monitoring. This includes designing and implementing the user interface, interactive map functionality, and video playback features. Web technologies such as HTML, CSS, and JavaScript are utilized, along with libraries like OpenLayers for map visualization and video player frameworks for playback.

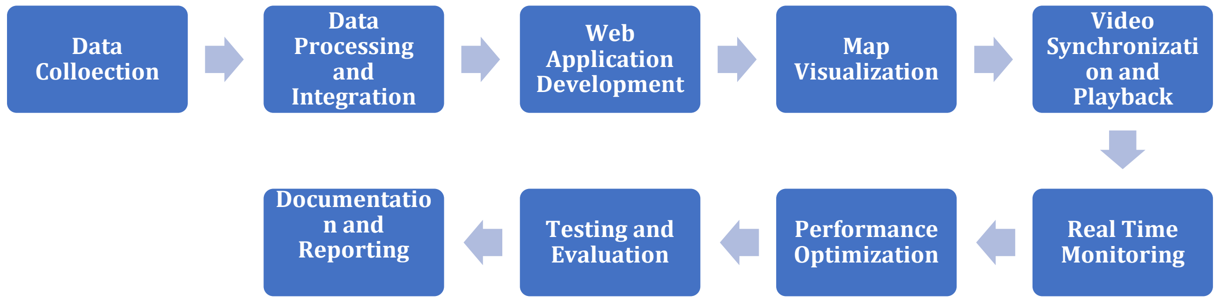


Figure1. Structural presentation of proposed methodology

Figure1 represents the structural presentation of proposed methodology and each step has been discussed briefly in this section.

Map Visualization
The developed web application incorporates an interactive map that displays the road segments based on the GPS track data. The map is created using a mapping library like OpenLayers, allowing for customization and overlaying road paths on base map layers such as OpenStreetMap. The map supports zooming, panning, and switching between different map views, facilitating user exploration and analysis.

Video Synchronization and Playback
The GPS track data and associated videos are synchronized to provide a visual representation of road surface conditions. Video player functionality is integrated into the web application using frameworks or HTML5 video elements. The synchronization is achieved by linking the video playback with the GPS track data timestamps, ensuring that the corresponding video frames are displayed as the user progresses along the road segment.

Real-Time Monitoring
The web application is designed to enable real-time monitoring of road conditions. As the user plays the video, the system dynamically updates the displayed GPS track data, showing the current location on the map and providing information about surface abnormalities such as roughness, cracks, or potholes. This allows users to accurately assess road conditions and identify areas requiring attention.

Performance Optimization
To ensure optimal performance, various optimization techniques are implemented. This includes optimizing data loading and rendering processes, minimizing latency in video playback, and implementing caching mechanisms to improve overall user experience. These optimizations enhance the responsiveness and efficiency of the web application.

Testing and Evaluation
The developed web application undergoes thorough testing to ensure functionality, usability, and reliability. Different scenarios and test cases are considered to validate the synchronization of GPS track data with video playback and the accuracy of the displayed road surface conditions. User feedback and evaluations are collected to identify areas for improvement and refine the application's features.

Documentation and Reporting
Comprehensive documentation is prepared, including user manuals, technical specifications, and guidelines for system maintenance and updates. Additionally, a report is generated summarizing the methodology, findings, and potential benefits of the Road Surface Monitoring system. This documentation serves as a reference for users and provides insights into the system's implementation and outcomes.

By following this methodology, the Road Surface Monitoring system aims to deliver an efficient and user-friendly web application that enables accurate assessment and monitoring of road surface conditions. It leverages GPS track data and video visualization to enhance road maintenance practices and optimize resource allocation for transportation authorities, maintenance crews, and engineers.

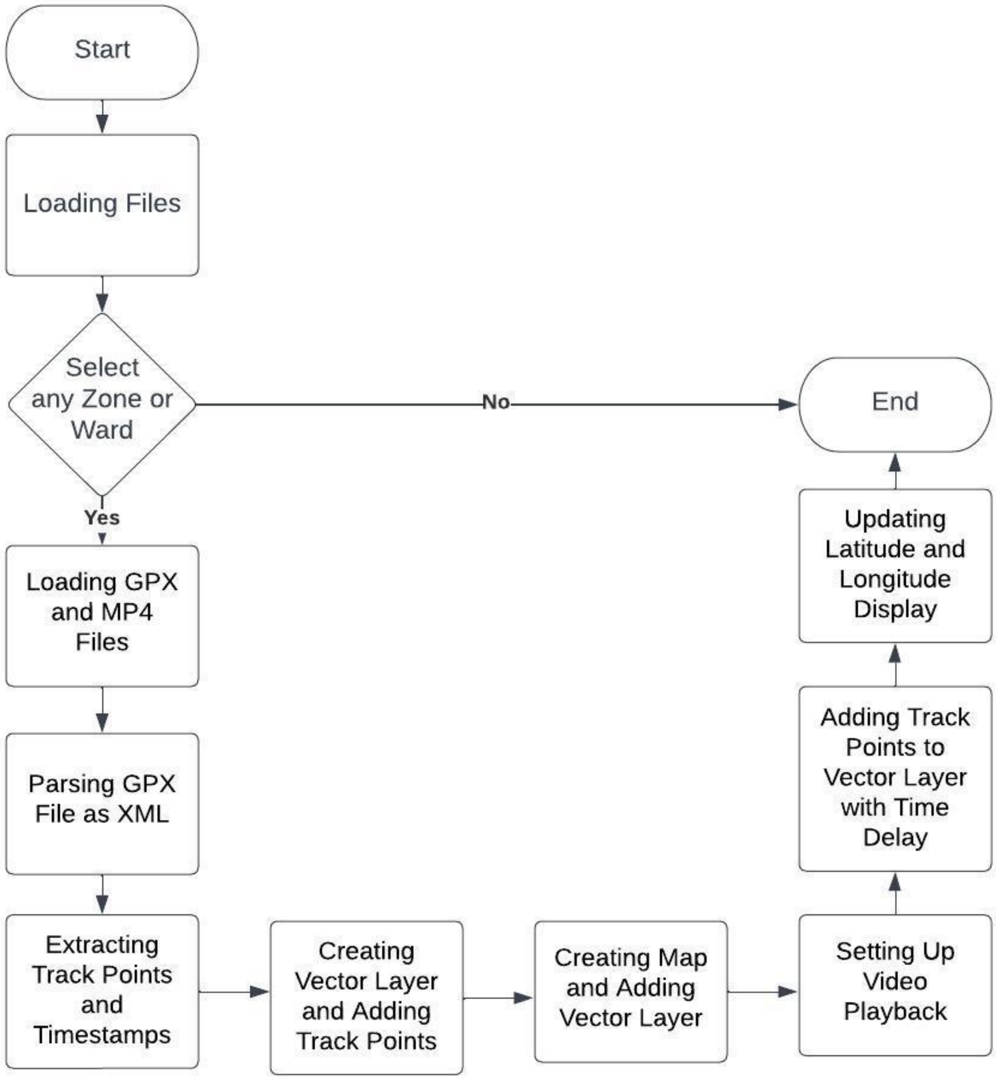


Figure 2. Flowchart

The flowchart in figure2 illustrates the sequential steps and decision points involved in a system. It begins with a terminal symbol, marking the start. The process begins with the user selecting a file, represented by the "Loading Files" symbol. Next, a decision symbol checks if a file is selected or not. If a file is selected, the flow progresses; otherwise, it stops as no file is chosen. The flow continues to load GPX and MP4 files based on the selected file, followed by parsing the GPX file as XML and extracting track points and timestamps. A vector layer is created, and track points are added as features. Additionally, a map is created, and the vector layer is added to it. Video playback is set up, including loading the MP4 file and configuring the video player. The flow then enters a loop where track points are added to the vector layer with a time delay based on the time difference between points and the video time. As each track point is added, the latitude and longitude display on the webpage is updated. This loop continues until all track points have been added. Finally, the flow reaches the end of the flowchart, denoting the system's completion. The flowchart provides a visual overview of the entire process, ensuring a clear understanding of how the different components are connected and interact with each other.

4. Results and Discussion

The results obtained from the Road Surface Monitoring (RSM) system are significant in improving road maintenance and infrastructure. Here are some of the key features of the designed system:

Accurate Road Condition Assessment: The system provides accurate and real-time monitoring of road conditions. By synchronizing GPS track data with video playback, the system enables users to identify and analyze surface issues such as potholes, cracks, and roughness. This leads to precise assessments of road conditions.

Informed Maintenance and Repair Decisions: With comprehensive road condition data available through the system, transportation authorities, maintenance crews, and engineers can make informed decisions regarding maintenance and repairs. They can prioritize resources effectively, focusing on areas that require immediate attention.

Optimization of Resource Allocation: By utilizing the system's capabilities, authorities can optimize resource allocation for road maintenance. They can allocate budgets, personnel, and equipment based on accurate assessments and identified road surface issues. This ensures efficient utilization of resources and maximizes the impact of maintenance efforts.

Enhanced Road Safety and Driving Experience: The RSM system contributes to enhancing road safety and improving the overall driving experience. By identifying and addressing road surface abnormalities promptly, the system helps mitigate potential hazards, reduce accidents, and enhance the comfort and safety of road users.

Data-Driven Analysis and Reporting: The system facilitates data-driven analysis and reporting. Authorities can generate comprehensive reports based on the collected road condition data, enabling them to identify trends, patterns, and areas requiring long-term maintenance strategies. This allows for evidence-based decision-making and continuous improvement of road maintenance practices.

Overall, the Road Surface Monitoring system provide valuable insights and tools for optimizing road maintenance, improving road safety, and enhancing the overall transportation infrastructure.

As shown in figure3, the default front page of the website for the Road Surface Monitoring system features a header with the system name, logo, and information about the Punjab Remote Sensing Centre. It also includes a file selector for choosing GPX files and a map section for visualizing road segments. Additionally, there is a video player section for playing associated road surface videos and displaying latitude and longitude information.
Presented in figure4, the file selection feature in the system's website allows users to choose GPX files representing road segments. This enables users to load specific road data for monitoring and analysis, enhancing their ability to assess road surface conditions accurately.

The website of the Road Surface Monitoring system displays the latitude and longitude of the current location on the map. This information provides users with the precise geographic coordinates of the road segments being monitored. It helps in the visualization and assessment of road conditions based on the displayed GPS track data, allowing users to identify specific areas of concern and make informed decisions for maintenance and repairs. Figure 5(a) and5 (b) represents the above mentioned features of the designed system.

The application of GIS visualization to the monitoring of road conditions provides many real-life benefits. The following conclusions can be made in light of the experimental findings: The performance of the system may be affected by the size and complexity of the GPX files, the length of the associated videos, and the number of track points to display. Large datasets or extended videos can impact the system's performance, such as loading times, map rendering, or video playback. Optimization techniques or hardware upgrades may be required to handle larger datasets efficiently. The system may require periodic maintenance and updates to address bug fixes, security vulnerabilities, or compatibility issues with evolving web standards or dependencies. Regular maintenance activities should be planned to ensure the long-term usability and reliability of the system.

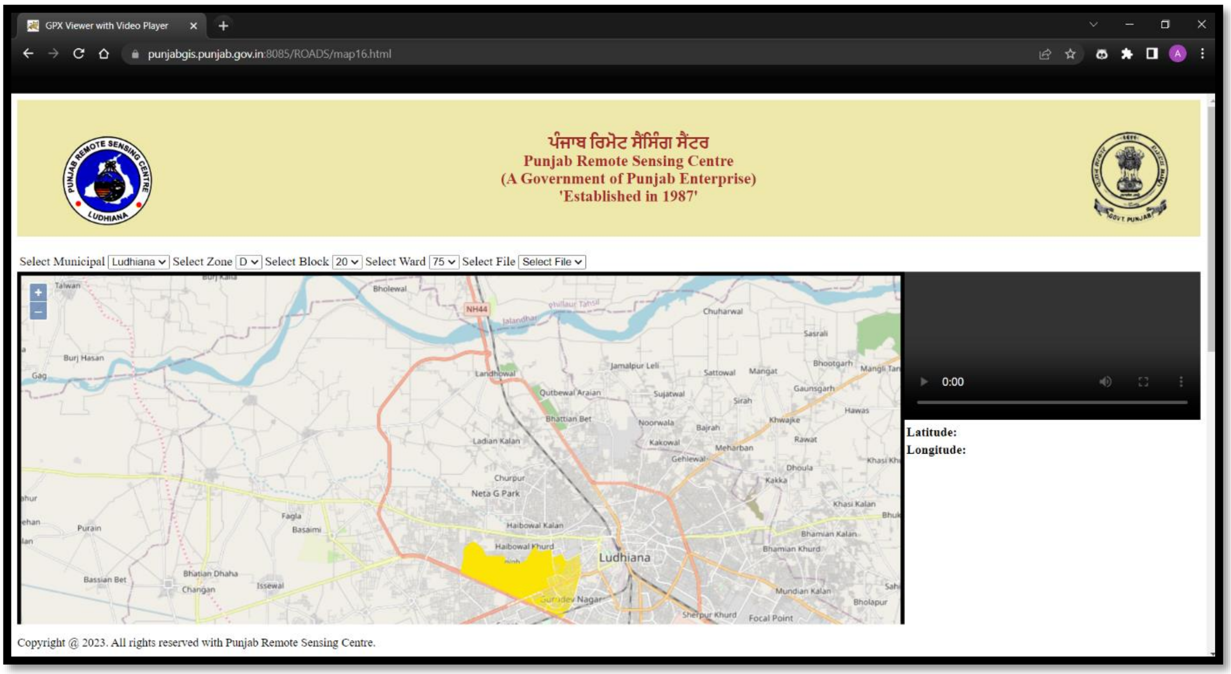


Figure 3. Default front page of the System Website

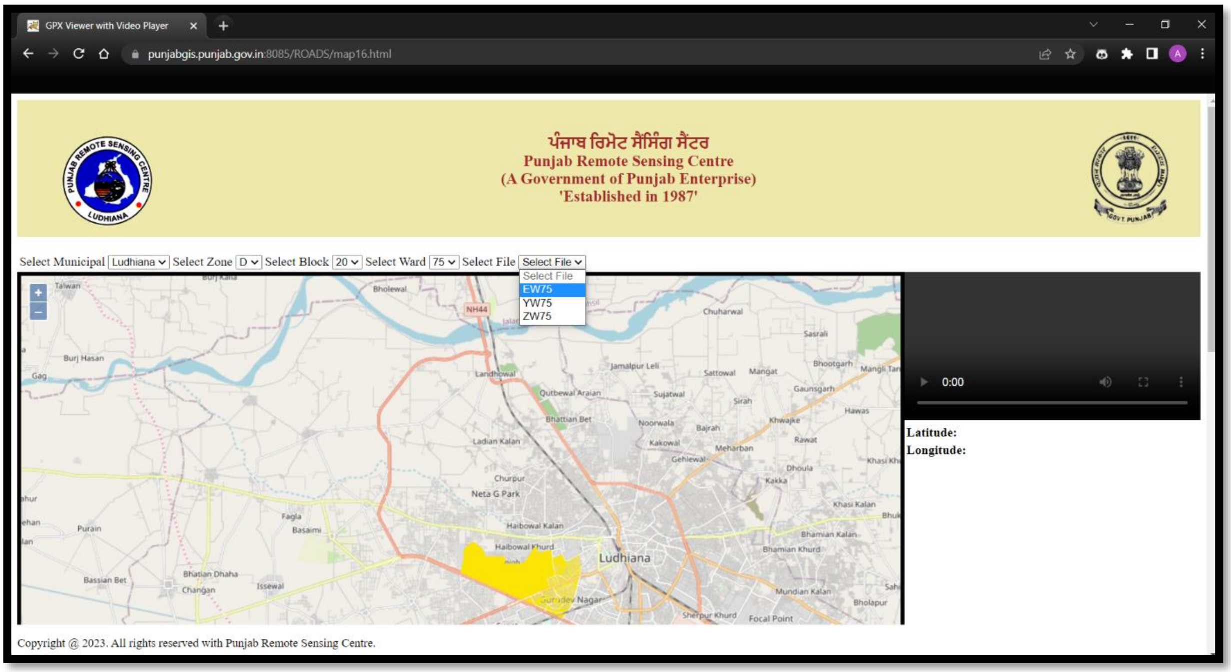
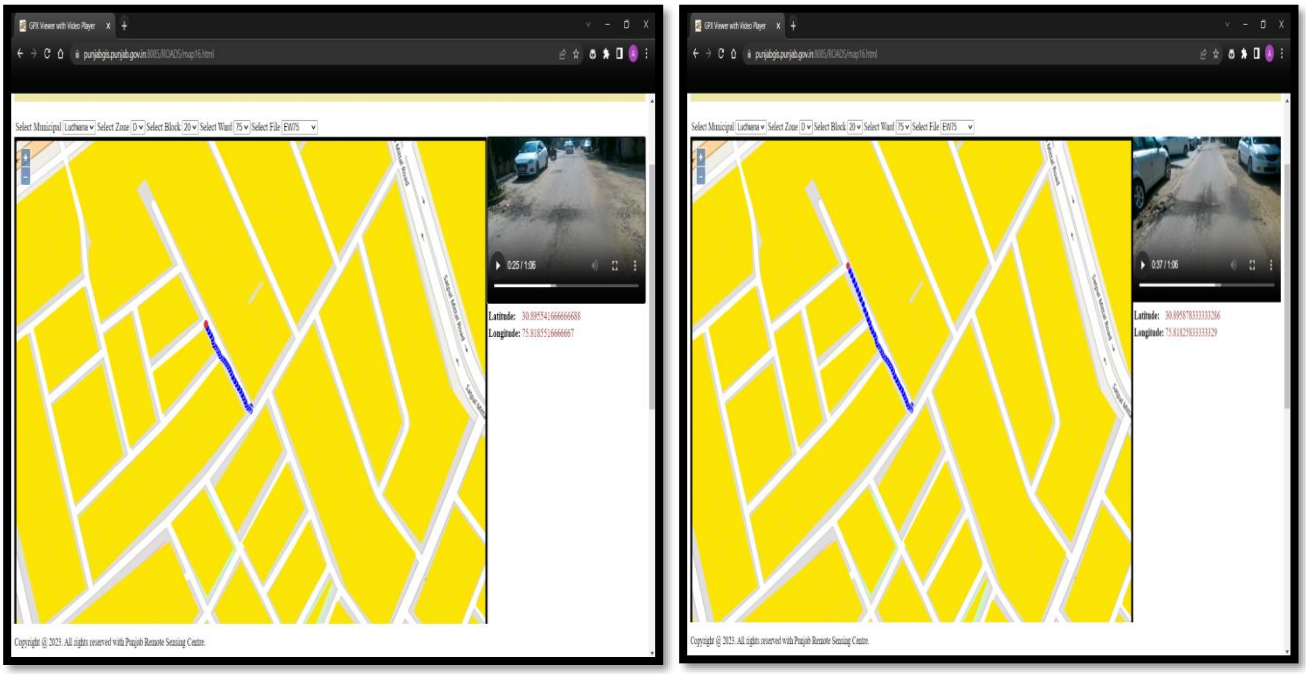


Figure 4. File selection



(a) (b)

Figure 5. Working of System

While the web application demonstrates remarkable robustness and generalization performance, there are still some notable flaws in the study. Firstly, the system heavily relies on the availability of GPX files containing GPS track data and corresponding video files capturing road surface conditions. Insufficient access to reliable and up-to-date data, or poor data quality, can impede the system's effectiveness. Secondly, specific hardware and software requirements must be met for the system to function correctly. This includes possessing a device capable of running modern web browsers, supporting HTML5 video playback, and meeting the mapping library's minimum system requirements. Outdated software or inadequate hardware may result in performance issues or incompatibility. Thirdly, a stable internet connection is necessary as the system may require access to external resources such as map tiles or remote video files. Limited or unreliable internet connectivity can restrict the usability of the application. Fourthly, the system assumes compatibility with GPX files for GPS data and video files in a supported format. Incompatibility with different file formats or versions may hinder the correct loading and parsing of data. Users must ensure their files adhere to the required formats. Lastly, the accuracy of GPS data in the GPX files can vary based on the quality of the GPS devices used during data collection, environmental conditions, and device limitations. Potential errors or inaccuracies may arise, and users should be aware of these limitations. Despite the web application's strengths, these flaws must be addressed to enhance the system's overall performance and reliability.

5. Conclusion and Future Work

Unlike simple video display systems, the RSM system synchronizes GPS track data (in GPX format) with video footage to provide a dynamic, real-time visual representation of road conditions. This integration enables users to not only watch a video but also understand the exact location of surface abnormalities in relation to the geographic context.

In this study, the designed system allows the user to select a GPX file and an MP4 video file. The GPX file is parsed to extract the latitude and longitude coordinates of the track points, which are then displayed on a map using the Open Layers library. The video is also displayed on the same page with controls for playing and pausing.

As the video plays, the program adds markers to the map that correspond to the location of the video at each point in time. This allows the user to see the location of the video at any given time and how it relates to the surrounding geography. Additionally, the latitude and longitude of the current video position are displayed in a table next to the video. Thus, gives you a clear view about the condition of the road.

The developed RSM system goes beyond simply displaying information—it enables transportation authorities and maintenance crews to make informed decisions about road maintenance. By offering synchronized GPS and video data, the system facilitates efficient prioritization of repair work. This data-driven approach helps authorities allocate resources where they are most needed, improving the overall strategy for infrastructure management.

As a Web-GIS tool, the RSM system incorporates geographic information systems to enhance the process of road surface monitoring. This is a significant step beyond basic video playback or simple web-based visualization. The combination of GPS data, interactive mapping, and video content creates a robust platform for evaluating road conditions in a comprehensive, data-rich environment, offering more than just a passive experience

Overall, this program can be useful for visualizing the spatial context of a video recording, particularly in situations where the video is capturing a journey or movement through a geographic area. It could be used for a variety of applications such as tracking wildlife, surveying a site, or documenting a trip.

The Road Surface Monitoring system is more than just a web-based visualization tool or a video display system—it is a comprehensive, interactive, and data-driven platform that enhances the efficiency and effectiveness of road maintenance efforts. By combining GPS data, interactive mapping, and synchronized video playback, the system provides realistic view and actionable insights that help decision makers, and policy makers to prioritize repairs, improve safety, and optimize infrastructure management. This level of innovation and functionality goes far beyond traditional methods of road surface inspection, making it a unique and valuable tool in the field of transportation infrastructure.

The future scope of the study "Geo-Tagged Video Visualization using Web-GIS technology" includes several exciting possibilities. such as, integrating the program with other data sources like weather, traffic, and social media data would enhance visualizations, providing users with more comprehensive and dynamic insights. Secondly, there is potential for real-time data visualization, enabling users to access geo-tagged video footage as events unfold, making it valuable for news consumption. Additionally, transforming the program into a smartphone app would allow users, such as journalists and first responders, to record and geo-tag videos in real-time, providing a powerful tool for swift documentation. Another exciting aspect involves incorporating augmented reality (AR) technology, enabling users to view geo-tagged films superimposed on real-world surroundings using mobile devices or AR headsets. Lastly, machine learning techniques can be employed to extract and identify objects, events, and places automatically from the vast amount of geo-tagged video data, simplifying data analysis for users. These advancements would greatly enhance the program's capabilities, expanding its potential and utility.

Declarations

Competing interests

On Behalf of all the authors, we are ensured that the manuscript is not submitted to elsewhere simultaneously, it is confirmed that the submitted work is original and have not been published elsewhere in any form or language. Manuscript describes the development of the Web GIS system for geo-tagged video visualization using open source technologies. This work is demonstrated as geo-visual techniques development to enhance the interactive visual techniques for road conditions monitoring using spatial sciences. We do not have any financial interest for this manuscript publication. Results are mentioned clearly and persons involved directly or indirectly are acknowledged.

Authors' contributions.

Dr. Shashikant Patel: Conceptualization of research Work and defined work flow of methodology with technical implementation as Web-GIS application development.

Mr. Ashwin Mohan: Video Integration with Open Source Web-GIS application. GPX file Reading and Programming in Java to synchronization of Videos and GPX Points.

Ms. Baljit Kaur: Data Pre-processing GPX data reading and Design and development of a centralized database along with connections to the various server viz. application server and web server.

Dr. Ajay Mathur: Methodology conceptualized for field data collection using GPS and Video Camera. Captured

Field data (Video & GPS), Pre-Processing and desktop implementation.
Dr. Brijendra Pateriya: Overall Guidance and Provided Technical Suggestions to formulize research article.

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Availability of data and materials
This is Open source Web-GIS Application, thus all the data set will be available to the users from web portal.

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