IoT Road Health Monitoring Platform for Secure Urban Mobility in Smart Communities

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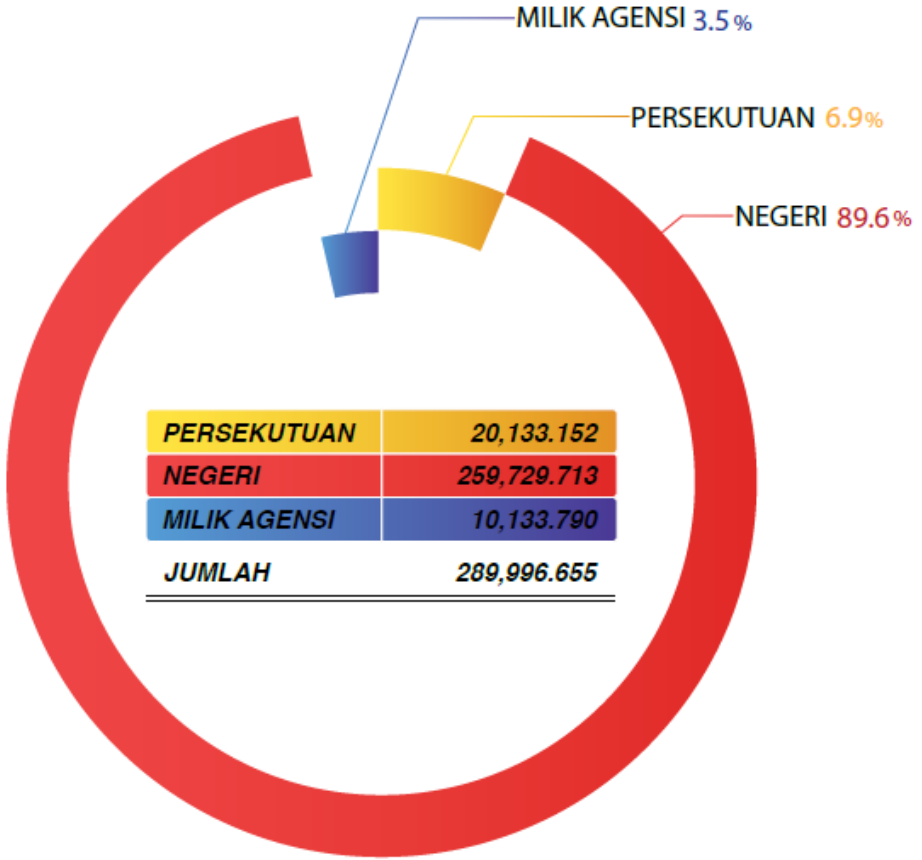
Background and Motivation

- Almost 90% of the roads in Malaysia are managed and maintained by state governments.
- To monitor road health, the State Public Works Department typically collaborates with concession companies to periodically collect data, such as the International Roughness Index (IRI).
- However, the vast size of the road network means that a significant portion of state roads is not covered in the data collection process.
- This is primarily due to the limited availability of Class 1 instruments and the labor-intensive, time-consuming nature of data analysis.

The Percentage of Federal and State Roads as of December 31, 2022



Source: Malaysia Road Statistics 2023 Edition, Road Facility Maintenance, Public Works Department Malaysia.

Background and Motivation

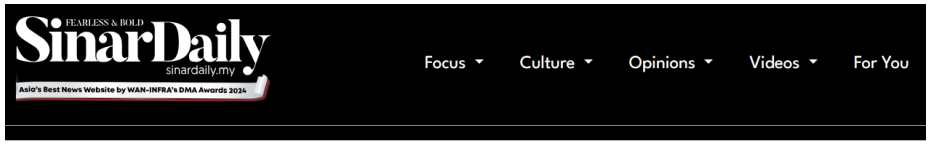
Potholes and politics: Fixing Malaysia's roads requires more than patchwork solutions

Experts call for action on aging infrastructure

By WAN AHMAD ATARMIZI Follow

28 Jan 2024 08:45am

Quoted from the news article



FOCUS FOLLOW

Potholes plaguing Malaysian roads: New solution found?

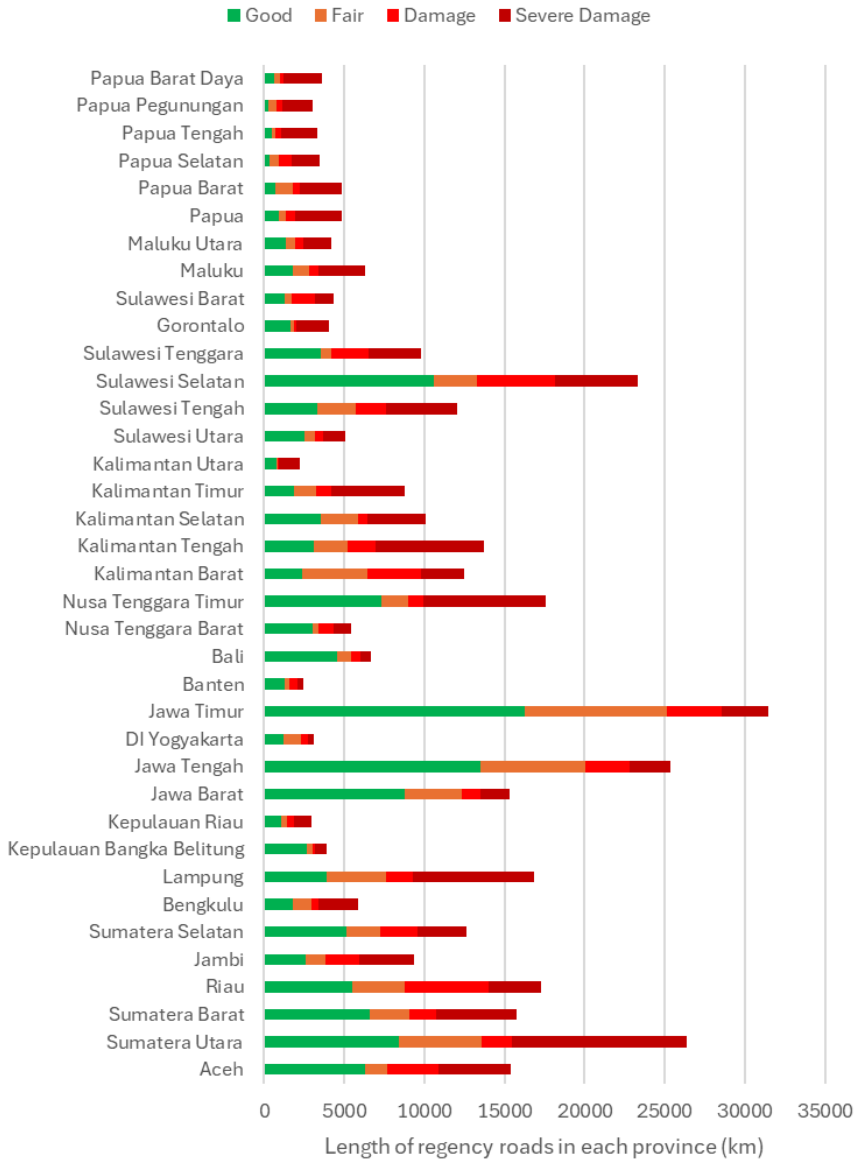
According to statistics released by the Road Accident Management System, Works Ministry, a total of 181 road accidents, including 23 fatal cases, due to potholes were recorded between 2022 and July this year.

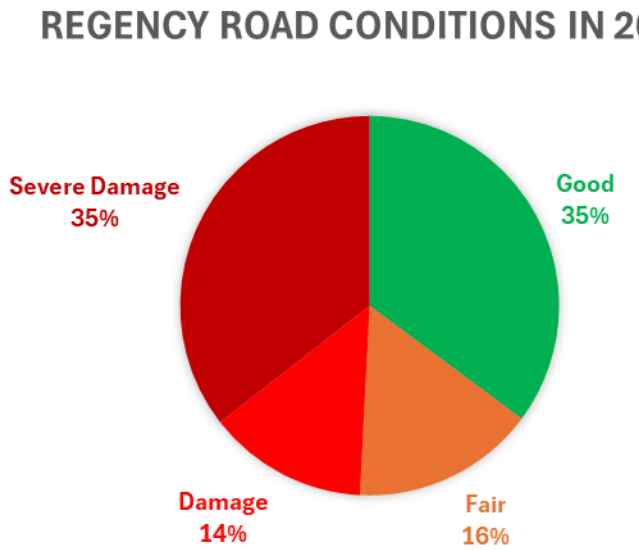
16 Sep 2024 09:02am

"Monitoring the progress of patching potholes can be achieved through a combination of surveillance methods, incorporating both manual monitoring and advanced technology.

"The utilisation of the Internet of Things (IoT) and artificial intelligence (AI) can significantly enhance these tracking efforts.

Background and Motivation





Source: Open Data, Ministry of Public Works and Housing, Republic of Indonesia, https://data.pu.go.id/dataset/

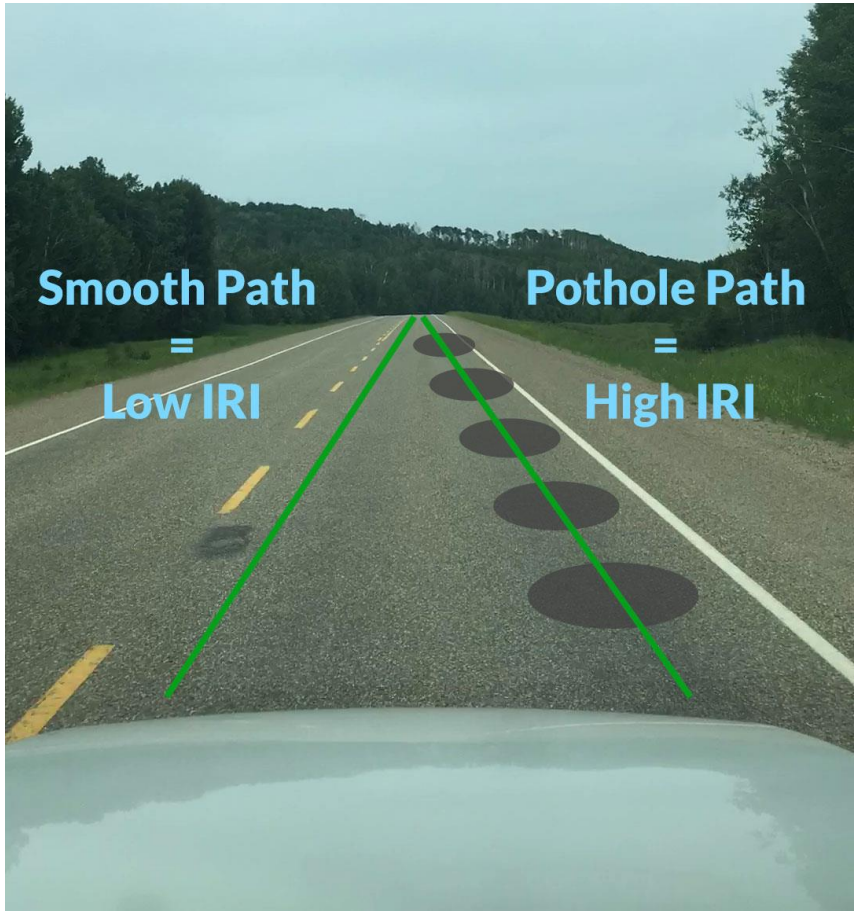
- Nearly half of Indonesia's regency roads are in severely damaged and poor condition.
- Currently, International Roughness Index (IRI) data collection is conducted only for national roads, leaving a significant gap in monitoring the health of regency and urban roads.

Background and Motivation

- There is no established system in place to collect road health data for regency and urban networks, leading to delays in maintenance and repair.
- Moreover, without reliable data, there is no proper justification or system in place for authorities to effectively prioritize budget allocation for road maintenance.
- Implementing a comprehensive data-driven monitoring system is crucial for improving infrastructure and ensuring safer urban mobility.

Proposed Method

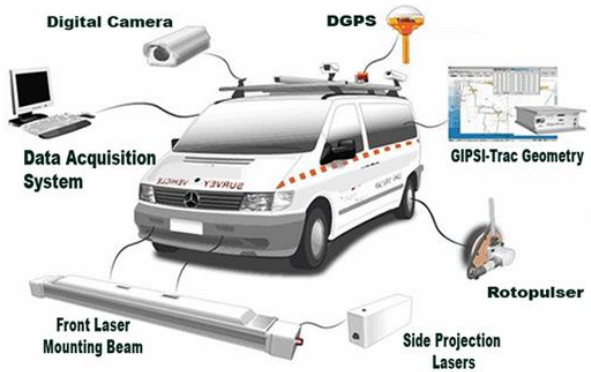
- The International Roughness Index (IRI) is a widely recognized standard for evaluating road health, providing a numerical value that allows comparison of roughness across different road segments.
- Transportation agencies around the world use IRI to prioritize maintenance and repair activities.
- This project aims to measure IRI using wireless IoT technology by empowering the urban community through crowdsourcing approach.
- The project is driven by three key objectives:
    1) To design and develop an IoT platform for wireless IRI measurement.
    2) To validate the collected IRI data using a class 1 instrument.
    3) To test the developed IoT platform with crowdsourced data.

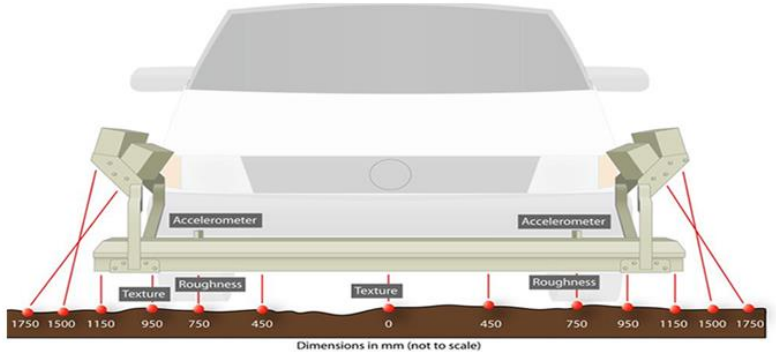


Proposed Method

How does the proposed project improve current road data collection methods?

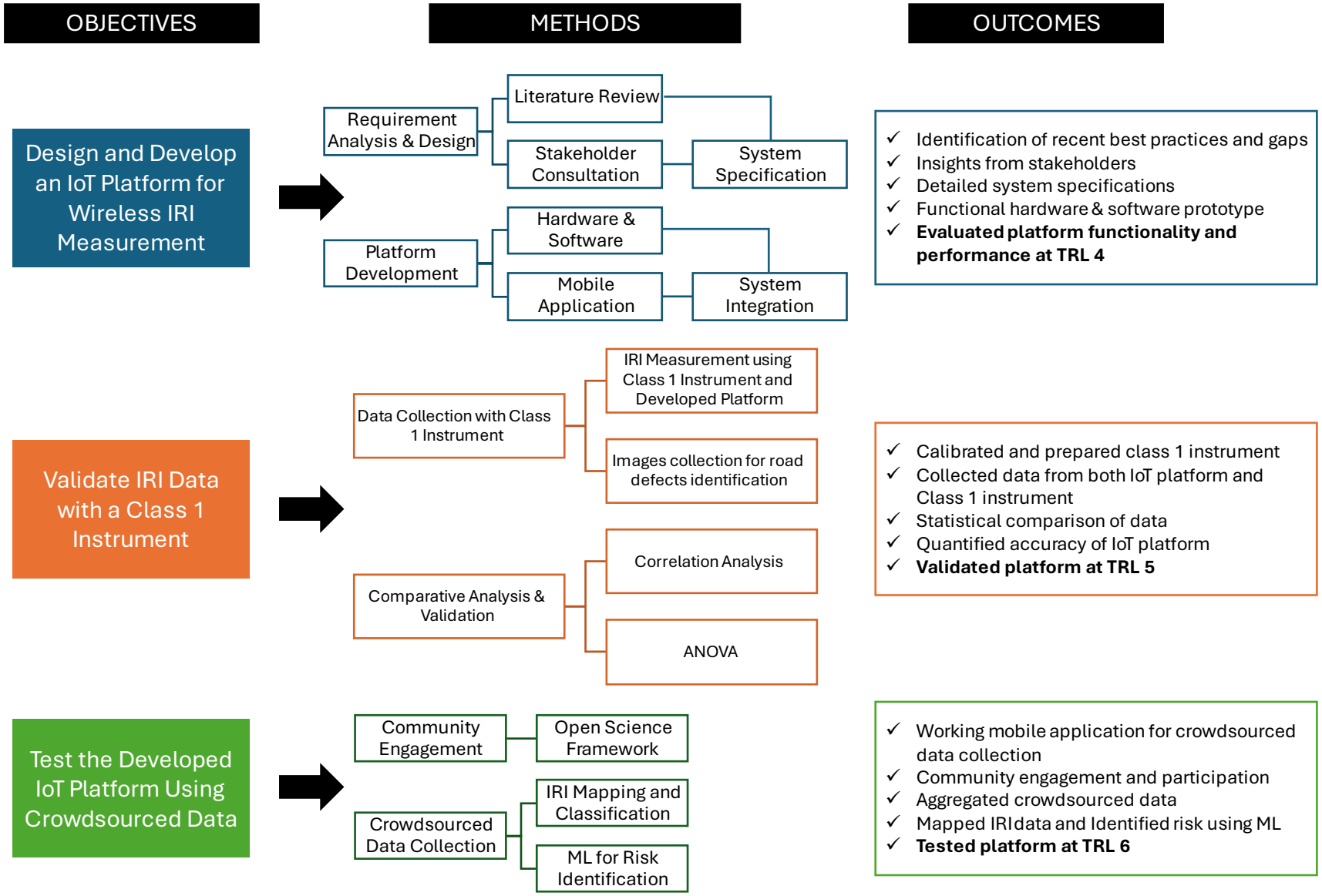
- Currently, the most common method for collecting IRI data involves using a laser profiler vehicle equipped with GPS sensors (Class 1 instrument).
- The data collected on-site is then stored on bulky hardware and later analyzed off-site. This process requires operators to travel long distances, sometimes hundreds of kilometers, for data collection before returning to the station for data transfer and analysis.
- This approach is **labor-intensive** and **time-consuming**.
- The proposed project offers a significant improvement by enabling the **wireless transmission of data** in real-time during collection.
- Additionally, by incorporating machine learning algorithms to predict IRI values, the project can cover more state roads efficiently, speeding up the data collection and analysis process.





Class 1 instrument used by the road maintenance company to measure the International Roughness Index (IRI)

Proposed Method



Proposed Method

Feedback to stakeholder

Requirements analysis

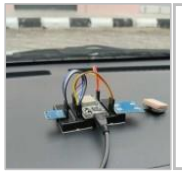
STEP 1

Development of detailed system specifications

Stakeholder engagement

STEP 2

Hardware development

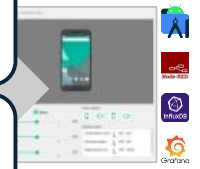


Sensors & Connectivity

- 3-Axis Accelerometer
- GPS Module
- Microcontroller+WiFi

Software development

- Android Studio for Mobile App Development
- Node-RED for Automation and Data Flow
- Influx DB for Time Series Databases
- Grafana for Real-time Dashboard



STEP 3

Data Collection and Validation

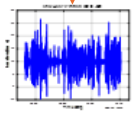
Image taken by road users and uploaded to Roboflow platform

Images

Signals

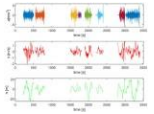
Vertical acceleration signals

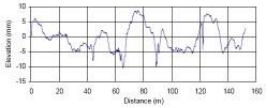
Road profile from laser profiler



Data segmentation

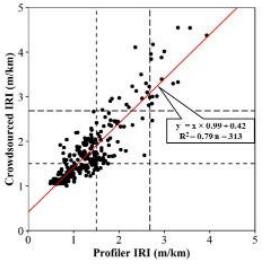
Double integration





$$IRI = \frac{\sum_{i=2}^{n} |h_i - h_{i-1}|}{s} = \iint_{t_{start}}^{t_{stop}} |a_v| (dt)^2$$

Correlation Analysis

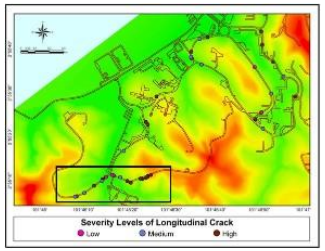


IRI measured using response type method i.e. Smartphone and IoT devices

IRI measured using class 1 instrument i.e. Laser profiler

Validation

Road health conditions index

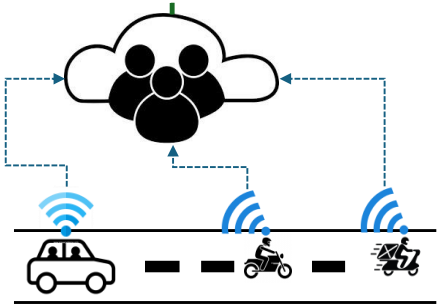


IRI Mapping

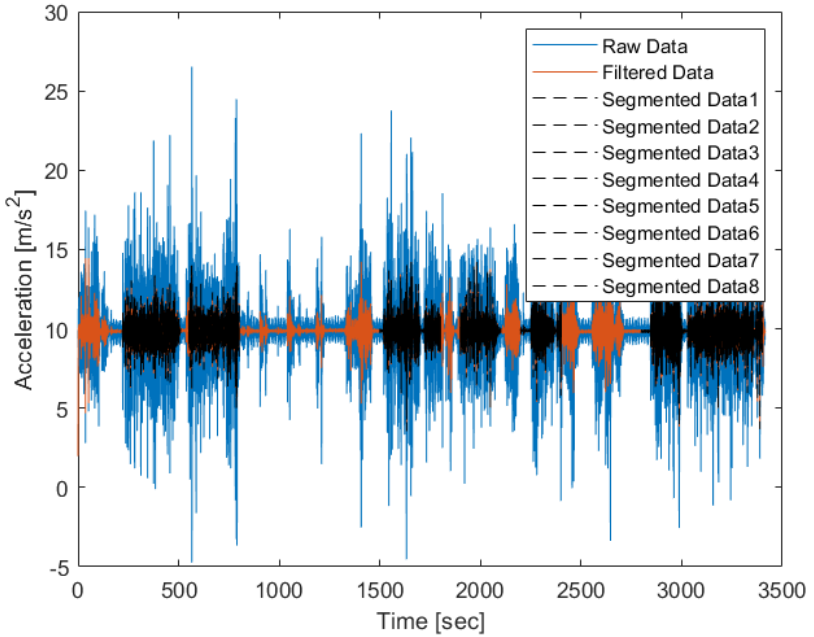
Heatmap of road defects

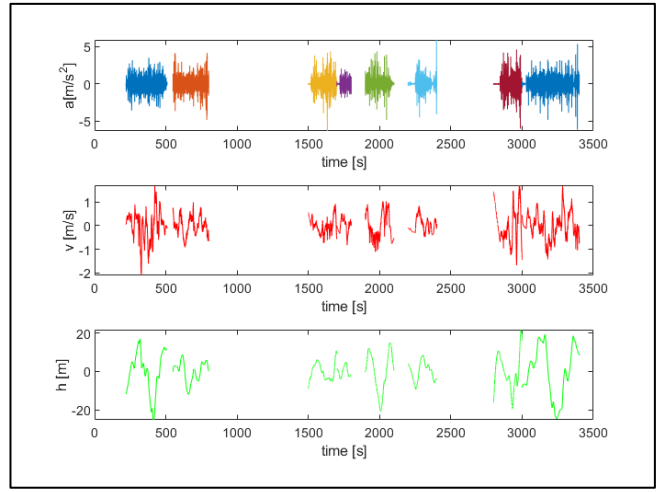
STEP 4

Testing with Crowdsourced Data



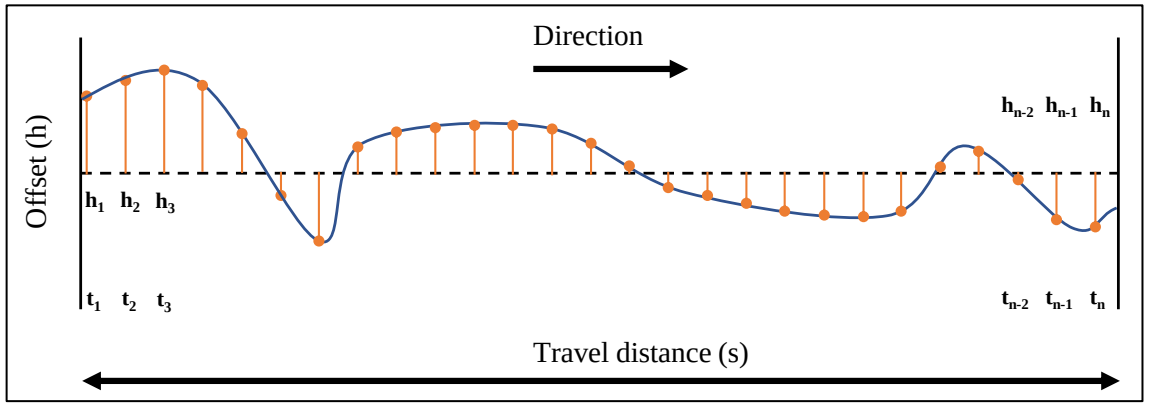
Proposed Method (Current Results)





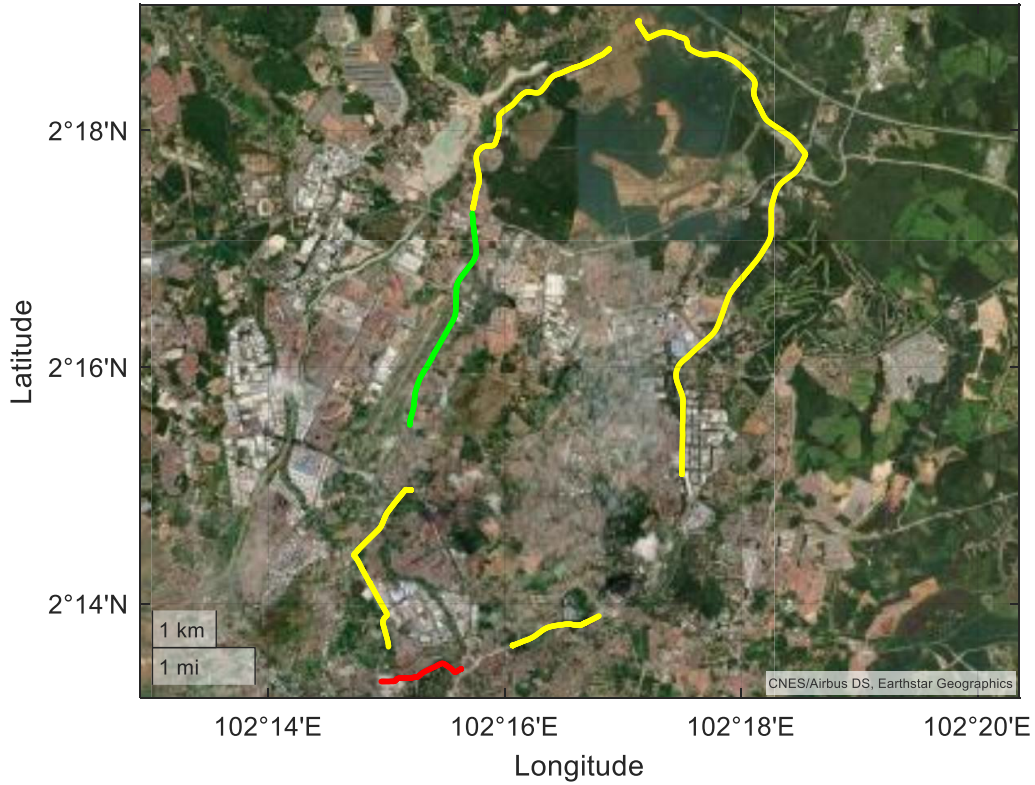
$$IRI = \frac{\sum_{i=2}^{n} |h_i - h_{i-1}|}{s} = \iint_{t_{start}}^{t_{stop}} |a_v| (dt)^2$$

$$s = 2R\ arcsin\sqrt{sin^2\alpha + cos\varphi_1 \cdot cos\varphi_2 \cdot sin^2\beta}$$



Proposed Method (Current Results)

No.	Segmented Data	Mean IRI Value [m/km]	Pavement Condition
1	Segmented Data 1	2.3204	Fair
2	Segmented Data 2	1.2412	Good
3	Segmented Data 3	2.0404	Fair
4	Segmented Data 4	2.1217	Fair
5	Segmented Data 5	6.5083	Bad
6	Segmented Data 6	2.7990	Fair
7	Segmented Data 7	2.2421	Fair
8	Segmented Data 8	2.2421	Fair



Pavement Condition	IRI (m/km)
Good	< 2
Fair	2 - 3
Poor	3 - 3.8
Bad	> 3. 8

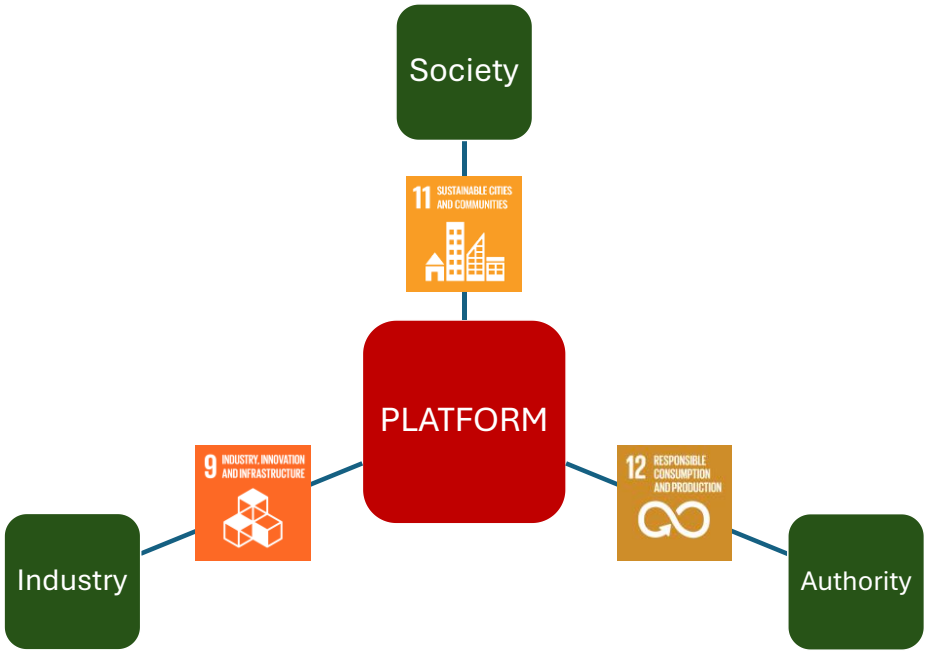
S. N. Baskara et al., "Influence of pavement condition towards accident number on Malaysian highway," IOP Conf. Ser. Earth Environ. Sci., vol. 220, no. 1, pp. 0–8, 2019.
Projek Lebuhraya Utara Selatan (PLUS) 2014 Pavement Condition Assessment Along Section S6, Malaysia-Singapore Second Crossing for Year 2014. Final Report.
Projek Lebuhraya Utara Selatan (PLUS) 2013 Pavement Condition Assessment Along NorthSouth Expressway for Year 2013, Southern Region. Final Report.

Impact

The IoT platform for road health monitoring is central to this project, benefiting society, industry, and authorities.

Impact on Society:

- Provides real-time road condition data through digital visualization tools.
- Enables the public to monitor road health and make informed travel decisions, reducing mobility risks like potholes and uneven surfaces.
- Enhances road safety by lowering accident risks and vehicle damage.
- Encourages community involvement through crowdsourced data collection.
- **Supports SDG 11** (Sustainable Cities and Communities) by promoting safe, inclusive, and resilient urban mobility.



Integrated Impact Model Linking Society, Industry, and Authority

Impact

Impact on Industry and Authority:

- **Technology Transfer:** The road maintenance industry benefits from the adoption of wireless IRI data transmission, assisting or replacing conventional methods, leading to more efficient and innovative approaches.
- **Data-Driven Operations:** Access to public-use datasets generated by the platform helps both industries and authorities optimize maintenance operations and adopt predictive and prescriptive strategies, resulting in more efficient resource use.
- **Improved Decision-Making:** The platform enables better decision-making for both industries and authorities, allowing them to prioritize repairs and allocate budgets more effectively.
- **Support for SDG 9** (Industry, Innovation, and Infrastructure): The project fosters innovation in road maintenance by enhancing industrial efficiency and promoting sustainable infrastructure development.
- **Support for SDG 12** (Responsible Consumption and Production): The platform helps authorities allocate resources (e.g., labor, equipment, budget) more efficiently, reducing waste and ensuring that road maintenance efforts are focused on the areas that need it most.

Output/Outcome

Scientific

- A new framework for road data collection using wireless IRI transmission.
- Creation of a scalable IoT platform for real-time road health monitoring.
- Introduction of predictive and prescriptive maintenance strategies.

Societal

- Generation of public-use road health datasets.
- Contribution to standards organizations with road health data and analysis, potentially influencing new guidelines for road maintenance practices.

Collaborative

- Strengthened partnerships between public authorities, road maintenance industries, and academic institutions.
- Opportunities for cross-country collaboration within ASEAN, along with potential partnerships with technology companies for further platform scaling and enhancement.

Conclusion

- This project targets urban commuters, road maintenance industries, and public authorities. Urban commuters will benefit from safer roads through real-time road condition data, while industries will gain more efficient maintenance methods, and authorities will improve decision-making on repairs and budgeting.
- The idea is to create a scalable IoT platform for real-time road health monitoring using wireless IRI data transmission and machine learning for data analysis.
- The output is a comprehensive IoT platform that includes:
  - ✓ IoT devices (smartphone, microcontroller with sensors and GPS) to collect road roughness data.
  - ✓ Communication networks (Wi-Fi, 4G/5G) to transmit data from the IoT devices to the cloud.
  - ✓ Cloud storage and computing for storing the collected data and performing real-time or batch data analysis.
  - ✓ Data processing and analytics for predictive and prescriptive maintenance strategies.
  - ✓ User interface/dashboard: A mobile dashboard for road users to capture and visualize road conditions in real time, and a web-based dashboard for industries and authorities to monitor data, generate reports, and prioritize road repairs based on data-driven insights.