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A COMPARATIVE EVALUATION OF INTERNATIONAL ROUGHNESS INDEX (IRI) TECHNIQUES BETWEEN MOBILE LASER SCANNER (MLS) AND DIPSTICK

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ABSTRACT

Assessing road surface quality is essential for maintaining and ensuring the safety of transportation infrastructure. This study evaluates the effectiveness of Mobile Laser Scanning (MLS) using the Leica Pegasus TRK 700 Evo in comparison to the conventional Dipstick method for measuring the International Roughness Index (IRI) on road surfaces. IRI data were collected from five sample locations, with observed differences between the two methods ranging from 0.02 m/km to 1.00 m/km and an average deviation of 0.19 m/km. The results suggest a high degree of compatibility between the IRI values generated by both methods, indicating that MLS can serve as a reliable alternative for road condition surveys. The Leica Pegasus TRK 700 Evo demonstrated operational efficiency, capable of surveying 40 to 100 kilometers of road per day under typical field constraints, such as equipment setup and GNSS base station relocation every 15 kilometers. Data processing required approximately four hours for every hour of field measurement. A field deployment scenario was developed, detailing the necessary resources, including a survey vehicle equipped with the MLS unit (staffed by a driver, operator, and section owner), a support vehicle for high IRI zones, a GNSS base station transport vehicle, and a two-person data processing team. The findings demonstrate that MLS technology is a practical and efficient tool for road condition assessment and offers a flexible, reliable alternative to traditional survey techniques in managing transportation infrastructure.

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INTRODUCTION

Pavement roughness, quantified by the International Roughness Index (IRI), significantly impacts ride quality, vehicle operating costs, and road safety (Mahlberg et al. 2022). Accurate prediction of IRI is essential for effective pavement management and maintenance. Studies have increasingly employed machine learning algorithms, such as Artificial Neural Network (ANN), Random Forest (RF), and Support Vector Machine (SVM), to predict IRI, comparing their performance with traditional techniques (Bashar and Torres-Machi 2021).

Connected vehicle data and on-board sensors integrated in Original Equipment Manufacturer (OEM) vehicles have been explored for crowdsource estimation of ride quality using IRI (Mahlberg et al. 2022). This approach leverages sensor technology and data collection for real-time assessments of pavement quality, offering an alternative to conventional methods. Additionally, smart structural health monitoring and machine learning methods have been investigated for evaluating pavement smoothness, highlighting the potential for advanced technologies to enhance IRI assessment (Karballaeezadeh et al. 2020).

The impact of pavement roughness, as measured by IRI, on freeway safety has been studied using data from different states, demonstrating the relevance of IRI in assessing road safety and its implications for transportation infrastructure management (Lee et al. 2020). These findings underscore the importance of accurate and reliable IRI measurements for informing safety performance functions and guiding decision-making processes.

In the context of pavement design and construction, the IRI has been identified as a critical parameter, influencing the mechanistic-empirical design of full-depth reclamation projects and the calibration of predictive models (Beesam and Torres-Machi 2021). This emphasizes the integral role of IRI in the design and construction phases of pavement infrastructure, further highlighting the significance of accurate evaluation techniques. MLS has emerged as a promising technology for assessing pavement roughness and IRI. Studies have investigated the feasibility of using MLS for road rut depth measurement, as well as for the instance-aware semantic segmentation of road furniture in MLS data (Issaoui et al. 2021). These advancements in MLS technology offer new opportunities for enhancing the accuracy and efficiency of IRI assessment, presenting a potential alternative to conventional methods.

The assessment of IRI with MLS involves the crucial decision of whether to analyze it on a point cloud or a processed Digital Elevation Model (DEM). This decision significantly impacts the accuracy and reliability of the IRI assessment. Several comparisons can be made to determine which method is better suited for the analysis of IRI with MLS. Analyzing IRI on a point cloud offers the advantage of directly working with the raw data, allowing for detailed and precise measurements of pavement roughness.

(Fu et al. 2021) present a robust coarse-to-fine registration scheme for MLS point clouds, emphasizing the identification of correct corresponding point pairs and the calculation of the transform matrix. This approach highlights the potential of point cloud analysis for accurately capturing the intricate details of pavement surfaces, which is essential for precise IRI assessment. On the other hand, processing the MLS data into a DEM provides a structured and organized representation of the terrain, facilitating the extraction of specific features relevant to IRI assessment. (Gesch et al. 2020) demonstrate the use of a high-resolution, high-accuracy DEM derived from unmanned aircraft system (UAS) imagery processed with structure-from-motion (SfM) techniques for inundation exposure assessment. This indicates the potential of processed DEMs for generating accurate representations of the pavement surface, which can be advantageous for IRI analysis.

In addition, (Perpetuini et al. 2023) aim to assess correlations between metrics estimated from electromyography (EMG) and IRI features, despite their different natures and the fact that they are indicative of different physiological processes. While not directly related to point cloud or DEM analysis, this study underscores the importance of considering the nature of the data and its relevance to the specific assessment of IRI.

Based on the provided references, the analysis of IRI from MLS data should be conducted on point cloud data rather than on processed DEMs. (Jiang et al. 2022) emphasize the use of point cloud data by discussing the fitting algorithm of scattered point clouds based on 3D laser scanning. (Wang and Liu 2021) provide a detailed review of segmentation technology based on 3D point cloud data, emphasizing the advantages and disadvantages of point cloud segmentation methods. This review underscores the importance of point cloud data for advanced segmentation techniques, indicating its relevance for precise analysis and feature extraction. (Balado et al. 2020) discuss a novel approach to automatic traffic sign inventory based on MLS data and deep learning, highlighting the speed and optimization of artificial intelligence techniques when applied to point cloud data. This suggests that point cloud data is more conducive to advanced analysis and automated processes compared to processed DEMs.

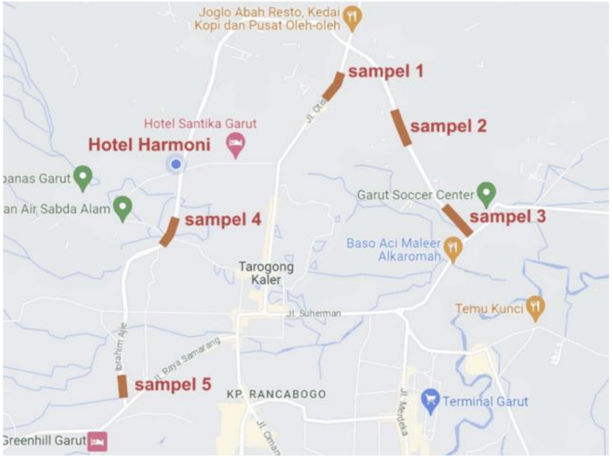
Given the growing demand for rapid, scalable, and accurate methods to evaluate road surface conditions, there is an urgent need to validate the effectiveness of modern technologies like MLS against established conventional methods. This study aims to assess the feasibility of using the Leica Pegasus TRK 700 Evo MLS device as an alternative to the Dipstick method for measuring the IRI. The evaluation focuses on comparing both methods across several criteria: IRI value deviation, measurement efficiency, operational speed, resource requirements, and data processing time. This study is expected to provide practical insights into the reliability and operational benefits of adopting MLS for road condition surveys, particularly in contexts where speed, coverage, and resource optimization are critical.

METHODOLOGY

This research involved a structured field deployment of the Leica Pegasus TRK 700 Evo MLS to evaluate its performance in Road Condition Surveying, specifically for measuring the IRI. A comparative analysis with the Dipstick method was conducted over a two-day field campaign in Garut Regency, West Java.

Site Selection

Five road segments exhibiting varied surface conditions and IRI levels were selected within Garut Regency. The selection ensured diverse road profiles for a representative comparison between MLS and Dipstick results. The data acquisition phase ensued, involving the capture of point cloud data along the five road sections within Garut Regency as shown in Figure 1.



Source: Google Maps with location overlay (2024)

Figure 1. Five samples location on Garut Recency, West Java, Indonesia

Five road segments within Garut Regency, West Java, were selected for this study based on the following criteria:

- Surface condition diversity: The chosen segments exhibited a wide range of pavement conditions—from smooth, recently paved roads to deteriorated sections with visible surface irregularities. This variation was essential for capturing a representative spread of IRI values and testing the adaptability of both measurement methods.
- Accessibility and logistical feasibility: The segments were accessible for both conventional Dipstick measurements (which require walking along the pavement) and for safe passage of the MLS-equipped survey vehicle.
- Operational relevance: Garut Regency was selected due to ongoing local government interest in adopting advanced road survey technologies, offering practical alignment between research and real-world infrastructure needs.
- Data comparability: The selected locations ensured minimal interference from traffic, parked vehicles, or vegetation overgrowth, which could otherwise compromise the quality of both point cloud and manual data.

This strategic site selection enabled a robust comparison between the Mobile Laser Scanning system and the Dipstick method across varied real-world conditions.

Dipstick Measurement (Day-1)

On the first day, IRI measurements were performed using a Dipstick profiler across the five selected segments. These measurements served as the benchmark for evaluating the accuracy of the Leica Pegasus TRK 700 Evo MLS system.

Source: Author’s documentation (2024)

Figure 2. Conventional IRI measurement with Dipstick

MLS Data Acquisition (Day-2)

The second day commenced with the installation of the Leica Pegasus TRK 700 Evo system onto the survey vehicle. The Leica team provided detailed instructions and explanations regarding each component, as illustrated in Figure 3.

Source: Author's documentation (2024)

Figure 3. Leica Pegasus TRK 700 Evo assembly process

Following system setup, a GNSS base station was established to support accurate positioning, and the MLS measurement route was configured via the main tablet interface, as shown in Figure 4.

Source: Author's documentation (2024)

Figure 4. GNSS base station and trajectory location on main tablet.

Data Processing and IRI Analysis

The third day focused on processing the collected MLS data. Initial data handling was carried out using Leica Pegasus Field via the tablet control unit. Subsequent processing steps were conducted using Pegasus Office and Cyclone 3DR. The Leica TruView Viewer within this suite facilitated point cloud classification into key categories: ground, pavement, vegetation, buildings, utility poles, and other road-related features. This classification supports extended applications such as road inventory management and road safety enhancement through spatial data analytics.

Source: Author's documentation (2024)

Figure 5. Example of point cloud classification results.

Configuration and Processing Steps

Summary of MLS system settings and operational parameters is provided in Table 1 and Data processing steps and their durations are outlined in Table 2.

Table 1. MLS Configuration summary.

IRI Measurement by MLS Project			
Hardware type	Pegasus TRK700 Evo	Type of Job	Road
Control unit	444128	Positioning	No RTK
Sensor unit	297035	Image anonymisation	No
Capture date	25/09/2023	OMI	No
Total distance (km)	1.99	2nd antenna	Yes
Capture time	4348	Images	ON
Activation time	42720	Image distance (m)	3
Deactivation time	05:11.1	Scanline spacing (cm)	10
Total number of Tracks	5	Profiler rotation (Hz)	267
Total number of Frames	659	Profiler points/sec	1000000
Average speed (km/h)	2.73	Max. scanner range (m)	182
Space on the drive	102GB	Max. recommended speed (km/h)	75

Source: MLS Pegasus TRK700 Evo project report (2024)

Table 2. Steps taken and total duration.

Step	Task	Subtask	Software	Duration (minutes)
1	Data migration and control			5
2	Base station processing			5
3	Import and project data processing	Project creation	Cyclone Pegasus Office	5
		Base station registration		5
		Coordinate system registration		5
		Trajectory processing		60
4	Finalize and exporting data	High density point cloud		30
		RGB colorization		40
		Deliverables		40
5	Report			5
6	Final quality check			10
7	IRI analysis		Pegasus Manager/ Proval	30
	Total			240

Source: Author's (2024)

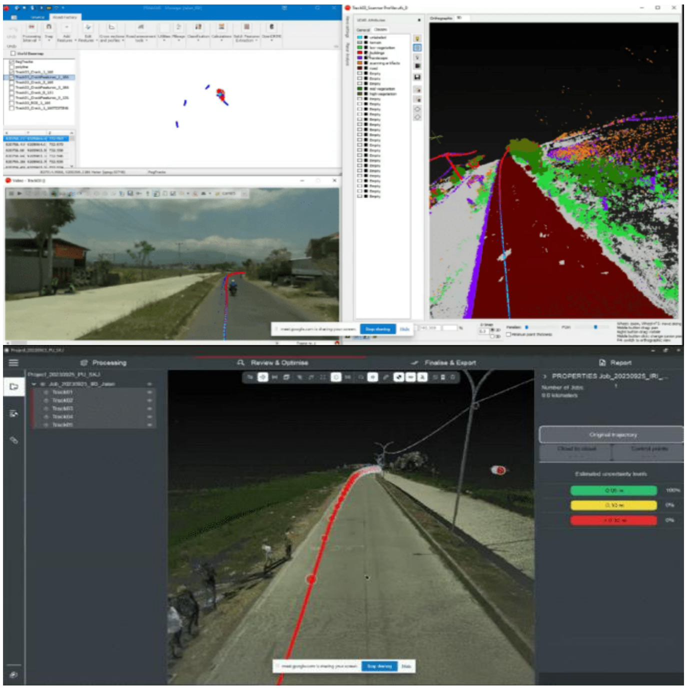
Operational and Requirements

The Leica Pegasus TRK 700 Evo, as outlined in Table 1, features dual laser scanners, a 24 MP 360-degree panoramic camera, a hybrid GNSS/IMU module, and a modular platform compatible with various four-wheeled vehicles. Weighing 26 kg, it is deployable by one to two personnel and supports acquisition at a rate of 2 million points per second.

The control system includes a main unit and two batteries, with the interface operated through a tablet. The system supports SLAM to compensate for potential GNSS signal loss. Additionally, it includes four auxiliary 48 MP cameras offering panoramic imaging to support outputs like PCI (Pavement Condition Index).

The point cloud produced features a resolution of 2 mm point spacing with a line spacing of 4.9 cm. The optimal scanning range spans 50–70 meters, although the device's technical capability extends up to 182 meters. Key acquisition parameters such as image interval, scanline spacing, and scan speed can be tailored based on the project's objectives.

During the survey, GNSS data from a base station ensured positional accuracy. The total survey covered 1.99 km of road and resulted in the collection of high-density point clouds and 360-degree images from five sample sites. The entire process, from equipment setup to IRI result generation, took approximately four hours (see Table 2).



Source: Author's documentation (2024)

Figure 6. Point cloud data, trajectory, and imaging results of Leica Pegasus TRK 700 Evo

FINDINGS

The difference between the IRI values generated from the dipstick device at 5 (five) sample locations shows the largest difference of 1 m/km and the smallest difference of 0.02 m/km, with an overall average difference of 0.19 m/km.

While the dipstick method has historically been reliable, the variations observed in the obtained IRI values underscore the potential for discrepancies and the influence of localized conditions on measurements as demonstrated in the Table 3, these results indicate that the MLS device, Leica Pegasus TRK 700 Evo, can be considered as a viable alternative for conducting road condition surveys, particularly in obtaining IRI values.

Table 3. Comparison IRI value from MLS and conventional method

Sample	STA	Dipstick				MLS Leica Pegasus TRK 700				Deviation			
		Right	Left	Avg /100m	Avg /300m	Right	Left	Avg /100m	Avg /300m	Right	Left	Avg /100m	Avg /300m
		m/km	m/km	m/km	m/km	m/km	m/km	m/km	m/km	m/km	m/km	m/km	m/km
Sample 1	0+100	3.61	3.43	3.52		2.98	3.12	3.05		0.63	0.31	0.47	
Otista	0+200	2.37	2.43	2.40	2.72	2.26	2.03	2.15	2.43	0.11	0.40	0.26	0.29
	0+300	2.04	2.43	2.24		2.10	2.09	2.10		0.06	0.34	0.20	
Sample 2	0+100	6.62	6.64	6.63		6.25	5.64	5.94		0.37	1.00	0.69	
Masadad	0+200	4.50	4.87	4.69	5.98	4.30	4.37	4.34	5.73	0.20	0.50	0.35	0.25
	0+300	5.46	7.76	6.61		5.66	8.15	6.90		0.20	0.39	0.29	
Sample 3	0+100	9.78	9.07	9.43		9.19	9.44	9.32		0.59	0.37	0.48	
Masadad	0+200	10.44	11.43	10.94	9.68	10.97	11.52	11.25	9.79	0.53	0.09	0.31	0.11
	0+300	9.57	7.78	8.68		9.03	8.56	8.80		0.54	0.78	0.66	
Sample 4	0+100	5.75	5.76	5.76		5.13	5.77	5.45		0.62	0.01	0.32	
Ibrahim Aji	0+200	6.22	5.62	5.92	6.17	6.11	5.77	5.94	6.11	0.11	0.15	0.13	0.07
	0+300	6.61	7.06	6.84		6.31	7.54	6.93		0.30	0.48	0.39	
Sample 5	0+100	5.58	6.52	6.05		5.42	6.62	5.97		0.16	0.01	0.08	
Ibrahim Aji	0+200	4.69	5.42	5.06	5.39	4.91	5.88	5.40	5.60	0.22	0.46	0.34	0.20
	0+300	4.68	5.46	5.07		4.92	5.92	5.42		0.24	0.46	0.35	
									Average	0.33	0.38	0.35	0.18
									RMSE	0.38	0.46	0.39	0.27
									Max	0.63	1.00	0.69	0.29
									Min	0.06	0.00	0.08	0.07

These findings serve as pivotal evidence suggesting the credibility of utilizing the MLS device, specifically the Leica Pegasus TRK 700 Evo, as a feasible alternative for executing road condition surveys, especially when deriving IRI values. Contrarily, the MLS device presents a consistent and competitive performance, demonstrating its capability to provide IRI values with a level of accuracy that aligns closely with the established dipstick standards. This convergence between MLS-derived IRI values and the dipstick's validated outcomes attests to the reliability and efficacy of the MLS technology in measuring IRI along highways, affirming its potential as a trustworthy tool for comprehensive road condition assessments.

DISCUSSION

The comparative analysis between the Dipstick and the Mobile Laser Scanning (MLS) methods revealed an overall average IRI deviation of 0.18 m/km (based on 300-meter sampling intervals), with the maximum deviation recorded at 1.00 m/km and the minimum at 0.01 m/km. These findings reflect a generally strong agreement between the two measurement methods, indicating that the Leica Pegasus TRK 700 Evo is capable of delivering IRI outputs that approximate those obtained from the conventional Dipstick technique. However, slight deviations in certain segments warrant closer examination.

Interpretation of IRI Differences

The observed deviations between Dipstick and MLS measurements can be attributed to their differing data acquisition principles. The Dipstick profiler relies on sequential point-by-point manual readings, capturing micro-scale surface irregularities with high vertical precision. This makes it particularly effective for localized quality assurance, such as pavement acceptance testing or forensic inspection, where small-scale undulations are critical.

Conversely, the MLS technique produces a continuous 3D surface model that effectively averages pavement irregularities over broader intervals. This yields smoother profiles that reflect macroscopic roughness trends across longer segments. The resulting IRI values tend to be slightly less sensitive to abrupt, isolated defects, but more representative of overall ride quality. Consequently, the Dipstick may record higher variability within short sections, while the MLS output remains stable and repeatable across extended runs.

Strengths and Limitations of The MLS System

The Leica Pegasus TRK 700 Evo demonstrated significant operational efficiency, surveying up to 100 km per day while generating dense point clouds and panoramic imagery. This high productivity and its integration of GNSS/IMU sensors enable rapid condition assessments with minimal disruption to traffic. Furthermore, the 3D data produced by MLS can support multiple applications beyond IRI including rut depth analysis, asset inventory, and road safety audits which extends its value beyond a single indicator.

However, MLS deployment involves high capital and operational costs, the need for skilled operators, and substantial post-processing time (four hours of processing per field hour). The technology’s accuracy is also affected by GNSS signal quality, surface reflectivity, and environmental conditions such as shadows or vegetation. Without rigorous calibration against ground truth data, MLS results may vary across instruments and survey configurations.

Future Recommendation

Rather than viewing the Dipstick and MLS as competing technologies, this study suggests they should be regarded as complementary. The Dipstick provides a reliable reference for ground validation and calibration, while MLS offers scalable coverage for network-level monitoring. Combining both methods using Dipstick data for verification of MLS outputs could yield a hybrid workflow that leverages the accuracy of traditional methods and the efficiency of modern sensing. Such integration aligns with current trends in intelligent infrastructure management, where multi-sensor fusion supports evidence-based decision-making.

CONCLUSION

This comparative study between the conventional Dipstick method and the Leica Pegasus TRK 700 Evo Mobile Laser Scanning (MLS) system demonstrates that both techniques provide consistent International Roughness Index (IRI) results within acceptable deviation ranges. While MLS offers significant advantages in efficiency, data richness, and scalability, the Dipstick retains essential strengths in precision, regulatory acceptance, and simplicity. Several key insights have emerged,

The mean IRI deviation of 0.18 m/km (for 300 m intervals) and 0.35 m/km (for 100 m intervals) confirms that MLS can approximate Dipstick readings with acceptable accuracy. Nevertheless, Dipstick measurements remain the reference standard for fine-scale calibration and validation.

MLS’s ability to survey 40–100 km per day provides a substantial improvement in productivity compared to the manual Dipstick, which typically covers less than one kilometer daily. However, this gain comes at the expense of higher setup complexity, data volume, and processing time.

The Dipstick remains advantageous for small-scale, high-precision applications, while MLS is more suited for large-scale network surveys requiring spatial context and integration with digital platforms (e.g., BIM, GIS, or digital twins).

The high initial and operational cost of MLS currently limits its widespread adoption, especially for smaller agencies. In contrast, the Dipstick's affordability and ease of use make it accessible for routine or regulatory assessments.

The high initial and operational cost of MLS currently limits its widespread adoption, especially for smaller agencies. In contrast, the Dipstick's affordability and ease of use make it accessible for routine or regulatory assessments.

In summary, while the Leica Pegasus TRK 700 Evo demonstrates strong potential as a next-generation tool for road surface evaluation, the Dipstick method remains indispensable for maintaining accuracy standards and ensuring regulatory continuity. The true value lies in the integration of both techniques, where conventional precision and advanced mobility converge to support sustainable and intelligent pavement management.

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