

ASSESSMENT OF GOPRO'S APPLICABILITY IN INTERNATIONAL ROUGHNESS INDEX MEASUREMENT FOR ROAD PAVEMENTS

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ABSTRACT: The percentage of infrastructures that are approximately 50 years old in Japan is rapidly increasing. In particular, the stock of roads is enormous, with more than 1,220,000 km of road length. In rural areas, prefectural and municipal roads account for more than 95% of the total road length, and pavement deterioration is progressing at many locations, requiring effective road maintenance and management. On the other hand, the maintenance and management of pavements is conducted under a severe system due to a significant decrease in public works budgets and a shortage of engineers. Under these circumstances, pavement inspection methods using visual inspection and equipment have been introduced for proper pavement inspection and preventive maintenance of pavements. In this study, a commercially available action camera is mounted on an ordinary vehicle, and vibration acceleration and GPS data are acquired by driving the vehicle. The objective of this study is to develop a road surface condition evaluation method that enables sustainable maintenance and management by estimating the International Roughness Index (IRI), an index used to evaluate pavements to riding comfort and pavement damage, from the acquired data. As a result, regression analysis using data from Niigata City with the proposed method yielded a correction function with a coefficient of determination (R^2) of 0.70. This demonstrates that IRI estimates can be obtained using this approach, confirming the effectiveness of GoPro-based measurement methods.

Keywords: Road Surface Investigation, IRI (International Roughness Index), GoPro, GPS, World Bank

1. INTRODUCTION

In developing countries with advancing economic development, various infrastructure projects are rapidly progressing with support from donor countries and institutions, including Japan, in response to the growing demand for infrastructure development. On the other hand, the rate of infrastructure aging is not solely determined by the number of years since construction but varies depending on factors such as location, surrounding environment, maintenance, and management status. In general, after 50 years, damage progresses and components that need to be considered for renewal or repair begin to stand out. Therefore, even in Southeast Asian countries, where a significant amount of infrastructure was built after the 1970s, the governments have recognized that the increase in maintenance and renewal costs is an urgent issue [1].

Road infrastructure significantly contributes to the overall socio-economic development and provides vital social benefits. Globally, approximately 1.35 million people lose their lives in traffic accidents annually, with 90% of these fatalities occurring in developing countries. Therefore, efficient road management directly contributes to preventing traffic accidents and reducing road traffic fatalities. Additionally, it improves access to public services, delivering immediate and sometimes dramatic benefits to road users. It also enhances vehicle fuel efficiency and reduces emissions.

Thus, research on road management brings a wide range of benefits and serves as a crucial element in supporting sustainable development [2].

Considering this background, developing countries are also focusing on and considering the introduction of asset management concepts and methods into maintenance and management operations for roads, bridges, and other infrastructures. The goal is to reduce costs and extend the service life of these structures. However, while advanced pavement condition survey vehicles equipped with high-precision measurement technologies are available, their high implementation and operational costs have limited their widespread adoption in rural infrastructure management. Furthermore, the frequency of surveys is as low as once every five years, making it challenging to respond promptly to emerging issues.

In previous studies, we installed a high-definition camera, a three-axis motion sensor, a GPS antenna, and a PC for recording on an ordinary vehicle and evaluated road surfaces. However, measurement devices such as three-axis motion sensor are costly because of precision instruments. In addition, installing high-definition cameras inside the vehicle raises concerns about the potential degradation of image quality.

Therefore, this study focuses on IRI, which is becoming increasingly standardized worldwide [3-6]. It aims to assess the effectiveness of using a GoPro camera for IRI measurement, with the goal of

simplifying and improving the efficiency of pavement condition surveys. To address the concerns regarding measurement equipment highlighted in previous studies, a single commercially available action camera is utilized to reduce costs and simplify the system. Additionally, mounting the action camera on the vehicle's hood improves image quality. Furthermore, by equipping ordinary vehicles with the action camera, vibration acceleration and GPS data are collected to estimate the International Roughness Index (IRI), aiming to enhance operational efficiency.

2. RESEARCH SIGNIFICANCE

This study aims to contribute to sustainable road maintenance and management in developing countries and local governments. Currently, evaluation methods rely on expensive specialized equipment, making extensive surveys and frequent monitoring challenging. In this research, we aim to develop a new indicator for quantitatively assessing road surface deterioration by utilizing data obtained from a GoPro and integrating machine learning techniques, such as regression analysis and image processing. This approach seeks to achieve a low-cost and efficient evaluation method. Therefore, this study focuses on verifying the measurement accuracy of the IRI using vertical acceleration data collected via a GoPro, thereby demonstrating its practicality.

3. IRI OVERVIEW

3.1 What is IRI?

The International Roughness Index (IRI) is an evaluation index of pavement roughness. It was proposed by the World Bank in 1986 for the

intercomparison of roughness measurement values obtained from various devices around the world [5,6]. It is said to be associated with the level of comfort during the ride and is currently utilized in numerous countries worldwide.

The IRI can be used as a universal index applicable to a wide range of roads, including paved roads for high-speed driving and unpaved roads for low-speed driving, making it suitable for use in many countries. In addition, the use of IRI as a common index allows for comparison among countries, and the four-step method can be adapted to suit each country's specific circumstances.

3.2 Measurement Class

IRI measurement methods can be classified into four classes, ranging from highly precise methods using measuring instruments and devices to experiential evaluation and others (Table 1).

Class 1 is the method that produces the most accurate IRI. The method is calculated from a longitudinal profile of level surveying, etc. The IRI is evaluated as the true IRI. Class 2 is the method to obtain the IRI with the second highest accuracy after Class 1. It is based on the longitudinal profile obtained from an arbitrary longitudinal profile measuring device. Although it is less accurate than Class 1, it can still be used for relatively accurate and efficient measurements as it can measure while in motion. Class 3 is a method to quantify the degree of longitudinal unevenness of the road surface based on the amount of vertical movement of the wheel axle, vertical acceleration, etc., and convert it to IRI using a correlation equation; since IRI cannot be calculated directly, the measurement accuracy is reduced. Class 4 is a method for obtaining an approximate IRI

Table 1. Methods of measuring longitudinal road surface irregularities and calculating IRI [5,6]

Class	Methods for measuring road surface irregularities, etc.	IRI calculation method
1	Leveling survey	The longitudinal profile is calculated by level surveying at intervals of 250 mm or less, and the IRI is calculated by QC simulation.
2	Arbitrary longitudinal profile measuring device	Measure the longitudinal profile with an arbitrary longitudinal profile measuring device and calculate the IRI by QC simulation.
3	RTRRMS (Response-Type Road Roughness Measurement System)	The RTRRMS (Response-Type Road Roughness Measurement System) measures the roughness index of any scale and converts it to IRI using a correlation equation.
4	Experiential and visual experience of investigators riding in a patrol car	The IRI is estimated by the experience and visual observation of the surveyor riding in the patrol car. The inspection procedure provides examples of the relationship between pavement condition and IRI for each level of pavement damage, including photographs of four levels of pavement condition.

through visual evaluation by comparing photographs and using the experience of the surveyor while driving a patrol car or similar vehicle.

3.3 IRI Calculation Method

3.3.1 Calculation method

Conventional roughness measurement devices are classified into two types: profile and response methods [5,6]. The profile method measures the actual shape of longitudinal unevenness and undulations of the road surface. There are various types of devices, ranging from manual measurement with a scale to automatic measuring vehicles capable of measuring at the same speed as a normal vehicle. The response method measures the dynamic response of the vehicle body to the road surface, mainly in the form of acceleration. The measurement data varies based on the type of vehicle, driving style, time of measurement, weather conditions, and other factors. There are four different methods for calculating IRI (Table 1). The most practical method is the Class 2 method. This method involves measuring the longitudinal profile of the road surface with any measuring device and then using a quarter car (QC) simulation to calculate the IRI.

3.3.2 Calculation procedure

The method for calculating IRI using QC simulations for Classes 1 and 2 is as follows[5,6].

- ① One measuring line is set in the longitudinal direction of the survey point, and the longitudinal profile is measured. The measurement interval should be less than 300 mm.
- ② The gradient between measurements is considered constant and the profile is smoothed.
- ③ Apply QC simulation to the smoothed profile.
- ④ The vertical motion of the vehicle suspension system from the simulation is added and divided by the profile extension to calculate the IRI.

3.3.3 QC simulation

The QC is a virtual vehicle model that represents a single wheel of a typical 2-wheel, 4-axle passenger vehicle [5,6]. When the QC is in motion on a road surface, it is represented by the dynamic system (Fig. 1). The IRI is the ratio of the accumulated vertical displacement (mm) of the vehicle to the mileage (m). The IRI calculated by the QC simulation is expressed by Eq. (1).

$$IRI = \frac{\left\{ \int_0^L \sqrt{|\dot{z}_s - \dot{z}_u|} dt \right\}}{L} \quad (1)$$

where, z_s represents the height of the sprung mass (mm), and z_u represents the height of the unsprung mass (mm). Additionally, \dot{z}_s and \dot{z}_u denote the time

derivatives of z_s and z_u , respectively, with units of m/s. Furthermore, L indicates the travel distance (km), V represents the driving speed (22.2 m/s = 80 km/h), and t denotes the time (s).

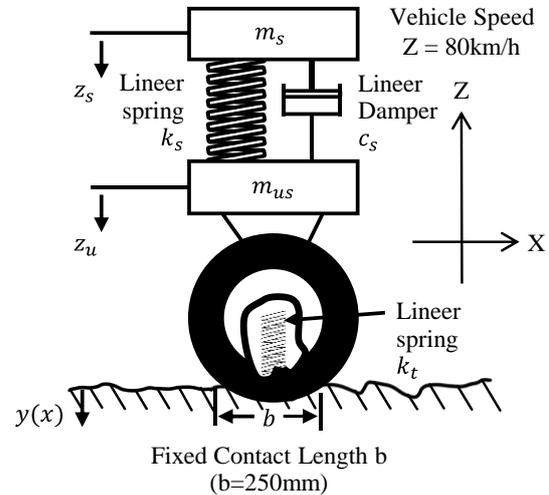


Fig.1 QC Models [5,6]

3.4 Evaluation Of Road Surface By IRI

IRI roughness scale (Fig. 2), which can be used to measure the roughness in the longitudinal direction, ranging from an unimproved unpaved road to a runway requiring very high flatness, all on the same scale. The degree of pavement surface deterioration is typically assessed based on the International Roughness Index (IRI). The evaluation is classified into three levels: IRI < 4 is considered "Good," 4 ≤ IRI < 8 corresponds to the "Fair," and IRI ≥ 8 indicates the "Poor" [6-8].

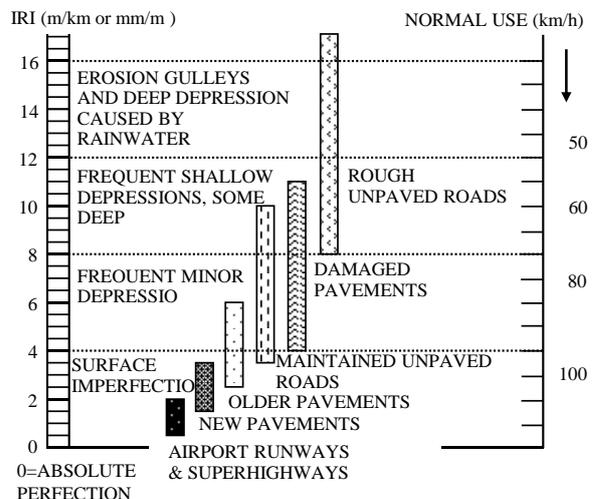


Fig.2 Roughness Scale by IRI [5,6]

4. EXPERIMENTAL WORK AND OUTCOME

4.1 Measuring Methods and Equipment

Overview of the measurement vehicle of this technology (Figs. 3,4). This study used a GPS-equipped GoPro HERO11 camera, which was mounted on the hood of a regular vehicle. We collected data on vertical vibration acceleration (100Hz), GPS (100Hz), and driving speed (100Hz), and recorded videos at 60 frames per second (fps) while driving. To extract the measurement data, we used a free third-party web application called "Telemetry Extractor for GoPro." The camera was mounted on a genuine GoPro suction cup mount, directly connected without any additional installation device to enhance sensitivity to road surface vibrations. Additionally, the GoPro was mounted at a fixed angle of 15° to ensure consistent data collection from the accelerometer and vibrations. The driving speed ranged from approximately 40 to 60 km/h.

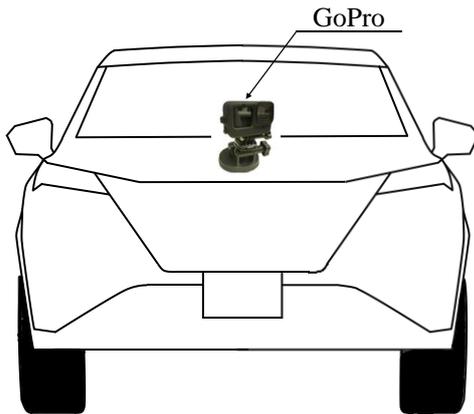


Fig.3 Installation Method of GoPro on a General Vehicle [9]

4.2 Camera Settings and Data Extraction Methods

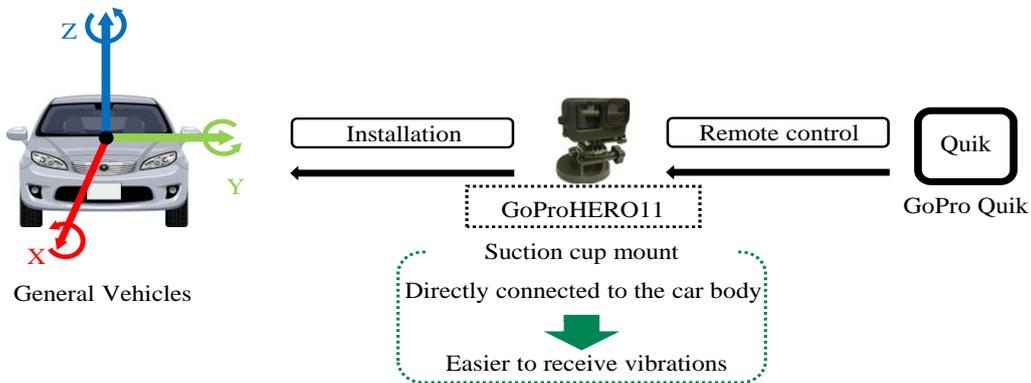


Fig.4 Overview of the Measurement Method

In the camera settings, the angle of view is set to 3.5 m (width) and 5.0 m (height) to match the width of the travel lane (Fig. 5). This configuration was designed to accommodate the standard lane widths of local roads, national highways, and expressways in our country. The image size, frame rate, angle of view, and image stabilization should be adjusted appropriately to support image analysis and machine learning. In this study, images are captured at a resolution of 1920 pixels × 1080 pixels (Full HD) with a frame rate of 60 fps. The shooting is conducted in wide-angle mode, and the image stabilization feature is set to OFF. The GPS function is enabled, and the recording starts only after the GPS signal is fully acquired, followed by the commencement of driving. For the extraction of driving data, the free third-party web application "Telemetry Extractor for GoPro" was used. The driving video data was inserted into the application, and the position information and acceleration data were output in CSV format. Additionally, since these variables are used in the analysis, the data frequency is set to 100 Hz, and the number of location and acceleration data points is synchronized.

4.3 Road Surface Measurement



Fig.5 Camera Field of View (FOV) Setting

In this study, accurate data were collected by a simple IRI measuring device, a Class 2 technique, in the IRI survey. The IRI survey was conducted by Niigata City, which provided the data.

The “Niigata Kameda-Uchino-Line (uphill)” provided by Niigata City was selected as the target route for the measurement. In the MLIT test, a test section with a total length of 1 km was set up on a section of asphalt-paved national highway, and diagnostics were conducted for each block divided into 20 m sections. However, since it is difficult to measure true values using Class 1 technology, data measured using Class 2 technology, which is now in practical use, shall be used. Measurements for this technique were performed using a Class 3 technique using a standard vehicle with a GoPro installed. In this study, both data were combined with location-based measurement sections and a test section of 396 m was set up, with 18 blocks divided into 20 m and one block divided into 36 m as the verification section.

4.4 Calculation Method and Results

The measurement method used in this study quantifies longitudinal road roughness based on the vibration acceleration experienced by the vehicle body (Table 1). The calculation follows a Class 3 measurement method, which converts the roughness data into the International Roughness Index (IRI) using a correlation formula.

In the calculation method for Class 3, the roughness index is measured on an arbitrary scale. Therefore, the roughness index (vertical acceleration) obtained from the GoPro is substituted into the motion displacement in Eq. (1), and the vertical acceleration is adjusted by subtracting the gravitational acceleration to calculate the longitudinal displacement. Then, the ratio of the cumulative value of the vertical motion displacement (mm) experienced by the vehicle body while traveling on the road surface at a constant speed to the travel distance (m) is represented in Eq. (2).

$$IRI = \frac{\left\{ \int_0^L \sqrt{|Z - g|} dt \right\}}{L} \quad (2)$$

where, Z represents the vertical acceleration (m/s^2), and g denotes the acceleration due to gravity (m/s^2). Furthermore, L indicates the travel distance (m), V represents the driving speed ($22.2 \text{ m/s} = 80 \text{ km/h}$), and t denotes the time (s).

The results calculated from Eq. (2) are presented. A calculation method based on the true value of IRI showed a tendency for underestimation (Fig. 6) [10]. Therefore, using the calculation method for Class 3 (Table 1), a regression analysis was conducted using data from this technology and Niigata City (Fig. 7),

and a correction function was calculated. The reason for adopting regression analysis is to derive a correlation equation that predicts the IRI from the explanatory variables. In this study, since regression analysis was performed with a limited dataset, a power regression, which appeared with a high coefficient of determination, was adopted. The coefficient of determination $R^2 = 0.70$ was obtained from the results, so Eq. (3) was adopted as the correction function. The value obtained from Eq. (2) was then substituted into Eq. (3) to calculate the IRI as an estimated value.

$$IRI = 5.0464 \times IRI^{2.2483} \quad (3)$$

There is a graph that compares the IRI estimates calculated using the correction function obtained from the regression analysis with the Niigata City data (Fig. 8). The results demonstrate that the method of measuring the roughness index using GoPro based on the Class 3 calculation method, and then determining the IRI using the correlation equation, was successful in quantifying the degree of road surface irregularities.

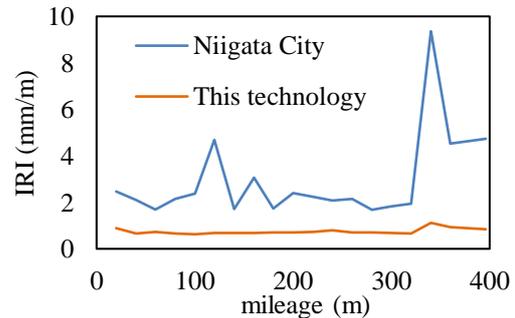


Fig.6 Comparison of IRI Evaluation Results Between Niigata City and the Proposed Method

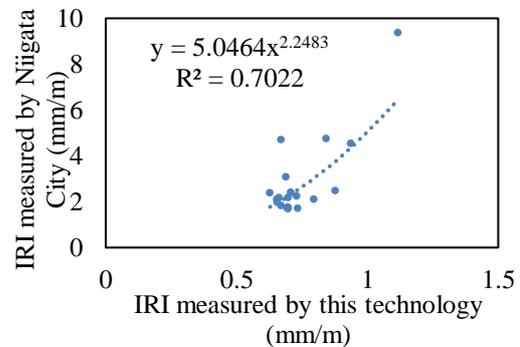


Fig.7 Correlation Plot of IRI Evaluation Results Between Niigata City and the Proposed Method

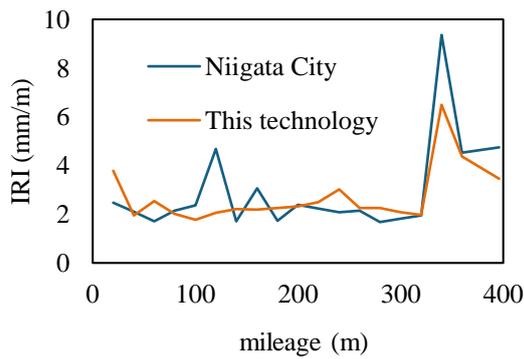


Fig.8 Comparison of IRI Evaluation Results for Niigata City and the Corrected IRI Evaluation Results from the Proposed Method technology after correction

4.5 IRI Considerations

4.5.1 Evaluation of road surface liquefied by earthquake

In this study, IRI was measured at locations with liquefied pavement conditions, and the hypothesis that pavement deformation due to liquefaction contributes to the increase in IRI values was tested. The aim was to verify the validity of the measurement results and clarify the scope and limitations of this method.

The target routes were selected from those reported to be severely damaged by liquefaction. That the IRI estimates for the road surface that was partially destroyed by liquefaction and became gravel were much larger than those for the road surface that was partially destroyed by liquefaction (Fig. 9). The road was evaluated as an unpaved road in poor condition (Fig. 2). Generally, IRI values vary depending on the circumstances in different countries around the world, but 10 mm/m or more is very bad. IRI has no theoretical upper limit. In Japan, the maximum value may reach 20 mm/m. In this case, the accuracy of the measuring instrument may decrease, and measurement may become difficult, making reliable measurement difficult. Consequently, the estimated IRI values measured using this method significantly exceeded the roughness scale indicated by the IRI (Fig. 2). Furthermore, these values far surpassed the general upper limits of IRI. The factors contributing to the significant increase include the sensitivity of the sensors and the measurement principles. In particular, when the IRI becomes abnormally high, it may not be measured correctly. In liquefied pavement conditions, where rapid height fluctuations occur continuously, the evaluation may exceed the definition of IRI. Additionally, while the driving speed during measurements was set to be similar to that used for the "Niigata Kameda Uchino Line (upward)", this setting proved to be insufficient for determining an appropriate measurement speed

for the pavement conditions, which is one of the contributing factors.

This suggests that the calculation method and IRI index used in this study are unsuitable for evaluating severely damaged pavement, which falls outside the measurable range. Therefore, alternative methods, such as visual inspections, should be employed depending on the road conditions.

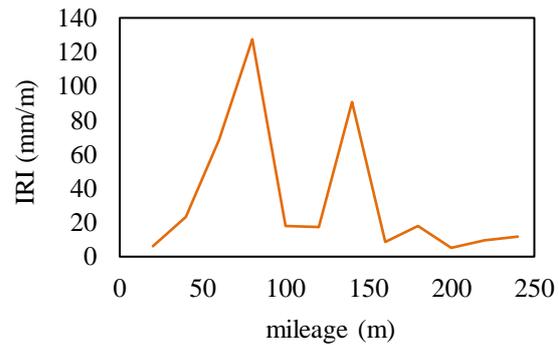


Fig.9 IRI Evaluation Results for Liquefied Pavement Surfaces Using the Proposed Method

4.5.2 Effect of speed

In this study, road surface condition data were collected by mounting measurement equipment on a vehicle and conducting measurements on high-traffic public roads. However, due to traffic conditions and the presence of traffic signals, maintaining a constant driving speed was challenging, resulting in variations in measurement conditions. In particular, the measurement of the IRI is highly sensitive to driving speed, as it affects the characteristics of the acceleration data. Therefore, this study examines the impact of driving speed on IRI measurement values.

An ideal measurement environment should ensure road surface uniformity and minimize the influence of lateral deviations in driving position. Granite slab pavement or other surfaces with uniform texture are preferable for such conditions. However, since it was not feasible to establish a dedicated test environment in this study, a relatively smooth section of an actual paved road was selected for data collection at varying driving speeds.

For the investigation, acceleration data were recorded over a 100-meter road segment, with the vehicle traveling at speeds ranging from 10 km/h to 50 km/h in increments of approximately 10 km/h. The analysis revealed that as driving speed increased, both the peak vertical acceleration values and the estimated IRI values exhibited an increasing trend (Figs. 10,11). This indicates that IRI values exhibit a strong dependence on driving speed.

Generally, IRI quantifies the longitudinal roughness of a road surface, and its calculation is influenced by the vehicle's dynamic response

characteristics. In particular, as speed increases, the vehicle's suspension system increasingly responds to higher-frequency vibration components, leading to an amplification of acceleration values. Consequently, the estimated IRI values tend to be relatively higher at increased speeds. Therefore, to ensure accurate IRI evaluation across different road conditions, it is essential to establish appropriate speed settings during measurement.

Additionally, setting appropriate driving speeds based on road characteristics contributes to improving the accuracy of IRI measurements (Fig. 2). Future studies will aim to conduct a more comprehensive analysis of the impact of driving speed and enhance IRI estimation accuracy under various road conditions. Furthermore, the development of a machine learning-based speed correction model will be explored to further refine the measurement methodology.

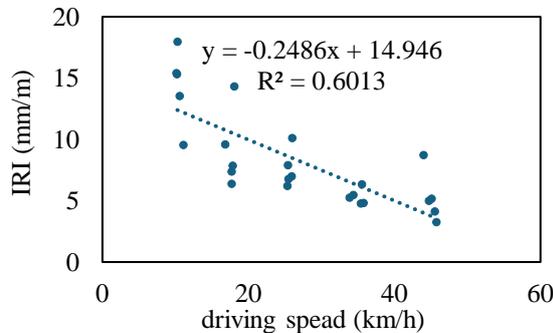


Fig.10 Effect of Travel Speed on IRI

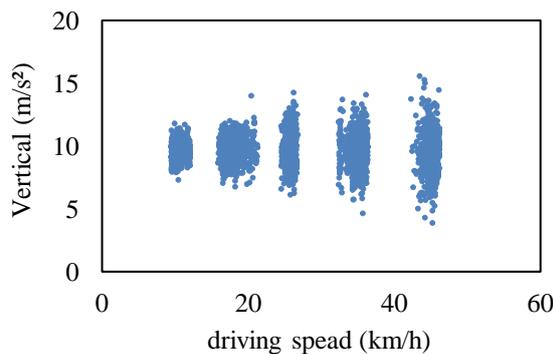


Fig.11 Effect of Travel Speed on Vertical Acceleration

5. CONCLUSION

In our study, we derived acceleration data using the IRI calculation method (Eq. 1). However, the vertical acceleration obtained from the measurement data did not allow for accurate calculation of road surface displacement because it was influenced by gravity acceleration, even when the vehicle was

traveling on a flat surface. As a result, we needed to reassess our calculation method and revise it. To accurately quantify the degree of road surface irregularity, we referred to the Class 3 calculation method and used the obtained vertical acceleration minus the gravitational acceleration. By applying the general calculation method of Class 3, which utilizes a correction function to convert road surface displacement into IRI, we were able to estimate the IRI, an index of longitudinal road surface irregularity.

The factors contributing to the discrepancy between the calculated IRI estimates and the data from Niigata City include the unknown driving speed of the training data and the uncertainty of whether the measurements were taken at an appropriate driving speed. As explained in the session on the effects of speed, it is known that the acceleration increases with higher speeds. Therefore, two possible sources of error are the difference in speed between the training data and our measurements, and the possibility that the measurements were not taken at an appropriate speed. Additionally, the lack of GPS accuracy and discrepancies in the driving position are also contributing factors. GPS accuracy is affected by weather conditions, and slight errors may have occurred due to cloud thickness. Furthermore, regarding the driving position, the tread width and tire width of the measurement vehicle in this study were not the same as those of the vehicle used in the training data, which likely resulted in pavement deterioration that was not captured. This discrepancy may have prevented the accurate reflection of the actual pavement condition, leading to some pavement deterioration being missed in the measurements. In this study, we compared the equipment used in previous studies with the equipment used in our technique. The previous study utilized multiple expensive devices for measurements, while our study used a commercially available action camera, the GoPro, to simultaneously capture video, GPS, acceleration, and other measurement data. This made the installation and measurement methods much simpler. Additionally, this technology has been proven to be cost-effective and straightforward, as it doesn't necessitate precise equipment like the three-axis motion sensor used in previous studies. The utility of the GoPro, with its multiple functions, has also been confirmed. However, with the evaluation method of this technology, a correction function was calculated using a power approximation, resulting in a coefficient of determination $R^2 = 0.70$. However, since the calculation method has not been established, it is believed that it has not yet reached practical application. In principle, IRI should have a certain correlation with explanatory variables, and a nearly linear relationship should exist, making linear

regression appropriate. Furthermore, it is generally recognized that a coefficient of determination $R^2 \geq 0.80$ indicates a high predictive accuracy, but the evaluation criteria for the purpose and accuracy may vary. Therefore, in this study, it is necessary to develop evaluation indicators that meet the criteria, and there are challenges in data collection and the establishment of a calculation method to achieve this.

In the future, efforts will be made to further share data from Niigata City and aim to collect various pavement data. Additionally, to establish a reliable calculation method, the focus will be on improving the accuracy of IRI estimation through machine learning, and using video analysis to detect crack rates. ElasticNet, a machine learning method, employs a linear regression model with L1 and L2 regularization terms to prevent collinearity and over-training. Its high adaptability and versatility make it a promising technique for this study. The environmental variables considered include running speed, crack rate, and vertical vibration acceleration, which are presumed to impact road surface irregularities, thus improving the accuracy of IRI estimation. For video analysis, YOLO is utilized for AI object detection to calculate the crack rate, aiming to streamline data organization. Our objective is to establish these systems and develop a comprehensive set of methods for evaluating road surface condition.

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