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A Measurement System of Vibration Discomfort in Cycling by using Simple Prove Bicycle with Action Camera

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Abstract: In recent years, since the popularity of long cycling tour has increased, improvement of the driving environment has been proceeding actively. However, there are few survey methods for discomfort spots caused by deterioration of pavement and vibration. In this research, we developed a measurement system which evaluates and visualizes the degree of the discomfort (*DDC*) by using video analysis and simple prove bicycle with an action camera. First of all, optical flow and spectral analysis were applied to the video to calculate the power spectral density of camera shake (*PSDS*). We clarified that the fluctuation of around 10 Hz ($PSDS_{10}$) have stronger correlation with *DDC*, and obtained the model which estimates *DDC* from $PSDS_{10}$. As a result of the test for the model, the correlation coefficient of estimated and observed values shows around 0.7 or more and *RMSE* indicate around 0.6 in those route.

Keywords: Cycling Route, Road Surface, Low-cost Measurement, Video Analysis, GPS

1. INTRODUCTION

In Japan, the number of tourists, especially from the Asian region, is increasing. In order to improve the satisfaction of tourists and increase the number of tourists further, each region have enhanced various services and contents. Besides, in recent years, the cases of enjoying long cycling tour is rapidly increasing. Under these circumstances, Ministry of Land, Infrastructure and Transport is currently considering the introduction of “The national cycling route program”. Furthermore, many municipalities have started various activities for cycling tourists, such as improving cycling environment, information disclosure about attractive routes and places, setting signs in multiple languages, enriching bicycle ports, etc.

While there is a movement as described above, it is pointed out that there are many spots where cyclists feel discomfort caused by deterioration of pavement and vibration. In Japan, it is difficult to enrich pavement repair, especially in suburbs and mountain areas, because there are restrictions on the budget and personnel for road maintenance. In order to improve the satisfaction of cycling tourists, in the beginning, it is necessary to quantitatively and comprehensively grasp the discomfort spots, and to dispatch the information for prospective visitors. If it is possible to grasp the discomfort spots on the road network,

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pavement repair and information disclosure can be conducted more effectively. In order to realize these, simple and low-cost system is necessary.

In this research, we developed a measurement system of the discomfort caused by vibration in cycling by using simple prove bicycle with an action camera. First, the driving experiment was conducted on some routes, and the degree of discomfort (*DDC*) while driving was scored by the research participants. Next, Optical flow and spectral analysis was applied to the video taken while driving to calculate the power spectral density of camera shake (*PSDS*), and a model which estimates *DDC* was proposed. Finally, the accuracy of the proposed model was verified based on the results of the driving experiment on other routes.

2. LITERATURE REVIEWS

Studies on the road surface condition have been carried out in the field of pavement engineering for motor vehicles. In contrast, there are a few studies considering the point of view of bicycle and cyclists. For example, Landis et al. (1997) conducted driving experiment on actual road and revealed that pavement condition is the one of the most important factor in the quality of bicycle path based on model analysis. According to the studies done by Li et al. (2012) and Kang et al. (2013), the importance of road surface is clarified from a statistical point of view and the results of large-scale questionnaire survey. In recent years, the method of quantitatively evaluating the comfort and safety of bicycle driving by the equipment such as GPS (Global Positioning System) and accelerometer for measurement of the bicycle behavior has become mainstream. Hunt et al. (2007) developed a probe bicycle consisting of GPS, accelerometer and gyro sensor, and proposed a model to estimate the comfort value of bicycle driving from the measured values. Giubilato et al. (2012) and Watanabe et al. (2018) applied spectrum analysis to the acceleration data measured by probe bicycle, and revealed that the surface roughness and the cruising speed greatly affect the comfort. After the 2010s, more various measurements became possible because of downsizing and cost reduction of digital devices. Lee et al. (2014) developed a probe bicycle that can measure not only acceleration but also heartbeats, eye position, facial expression, ambient sound, etc. In addition, they assessed the investment rate of return to infrastructure for cyclists based on the measurement results by prove bicycle. In the same way, Higuera et al. (2014) evaluated the comfort of cycling by utilizing a smartphone with gyro sensor. Their simple measurement system made it possible to grasp the comfort spots over the entire road network, and they tried to improve the efficiency of road maintenance and management based on the results.

From various questionnaire surveys and driving experiments such as described above, it is shown that the road surface condition is an extremely important factor in considering the comfort and safety of cyclists. In order to quantitatively evaluate the road surface condition, specialized equipment such as accelerometer is currently adopted. However, it is difficult to comprehensively evaluate long-distance routes and potential routes by using existing methods from a standpoint of the initial cost of devices and the simplicity of operation.

For that reason, we proposed a low-cost and simple system for screening survey of bicycle driving environment. The proposed system allows an efficient detection and visualization of discomfort spots by using simple prove bicycle with an action camera. Because the cyclist's demands are diversifying, the evaluation of cycling environment from various viewpoints will be necessary in the future. It is can be said that the visual information analysis like our method will greatly contribute to the multifaceted evaluation for driving environment.

3. THE DRIVING EXPERIMENT FOR EVALUATION OF DISCOMFORT

3.1 Simple Prove Bicycle

In recent years, the demand for long touring has increased, and it is expected that the cycling tourists by road bike will increase in the future. Therefore, in this study, a road bike was used for the experiment. In addition, in order to propose a highly versatile method, we used the “simple probe bicycle” consisting private bicycle and an action camera.

The simple probe bicycle has GoPro HERO 5 (manufactured by GoPro, Inc.) which is the action camera with GPS function. The location information by GPS is recorded as metadata in the video data file. Therefore, it is easy to combine the driving location and each frame (still image) in the video. Figure 1 is an example of the simple prove bicycle and abstract of camera setting. The camera is installed near the center of the handlebars.

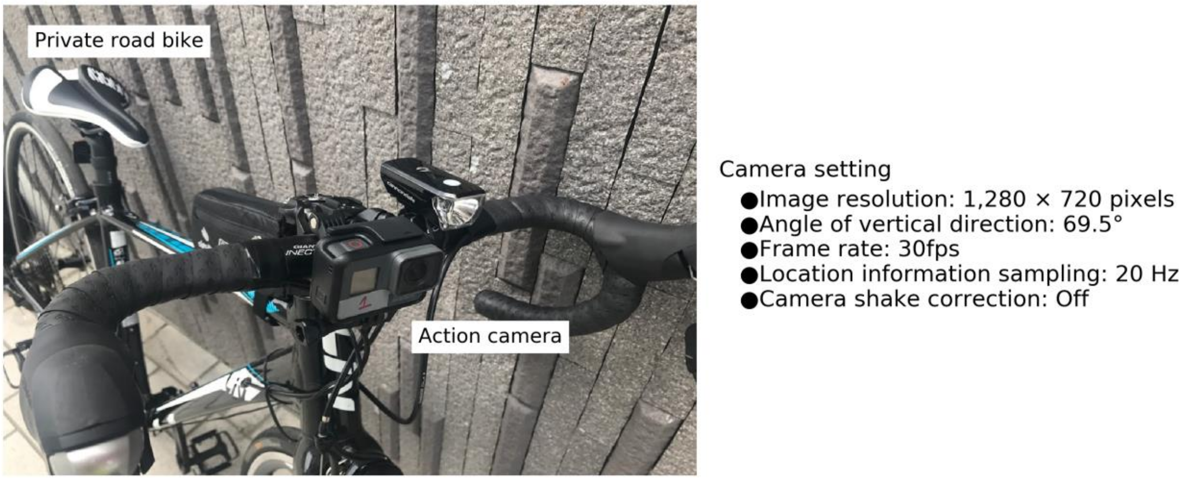

Figure 1. Simple prove bicycle and camera setting

3.2 Experiment Condition

The experimental route was located near Muroran Institute of Technology in Hokkaido, Japan. The route was divided into the following two. One is “Learning route (3.9 km)” to create a model which estimates the degree of discomfort (*DDC*) due to vibration. The other is “Test route” for verifying the accuracy of the model. In order to analyze the movement of the scenery in the video, three test routes (total 6.4 km) differ in the scenery were selected.

In the section with a larger longitudinal slope, the cyclist’s attentiveness of physical load and fall avoidance becomes higher. On the other hand, the awareness and importance of discomfort due to the road surface condition decrease. Therefore, the sections where the longitudinal slope is 2% or more excluded from the object in this study.

The research participants are students of cycling club of Muroran Institute of Technology. Ten participants drove on learning route. In the test routes, eight different students conducted the experiment. The driving experiment was conducted in the morning on a fine day during the summer of 2018.

Each research participant scored *DDC* in five grades during bicycle driving with their voice by using the microphone of the camera. Score 1 means smooth road surface that everyone does not feel a problem. Score 5 means road surface that large vibration occurs and repair is urgently required. The participants were instructed to make the driving speed around

20 km/h. After the driving on experiment route, participant returned to our laboratory in Muroran Institute of Technology and corrected their score while checking the video on PC screen. The unit of the score is 3 seconds. For the analysis below, it is necessary to spatially align the scores of each research participant. Therefore, the value based on linear interpolation at 15 m intervals (2.7 sec at 20 km/h) was calculated based on the location data with GPS.

3.3 The Variation of *DDC*

Figure 2 shows the mean of *DDC* (*MDDC*) in all participants in each section. The standard deviation (σ) is also shown in Figure 2. Because *DDC* is evaluated subjectively, the small variance is shown in each section. Figure 3 shows that the standard deviation concentrates on about 0.7, and the ratio of 1 or more is less than 10%. Therefore, there are a few individual differences in *DDC*. The evaluation of *DDC* in this experiment was carried out based on an appropriate criterion because the participants could understand a simple question "discomfort due to vibration" and confirm sample movie before their driving.

In addition, when comparing the profile of *DDC* among participants, the phases were similar. It was confirmed that there was almost no error in the location data acquired by GPS in the camera.

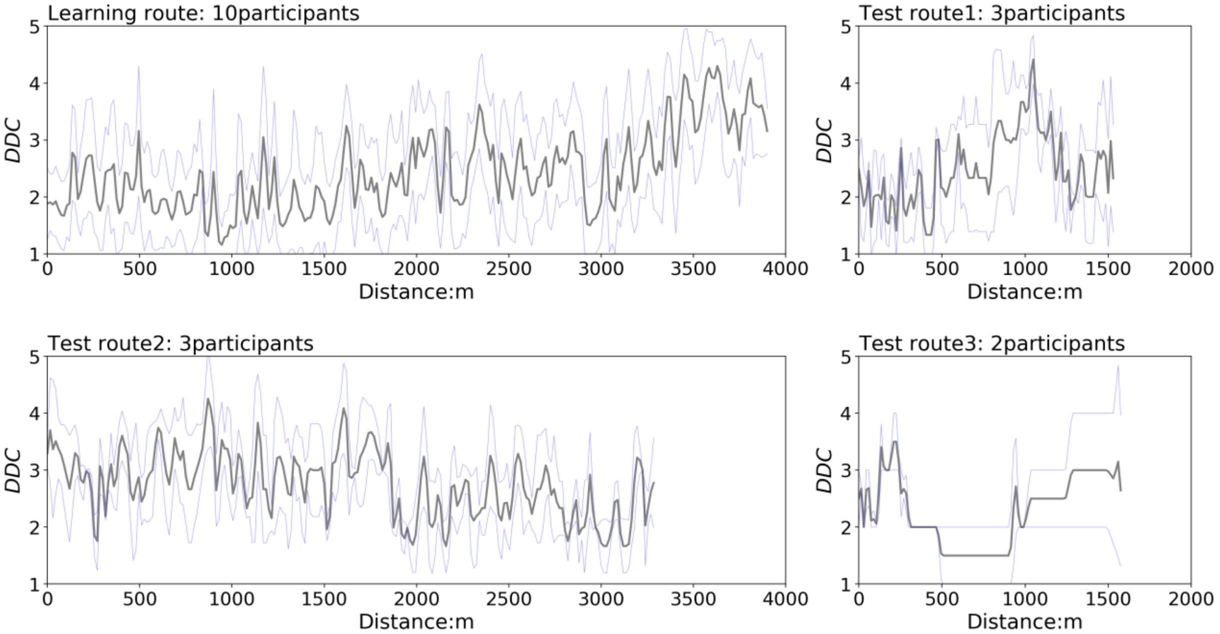

Figure 2. The profile of *DDC* (mean and mean $\pm\sigma$)

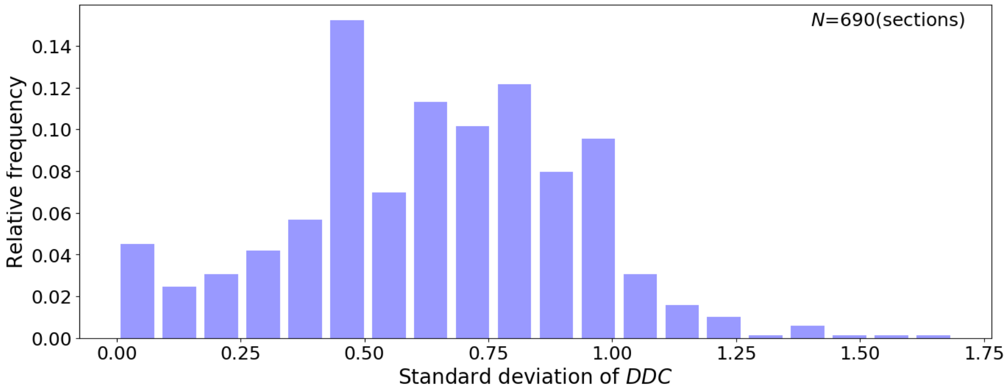

Figure 3. The standard deviation of *DDC* in each section

4. QUANTIFICATION ON VIBRATION BY VIDEO ANALYSIS

4.1 Analysis Procedure

Optical flow and spectral analysis was applied to calculate power spectral density of the camera shake (*PSDS*) from the video data recorded in bicycle driving The procedure of video analysis is shown in Figure 4. We focused "fluctuation of the scenery" in the video motion caused by camera shake transmitted from the road surface. Optical flow can detect and trace the feature points in video frames, and calculate continuously the displacement and direction of their points.

First, optical flow is applied to the video data, and time series data of fluctuation of feature points are obtained. As shown in Figure 4a, the areas of left side and the right side are excluded due to the noise. The center area is selected as the target of this analysis. As shown in Figure 4b, because some feature points disappear from the frame with time, there are some cases that data is not enough to analysis. Therefore, we decided to apply optical flow every 32 frames (approximately 1 second).

Next, FFT (Fast Fourier Transform) is applied to this time series data, and the power spectral density of feature points is calculated. As shown in Figure 4c, *PSDS* of feature points are averaged, and logarithmically transformed. Therefore, *PSDS* of 14 frequency numbers can be obtained in 32 frames.

Finally, as shown in Figure 4d, the space interval value is calculated every 15 m by using linear interpolation on the basis of location information by GPS. By this processing, the spatial positions of *PSDS* and *DDC* of all participants are aligned.

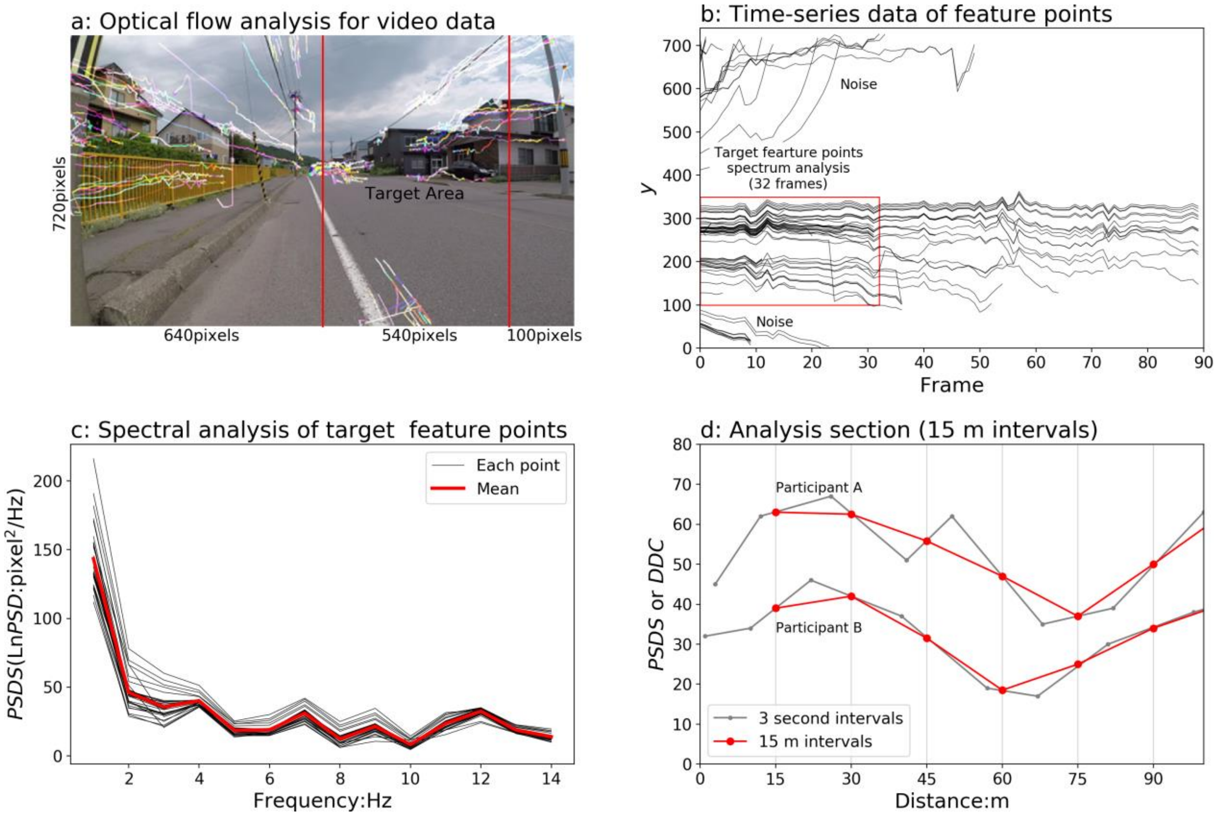

Figure 4. The procedure of video analysis

4.2 The Variation of *PSDS*

There is a possibility that the *PSDS* varies caused by external factors such as bicycle body specifications, driving skills of rider, passing position on the road, etc. Therefore, it is necessary to confirm how much the variation of *PSDS* will occur.

As an example, the profile of $PSDS_{10}$ is shown in Figure 5. Similar fluctuations in *PSDS* of each participant is shown, but there is some variation in each section. In order to compare this variation with the other *PSDS*, the standard deviations were calculated every 15 m section and their histogram (cumulative frequency distribution) were created (Figure 6). The standard deviations tend to be larger as the *PSDS* with higher frequency is higher. Especially at a frequency higher than 13 Hz, the tendency is remarkable. Such fluctuations of periods shorter than about 0.08 seconds as described above are likely to cause a difference depending on the characteristics of the vehicle body and the installation condition of the camera. The fluctuations of periods shorter than about 0.08 seconds as described above are likely to cause a difference depending on the characteristics of the vehicle body and the installation condition of the camera. However, the standard deviations are 0.3 in over 80% of all sections. Therefore, it can be said that there is no major problem in vibration measurement by a simple probe bike with different bicycle body and driver.

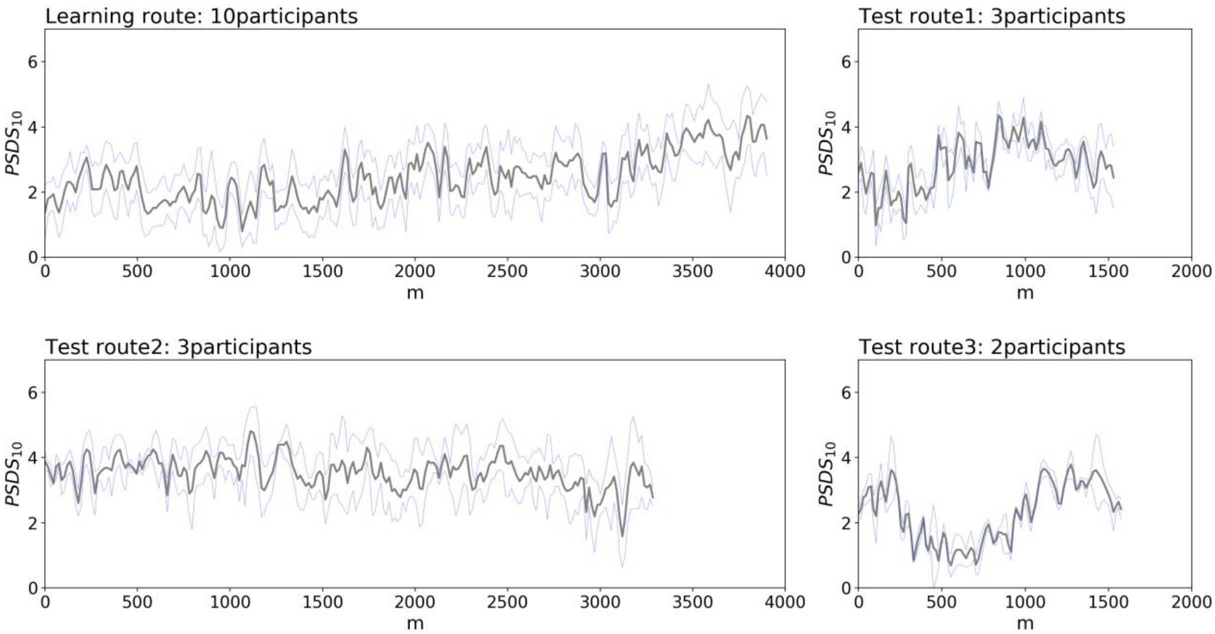

Figure 5. The profile of $PSDS_{10}$ (mean and mean $\pm\sigma$)

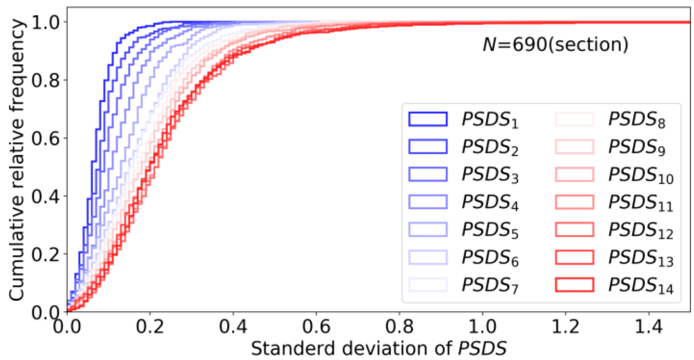

Figure 6. The standard deviation of *PSDS* in each section

5. ESTIMATION OF DISCOMFORT BY VIDEO RECORDED IN CYCLING

5.1 The Relationship between *DDC* and *PSDS*

We proposed a model which estimates the degree of discomfort (*DDC*) caused by vibration from *PSDS* calculated by using video analysis. First, we examined the relationship between *DDC* and *PSDS*. In following analysis, the mean of *DCC* (*MDDC*) is used as representative value of the sections in route . As shown in Figure 7, *PSDS* on the high frequency side tend to have more participants with a larger correlation coefficient. In addition, the case of using the mean of *PSDS* (*MPSDS*), the correlation coefficient is larger than case of using individual *PSDS*. The peak of this correlation coefficient is shown at a frequency of approximately 10 Hz. The relationship between $MPSDS_{10}$ and *MDDC* is shown in Figure 8. Because the correlation coefficient is approximately 0.9, it can be said that the accuracy of this linear regression model is high. *MDDC* can be calculated by the following Equation 1.

$$MDDC = 0.84MPSDS_{10}+0.29 \quad (1)$$

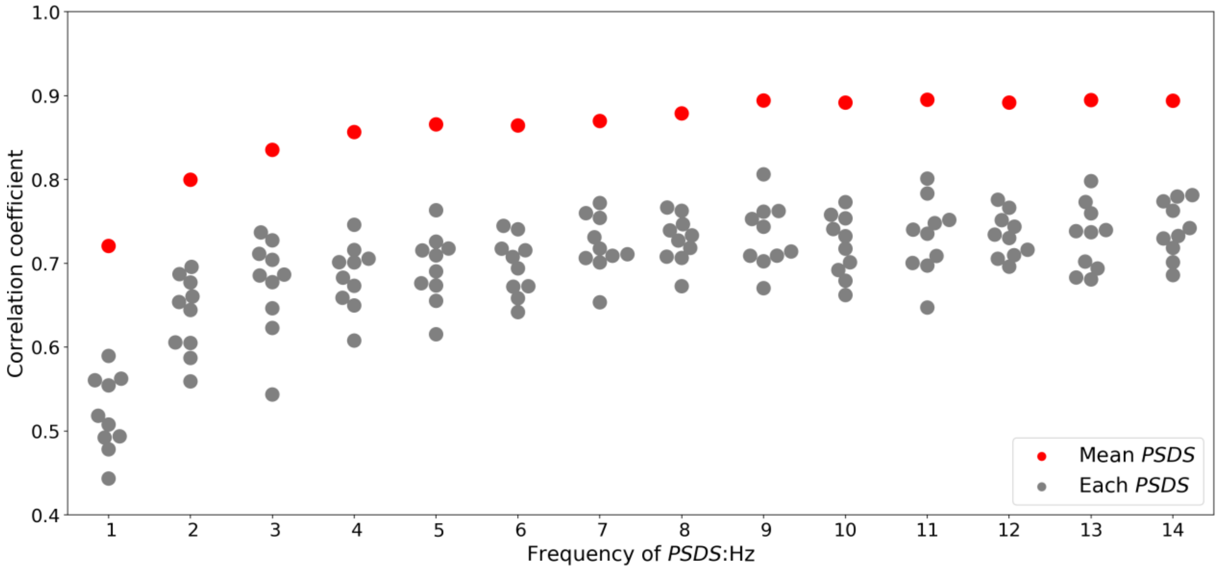

Figure 7. The relationship between frequency of *PSDS* and *MDDC*

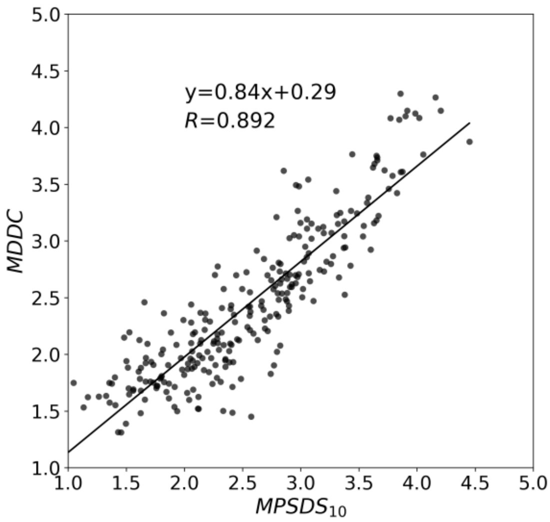

Figure 8. The relationship between mean $MPSDS_{10}$ and *MDDC*

5.2 Test for the Proposed Method

It is necessary to verify the accuracy of proposed method and the model for other routes with different scene and environment. Figure 9 shows the correlation coefficient of $PSDS_{10}$ and *MDDC* in all routes. In the estimation by the *PSDS* of each participant, the correlation coefficients are around 0.6 over in test route 1 and 3. In the case of using the mean *PSDS* (*MPSDS*), it is shown that the correlation coefficient becomes larger than each *PSDS* and the correlation coefficient show around 0.7 or more in Test route 1 and 3. As shown in Figure 9, *RMSE* (Root Mean Square Error) indicate around 0.6 in those route.

Next, the estimated and observed values on GIS were shown in Figure 10. In test route 2, there are many cases that are overvalued. In this route, road surface damage is remarkable, and large vibration occurs over a long section. Therefore, there is a possibility that the *DCC* was underestimated because the rider got accustomed to large vibration. However, in the other sections, it is shown that *MDDC* is accurately estimated.

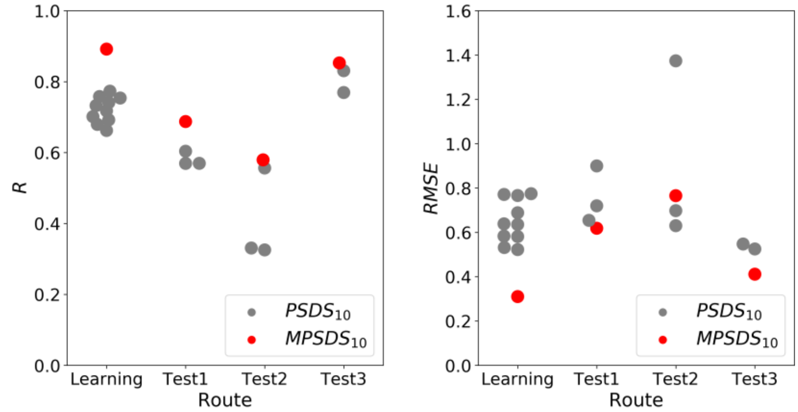

Figure 9. The correlation coefficient and *RMSE*

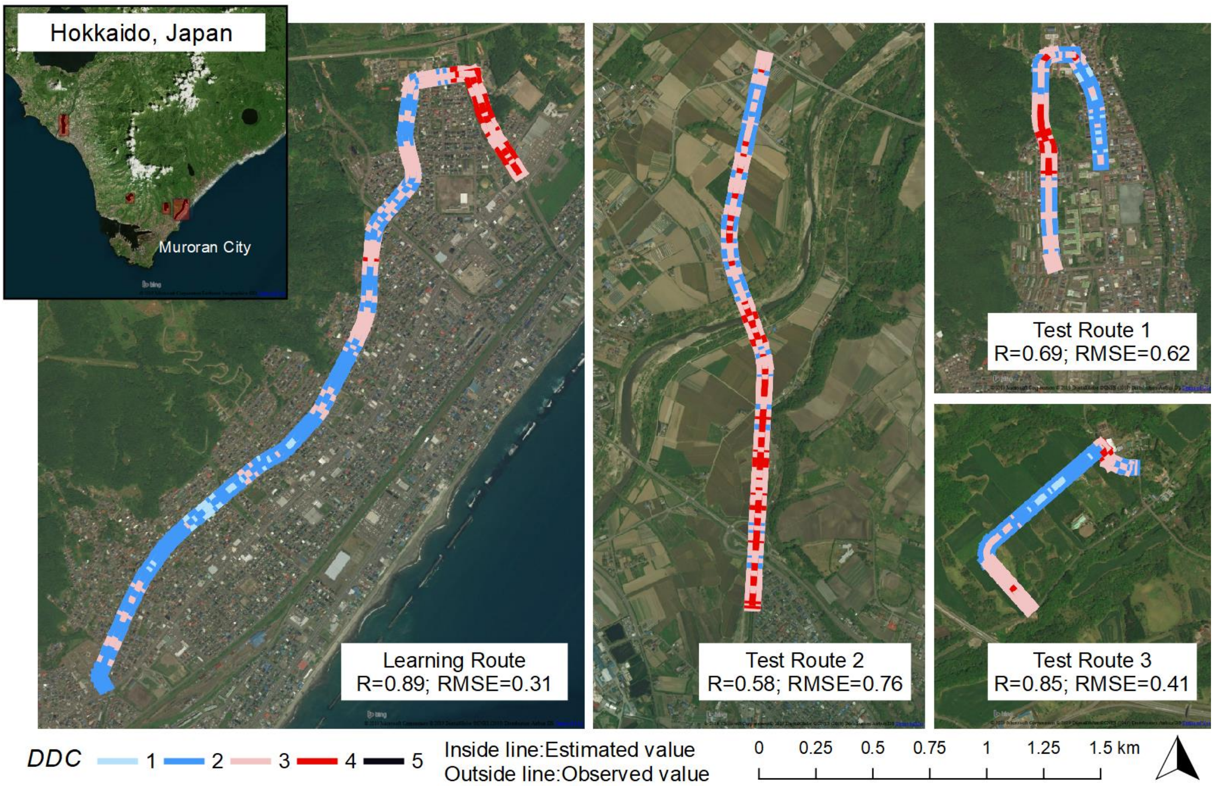

Figure 10. The visualization of *MDDC* estimated by $MPSDS_{10}$

5.3 The Advantages of the Proposed Method

As described above, the proposed method can visualize discomfort becaues of vibration on GIS by recorded video while bycycle driving with an simple camera unit. Several advantages of this approach are listed below.

Recently marketed action cameras usually have a GPS function. In this study, we conducted a driving experiment with four routes, and there was not a big problem regarding acquisition of position information in almost all research participants. Most of the cycling route passes through suburbs and mountainous areas where there are few influences of high-rise buildings, so there are many routes to which the proposed method can be applied.

For example, there are cases in which subjective evaluation is performed during driving or after driving such as the evaluation of *DDC* in this study. However, as shown the result of Test route 2 (Figure 10), it is pointed out that such a method affects the result with bias because of "experience" over time. Also, there are multiple task states of traveling and evaluation, which may reduce driving safety. In the proposed method, since the rider can drive without being conscious of the camera and the objective evaluation result is obtained. Therefore, it is a great merit that the long distance can be safely and smoothly measured by using the proposed method.

In addition, there is a problem that the road surface evaluation using the acceleration and the profiler depends on the passing position of the wheel of the measuring vehicle.Since the proposed method adopts a low cost and simple unit, it is easy to measure with a plurality of units, and it is possible to reduce the influence of the variations as described above. Therefore, in practical use, it is possible to conduct a regional evaluation by conducting surveys by multiple riders in survey or trial operation, etc. and collecting video data from general cyclists as monitor.

6. CONCLUSION

In this research, we developed a measurement system of discomfort caused by vibration in cycling by using simple prove bicycle with an action camera. The results of this study are shown below.

- The driving experiment on evaluation of discomfort (*DDC*) was conducted. The standard deviation of *DDC* in each section was calculated and it was shown that the standard deviation concentrates on about 0.7, and the ratio of 1 or more is less than 10%. Therefore, there are a few individual differences in *DDC*.
- Optical flow and spectral analysis was applied to calculate power spectral density of the camera shake (*PSDS*) from the video data recorded in bicycle driving. The standard deviations of *PSDS* were calculated and it was shown that the standard deviations were 0.3 in over 80% of all sections. Therefore, it can be said that there is no major problem in vibration measurement by a simple probe bike.
- The relationship between the mean of *DDC* (*MDDC*) and the mean of *PSDS* (*MPSDS*) was confirmed and the correlation coefficient between *MDDC* and $MPSDS_{10}$ shows approximately 0.9. It can be said that *MDDC* can be calculated this linear regression model.
- The proposed method and the model applied three test routes. The correlation coefficient of estimated and observed values shows around 0.7 or more. *RMSE* (Root Mean Square Error) indicate around 0.6 in those route.

In the future, we will add test routes to improve the model. Furthermore, we are planning to develop a cycling environment evaluation system with simple prove bycycle that evaluates not only the vibration but also landscape (Asada et al. 2016), pavement cracks (Asada et al. 2018) and road markings (Asada et al. 2012), etc.

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