Remote Monitoring System for Road Condition Assessment and Its Application

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ABSTRACT: This paper introduces a newly developed road pavement condition assessment system (called "Ippo-Campo") that can be used to perform a visual assessment of the condition of not only the pavement but also the road structures such as appurtenances, slopes and vegetation, and its practical application to road maintenance decision-making. Ippo-Campo is a road pavement maintenance evaluation system based on a moving vehicle and obtains data from a motion sensor, moving vehicle video, sound and GPS data. It is a simple evaluation system that provides a systematic, consistent approach to the evaluation of the condition of a road pavement surface. In addition, the video file produced by Ippo-Campo can be used for making a multi-criteria-based decision. In this paper, it also makes practical applications the system to the Mine-city road network in Yamaguchi Prefecture, Japan for confirming the effectiveness of the system.

1 INTRODUCTION

Road networks are one of the most important key infrastructures that contribute to rapid economic growth. At the same time, there is an increasing demand for reasonable preventive maintenance including repairs to the road pavement and other facilities within the road networks, while the roads remain in service, despite limited budgets and human resources. Regarding the road pavement, for example, the maintenance control index (MCI) is used in Japan as an index for judging asphalt pavement damage [Miyamoto et al. (2009)]. MCI parameterizes the cracking ratio, roughness and rutting depth, but it can also be used as an index based on two attributes or even just one attribute [Committee on Earth Structures and Foundations of Japan, 1993]. The MCI inspection of the road pavement is undertaken using a specially designed vehicle [Government of Japan (2008)].

In the United States, the current level of serviceability of a pavement is expressed with AASHTO's present serviceability index (PSI) developed by American Association of State Highway and Transportation Officials (AASHTO) [AASHTO (1993)]. Another useful index is the international roughness index (IRI) proposed as an indicator by the World Bank, which mainly focuses on ride quality and the roughness of road surface including but not limited to asphalt pavements. The IRI is an index defined by applying an algorithm to a measurement of the longitudinal profile.

For the indices mentioned above, the soundness of the road pavement is usually evaluated by using an inspection vehicle. Such a vehicle is capable of accurate quantitative evaluation, but its initial and operating costs are usually relatively high, while such vehicles tend to be used infrequently. Other constraints include the road width, radius of curvature and slope which cannot be measured with the road inspection vehicle. In addition, there are many features of a road that must be regularly checked such as road appurtenances and filled/cut slopes. Therefore, there is a need for an efficient and low-cost system to facilitate the evaluation of the serviceability of an existing road pavement surface. The aim of this paper is to introduce a newly developed road condition assessment system(Ippo-Campo) that can be used to perform a visual assessment of the road facilities condition and its practical application to road maintenance decision-making. Ippo-Campo is a pavement maintenance evaluation system based on a moving vehicle and obtains data from a motion sensor, moving vehicle video, sound, and GPS data. It is a simple evaluation system that provides a systematic and consistent approach to the evaluation of the condition of a pavement surface. In addition, the video file produced by Ippo-Campo can be used for making a multi-criteria-based decision. It supports decision making with regard to complex sustainability issues and can help to recognize and define a problem in detail. In this paper, it also makes practical applications the system to the Mine-city (Japan) road network for confirming the effectiveness of the system as a specific example.

2 DEVELOPMENT OF A ROAD CONDITION ASSESSMENT SYSTEM

2.1 Concept of the system

This section briefly overviews how data analysis is performed. Data are obtained using a three-dimensional motion sensor combined with a GPS system with a gyro and acceleration sensors. Fig. 1 shows the equipment installed in a vehicle. It takes about 20 min to install and start-up the measuring equipment. The system sensor acquires GPS log data. Thus, the acceleration, time (GMT), angular velocity, geomagnetic and orientation sensor information, orbital plan view and satellite reception conditions can be recorded. The time in GMT is very important to the synchronizing of the video information with the sensor information. In addition, items displayed on this screen can be selected independently; the scale of the viewing area is arbitrary [Miyamoto et al. (2013)]. Fig. 2 shows an example of the system's signal display. The noise from the car and the car's motion data, as obtained from the video and the motion sensor are obtained from a car travelling along a selected road. The recommended speed of the car is 50 km/h to 60 km/h. It is possible for one person (the driver) to check the status of the installation of the equipment and capture the data [Hugo et al. (2014)].

Figure 1. Arrangement of measuring equipment installed in a car.

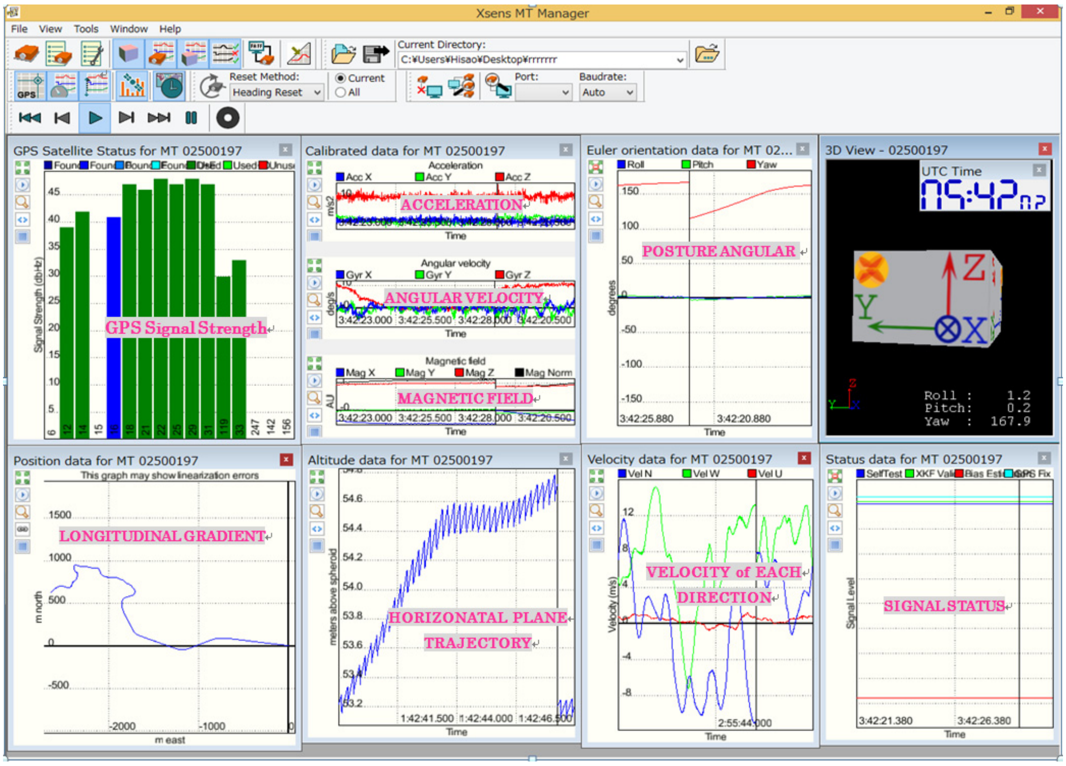

Figure 2. Example of signal display in the system.

2.2 *Configuration of the system*

An evaluation of the road pavement condition using the Ippo-Campo assessment system and the obtained three-dimensional motion sensor data, video data and sound data involves several steps. Fig. 3 shows an example of the system's menu screen. It was developed using the Visual Basic application from Microsoft Excel [Miyamoto et al. (2013)]. Fig. 4 shows the configuration of the functions of the system. Motion sensor data, driving video data, sound data,

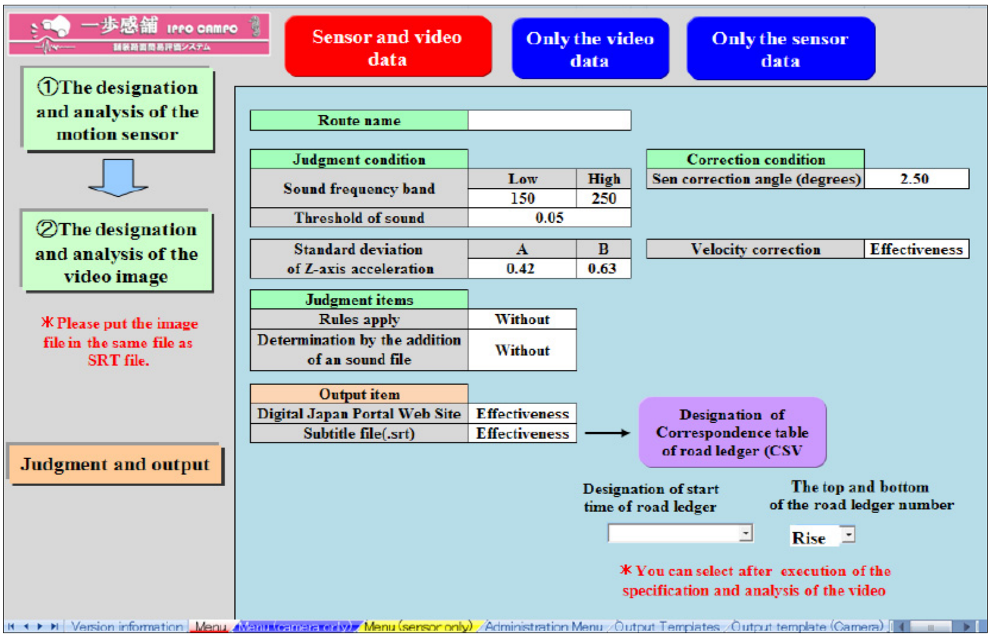

Figure 3. Menu screen of the road condition assessment system.

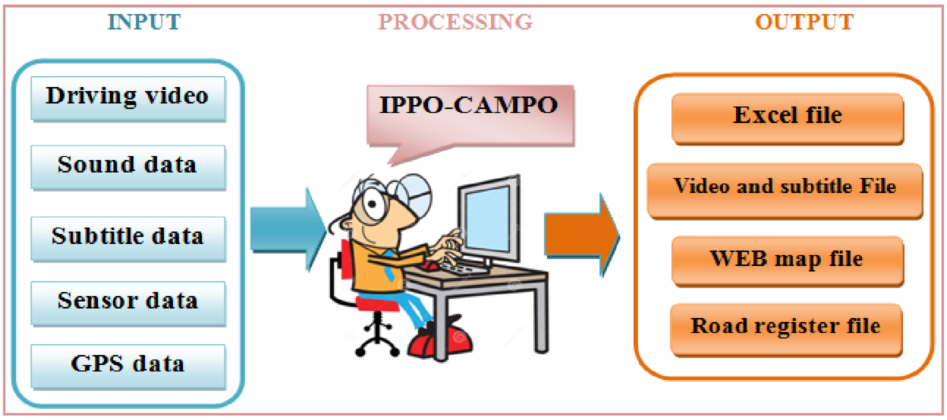

Figure 4. Configuration of the system functions.

subtitle data and GPS data are acquired by the system. By connecting these data, an evaluation of the road surface is output per second of longitude, latitude, X and Y coordinates, point distance, etc. to Excel as "good","moderate" or "bad". In addition, by linking the system with online maps by using the GPS data, the evaluation results can also be displayed on a map. Then, by converting the world geodetic system into latitude and longitude information, it is possible to reflect the results of the evaluation on the road register map data [Hugo et al. (2014)].

2.3 Determination of threshold values for the system

The determination of the threshold points for the pavement surface uses the standard deviation of the Z-axis acceleration rate signal. The threshold was decided by conducting a road surface measurement test as part of a cooperative study undertaken by Yamaguchi Prefectural Government and Yamaguchi University. The defined value was obtained by evaluating the data between the MCI and the Z-axis acceleration. The results assumed that the threshold level for pavement management for the standard deviation of the Z-axis acceleration is described as: 0 to 0.4 is "good," indicated in green and with the ○ symbol; 0.4 to 0.6 is "moderate," indicated in yellow and with △ symbol; and more than 0.6 is "bad," indicated in and with the × symbol. Fig. 5 shows the correlation between the MCI and the standard deviation of the Z-axis acceleration. The regression equation and correlation coefficient are derived from the relationship between the MCI standard and obtained data for the Z-axis acceleration. It is assumed that the value of 0.4 for the standard deviation of the Z-axis acceleration is equivalent to ≥ 6 for the MCI that represents the "good" condition of the road pavement. A value of 0.6 for

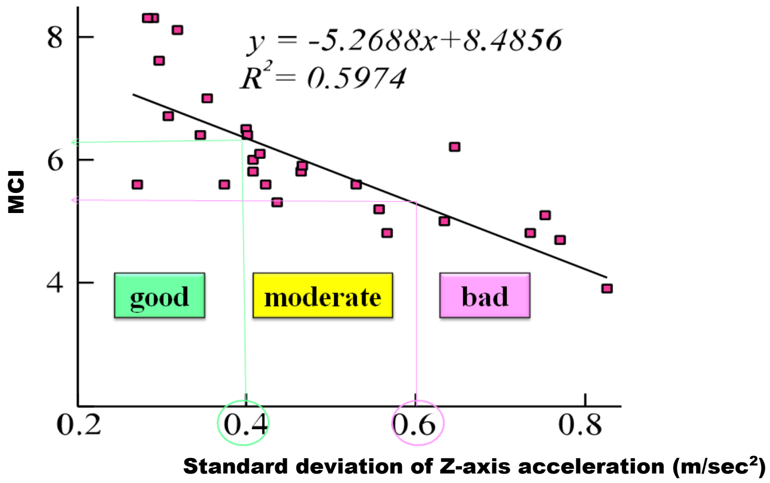

Figure 5. Correlation of MCI and the standard deviation of Z-axis acceleration.

the standard deviation of the Z-axis acceleration is equivalent to ≥ 5 for MCI and represents the “moderate” condition of the road pavement. Moreover, a value of ≥ 0.6 for the standard deviation of the Z-axis acceleration is equivalent to ≥ 5, corresponding to the “bad” condition of the road pavement [Hugo et al (2014)]. Table 1 shows an example of the output data from an excel file. And Figs. 6(a) and (b) show an example of video and subtitle file which illustrates the situation of road by showing the sub title data through the movie file (Fig. 6(a)) and an example of output data which shows the condition of the road trough web map data in which illustrates in 3 highlighted colors, red as a bad condition, yellow as moderate and green represented the good condition as mentioned above (Fig. 6(b)), respectively.

2.4 *Determination of evaluation signal using a motion sensor*

The determination of the evaluation signal was decided by choosing a target route and conducting measurement for it to understand the degree of change in the sensor data before and after the pavement repair work. The measurement was performed four times. Two

Table 1. Example of output data of evaluation results from an excel file.

10	JST	Latitude	Longitude	Map	Point distance	Cumulative distance	Longitudinal gradient	Number of satellites	Judgment
553	2012/2/16 16:08:20	34.17839	132.0643	Map	14.07224488	6350.2716	−2	7	○
554	2012/2/16 16:08:21	34.17839	132.0642	Map	12.65927545	6362.930875	−2	7	△
555	2012/2/16 16:08:22	34.1784	132.064	Map	14.1230363	6377.053912	−1.3	7	△
556	2012/2/16 16:08:23	34.17841	132.0639	Map	14.12303446	6391.176946	−0.9	7	△
557	2012/2/16 16:08:24	34.17843	132.0637	Map	14.22408505	6405.401031	−0.7	7	×
558	2012/2/16 16:08:25	34.17845	132.0635	Map	15.61633777	6421.017369	−0.5	7	×
559	2012/2/16 16:08:26	34.17847	132.0634	Map	14.22407889	6435.241448	0.3	7	×
560	2012/2/16 16:08:27	34.17845	132.0635	Map	12.91129266	6448.152741	1	7	×
561	2012/2/16 16:08:28	34.17852	132.06331	Map	14.29311293	6462.445854	2.8	7	×

Figure. 6(a) Example of evaluation results using movie file with subtitle.

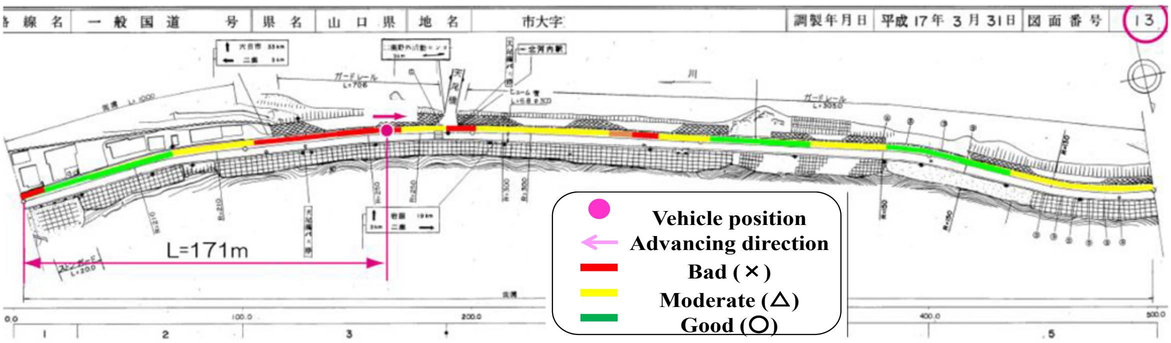

Figure 6(b). Example of evaluation results using web map file.

measurements were performed in April and May 2010 to determine the road condition before the pavement repair while the other two were conducted in August 2010 and January 2011 to determine the condition existing after the pavement repair.
The evaluation signal consists of two standard deviations, sound data, and acceleration data. It is obtained by analyzing the relationship between the standard deviation and the sound data for the road surface. The sound data was obtained by running a sound test in the test car. The movement of the car along the road resulted in road noise at 20 to 20,000 Hz. The frequency band of the road noise produced when traveling over a road surface with an irregular roughness was around 10 to 1000 Hz. Therefore, to analyze the frequency band representing the condition of the road surface, the sound data at 10,000 Hz was divided by a sound band-pass filter (BPF). Fig. 7 shows how the band is partitioned into three parts, especially 50 to 150 Hz, 150 to 250 Hz and 200 to 300 Hz. The data for 50 to 150 Hz and 200 to 300 Hz are not suitable for use as a sound evaluation signal [Miyamoto et al. (2013)]. However, the sound data for 150 to 250 Hz is suitable for use as an evaluation signal because it is clearly discernible despite having different values before and after the pavement repair works [Hugo et al. (2014)]. Meanwhile, the evaluation signal for the acceleration data was also obtained. Fig. 8 shows the standard deviation of the acceleration using three-axis vehicle vibration data. It illustrates that the X and Y-axis accelerations are not suitable for use as an evaluation signal. However, the Z-axis acceleration is suitable for use as an evaluation signal because it is clearly discernible despite having different values before and after the pavement repair work.

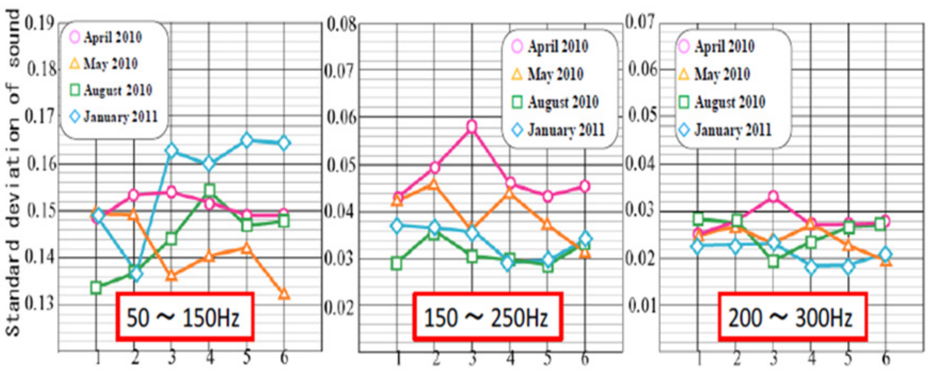

Figure 7. Standard deviation of sound of running vehicle by frequency band.

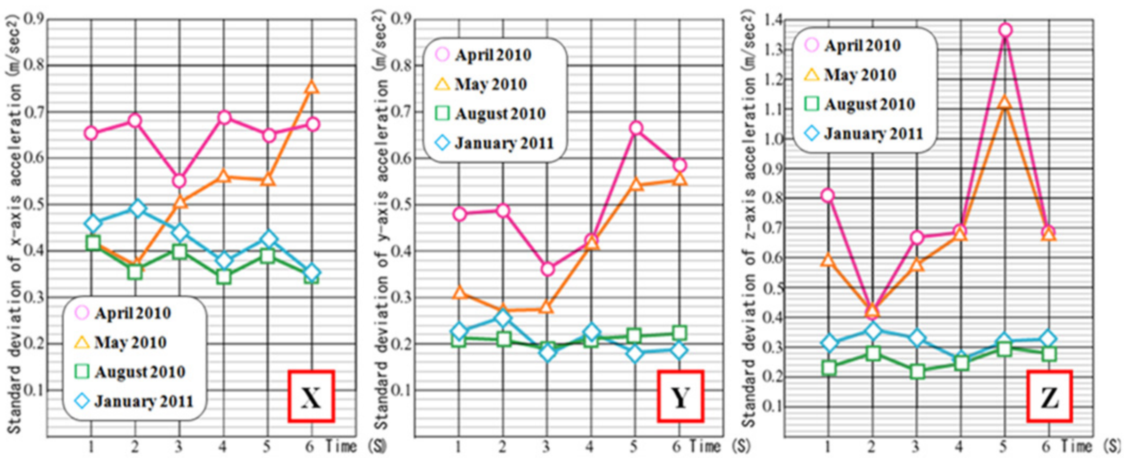

Figure 8. Standard deviation of the acceleration obtained from vehicle vibration data.

2.5 Determination of dependent velocity of the system

The dependent velocity of the system was determined by evaluating the velocity change of a vehicle while in motion to determine the evaluation signal influence. The study was conducted on a public road by using a vehicle to drive over concrete blocks placed in front of both front wheels, as shown in Fig. 9. This examination was performed to obtain the data for the pavement surface by changing the velocity of the vehicle. Starting with a velocity of 5 km/h, the velocity range of the examination was 20 to 50 km/h over a distance of 30 m [Hugo et al. (2014)]. Fig. 10 shows the result of the examination. It shows the relationship between the velocity and the standard deviation of the Z-axis acceleration in the evaluation signal. The data illustrates that the standard deviation of Z-axis acceleration (y) increases with the running speed of the vehicle (x). Therefore, the regression equation and correlation coefficient were derived from the relationship between the evaluation signal and the velocity, defined as follows [Miyamoto et al. (2013)].

$$y = 0.0061x + 0.00937 \tag{1}$$

Eq.(1) is used as a speed correlation formula for outputting the evaluation result of a road pavement surface.

Figure 9. Set up in measurement vehicle.

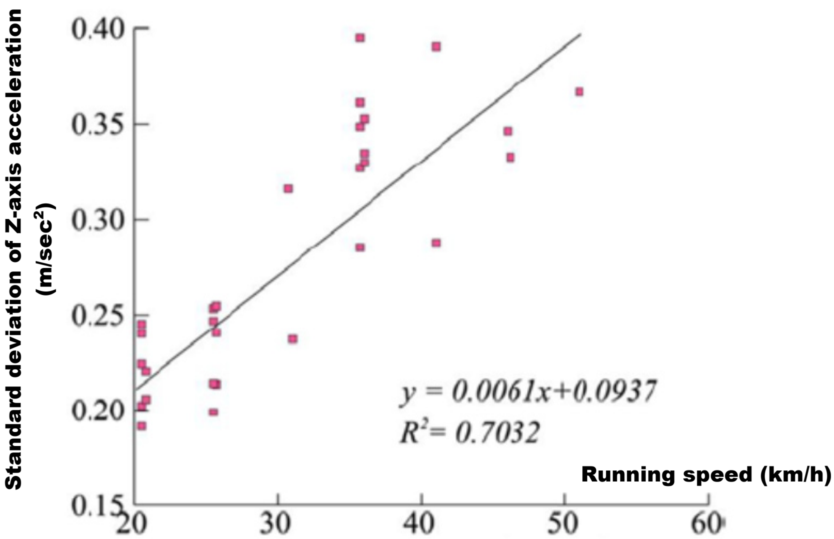

Figure 10. Relationship between the running speed and standard deviation of Z-axis acceleration.

3 PRACTICAL APPLICATION OF THE SYSTEM TO A ROAD NETWORK

3.1 Target road route

The assessment of the road pavement condition was conducted in the Mine-city (Yamaguchi prefecture, Japan) jurisdiction road network, belonging in the "Ube Civil Engineering Mine branch office". As shown in Fig. 11, the target roads are also located in the Mine-city and the total distance of the measured road is 8,050m. Table 2 listed the detail of line name, type of road and the distance of each target road route. The reason to conduct the field test in the Mine-city is that of the Yamaguchi Prefecture was doing repairing works of the road pavement in this location. The measurement was doing in two ways, at first the "Ube Civil Engineering Mine branch office" conducted a road evaluation by using a patrol car. The objective is to collect the information of the rut depth with maximum volume more than 40 mm. As the second way, there was conducted a measurement by using Ippo-Campo.

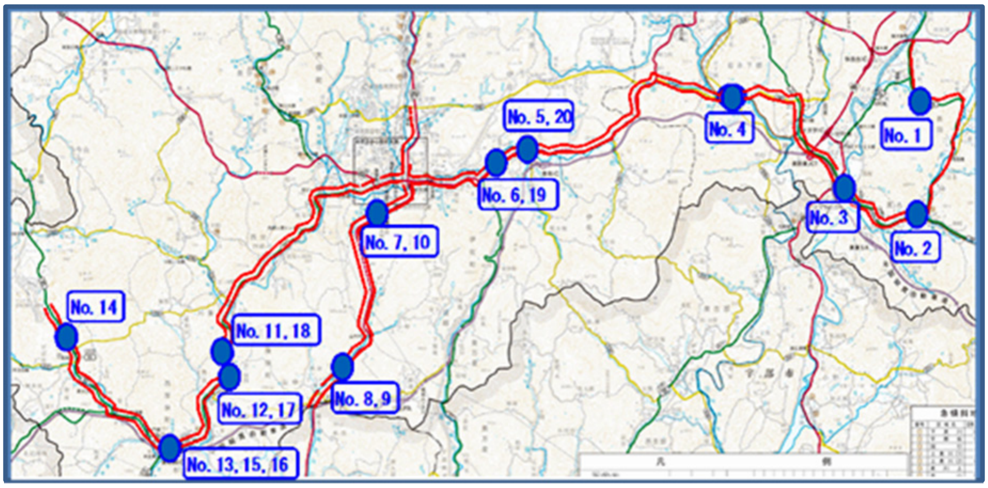

Figure 11. Map information and numbering of the target road route.

3. 2 Measurement details

In this study, the data was obtained on the road measurement using a sedan-type of car. The car was driven at the speed of 50 km/h~60km/h and the Mti-G configuration sampling rate is 100 Hz. The measurement was doing in two ways recording, from start point to the end point and overturn. This measurement was conducted in condition before and after repair of the road pavement. The objective of measurement is to compare with the results of both conditions and to confirm the efficiency of the system. The confirmation evaluation result of the output data is using GPS data, movie data and road register data. The interval time of measurement is recording the data on every second. As shows in Table 3, it records the condition of road at every second in Japan System Time (JST). In this practical

Table 2. Detailed information about the target road route.

No	Type of road	Line No.	Line name	Length (m)
1	Prefecture road	28	Ogouri misumi line	350
2	Prefecture road	31	Mito line	400
3	Prefecture road	31	Mito line	550
4	Prefecture road	240	Yunoguchi Mine line	700
5	National road	435	435 line	600
6	National road	435	435 line	200
7	National road	316	316 line	650
8	National road	316	317 line	350
9	National road	316	318 line	350
10	National road	316	319 line	650
11	Prefecture road	33	Shimonoseki Mine line	300
12	Prefecture road	33	Shimonoseki Mine line	350
13	Prefecture road	33	Shimonoseki Mine line	400
14	Prefecture road	65	Sanyou Toyota line	200
15	Prefecture road	33	Shimonoseki Mine line	400
16	Prefecture road	33	Shimonoseki Mine line	150
17	Prefecture road	33	Shimonoseki Mine line	350
18	Prefecture road	33	Shimonoseki Mine line	300
19	National road	435	435 line	200
20	National road	435	435 line	600

application, there are principal notes that been excluded due to avoiding the efficiency of data measurement such as small sample number (less than 4 points), bridge interval, railways, tunnels and traffic jam.

3.3 Results and discussions

In Table 3, the data verification results show an example of the road repair point. The highlighted sign indicates the repair interval and the output result by using Ippo-Campo. It also illustrates the condition before and after repair. The uper site of table shows how bad of the road condition before repair which is dominant by × symbol. However, the bottom site of table is represented the road condition after repair, which is dominant by ○symbol, signified that the road is in good condition. The total road pavement repair points are 57, excluded 23 points as the number of sample less than 4. It used two methods of data processing, standard deviation of Z-axis acceleration and the combination with sound data. Table 4 shows the remaining sample that has more than 4 numbers of samples and the result of comparison road pavement condition before and after repair. The result illustrates percentage of comparison between the bad point and the number of sample for before repair condition is higher than condition after repair. It is also found that there are still 5 missings (sample No. 4, 8, 9, 24 and 32) that the percentage of the bad point are not change because the rut depth is bigger than wheel path.

Table 3. Verification results of pavement condition before and after repair.

JST	Cumulative distance	Repair interval	Z-axis acc.	Velocity of the car	Judgement using Z-axis acc.	Judgement using Z-axis acc. and sound data
Before repair						
2013/2/23 9.26.03					×	×
2013/2/23 9.26.04					×	×
2013/2/23 9.26.05	0.0		0.343	52.8	×	×
2013/2/23 9.26.06	14.7		1.222	52.8	×	×
2013/2/23 9.26.07	29.3		0.203	52.8	×	×
2013/2/23 9.26.08	43.8		0.362	52.8	×	×
2013/2/23 9.26.09	58.4		0.972	52.8	×	×
2013/2/23 9.26.10	73.1		0.347	52.8	○	×
2013/2/23 9.26.11	87.8		0.376	52.0	○	○
2013/2/23 9.26.12	102.2		0.266	51.8	○	○
2013/2/23 9.26.13	116.6	1	0.243	51.8	○	○
2013/2/23 9.26.14	131.0		0.306	54.3	○	○
2013/2/23 9.26.15	146.6		0.246	52.0	○	○
2013/2/23 9.26.16	160.5		0.223	53.6	○	○
2013/2/23 9.26.17	175.4		0.239	52.8	○	○
2013/2/23 9.26.18	190.0		0.285	53.6	○	○
2013/2/23 9.26.19	204.9		0.247	52.0	○	×
2013/2/23 9.26.20	219.4		0.204	53.3	○	☆
2013/2/23 9.26.21	234.2		0.202	53.6	○	☆
2013/2/23 9.26.22					△	△
2013/2/23 9.26.23					○	○
After repair						
2013/11/16 10.20.23					○	○
2013/11/16 10.20.24					○	○
2013/11/16 10.20.25	0.0		0.267	32.1	○	○
2013/11/16 10.20.26	8.9		0.267	32.1	○	○
2013/11/16 10.20.27	17.8		0.250	32.4	○	○
2013/11/16 10.20.28	26.8		0.324	37.9	○	○
2013/11/16 10.20.29	37.4		0.210	36.9	○	○
2013/11/16 10.20.30	47.6		0.308	40.9	○	○
2013/11/16 10.20.31	59.0		0.231	39.9	○	○
2013/11/16 10.20.32	70.1		0.243	43	○	○
2013/11/16 10.20.33	82.0	1	0.224	41.4	○	○
2013/11/16 10.20.34	93.5		0.208	43	○	○
2013/11/16 10.20.35	105.4		0.224	44.5	○	○
2013/11/16 10.20.36	117.8		0.283	44.5	○	○
2013/11/16 10.20.37	130.1		0.215	46	○	○
2013/11/16 10.20.38	142.9		0.200	46	○	○
2013/11/16 10.20.39	155.7		0.207	48.3	○	○
2013/11/16 10.20.40	169.1		0.206	46	○	○
2013/11/16 10.20.41	181.9		0.200	47.5	○	○
2013/11/16 10.20.42	195.1		0.193	48.7	○	○
2013/11/16 10.20.43	208.6		0.204	45.7	○	○
2013/11/16 10.20.44					△	△
2013/11/16 10.20.45					×	×

4 CONCLUSIONS

The Ippo-Campo system is a low-cost IT-based road condition assessment system which has been developed based on digital video, vehicle vibration, audio and GPS data. It can easily obtain output data in various formats that are both effective and efficient. The main conclusions obtained in this study can be summarized as follows:

1. An IT-based road condition assessment system (Ippo-Campo) has been developed based on digital movie, vehicle vibration and sound with GPS data and low cost constraint. The system helps to shear easily the information among road administrators, then it can make the priority of repairing works of road facilities.

2. The proposed system was applied to an actual road network (target route) in Mine-city, Yamaguchi area, Japan to evaluate its effectiveness. As the results, it will be able to make a rational maintenance strategy for repairing works based on the condition assessment.

Table 4. Comparison between before and after pavement repair using acceleration and wheel sound.

No	Type of road	Line No.	Line name	Length	Before repair				After repair			Validity
					number of sample (S)	X☆△ (B)	B/S (%)	B/S < 50%	number of sample (S)	X☆△ (B)	B/S(%)	
1				200	17	9	53		19	0	0	
2	Prefecture	28	Ogouri misumi line	310	23	16	70		25	4	16	
3	Prefecture	31	Mito line	480	39	32	82		36	3	8	
4	Prefecture	31	Mito line	450	31	4	13	!	32	2	6	
5	National	435	435 line	270	21	16	76		20	0	0	
6	National	316	316 line	580	41	39	95		41	2	5	
7	National	316	316 line	420	27	23	85		28	4	14	
8				170	16	7	44	!	14	0	0	
9				80	7	2	29	!	6	1	17	
10	National	316	316 line	270	17	17	100		21	1	5	
11	National	316	316 line	600	37	37	100		31	2	6	
12	Prefecture	33	Shimonoseki Mine line	320	23	16	70		23	5	22	
13	Prefecture	33	Shimonoseki Mine line	200	14	14	100		12	3	25	
14				150	11	11	100		11	0	0	
15	Prefecture			150	10	6	60		11	2	18	
16		65	Sanyou Toyota line	440	30	19	63		26	4	15	
17				420	29	20	69		25	8	32	
18				140	11	9	82		9	1	11	
19				120	10	8	80		9	2	22	
20	Prefecture	33	Shimonoseki Mine line	100	7	7	100		8	1	13	
21	Prefecture	33	Shimonoseki Mine line	170	10	10	100		12	2	17	
22	Prefecture	33	Shimonoseki Mine line	180	13	7	54		12	5	42	
23	Prefecture	33	Shimonoseki Mine line	320	22	12	55		21	3	14	
24	Prefecture	33	Shimonoseki Mine line	80	9	4	44	!	5	1	20	
25				160	12	6	50		12	1	8	
26				150	10	10	100		11	3	27	
27				160	12	12	100		12	5	42	
28				230	15	11	73		15	6	40	
29	National	435	435 line	290	21	19	90		20	7	35	
30	National	435	435 line	520	38	38	100		45	18	40	
31				590	37	37	100		37	8	22	
32				250	17	5	29	!	16	3	19	
33				230	15	10	67		16	2	13	
34				250	15	9	60		61	6	10	

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