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PAPER TITLE (90 Characters Max)	**Collecting Pavement Big Data by using Smartphone**		
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Response type, road profile, big data, disaster response, smartphone

ABSTRACT:

Japan has many earthquakes. In 2011, the Great East Japan Earthquake was occurred, that bring huge damages. On these situation quick survey of road condition is important for quick relief operation. For this survey, convenience method was developed to collect road damages that are the smartphone put on the vehicle dashboard and drive normally. This method is useful not for only relief operation under the disaster, but also for pavement management at usual time.

In this paper, at first, measurement principle of the smartphone application BumpRecorder is explained. This application collect sprang acceleration data from accelerometer of smartphone and position data from GPS. After that vehicle spring condition will be estimated, and then unsprung movement that is wheel axle movement will be estimated. So, this application can be measured pavement roughness without influence of vehicle type and driving speed. And next, an analysis result from collected big data of over 300,000 km is explained. From 2011, the data is collected many places and continuously. The big data usage is explained.

Collecting Pavement Big Data by using Smartphone

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1 INTRODUCTION

This bump-collecting project was starting from disaster response usage. Japan is a one of the most highest seismicity country. It is still fresh in memory, at March 11 2011, the grate east Japan earthquake was occurred. During like these situation, immediate survey is an important for relief operation. If information of road damage can be collected conveniently and quantitatively, it will be helpful and effective for relief operation.

Figure 1 shows road damages at Niigata Chuetsu-oki earthquake 2007. An up side photograph was taken at foot of a bridge. This road collapse down, and occurred road bump. A bottom side photograph was taken at near the agricultural land. This road occurred heavy waviness. From this earthquake, our bump- collecting project was starting. In this time, the pedometer was used for bump detector. It was installed on a vehicle dashboard vertical surface. When the vehicle is driven over the road bump, the pedometer is counting up. This counting signal is recording with millisecond timestamp by board computer. At same time, location is recording by GPS. Figure 2 shows an actual installation. By using this data, number of bumps is counting for each 1[km]. This result is drawn on Figure 3. In this figure, a seismic intensity distribution map is used for background map. And cross point indicate the epicenter. Circle makers indicate road bump, and this diameter indicates number of bumps. Look at this figure, this trial method is very simple, and result matches with area damages. It means that vehicle vibration is effective information to evaluate road damage. In this trial, commodity parts were used, but this assembly is specialized system. That is not convenient for spread. From 2007, smartphone was appeared. It has accelerometer and GPS. So smartphone application developing was started.

Figure 1. Road damage at Niigata Chuetsu-oki Earthquake 2007.

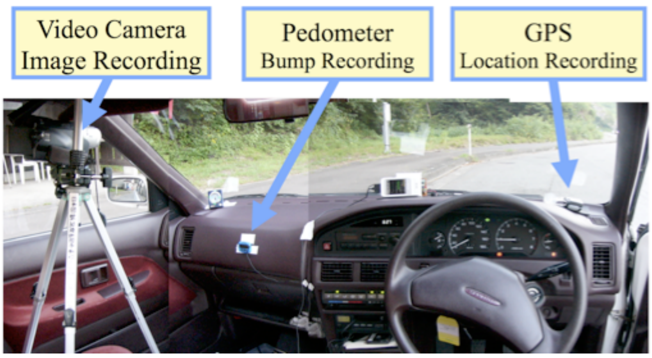

Figure 2. Measurement equipment installation.

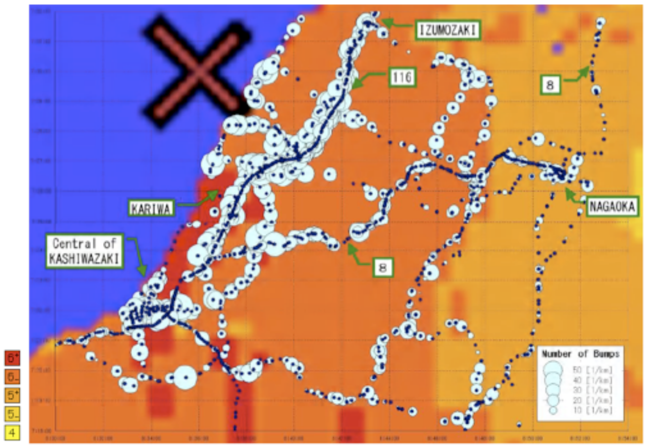

Figure 3. Result of bump recording by pedometer, seismic intensity map is used base map.

2 MEASUREMENT METHOD OF BUMP SIZE

When using pedometer, only the number of bumps can be counting. When using smartphone, bump size can be measured. Basic principle of measuring bump size is very simple. Smartphone is installed on the vehicle dashboard, and vertical acceleration is collected. And to get vertical movement, double integral of acceleration is calculated. But in an actual situation, double integral has large cumulative error. It cannot calculate simply. Here, before each integral, values will be corrected as follows.

Step 1: Correcting vertical acceleration. A recording cycle number is defined H[Hz]. At recording order number (i), vertical acceleration is defined Z(i)[m/s2]. A recorded vertical acceleration includes gravity. To calculate dynamic acceleration value dZ(i)[m/s2], it is assumed that a gravity equal to 10[sec] average of acceleration. And next, vertical velocity Vz(i)[m/s] is calculated by summation of dynamic acceleration value dZ(i). That is calculated by equation 1 and 2.

$$dZ(i) = Z(i) - \frac{\sum_{j=i-5H+1}^{i+5H} Z(j)}{H} \quad (1)$$

$$Vz(i) = Vz(i-1) + \frac{dZ(i)}{H} \quad (2)$$

Step 2: Correcting vertical velocity. At uphill and downhill, vertical velocity will be occurred, but it is not occurred by road bump. Uphill and downhill speed is assumed equal to 10[sec] average of velocity Vz(i)[m/s]. And bumping velocity dVz(i)[m/s] is calculated by excluding a average speed. And finally, vertical movement Lz(i)[m] is calculated by summation of bumping velocity dVz(i). That is calculated by equation 3 and 4.

$$dVz(i) = Vz(i) - \frac{\sum_{j=i-5H+1}^{i+5H} Vz(j)}{2H} \quad (3)$$

$$Lz(i) = Lz(i-1) + \frac{dVz(i)}{H} \quad (4)$$

Here, bump height is defined by differences between proximity maximum Lz and minimum Lz. Bump length is defined by driving distance between above proximity extreme points. When bump height is large, it indicates that this bump is heavy. And when bump length is long, it indicates that this bump is not heavy.

3 EMERGENCY SURVEY AT THE GREAT EAST JAPAN EARTHQUAKE 2011

Using above method, smartphone application named BumpRecorder was provide at March 2nd 2011. One week after, the great east Japan earthquake was occurred. One month after earthquake, our developing team was starting emergency survey at Tohoku region where was concerned damages (YAGI 2011). Figure 4 shows a measurement result on Google Maps. The red circle indicates the epicenter. Blue circles indicate bump positions. This circle diameter indicates sum of square of bump height for each 1[km] long. When there is large bump and there are many bumps, this circle is large. At that time, this map was reported to stakeholders.

Look at this figure large blue circles are concentrated at south part of the epicenter. At this earthquake, terrible Tsunami attacked at north coast of the epicenter, and over 20,000 peoples died at this area. So, many of the news on news papers, TVs were reporting about this north coast area. These reports are important things. But on the other hand, it was not reporting that heavy damages were also occurred at south area by earthquake shake. It is afraid that these situations were influenced for relief operation. Our measurement result could report two month after the earthquake. That was too late to make good effect for relief operation.

A lessons learns from this experience is that penetration of an application and a service are very important for the immediate survey and report. To spread this smartphone application, it starts to apply for a pavement management.

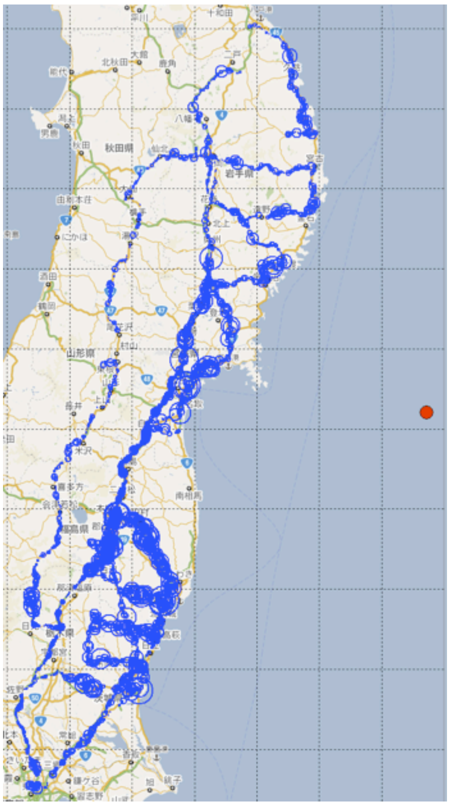

Figure 4. Sum of square of bump height for each 1[km] at Tohoku region after the earthquake 2011. This figure is using Google Maps.

4 SPECIALIZED FOR PAVEMENT MANAGEMENT

To apply pavement management, measurement accuracy is important. When BumpRecorder is used, smartphone is installed in the vehicle cabin for example on the dashboard. Vehicle cabin is located at over the vehicle suspension, a recording acceleration is a sprung acceleration. It is easily influenced from vehicle model and driving speed. Other study reported (Islam 2014), to get good accuracy, vehicle suspension parameter should be including in calculation. To improve measurement accuracy, an estimation method of unsprung vertical movement is developed.

5 ESTIMATION METHOD OF UNSPRUNG VERTICAL MOVEMENT

This estimation method is separated two steps. At the first step, vehicle spring condition is estimated. At the second step, unsprung vertical movement is calculated. And it is assumed that it is equal to road profile, then evaluate this result. The detail is as follows.

(1) Estimation method of vehicle spring condition

The vehicle is modeled by one mass spring model that is drawn in Figure 5. This model is defined by the equation of motion in equation 5. In this equation, Lz is sprung vertical movement, "u" is unsprung vertical movement, "ω" is angular frequency, "h" is damping ratio. "ω" is defined by equation 6. In this equation, "f" is a resonant frequency.

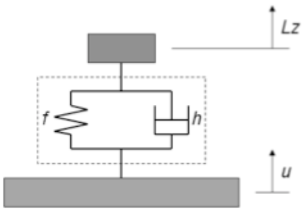

Figure 5. One mass spring model.

$$\ddot{L}z + 2h\omega(\dot{L}z - \dot{u}) + \omega^2(Lz - u) = 0 \qquad (5)$$

$$\omega = 2\pi f \qquad (6)$$

To calculate this equation, resonant frequency and damping ratio are required. To get these parameters, sprung acceleration is analyzed by FFT, and peak frequency is picked up around 1.5[Hz] for resonant frequency. And using half-width method, damping ratio of this frequency is estimated.

(2) Calculation method of unsprung vertical movement

To calculate the equation 5, is using dZ(i) of equation 1, is using dVz(i) of equation 3, Lz is using Lz(i) of equation 4. Unsprung vertical movement u(i) is defined by difference equation 7. And is used for of equation 5, u(i) is used for "u" of equation 5.

$$u(i) = u(i-1) + \frac{\dot{u}(i) + \dot{u}(i-1)}{2N} \qquad (7)$$

After applying u(0)=0, step by step unsprung vertical movement u(i) is calculated.

6 EXPERIMENTAL RESULT FOR VERIFICATION

(1) Experimental conditions

Accuracy of the proposed method was verified on the road of about 250[m] long at Tsukuba-city, Japan. On this experiment, vehicle speed was changed from 20[km/h] to 60[km/h], and the test drive was done two times for each speed. Figure 6 shows vehicle speed for each drive. Horizontal axis indicates latitude, and vertical axis indicates vehicle speed. The start point is low latitude side or left hand side of this figure, and the end point is high latitude side or right hand side of this figure. Look at around the start point and the end point, vehicle speed are not stable. So, period of latitude from 36.1092 to 36.1104 is used for this verification. This period has 160[m] long. On this experiment, for test vehicle, TOYOTA PRIUS was used which has 2,700[mm] wheelbase and 1,400[kg] weight. For test smartphone, Samsung Galaxy S2 was used which has 99[Hz] acceleration sampling cycle that is fastest cycle of this smartphone. And GPS recording cycle is 1[Hz].

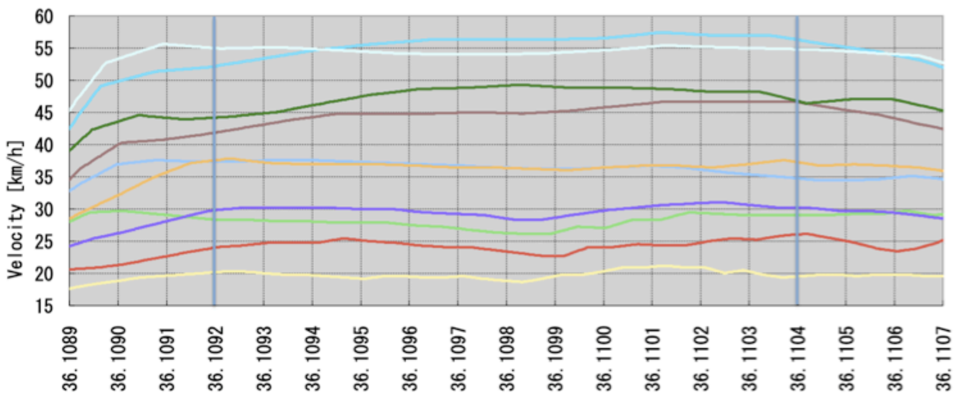

Figure 6. Vehicle speed of each test drive.

(2) Experimental results

Figure 7 shows sprung elevation of each position that is calculated by equation 4. These are measured vertical movement data on the vehicle dashboard. Look at period from latitude 36.1095 to 36.1096, sprung elevation profile of each speed are different. And look at period from latitude 36.1098 to 36.1099, it are different too.

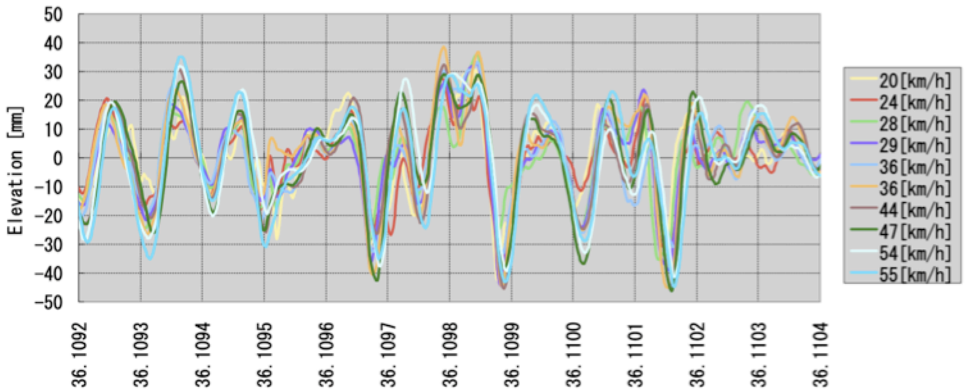

Figure 7. Sprung elevation profile.

Figure 8 shows unsprung elevation of each position that is calculated by equation 5, 6 and 7. These are estimated vertical movement data at the vehicle axle. Look at above two periods, unsprung elevation differences of each speed are smaller than sprung elevation. It means that unsprung elevation estimation is effective to get good reproducibility. And unsprung elevation can reproduce more pointed profile than sprung elevation profile. It means that unsprung elevation estimation provide higher response. When using unsprung elevation estimation, a vehicle can be driven faster speed with higher accuracy. This result said, this method could reduce spending time and cost for pavement measurement.

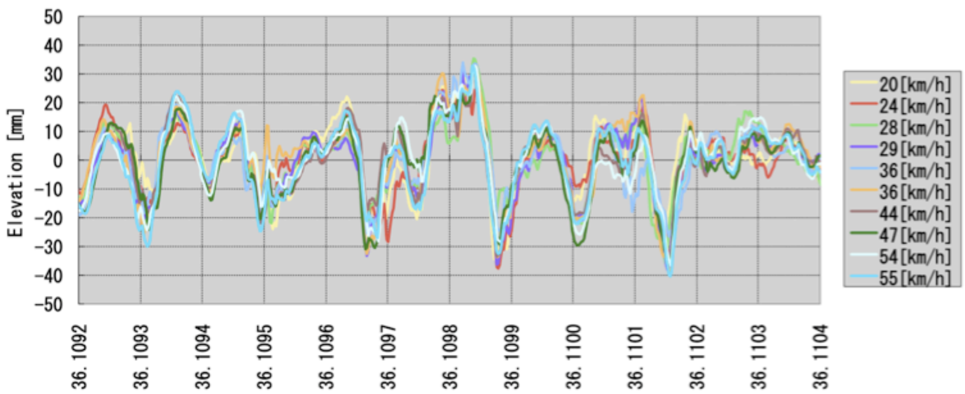

Figure 8. Unsprung elevation profile.

To compare both dispersion of the measurement sprung elevation and the estimated unsprung elevation, elevation standard deviation is calculated for each position. This value is drawn in Figure 9. It can easily understand unsprung standard deviation is smaller than sprung standard deviation. In this experiment, mean value of sprung standard deviation is 6.2[mm], and mean value of unsprung standard deviation is 4.4[mm]. When using estimated unsprung elevation, standard deviation is reduced to 70%.

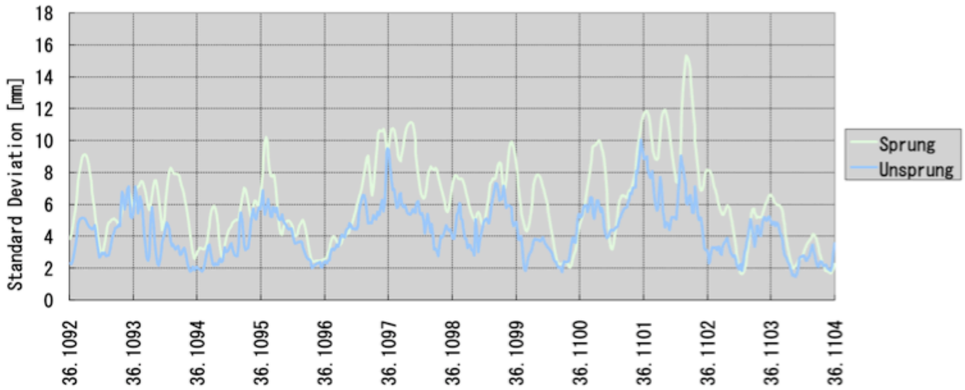

Figure 9. Elevation standard deviation.

7 REPORTING SERVICE

As mentioned above, using for pavement management, accuracy is an important. And unsprung elevation estimation is successfully improving accuracy. One more important issue is a reporting service (Forslöf 2012). Our development team was developing web service named "Bump- Recorder Web". Using smartphone, after measurement road bump, recorded data will be uploaded to web server. Then, unsprung elevation will be estimated on the server. Finally, this data will be displayed on the web browser. From data upload to data display, typically it spends 5 or 10 minutes.

Figure 10 shows this web site screen, on the GSI Maps, that is maps of Geospatial Information Authority of Japan, brown lines draw measured roads, and blue triangular draw measured bumps. A size of the triangular indicates bump height. On this web site, right hand side has a control panel that is used for searching data and analyzing data.

Figure 10. Sample screen of a bump height.

BumpRecorder estimates an unsprung elevation, and it assumed equal to road profile and calculates IRI, which is an International Roughness Index. Figure 11 shows the sample screen of the IRI with the distance-post graph. On this screen, after selecting two positions, the distance-post graph will be displayed. Figure 12 shows the sample screen of IRI data with the time series graph.

Figure 11. IRI data with distance-post graph.

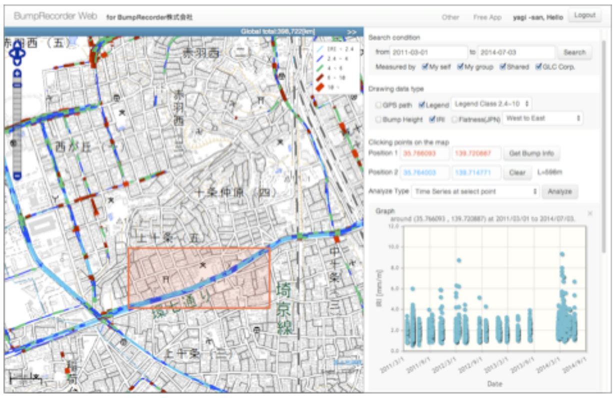

Figure 12. IRI data with time series graph.

On this web site, not only bump height and IRI, but also Japanese flatness named "Heitansei" can be displayed. And analyzing result can be displayed by histogram. In addition for the background map, using not only GSI Maps, but also Google Maps, Google Satellite, and Open Street Map can be selected.

Figure 13 shows the IRI data at Tokyo, Japan. For the north to south direction road that locate at the center of the map, the IRI data was recorded many times. Lower right graph shows the IRI data distance-post graph for north to south direction. Data were recorded from March 2011 to July 2014. First half data before November 2012 is drawn by orange line. Second half data after November 2012 is drawn by green line. These two data have same trend. It means that road profile is not changing.

Figure 14 shows opposite direction, south to north direction. At distance from 100 to 600, orange line data are large than green line data. It means that this road was repaired and road profile was improved.

Figure 13. Distance-post graph for North to South direction.

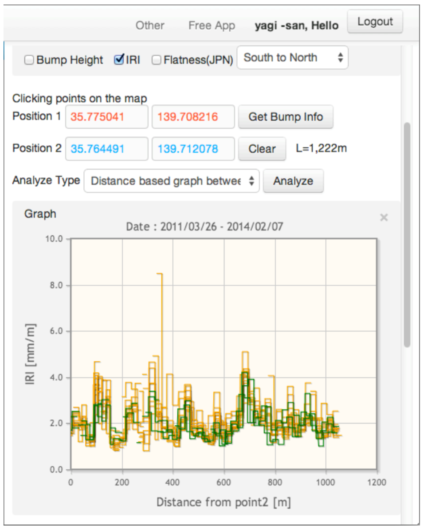

Figure 14. South to North direction.

These situations can be found by using collecting pavement big data from smartphone. In Japan, collecting bump data is over 450,000[km] long, it is becoming pavement big data.

8 NEW TYPE NAVIGATION - BUMP NAVI -

This pavement big data bring new type of navigation that is bump navigation. Smartphone application Bump Recorder has [Navi] mode screen. Figure 15 shows sample screen of bump navigation. On this screen, your position is drawn by light blue circle, and road bump and IRI are also displayed. Using this navigation, it is easy to find the road bump before vehicle bumping. Especially, driving an ambulance car or delivering track of fragile articles or precision machines, this navigation is very useful and effective.

Figure 15. Sample screen of Bump Navigation.

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