AUTOMATIC DATA COLLECTION SYSTEM FOR INNOVATIVE BRIDGE HEALTH MONITORING BASED ON PUBLIC BUS VIBRATION

Akito Yabe[1]

ABSTRACT : In our country, a huge number of short and medium span bridges managed by local government on a limited budget and expert engineers. More reasonably and efficiently methods of the condition assessment have been needed than conventional visual inspection or monitoring systems. Therefore, a method of the condition assessment system was developed for existing short span (10m~20m span length) RC bridges based on monitoring data from public bus vibration. Now, because this system is composed by only acceleration sensor and manual operation data collection system, an automatic data collection system is one of a very important technique for more reasonably and efficiently monitoring sysytem. In this paper, a method of automatic data collection system was proposed applying GPS sensor. This system on the public bus makes a manual operation to be automatic and low cost.

KEYWORDS: SHM, GPS, public bus, vibration, characteristic deflection, automatic data collection system, short span bridge

1. INTRODUCTION

1.1. Summary of the condition assessment system based on monitoring data from public bus

In our country, about 70 percent of a total of nearly 670,000 bridges were constructed in the 1960s and 1970s. And almost they are short- or medium-span (10~20 m) bridges. Those huge number of short and medium span bridges managed by local government on a limited budget and expert engineers[1]. Now it's can't be said that carried out an inspection enough. In the future, because reconstruction of government finances and the birthrate declining be expected to arise, the conditions of bridge management will become more hard jobs. Therefore more reasonably and efficiently methods of the condition assessment have been needed than conventional visual inspection or monitoring systems. In view of such situation a method of the condition assessment system was developed for existing short span RC bridges based on monitoring data from public bus vibration as shown in **Figure 1**. This system is applied a method of extracting safety indices, namely "Characteristic Deflection"(shortened to CD) which is relatively free from the influence of dynamic disturbances due to such factors as the unevenness of the road surface, and a structural anomaly parameter[2,3,4].Now, this system is composed by only an acceleration sensor and manual operation data collection system. When measuring the acceleration of bus vibration someone must be on the bus and make a note of a time on passing the target bridge. Next, after measuring CD is extracting from acceleration data by manual operation. Because these processes will cost operating, an automatic data collection system is one of a very important technique for more reasonably and efficiently monitoring sysytem. In this paper, at first focused on a method of automatic data collection system applied using Global Positioning System (GPS). This system is pinpointing bus's position by GPS sensor data and judging the ups or downs of a road. If the bus is going on the target bridge, automatically this system measure acceleration data. This automatic data collection system will contribute to go low cost bridge management system.

[1] KOZO KEIKAKU Engineering Inc., Japan, Dr. Eng.

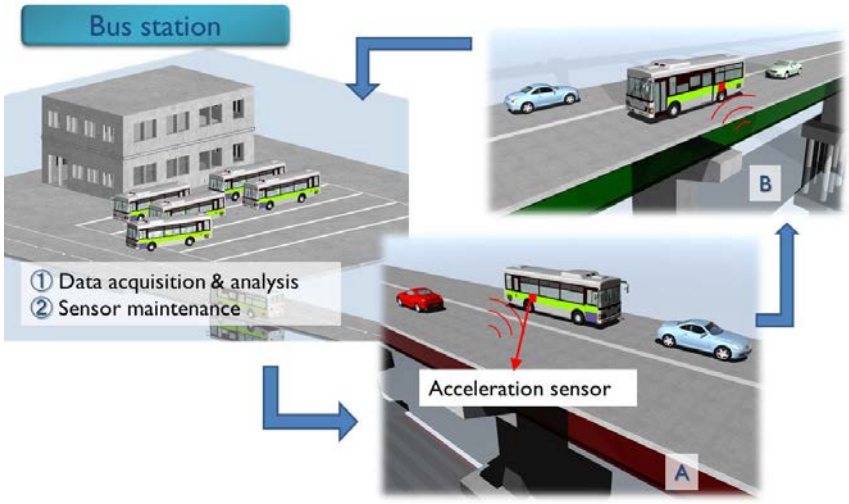

Figure 1. Concept of bus monitoring system for short- and medium-span bridges

1.2. Concerning the theory of "Characteristic Deflection"

The calculating CD process is one of the rational methods for extracting damage/deterioration-related information from measured rear wheel vibrations of a bus without being affected by the dynamic characteristics of the bridge and the vehicle and the road surface profile. A summary of the rationale for extracting CD is shown **Figure 2**.

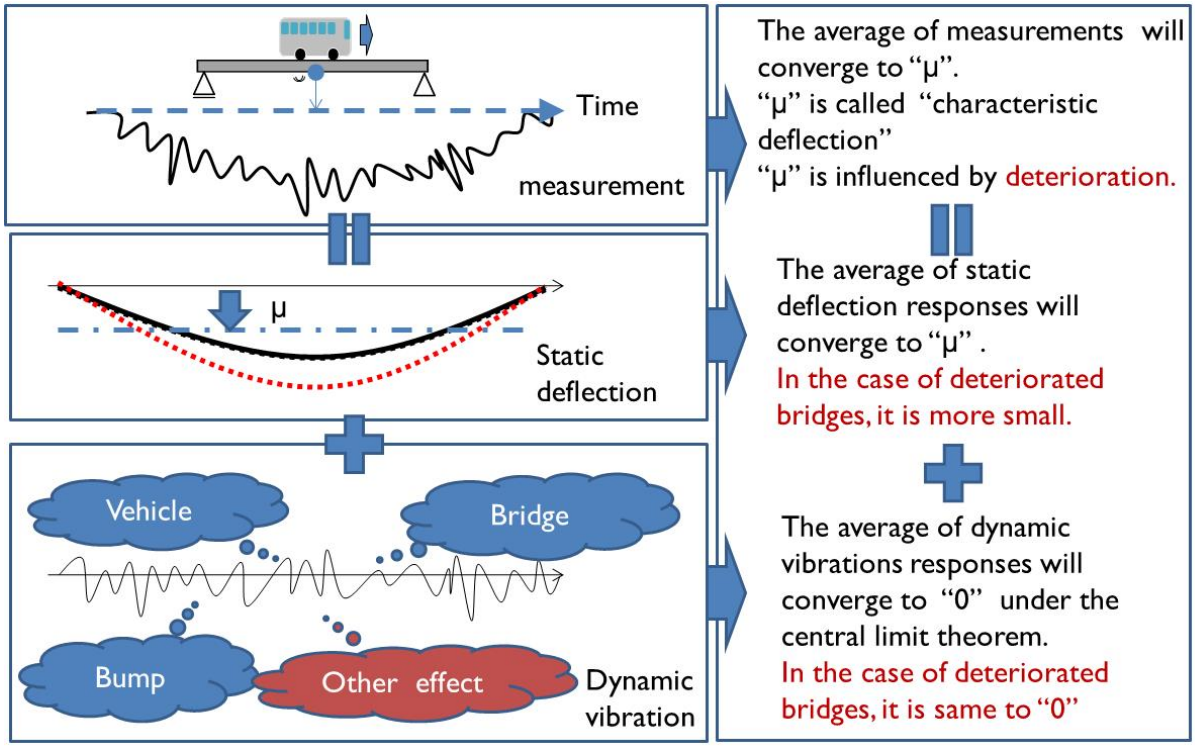

Figure 2. A summary of the rationale for extracting CD

The rear wheel vertical vibration $\delta_a(t)$ of a bus running at a constant speed can be expressed as the sum of static displacement $\delta_{sa}(t)$, which is dependent on the measured rear wheel vertical vibration of the bus, and dynamic displacement $\delta_{da}(t)$, which is dependent on the road surface profile and the vibration characteristics of the bridge and the vehicle:

$$\delta_a(t) = \delta_{sa}(t) + \delta_{da}(t) \qquad (1)$$

If it is assumed that the unevenness of the road surface can be expressed as a steady-state random Gaussian process with an average value of 0 and that dynamic displacement including bridge–vehicle interaction is ergodic and Fourier-series-expandable, the dynamic displacement $\delta_{da}(t)$ can be expressed as their sum:

$$\delta_{da}(t) = S_r(\Omega, t) + \int_{-\infty}^{+\infty} X(f) \cdot e^{2\pi f t i} df \qquad (2)$$

where
$S_r(\Omega, t)$: density function for unevenness of road surface.
Ω: spatial frequency of road surface profile.
$X(f)$: Fourier coefficient.

In Eq. (2), the sample mean in the second term is 0. The mean of a sufficient number (*N*) of samples obtained from $\delta_{da}(t)$ can be expressed as

$$\frac{\sum_{t=1}^{N} \delta_{da}(t)}{N} \fallingdotseq 0 \qquad (3)$$

Next, *k* samples are taken from measured values obtained from $\delta_a(t)$, and their mean is expressed as : $\overline{\delta a\,(t)}$

$$\overline{\delta a\,(t)} = \frac{\sum_{j=1}^{k} \delta_a(j)}{k} \qquad (4)$$

Because the sample mean follows a normal distribution in accordance with the central limit theorem, $\overline{\delta a\,(t)}$ converges to a certain value (μ_a). For the sample mean $\delta_a(j)$ of a sufficient number (*n*) of samples, the following equation holds true:

$$\mu_a = \frac{\sum_{i=1}^{n} \overline{\delta a\,(t)}_i}{n} = \frac{\sum_{i=1}^{nk} (\delta_a(j))_i}{nk} \qquad (5)$$

Sampling is made so that there is no overlap in the samples. If N is sufficiently large for $nk = N$ and $t = 1 \sim N$, the following approximation can be made:

$$\mu_a \fallingdotseq \frac{\sum_{t=1}^{N} \delta_a(j)_t}{N} \qquad (6)$$

This expresses the mean displacement of the rear axle of the bus passing over the bridge. From Eqs. (1) and (3), the following equation can be derived:

$$\mu_a \fallingdotseq \frac{\sum_{t=1}^{N} \delta_{sa}(t)}{N} \qquad (7)$$

This means that the mean displacement of the rear axle of the bus passing over the bridge obtained from a sufficient number (N) of samples can be extracted as a value, μ_a (referred to as "Characteristic Deflection value"), that is relatively free from the influence of the vibration characteristics of the bridge and the vehicle and the dynamic displacement due to the unevenness of the road surface.

Since the values of μ_a are extracted from measurements taken when the bridge under consideration is in a sound condition, values extracted from measurement taken after the occurrence of deterioration or damage are represented by μ_a'Then, the following equation can be defined :

$$\alpha = \frac{\mu_a'}{\mu_a} \qquad (8)$$

The rate of change α expressed by Eq. (8) is defined as the structural anomaly parameter. After a given value of α is set, the characteristic deflection is monitored continuously. When the characteristic deflection has exceeded a certain limit, it can be judged that the bridge of interest has moved from the acceleration stage on to the deterioration stage.

From the above, CD was calculated based on the law of classical mechanics such as Hooke's law and statistical feature data. If the condition is enough which Hooke's law influence is greater than others in measured rear wheel vibrations, only CD has the significant information of damage/deterioration-related. Therefore rear wheel vibrations have to be measured by a heavy vehicle such as a bus.

2. SUMMARY OF AUTOMATIC DATA COLLECTION SYSTEM

2.1. Composition of automatic data collection system

Conventional data collection system is composed by an acceleration sensor, a data logger, a personal computer and a buttery. This system's data logging sampling frequency is 1000Hz, so collecting a huge number of acceleration data is unable to keep all day. Because they are manual operation, when measuring the acceleration of bus vibration always, one operator is checking that the bus is approaching the target bridges, and another operator is pushing on the start button and making a note of a time going on the target bridge. On the other hands a new data collection system is added GPS sensor on the conventional system such as **Figure 3**. An acceleration sensor and a GPS sensor performance are shown **Table 1.** GPS sensor has two operating functions. One function is detecting that the bus is approaching the target bridges with judging the ups or downs of a road. Another function is a trigger for the start of measuring the acceleration of bus vibration.

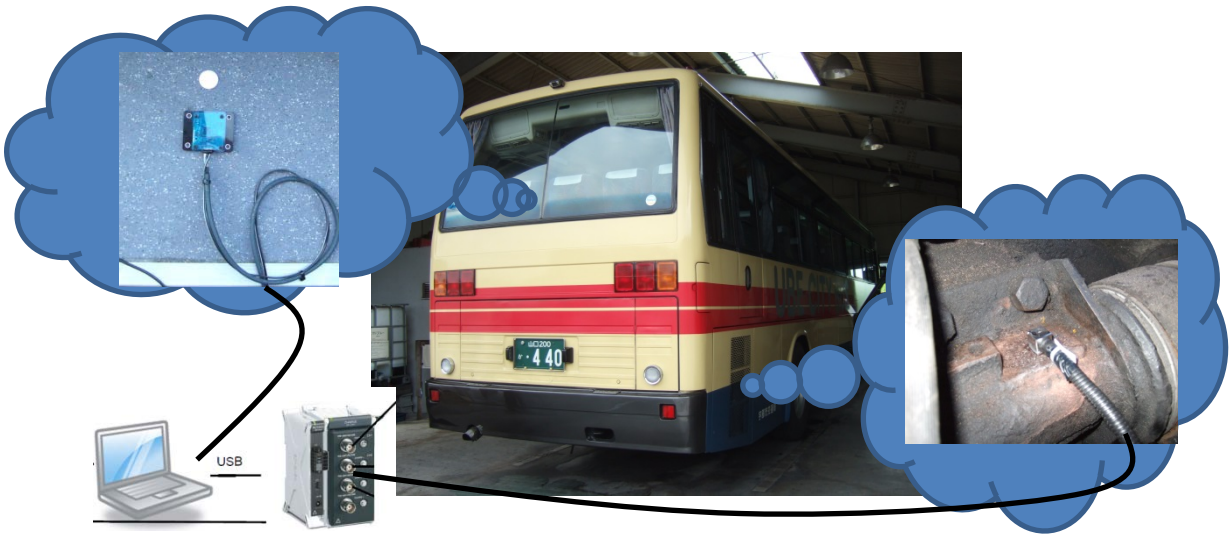

Figure 3. A new automatic data collection system

Table 1. An acceleration sensor and a GPS sensor

Acceleration sensor		GPS sensor	
Manufacturer	Fuji Ceramics co.	Manufacturer	ZMP Inc.
Type	Piezoelectric	Survey Accuracy	3m CEP(50%)
Frequency Performance	3Axis 1Hz～	Frequency Performance	5Hz
Sampling Frequency	1000Hz	Sampling Frequency	5Hz

2.2. A method of the target bridge discrimination

In the case of discriminating the measurement target bridge using GPS data there are three important problems which are detection approaching the target bridge, judgment the ups or downs and linkage Acceleration data. A method of detection approaching the target bridge is shown **Figure 4**. The two position area data were prepared for picking up GPS in the automatic data collection system. Such as Figure 3 at first the bus is going into the Picking up area 1 on the ups side lane, the system state become “Ready”. Next it is going into the Picking up area 2, the system state become “Measurement Start”. An acceleration data is logging while fixed enough time for passing on the bridge. When in the state of “Measurement” by area 2 trigger is off to change the state. After logging data the state become “Idle” and waiting next “Ready” area. On the other hands, the bus is going the downs side lane, passing another area 1 and 2. The system is able to judge the ups or the downs and detect approaching the target bridge.

This system has data base of linkage between picking up area number and the all target bridge. So every measured acceleration data is linkage with the target bridge together personal computer time.

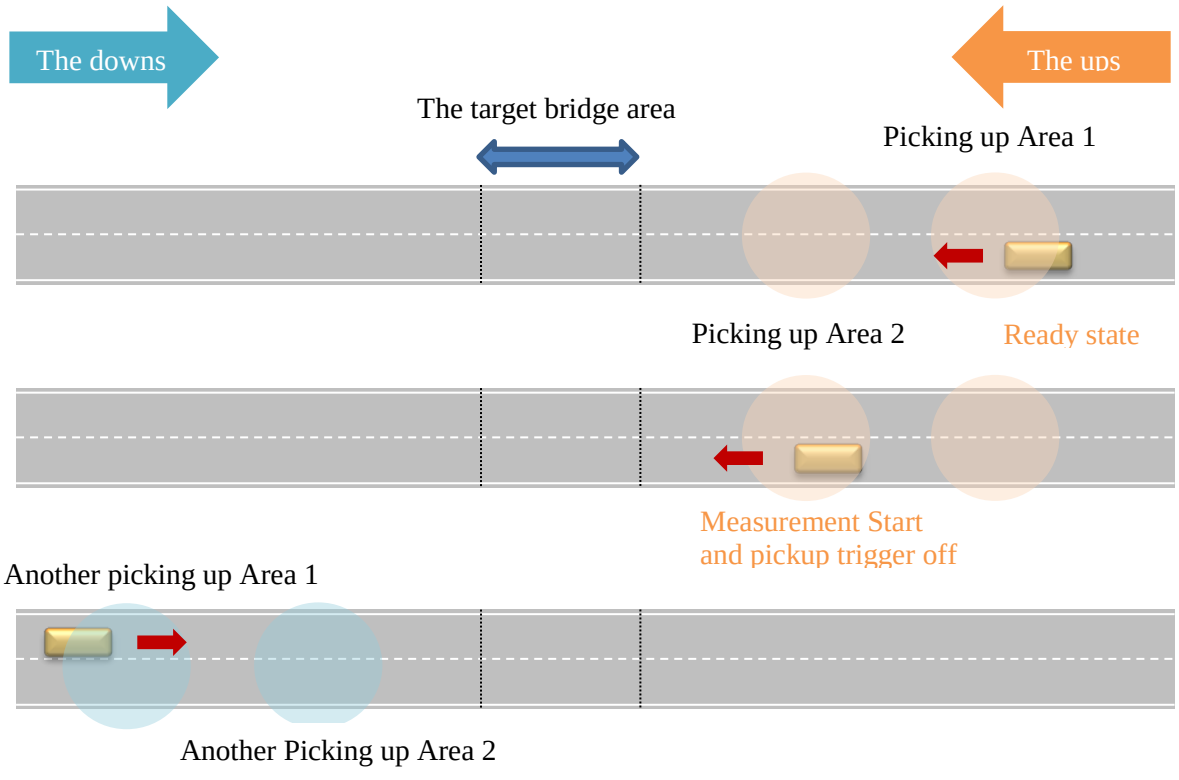

Figure 4. A method of detection approaching the target bridge

2.3. An automatic data collection system program

An automatic data collection program flow is shown **Figure 5**. This program is composed three modules and one database. They are a picking up area verification module, a state management module, an acceleration logging module and target bridges position data base. A picking area verification module is verifying between got GPS data and target bridges position data base while running. A state management module is changing system states in order of passed picking area numbers. An acceleration logging module saves acceleration data an order of a state management module. This program substitute manual operations for their modules corporation with each other. The target bridges position data base has 5 major items. Their items are shown **Table 2.**

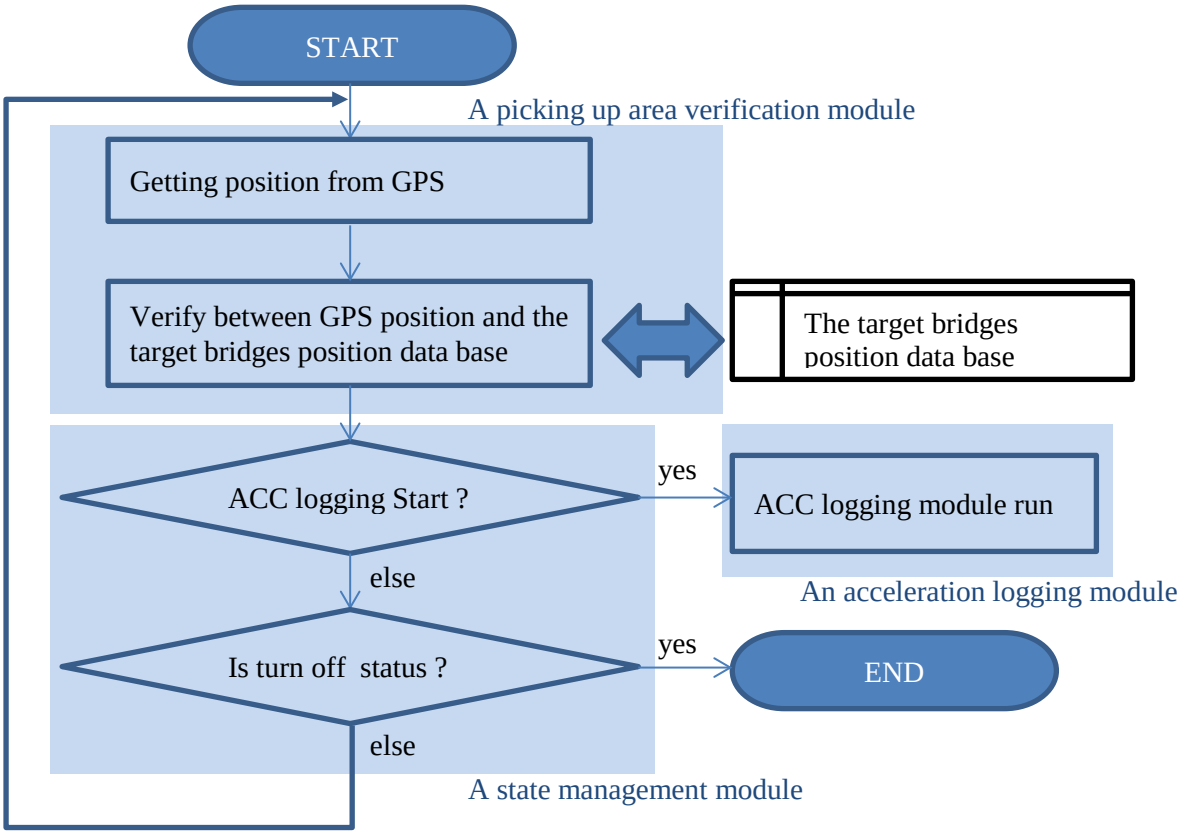

Figure 5. An automatic data collection program flow

Table 2. The target bridges position data base items

Items	Information
Target bridge name	A unique name by text
Ready Position (Area 1)	A center position's latitude and longitude
Measurement Start Position (Area 2)	A center position's latitude and longitude
Picking up range	A radius of a picking up circle area
Logging time	An acceleration logging time (second)

3. TEST OF AUTOMATIC DATA COLLECTION SYSTEM

3.1. GPS performance check

When the target bridge position data base items are decided, GPS performance is important information. At first picking up position discrepancies of used GPS was confirmed at stationary 10 seconds. The test location is KOZOKEIKAKU ENGINEERING Inc. at Tokyo **(Figure 6)**. A circle in **Figure 7** is shown an about 1.5m radius. The GPS performance was confirmed enough.

Figure 6. GPS stationary sampling test location

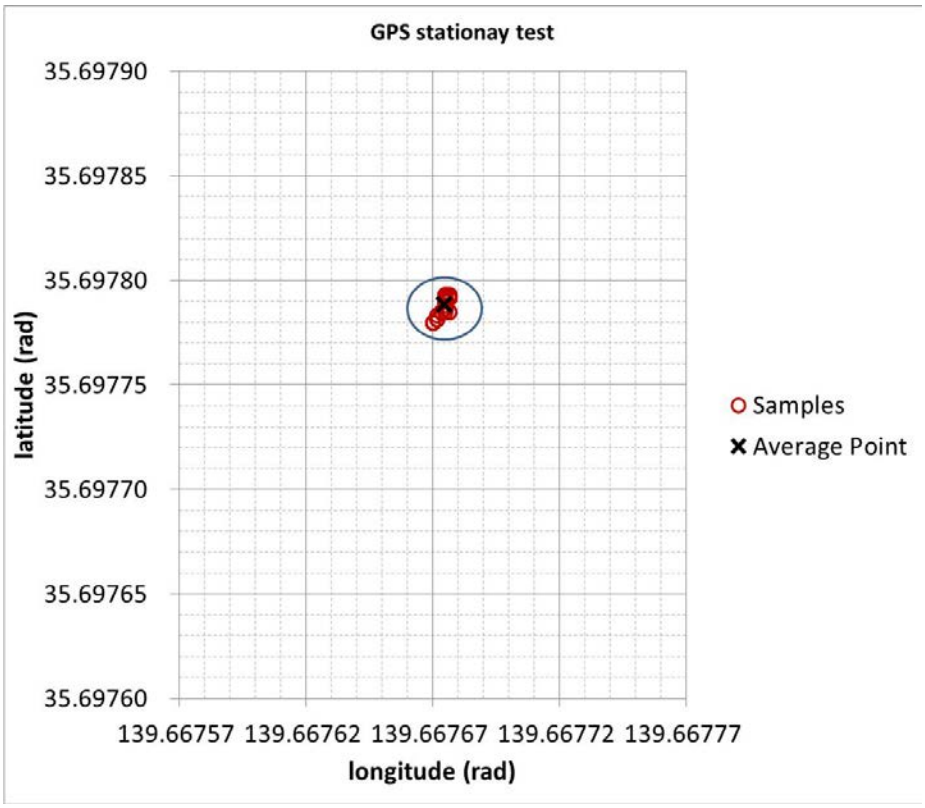

Figure 7. GPS stationary sampling test (10 seconds)

3.2. Data collecting test on “Shingondai-bridge”

Data collecting test was tried on “Shingondai-bridge”. In this case it was used a small rent-car without bus. “Shingondai-bridge” was constructed at 1998. This bridge is 22.4m span simple girder bridge. The width of load with this bridge both side is about 10m. When it will be running 50km/h, in 1 second it go about 14m. Because GPS sampling frequency is 5Hz, a sampling distance is 2.8m. So in this test case a radius of a picking up circle area is 10m. The distance between Area1, Area2 and the target bridge was decided 50m. Running tests was tried each two times in the ups and the downs. **(Figure 8,Figure9)**

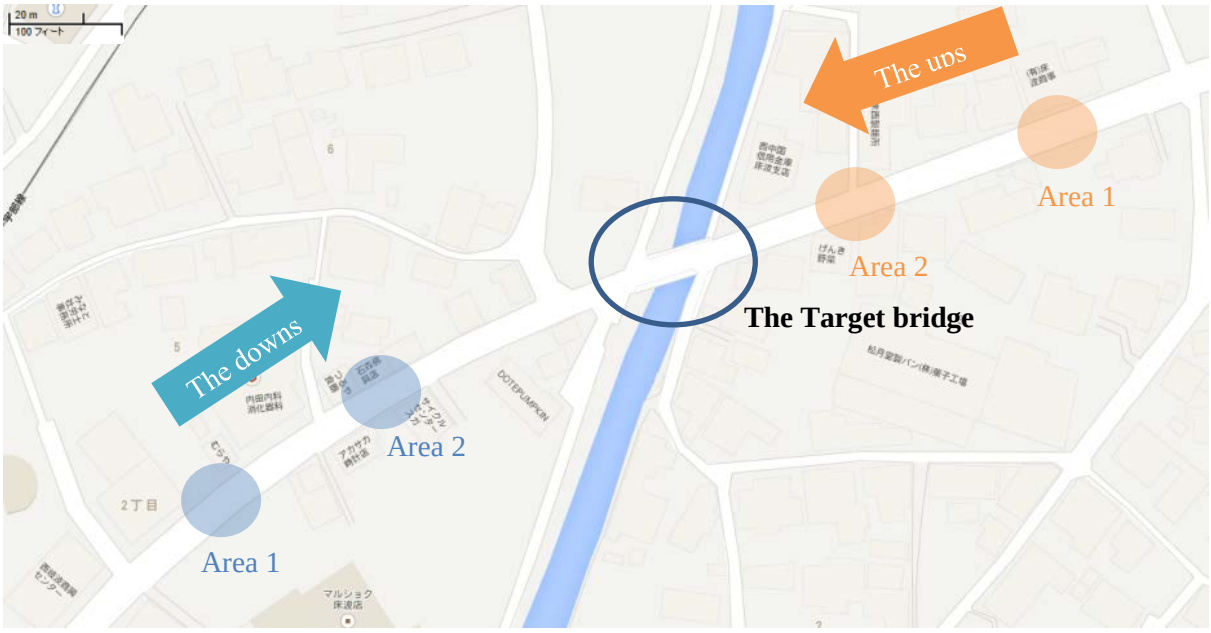

Figure 8. Shingondai-bridge location and condition

Figure 9. Shingondai-bridge

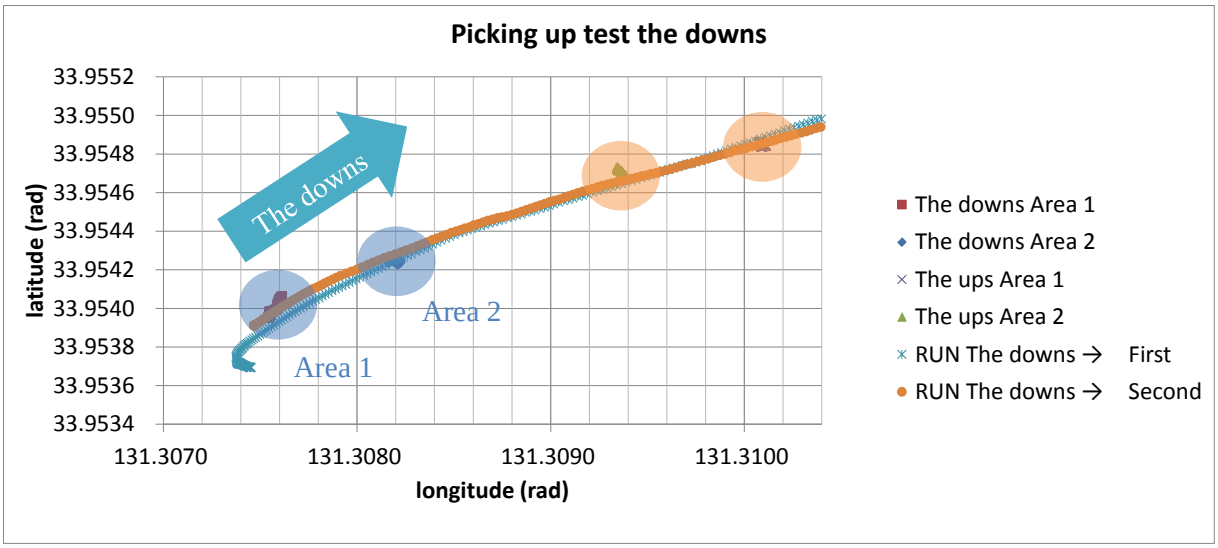

Figure 10. Result of GPS picking up test (the downs)

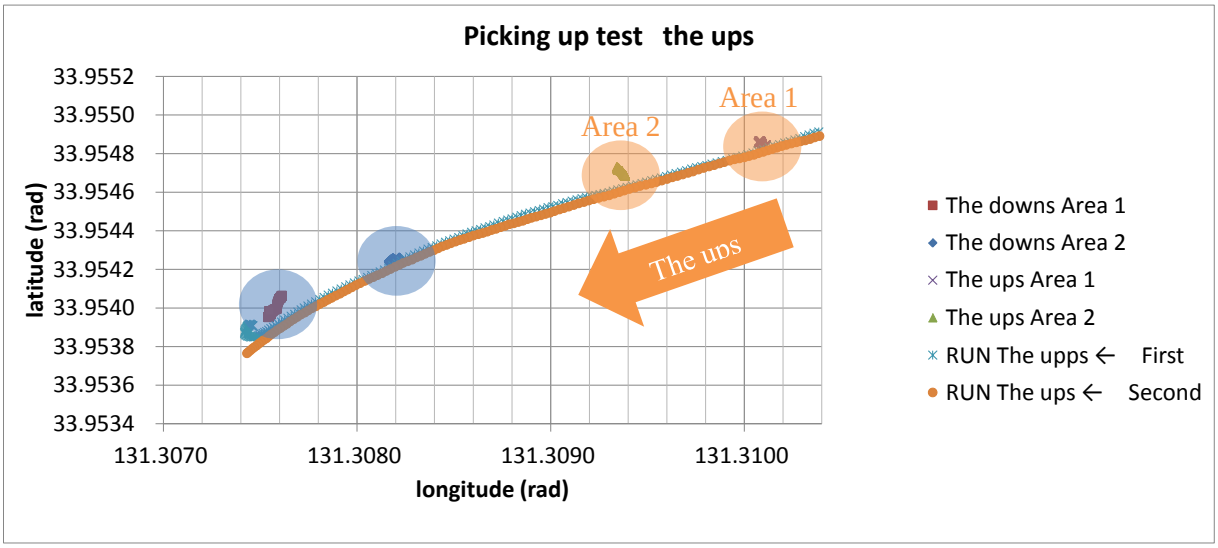

Figure 11. Result of GPS picking up test (the ups)

3.3. Result and consideration

The results of the test are shown **Figure 10** and **Figure 11**. Both case of the downs and the ups picking up area1 and area2 was operated normally. This applied GPS test shows some useful parameter for data collection system. Such as Shingondai-bridge at the each distance between an area 1, area 2 and the target bridge about 50m is feasible. And a radius of a picking up circle area is 10m too. A proposed data collection system applied GPS operate normally. Because their parameters are matched in only one case, there are more rational parameters for this system each any bridges.

4. CONCLUSIONS

In this paper, it focused on a method of automatic data collection system using GPS, and introduced an automatic data collection program flow. Their systems ware tested on the field, some results gave us useful parameters for this system. Main conclusions reached the results of verification experiments can be summarized as follows:

1) Under certain conditions using GPS is feasible for the automatic data collection system.

2) A running to the ups or the downs is able to detect by picking up Area1 and Area2 in this system.

For coming to pass the automatic data collection system some problems will be solve. What is more rational parameters for this system each any bridges? How is extracting CD from acceleration data by an automatic operation?

5. REFERENCES

[1] Japan Ministry of Land, Infrastructure, Transport and Tourism: http://www.mlit.go.jp/road/sisaku/yobohozen/yobo2_3.pdf,2011, 2011.

[2] Miyamoto, A. and Yabe, A.: Bridge Condition Assessment based on Vibration Responses of Passenger Vehicle, Journal of Physics(CS), Vol.305(1), pp.1-10, 2011

[3] Yabe, A. and Miyamoto, A.: Bridge Maintenance, Safety, Management and Life-Cycle Optimization, CRC Press (A Balkema Book), IABMAS'2010, Pennsylvania, USA, 2010.

[4] Yabe, A., Miyamoto, A., Isoda, S. and Tani, N.: Development of Bridge Monitoring System for Short- and Medium-span Bridges based on Bus Vibration, Journal of JSCE F4, Vol. 69, No. 2, pp.102–120, 2013.