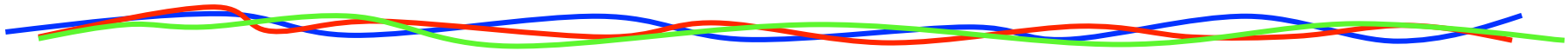
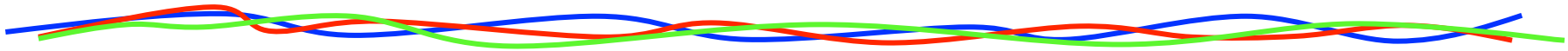
A MEASURING METHOD OF ROAD SURFACELONGITUDINAL PROFILE FROM SPRUNG ACCELERATION, AND VERIFICATION WITH ROAD PROFILER



2014 January 10

BumpRecorder Co., Ltd.
http://www.bumprecorder.com/
info@bumprecorder.com

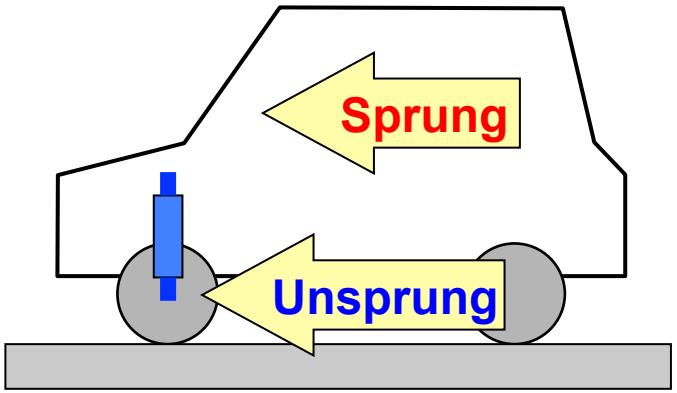
Features



Features

Previous Study

- Get unsprung acceleration by 2000Hz sampling (Tomizawa et al. 2011)
- Smartphone sampling of 100Hz is too slow (Nagayama et al. 2012)

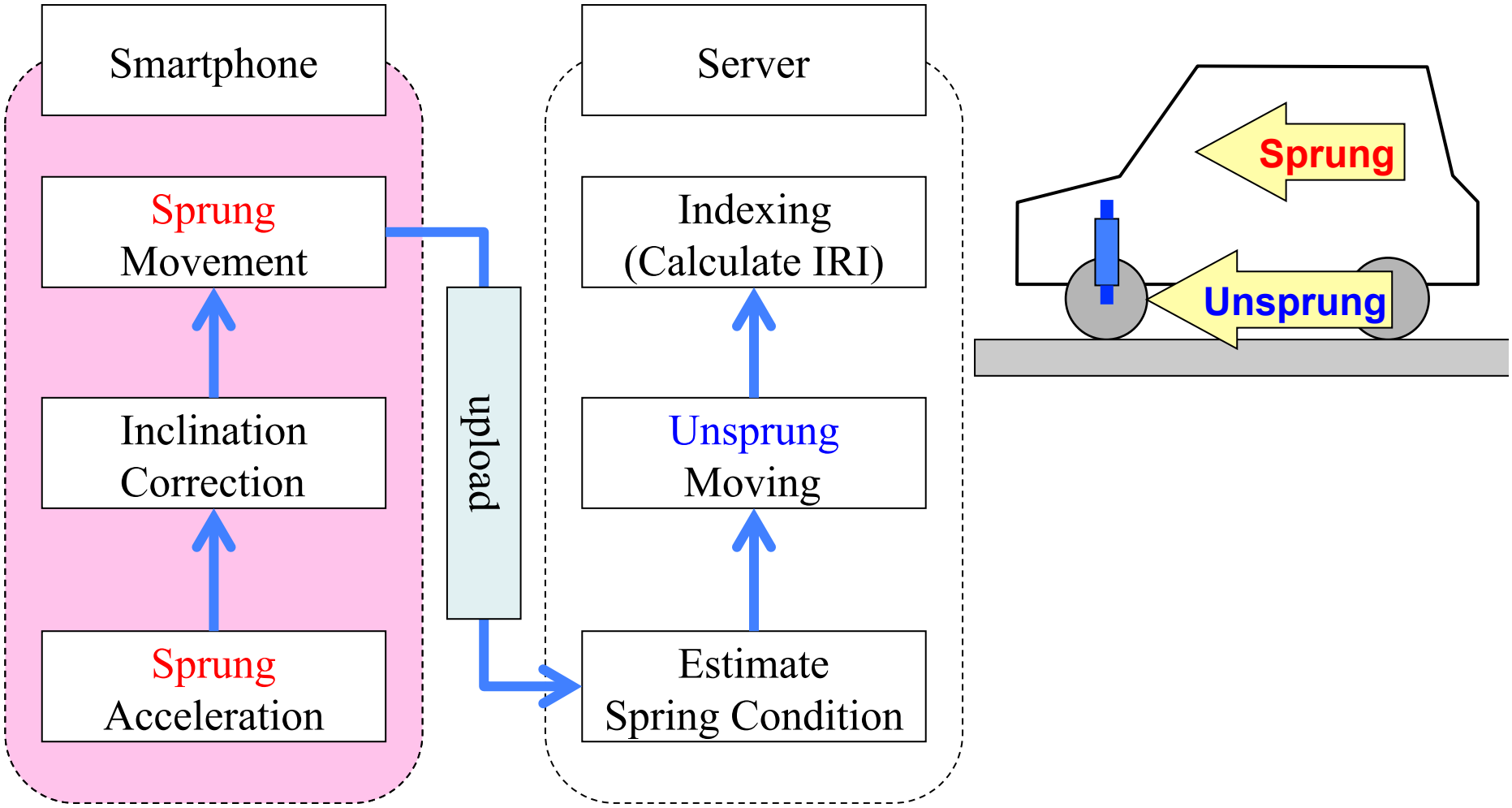


This Developing

Purpose : Want to know the situation immediately after earthquake, so using usual car and smartphone.

Methods : Smartphone is installed on vehicle dashboard and get sprung acceleration, then estimate unsprung moving.

Architecture



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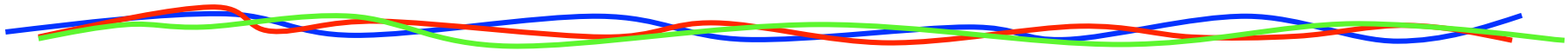
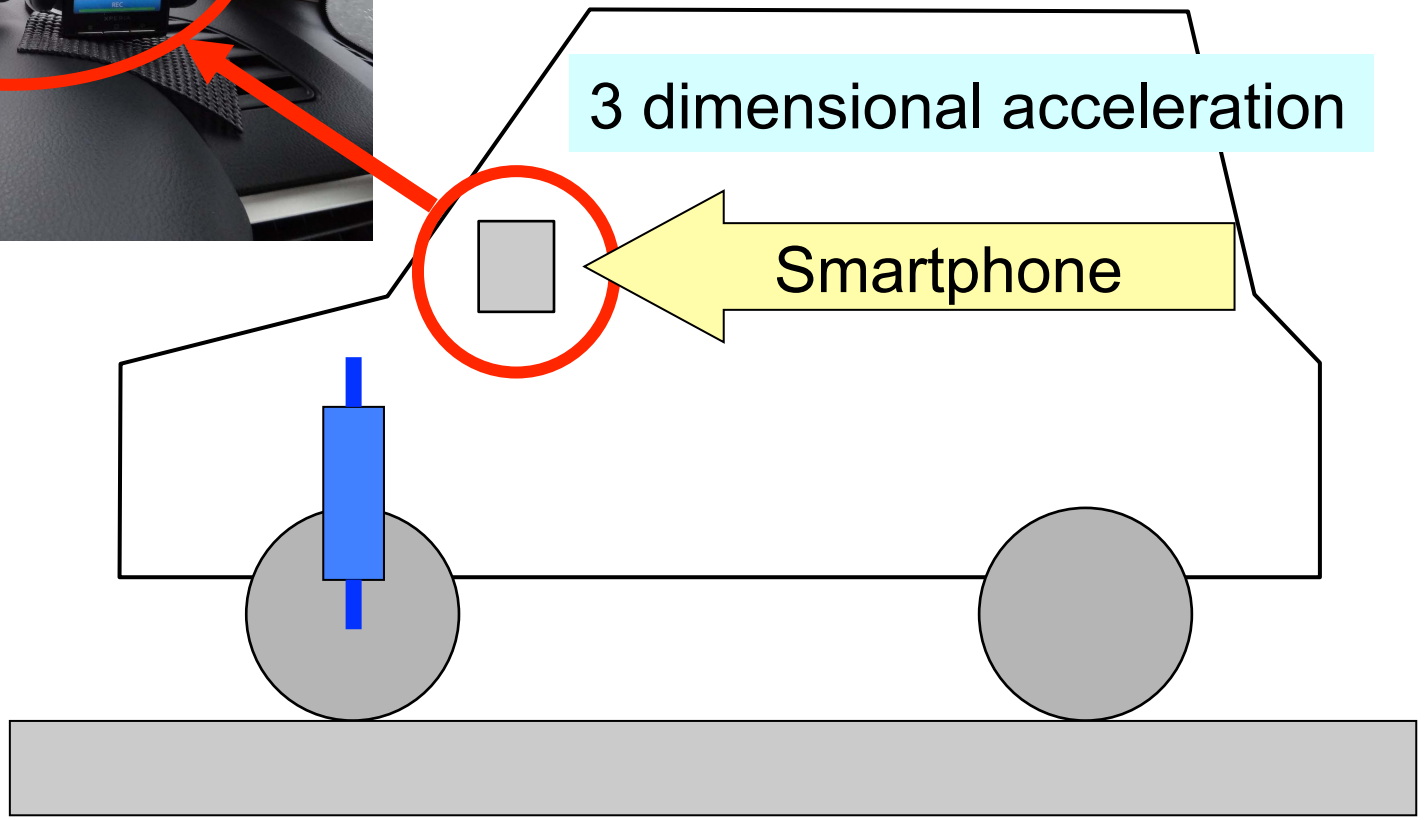
BumpRecorder

Coming soon

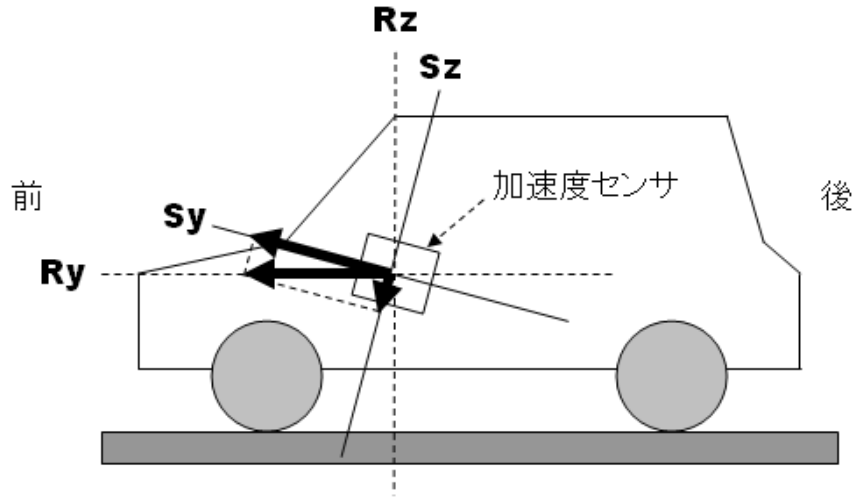
Methods of Sprung Movement Measurement

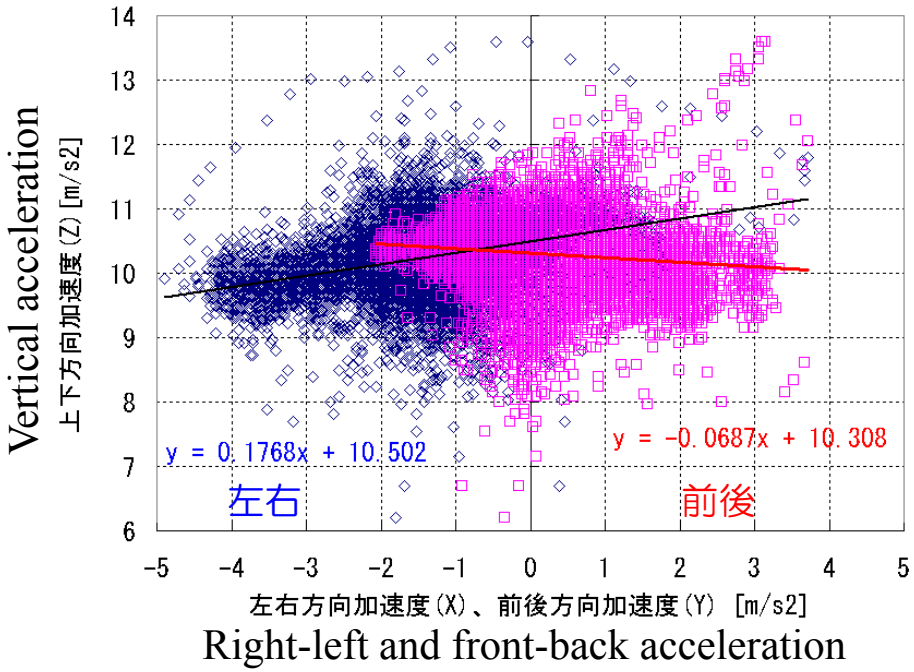


Measurement of Sprung Acceleration



Tilt Correction





Right-left and front-back acceleration

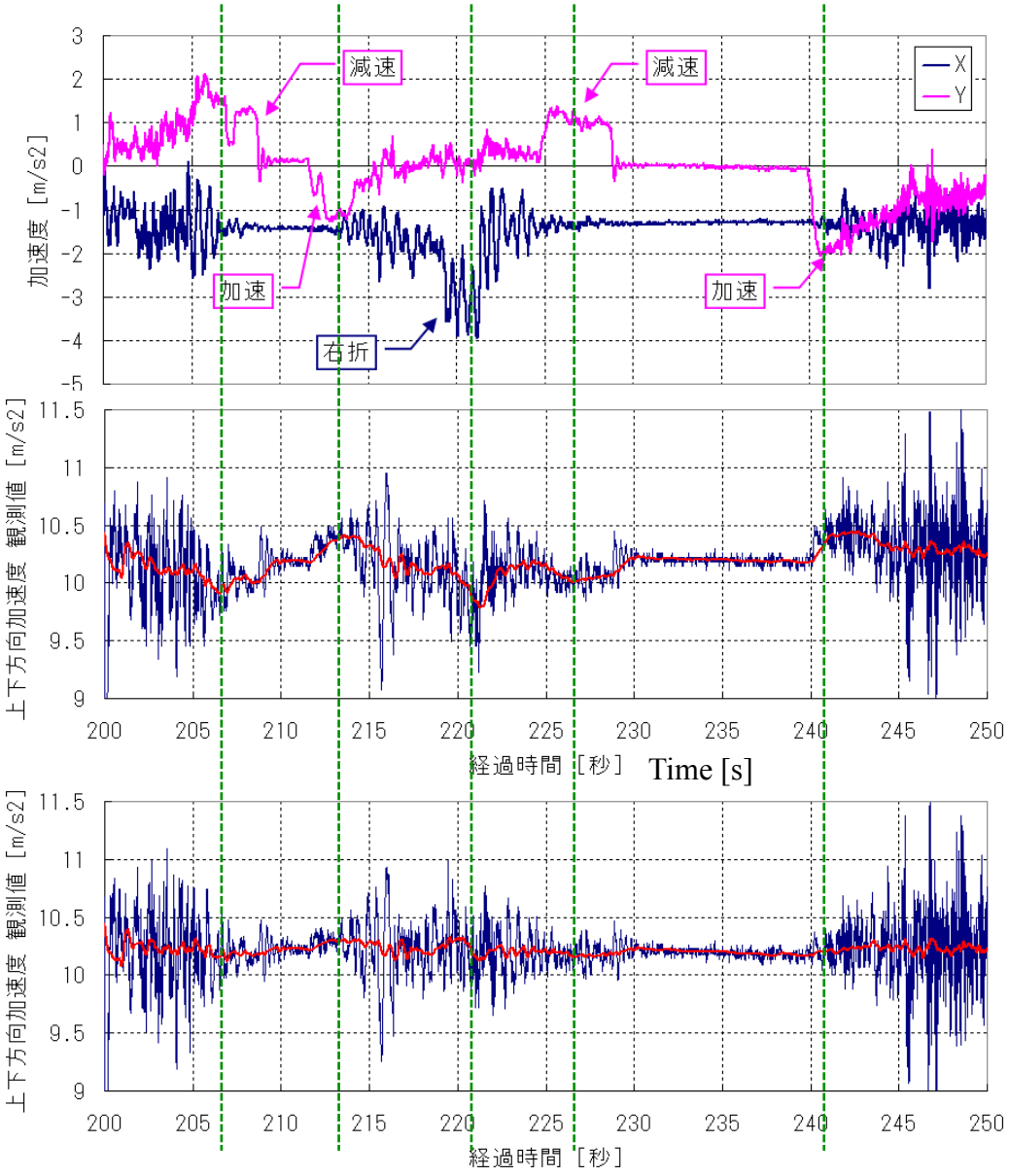
When an accelerometer is tilt, apparent acceleration will be measured on vertical axis at vehicle start, stop, and turn right and left.

Road has slope and cant, so if an accelerometer will be installed as horizontal, but it can not be canceled tilt influence.

Tilt will be estimated by acceleration relationship between front-back and right-left direction.

Effect of Tilt Correction

Acceleration : at start and stop, turn right



Vertical acceleration before correction

Tilt influence is appeared.

Vertical acceleration after correction

Tilt influence is suppressed.

Calculation : from Acceleration to Moving Length

Principle

Vertical moving length will be calculated by double integral of vertical acceleration.

Problems

Double integral becomes big error easily.

Solution

Correct values before each integral.

Value correction at each integral

1st Integral from acceleration to velocity

Acceleration correction

$$dZ(i) = Z(i) - \frac{\sum_{j=i-5N+1}^{i+5N} Z(j)}{10N}$$

Correction for static acceleration like as gravity and temperature drift.

Acceleration integral

$$Vz(i) = Vz(i-1) + \frac{dZ(i)}{N}$$

2nd Integral from velocity to moving length

Velocity correction

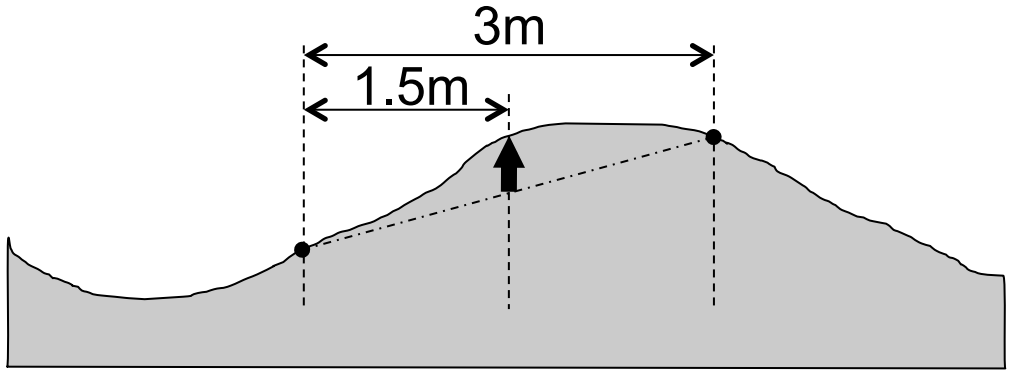
$$dVz(i) = Vz(i) - \frac{\sum_{j=i-5N+1}^{i+5N} Vz(j)}{10N}$$

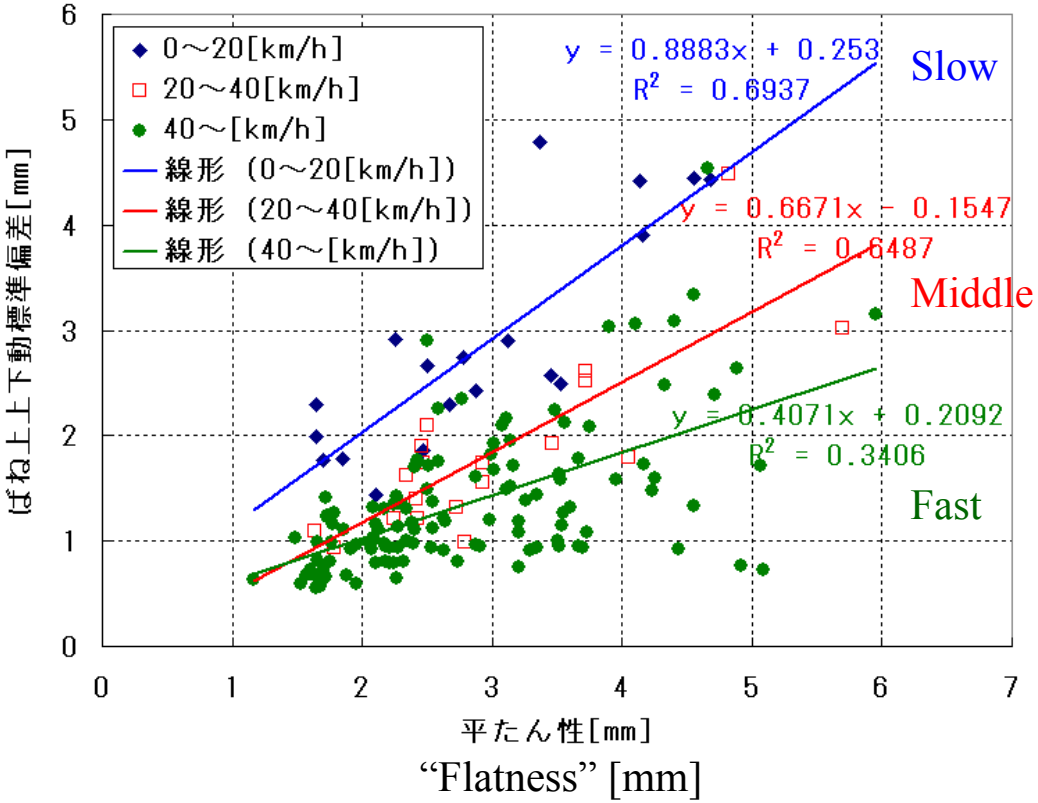
Correction for static velocity like as climbing speed.

Velocity integral

$$Lz(i) = Lz(i-1) + \frac{dVz(i)}{N}$$

Verification by “Flatness” Japanese Roughness Index





“Flatness” [mm]

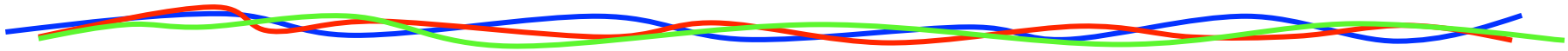
By using sprung moving length, calculate “Flatness” and compared with existing value.

- Correlated on slow speed range, but result is not good on middle and fast speed range.

Problems for utility

- Can not drive as usual.
- Take a time for measurement.

Improvement for more precision
Estimation of unsprung movement



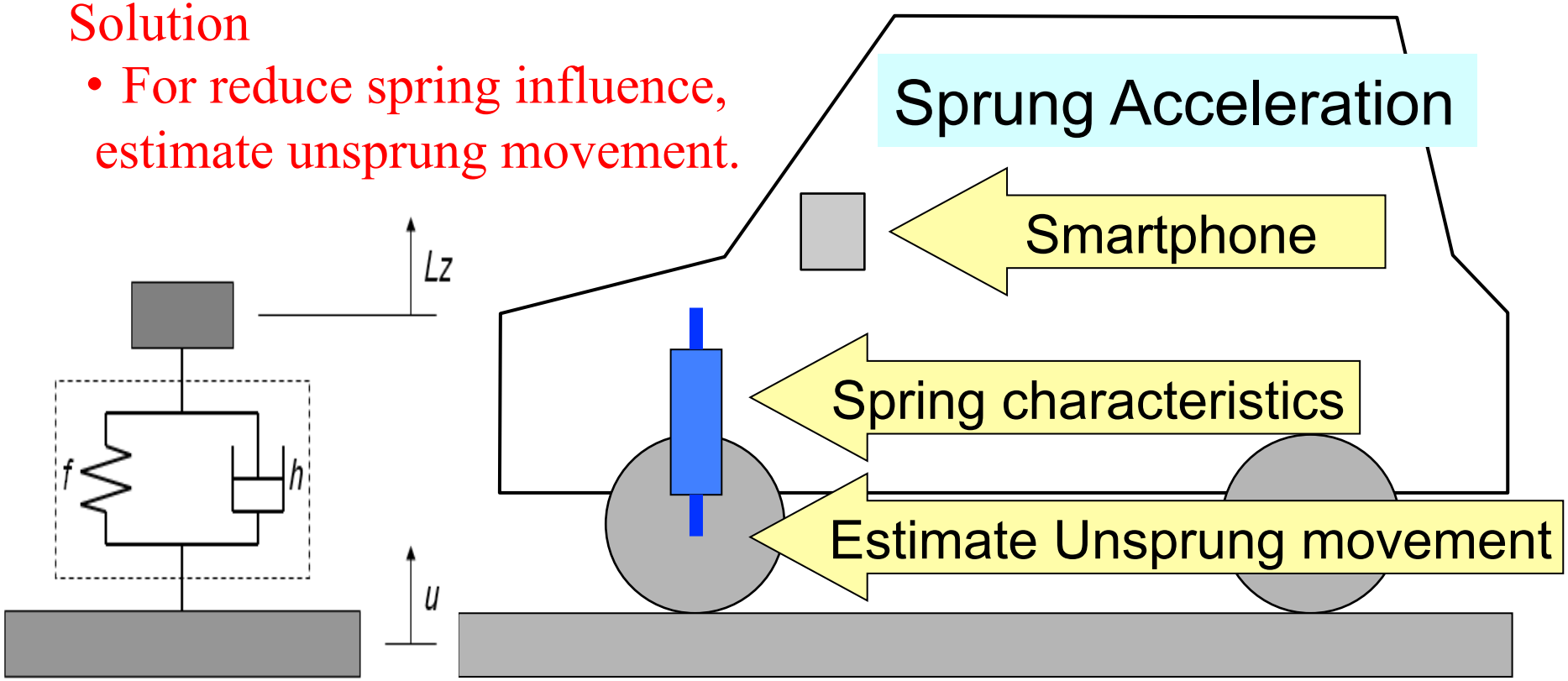
Estimation of unsprung movement

Reason of correlation down at medium and high speed.

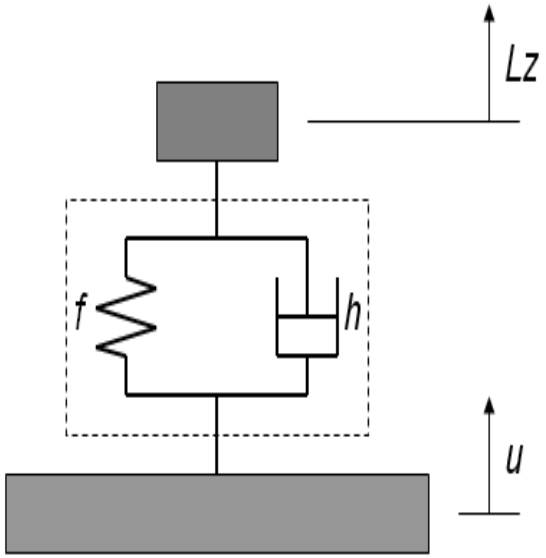
- Vehicle shock absorber will absorb vibration from road.
- This problem will appear at high speed notably.

Solution

- For reduce spring influence, estimate unsprung movement.



Estimation of Spring characteristics and unsprung moving



Spring constant : f

The FFT analyze is done for vehicle acceleration under driving, and pick-up peak frequency around 1.5[Hz] that should be shock absorber.

Damping ratio : h

Using analyzing result of FFT, estimate damping ratio for spring constant “f”.

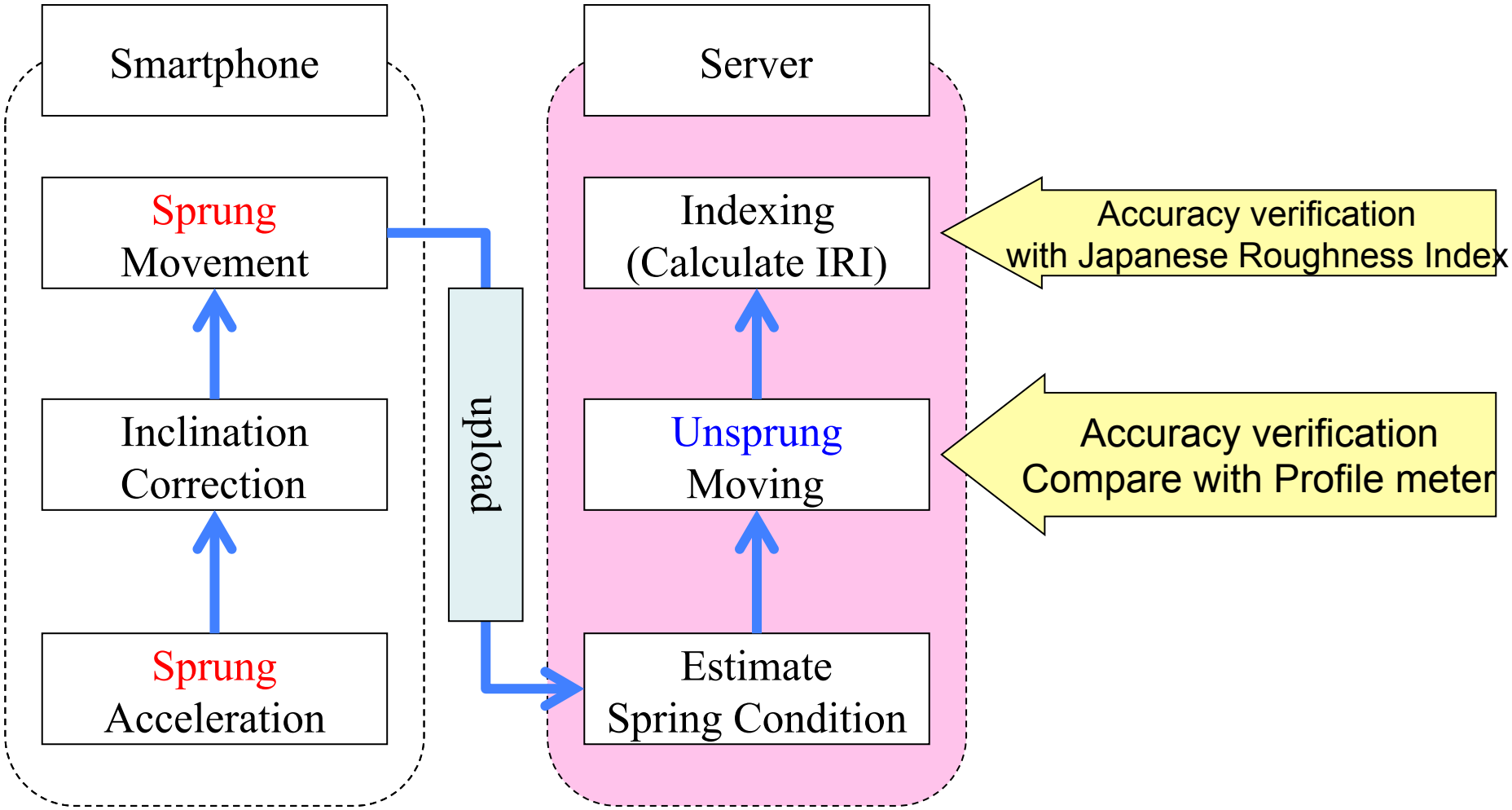
Solving equation of motion of single-degree-of-freedom spring model, using sprung moving “Lz”, estimate unsprung moving “u”.

$$\ddot{Lz} + 2h\omega(\dot{Lz} - \dot{u}) + \omega^2(Lz - u) = 0$$ Equation of motion

$$\omega = 2\pi f$$ Angular frequency

$$u(i) = u(i-1) + \frac{\dot{u}(i) + \dot{u}(i-1)}{2N}$$ Finite sum (Integral)

Architecture



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BumpRecorder

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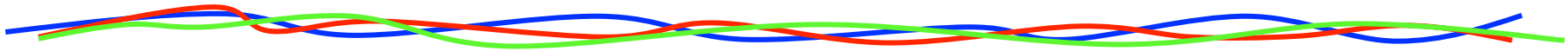
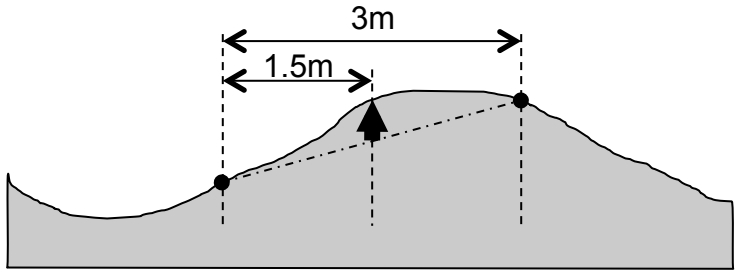
Accuracy verification result

Compare with Measurement value of 3m Profile meter and “Flatness” Japanese Roughness Index

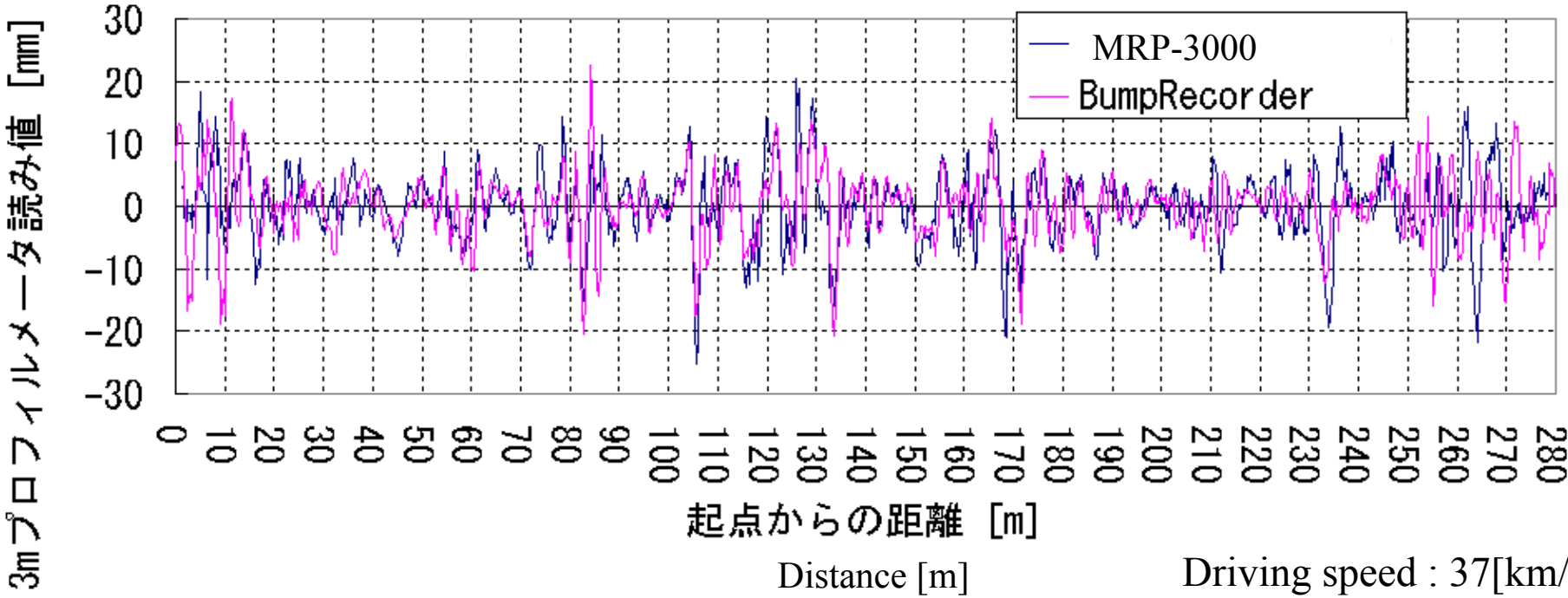


Compare with measurement value of 3m Profile meter

Using Road Profiler of KUMATAKA engineering MRP-3000,
Developed Smartphone Apps “BumpRecorder” was verified.



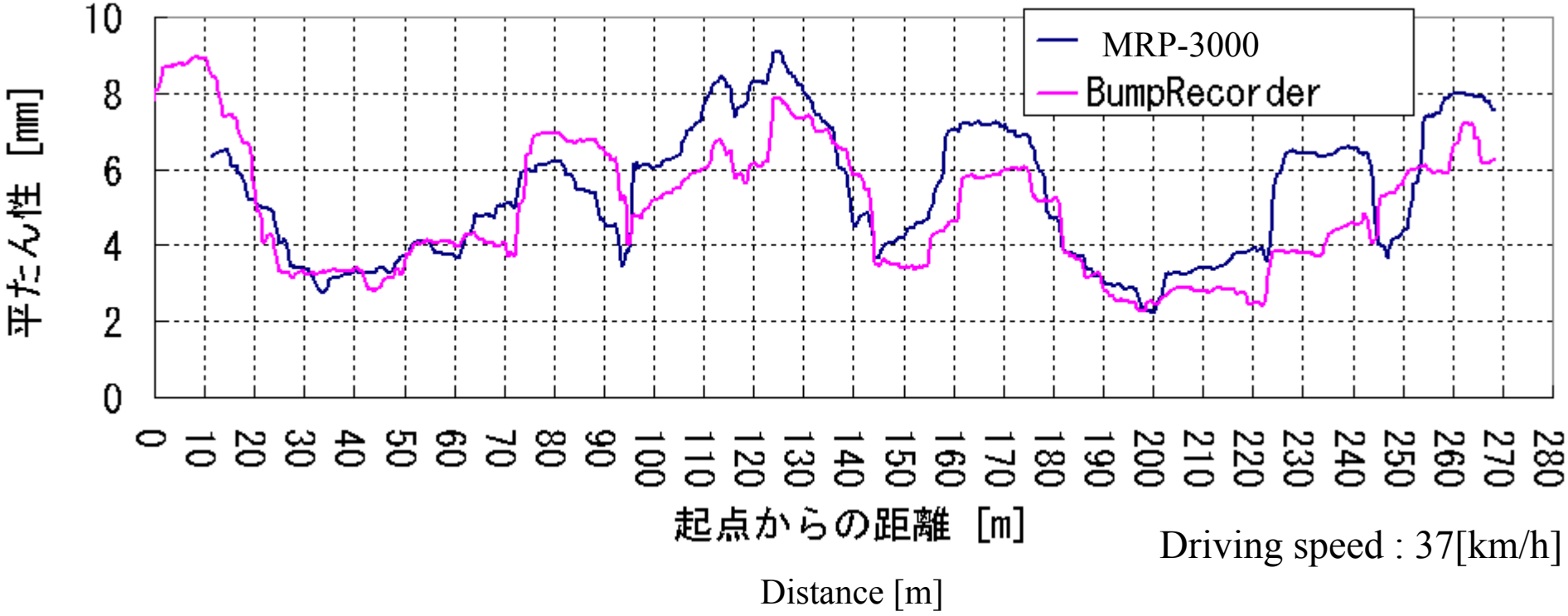
Trend of measurement value was same,
but looks like there is position gap.



Driving speed : 37[km/h]

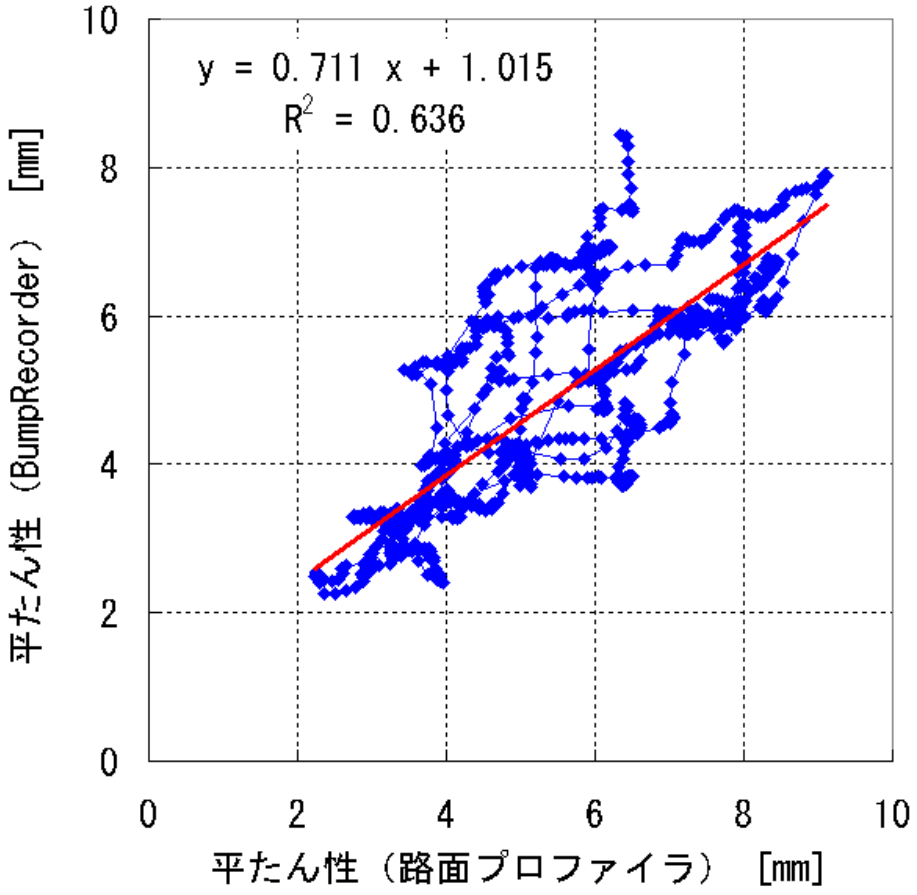
Compare by “Flatness” of Japanese Roughness Index

By using measurement value of 3m Profile meter,
calculate “Flatness” of Japanese Roughness Index,
compare MRP-3000 and BumpRecorder.



Driving speed : 37[km/h]

Verification Result : “Flatness”



“Flatness” by MRP-3000 [mm]

Driving speed : 37[km/h]

Liner regression was done,
by using result of MRP-3000
and BumpRecorder

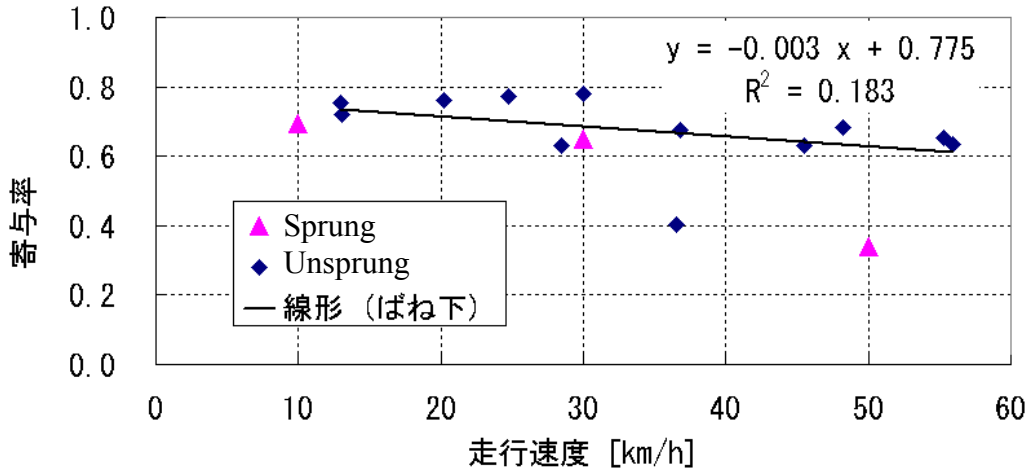
- Contribution Ratio : 0.63

= Correlation coefficient : 0.79

- Slope : 0.71

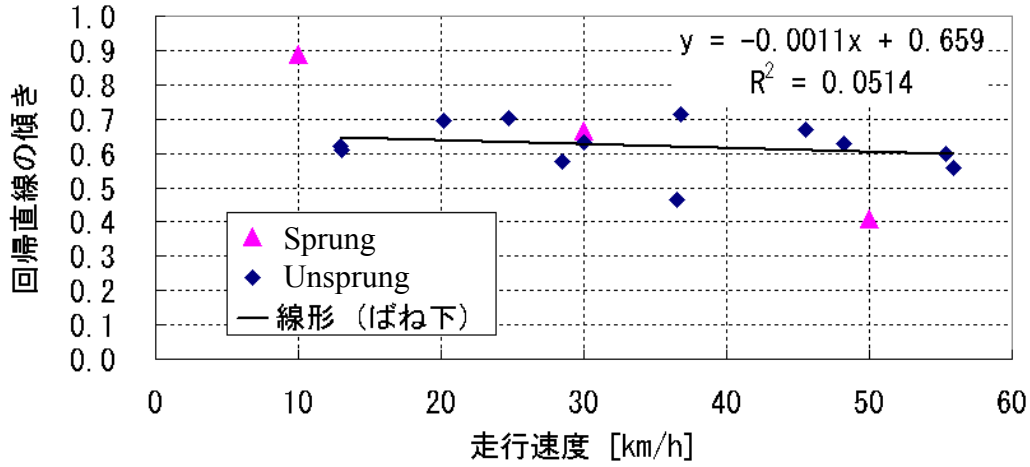
⇒Correlation is good,
but measurement value of
BumpRecorder is small.

Verification Result : “Flatness”



Driving speed [km/h]

- Estimation of unsprung moving is suppressing an influence of driving speed.

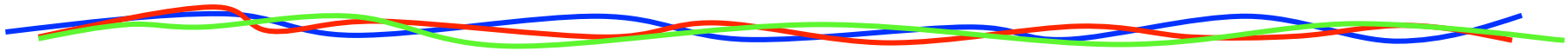


Driving speed [km/h]

- Result of RumpRecorder was small in 60-70%

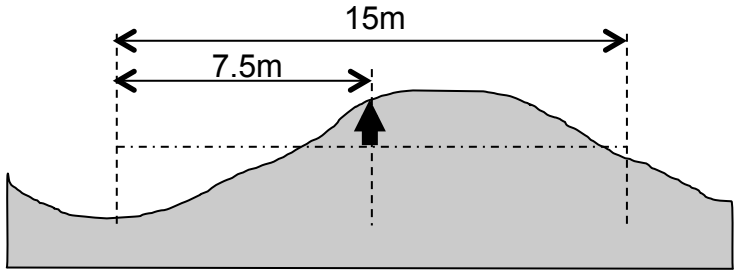
⇒Challenges for the future.

Accuracy verification result
Compare with longer wave
-relative height in 15[m] long-

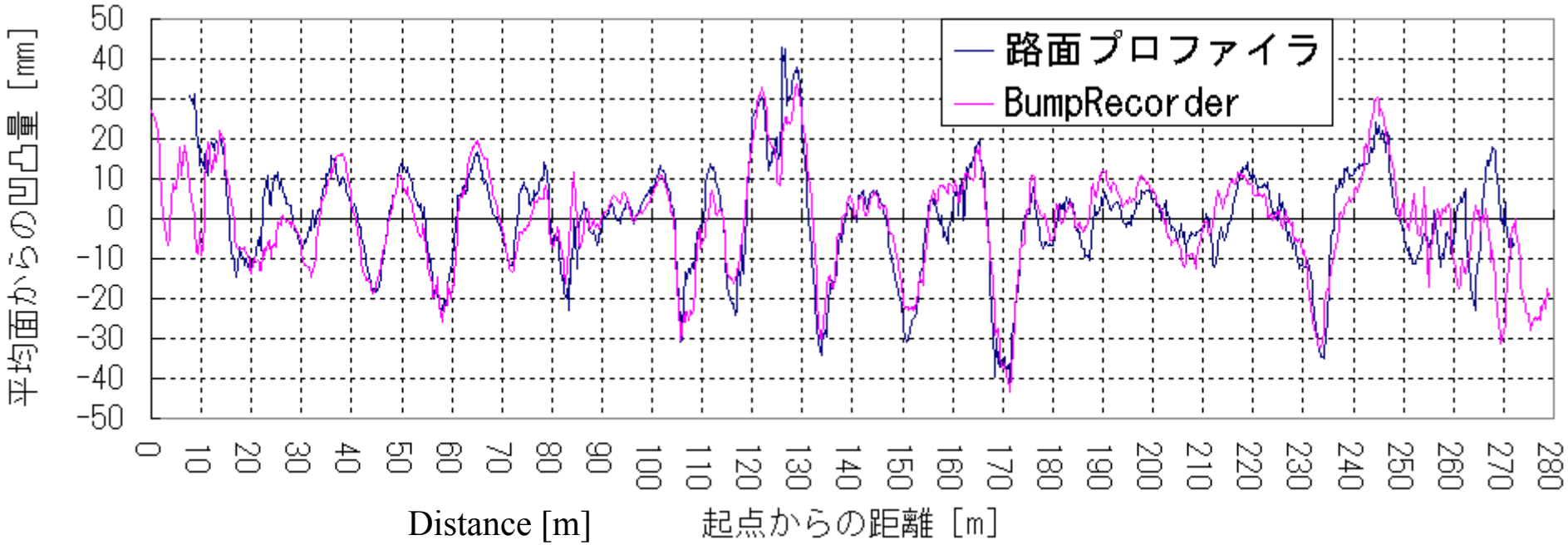


Verification result : Relative height in 15[m] long

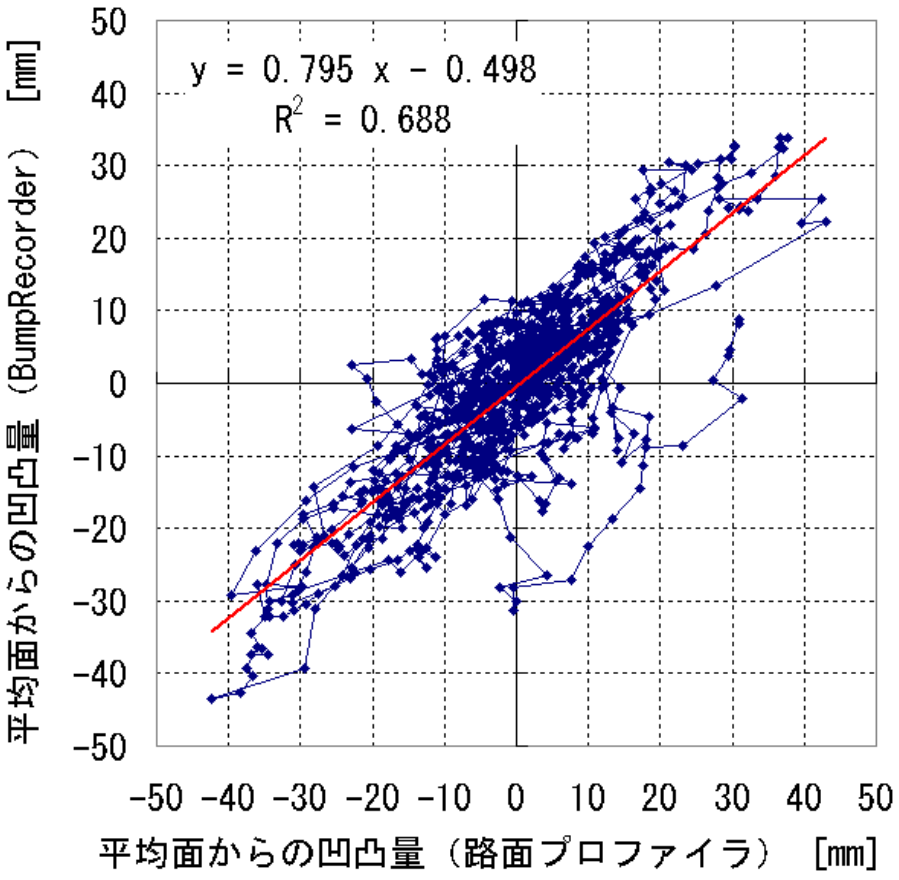
Calculating relative height in 15[m] long
for MRP-3000 and BumpRecorder.
Then comparing this two values.



Trend was consistent.
Position gap was not so large.



Verification result : Relative height in 15[m] long



Relative height by MRP-3000 [mm]

Liner regression was done,
by using result of MRP-3000
and BumpRecorder

- Contribution Ratio : 0.68
= Correlation coefficient : 0.82
- Slope : 0.79

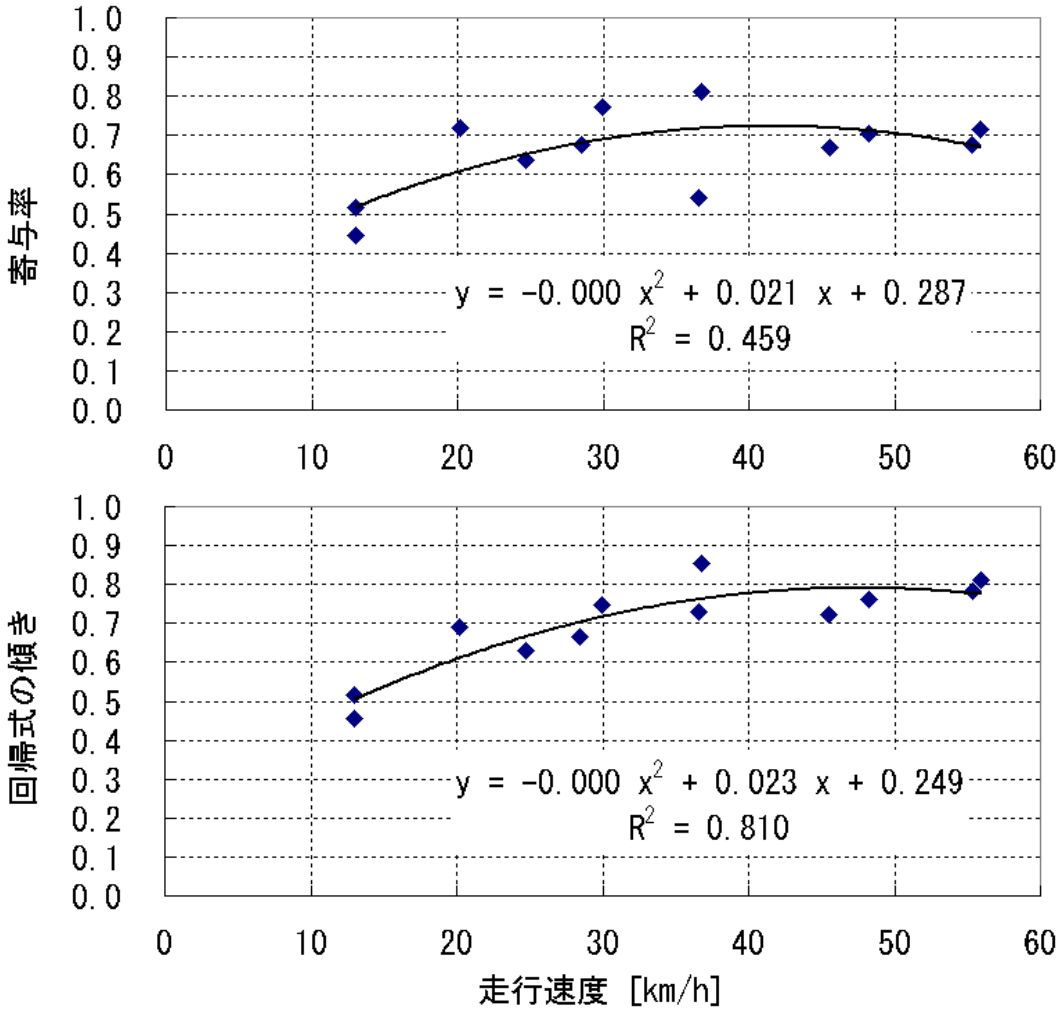
⇒Correlation is good,
but BumpRecorder value is small.

Verification result of “Flatness”

- Contribution Ratio : 0.63
= Correlation coefficient : 0.79
- Slope : 0.71

⇒BumpRecorder is more suite
for Longer wave.

Verification result : Relative height in 15[m] long



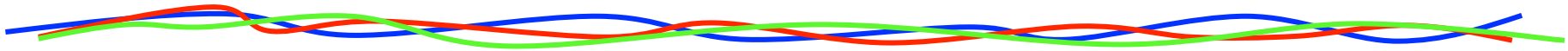
- Correlation is good over 20[km/h] situation.

⇒Accuracy on lower speed range is challenges for the future.

- Result of BumpRecorder is small 70-80%.
- It is smaller on lower speed range.

⇒Challenges for the future.

Conclusion



Conclusion

- Only using Smartphone, unsprung moving length that is about road profile, is estimated by measuring sprung acceleration.
- It is Suppressing to influence of vehicle speed, especially on middle and high speed. Utility is improved.
- This technology brings easy measurement during usual patrol etc.

Current tasks

- Fix result of BumpRecorder is small.
- Calculate and verify IRI.