

Smartphone Sensor-Based Cycling Environment Monitoring for Bicycle Navigation

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Bicycle Navigation Application

- Existing navigation applications recommend shortest routes
 - fail to consider the road conditions

Roads **in the sun** in summer

→ Temperature changes and sunburn of cargo

Roads with **uneven surfaces**

→ Vibration of cargo, flat tires



**Bicycle navigation application that recommends routes
considering cycling environment data**

Difficulty in Collecting Cycling Environment Data

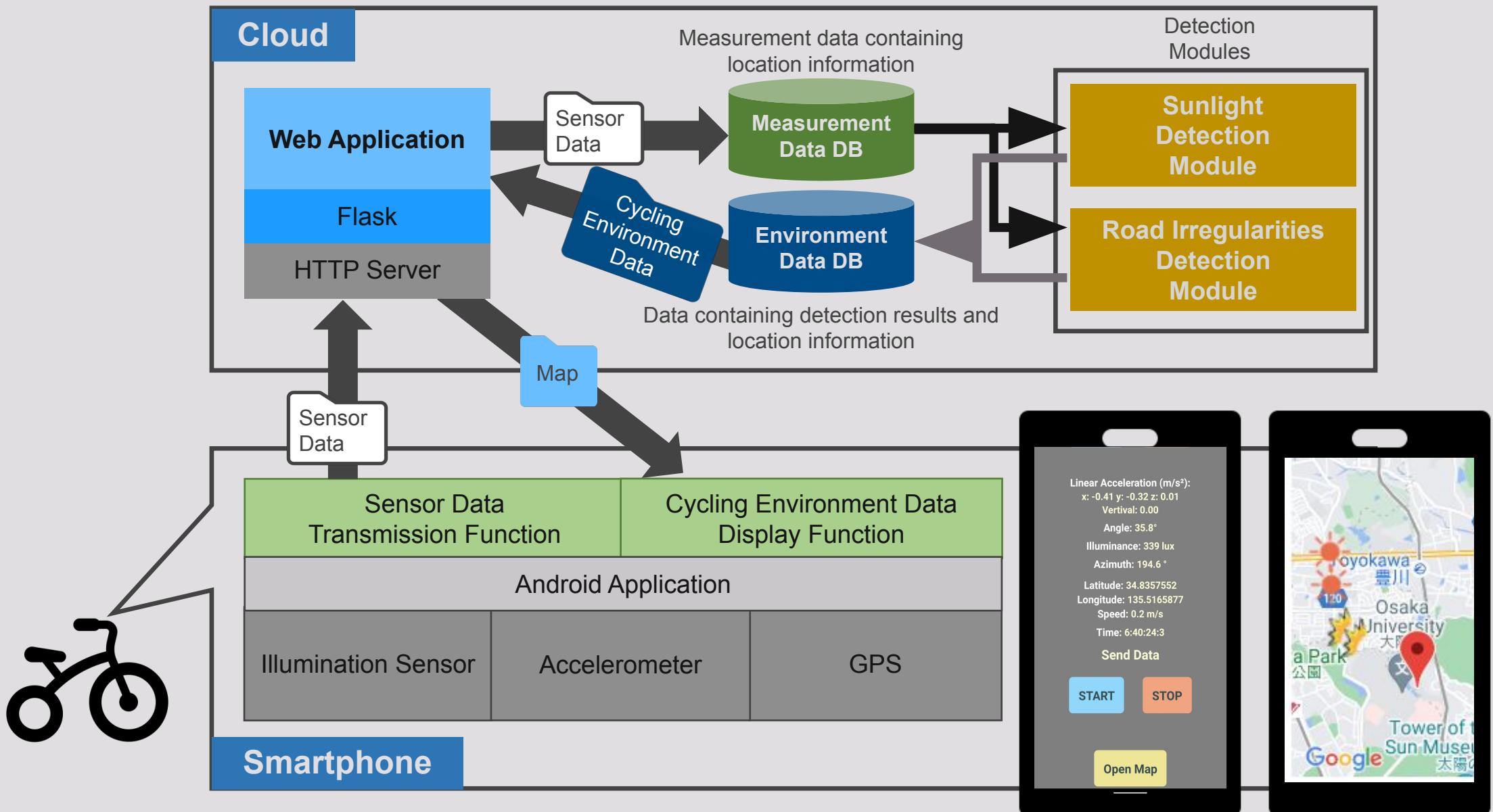
- Wide range of data must be collected to create a navigation app
- Smartphone has low-performance sensors,
but many people have smartphones



Previous study

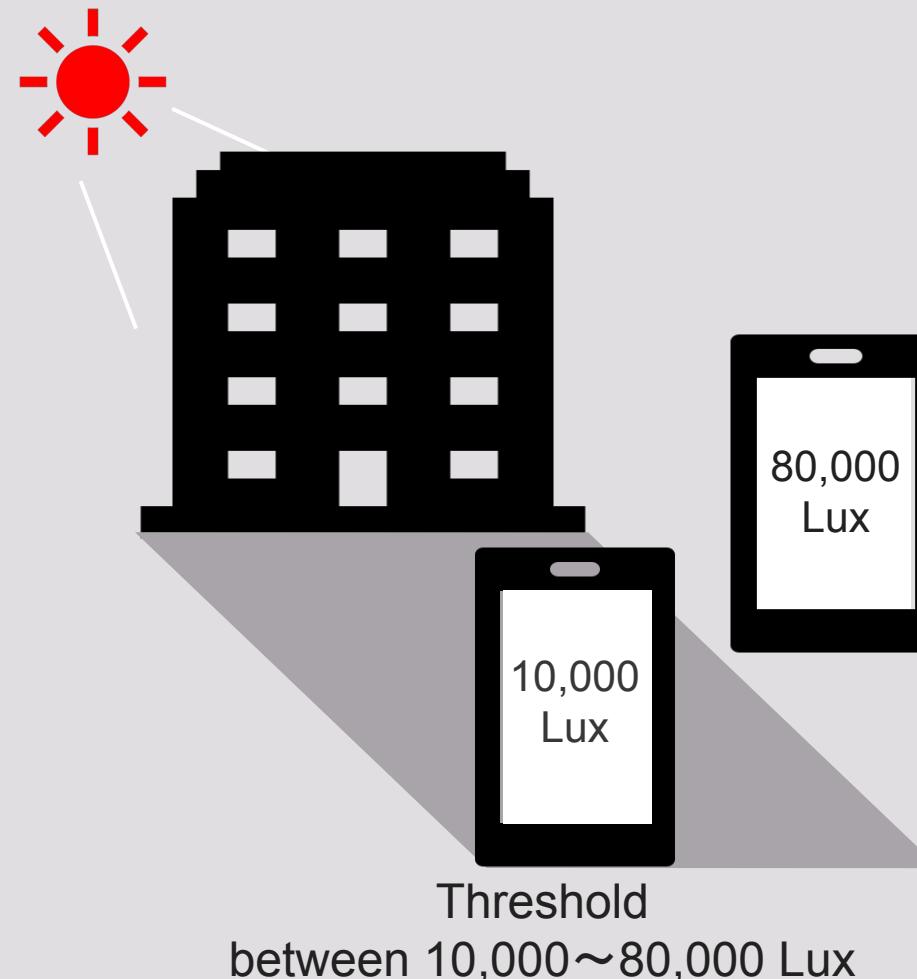
- Collecting cycling environment data from **smartphone sensors**
 1. Sunlight condition
 2. Road irregularities

System Architecture of Proposal Mechanism



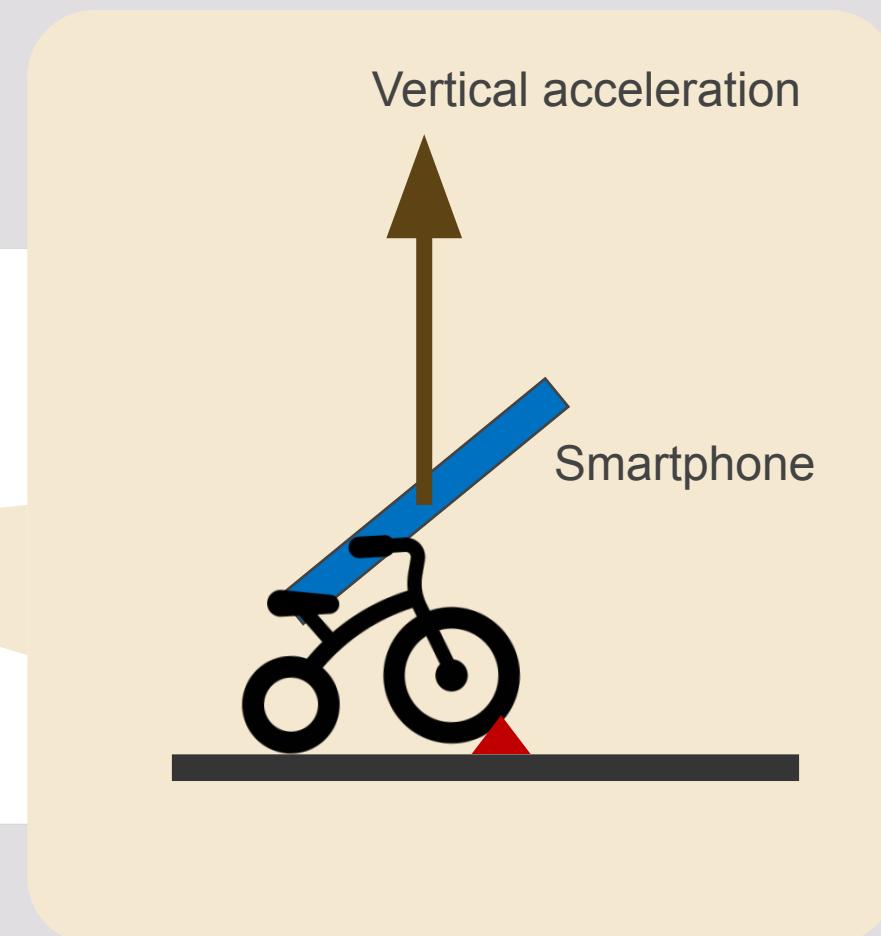
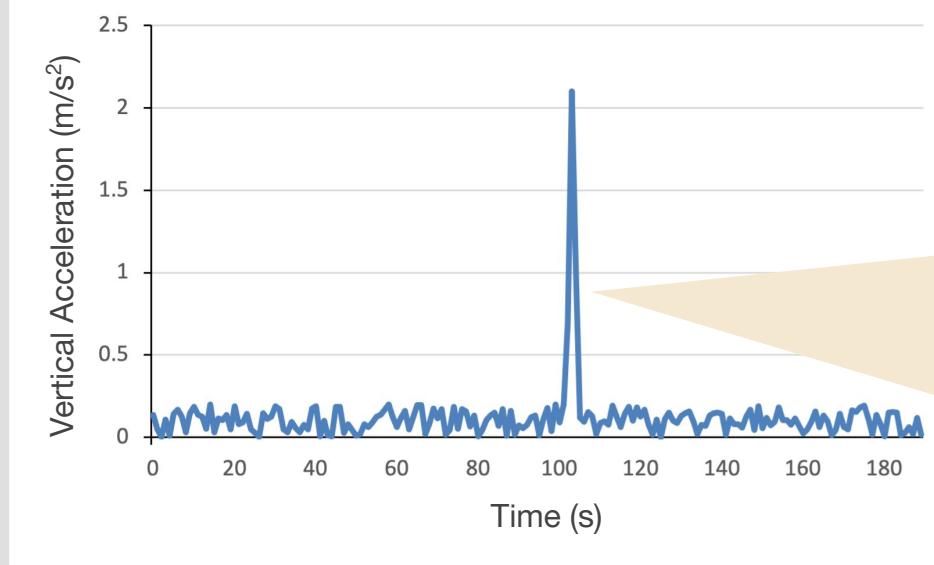
Sunlight Detection Module

- Difference in illuminance (Lux) between the sun and shade
→ Sunlight conditions can be determined by illuminance.



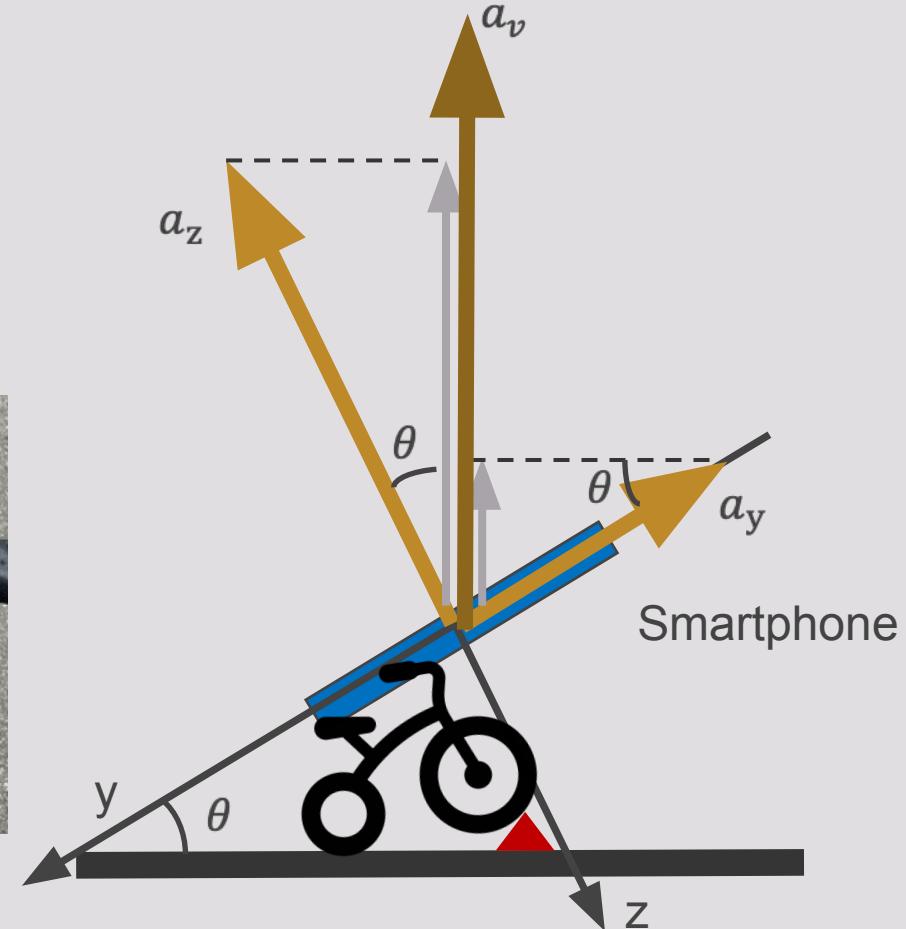
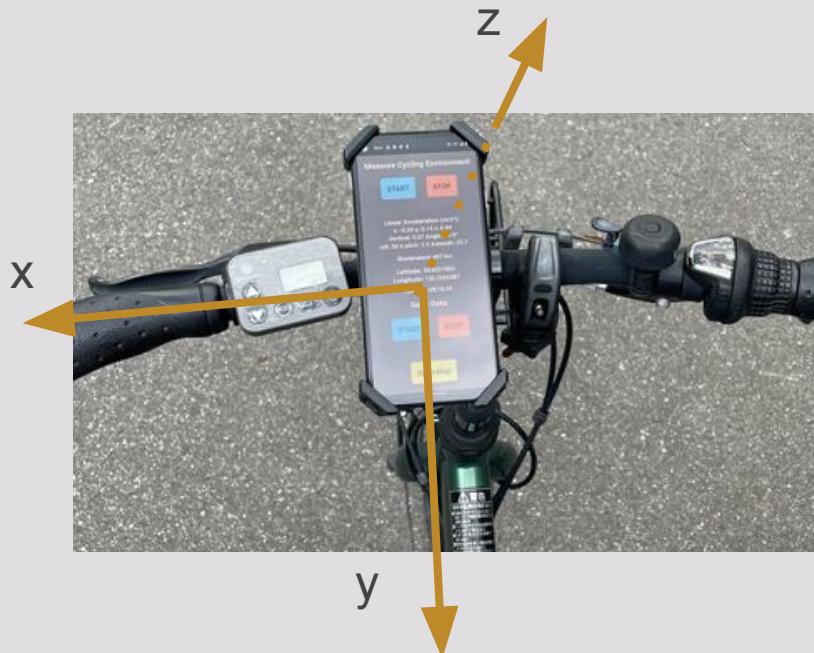
Road Irregularities Detection Module

- Vertical acceleration occurs when passing over uneven surfaces.
→ The degree of the vertical acceleration can discriminate the unevenness of the road surface.



Road Irregularities Detection Module

- Derivation of vertical acceleration $|a_v|$
 - Obtain 3-axis coordinate system acceleration excluding gravity
 - $|a_v| = \sqrt{(a_y \sin \theta + a_z \cos \theta)^2}$



Next Step for Cycling Environment Monitoring

- Cover more realistic situations
 1. Angle of smartphone changes
 2. Outbound and return routes

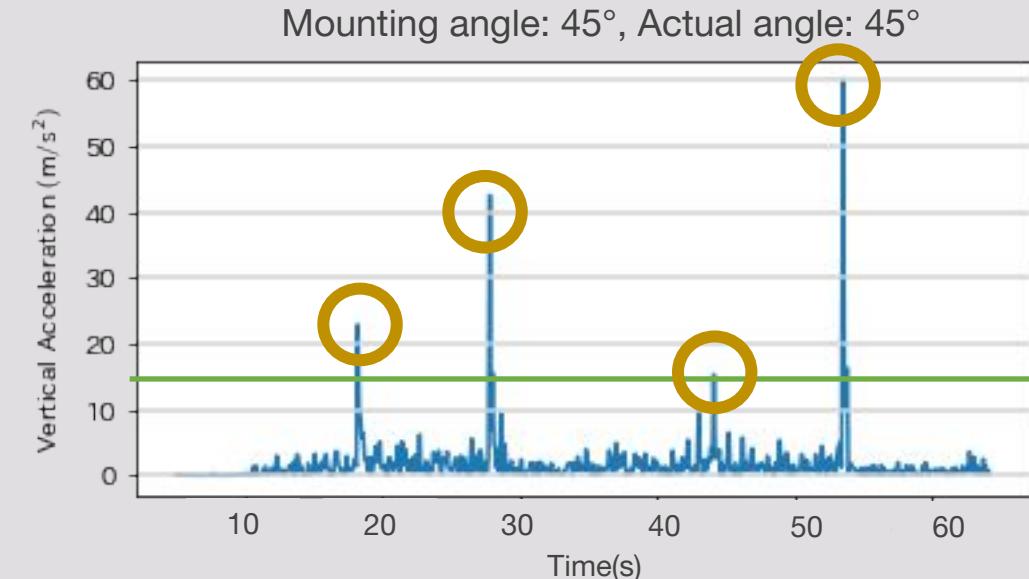
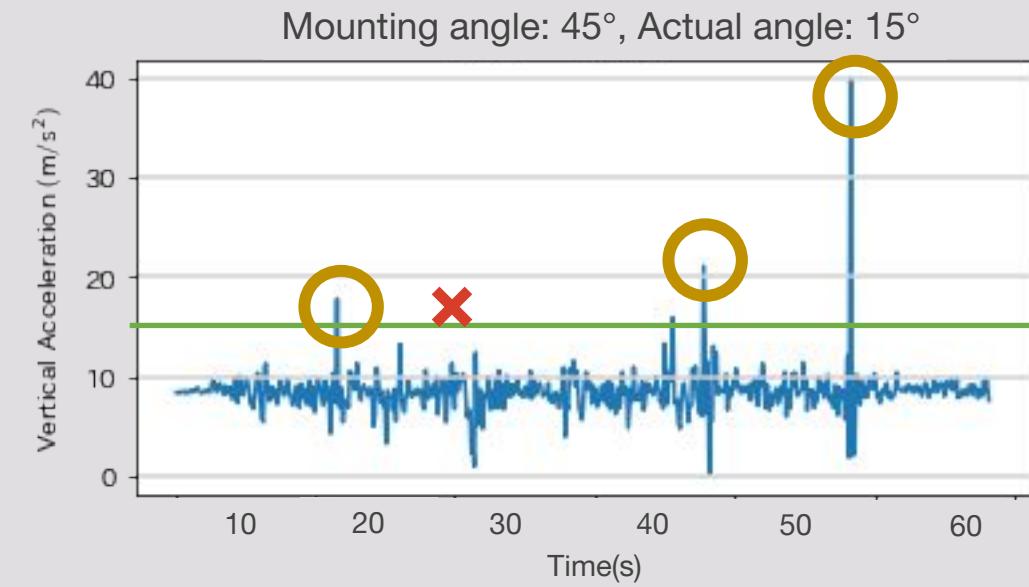


Change in Vertical Acceleration with Change in Angle

Smartphone mounted as 45°
but actual angle is 15°

- Undetected irregularities
compared to the actual angle of 45°

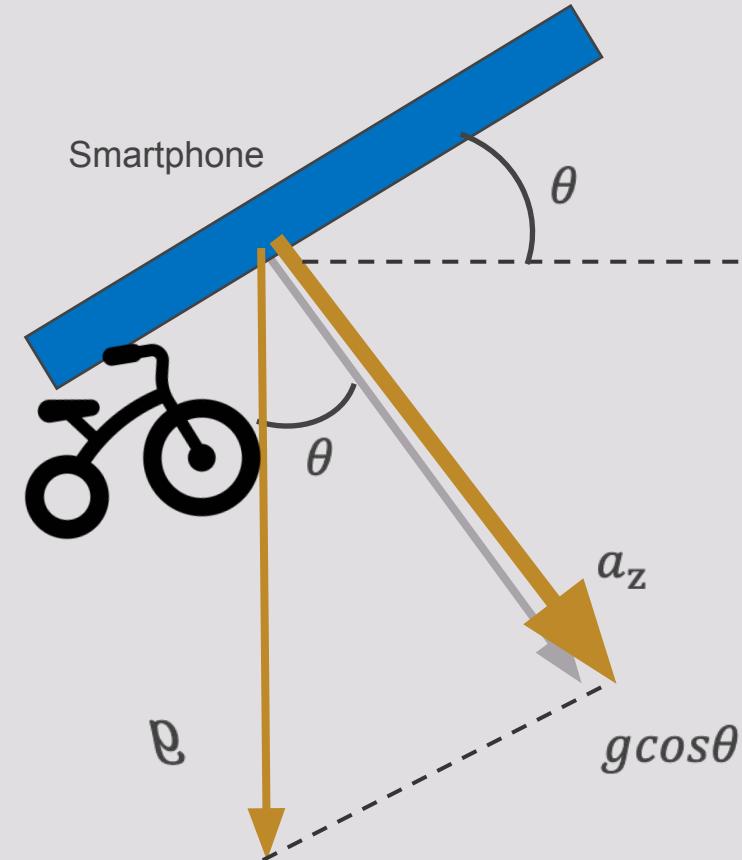
→ Need to correct angle changes
in smartphones.



How to Get the Angle of Smartphone

- Derivation of angle θ
- $a_z = g \cos \theta$

$$\theta = \cos^{-1} \left(\frac{a_z}{g} \right)$$

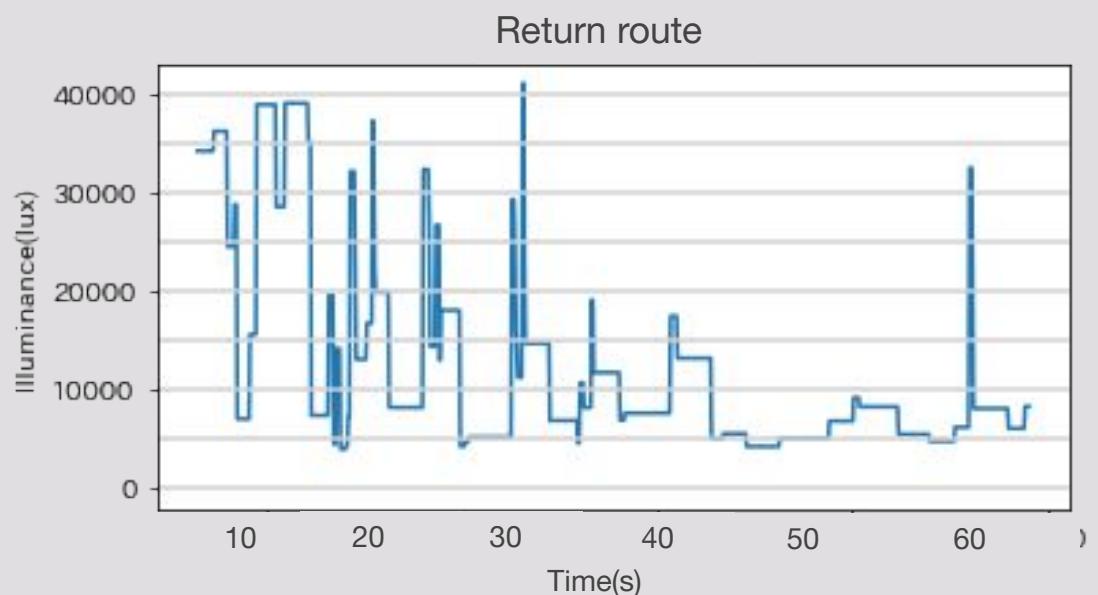
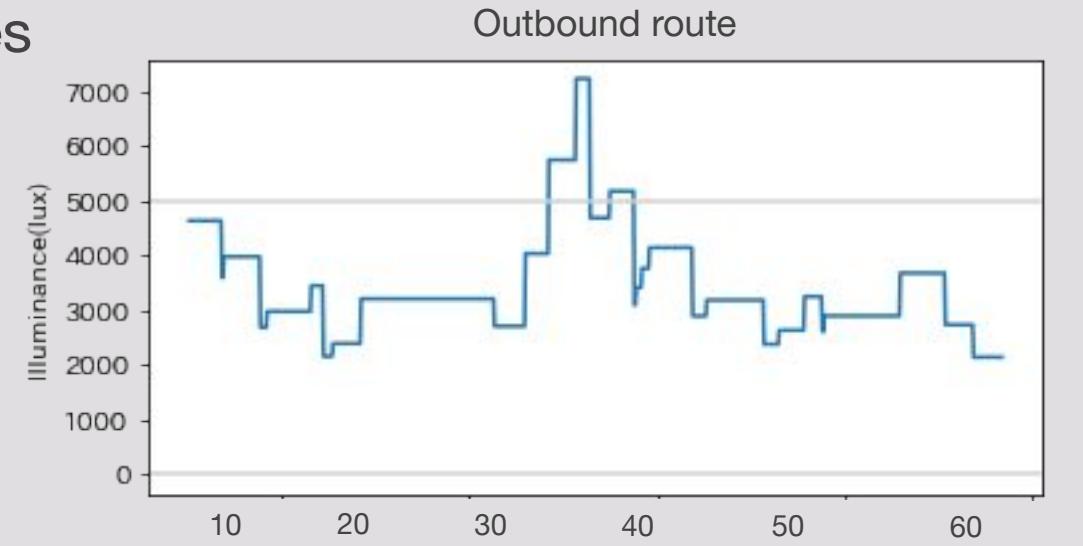


Differences in Road Characteristics by Round Trip Route

Illuminance between outbound and return routes

- Sunlight conditions are different on the two routes
- Mapping to the same road will mix up the information

→ Distinguish routes by using the direction of travel



How to Get Travel Direction

- Estimates smartphone posture from acceleration and magnetometer values and calculates azimuth

1. Calculation of pitch (vertical axis rotation) and roll (horizontal axis rotation) :

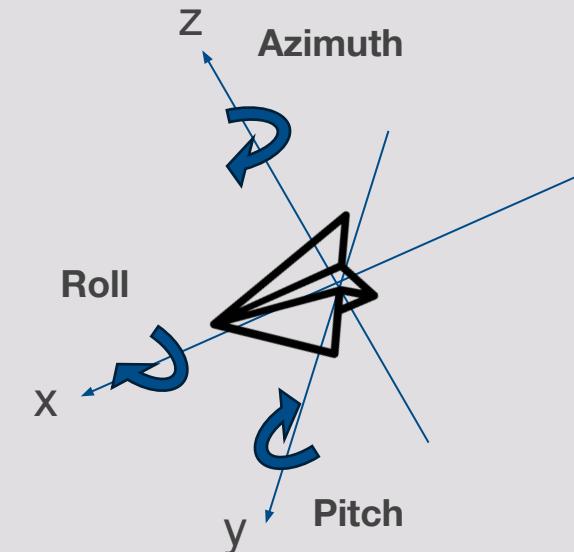
$\text{pitch} = \text{atan2}(-\text{accel.x}, \sqrt{\text{accel.y}^2 + \text{accel.z}^2})$ $\text{roll} = \text{atan2}(\text{accel.y}, \text{accel.z})$

2. Transformation of geomagnetic data in the device coordinate system:

$xh = \text{magneto.x} * \cos(\text{pitch}) + \text{magneto.y} * \sin(\text{pitch}) * \sin(\text{roll}) + \text{magneto.z} * \sin(\text{pitch}) * \cos(\text{roll})$
 $yh = \text{magneto.y} * \cos(\text{roll}) - \text{magneto.z} * \sin(\text{roll})$

3. Calculation of azimuth:

$\text{azimuth} = \text{atan2}(-\text{yh}, \text{xh}) * (180 / \pi)$



Evaluation Purpose and Experimental Summary

Evaluation Purpose:

Confirmation that the proposed methods can measure cycling environment

Experimental Summary:

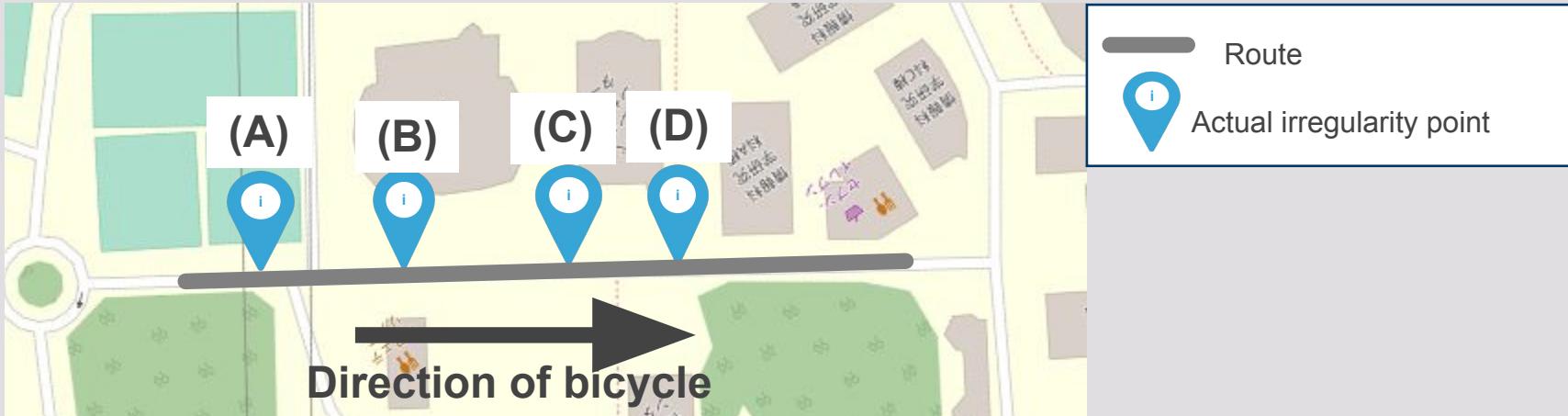
Actual data are measured to determine sunlight conditions and road irregularities.

- Cycling at 15 km/h on a 250 m route with both sun and shade and 4 uneven surfaces
- Sensor data measurement interval
 - Illuminance, acceleration and magnetic data: 100 ms
 - Location data: 1s

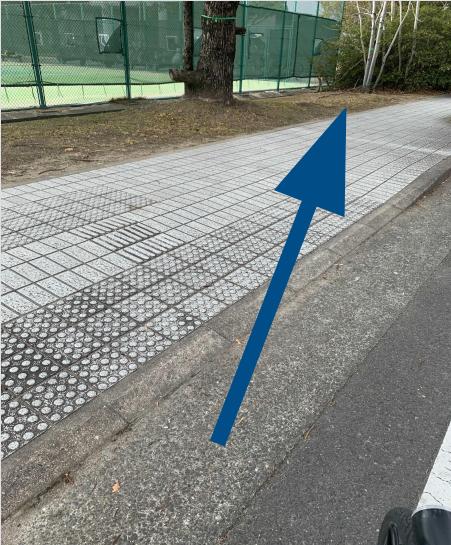


Experimental Environment

- Irregularities of various curb heights on the experiment route



(A)



(B)



(C)

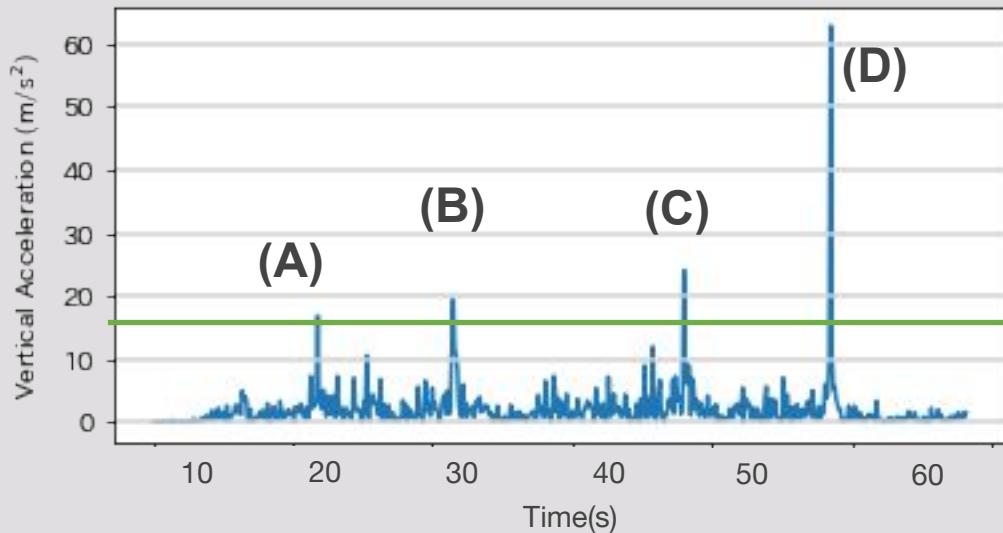


(D)

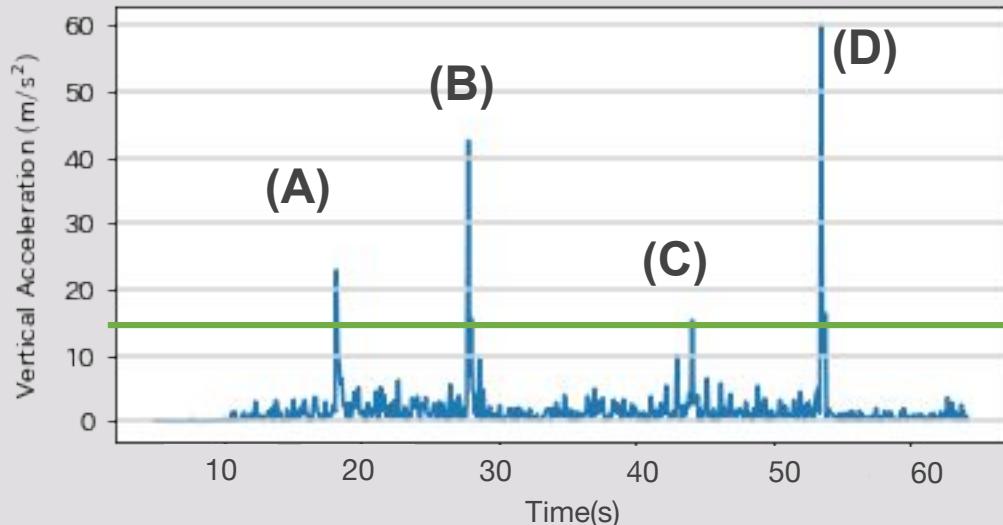


Angle correction result

Correction angle: 15°, Actual angle: 15°



Correction angle: 45°, Actual angle: 45°

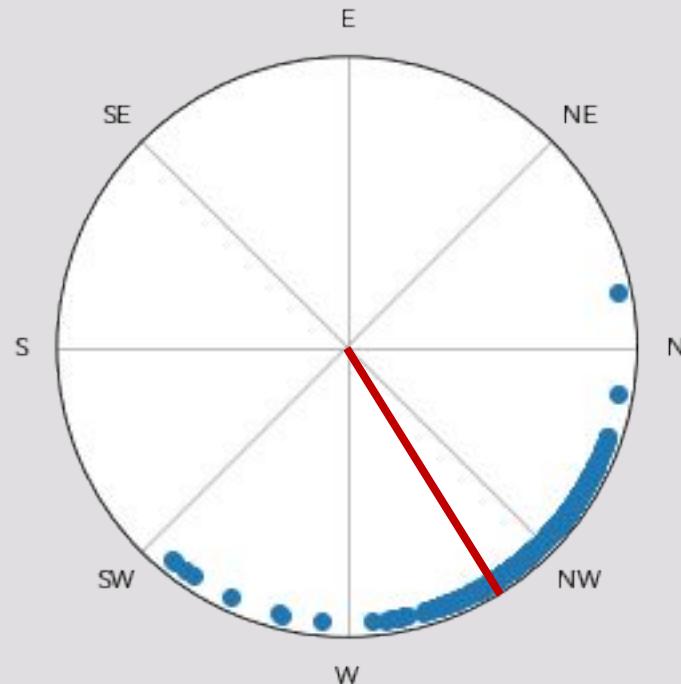


- Spikes in vertical acceleration at 4 locations
- Angle correction resulted in the detection of 4 road irregularity points (A ~ D)

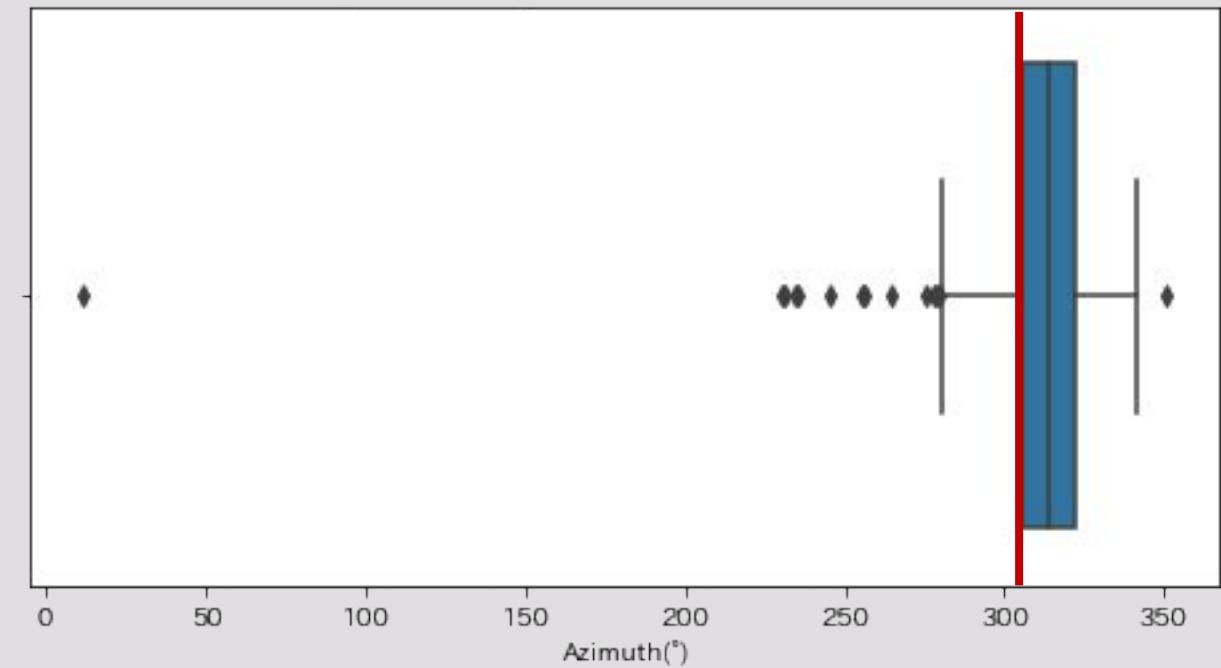
Discrimination Result of Direction of Travel

- Quartile Range Graphs
- Actual azimuth from origin to goal: 305°
→ Within the quadrant

Scatter plots in the direction of travel (polar coordinates)



Quartile range in the direction of travel



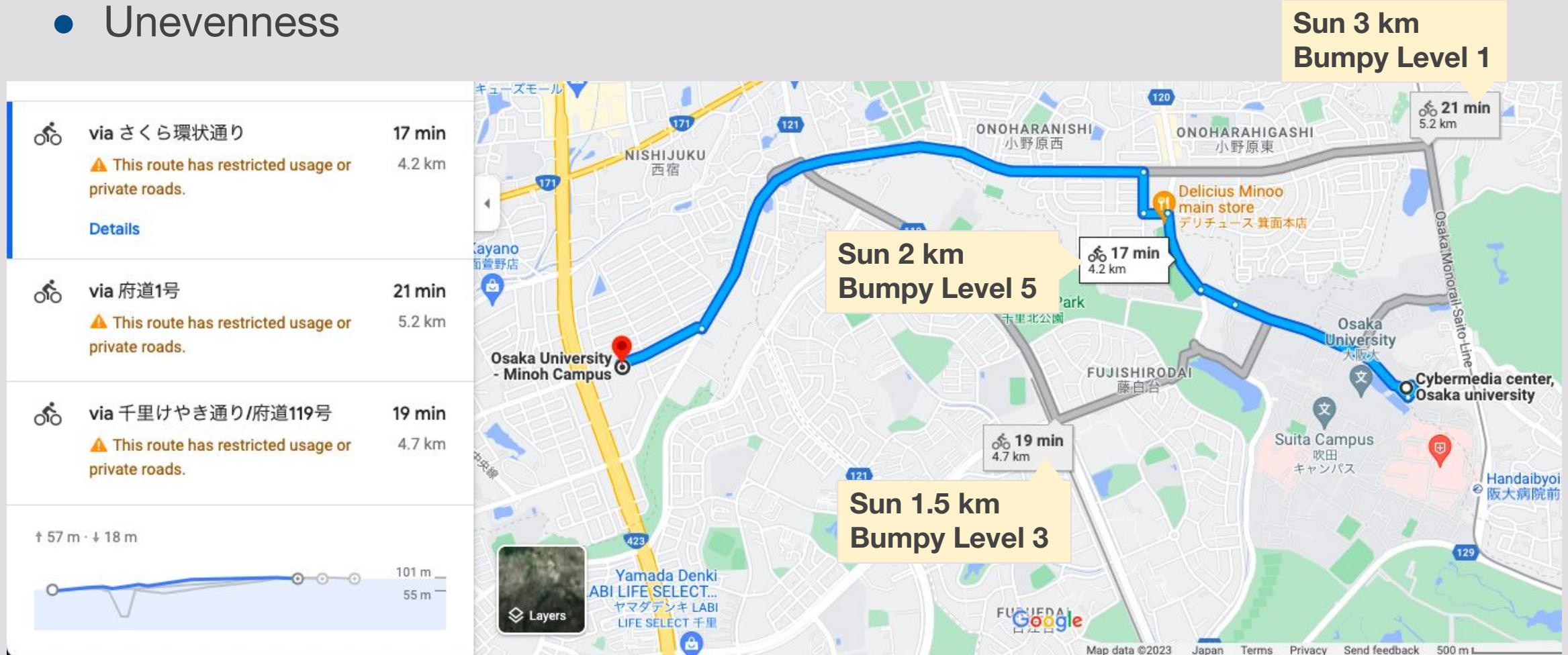
Conclusion

- Proposed and implemented a cycling environment measurement and analysis mechanism for a bicycle navigation application.
- Angle and direction of travel were confirmed to be of a quality that could be used to collect cycling environmental data.
- Aim to implement a navigation application that recommends routes that consider the cycling environment.

Bicycle Navigation Application

Show cycling environmental data

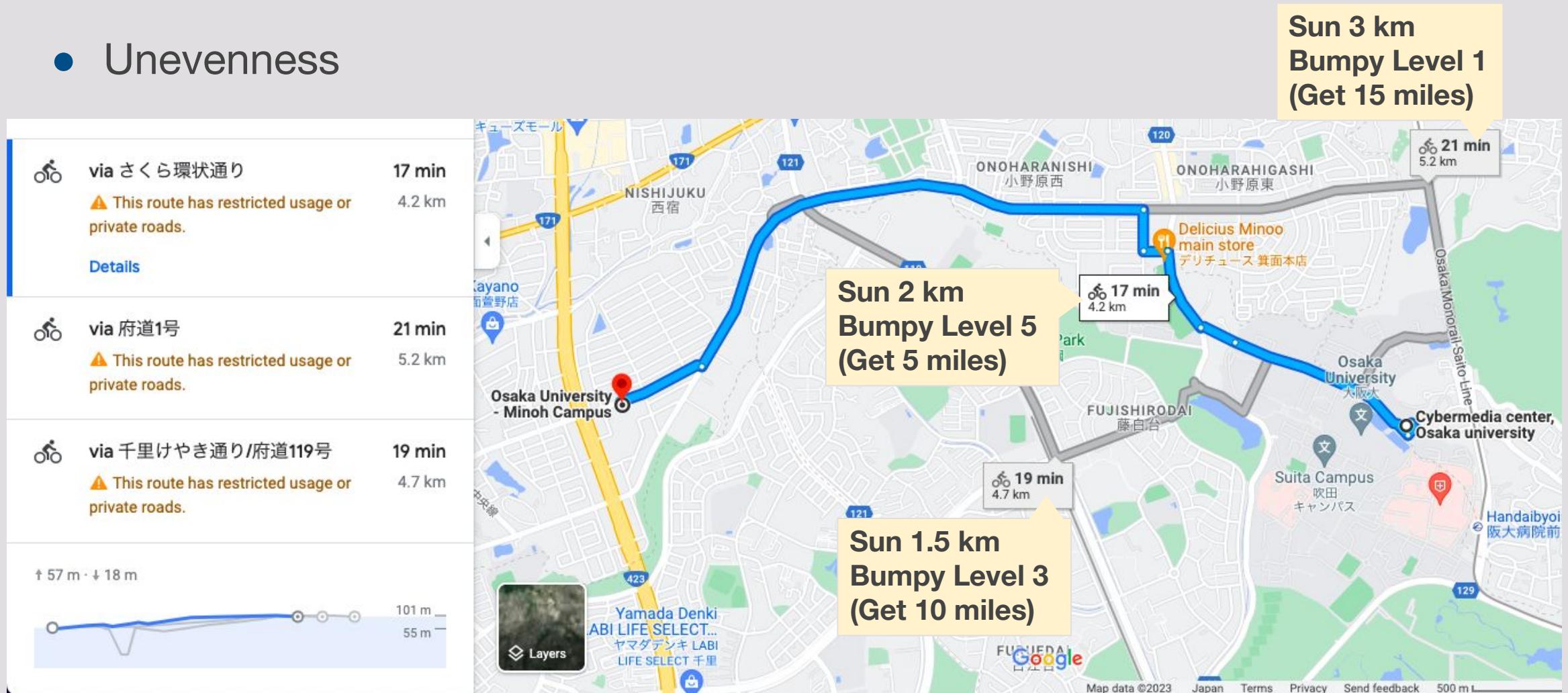
- Distance in the sun
- Unevenness



Bicycle Navigation Application

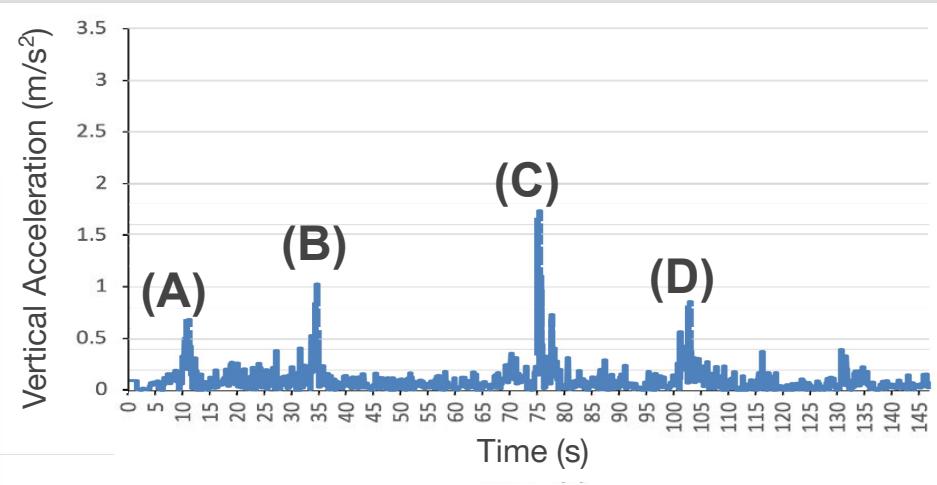
Show cycling environmental data

- Distance in the sun
- Unevenness

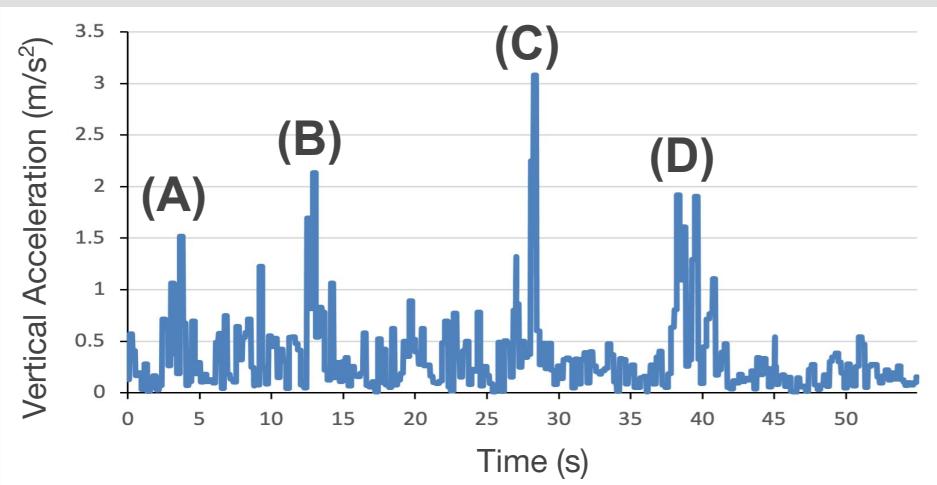


Varying Bicycle Speeds: 5 km/h and 15 km/h

Vertical acceleration at cycling speed of 5 km/h



Vertical acceleration at cycling speed of 15 km/h



- **Greater** vertical acceleration value when **Faster** speed



Scale unification of vertical acceleration

- Use of speed

$$\frac{a_v}{(\text{speed})}$$

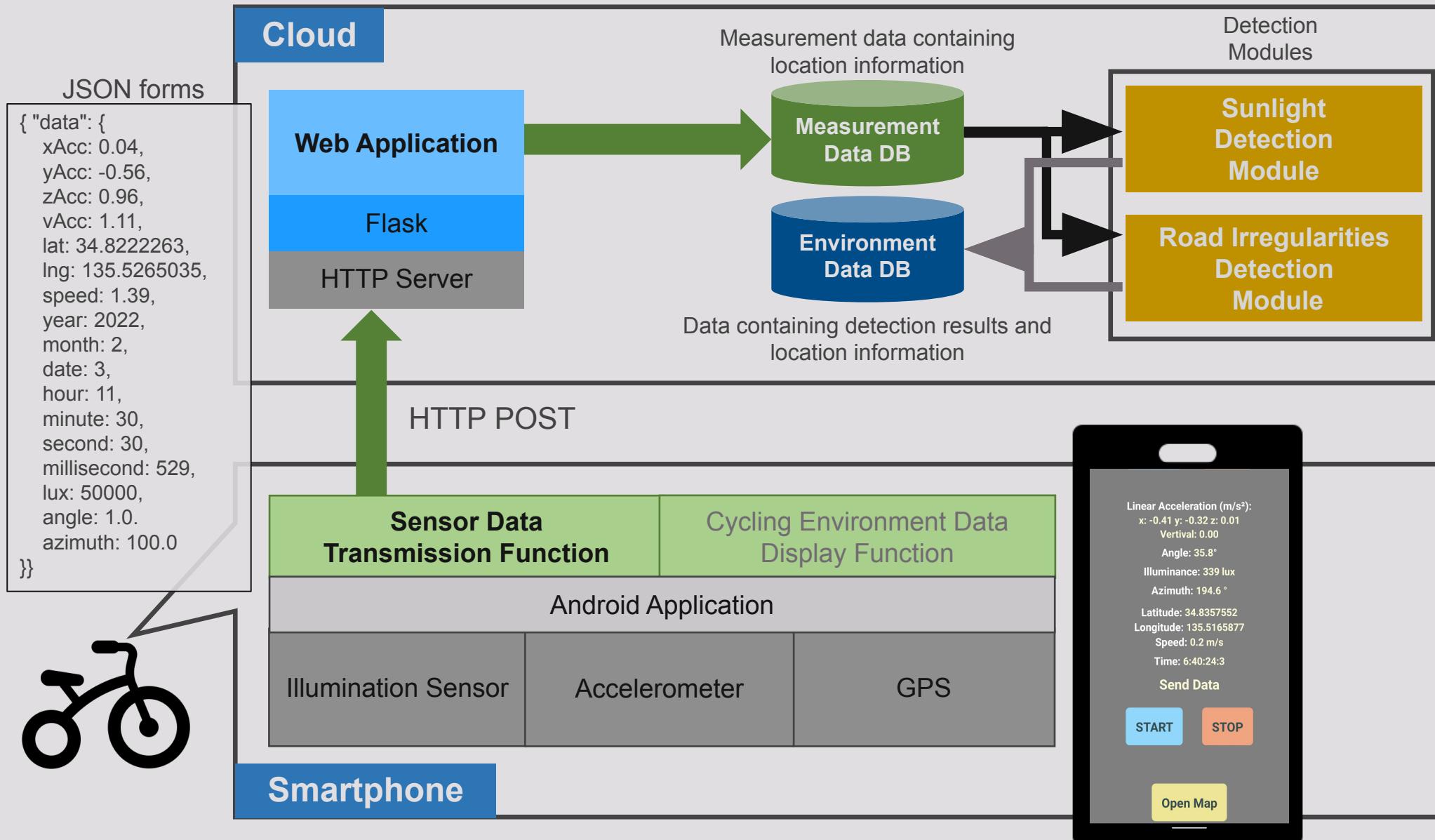
Bicycle Navigation Application

Existing bicycle navigation applications

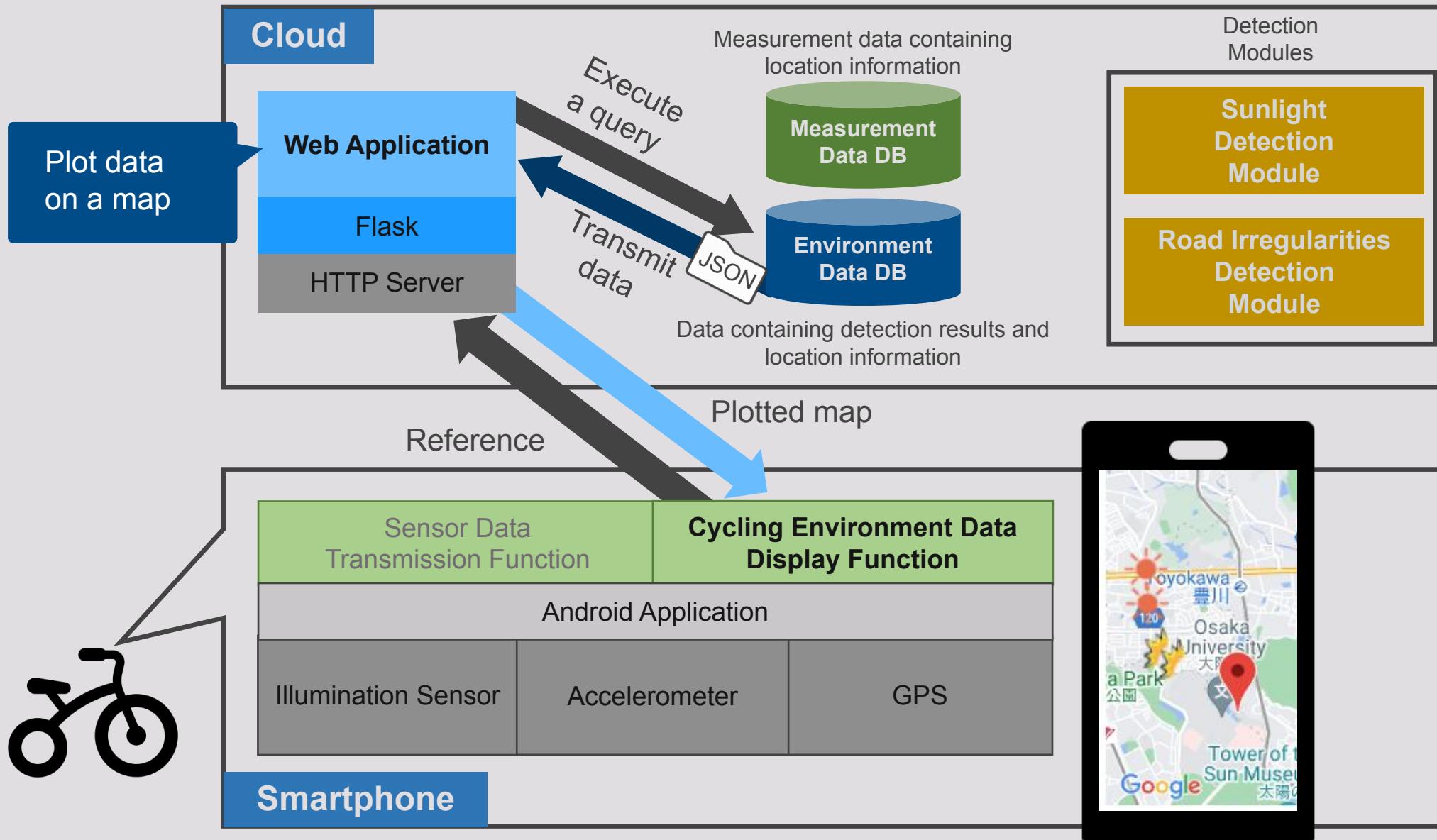
- Recommend **shortest route**
- Need to meet diverse user demands
 - Roads with less sunlight
 - Flat Roads with less unevenness



Process Flow of Sensor Data Transmission Mechanism

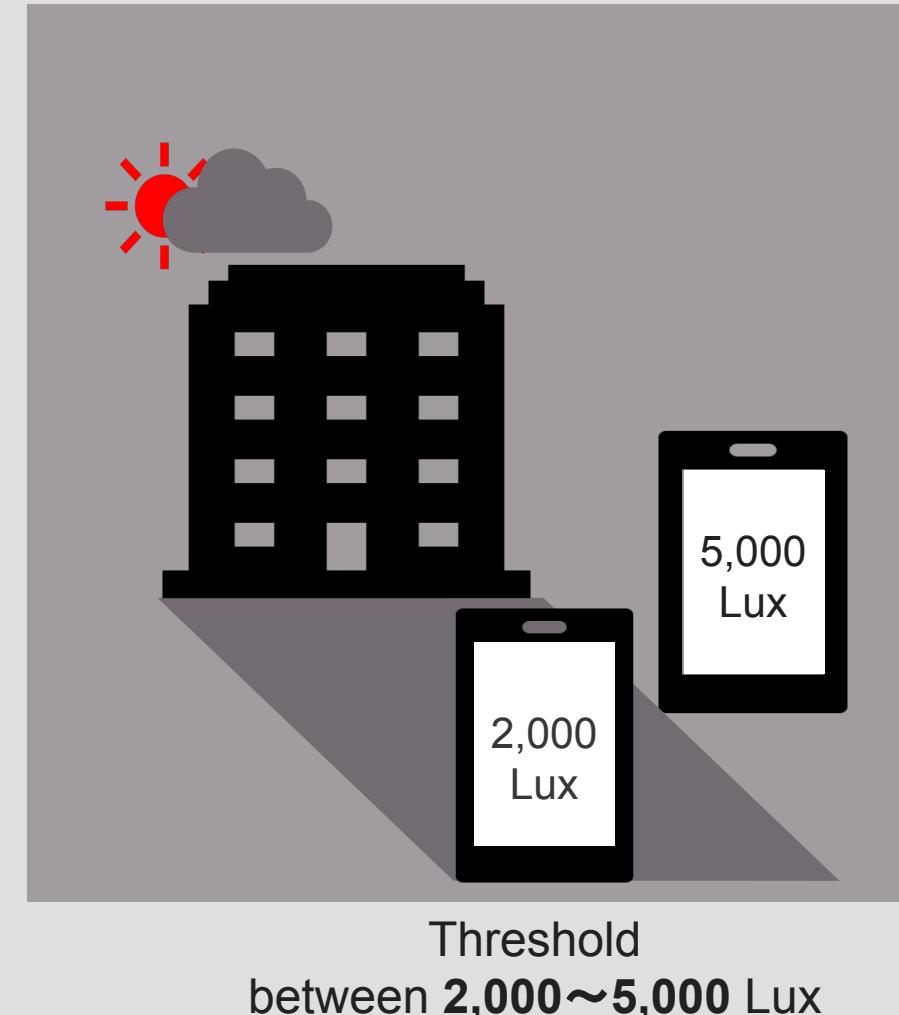
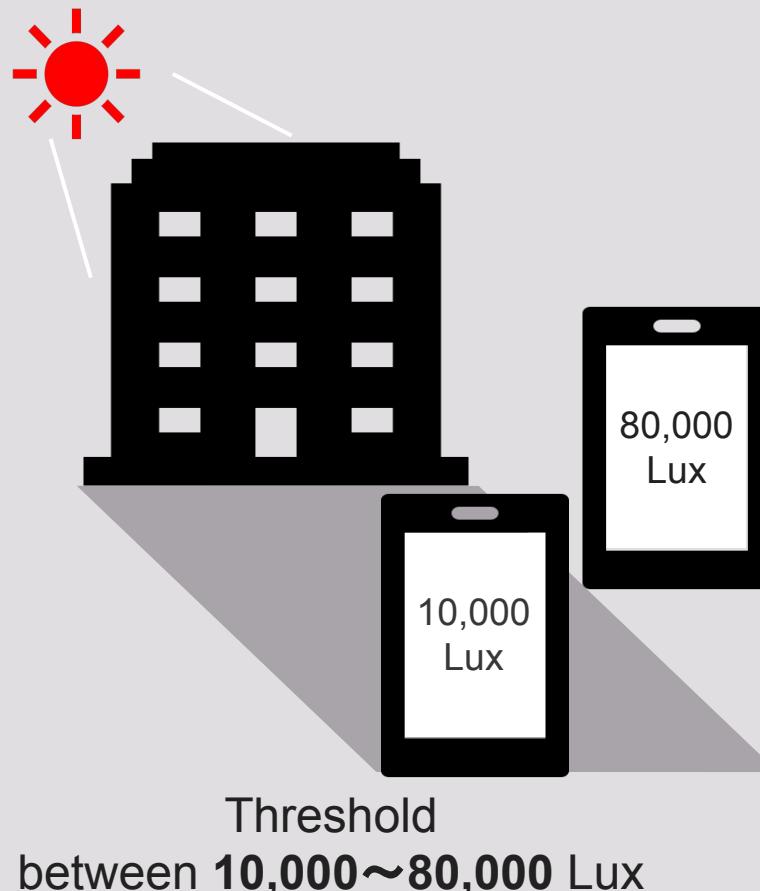


Process Flow of Cycling Environment Data Display Mechanism



Sunlight Detection Module

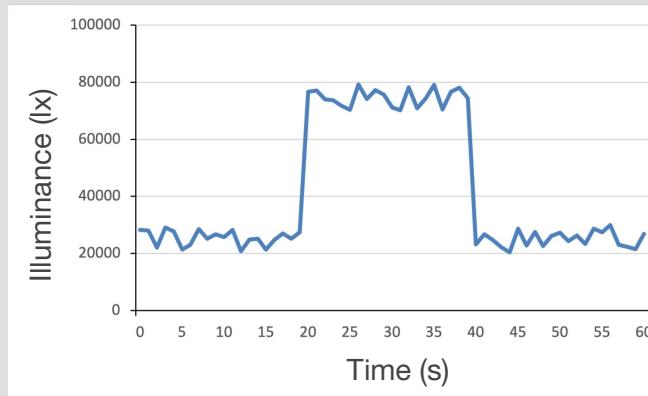
- Discriminate sun and shade even when there is **no sunlight** due to cloudy.



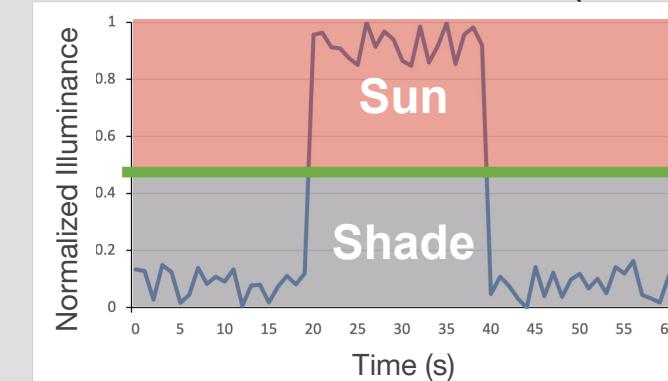
Sunlight Detection Module

- Normalize time series data of illuminance as the minimum illuminance: 0, maximum illuminance: 1

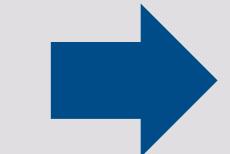
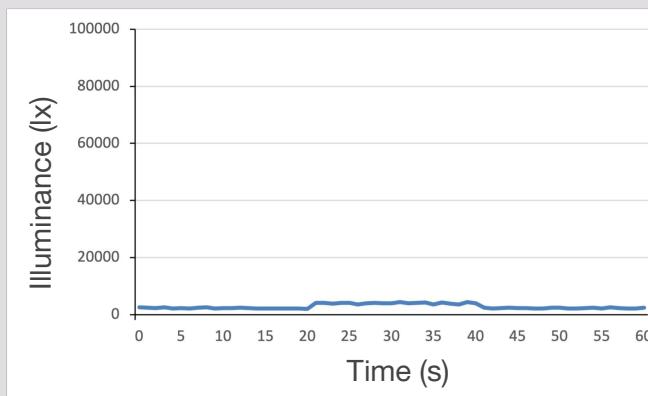
Time series data of illuminance (sunny)



Normalized illuminance (sunny)

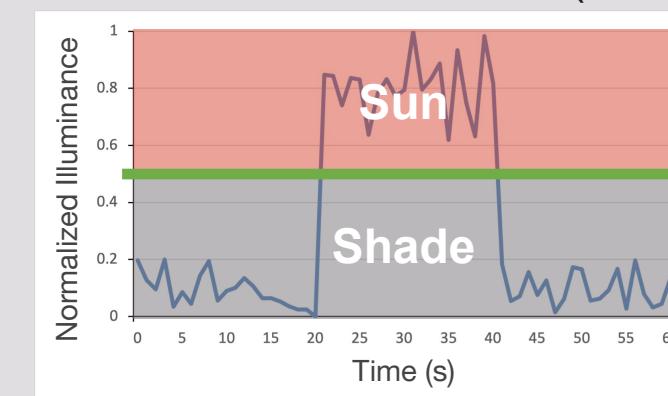


Time series data of illuminance (cloudy)



Normalize

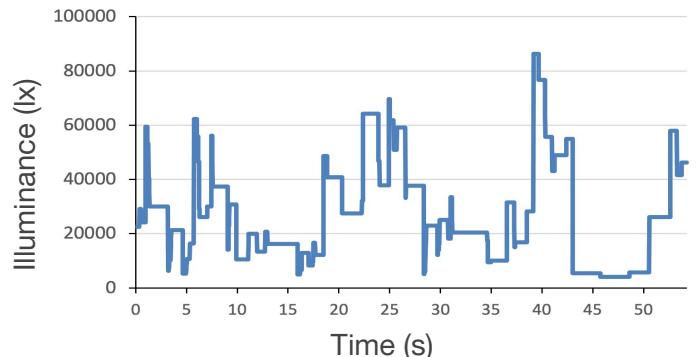
Normalized illuminance (cloudy)



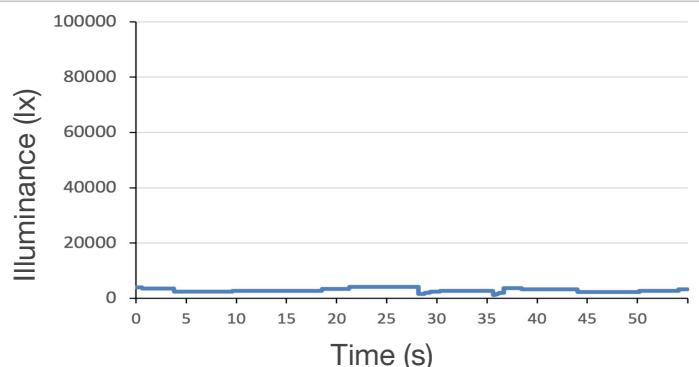
Sunlight Detection



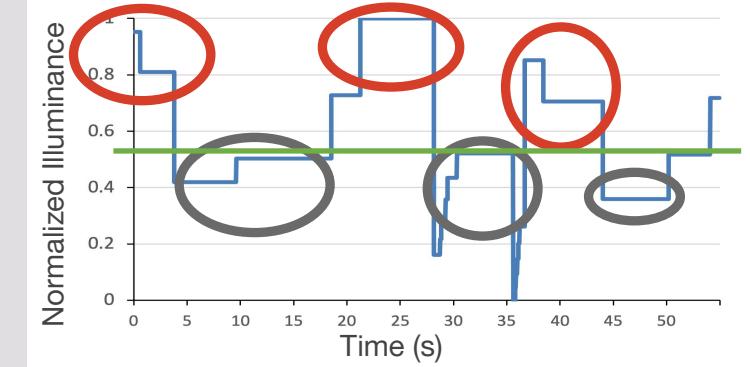
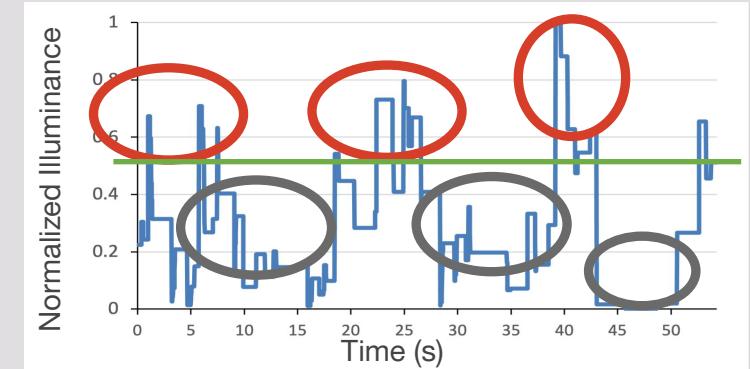
Illuminance at around 12:00 pm (sunny)



Illuminance at around 12:00 pm (cloudy)

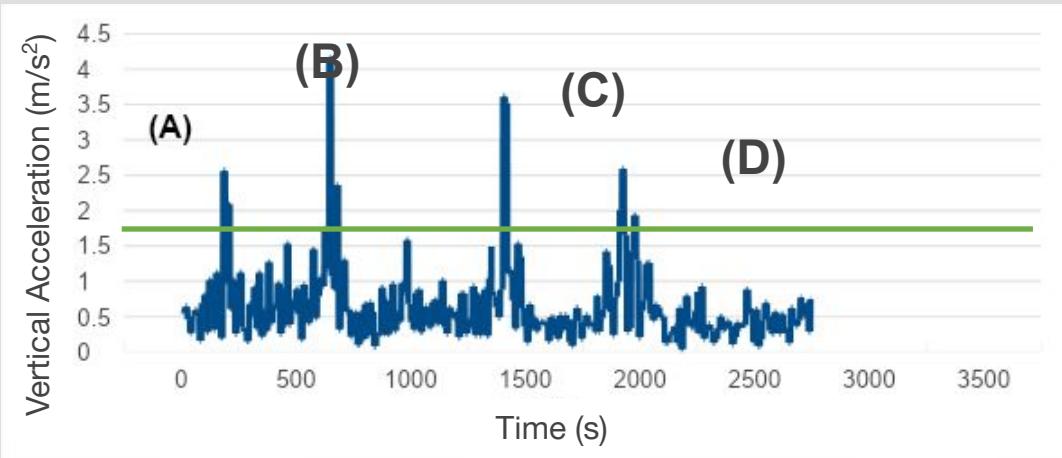


Normalize

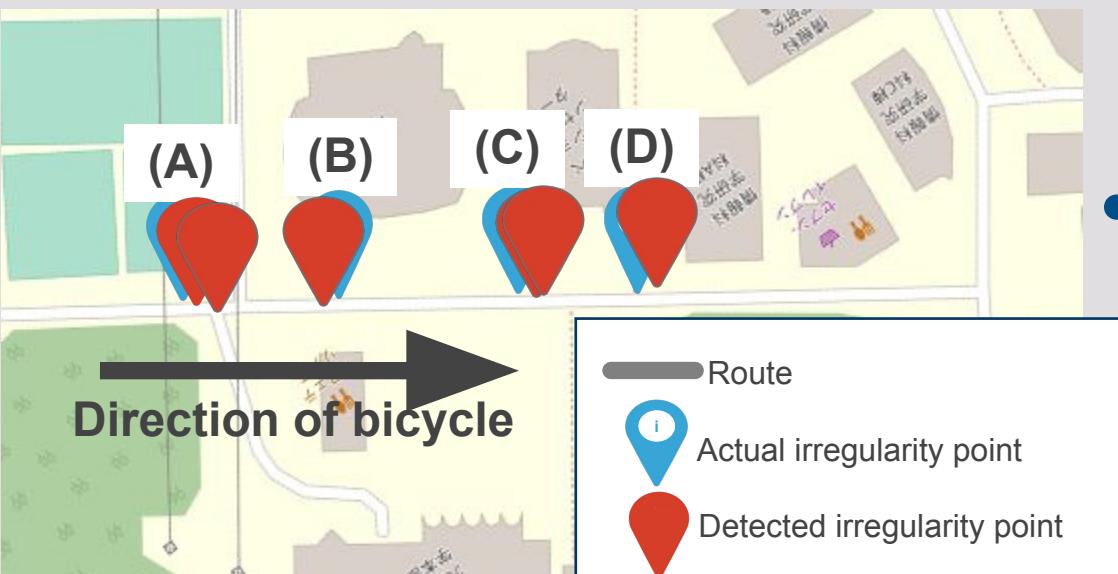


- Threshold cannot be determined due to different illuminance scales
- Same features
- Can process with the same threshold

Road Irregularities Detection



- Spikes in vertical acceleration at 4 locations



- Approximate match between detected irregularity points and actual irregularity points by thresholding