CRSM: Crowdsourcing based Road Surface Monitoring

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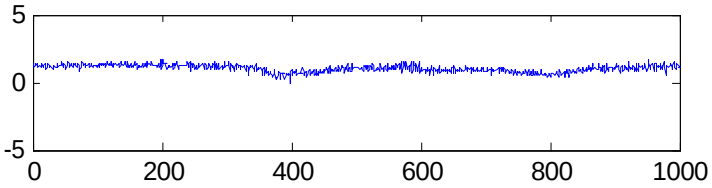
Motivation

- Road surface monitoring
  - Vehicles vibrate greatly on bad roads, which is harmful for vehicles healthy and passenger security
  - City municipalities periodically detect road condition, and cost millions of dollars each year

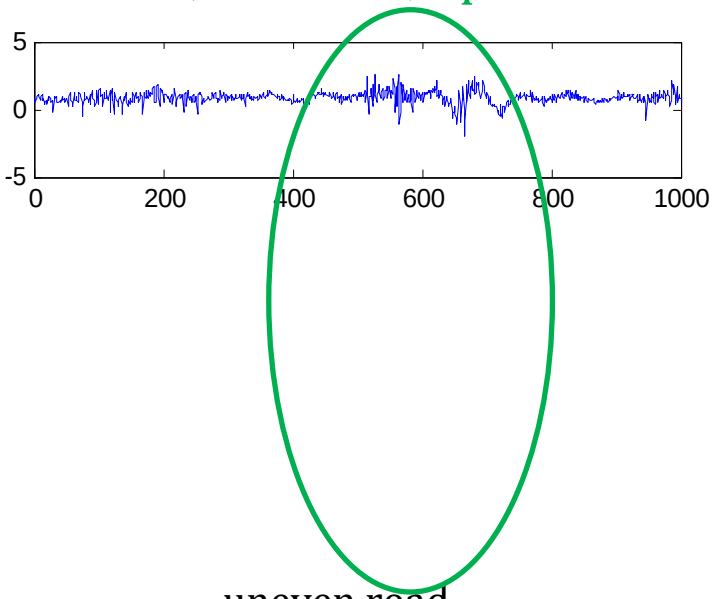
Any better solutions?

Motivation (Cont.)

- Related work
  - 3D laser scanning devices — complex modeling; expensive for popularization
  - Cameras to record images and videos — large dataset; huge analysis workload
  - Accelerometer + GPS — acc.:100Hz; GPS:1Hz, upload all original data



smooth road



uneven road

Motivation (Cont.)

- How to reduce upload data size?
  - discard data on smooth roads
  - upload “abnormal” data only, e.g. potholes

- Our contributions
  - A light-weight data mining algorithm *i-GMM*
  - Road surface monitoring system CRSM
    - Pothole detection — Find the locations of potholes
    - Road roughness classification — Evaluate road quality

CRSM

Vehicle

Hardware device

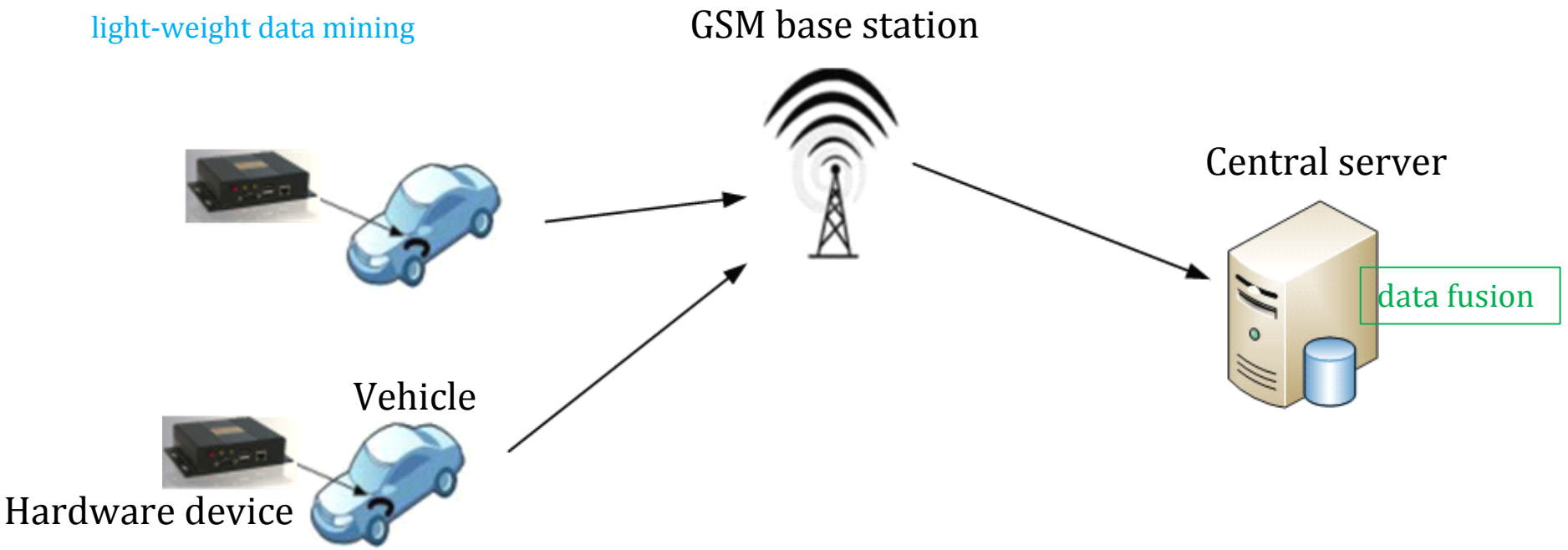
three-axis accelerometer

GPS module

Microcontroller (MCU)

light-weight data mining

CRSM


light-weight data mining
GSM base station
Central server
data fusion
Vehicle
Hardware device
three-axis accelerometer
GPS module
Microcontroller (MCU)
light-weight data mining

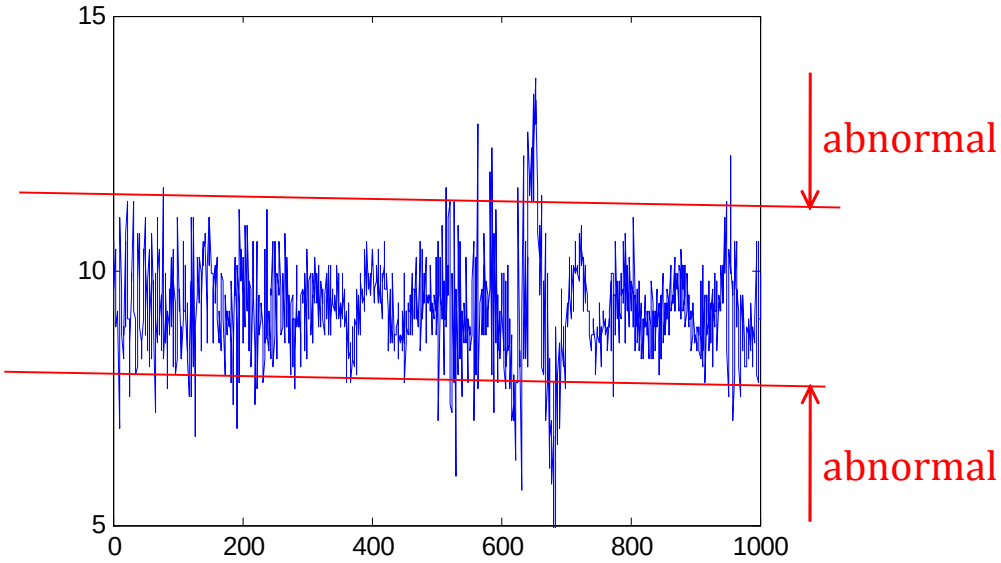
Road Pothole Detection

- Goal:
  - Find the locations of potholes
  - with abnormal signals only, not all original signals

- Questions
  - Q1: How to find abnormal signals?
  - Q2: How to extract potholes from abnormal signals?

Road Pothole Detection(Cont.)

- Q1: How to find abnormal signals?



Z-Peak:
larger than a predefined threshold

Problem:
Vibration vary greatly on different roads or different driving velocities

hard to determine a universal threshold

Road Pothole Detection(Cont.)

- Q1: How to find abnormal signals?

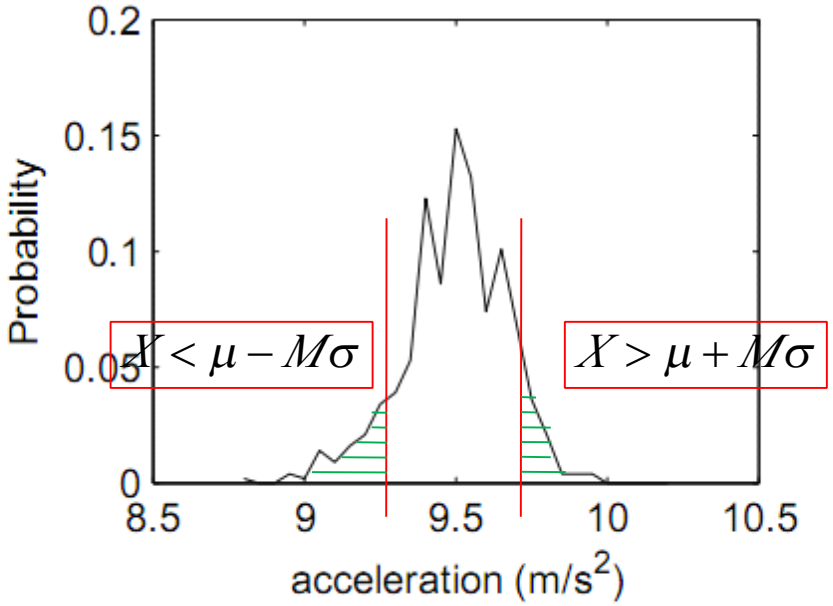


Fig. 2: Distribution of the z-axis acceleration from a smooth road.

$$\left|\frac{X-\mu}{\sigma}\right| > M_{th}$$

not matched →abnormal signal
→upload to server

$$\left|\frac{X-\mu}{\sigma}\right| \le M_{th}$$

matched →smooth signal →learn

$$\mu' = (1-\delta)\mu + \delta X$$
$$\sigma'^2 = (1-\delta)\sigma^2 + \delta(X-\mu)^2$$

single Gaussian model

Road Pothole Detection(Cont.)

- Q1: How to find abnormal signals?

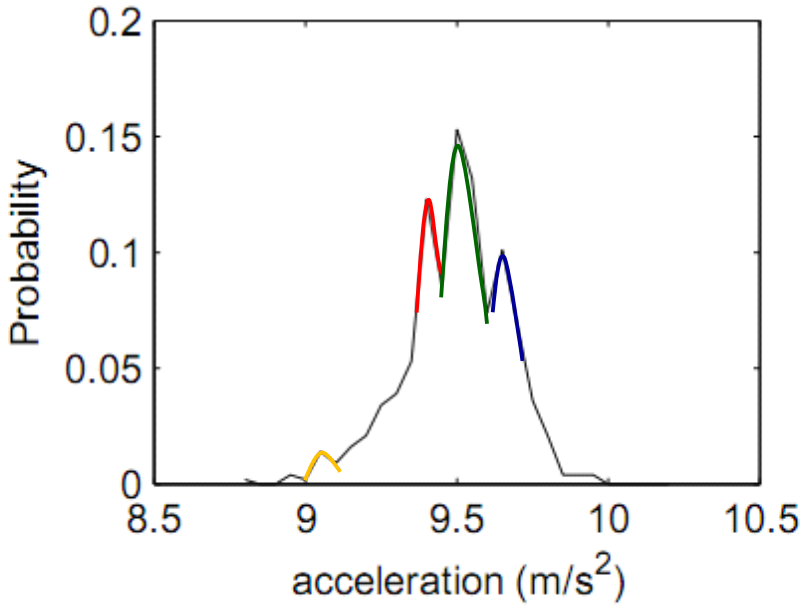


Fig. 2: Distribution of the z-axis acceleration from a smooth road.

Gaussian mixture model (GMM)

K Gaussian distributions
to capture the background signals

signal X

not matched →abnormal signal
→upload to server

matched →smooth signal →learn

Road Pothole Detection(Cont.)

GMM

Vehicles vibrate with high velocity.

$$X = f(\upsilon)$$

How to capture sudden changes quickly?
e.g. start, stop

Improved GMM (*i-GMM*)

Event detection threshold changes with velocity

$$M_{th} = f'(\upsilon)$$

Learn rate changes with velocity increment

$$\delta = g'(\Delta\upsilon)$$

Road Pothole Detection(Cont.)

- Q1: How to find abnormal signals?
- Q2: How to extract potholes from abnormal signals?
  - Abnormal signals has Many interrupt events
    - opening or closing the vehicle door
    - high velocity vibration
    - small bumps
    - expansion joints and contraction joints
    - etc

Road Pothole Detection(Cont.)

- How to extract potholes from abnormal signals?

Four filters

Filter	description	events
Velocity filter	$\upsilon < T_V$	opening or closing the door
Z-axis acc. Filter	$Z < T_Z$	small bumps
X-z acc. Ratio filter	$X/Z < T_{XZ}$	expansion joints and contraction joints
Velocity vs. z-axis acc. Ratio filter	$V/Z < T_{VZ}$	high velocity vibration

Road Surface Roughness Classification

- How to evaluate road quality according to accelerometer only?
  - Metric: Riding Quality Index (*RQI*)

TABLE I: EVALUATION STANDARDS FOR ROAD ROUGHNESS LEVELS.

v(km/h)	RQI	Pavement roughness level
v>80	RQI>3.6	excellent
	3.0<RQI<3.6	good
	2.5<RQI<3.0	qualified
	0<RQI<2.5	unqualified
40<v<80	RQI>3.2	excellent
	2.8<RQI<3.2	good
	2.4<RQI<2.8	qualified
	0<RQI<2.4	unqualified
v<40	RQI>3.0	excellent
	2.6<RQI<3.0	good
	2.2<RQI<2.6	qualified
	0<RQI<2.2	unqualified

Road Surface Roughness Classification (Cont.)

- How to evaluate road quality according to accelerometer only?
  - Metric: Riding Quality Index (RQI)
  - Relationship between RQI and signal variance

$$RQI = f(\sigma)$$

  - Signal variance→ RQI → Road roughness classification

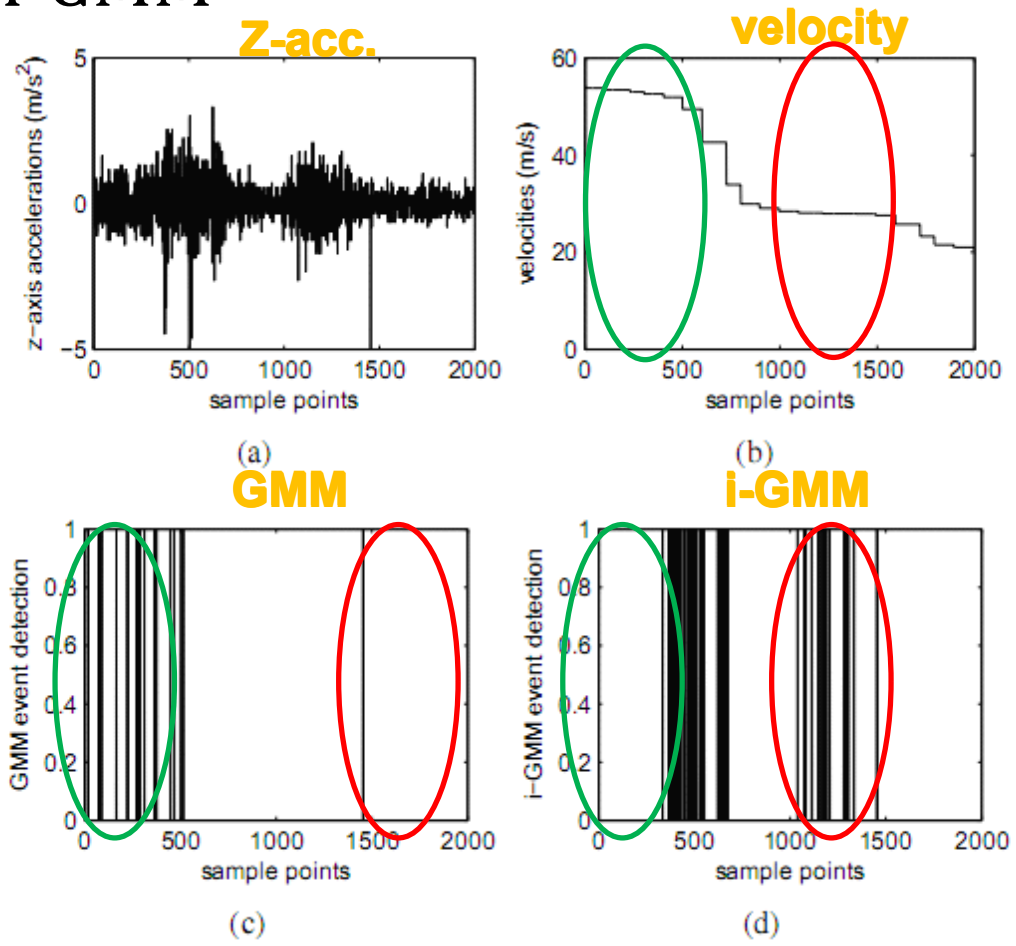
Evaluation

- Experimental settings:
  - 100 vehicles with CRSM devices in Shenzhen
  - 1Hz GPS and 100Hz acceleration samples

- Ground truth
  - another vehicle with a CRSM device and a camera

Evaluation (Cont.)

- GMM vs. i-GMM



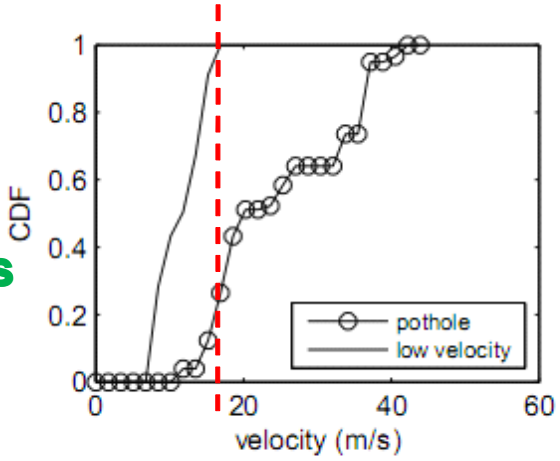
False alarms at high velocity

Missing events at low velocity

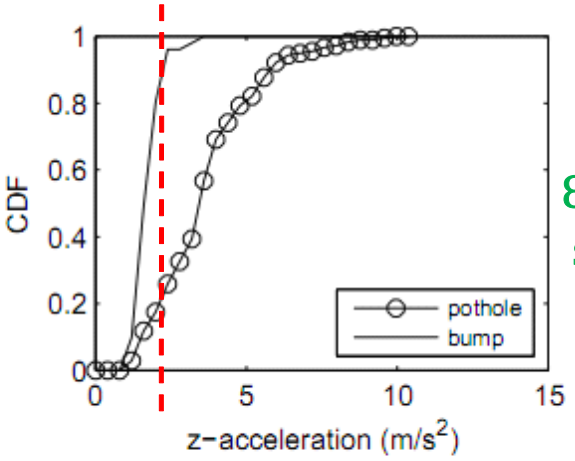
Evaluation (Cont.)

- Pothole filters

Accuracy: 88%
low velocity events



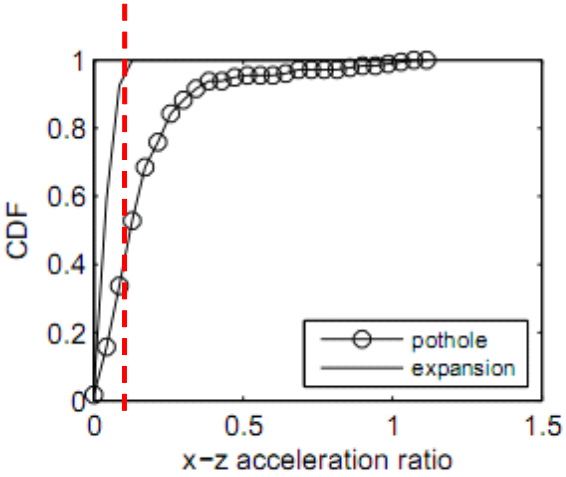
(a)



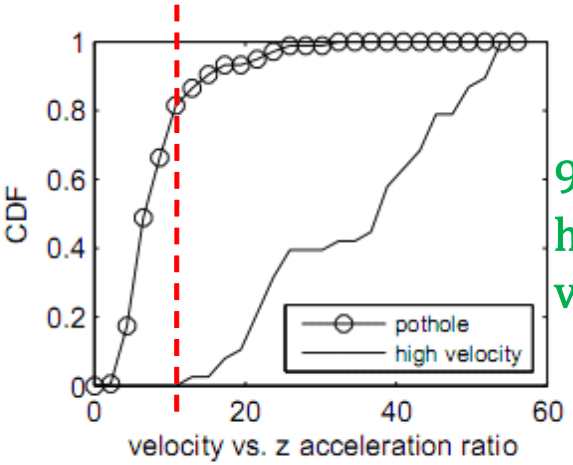
(b)

85%
small bumps

76%
expansion joints



(c)



(d)

92%
high velocity
vibration

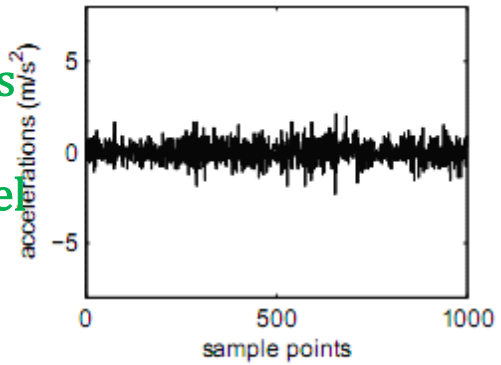
Evaluation (Cont.)

- Pothole filters (Cont.)
  - Central server
    - refuse pothole events with small report ratio
    - >90% accuracy
    - small false alarms

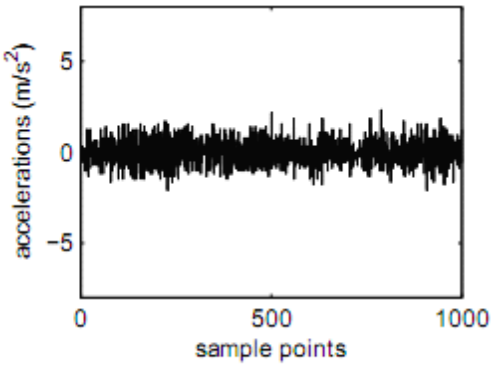
Evaluation (Cont.)

- Road roughness levels

Smooth roads
RQI=3.52
Excellent level



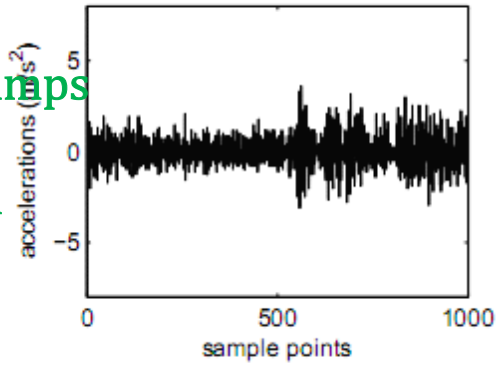
(a)



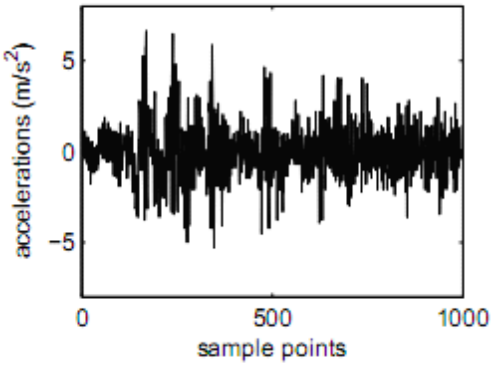
(b)

General roads
RQI=3.12
Good level

Roads with bumps
RQI=2.66
Qualified level



(c)



(d)

Road with potholes
RQI=1.14
Unqualified level

Conclusions

- CRSM: a crowdsourcing-based road surface monitoring system for pothole detection and road surface roughness evaluation.
- A light-weight data mining algorithm for event detection i-GMM, followed by fours filters for pothole detection.
- An online algorithm for road surface roughness evaluation in compliance with industry standards.
- Experimental results show that CRSM can detect road potholes with up to 90% accuracy, along with correct road roughness levels.

Q&A