Real-time 3D Scanning System for Pavement Distortion Inspection

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Pavement distress categories

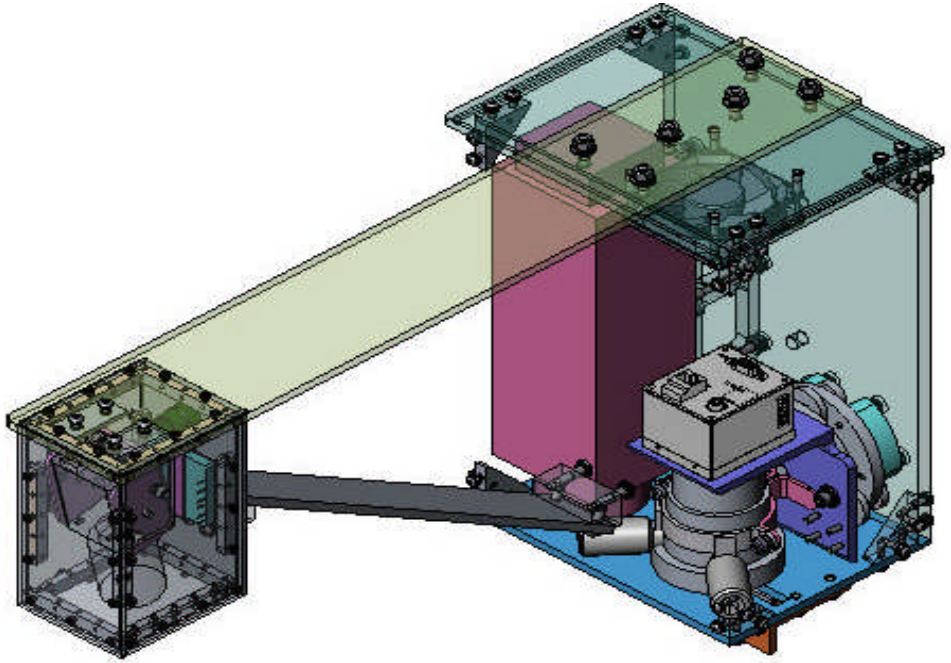
- Fracture (cracking, spalling and fatiguing)
- Distortion (rutting, corrugation and shoving)
- Disintegration (stripping, raveling)

Rutting and Shoving

- Rutting: surface depression in the wheel path.
- Shoving: longitudinal or transverse displacement
- Pothole: bowl-shaped holes of various sizes in the pavement surface

System principle

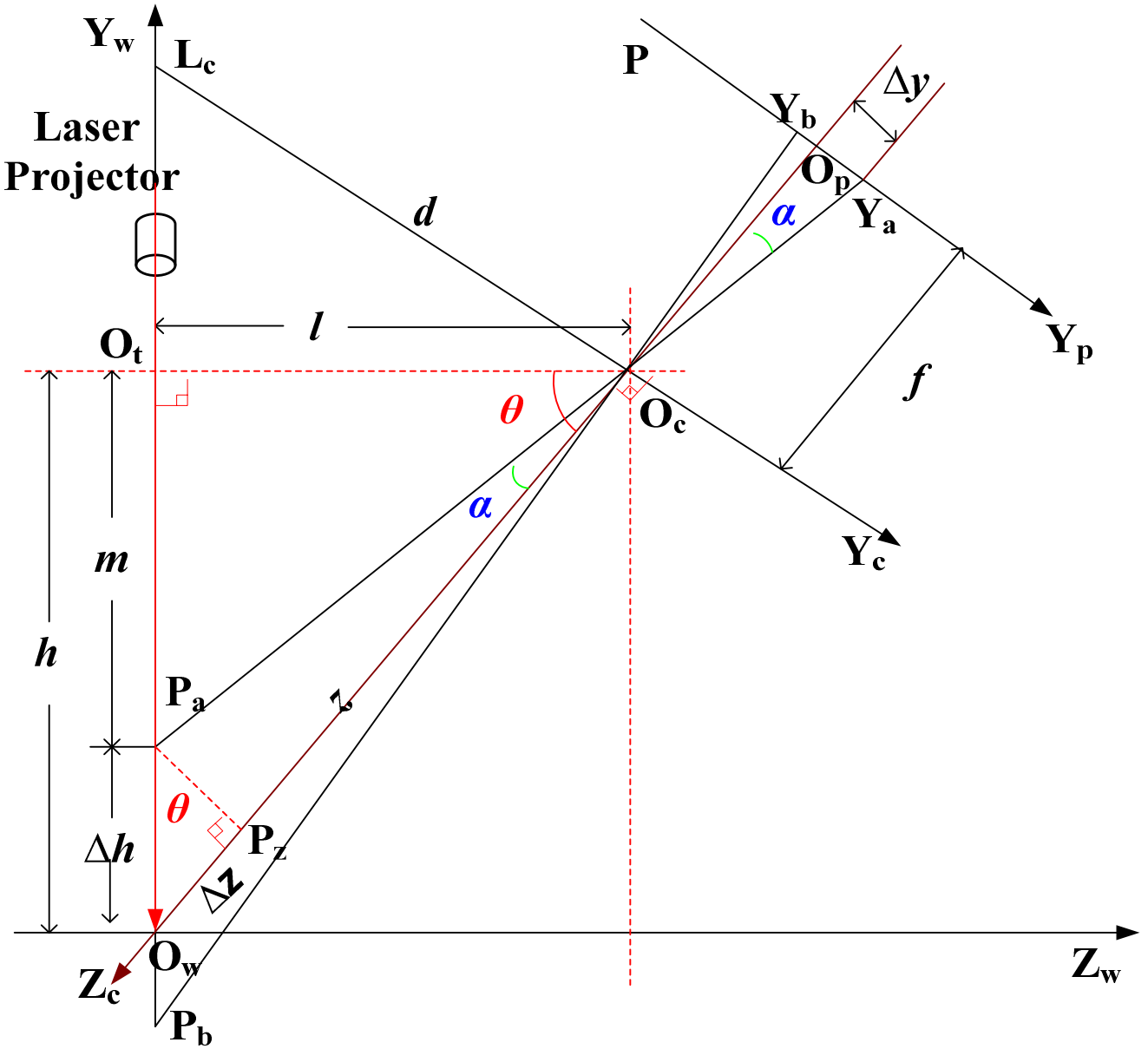
- Dynamic generation and characterization of 3D pavement profiles.
- Structured light.



System principle

- System Items
  - ✓ An infrared laser line projector
  - ✓ A GigE digital camera
- Laser line transversely covers pavement lane
- Camera captures consecutive laser line images while the vehicle moves forward
- Structured-light triangulation
- 3-D transverse profiles for distress detections

Triangulation



Elevation calculation

$$\begin{cases} \alpha = \arctan(y_a / f) \\ h = l \cdot \tan(\theta) \\ m = l \cdot \tan(\theta - \alpha) \\ \Delta h = h - m = l \cdot (\tan(\theta) - \tan(\theta - \alpha)) \end{cases}$$

The unknown parameters (f, l and θ) can be obtained through a calibration procedure.

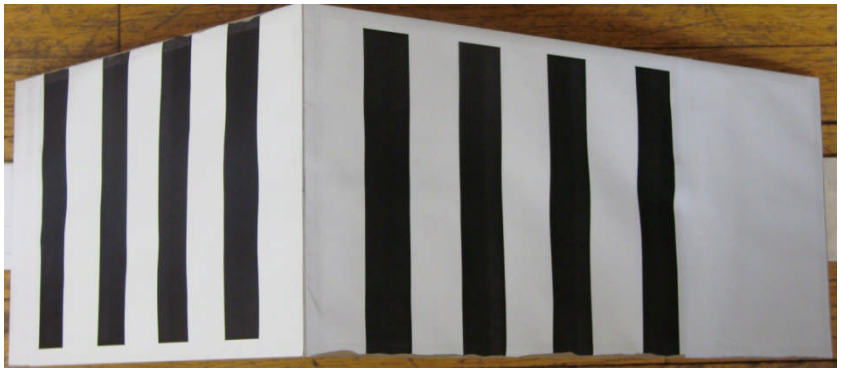
System specifications

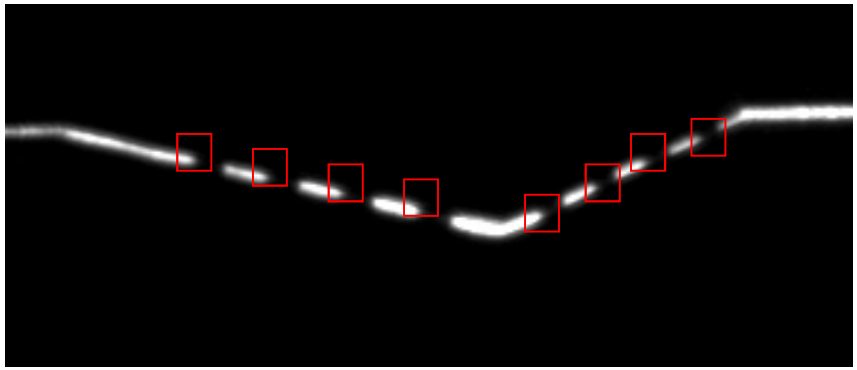
Maximum scan rate	200 lines/sec
Sample Points	1024 points/line /1 unit
Scan width	1830 mm/ 1 unit
Vertical resolution	2 mm
Horizontal resolution	1.79 mm
Profile spacing	76.3 mm @55km/h
Maximum vehicle speed	112 km/h

Calibration

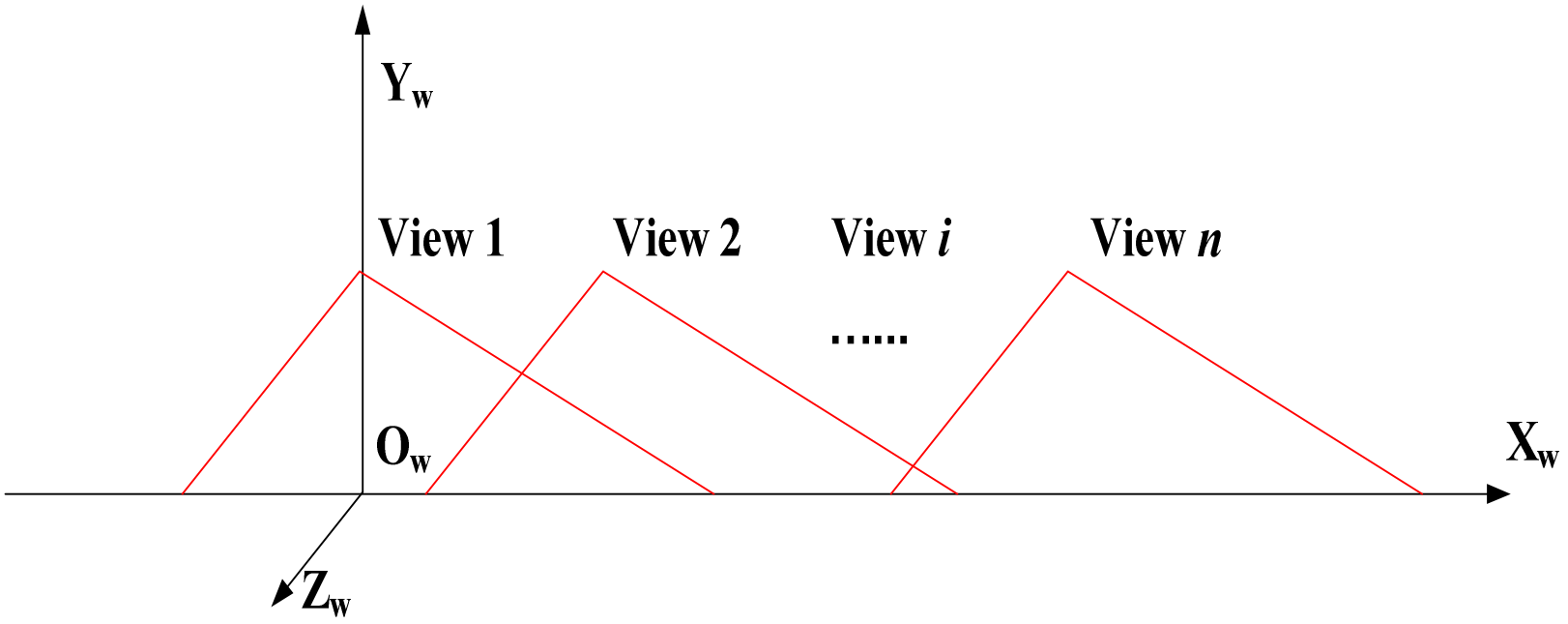
- An infrared filter eliminates the effect of the ambient lighting
- Only the points in the laser stripe are available
- The surface points are all located in the laser plane
- Tsai model is adopted to satisfy the coplanar calibration constrain

Calibration pattern and feature points





Multi-view scheme



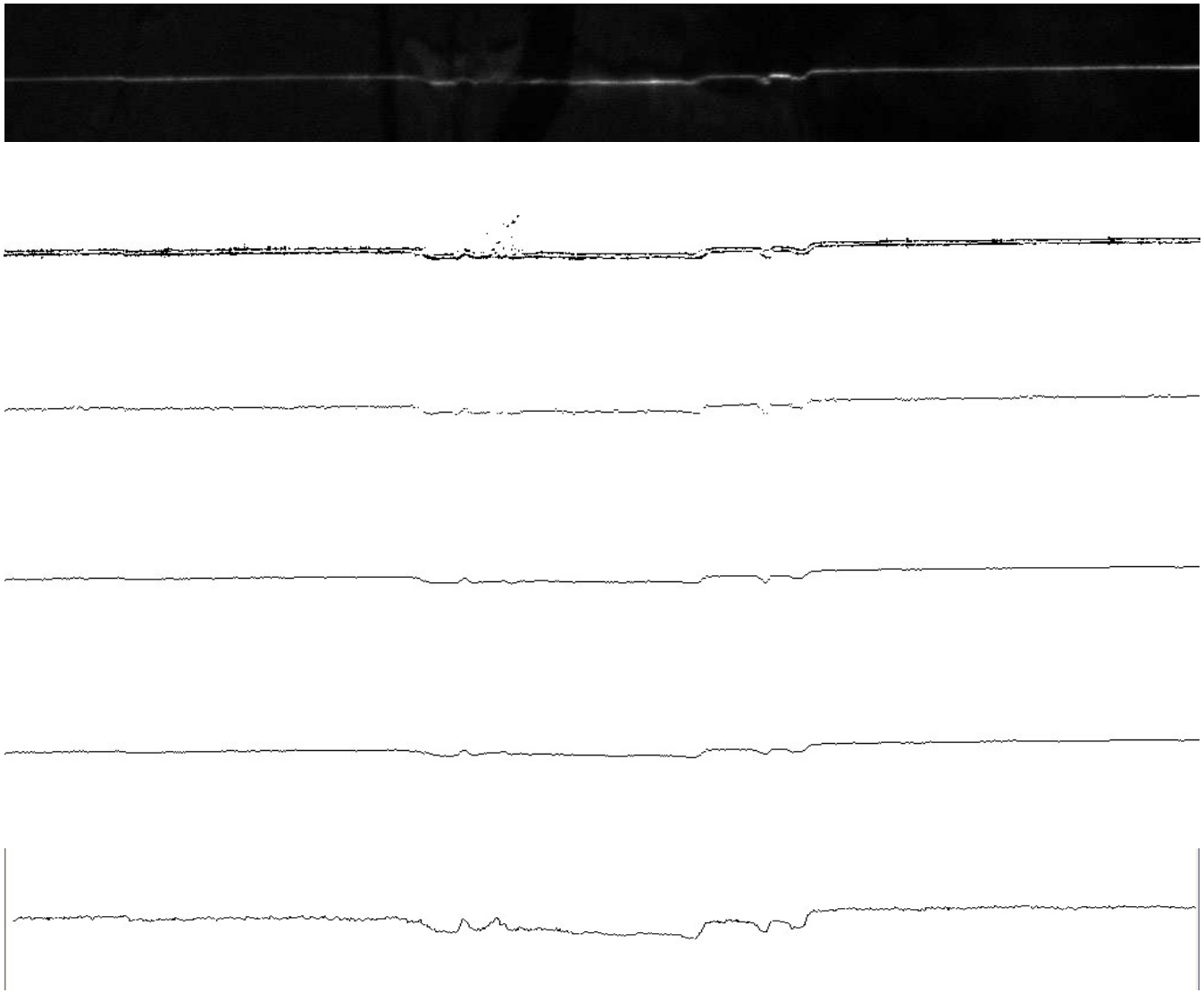
Laser stripe location

- The processing time < 5 ms
- Image frame rate up to 200 frames per second.
- Insensitive to lighting conditions and pavement textures.

Sub-pixel laser stripe location

- Median filtering
- Coarse edge detection
- Stripe curve interpolation by cubic splines
- Fine profile adjusting (sub-pixel)

Laser line locating procedure



Edge detection

$$\begin{cases} \text{if} \quad (avgGray \le threshold\_1) \,\&\&\, (ratioAvg2Bkg \le threshold\_2), & \begin{pmatrix} -5 & -35 & -5 \\ 0 & 0 & 0 \\ 5 & 35 & 5 \end{pmatrix} \\ else, \quad Canny \end{cases}$$

avgGray: average grey value of image

ratioAvg2Bkg: the ratio between average grey value and background of image

Canny operator: with dynamic thresholds (which change depending on the image average grey value) is applied.

Fine profile adjusting

$$Y = Y_r - k + \sum_{Y_r - k}^{Y_r + k} \mathrm{F}(i)(i - Y_r + k) \Big/ \sum_{Y_r - k}^{Y_r + k} \mathrm{F}(i)$$

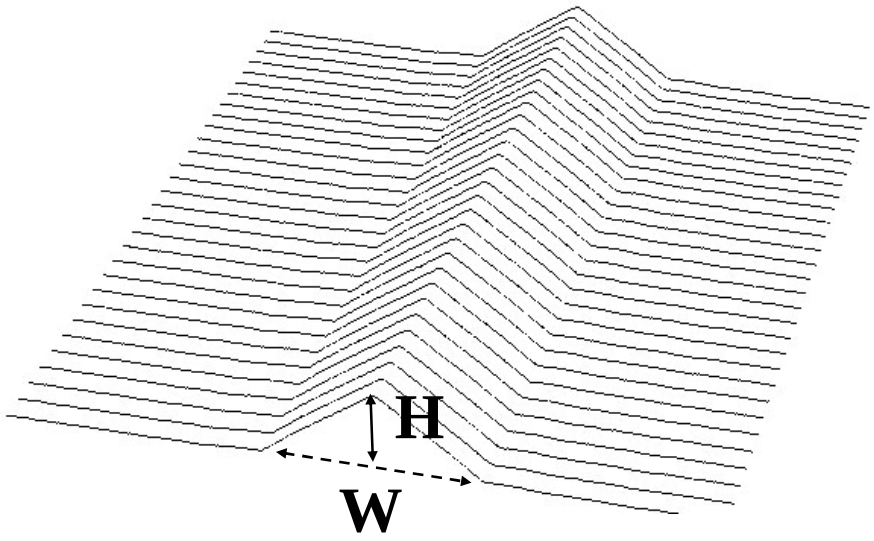
Y: final profile precise location.

Y_r: coarse position of the stripe obtained from last step.

$\mathrm{F}(i)$: the image grey value at pixel i.

Adjust the profile in each image column.

3D scans of a target



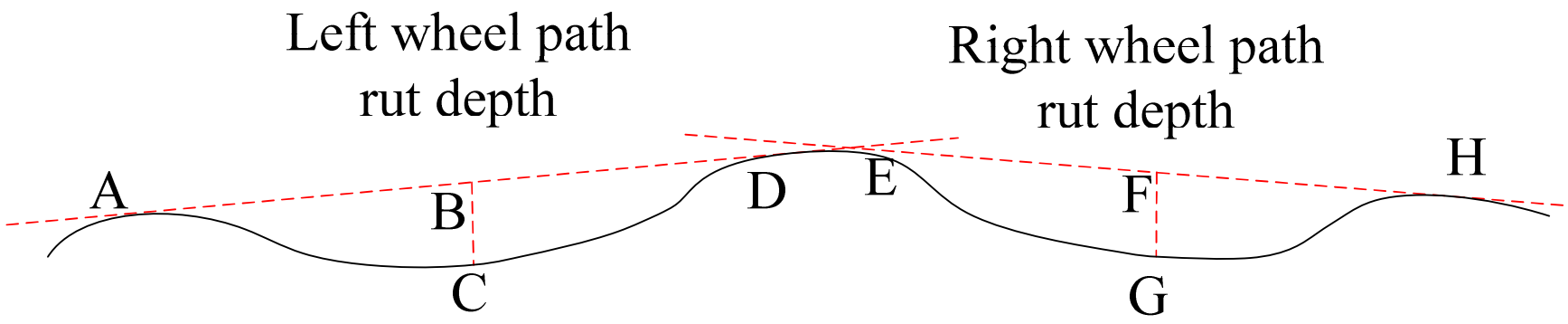
Triangular target	Actual (mm)	Scanned (mm)	
		Mean	S.D.
Height (H)	200.6	200.475	0.319
Width (W)	706.0	706.873	0.290

Pavement rutting measurement

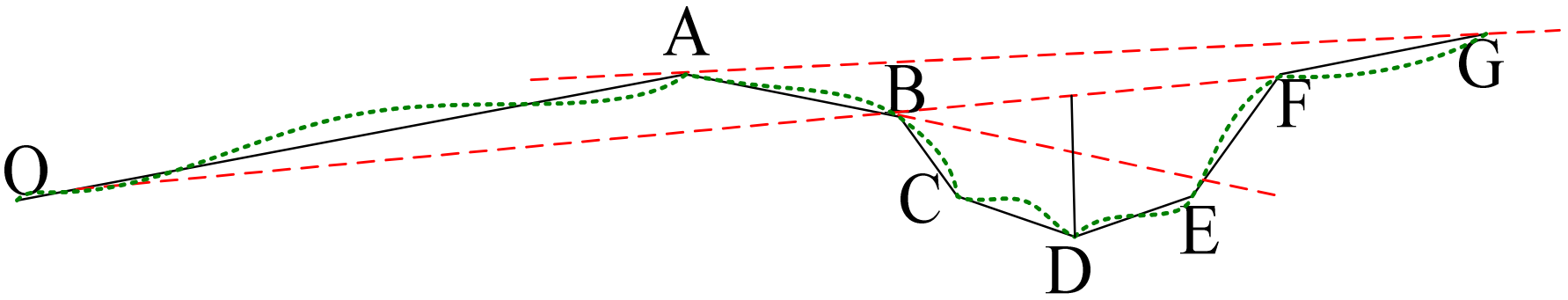
Pavement rutting refers to surface depression in the wheel path.

- Median filtering
- Approximating profile
- Calculating the 1st and 2nd order derivatives of the endpoints
- Searching the rut support point pair
- Calculating the rut parameters

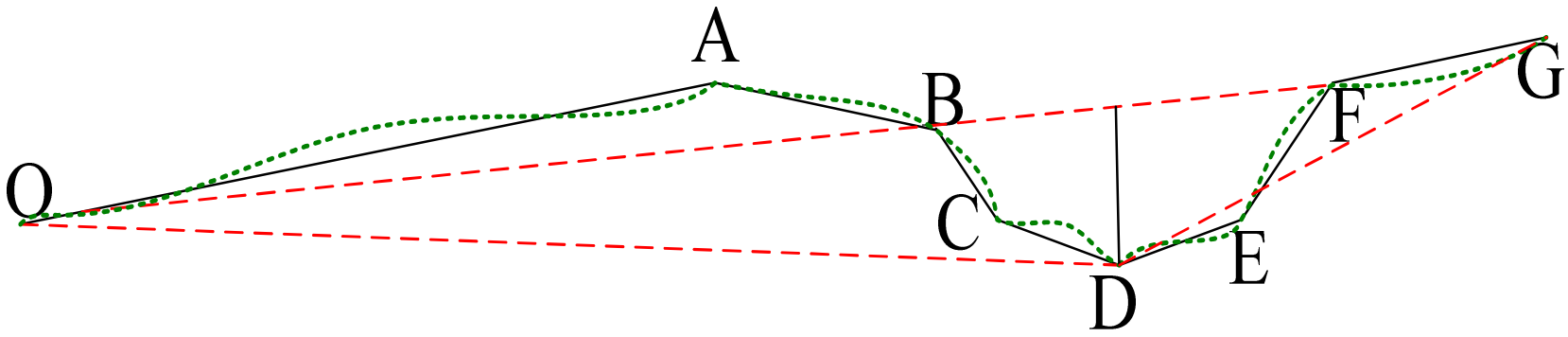
Rut depth measurement



Approximating profile



Searching rut support points



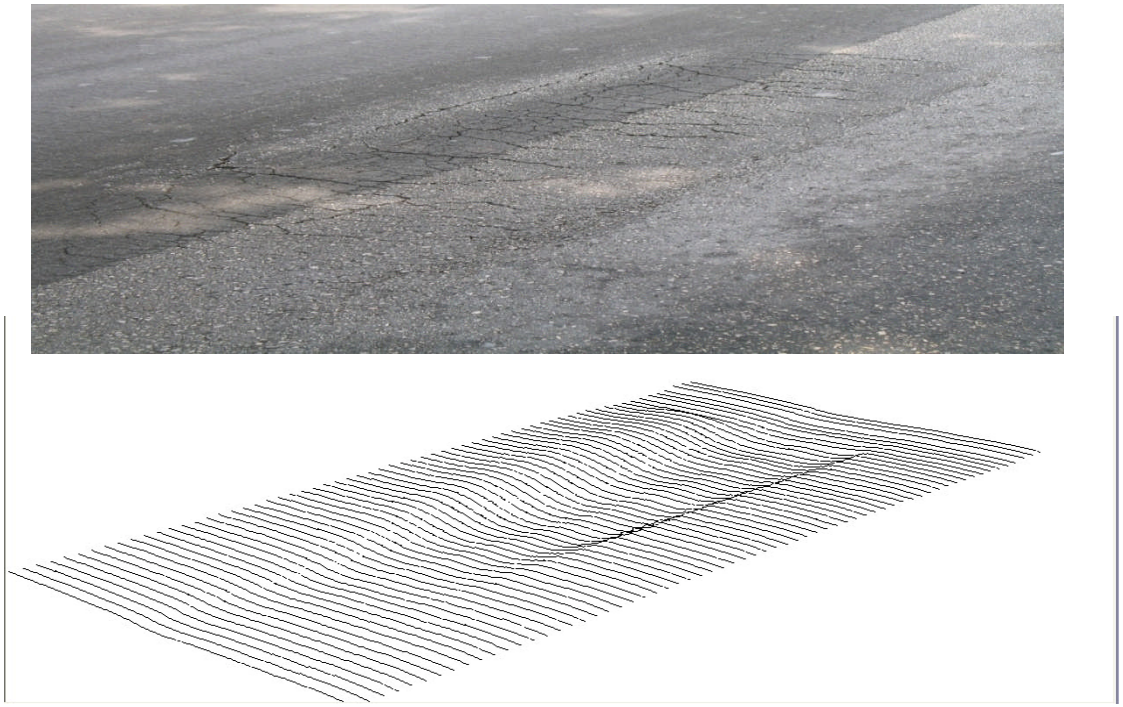
Calculating rut parameters

- Rut depth: The maximal distance between the line AG and the road profile

- Rut area: The area between the line AG and the road profile

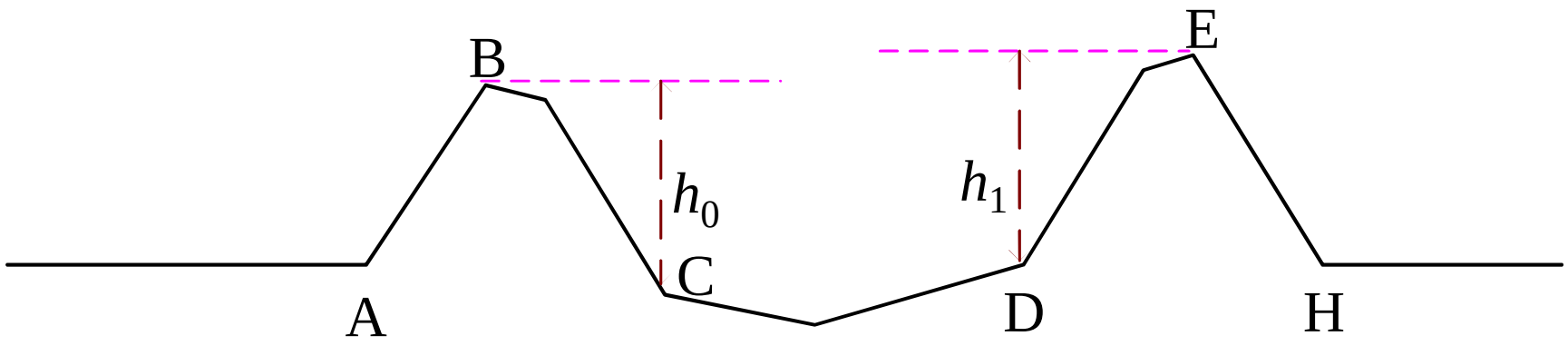
- Rut level: According to the rut depth, rut level is classified into 4 levels:
  - ✓ depth <6 mm 1
  - ✓ 6<=depth<12 2
  - ✓ 12<=depth<19 3
  - ✓ depth>=19 4

Rutting Measurements



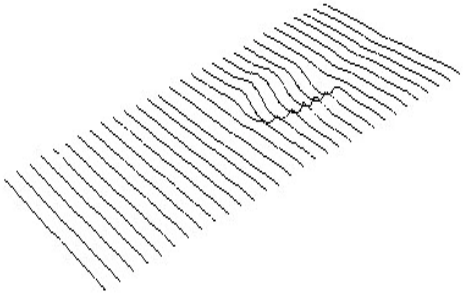
Parameter	Scanned			Manual
	Run 1	Run 2	Run 3	
Max rut depth (mm)	58.67	57.27	60.11	60
Rut depth (mm)	36.54	38.07	38.11	37.64
Rut area (mm^2)	37514.56	38053.42	40154.63	N/A

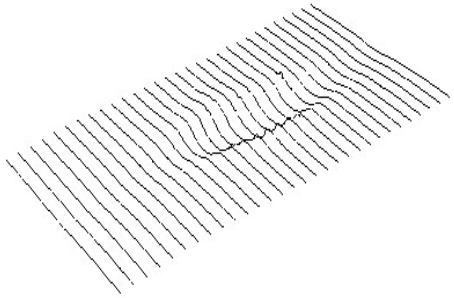
Shoving Measurements

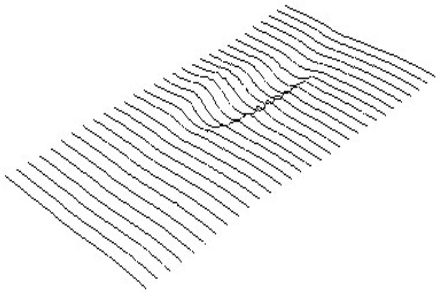


- **Locate support points of shoving profile (points B&E)**
- **Search bump root points A&C, and points D&H**
- **Calculate the heights of the bumps (*h_0* and *h_1*)**
- **Calculate the shoving width and depth**

Shoving Measurements

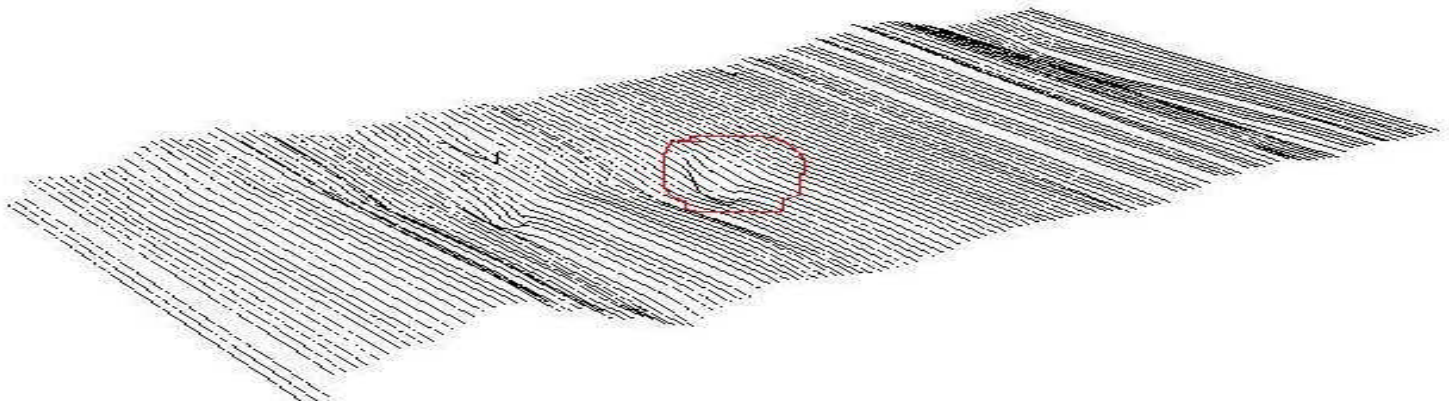






Parameter	Scanned			Manual
	Run 1	Run 2	Run 3	
Max depth (mm)	71.30	72.64	72.53	75
Max width (mm)	675.57	704.01	703.96	700

Pothole detection



Parameter	Scanned	Manual
Pothole depth (mm)	67.53	71
Pothole width (mm)	477.93	472

Summary

- 3D pavement profiles: real-time
- Structured light: reliable and inexpensive
- Multi-view coplanar calibration:
- Laser stripe locating method: sub-pixel accuracy
- Preliminary experiments: accurate rutting and shoving measurements.