



同濟大學  
TONGJI UNIVERSITY

# Tunnel Monitoring and Disease Screening Base on Mobile Laser

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Speaker : Jin Bao

# Content

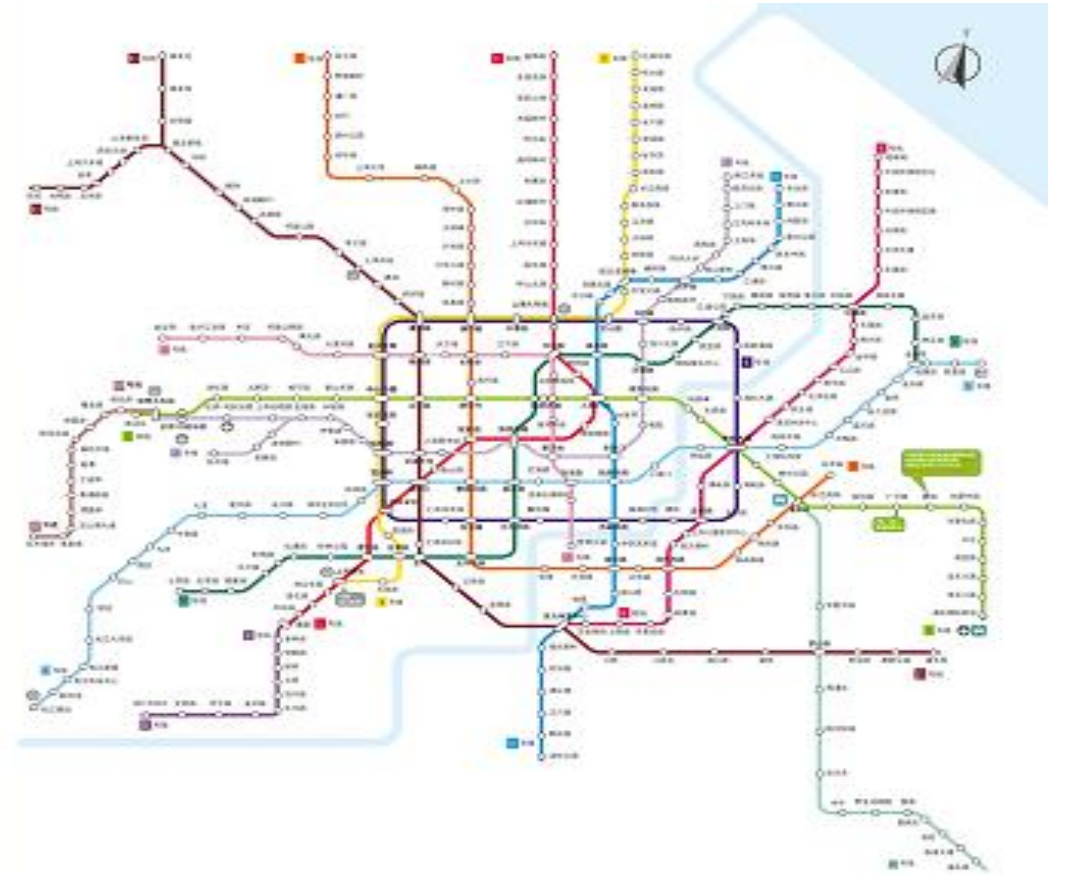
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1. Background
2. Research status
3. Principle
4. Algorithm
5. Consequence
6. Conclusion

With the leap-forward development of the metro industry, the rail transit network has been rapidly established.

Many engineering practices have proved that various construction activities along the line directly affect the safety of the subway structure in soft soil.

It is necessary to monitor and evaluate whether the rail transit structure exist the security risks.

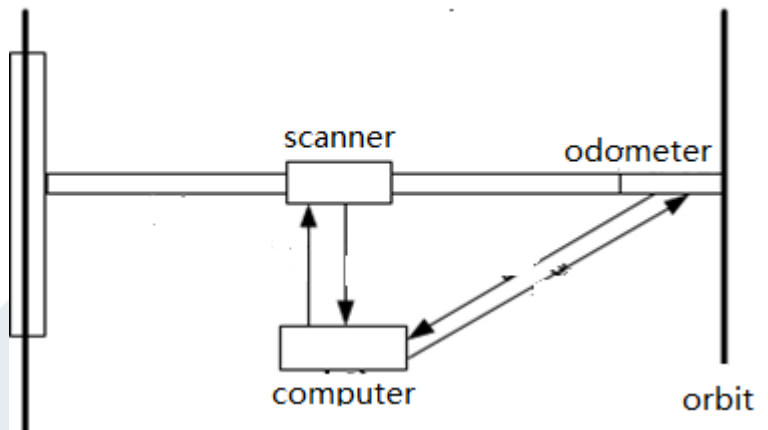


Shanghai metro line map

## Existing monitoring products

Product	Gauge Sensor	Odometer	Tilt Sensor	Scanner	Profiler	Inertial Measurement Unit
GRP3000	Y	Y	Y	N	Y	N
GRP5000	Y	Y	Y	Y	N	N
SiTrack One	Y	Y	N	Y	N	Y

Leica's new mobile orbit measurement system, SiTrack One, is the representative of mobile scanning systems in recent years. The hardware are too expensive, so we want to simplify the system and use software to compensate for angle and distance errors.



mobile monitoring system control

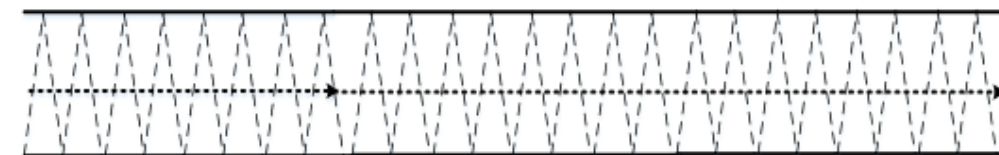


mobile 3D laser scanner system



one-dimensional  
mileage  
+  
two-dimensional  
cross-section  
=  
three-dimensional

The Subway Tunnel Points Cloud Restore the Top

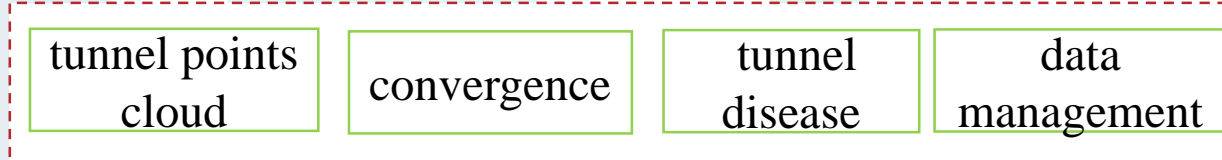


—— orbit      - - - - - direction      scanning lines

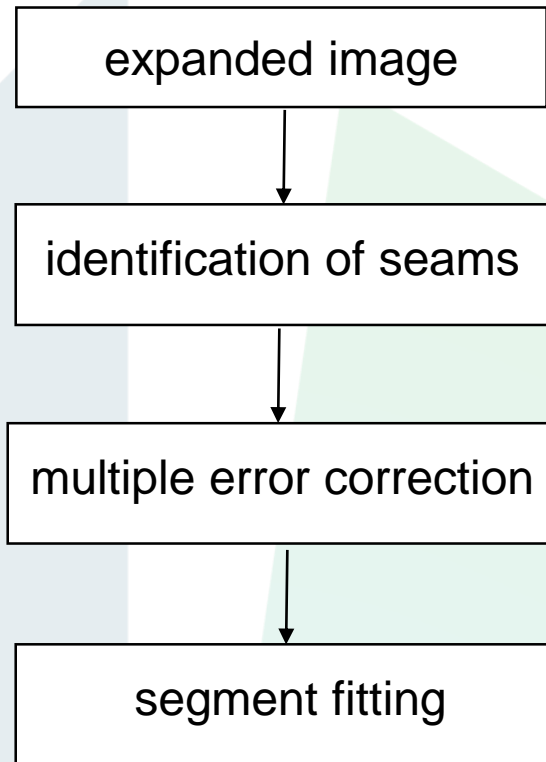
**hardware**



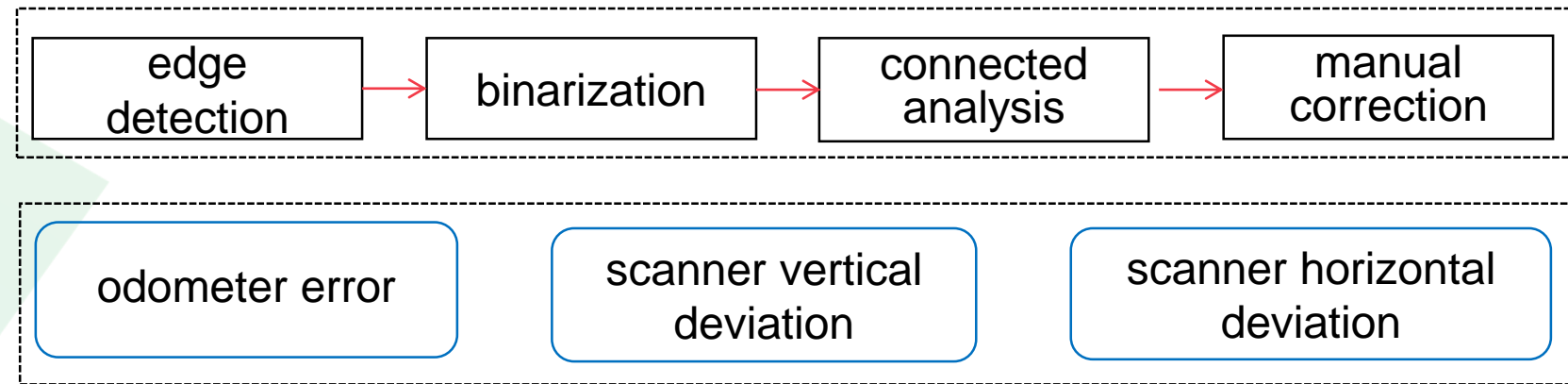
**software**



## Flow chart of core data processing



The 3D point is projected onto the plane and filled with the gray to the corresponding position.



## Image filling and smoothing

**Image Filling:** A BMP image of a certain size, the coordinates corresponding to the pixel position are calculated, and filled with the corresponding gray value of the point to obtain a tunnel tile.

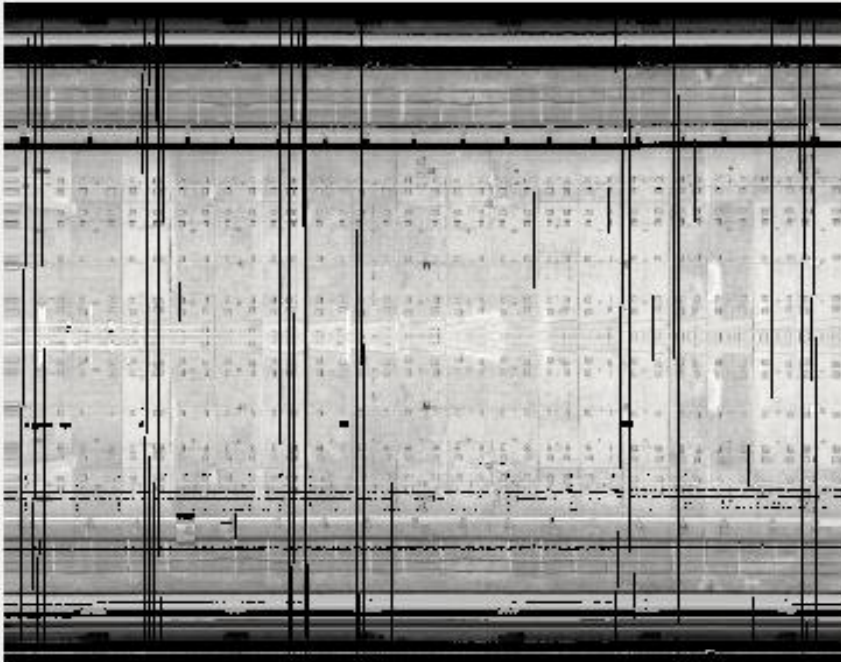


image filling

$$\begin{pmatrix} 0.35 & 0.45 & 0.50 & 0.45 & 0.35 \\ 0.45 & 0.71 & 1.00 & 1.00 & 0.45 \\ 0.50 & 1.00 & 0.00 & 1.00 & 0.50 \\ 0.45 & 0.71 & 1.00 & 0.71 & 0.45 \\ 0.35 & 0.45 & 0.50 & 0.45 & 0.35 \end{pmatrix}$$

interpolation operator

**Image smoothing:** The way is to give the gray value of the pixel without gray point. The interpolation weight operator is as follows.

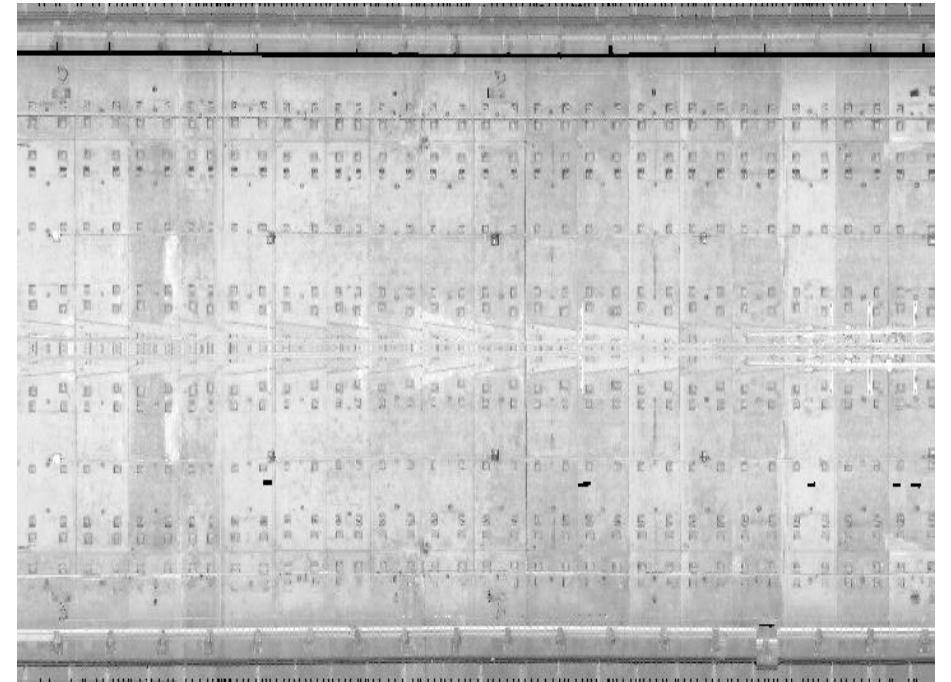


image smoothing

## Seams identification

**Edge detection:** Convolution are often used to approximate the gradient of the image using some small area templates.

prewitt gradient operator

robert gradient operator

sobel gradient operator

**Binarization :** Otsu algorithm that is an adaptive threshold determination method, which is a global-based binarization algorithm.

If image scale is  $M \times N$ ,  $N_1$  indicates that the gray value of the pixel is less than the threshold number, else is  $N_2$ :

$$\omega_1 = \frac{N_1}{M \times N}$$

$$\omega_2 = \frac{N_2}{M \times N}$$

$$N_1 + N_2 = M \times N$$

$$\omega_1 + \omega_2 = 1$$

$$\mu = \omega_1 \times \mu_1 + \omega_2 \times \mu_2$$

$$g = \omega_1 \times (\mu - \mu_1)^2 + \omega_2 \times (\mu - \mu_2)^2$$

-1	0	1
-2	0	2
-1	0	1

$G_x$

-1	-2	-1
0	0	0
1	2	1

$G_y$

Sobel gradient operator



Edge detection

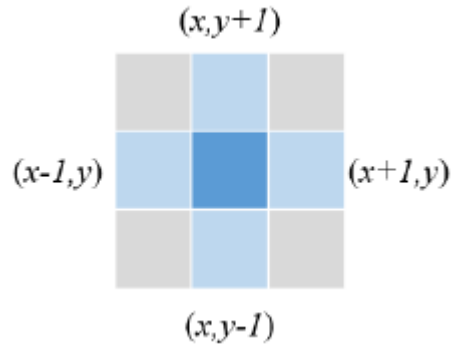
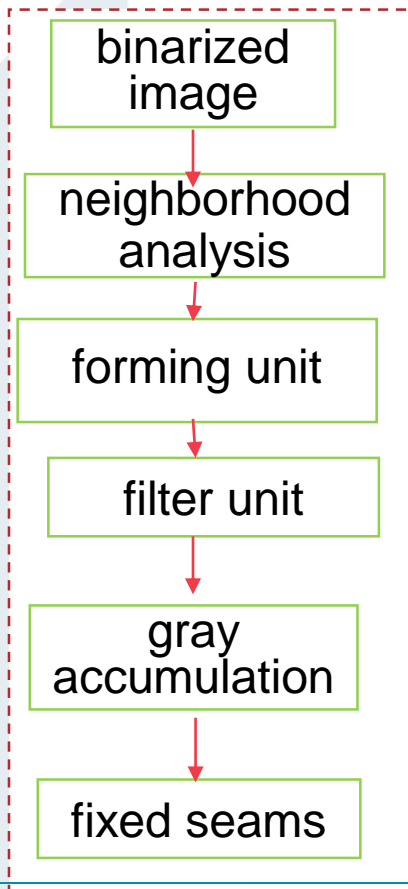
Binarization



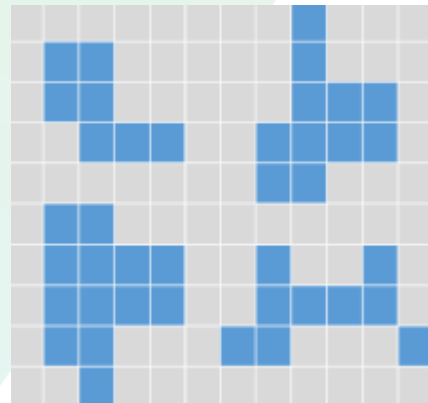


# Seams identification

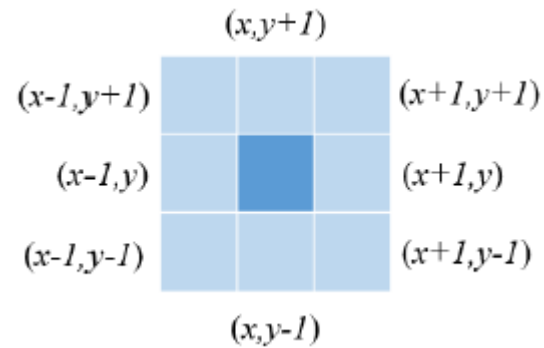
Connected analysis:



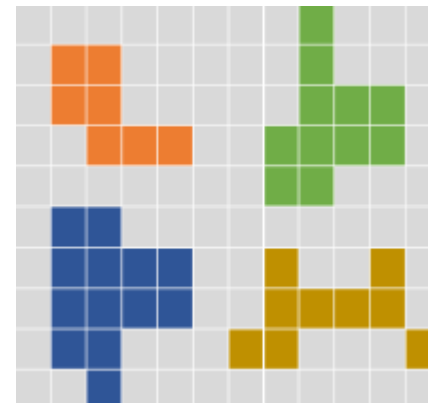
four neighborhood



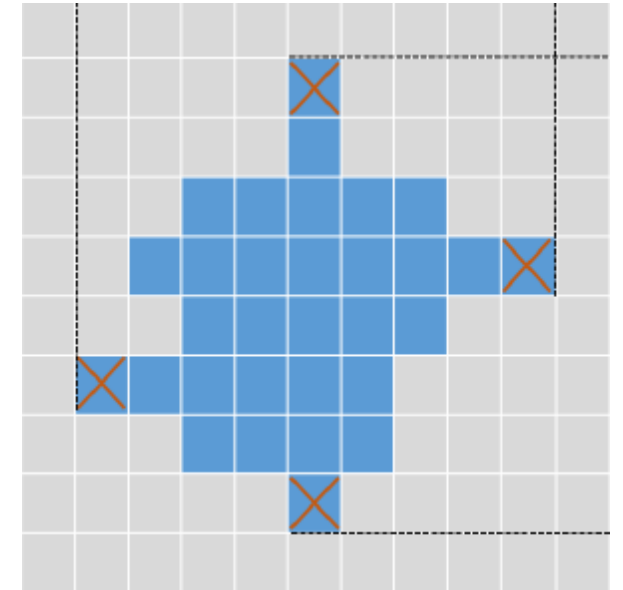
binarized image



eight neighborhood



forming unit



Unit Properties

$$mid\_x = \frac{1}{2}(max(x) + min(x))$$

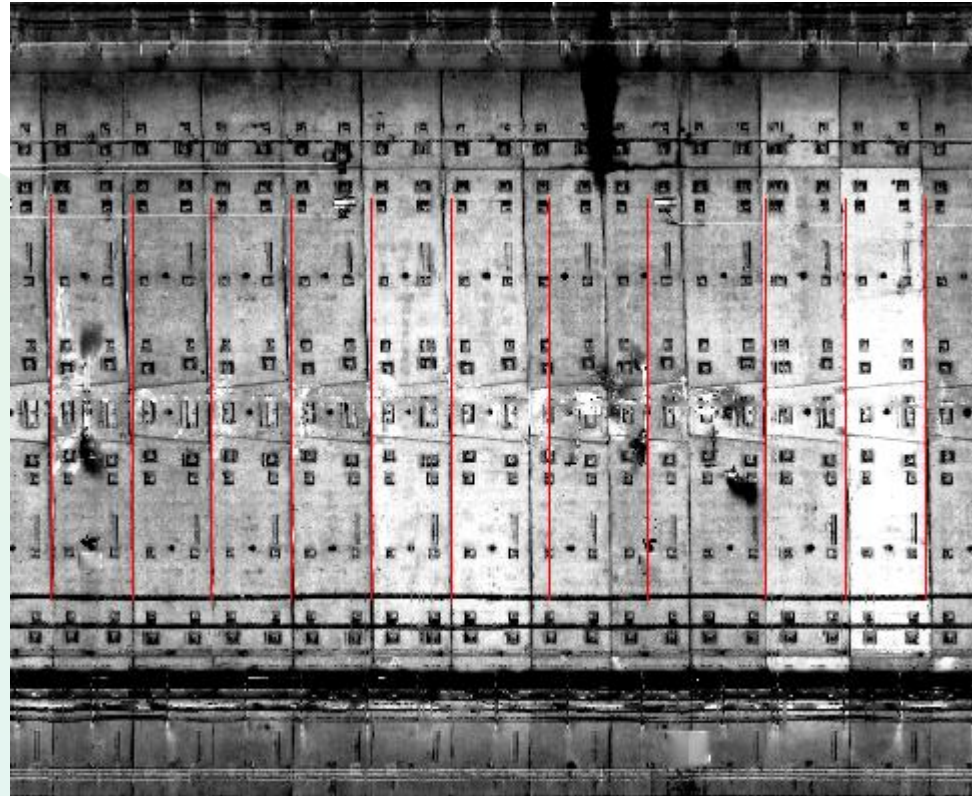
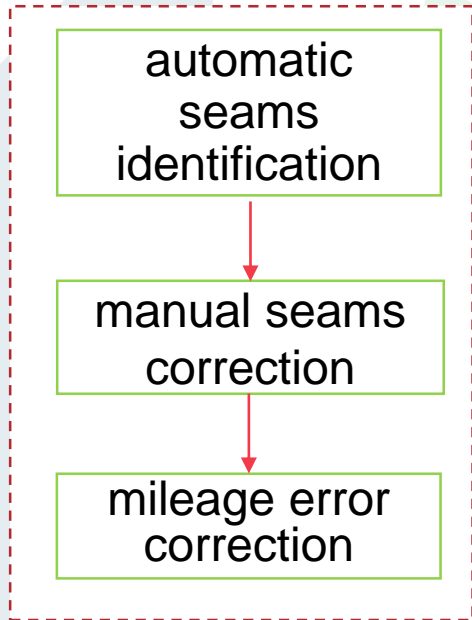
$$mid\_y = \frac{1}{2}(max(y) + min(y))$$

$$max\_weight = (max(x) - min(x))$$

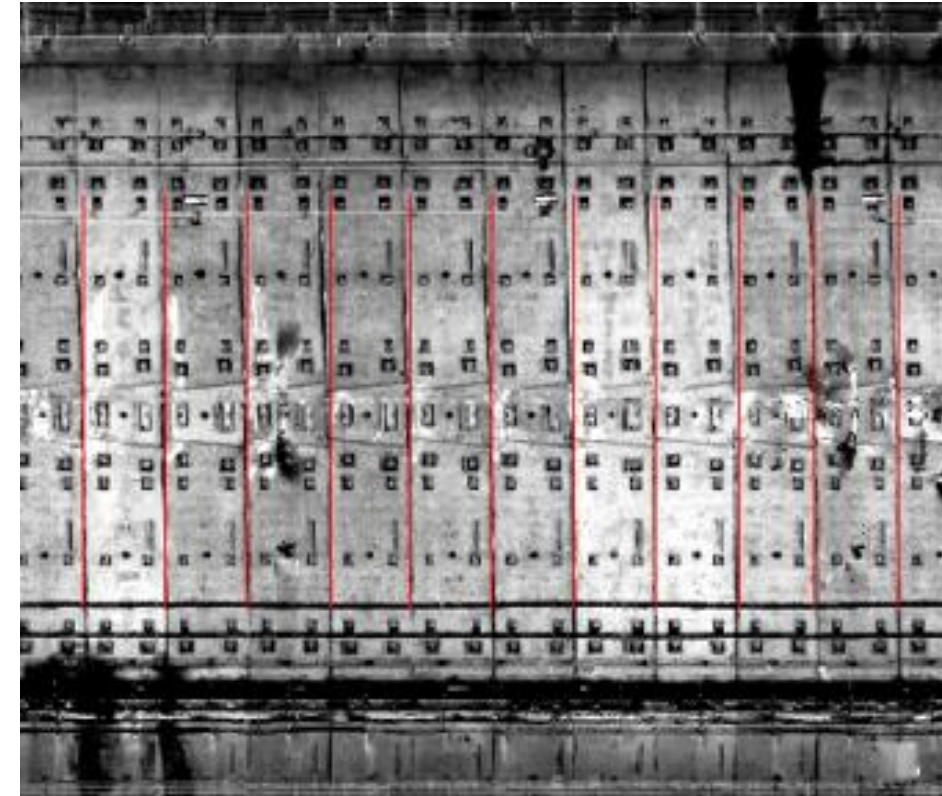
$$max\_height = (max(y) - min(y))$$

## Error correction

Odometer error:



automatic seams identification



manual correction

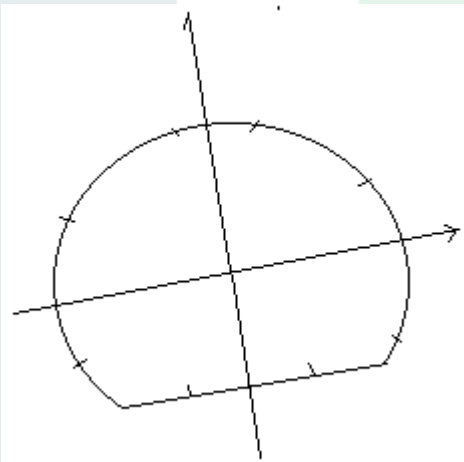
# Error correction

## scanner vertical deviation correction

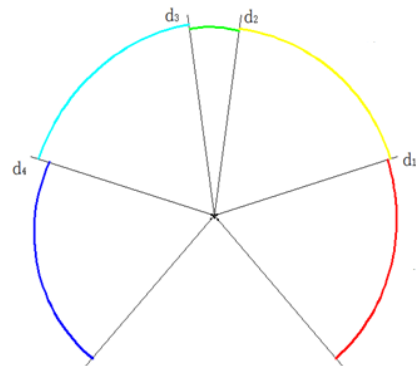
orbital error

instrument installation

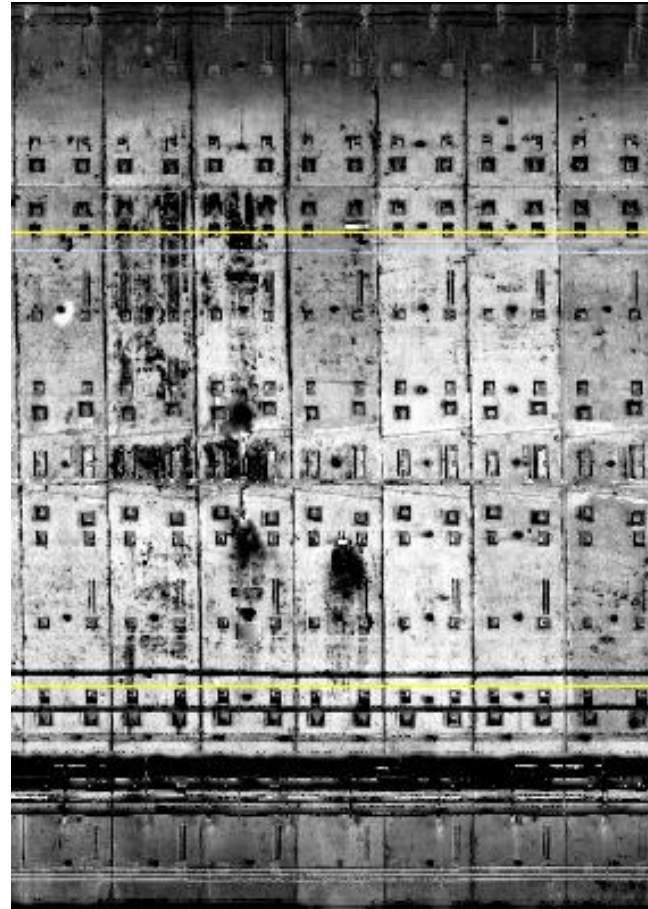
mobile jitter



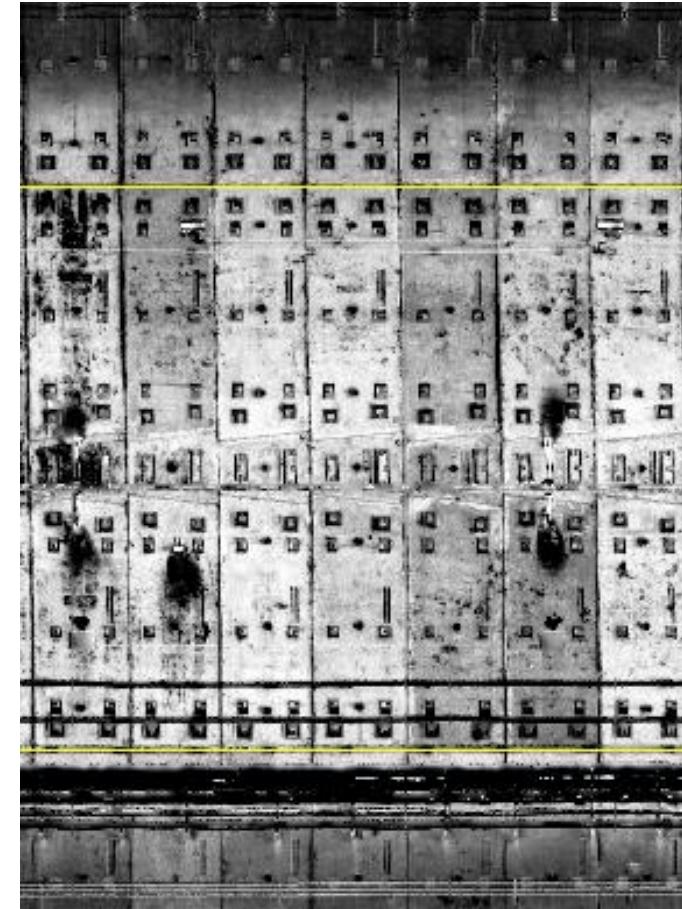
track super high



tunnel cross-section



scan vertical error



vertical error correction

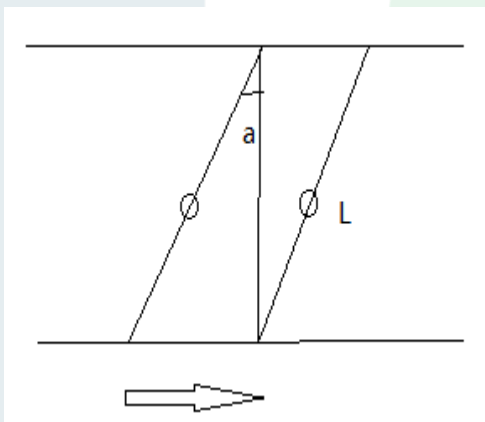
## Error correction

### scanner horizontal deviation

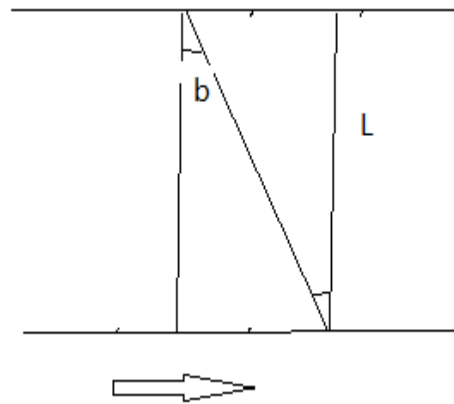
orbital error

instrument installation

mobile jitter

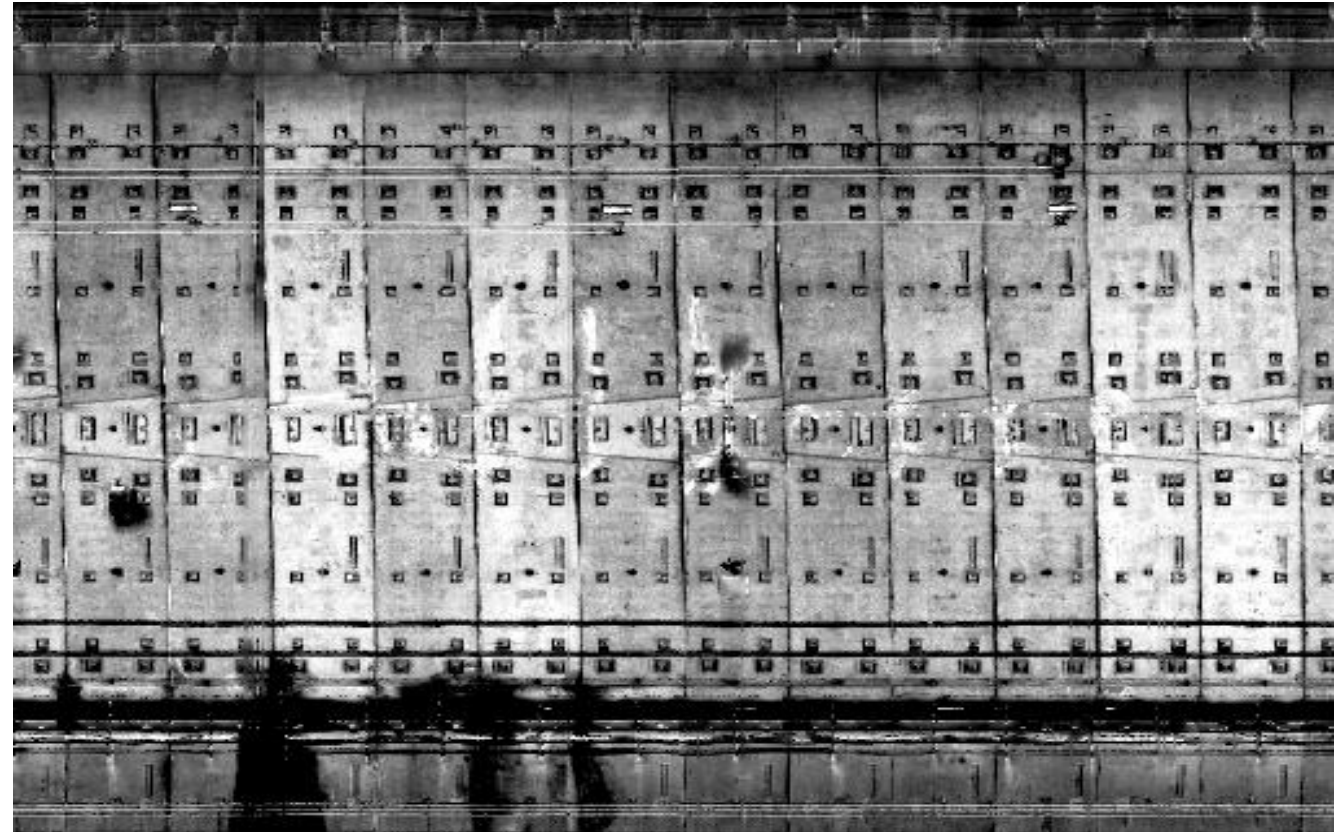


actual cross-section scan



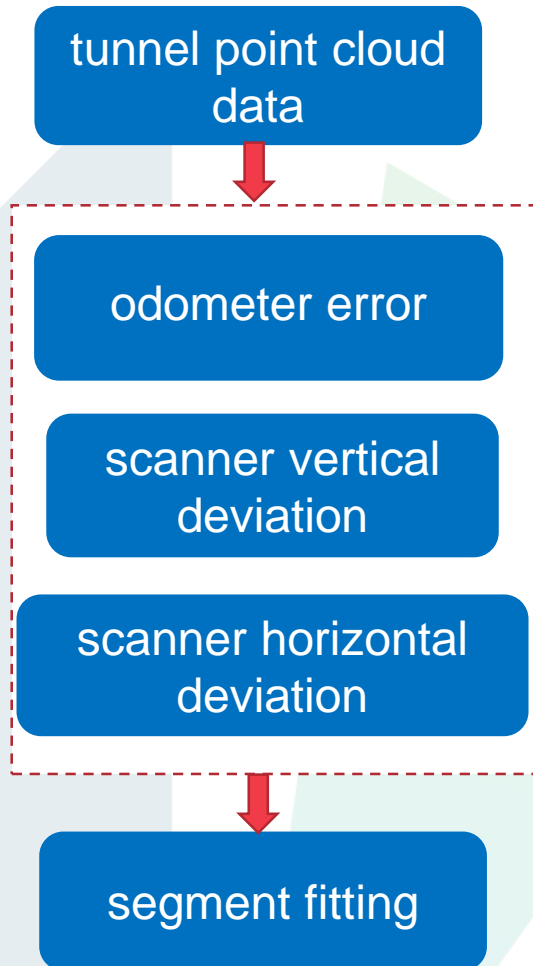
expanded image

$$L \cdot \sin(a) = L \cdot \tan(b)$$

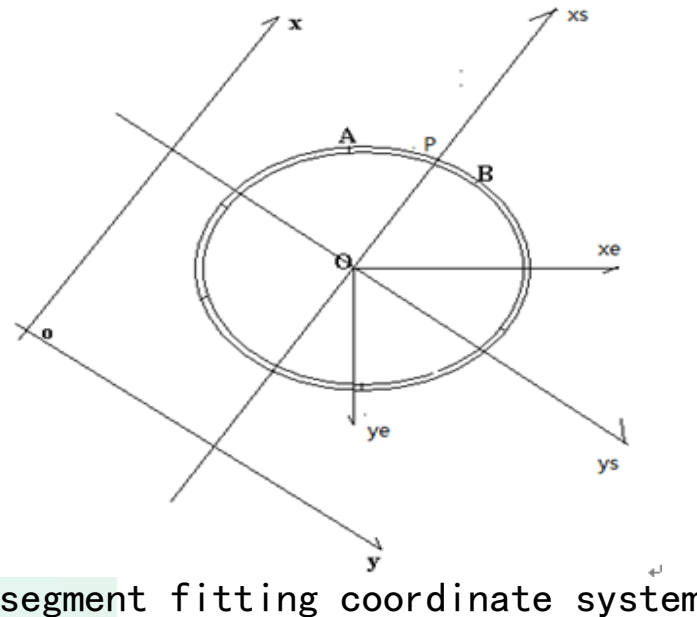


tilted seams image

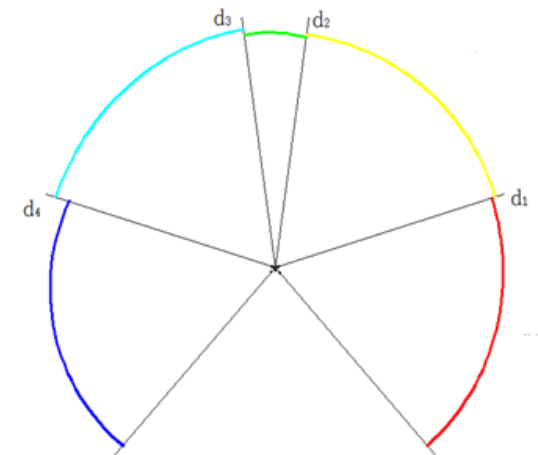
## Segment fitting



Each ring of the tunnel consists of 5 segments, and each of them is a rigid body. The amount of deformation consists of a rotation angle and a translation in order to match to the ellipse. The rotation angle is the rotation of the segment around the midpoint, and the translation is the direction of the segment from the center of the fitting to the center of the segment.

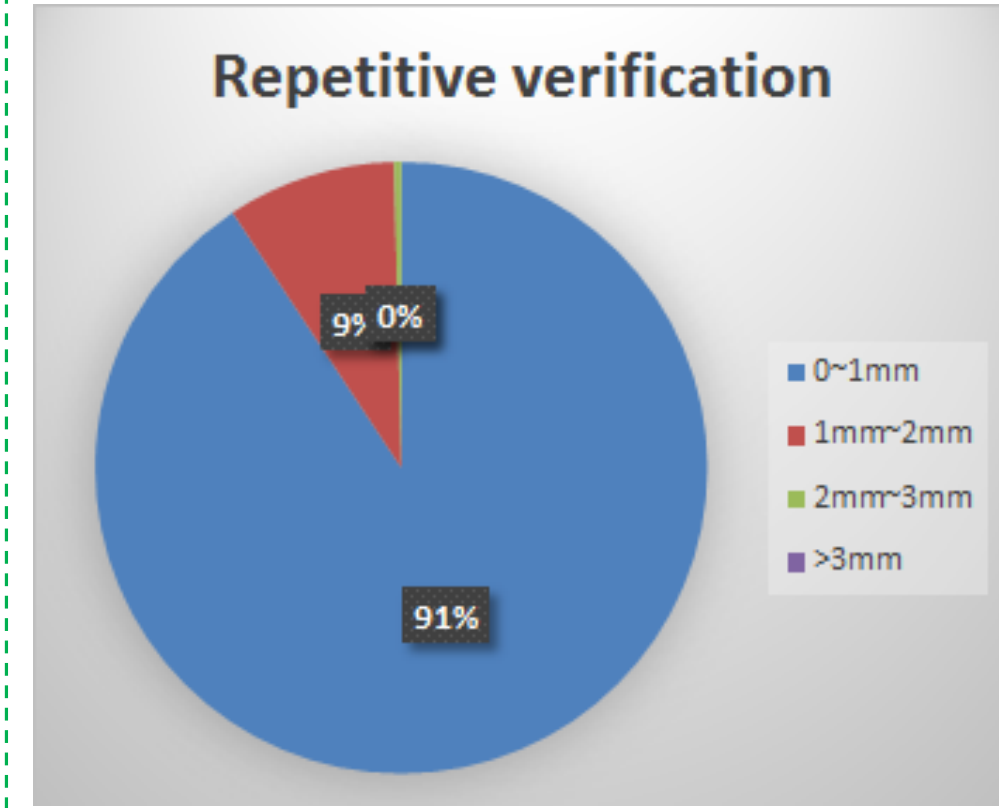
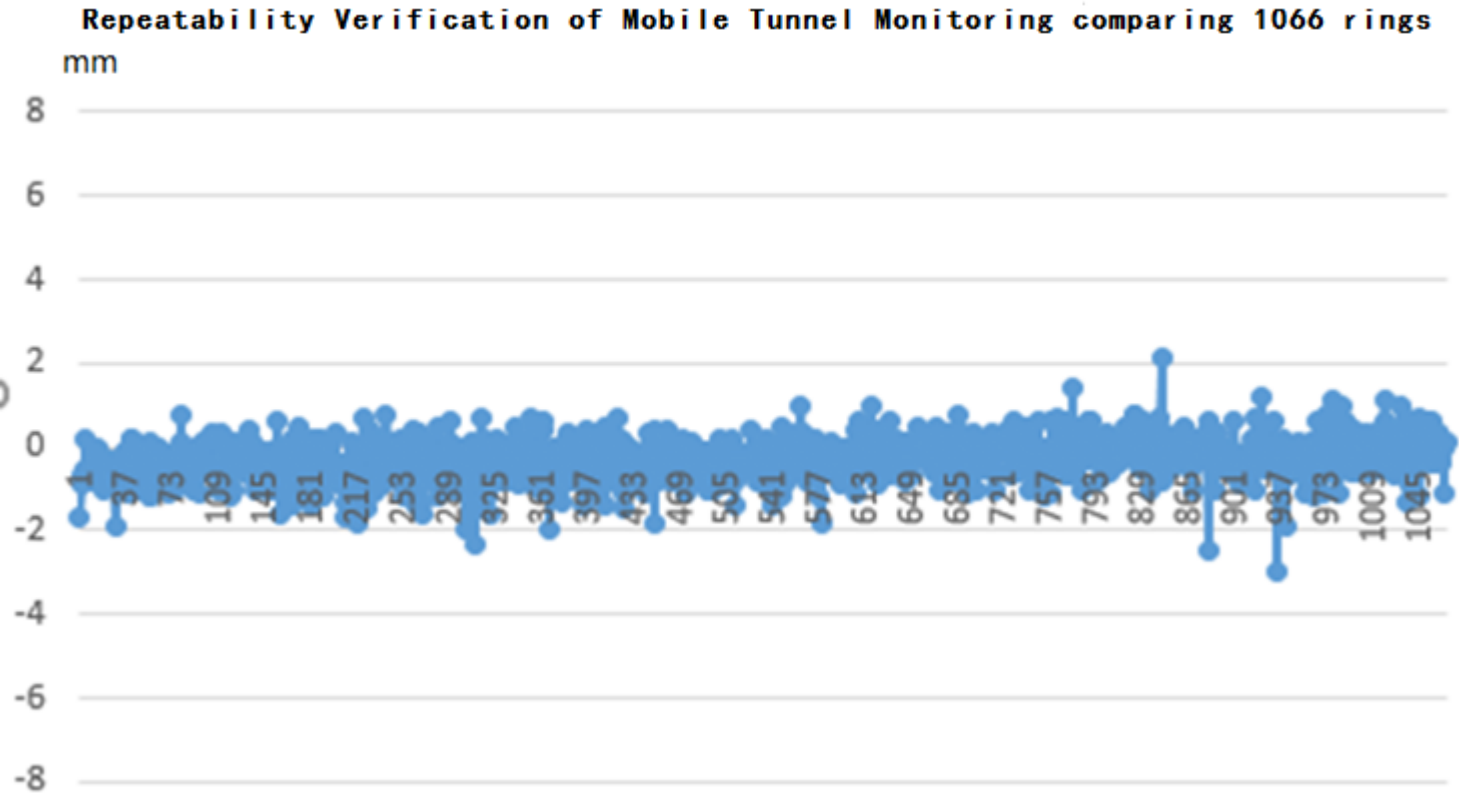


segment fitting coordinate system



Tunnel cross section

# Convergence verification of repeatability

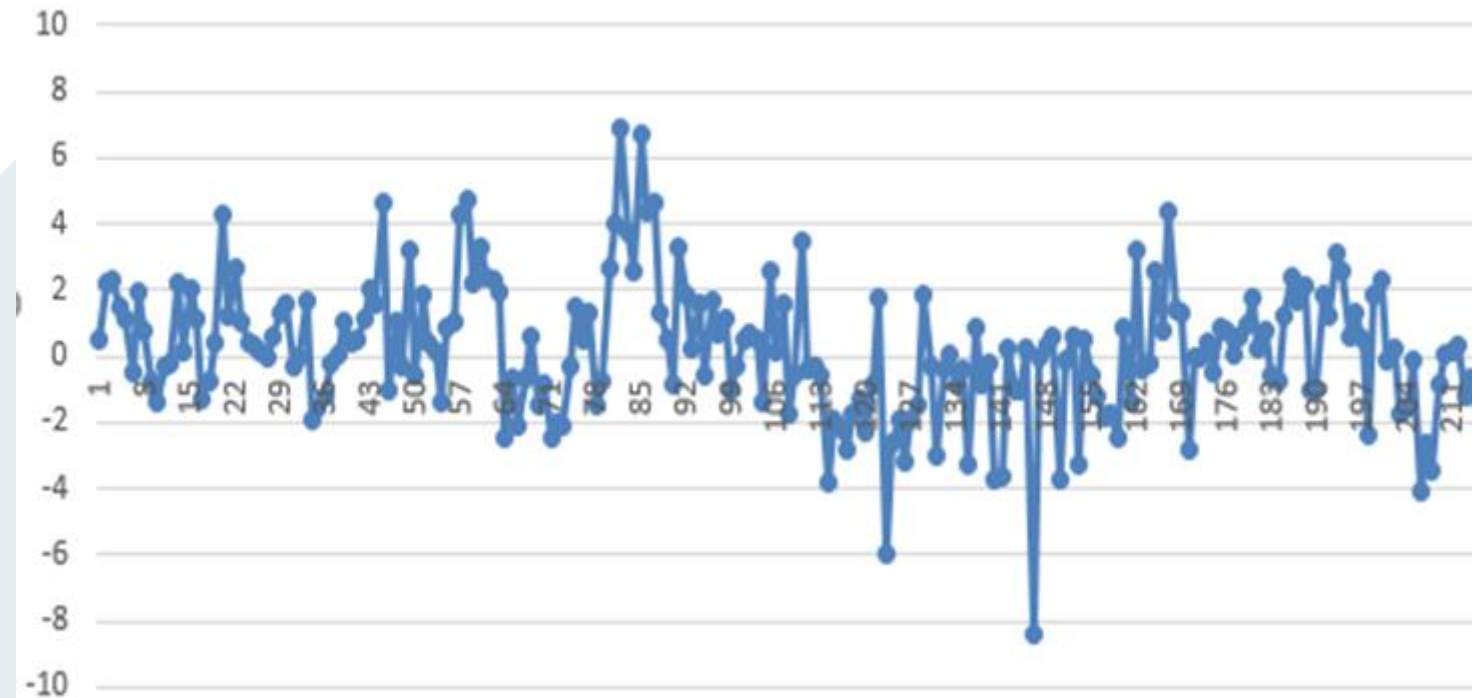


repeatability verification of mobile tunnel monitoring in a certain area of shanghai

Repeatability: approximately **100%** within **2mm**

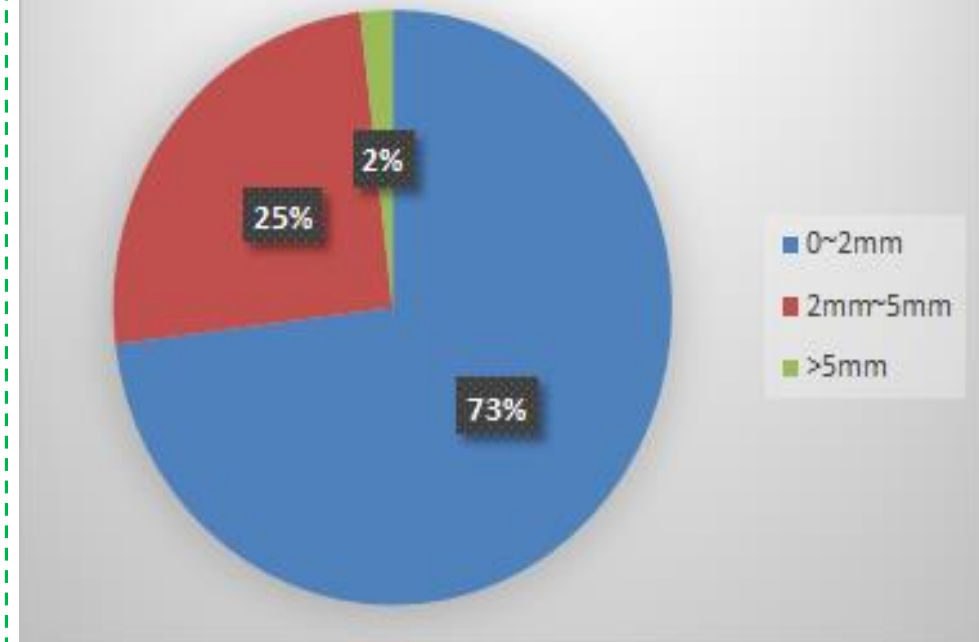
## Convergence verification of accuracy

Comparison with long-term convergence

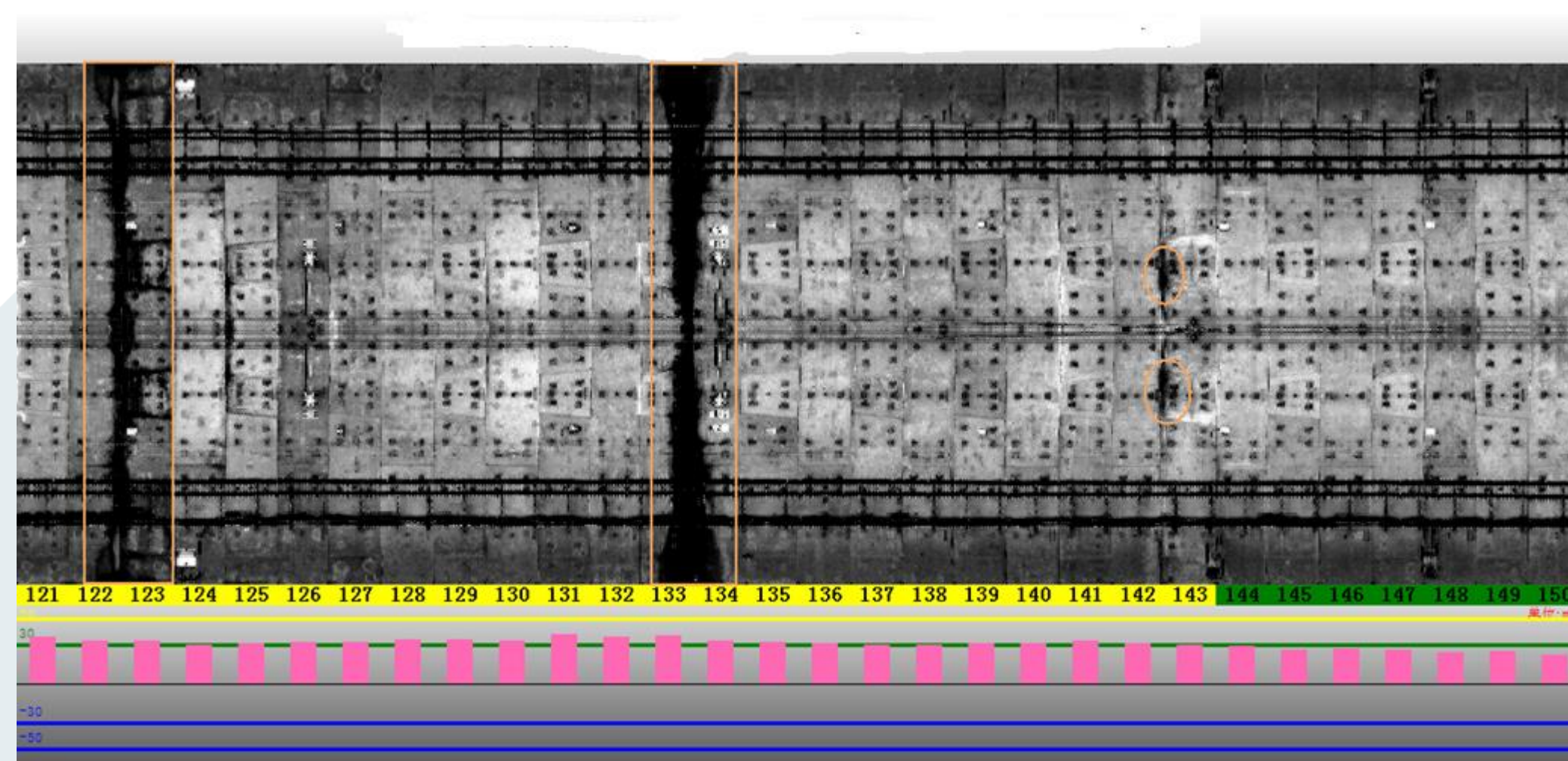


verification of the accuracy of mobile tunnel monitoring in a certain section of shanghai

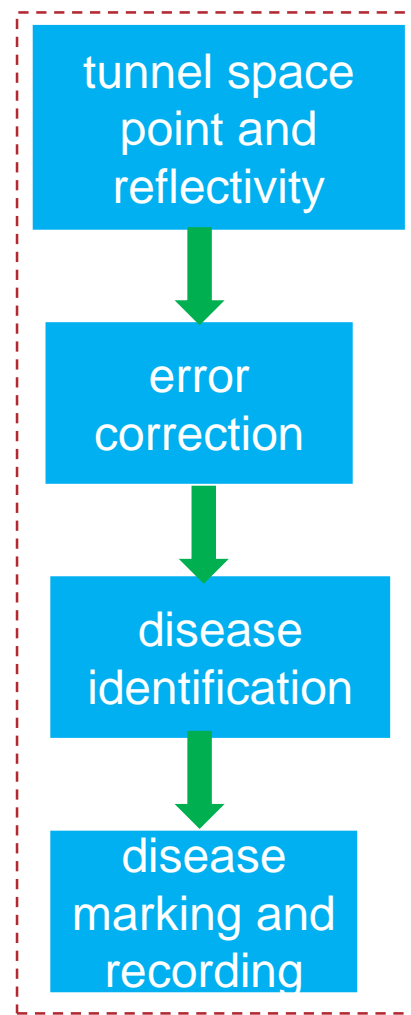
Accuracy verification



Accuracy:  
approximately **98%** within **5mm**



disease screening image



disease screening



(1) Low-cost and efficient monitoring systems have a wide range of needs.

(2) Through large-scale measured data calculating, it is verified that the system of repeatability is extremely high and stable, accuracy still need to improve and the tunnel image is clear, which can meet the engineering requirements.

## Future work

(1) Tunnel point cloud will correct the scanner horizontal angle error.

(2) Find ways to improve the accuracy of the convergence.



# Thank you for listening

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