# In-motion dense 3-D measurement of industrial surfaces with continuous extension

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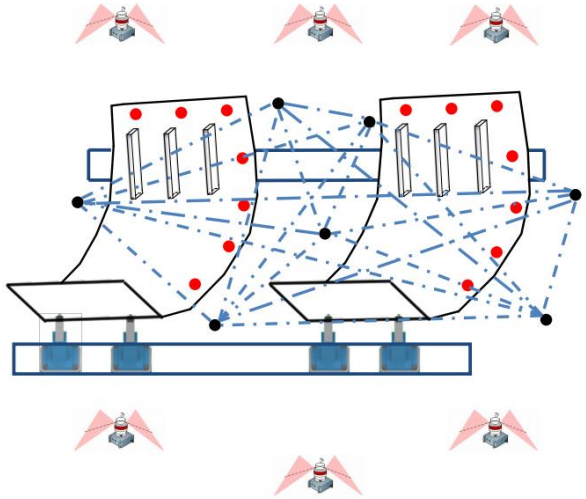
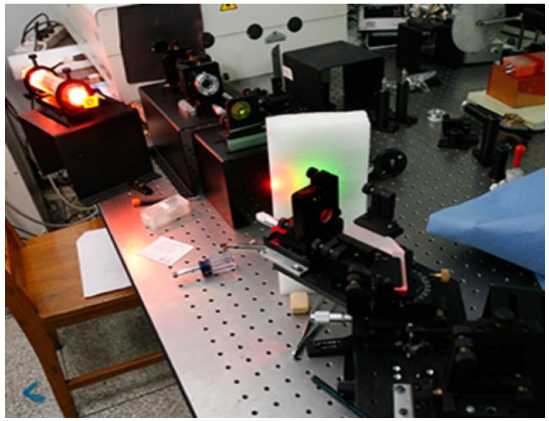
# Laser and Optoelectronics Measurement Technology Research Group

**Our research group mainly focuses on advanced laser and optoelectronics techniques to solve the measurement problems in the industrial field.**



Large-scale coordinate measurement

Vision measurement principles and methods



New technology of laser and photoelectric test

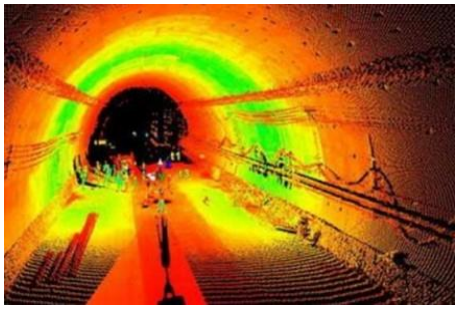
# Outline

- Backgrounds
- Point cloud profile acquisition
- Global control based on pose constraints
- Fine optimization based on point cloud constraints
- Relevant outcomes

# Backgrounds

## Train, track, tunnel, aircraft inspection in the industrial field

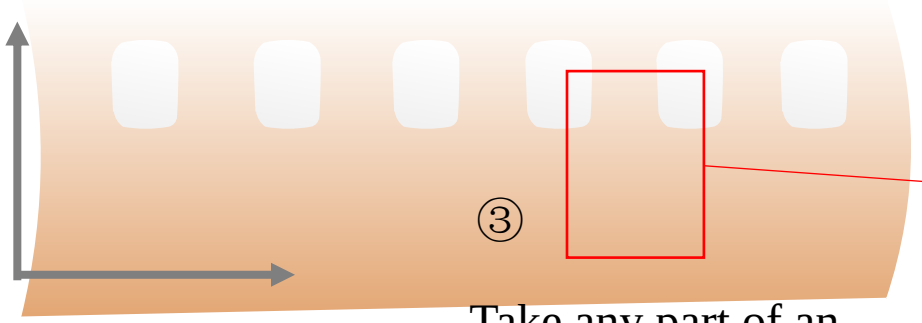





## Requirements

① Continuous extension

② High density in two directions

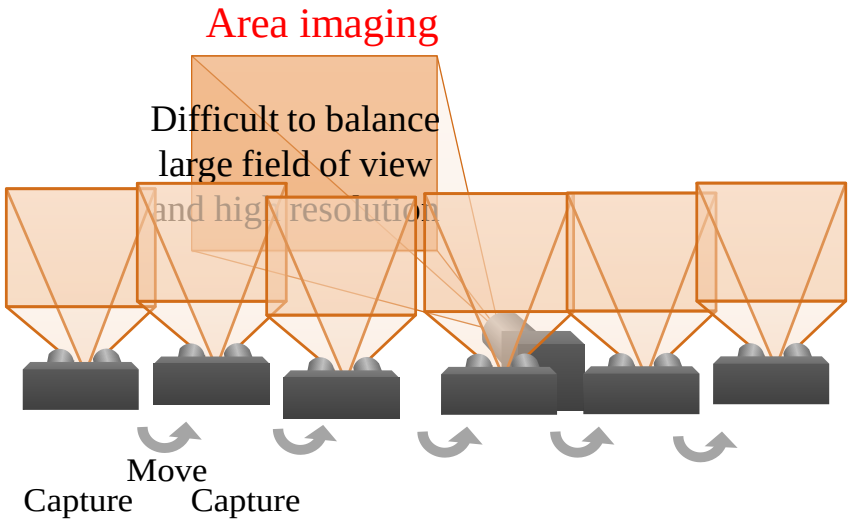



Take any part of an extending point cloud

The accuracy is controllable

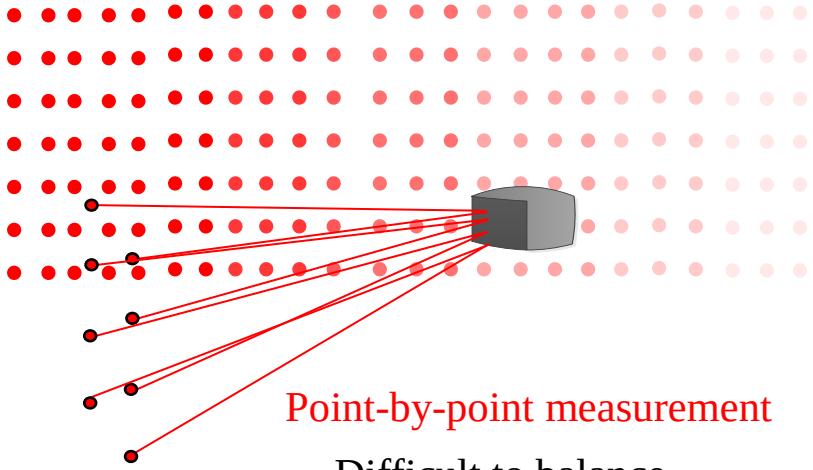
# Backgrounds

## Mainstream 3-D shape measurement methods




Discontinuous stitching

**3-D shape measurement based on area-scan camera**



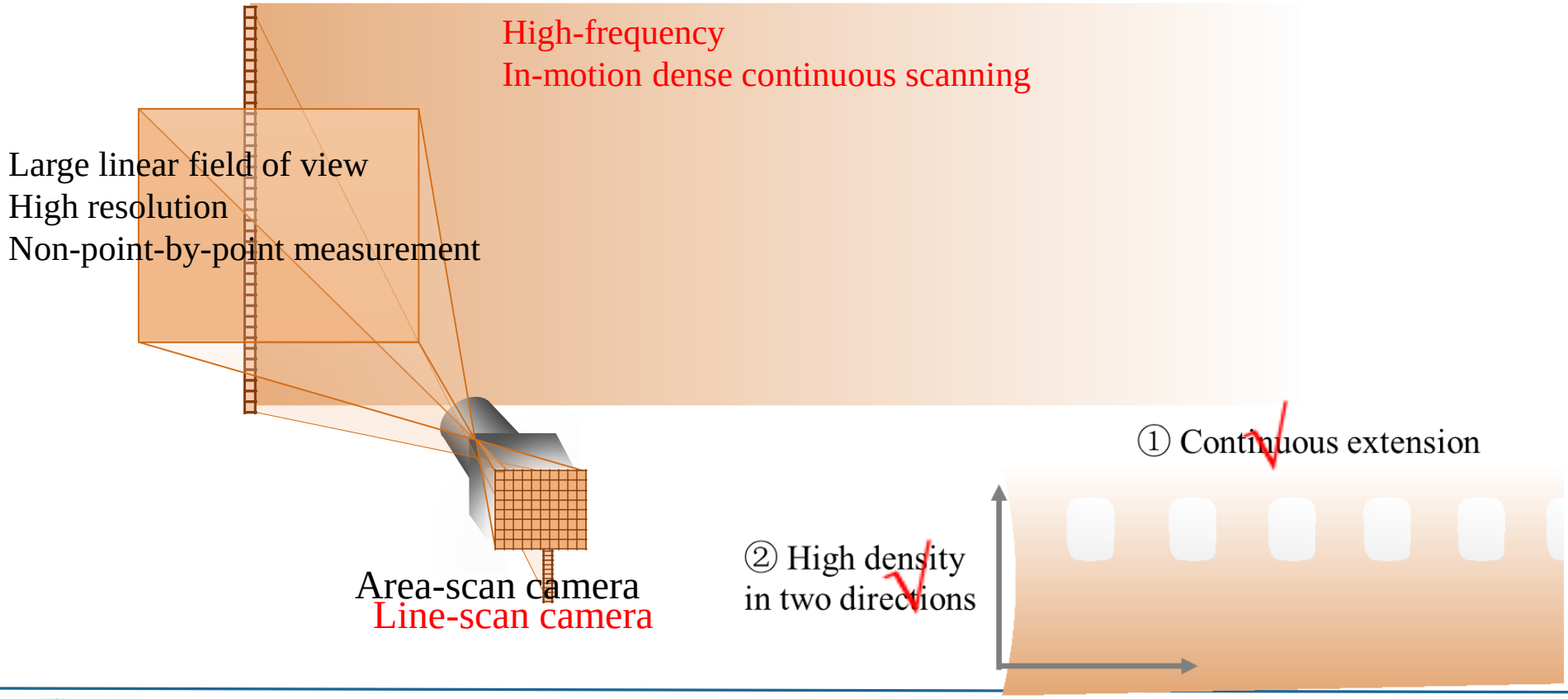
Point-by-point measurement

Difficult to balance
fast scanning and
high resolution

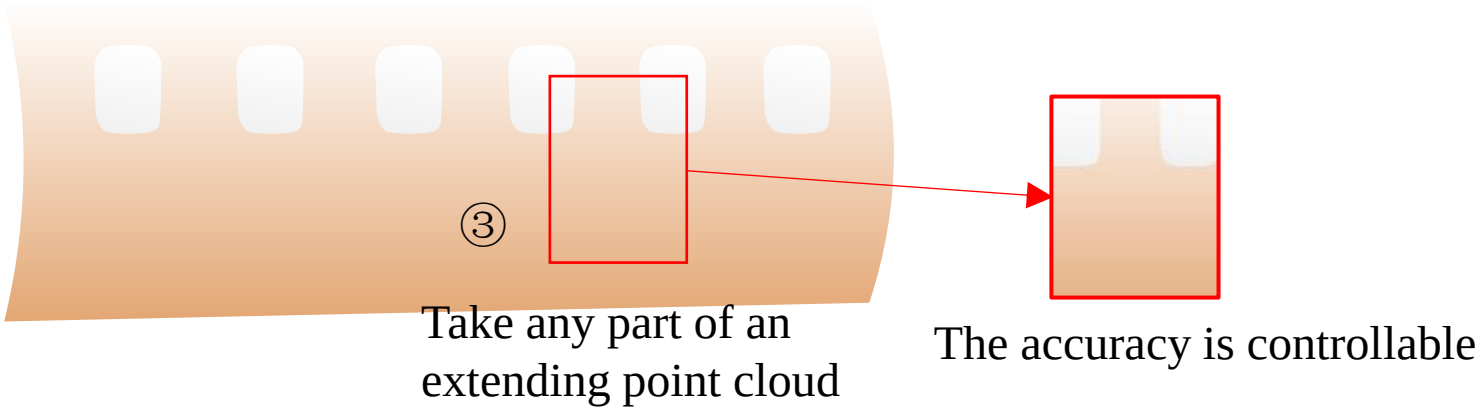
**3-D shape measurement based on laser scanner**

# Backgrounds

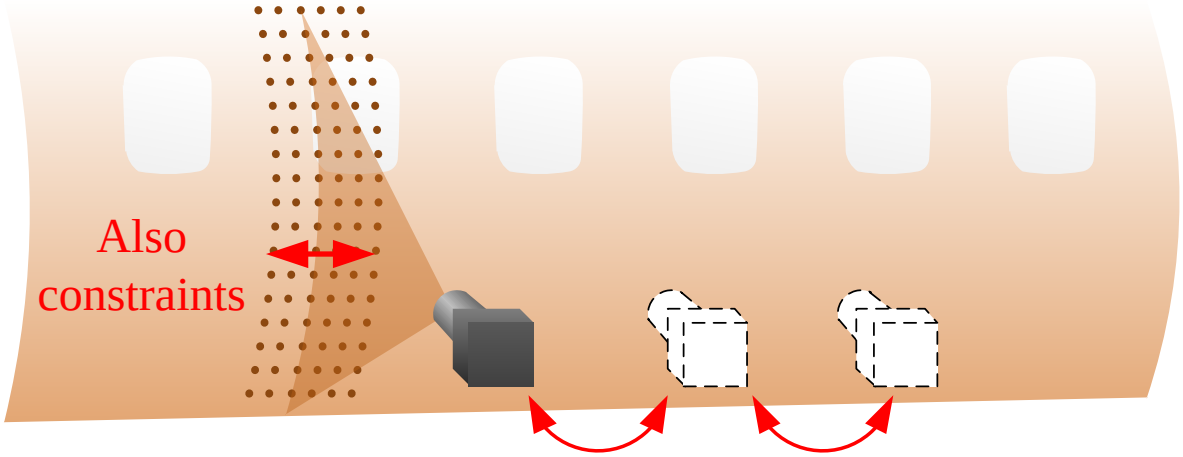
## Line-scan cameras (with linear array CCD or CMOS) have potential



# Backgrounds

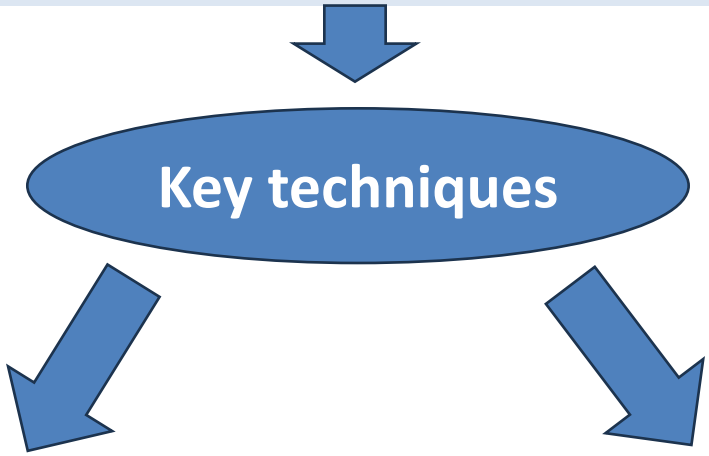



**Which means —— we need constraints for an extending point cloud**



# Backgrounds

In-motion dense 3-D measurement of industrial surfaces with continuous extension




Point cloud profile acquisition based on 1-D imaging

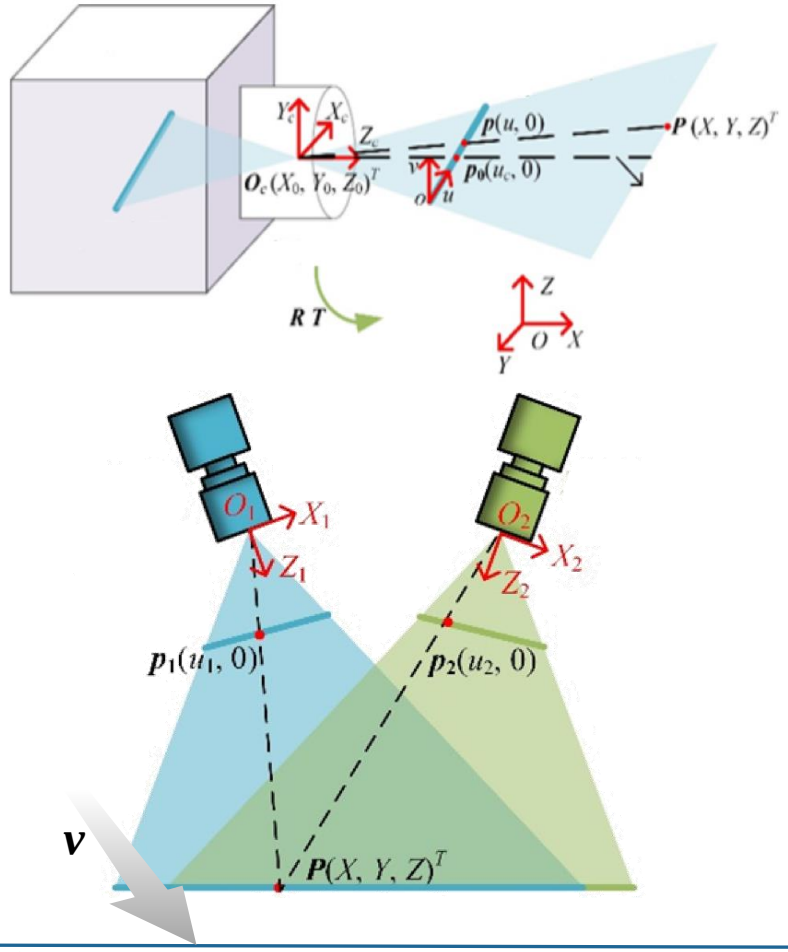
Constraint establishment for accurate extension

# Outline

- Backgrounds
- Point cloud profile acquisition
- Global control based on pose constraints
- Fine optimization based on point cloud constraints
- Relevant outcomes

# Point cloud profile acquisition

- **Measurement model**




### a. 1-D imaging formula

$$\begin{cases} u = u_c + \Delta u + f_x \dfrac{r_{11}X + r_{12}Y + r_{13}Z + T_1}{r_{31}X + r_{32}Y + r_{33}Z + T_3} \\ 0 = r_{21}X + r_{22}Y + r_{23}Z + T_2 \end{cases}$$

### b. Stereo vision

$$\begin{bmatrix} u'_1 r_{31}^1 - r_{11}^1 & u'_1 r_{32}^1 - r_{12}^1 & u'_1 r_{31}^1 - r_{11}^1 \\ r_{21}^1 & r_{22}^1 & r_{23}^1 \\ u'_2 r_{31}^2 - r_{11}^2 & u'_2 r_{32}^2 - r_{12}^2 & u'_2 r_{31}^2 - r_{11}^2 \\ r_{21}^2 & r_{22}^2 & r_{23}^2 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} T_1^1 - u'_1 T_3^1 \\ -T_2^1 \\ T_1^2 - u'_2 T_3^2 \\ -T_2^2 \end{bmatrix}$$

### c. Extension with motion

$$X_t = X - \int_{t_0}^{t} v_x dt$$

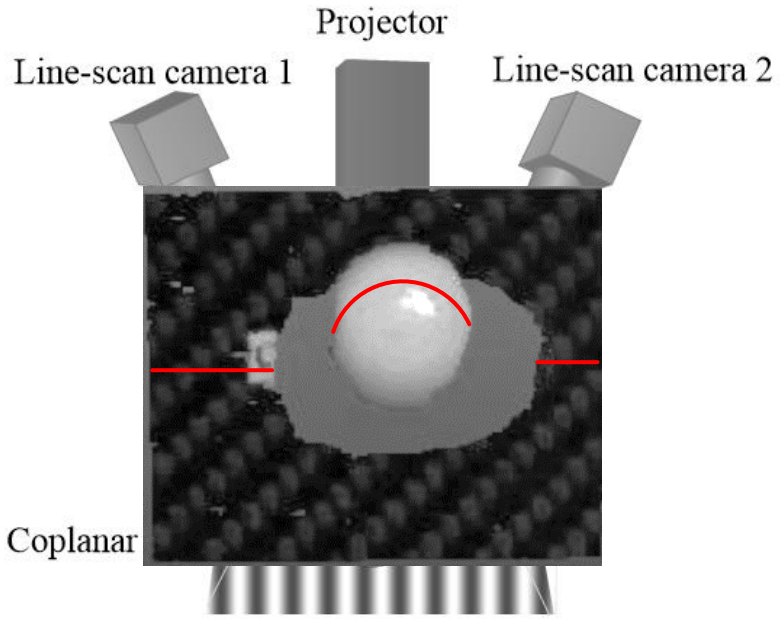
$$Y_t = Y - \int_{t_0}^{t} v_y dt$$

$$Z_t = Z - \int_{t_0}^{t} v_z dt$$

# Point cloud profile acquisition

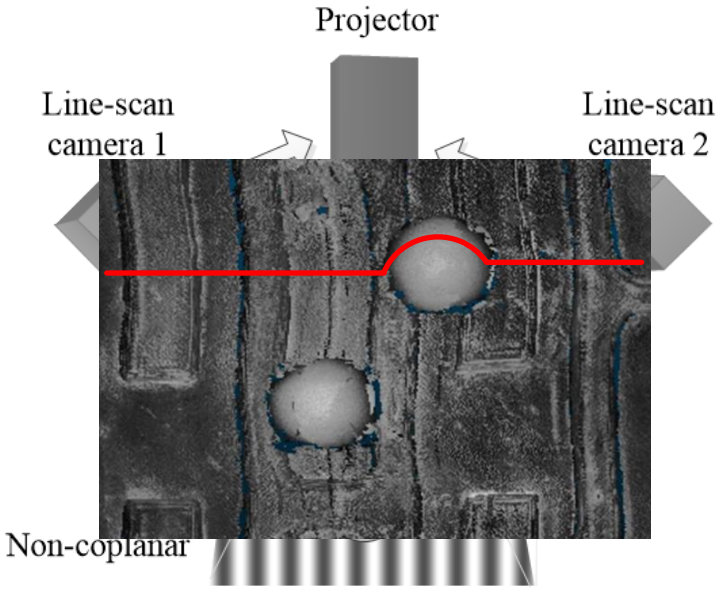
- **Structure analysis**

## Coplanar structure




High-precision point cloud profile

## Non-coplanar structure




High-integrity point cloud profile

# Point cloud profile acquisition

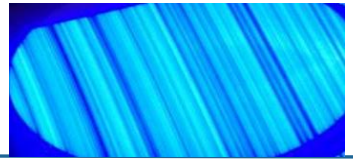
- **1-D image matching**

**Features are not obvious**

Error in

Matching based on texture

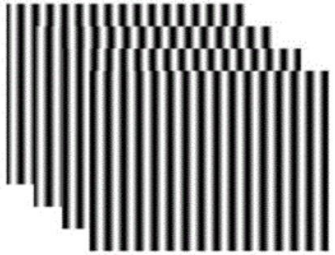
Matching based on random fringe



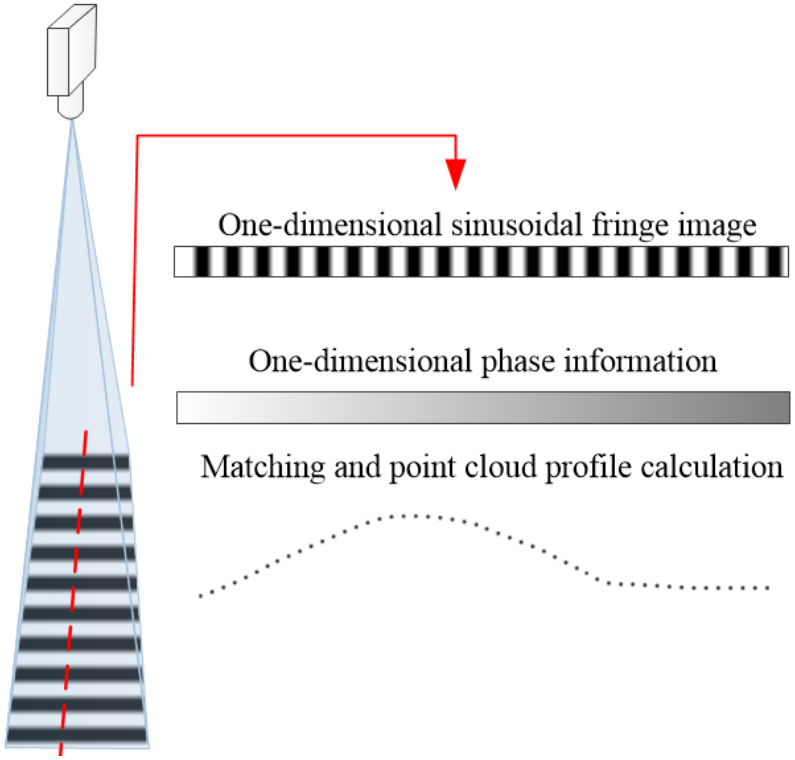
**Motion influence**

Not suitable

Matching based on phase shift



Matching based on Fourier transform profilometry (FTP)

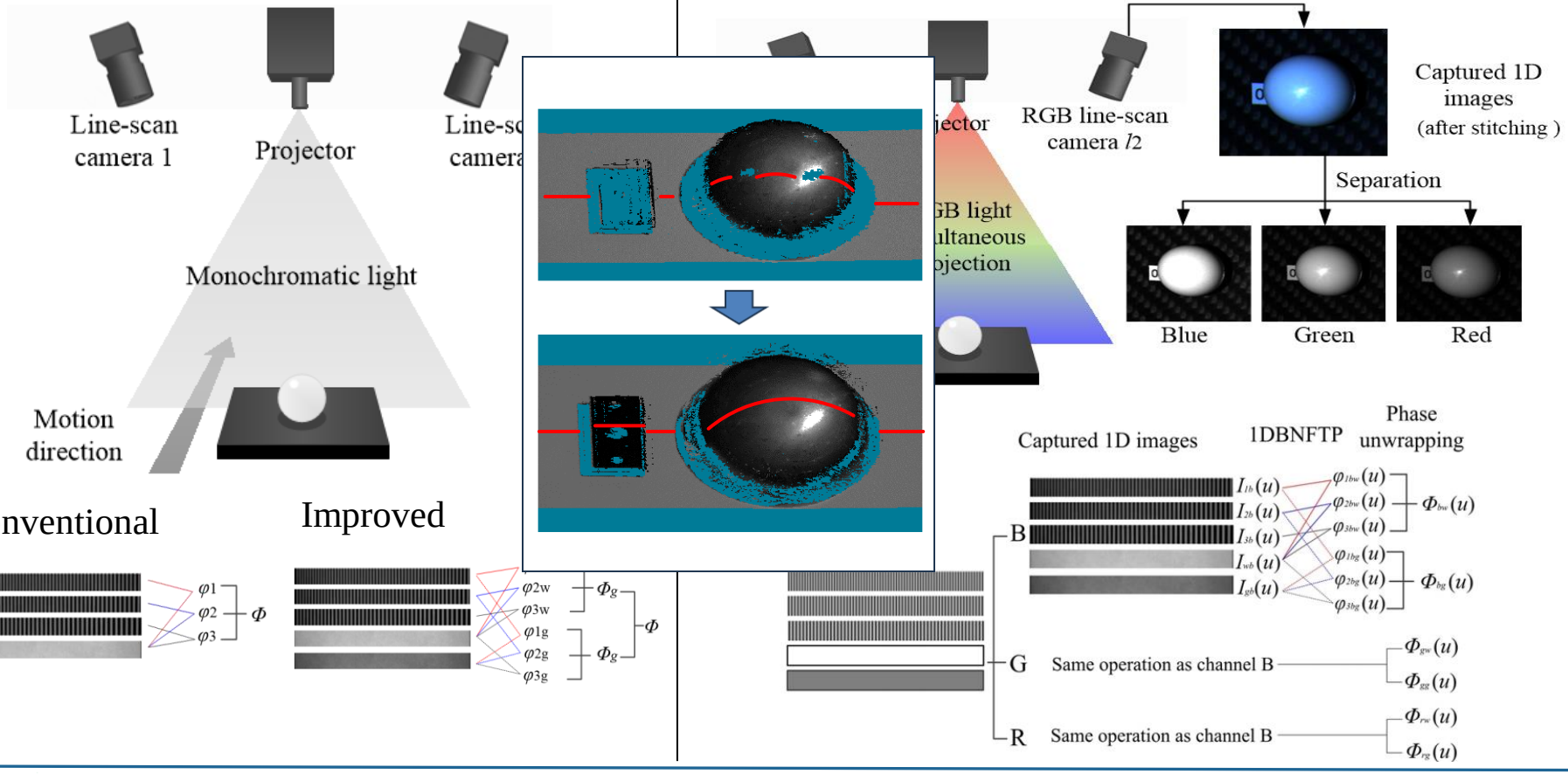


# Point cloud profile acquisition

- **1-D image matching**

FTP + Background normalization

Color structured light FTP



# Outline

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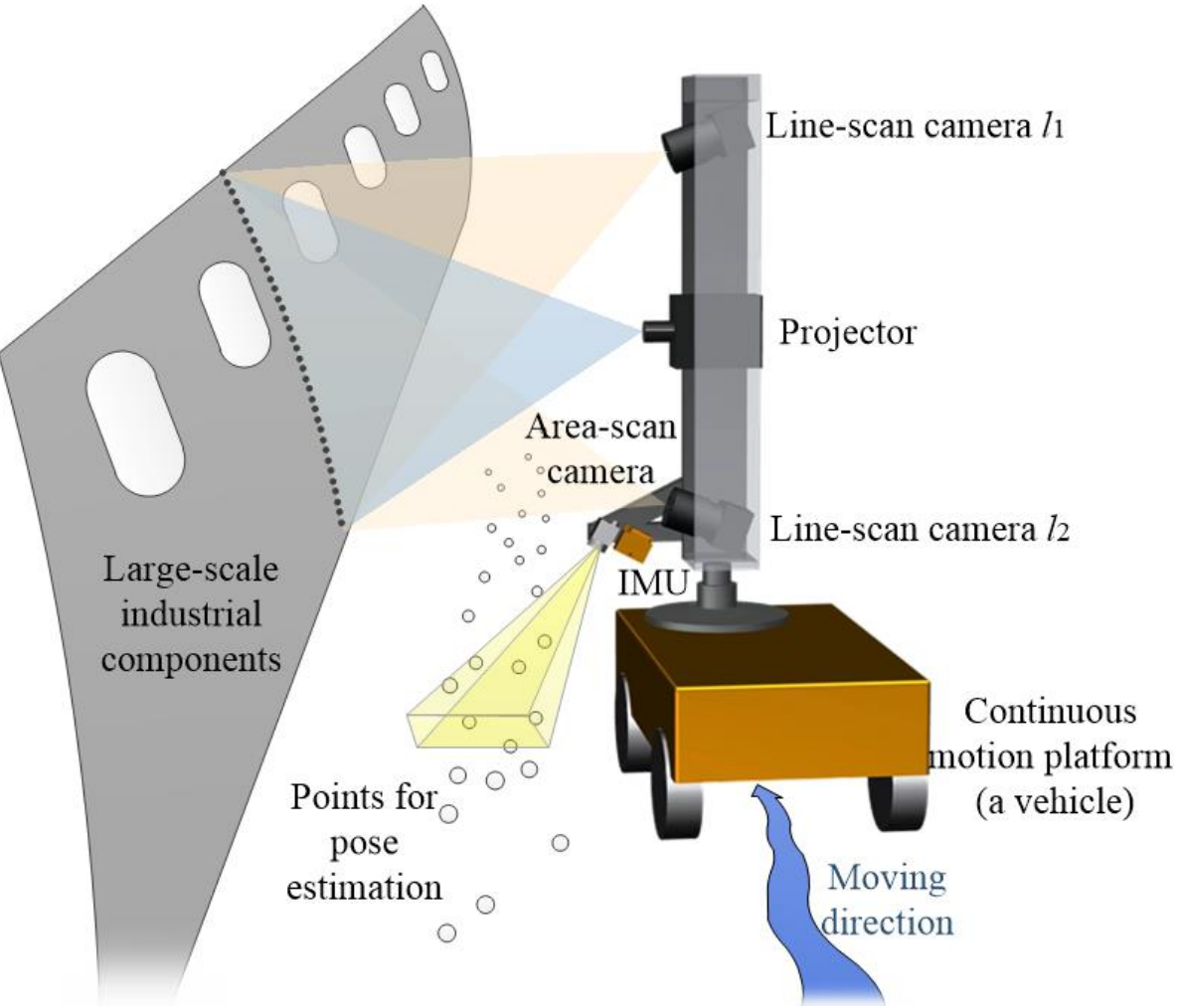
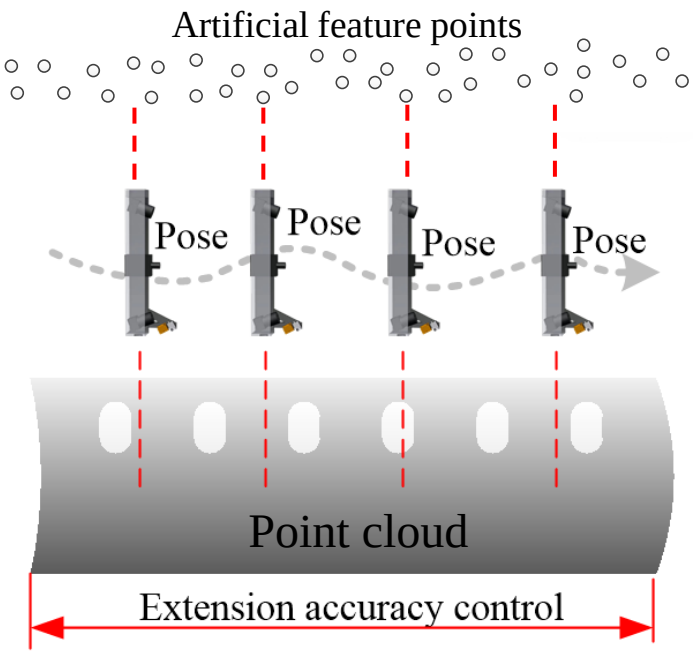
- Fine optimization based on point cloud constraints
- Relevant outcomes

# Global control based on pose constraints

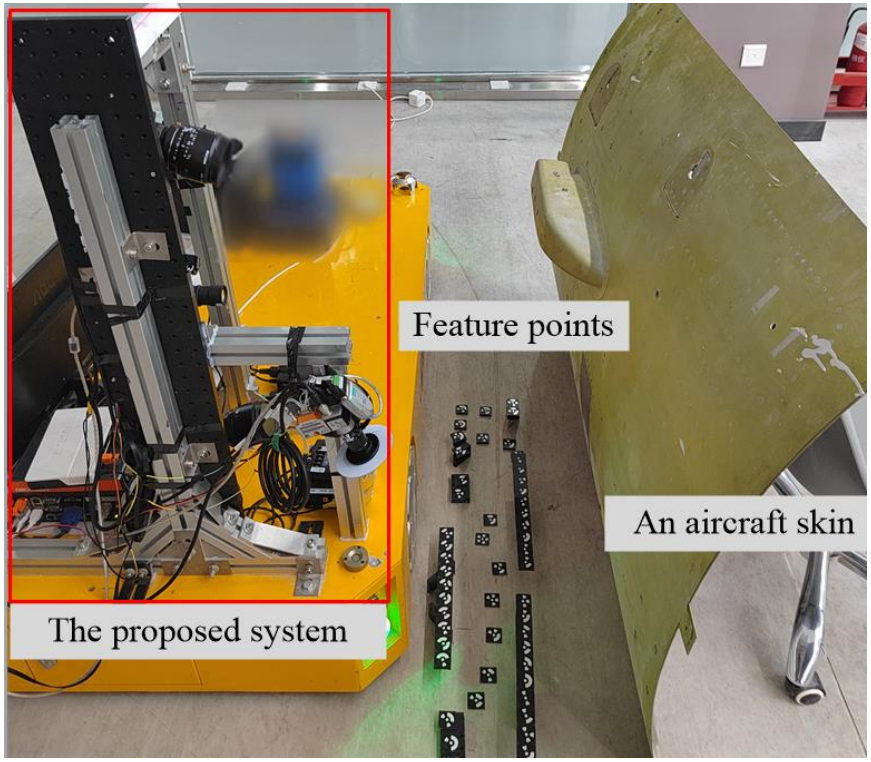
- **Using artificial feature points**



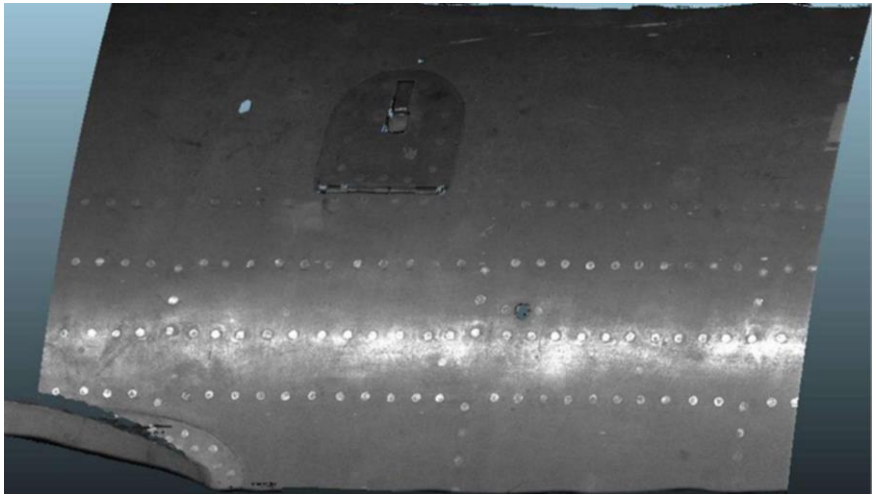
# Global control based on pose constraints

- **Using artificial feature points**




Measured point cloud of a ball-bar model

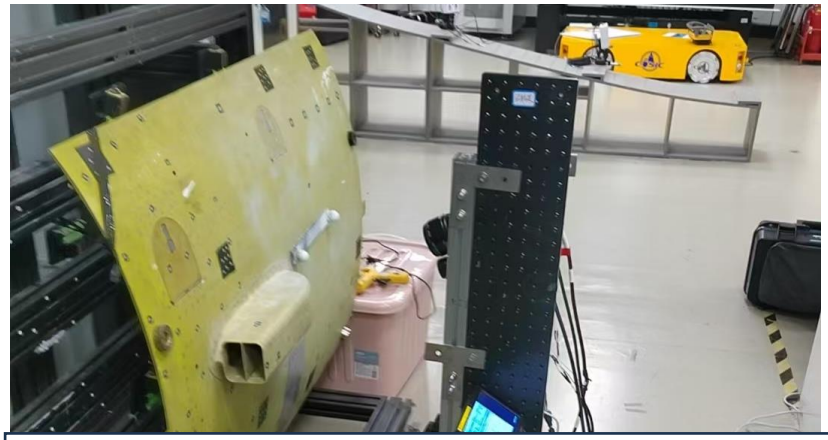
Sphere center distance error: about 0.3 mm

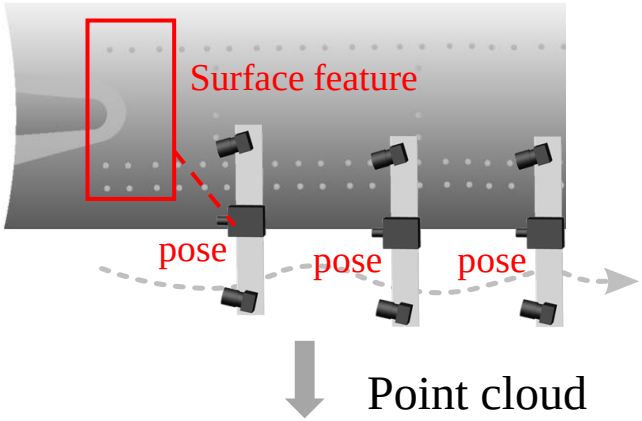


Measured point cloud of an aircraft skin

# Global control based on pose constraints

- **Current research—using the surface's own features**





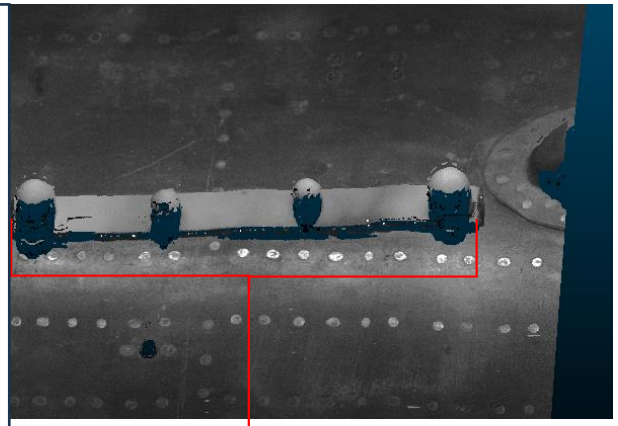

Noise

Insufficient frequency

Coordinate transformation error

**Using pose constraints is not enough**

**Further fine optimization is needed**



re center distance error: about 0.5 mm

# Outline

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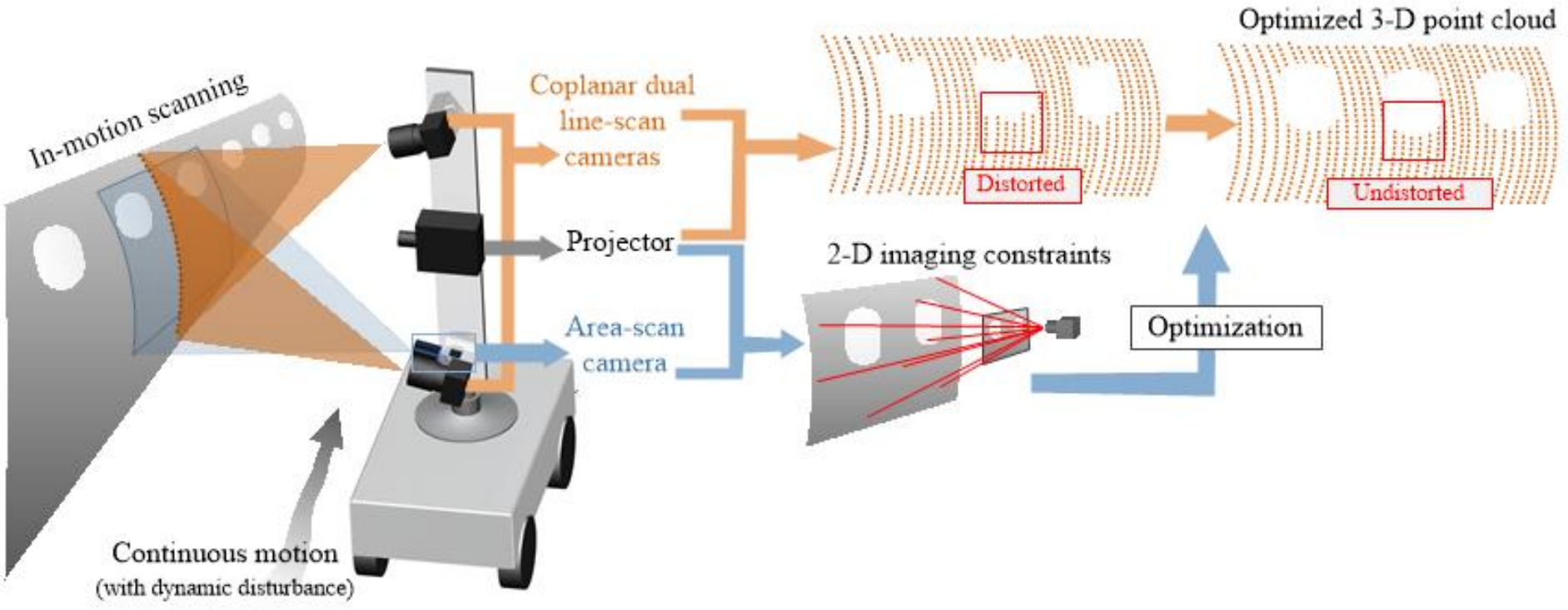
# Fine optimization based on imaging constraints

- **Using 2-D imaging constraints**

Line-scan cameras ➡ Continuously measure point cloud profiles in motion

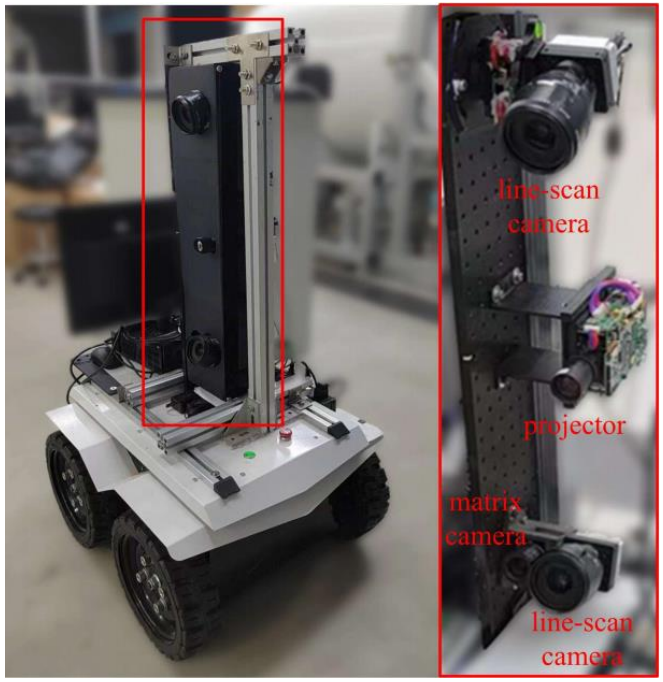
Area-scan camera ➡ Provide 2-D imaging constraints for point cloud profiles



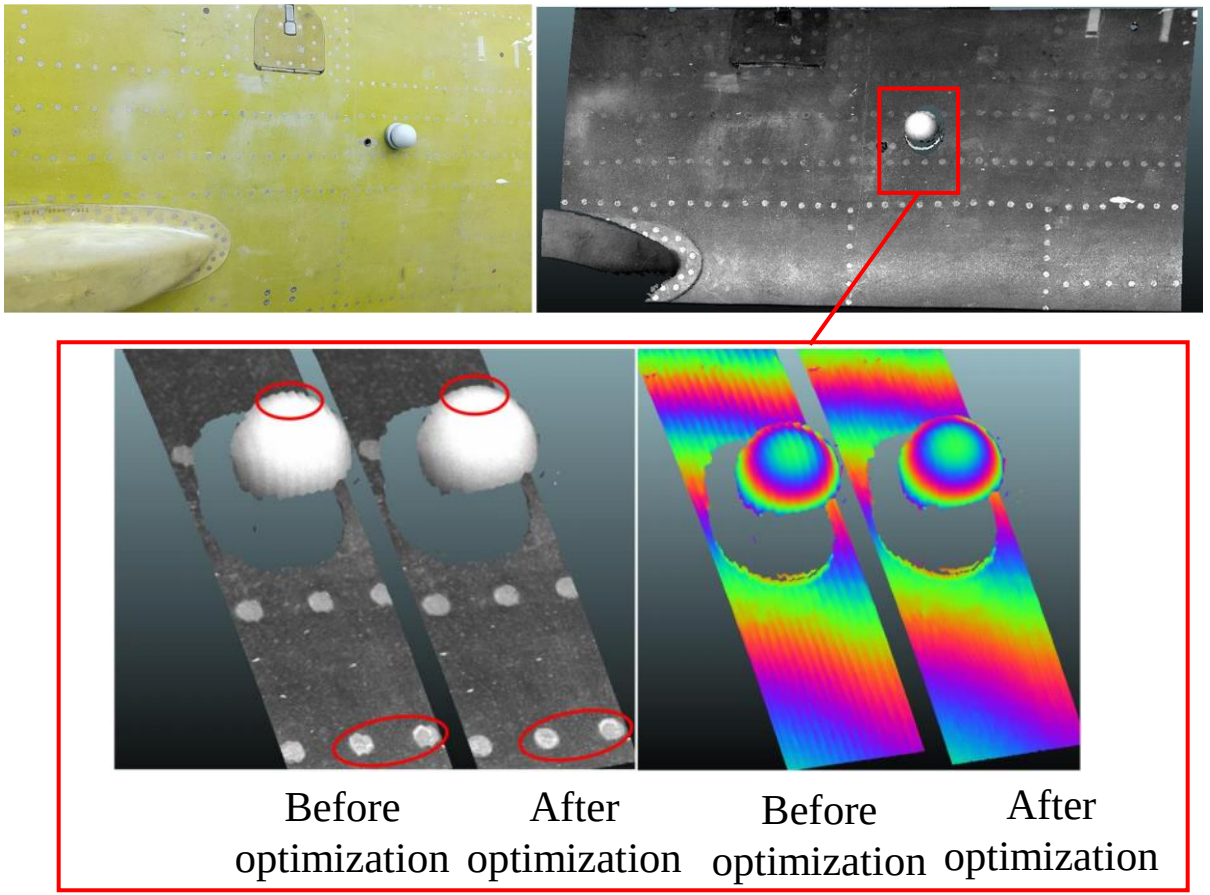
# Fine optimization based on imaging constraints

- **Using 2-D imaging constraints**

Measurement system



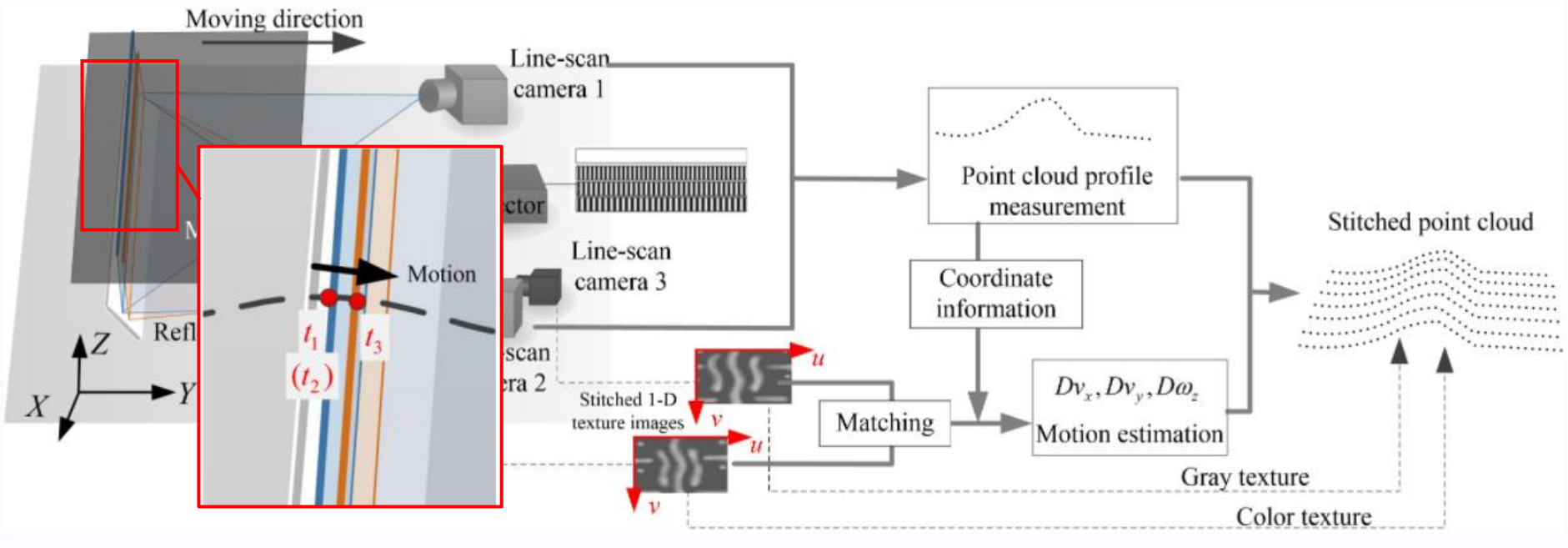

Optimization results




Sphere point cloud accuracy: about 0.1 mm

# Fine optimization based on imaging constraints

- **Using 1-D imaging constraints**

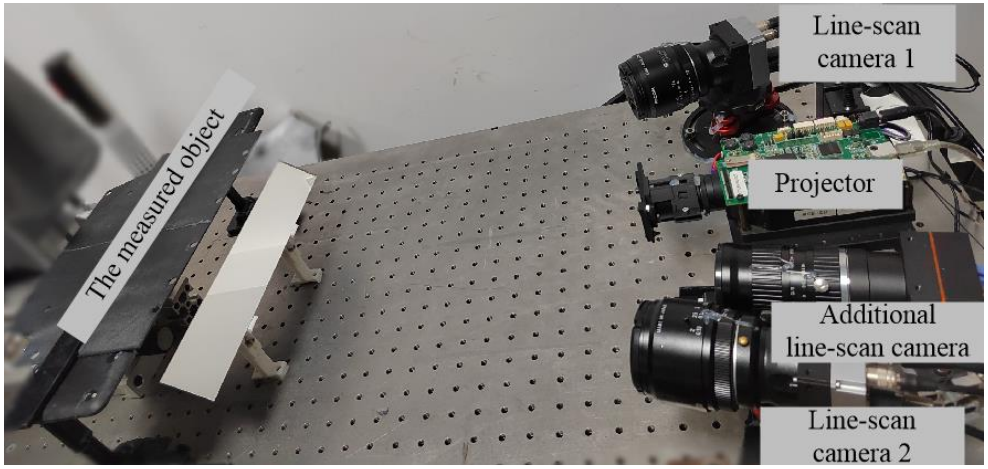



Advantage: more flexible light path, narrow space inspection
Disadvantage : error accumulation

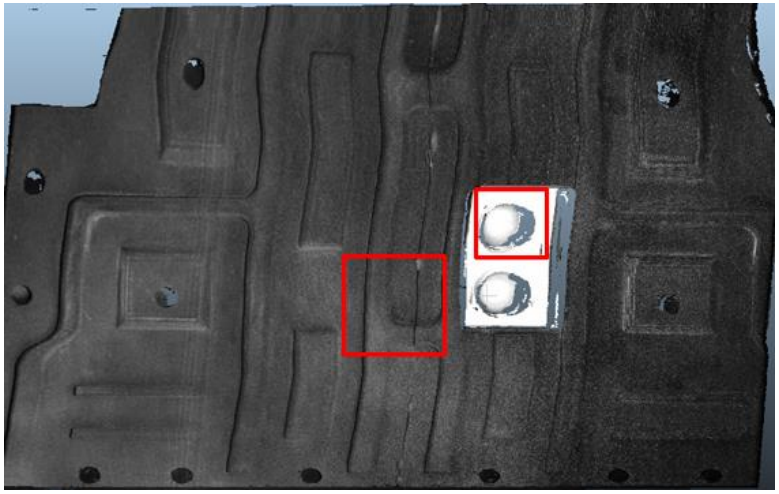
# Fine optimization based on imaging constraints

- **Using 1-D imaging constraints**

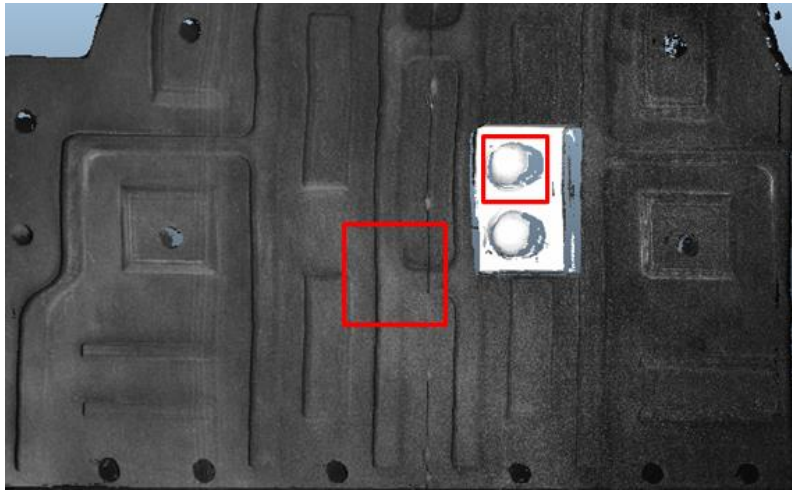
Measurement system




Optimization result



Before optimization



After optimization

Local point cloud accuracy: about 0.1 mm

# Outline

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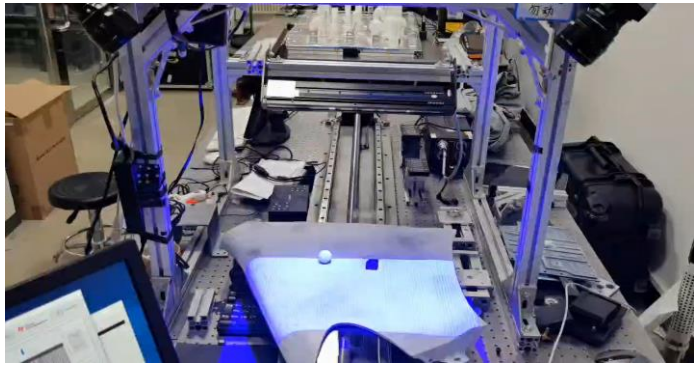
# Relevant outcome

- **Relevant systems**



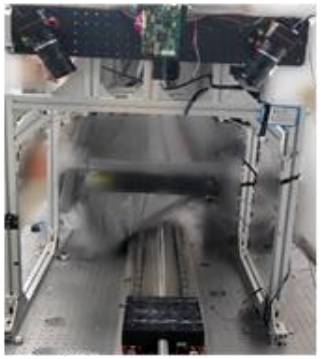
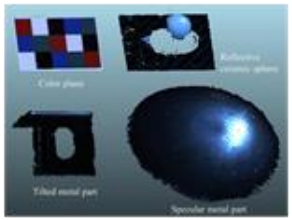
**Fixed 3-D measurement system**

**Moving 3-D measurement system**

**Engineering prototype**

# Relevant outcome

## Recent papers

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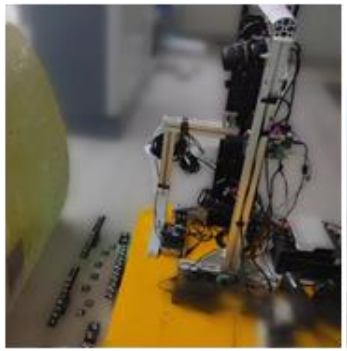
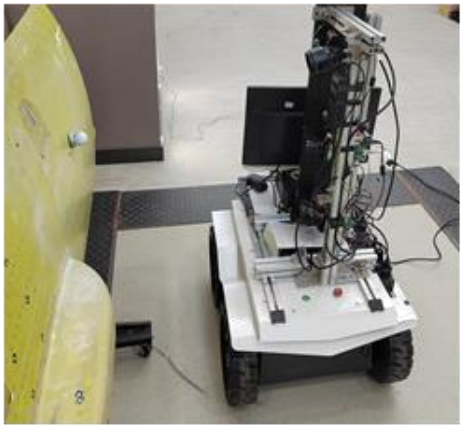
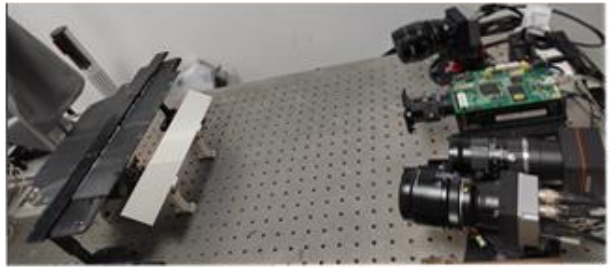



IEEE TIM, 2023,72




Measurement,2024,231

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# Thank you for listening!

## Welcome to visit Tianjin University

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