Design and Calibration of a High Speed and High Precision Measuring Instrument – Vision Measuring Instrument

Reporter：Luyan Zhang

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Content

1. RESUME

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Bachelor's degree in Aircraft Propulsion Engineering from Northwestern Polytechnical University

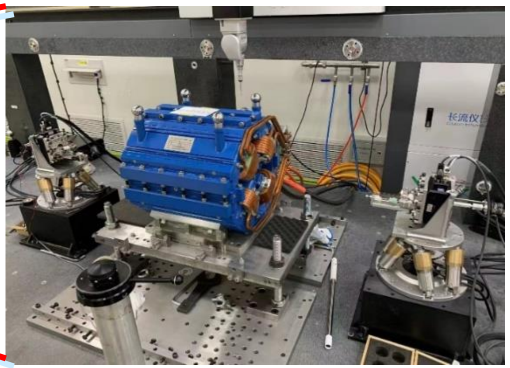
Master's degree in Mechanical Engineering from Florida International University

Currently pursuing Doctoral degree in Tianjin University

Alignment of BII-U

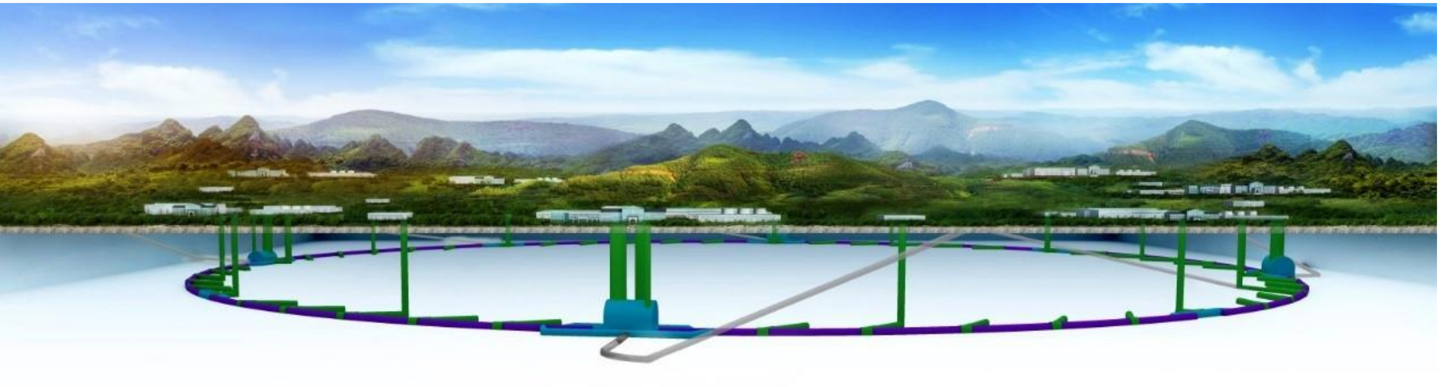
Alignment of CSNS

Alignment of HEPS



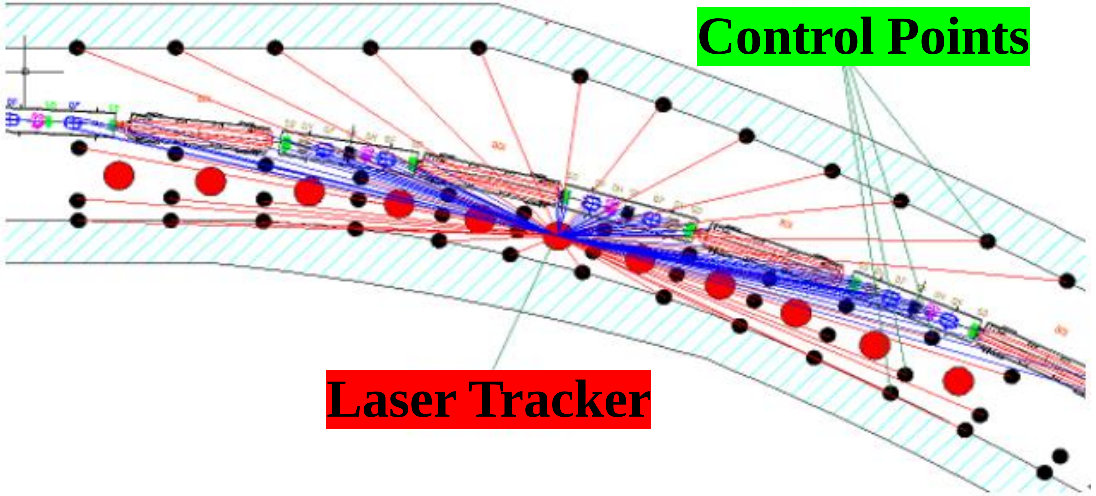
Magnetic Center Measurement of Booster Magnets

2. Background of Instrument R & D



Circular Electron-Positron Collider (CEPC)

Perimeter: 100 kilometers



HEPS Storage Ring:
1.4km
8 laser trackers/Groups
7 Days

2. *Background of Instrument R & D*

Laser Tracker

Advantage: High precision (long distance)
Mature operating system

Disadvantage: Low efficiency
Hard to achieve automatic measurement

2. Background of Instrument R & D

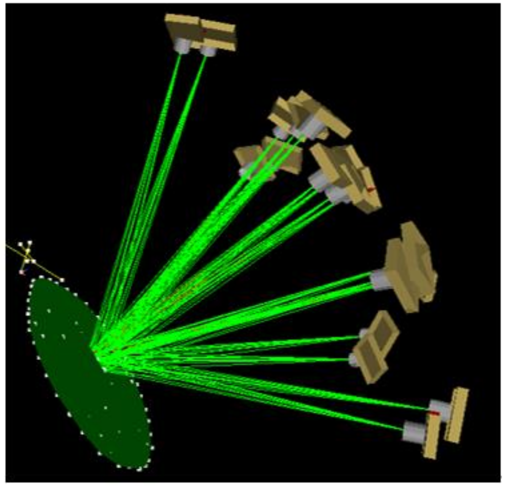
Photogrammetric System

Advantage: High effiency
Non-contact measurement
Automatic measurement

Disadvantage: Hard to identify point name
Hard to lap

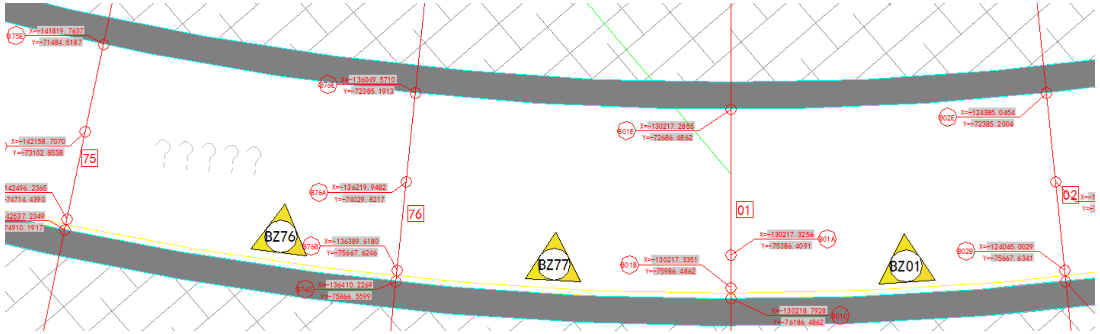
Widely used in aerospace, precision machinery manufacturing and other fields

2. Background of Instrument R & D



Good measurement condition

1. Cameras cover the targets from all directions.
2. The overlap points are dense enough.
3. Rulers should be evenly distributed.



Tunnel diagram

1. Tunnel is elongated.
2. Camera angles are limited.
3. Rulers are short for the long distance.
4. The point distribution is sparse.

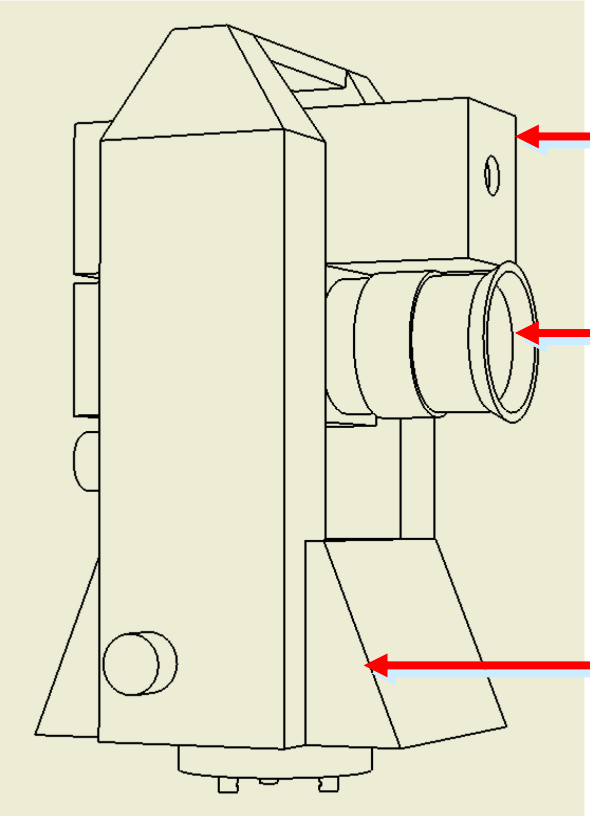
2. Background of Instrument R & D

High precision

High efficiency

?

3. Instrument R & D



Vision Measuring Instrument

Absolute laser rangefinder:
Long distance scale constraint

High precision industrial camera:
High speed, non-contact measurement
Provide angles of points in pohto

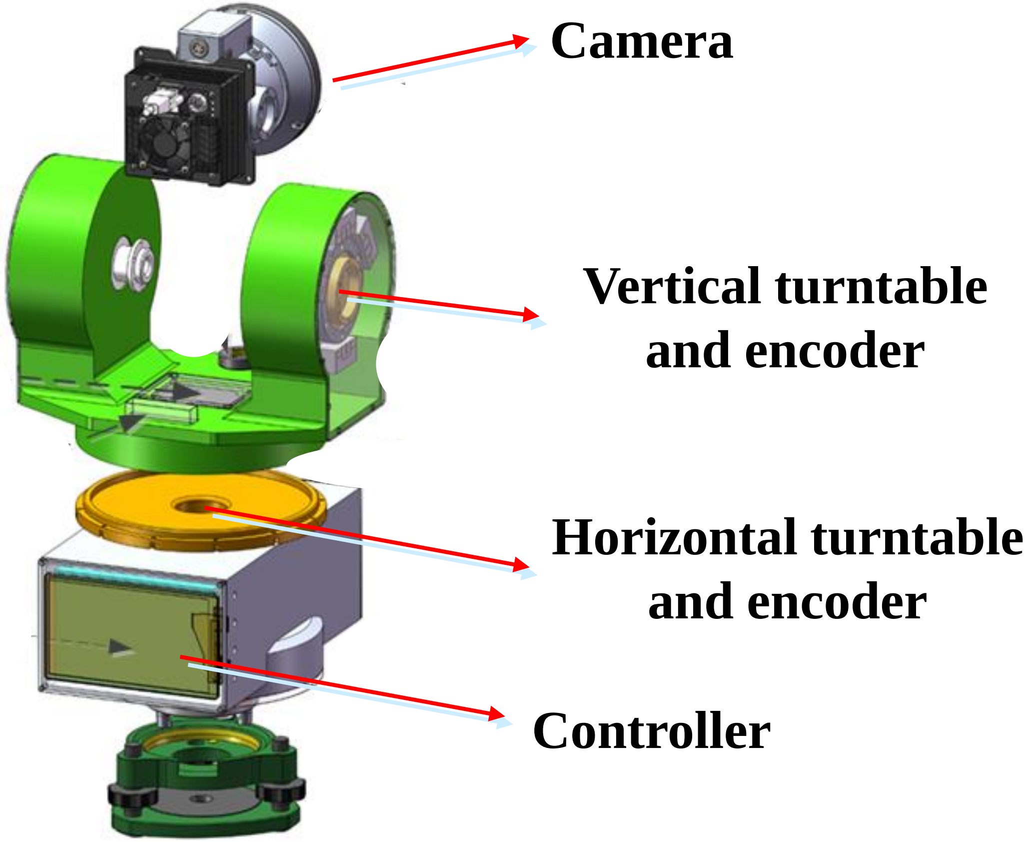
High precision two-dimensional turntable:
Angle constraint between photos

3. Instrument R & D

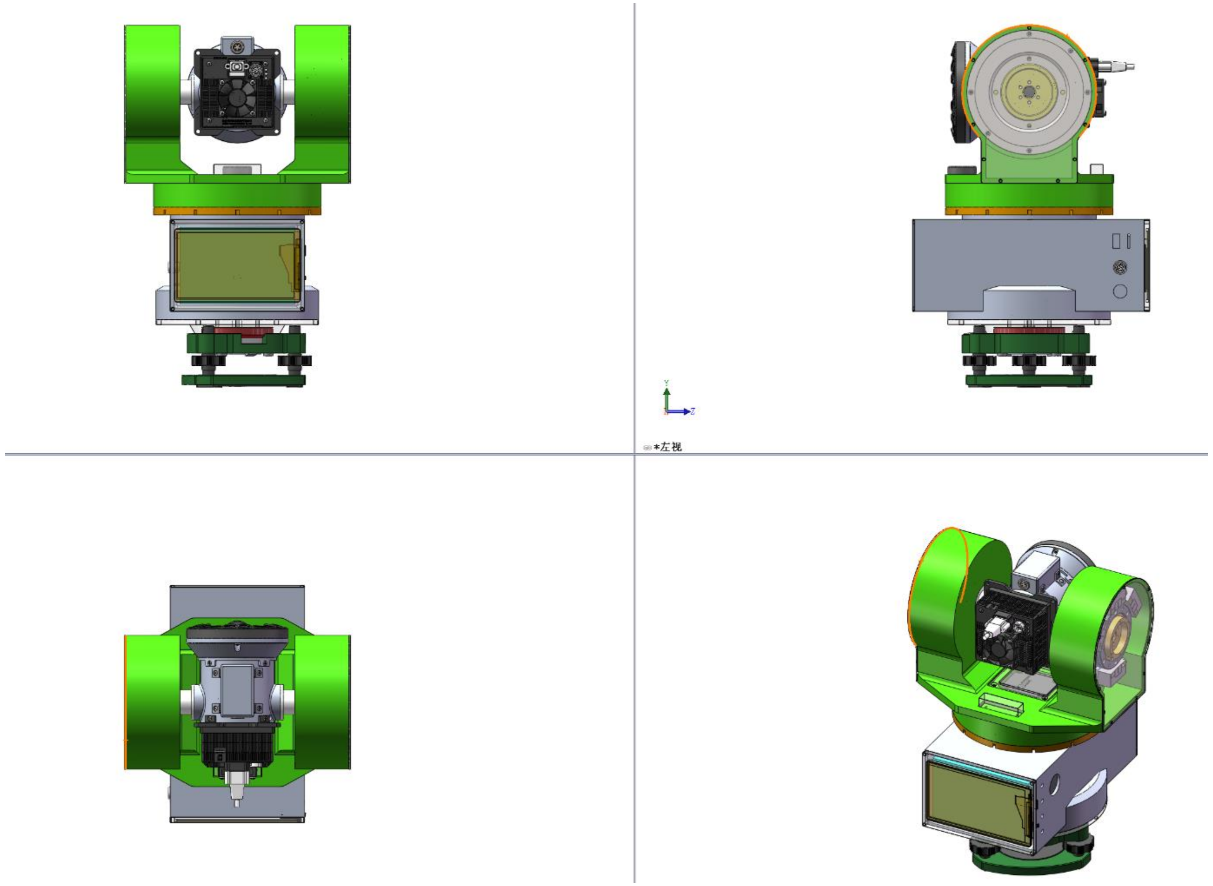
Vision Measurement Instrument

- High precision distance measuring module → Laser interferometry measurement
- High precision angle measuring module → High precision encoder
- Precision mechanical module → Center of gravity coincides with the main axis/Structural stability
- High precision photogrammetry technology → High precision CMOS camera
- Error compensation and numerical calculation → Bundle ajustment + Multivariate data fusion adjustment

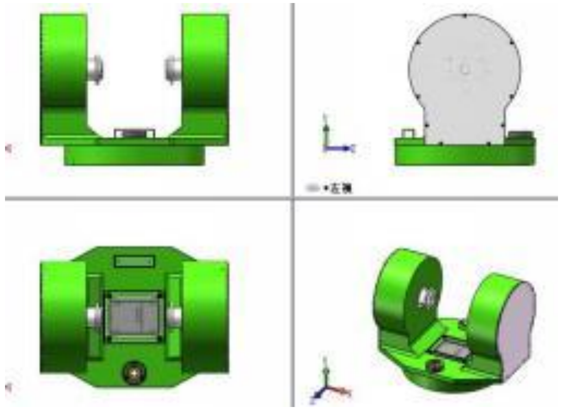
3. Instrument R & D



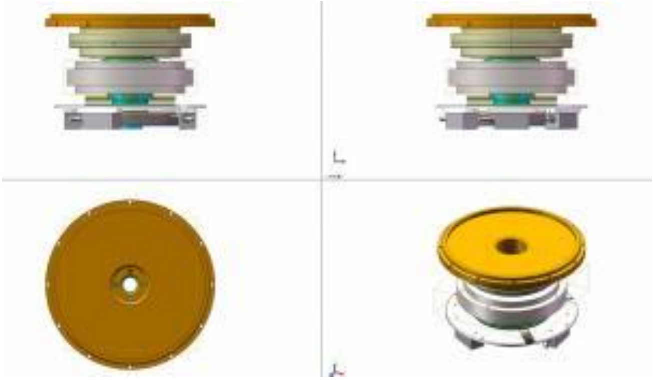
Instrument Diagram



3. Instrument R & D

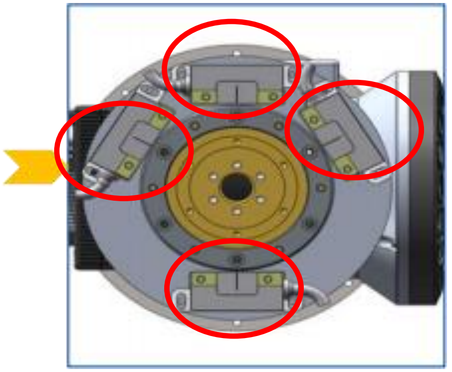


Vertical turntable and encoder



Horizontal turntable and encoder

Four reading head of encoder
Non-uniform mixing arrangement



Angular position accuracy: ≤4” (1σ)

Vertical rotation range: 45° ~ 315°

Horizontal rotation range: 0° ~ 360°

Eliminate the jitter error and eccentricity of the encoder

3. Instrument R & D

High precision CMOS camera

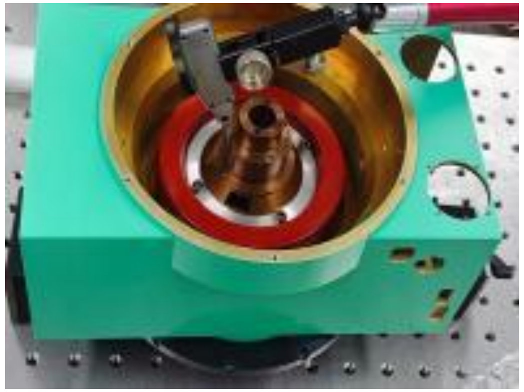
Spectrum: visible black and white image

Pixel: 2600W pixel (each pixel 4.5μm)

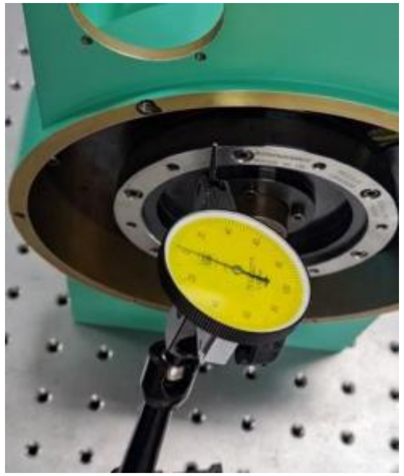
Maximum rate: 50HZ

Working distance: not less than 30m

3. Instrument R & D



Horizontal turntable install



Vertical turntable install

Camera install

Fully assembled

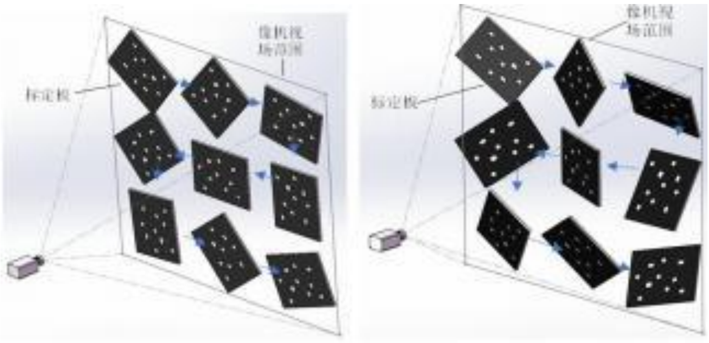
Interference installation:

The maximum radial runout is 1μm.

The eccentricity is within 5μm.

3. *Instrument R & D*

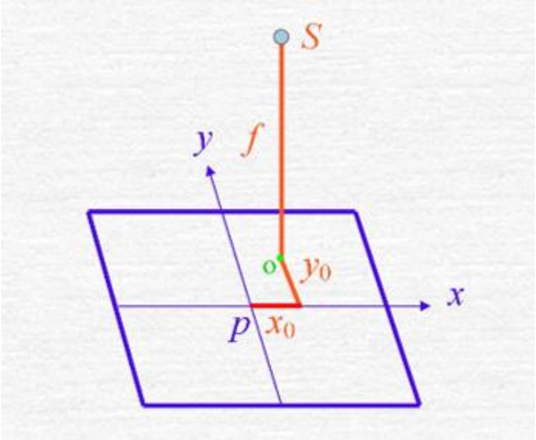
Camera calibration



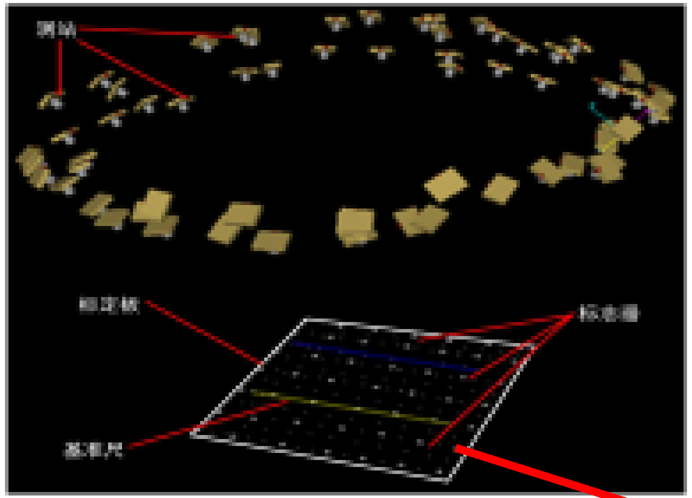
Instrument calibration

3. Instrument R & D

$$X_3 = (\underline{x_0 \quad y_0 \quad f} \quad K_1 \quad K_2 \quad K_3 \quad P_1 \quad P_2 \quad b_1 \quad b_2)$$



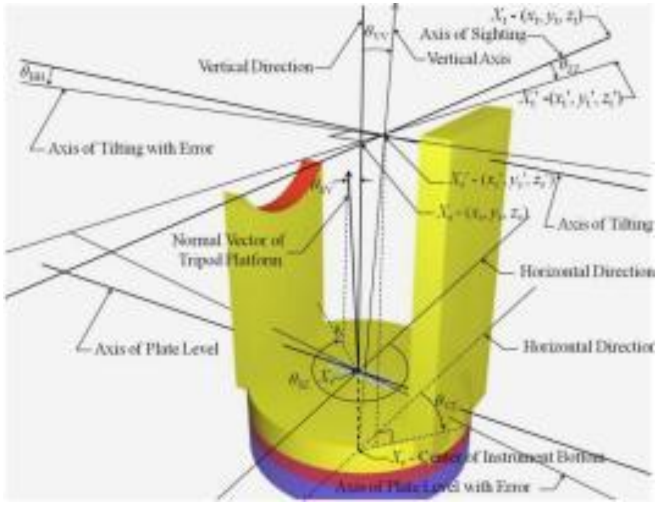
Camera calibration gives focal length, radial distortion, eccentric distortion, image plane distortion and internal orientation element error, and so on.



Camera calibration

Calibration board has a large number of points with known position information.

3. Instrument R & D



Instrument calibration

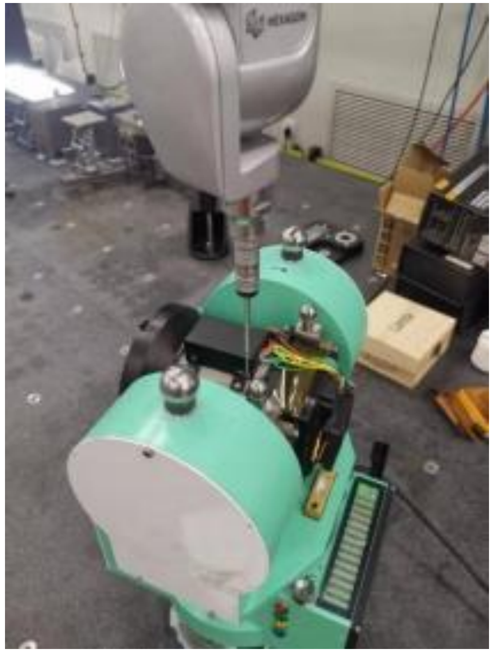
1. There is gap between vertical axis and horizonal axis.
2. Vertical rotating axis and horizonal rotating axis are not orthometric.
3. Camera's position need to be measured.

Direct measurement

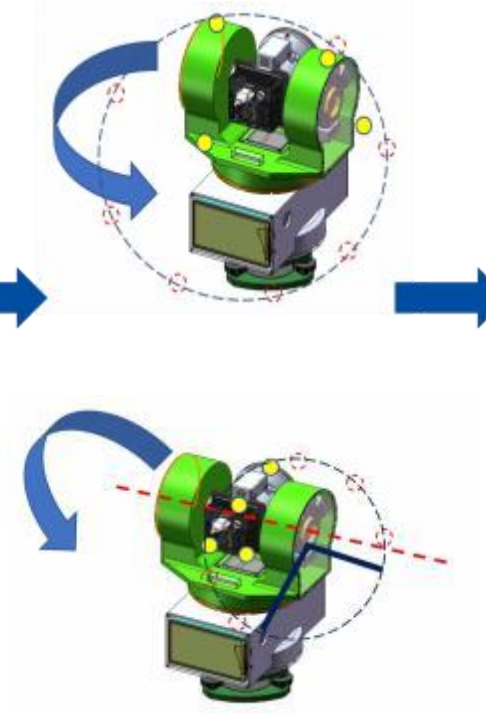
Indirect measurement

Instrument coordinate system → Transfer matrix → Horizontal Rotating axis Coordinate system ⇄ (Transfer matrix / Encoder data) ⇄ Vertical Rotating axis Coordinate system → Transfer matrix → Camera Coordinate system

3. Instrument R & D



CMM



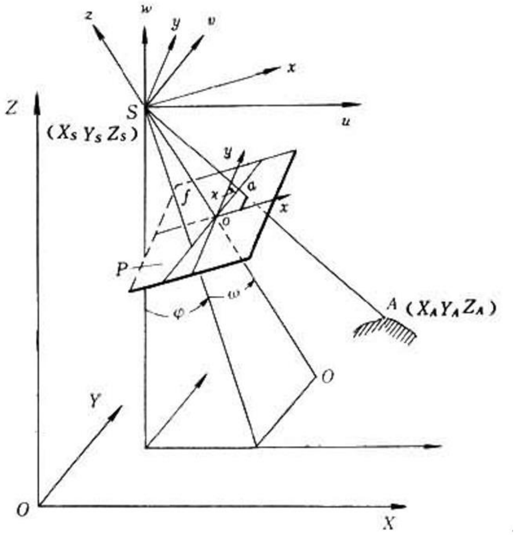
Measure axes

Gap	8μm
Angle	10”

3. Instrument R & D

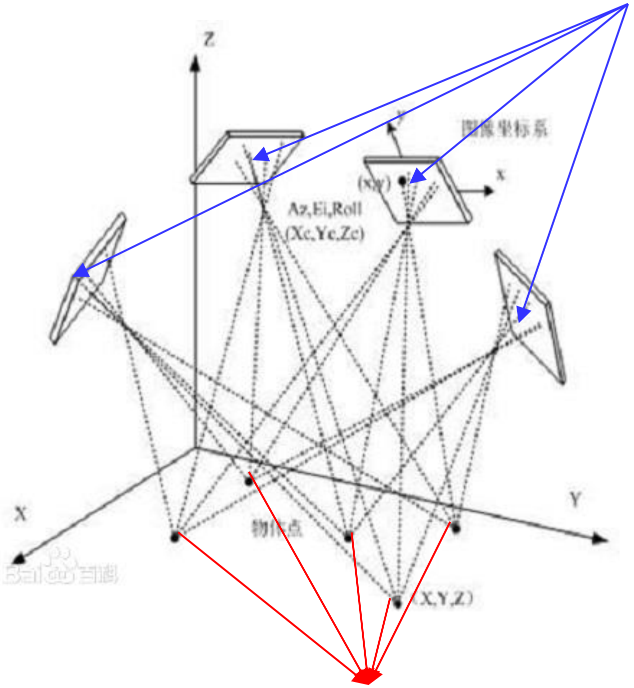
Vertical Rotating axis Coordinate system

Camera Coordinate system



Space resection

Picpointed coordinate



Points in the world coordinate system

3. Instrument R & D

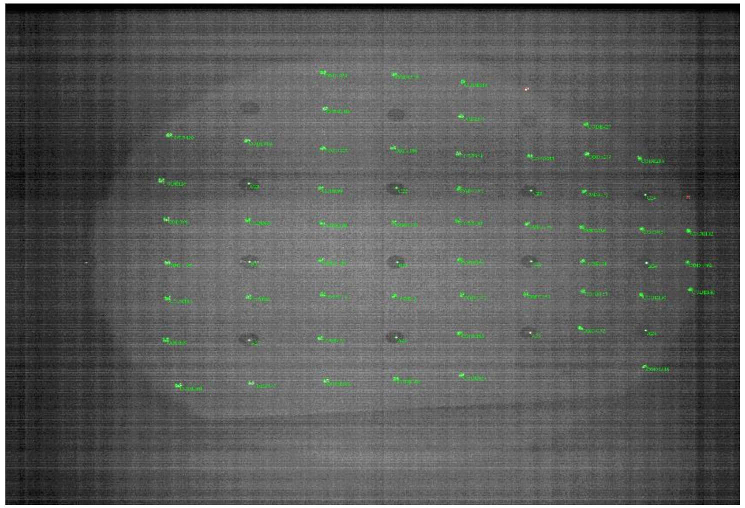
6m*6m*6m control network

Measured by laser tracker

Accuracy: 20μm

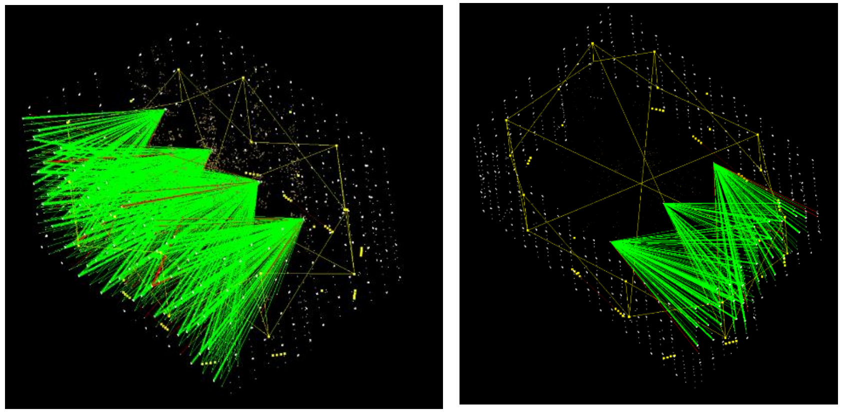
3. Instrument R & D

Instrument calibration

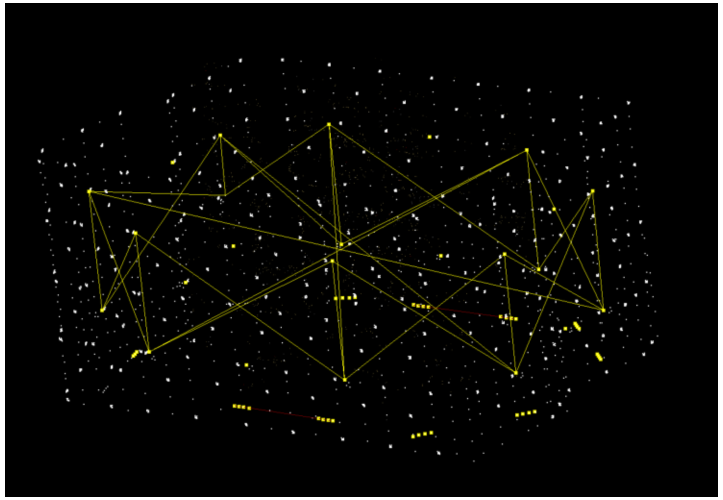


Photo

The difference between the angle of two rotating axes measured by control network and the angle measured by CMM is within 4”.

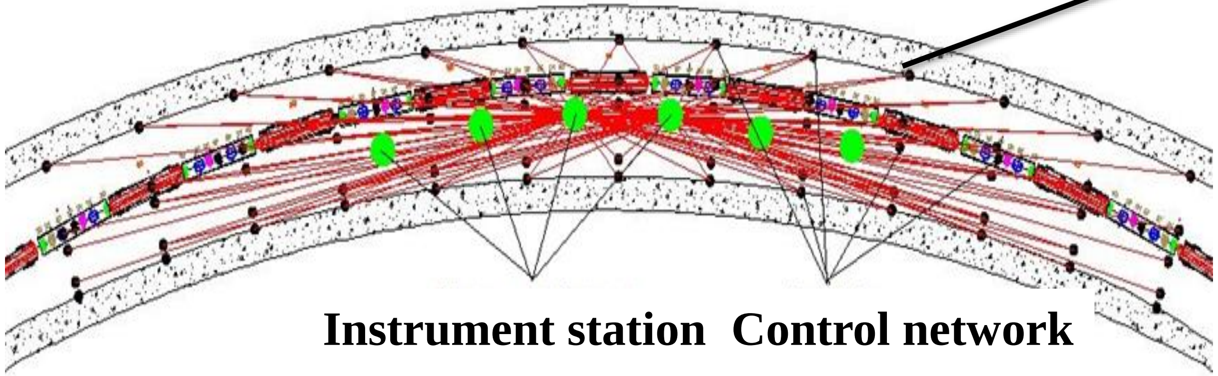


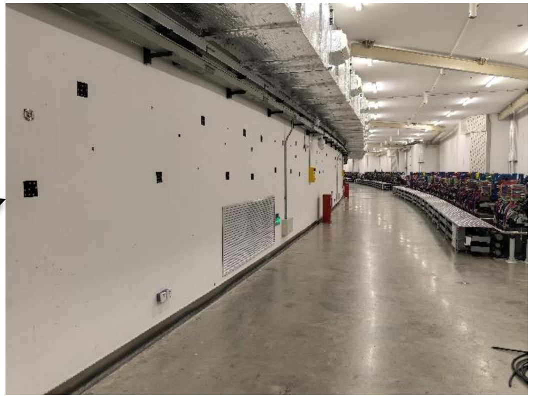
Camera position extracted



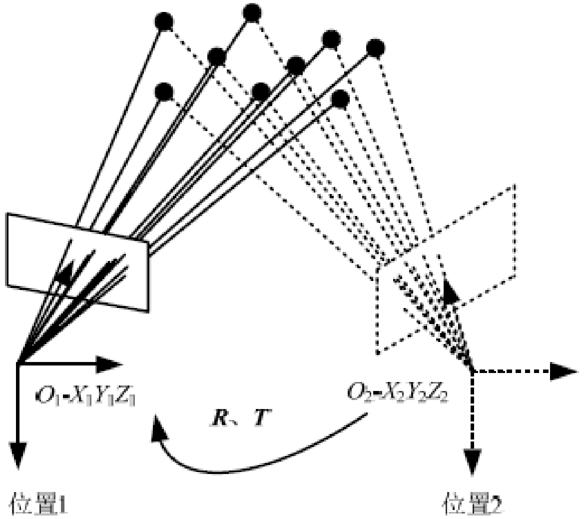
Control network measured by camera

3. *Instrument R & D*





Control network points



Control network is the basement. Firstly, position of instrument will be derived by the space resection, then all other point positions will be derived from space intersection.

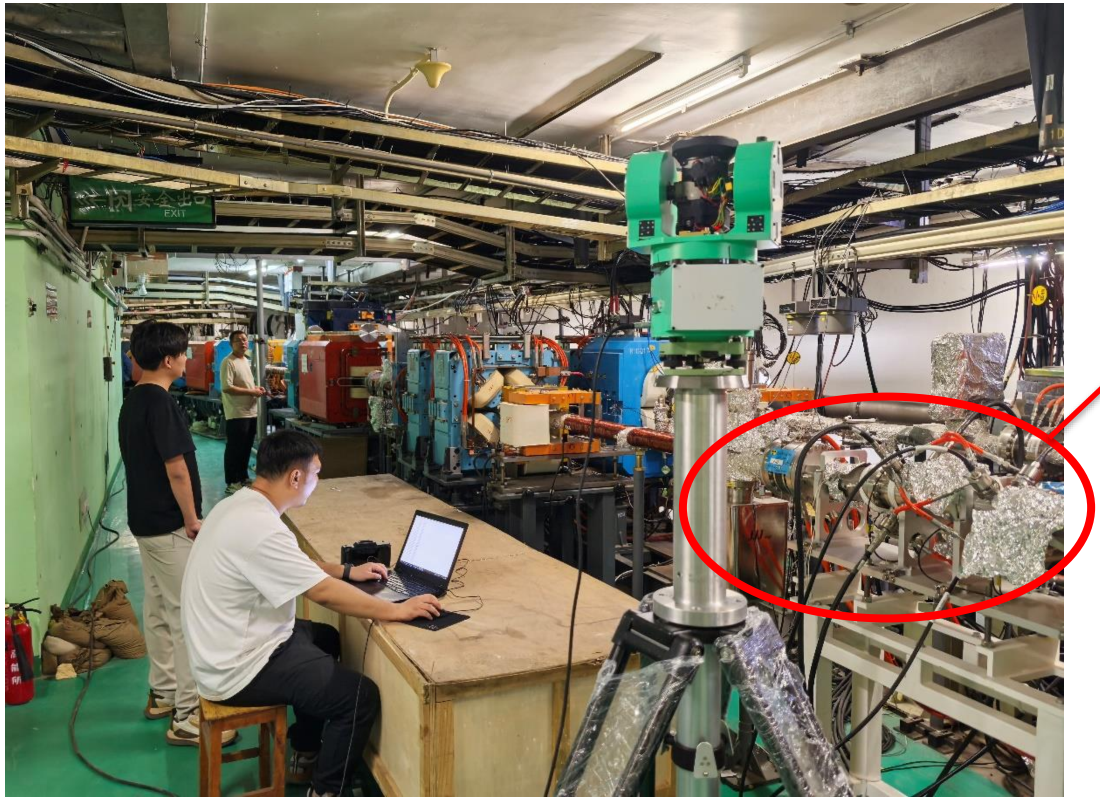
3. Instrument R & D

Experiments in HEPS

Compared with the results of laser tracker, the fitting error is 0.8mm.

4. Challenge and Improvement in the Future

Point Identification



The vacuum beam tube and aluminized paper reflects light.

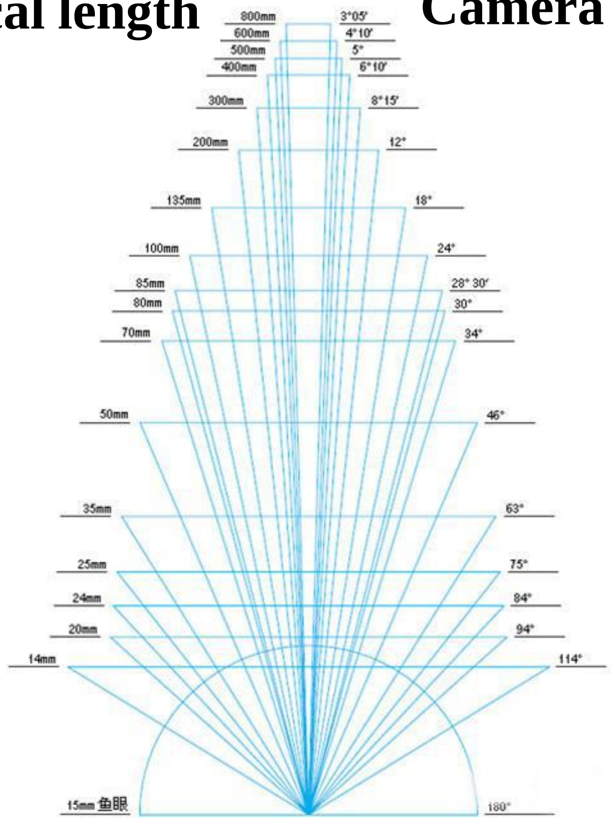
New image recognition methods need to be studied.

4. Challenge and Improvement in the Future

Camera angles are limited

Focal length

Camera angle



Relationship between focal length and camera angle

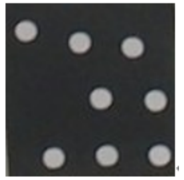
Camera angles are limited and targets need to be turned manually.

Pentahedral target

Target with five coded targets

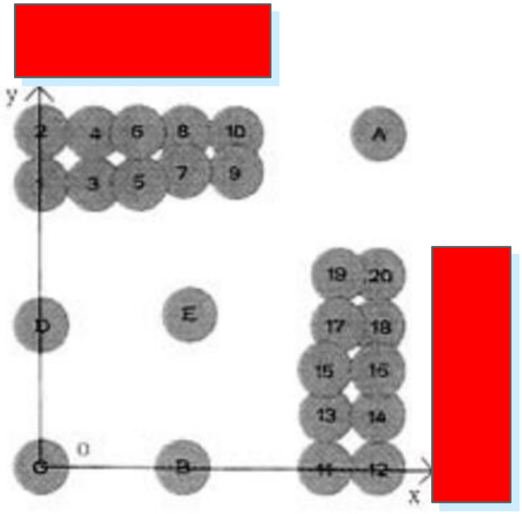
4. Challenge and Improvement in the Future

Number of coded targets are limited

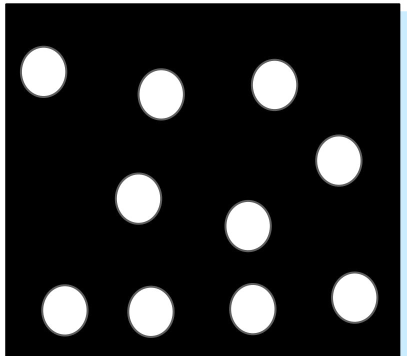


8 points coded targets

Hunderds of targets

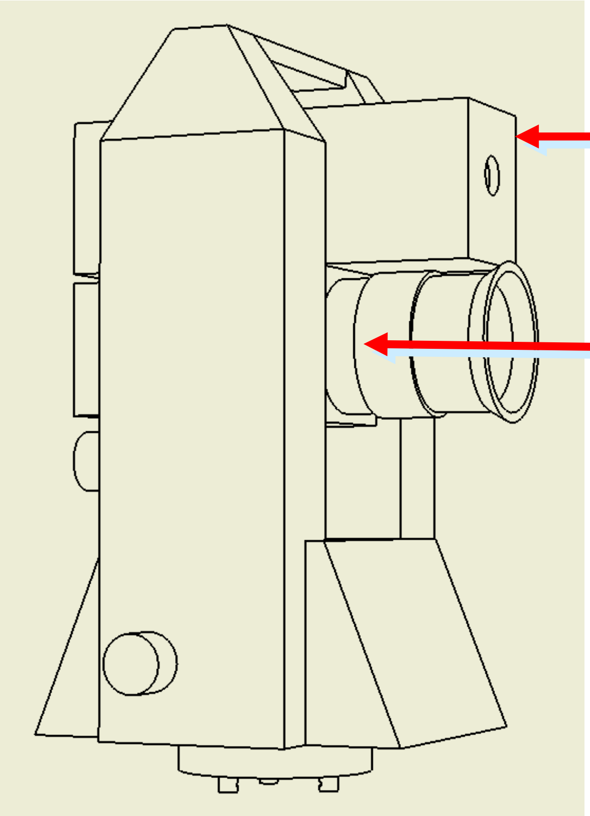


Millions of targets



10 points coded targets

4. Challenge and Improvement in the Future



Absolute laser rangefinder:

Long distance scale constraint

μ-base

FSI system

Vision Measuring Instrument

THANK YOU!