IWAA 2016

A Novel Laser Tracking System Based on Optical Frequency Comb

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Academy of Opto-eletronics,

Chinese Academy of Sciences

October 4th, 2016

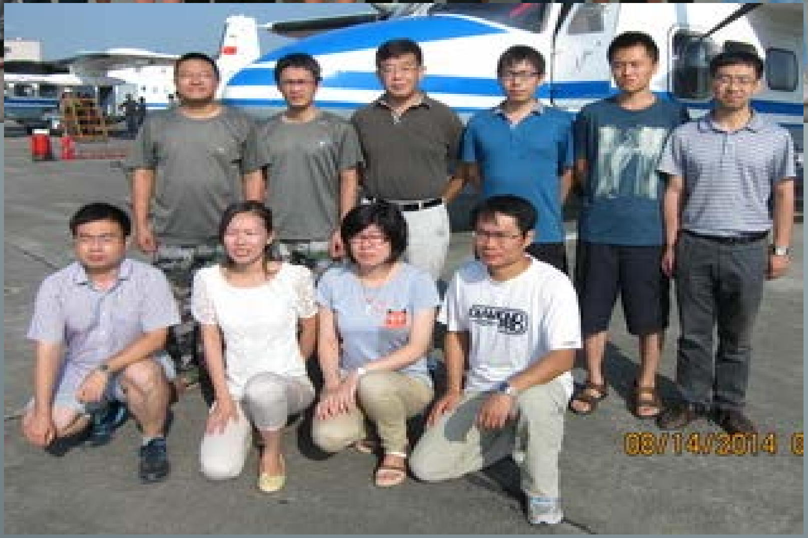
Content

Academy of Opto-electronics, Chinese Academy of Sciences (AOE)

- Founded in Dec. 2003
- Dedicated in the research and development of optical remote sensing, laser and its application, space science & technology.

The headquarter of AOE (Beijing)

Division of Laser Measurement Technology



Employee: 20

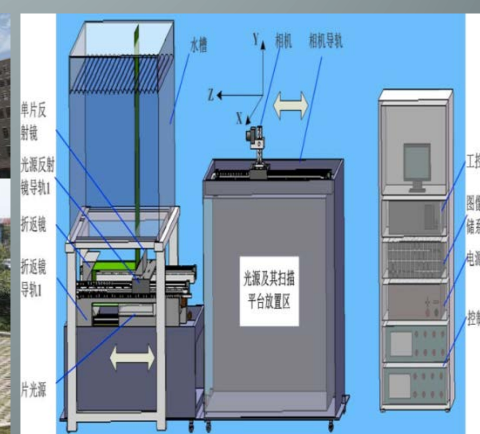
- **Professor: 1**
- **Research associate: 5**
- **Postdoctor: 2**

Students: 20

- **Doctor: 4**
- **Postgraduate: 2**

Laser measurement technology

- Traditional ranging technology
- Femtosecond laser ranging technology
- Angle measurement technology
- Precision tracking control technology
- Calibration and error copensation
- software



Traditional Laser Tracker

Application

Manufactures

Leica
Switzerland

API
USA

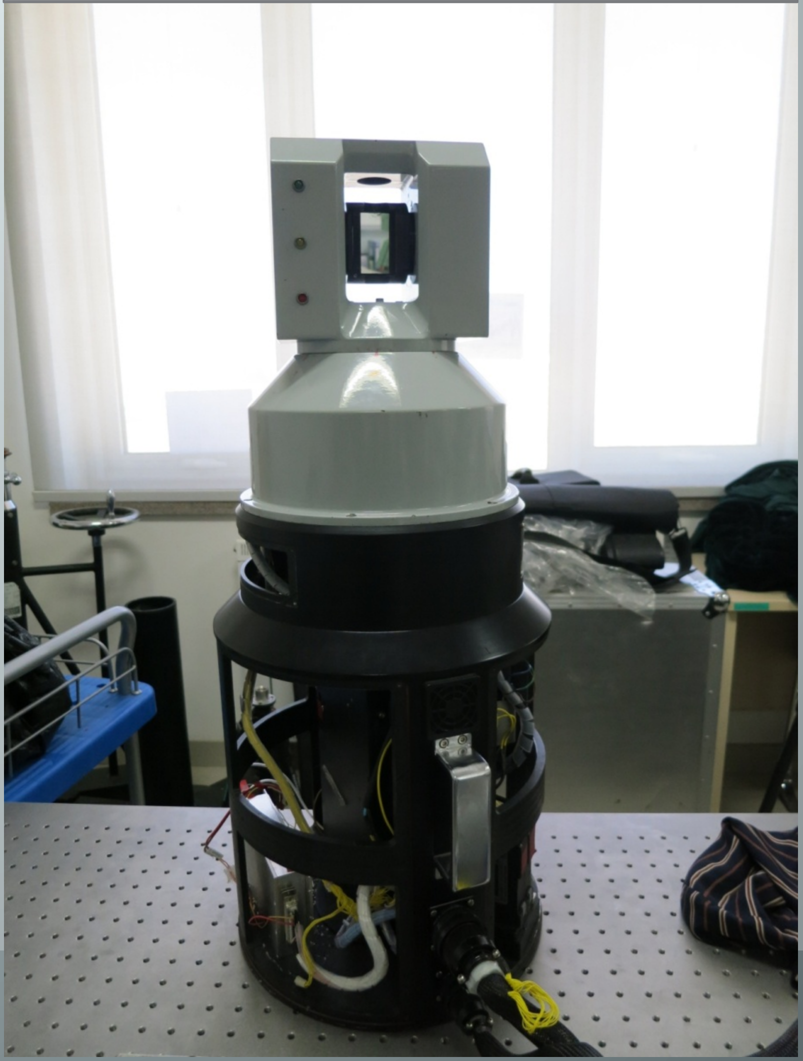
FARO
USA

PI
Germany

Prototype

- Measurement Range 0 ~ 42m
- Horizontal Angle Range ±270°
- Vertical Angle Range - 45° ~ + 60°
- Coordinate Uncertainty 17ppm
- Tracking Speed 2rad/s
- Tracking Acceleration 2rad/s^2
- Sampling Rate 1000pts@1s

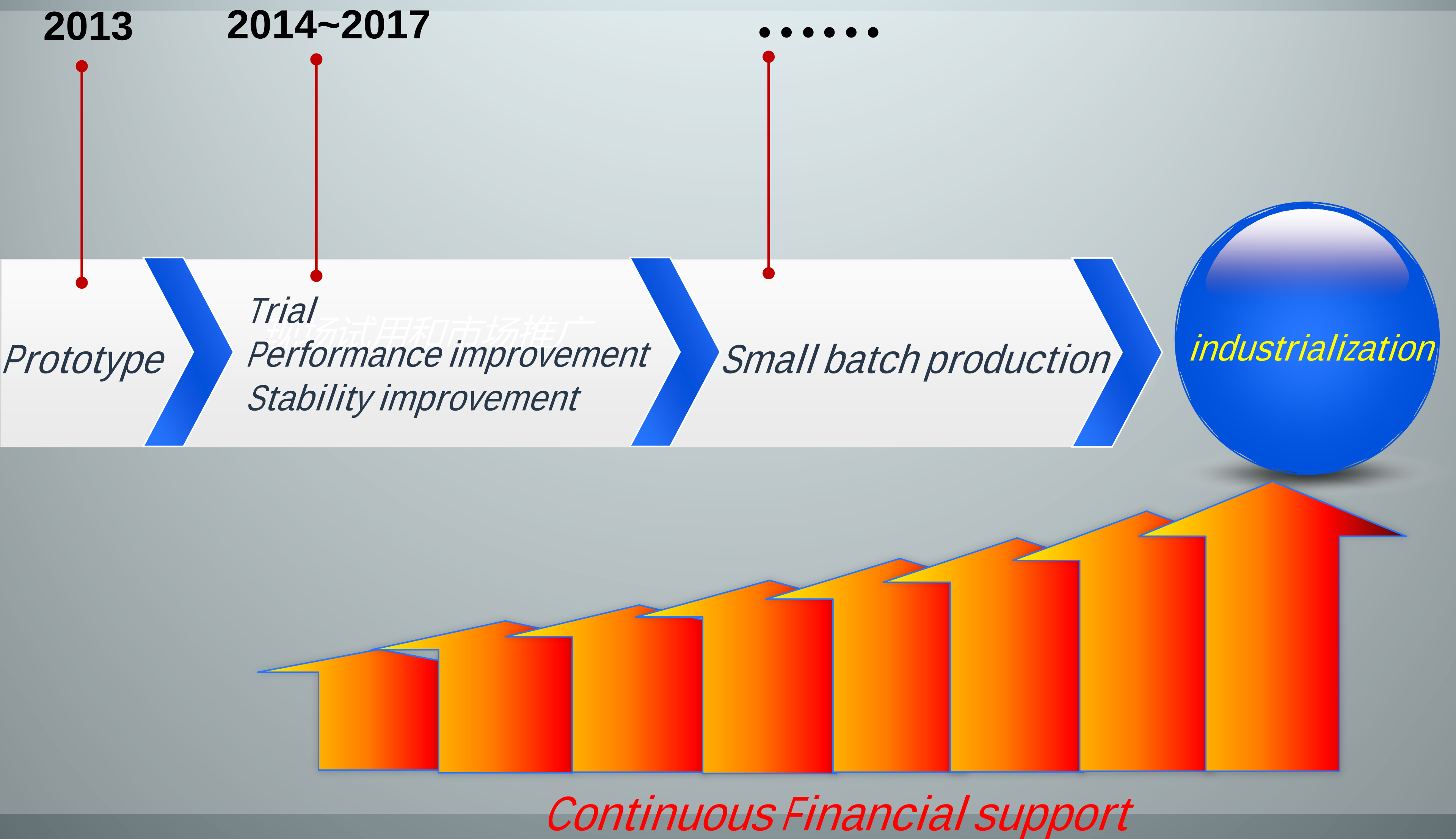
2013



Performance comparison

Specification	Leica (AT402)	Our prototype
Measuring scale	320m	42m
Horizontal angle Measuring scale	±360°	±270°
Horizontal angle Measuring scale	-145° ~+145°	45° ~+60°
Angle measuring accuracy	0.5"	1″
Distance measuring accuracy	±10μm	15μm/m
Coordinate measuring accuracy	±15μm+6μm/m	17μm/m
Data acquiring rate	3000pts/s	1000pts/s
Tracking speed	180° /s	2rad/s
Accelaration	360° /s^2	2rad/s^2

Development history and Orientation



Laser Tracker Based on Optical Frequency Comb

Supported by Ministry of Science and Technology of the People’s Republic of China

Goal of Project

（1）To develop Laser Trakers using Femto-second Laser Distance Measurement Technology . The function and performance of new tracker will reach the international level (Dist. resolution: 50nm， Accuracy: 0.5ppm）；

（2）Break through the key technology of Femto-second Laser Source, Femto-second Laser Frequency Comb Distance Measurement, Air Refractive Index measurement and Compensation;

（3）Develop engineering prototype and study application technology of new generation laser tracker;

（4）Promote the advancement of metrology technology.

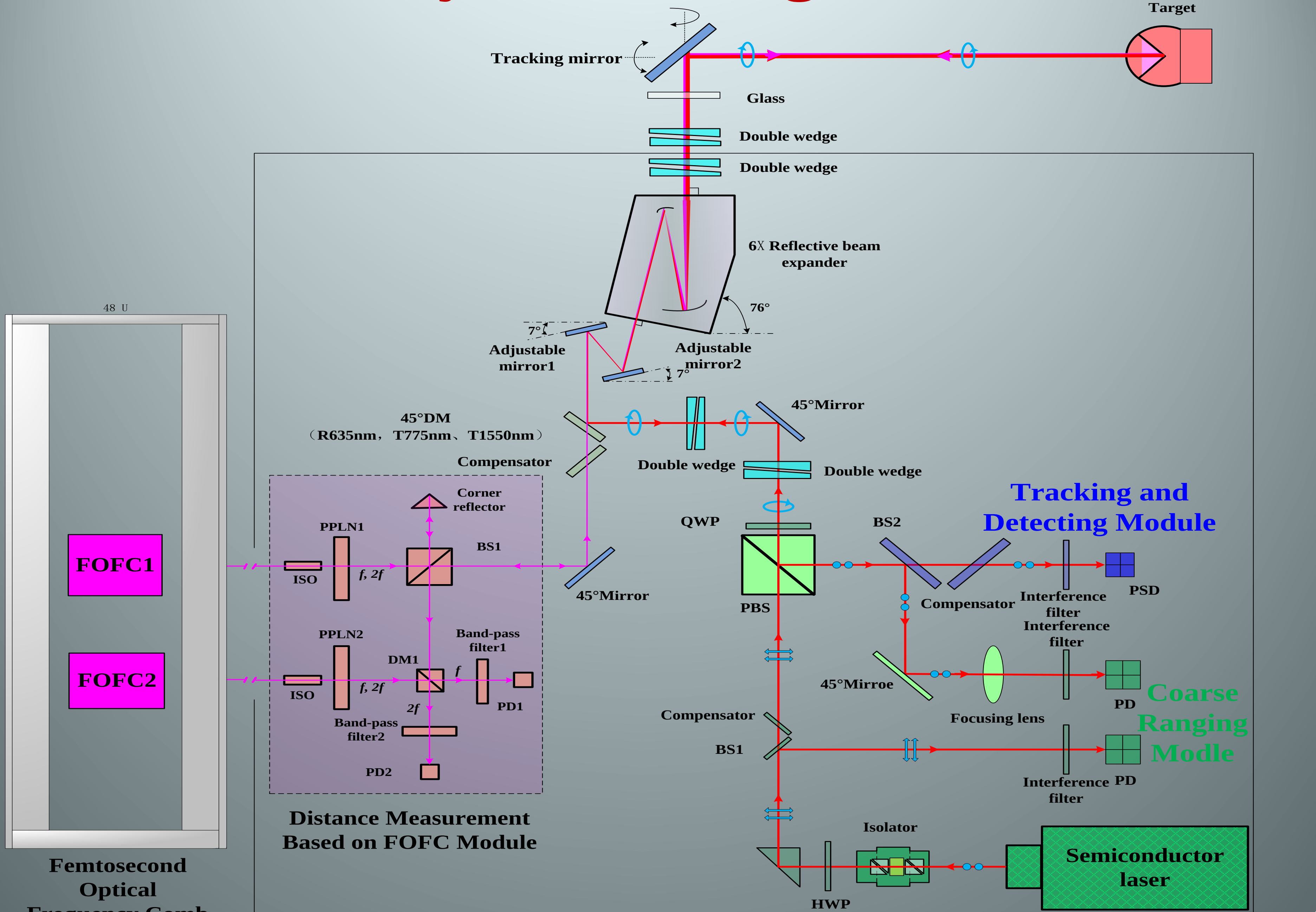
Performance expected

Title	Performance expected
Coordinate uncertainty	**10ppm(10μm/m)**
Measuring scale	**0-60m**
Distance measuring accuracy	**1μm+0.5μm/m**
Angle measurement accuracy	1.0"
Tracking speed	2rad/s
Tracking acceleration	1rad/s^2

Key Technology

- Distance Measurement
- Precision Angle Measurement
- Precision Tracking Control
- Model, Calibration and Error Compensation
- System Software
- Optical and Mechanical Integration

System Design



Dual-Comb

Atomic clock

Frequency synthesizer×2

Frequency counter

Pump current source

Phase locked loop

Servo×2

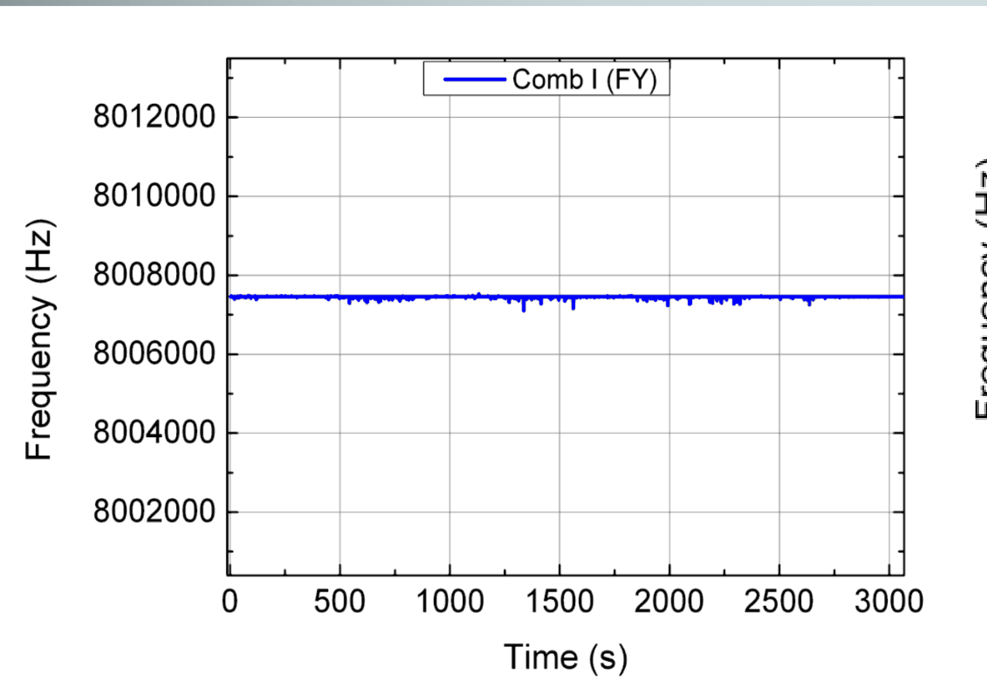
Coarse stabilization module of repetition rate

Temperature control module

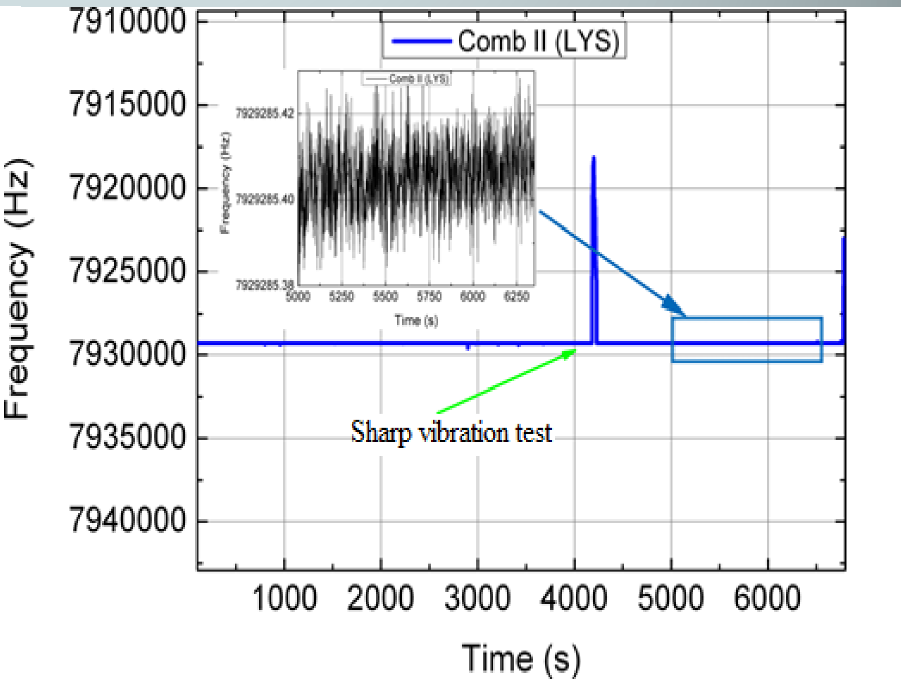
Oscillator×2

amplification and compression system×2

Stability of f_{ceo}



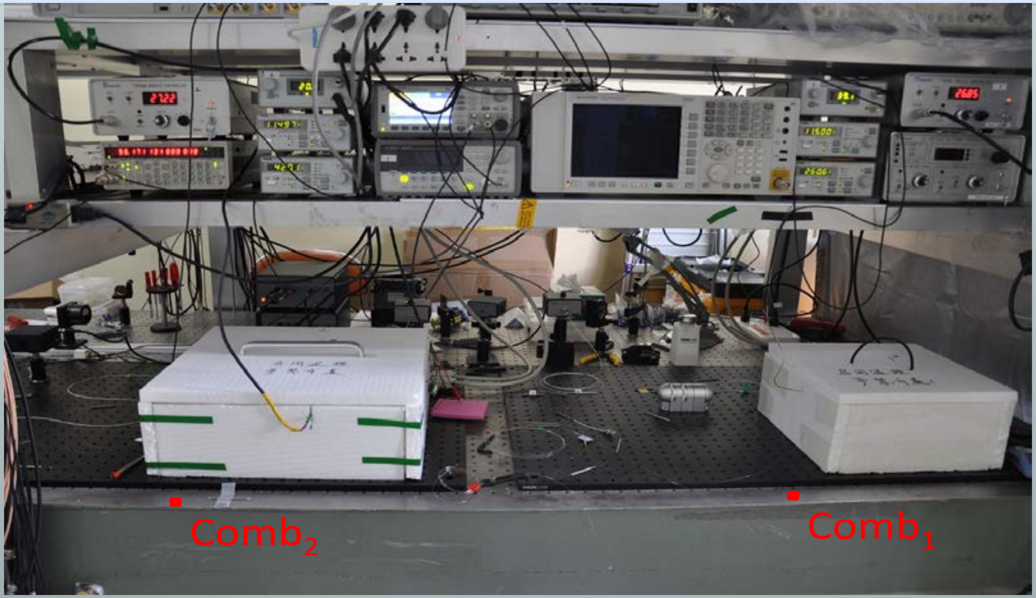
Comb 1

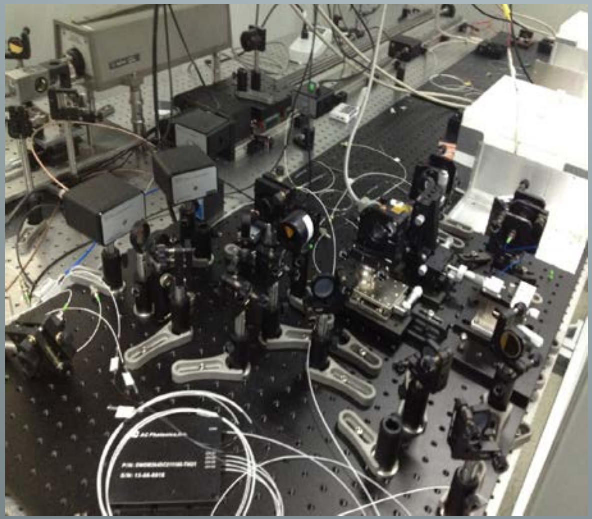


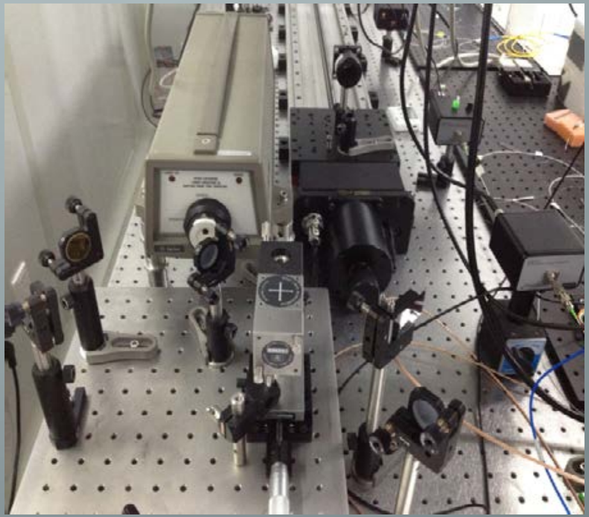
Comb 2

Carrier envelope offset frequency stability: $1.0*10^{-10}$/1S

Distance measurement Setup By Dual-comb



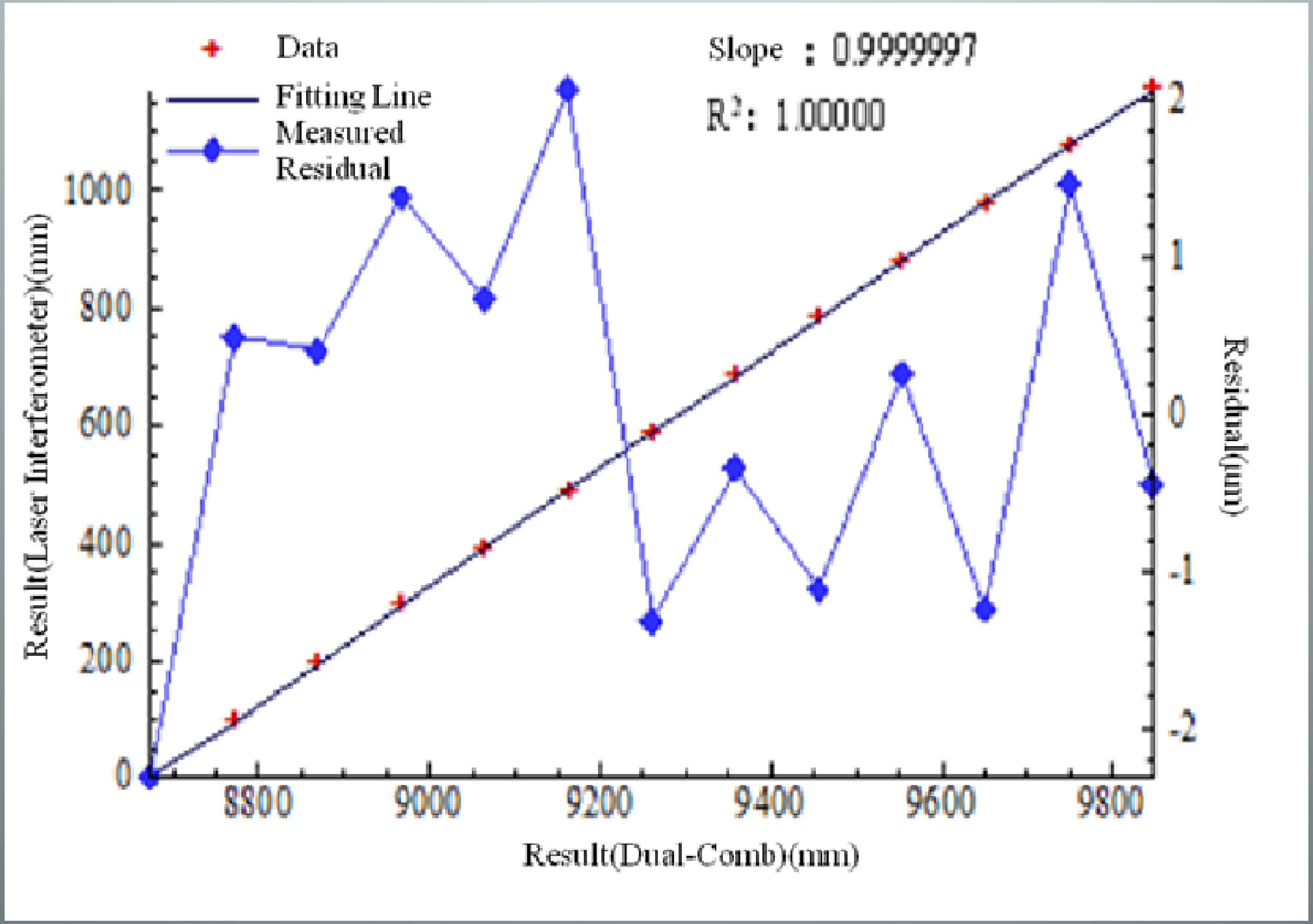




Distance Measurement Result

Standard deviation is ±2.3 μm when target is moved from 8.7m to 9.9m.

Relative error: 0.1ppm@9m



Air Refractive Index Compensation

$D_1 = n_1 D$ ……λ_1

$D_2 = n_2 D$ ……λ_2

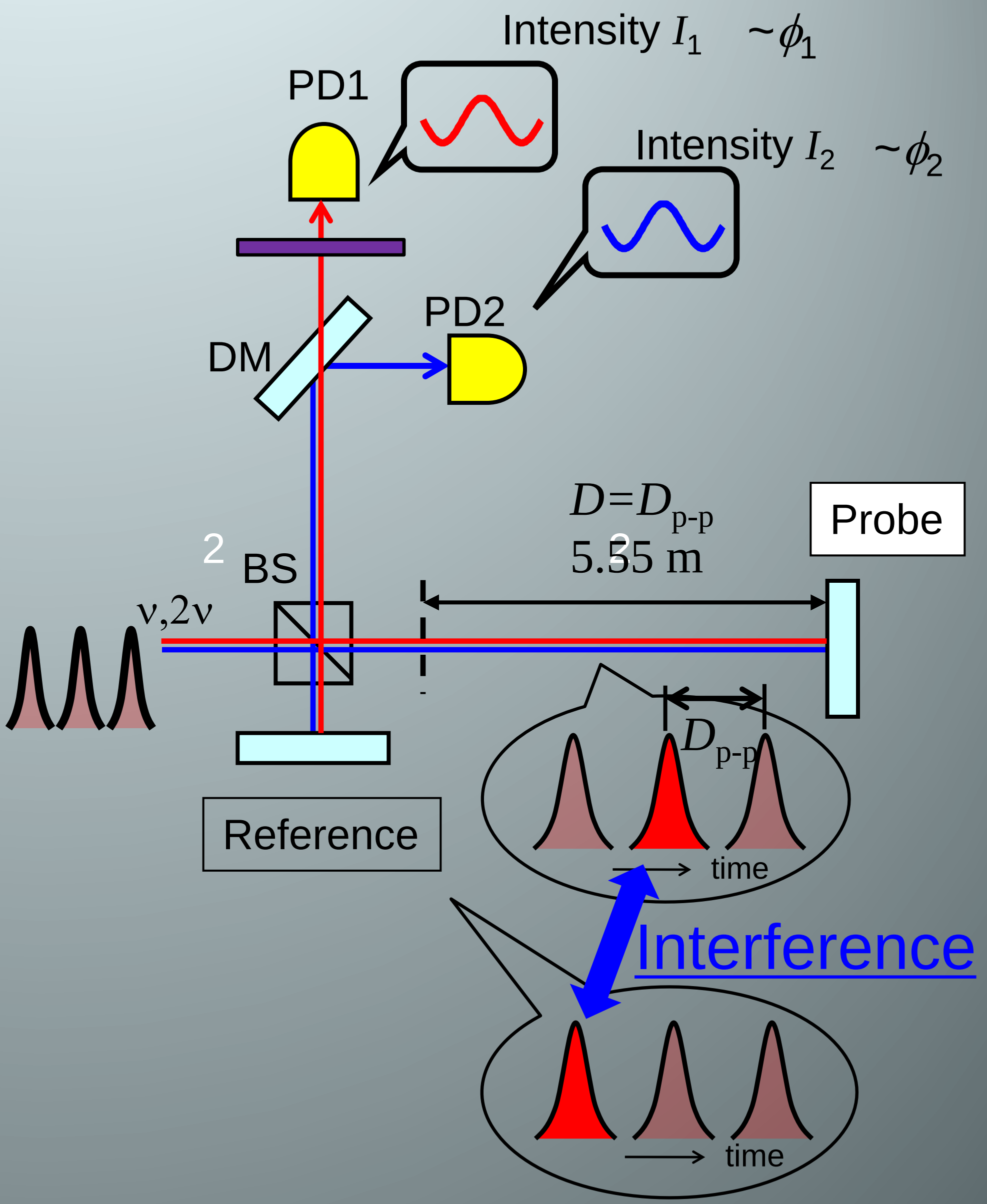
n_1 and n_2: air refractive index

$$A \equiv \frac{n_1 - 1}{n_2 - n_1} \approx const$$

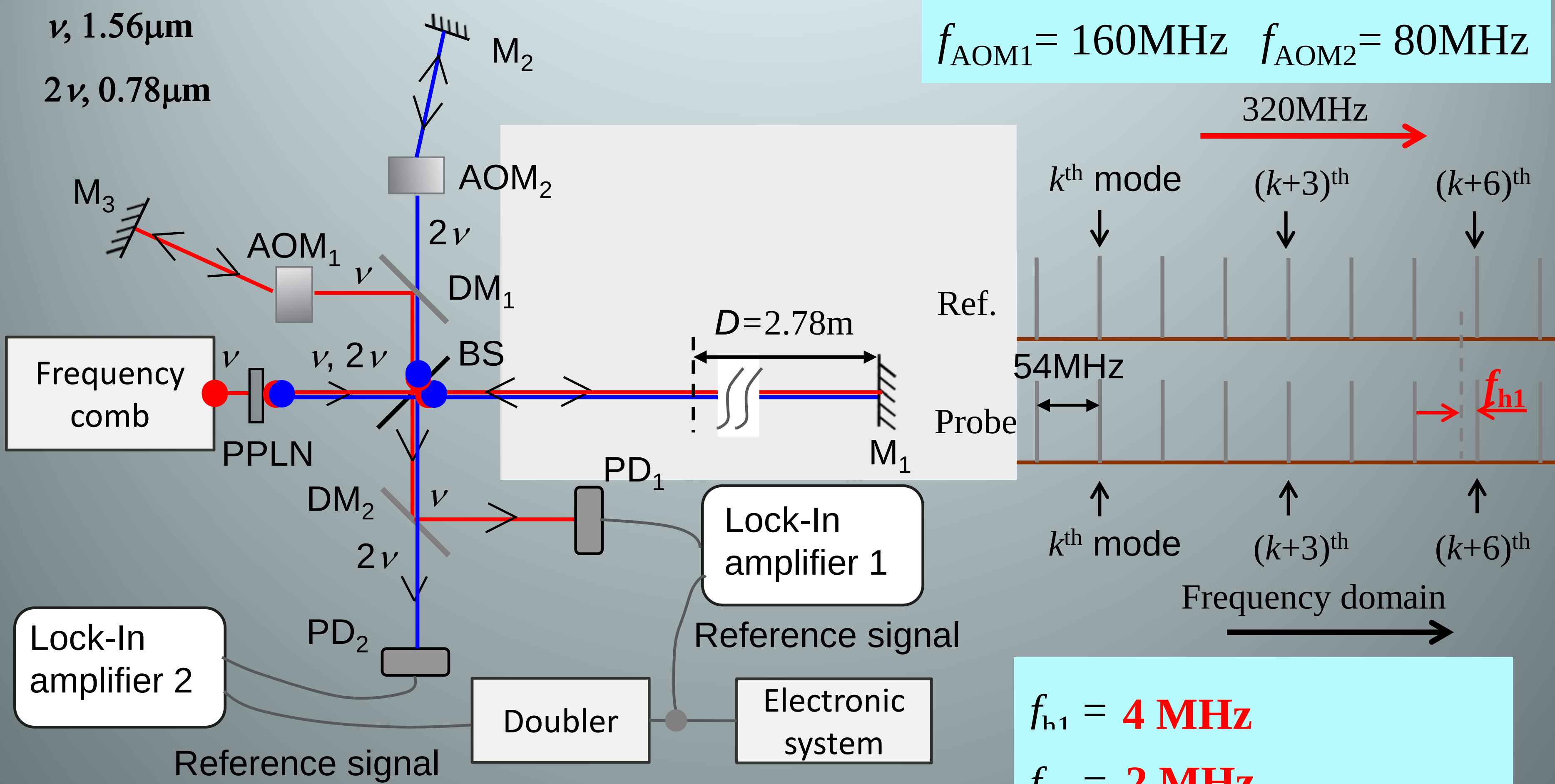
$$D = D_1 - A(D_2 - D_1)$$

For 1.56μm and 0.78μm :

$A = 141$



Air Refractive Index Compensation



f_{AOM1} = 160MHz f_{AOM2} = 80MHz

f_{h1} = **4 MHz**

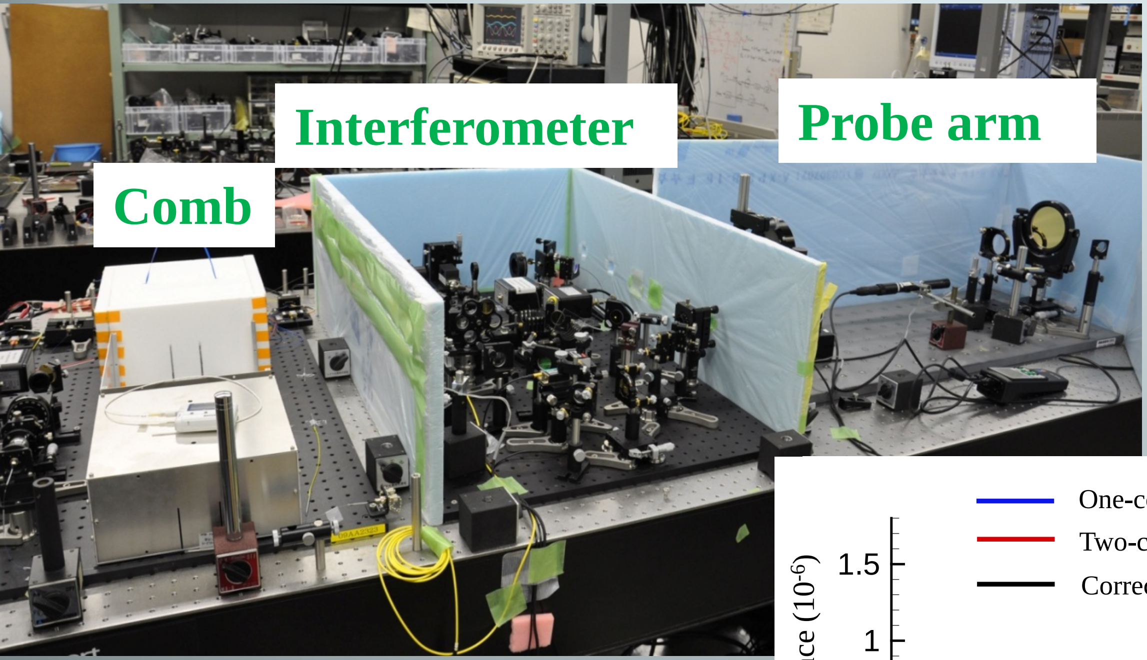
f_{h2} = **2 MHz**

$D_1 = \phi_1/2\pi \times \lambda_1/2$

$D_2 = \phi_2/2\pi \times \lambda_2/2$

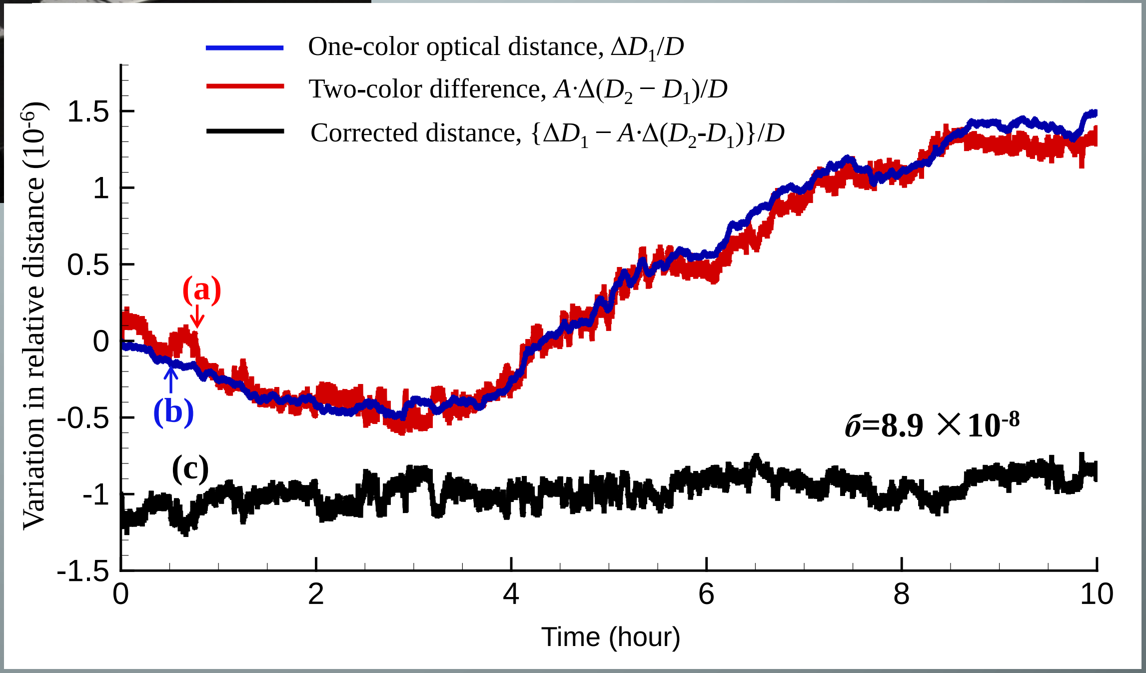
$M_{1\text{-}3}$: Mirror; BS: Beam splitter; $DM_{1\text{-}2}$: Dichroic mirror; $PD_{1\text{-}2}$: Photodetector; AOM: Acousto-optic modulator

Setup of Air Refractive Index Compensation

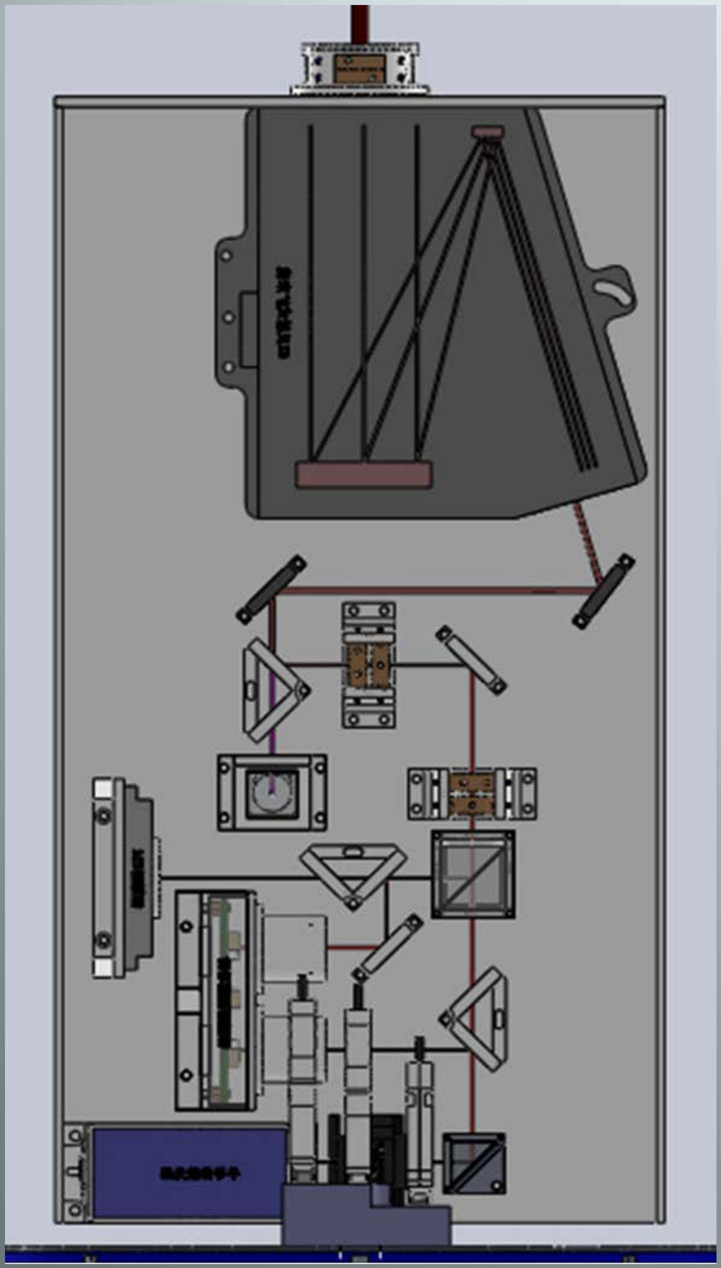


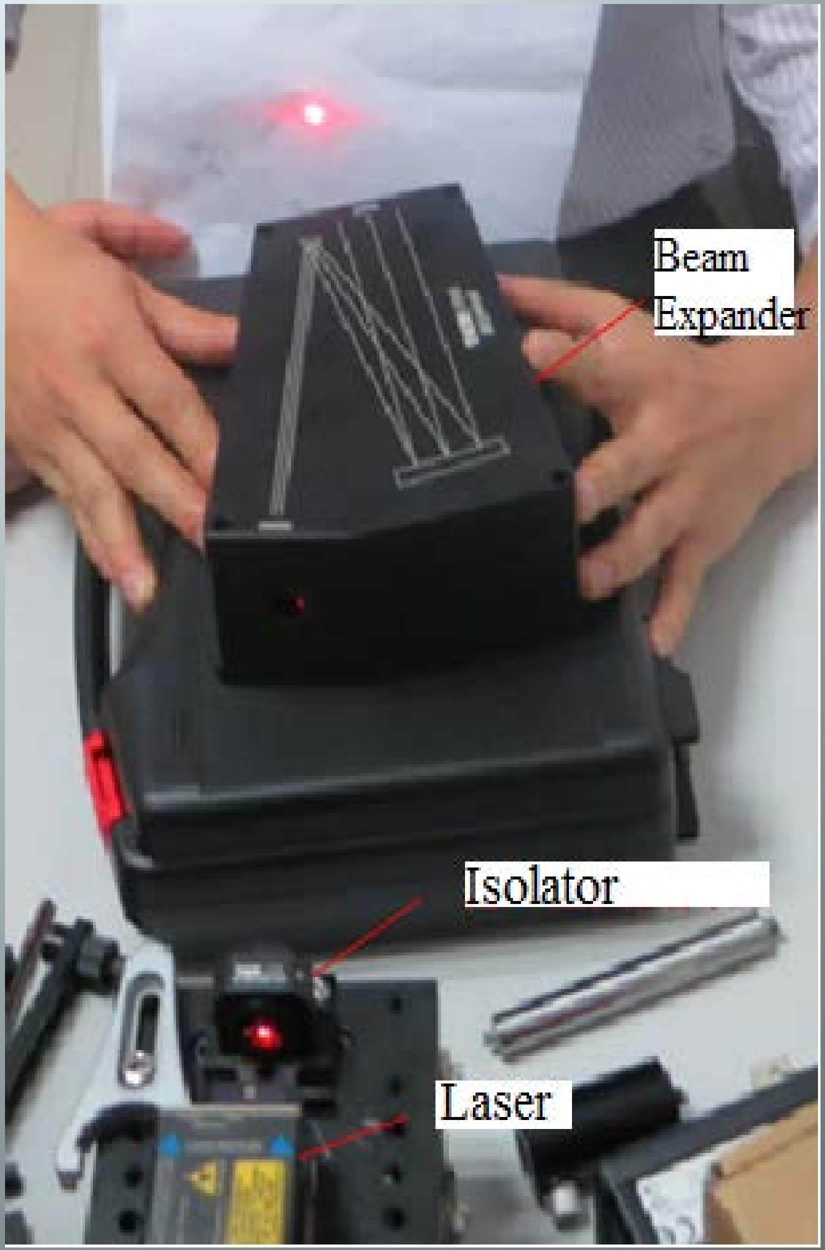
Setup of Air Refractive Index Compensation

Experiment Result

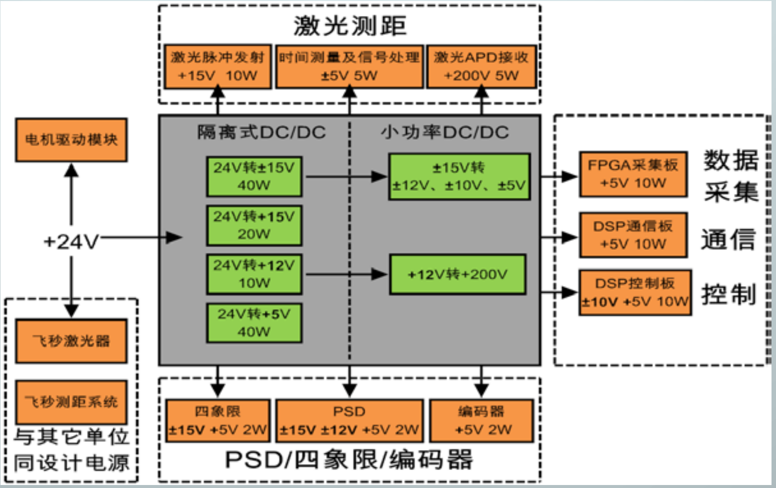


Optical Design

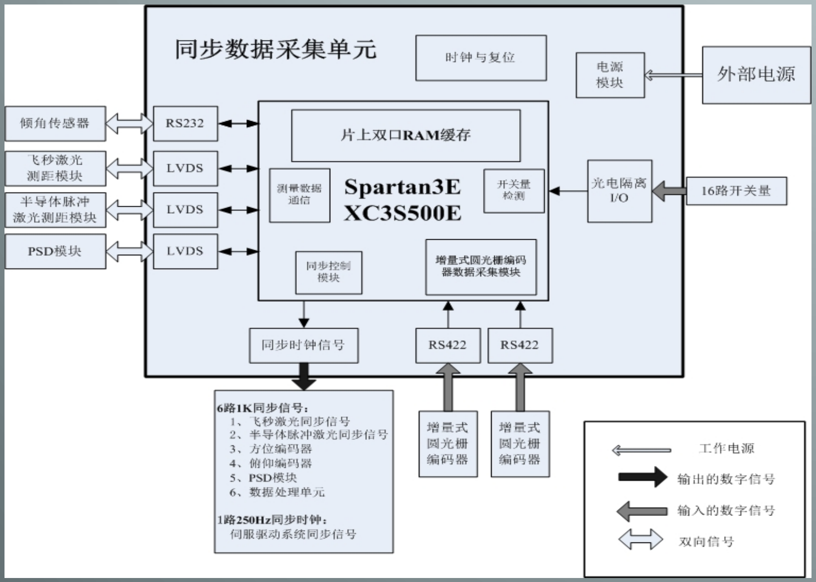




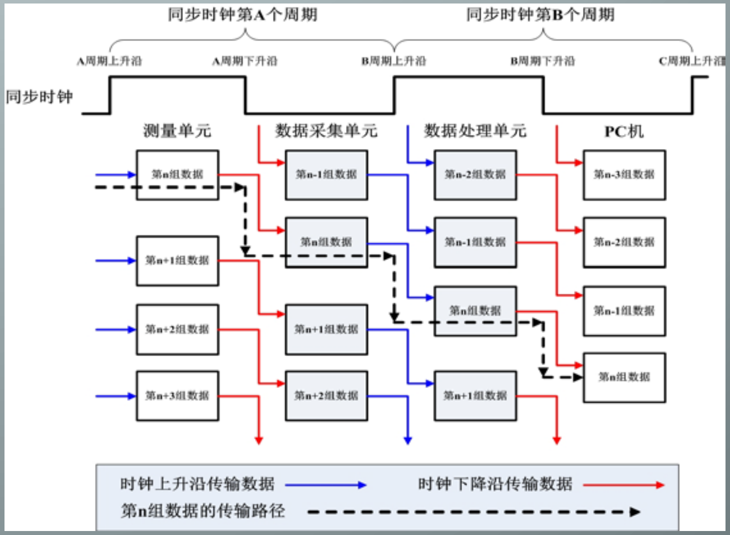
Electronics Design



Power unit

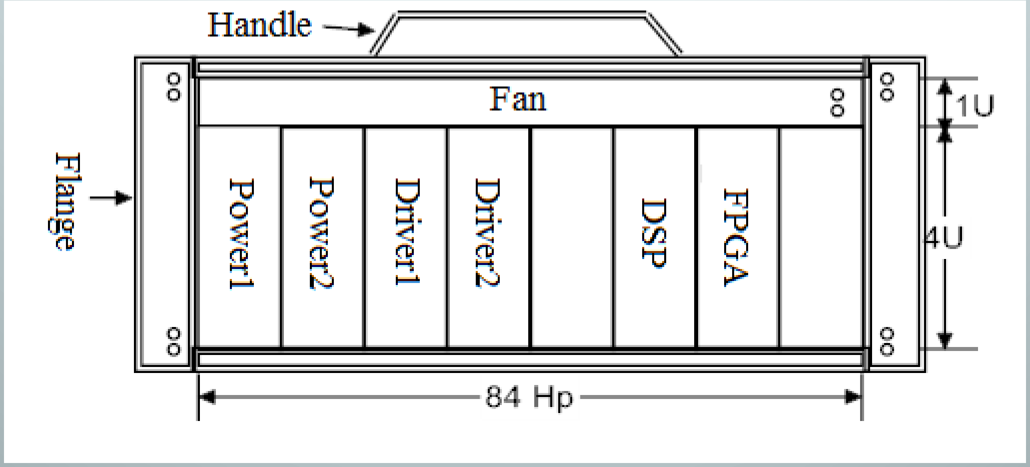


Data acquisition unit



Clock synchronization unit

Electronic Control Box



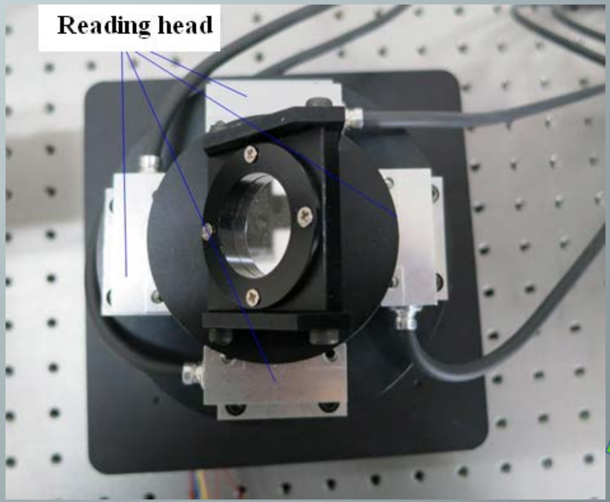
Precision Angle Measurement

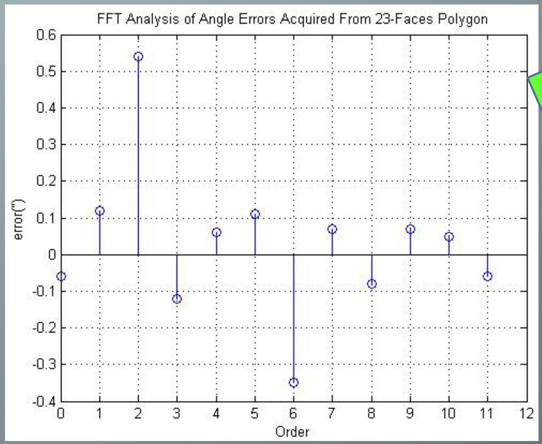
Circular Grating

Reading Head

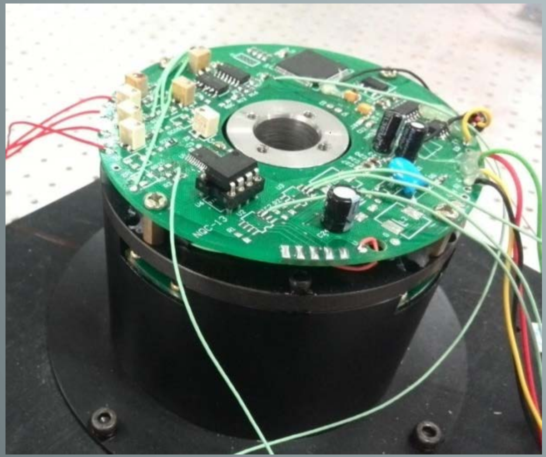
Multiple Reading Head → **Self-Calibration**

Metal circular grating with four reading head.
Without comp.:3.5″ With comp.:0.7″

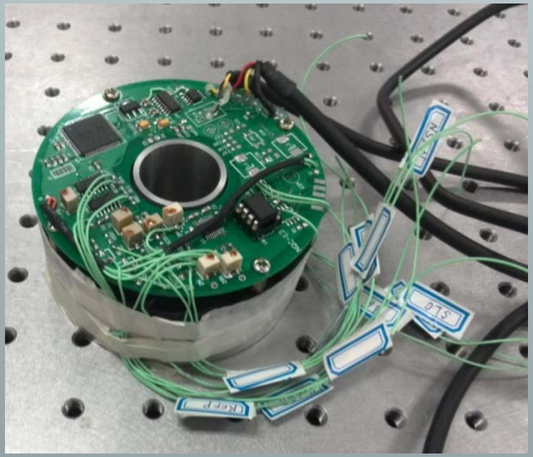




Error Mapping



Four Reading Head

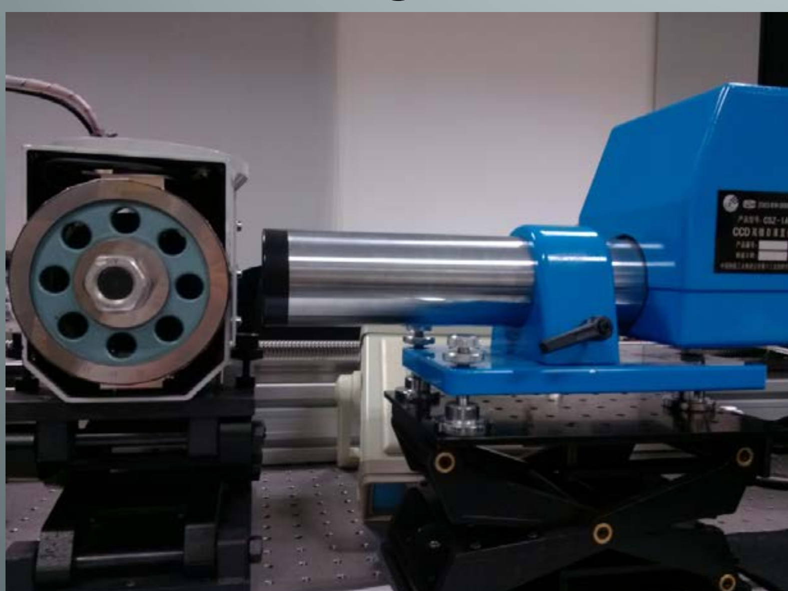


Five Reading Head

Glass circular grating.
Without comp.: 4 ″
With comp.: 1.5″

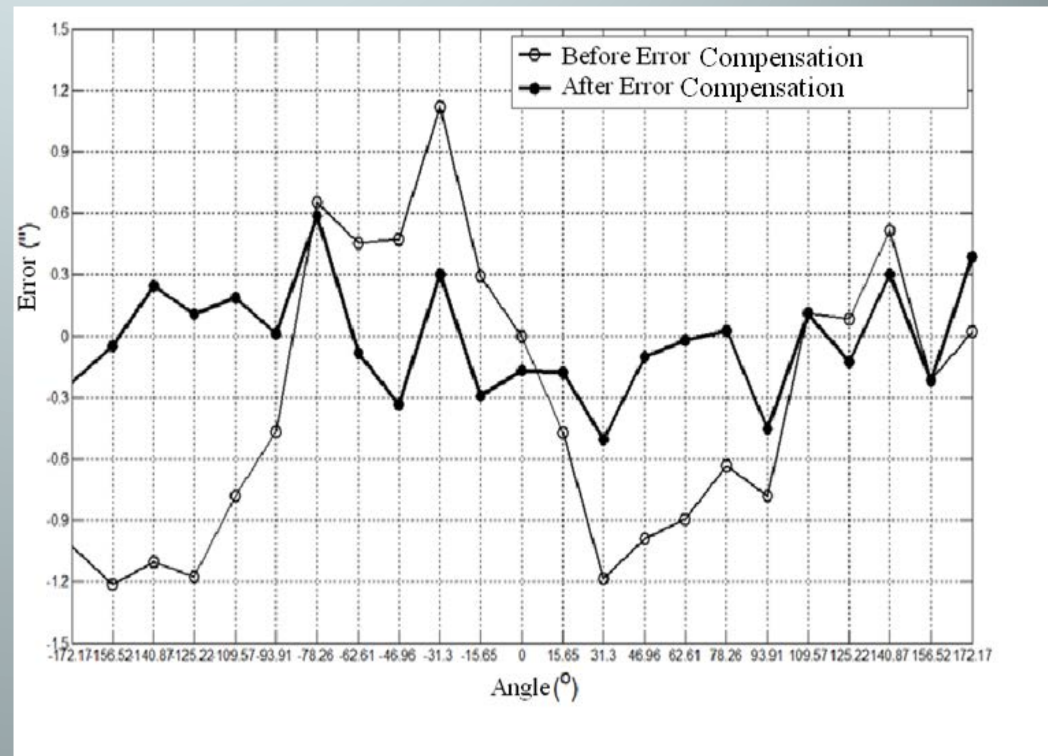
Error Calibration and Compensation

Horizontal Angle Calibration



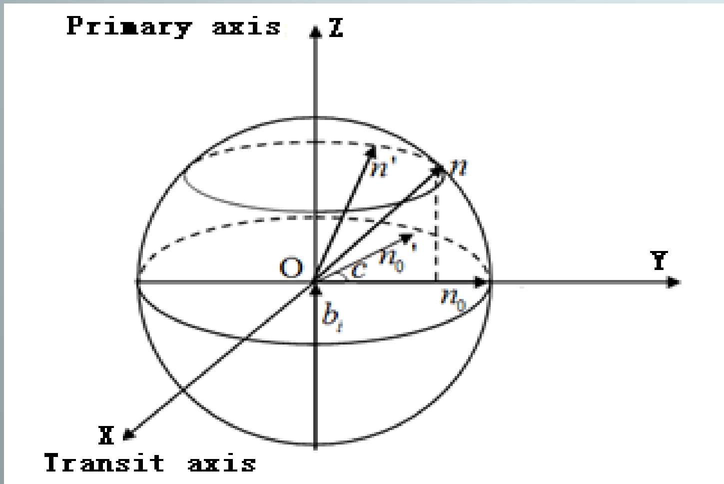
Vertical Angle Calibration

Angle Precision

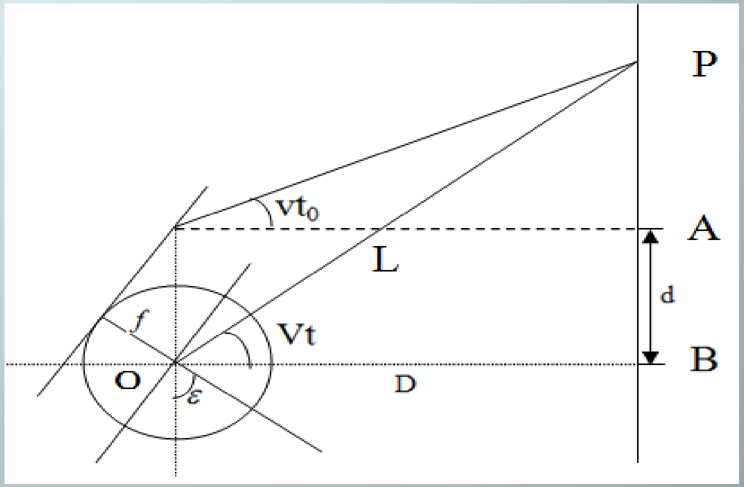


Before compensation: ±1.2″
After compensation: ±0.6″

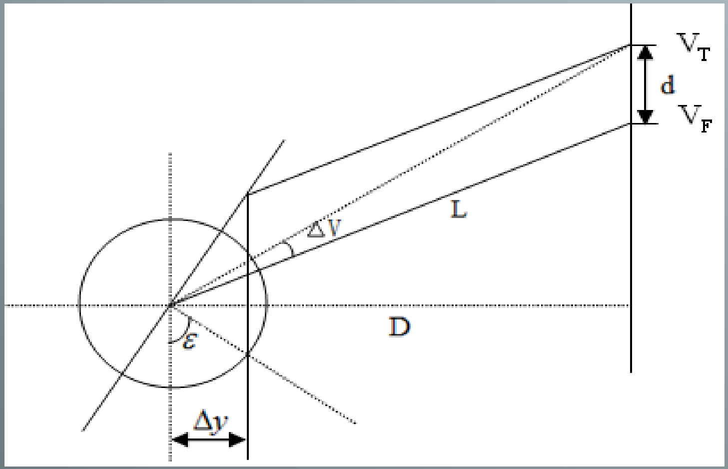
Error Calibration and Compensation



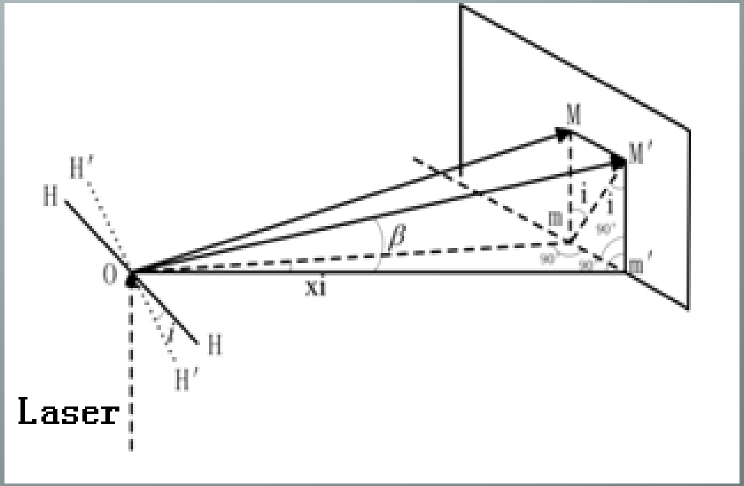
Tracking mirror tilt error



Tracking mirror offset error

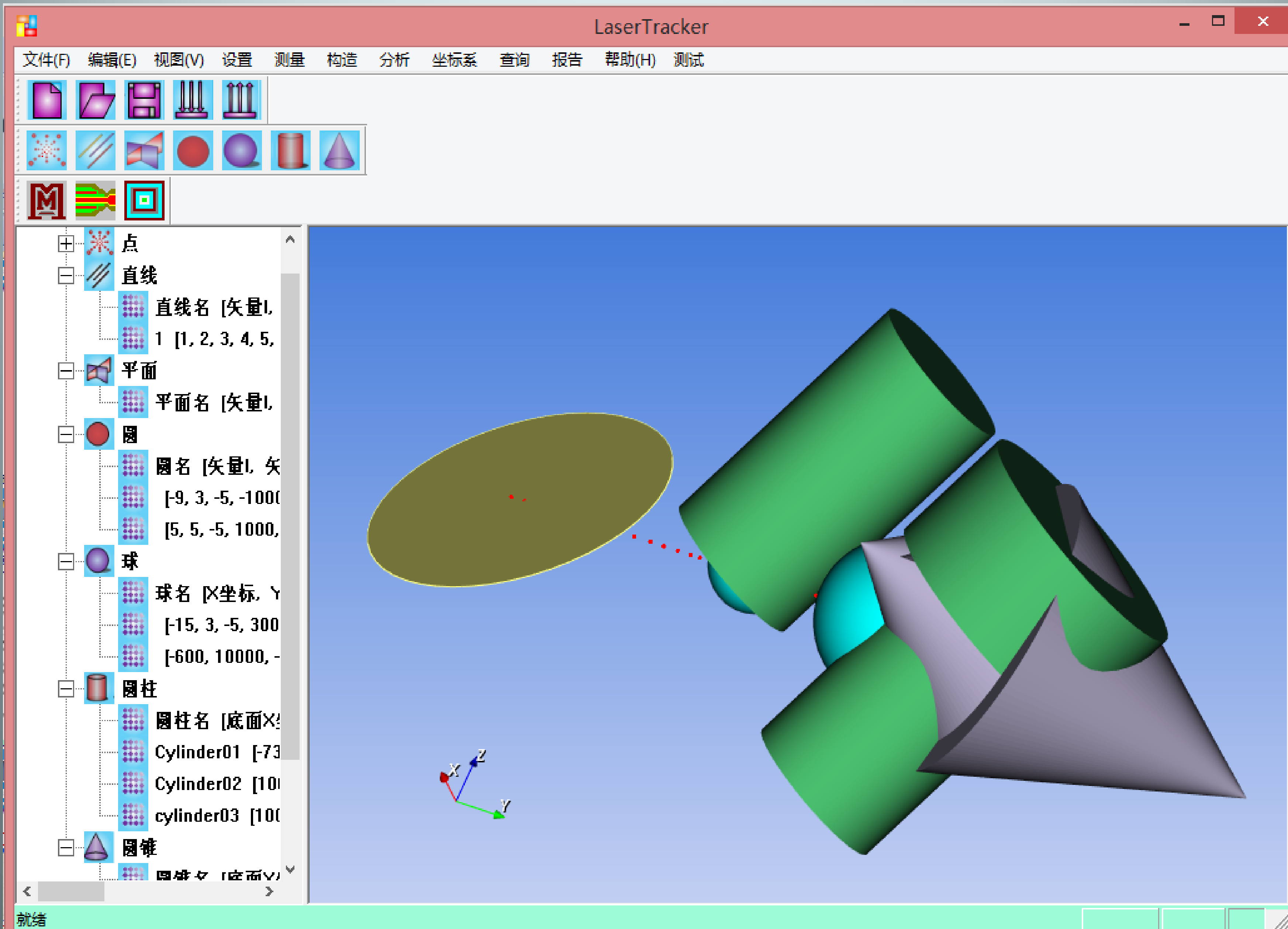


Laser beam offset error



Transit axis tilt error

Software



LaserTracker
文件(F) 编辑(E) 视图(V) 设置 测量 构造 分析 坐标系 查询 报告 帮助(H) 测试
点
直线
直线名 [矢量l,
1 [1, 2, 3, 4, 5,
平面
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[5, 5, -5, 1000,
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[-600, 10000, -
圆柱
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cylinder03 [10
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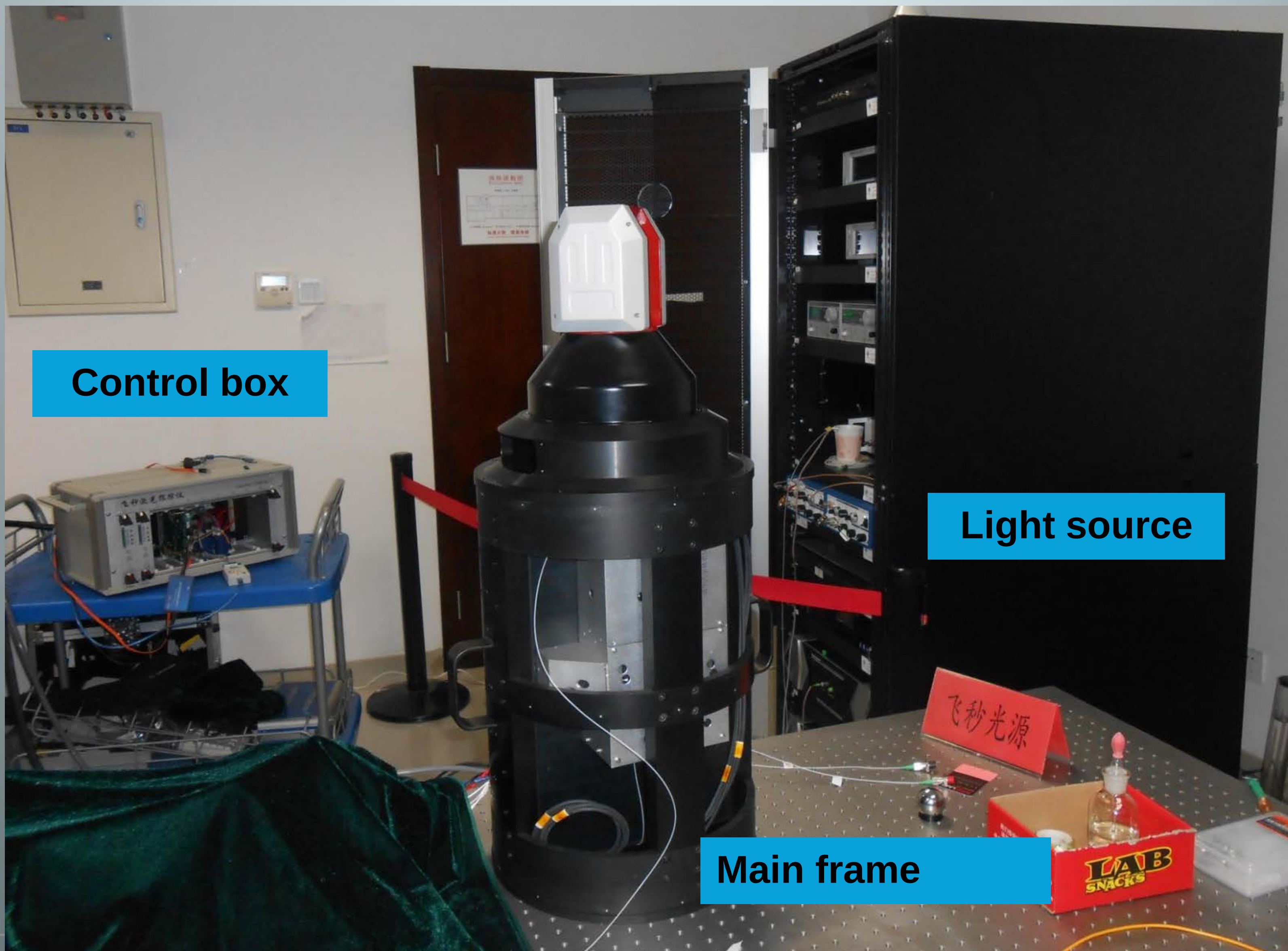
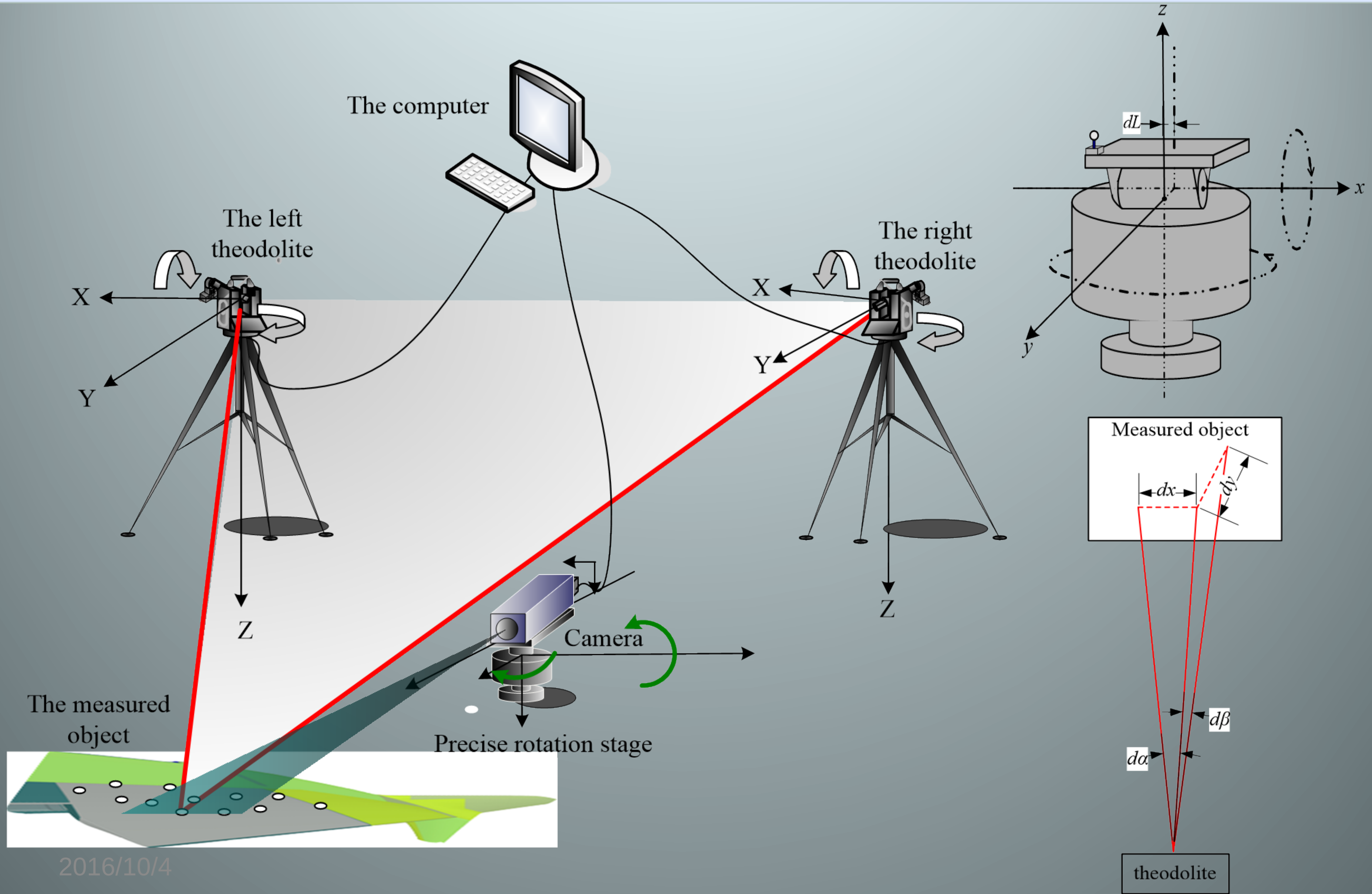
System integration



My research work

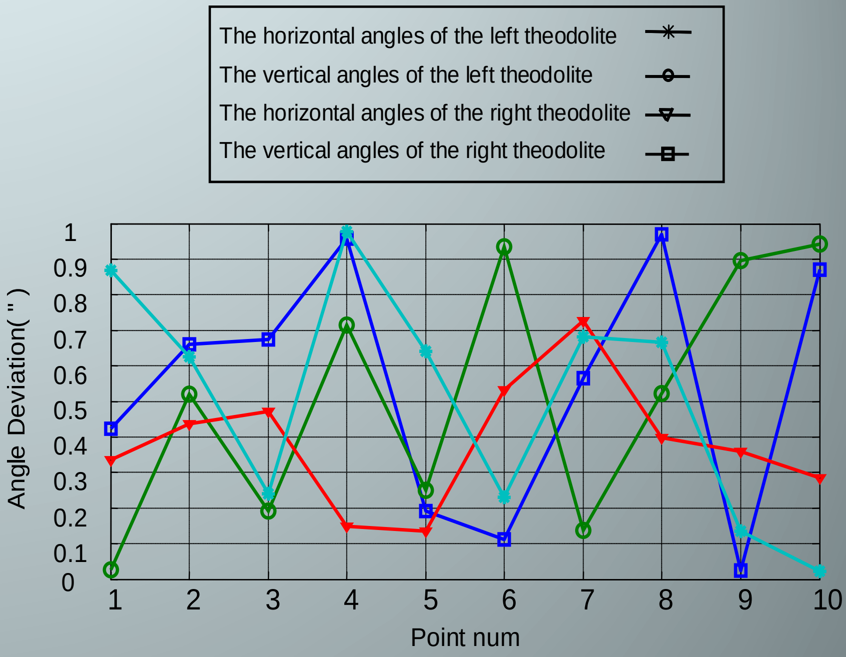
- Theodolite measurement system based on vision guidance
- Error Calibration and Compensation for laser tracker
- Software for measurement system
- Vision guided total station
- Photogrammetry

Theodolite measurement system based on vision guidance



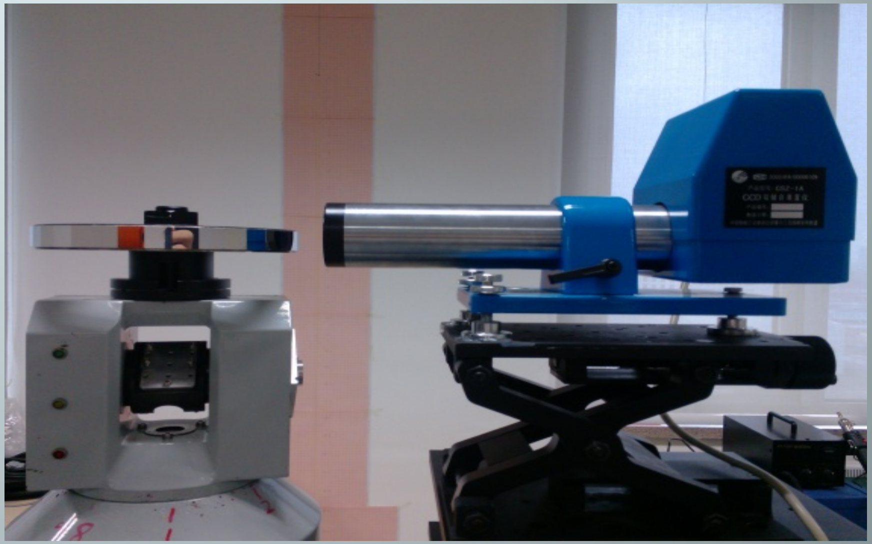
2016/10/4

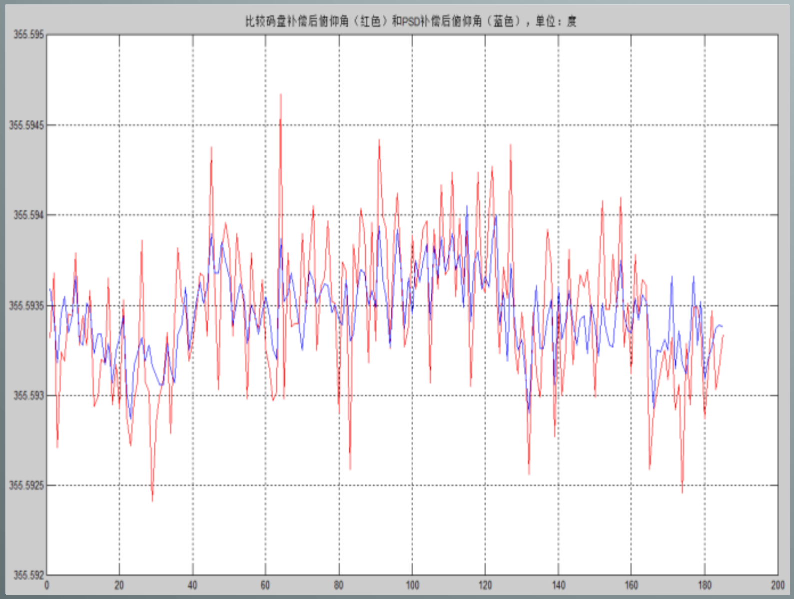
Theodolite measurement system based on vision guidance

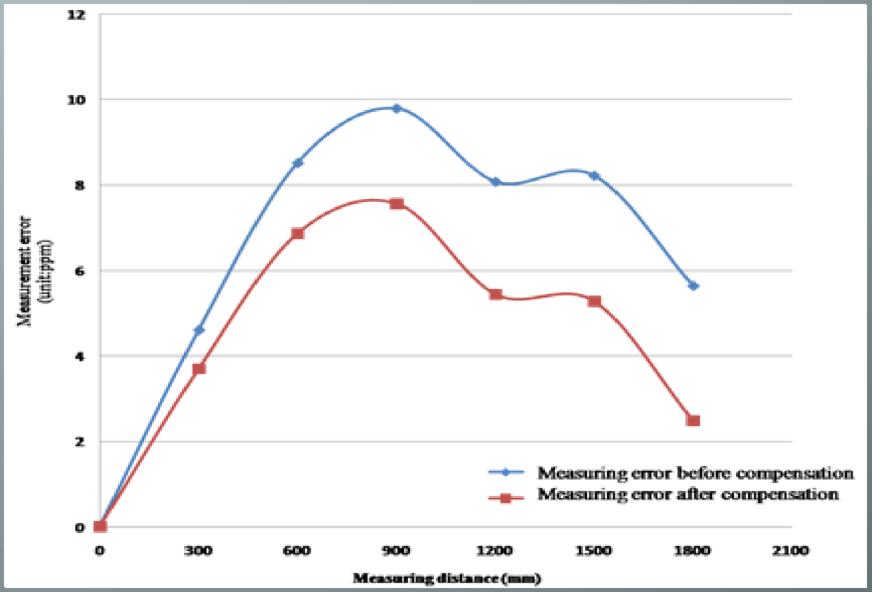


Point index	The measured results of the manual operation (mm)			The measured results of automatic theodolite (mm)			Deviation (mm)			
	x	y	z	x	y	z	Δx	Δy	Δz	Δd
1	760.083	370.834	5774.370	760.064	370.940	5774.319	-0.019	0.106	-0.051	0.119
2	951.053	374.758	5788.259	951.257	374.589	5788.401	0.204	-0.169	0.142	0.301
3	1148.296	359.947	5808.436	1148.210	360.245	5808.633	-0.086	0.298	0.197	0.367
4	652.664	389.054	5776.032	652.907	389.268	5775.839	0.243	0.214	-0.193	0.377
5	750.394	390.547	5792.920	750.662	390.420	5792.933	0.268	-0.127	0.013	0.297
6	1047.573	397.123	5813.998	1047.749	397.348	5814.071	0.176	0.225	0.073	0.295
7	698.130	394.013	5779.836	697.941	394.029	5779.921	-0.189	0.016	0.085	0.208
8	849.731	396.690	5797.828	849.919	396.796	5797.975	0.188	0.106	0.147	0.261
9	1046.761	404.634	5819.759	1046.879	404.918	5819.642	0.118	0.284	-0.117	0.329
10	751.594	409.217	5783.970	751.461	409.276	5784.127	-0.133	0.059	0.157	0.214

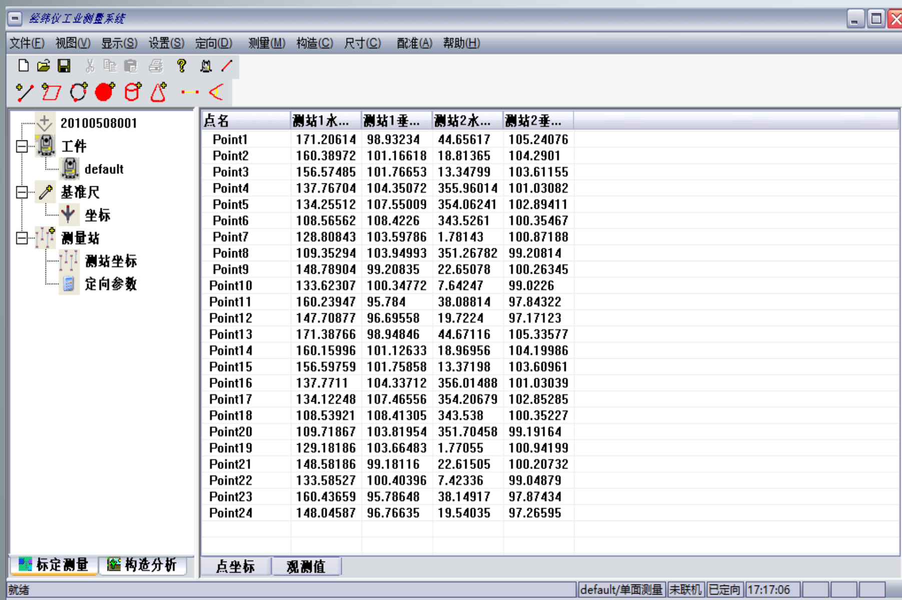
Error Calibration and Compensation for laser tracker



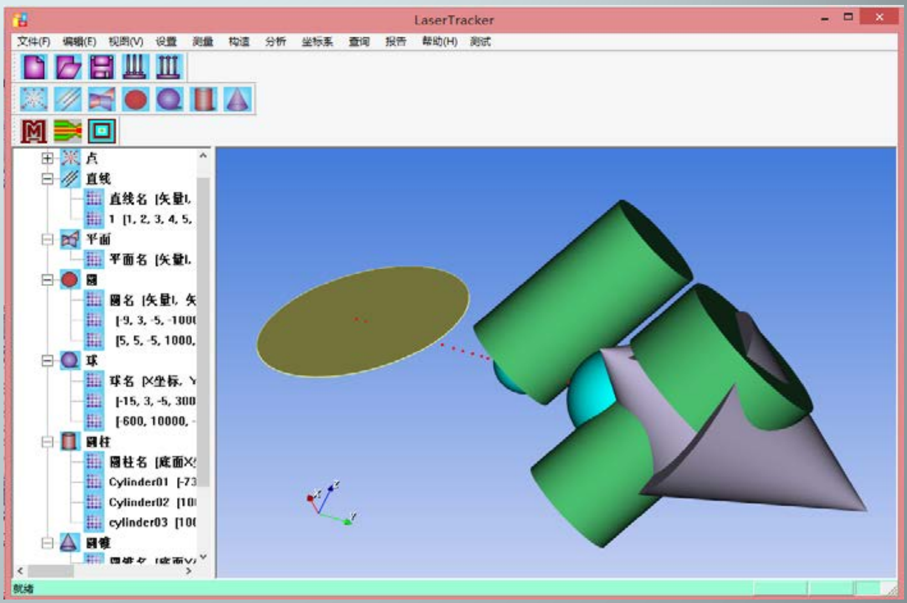




Software of measurement system

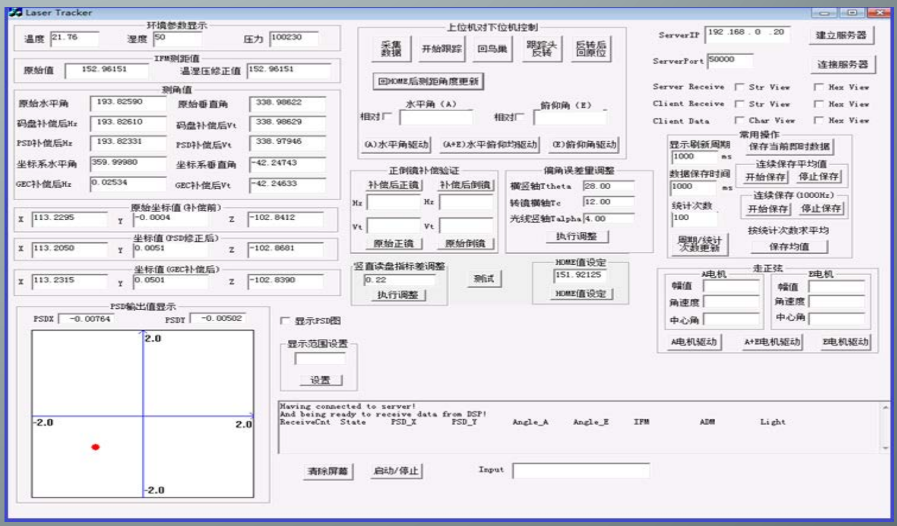


Theodolite



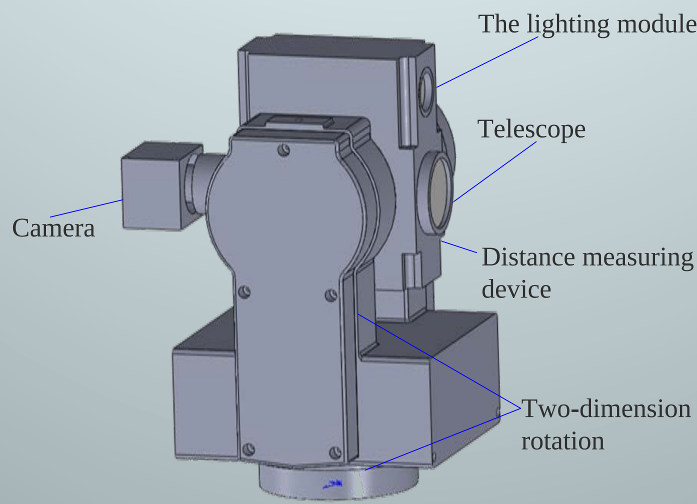
Laser tracker

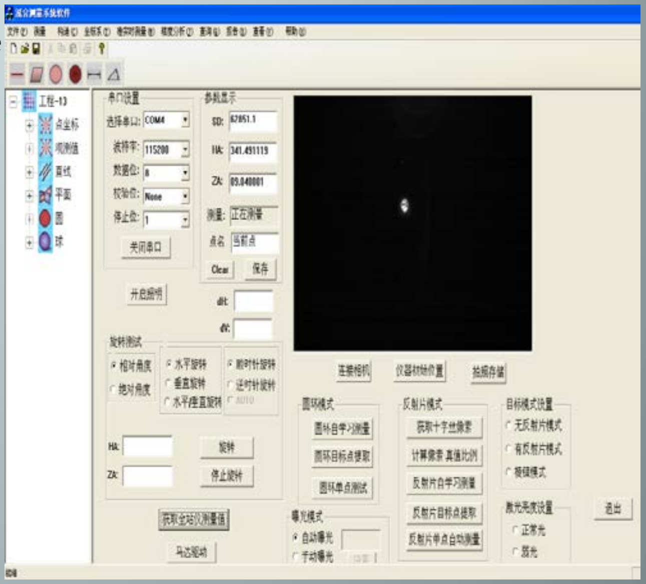
Antenna measurement system



Data analysis

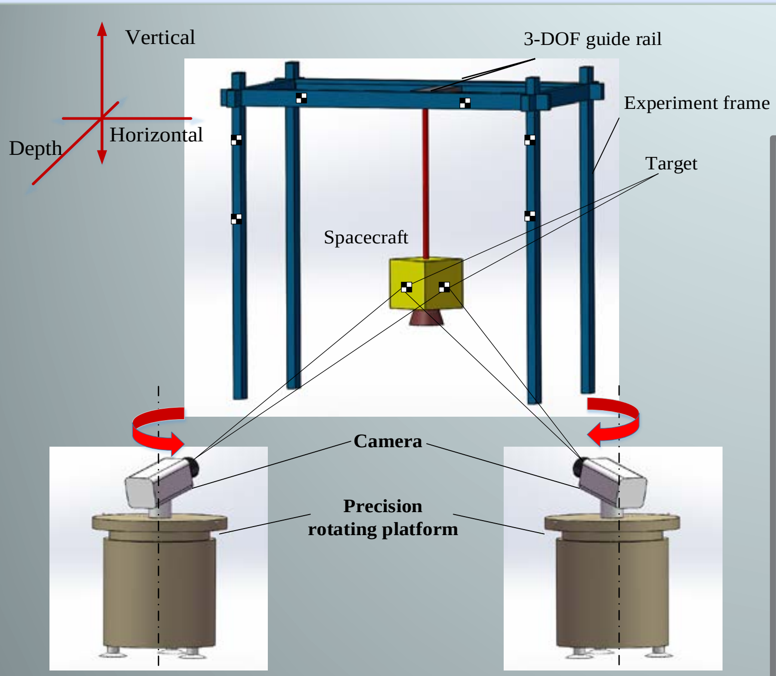
Vision guided total station

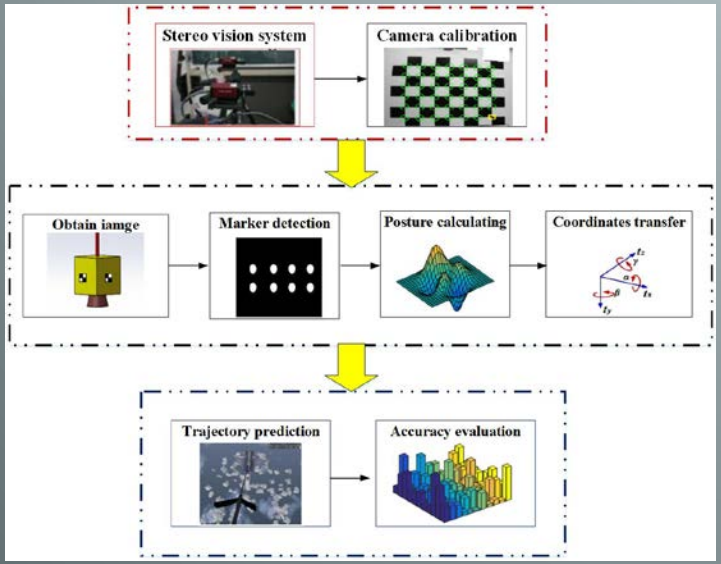


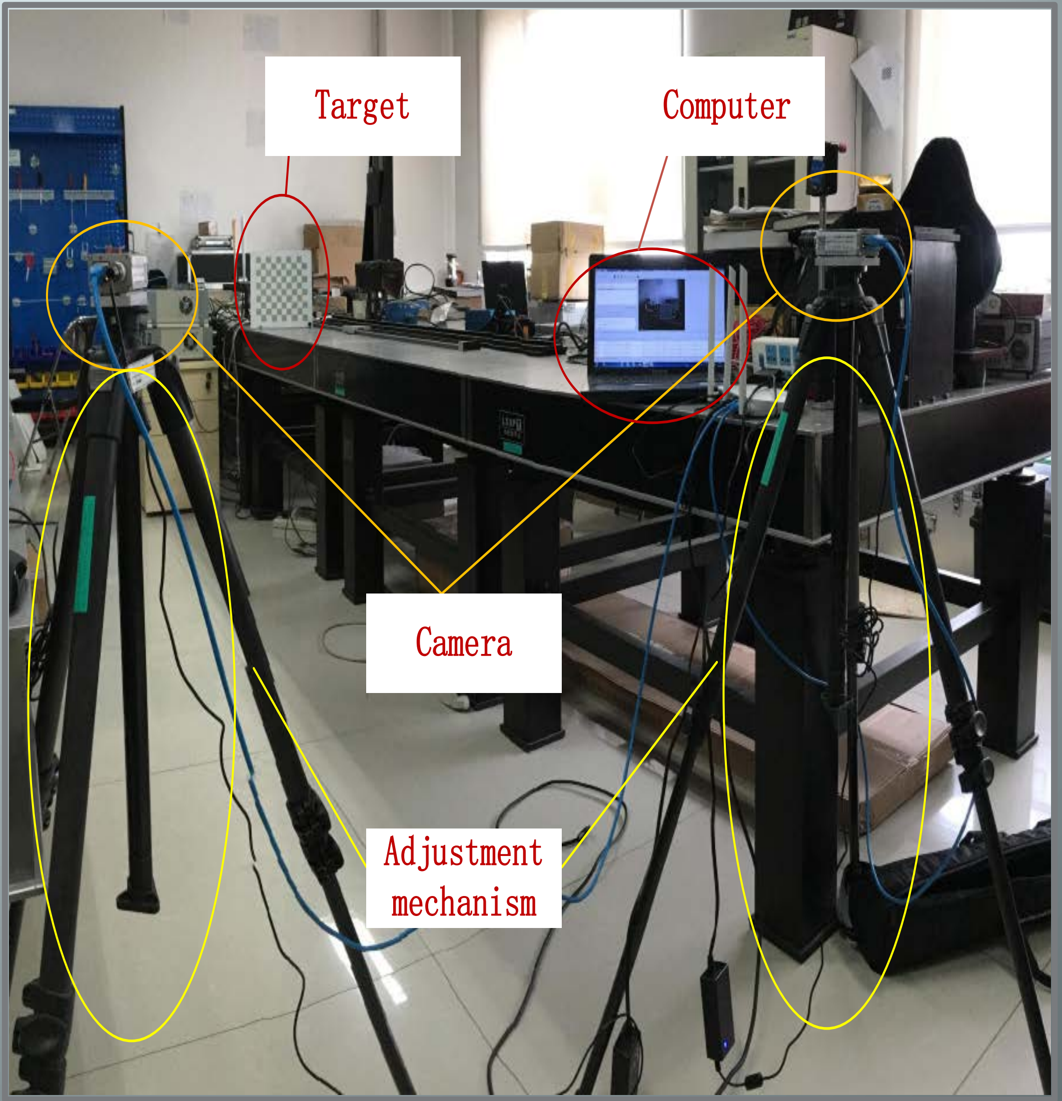


No.	X(mm)	Y(mm)	Z(mm)	Measured distance（mm）	Distance reference(mm)	Deviation (mm)
1	-58378.940	-13778.550	-327.386	\	\	\
2	-58387.970	-13742.860	-327.077	36.816	36.475	0.341
3	-58398.894	-13702.509	-326.446	41.808	41.627	0.181
4	-58405.762	-13675.406	-326.309	27.960	28.417	-0.457
5	-58413.977	-13644.681	-325.704	31.810	31.043	0.767
6	-58421.800	-13614.658	-326.434	31.034	31.053	-0.019
7	-58428.226	-13589.263	-326.330	26.195	26.546	-0.351
8	-58436.989	-13557.295	-325.914	33.150	33.184	-0.034
9	-58442.566	-13535.895	-325.710	22.116	22.671	-0.555
10	-58448.192	-13514.690	-325.620	21.939	20.986	0.953

Photogrammetry







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Beijing, 100094, China

Thank you for your attention！