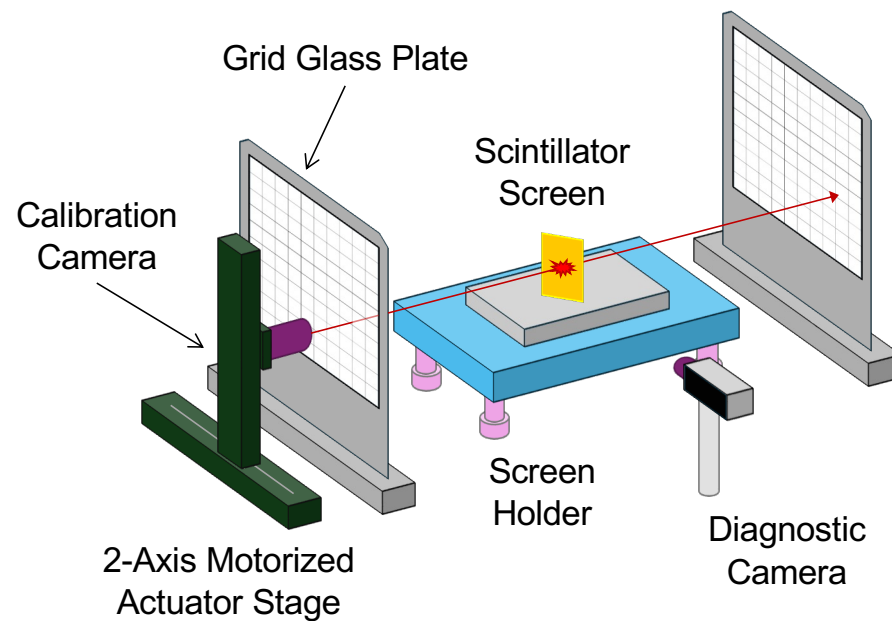


Defining the Error Terms of the Coordinate Calibration Device

31. October 2025

Juhwan Yoon

Introduction



Absolute Coordinate Calibration

- Transverse beam space defined by grid plate
- Moveable camera scanning grid points to trace the deviation from the ideal grid line

Coordinate Measurement Resolution

- Mechanical error: position reproducibility
- Camera digitization: image processing error

Coordinate Mapping

$$\vec{X}_{real} = \vec{X} + \boxed{\Delta\vec{X}} + \vec{\delta}_{error}$$

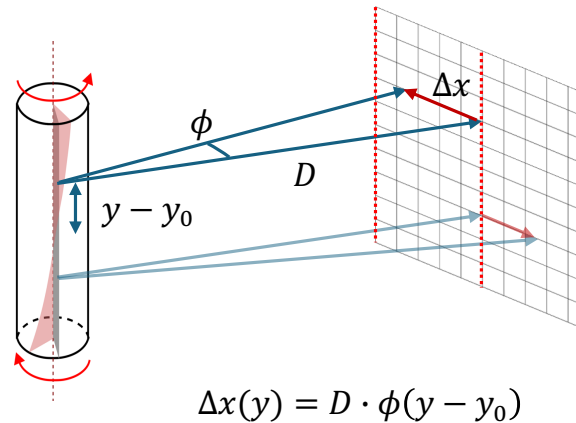
$\vec{X}_{real} = (x_{real}, y_{real})$: actual coordinates

$\vec{X} = (x, y)$: commanded coordinates

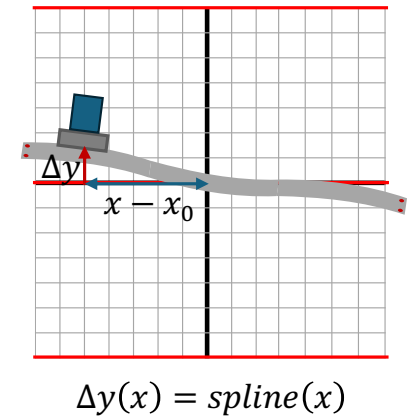
$\Delta\vec{X} = (\Delta x, \Delta y)$: deviation from grid line

$\vec{\delta}_{error} = (\delta_{error,x}, \delta_{error,y})$: systematic error

X-Coordinate Mapping (Δx)

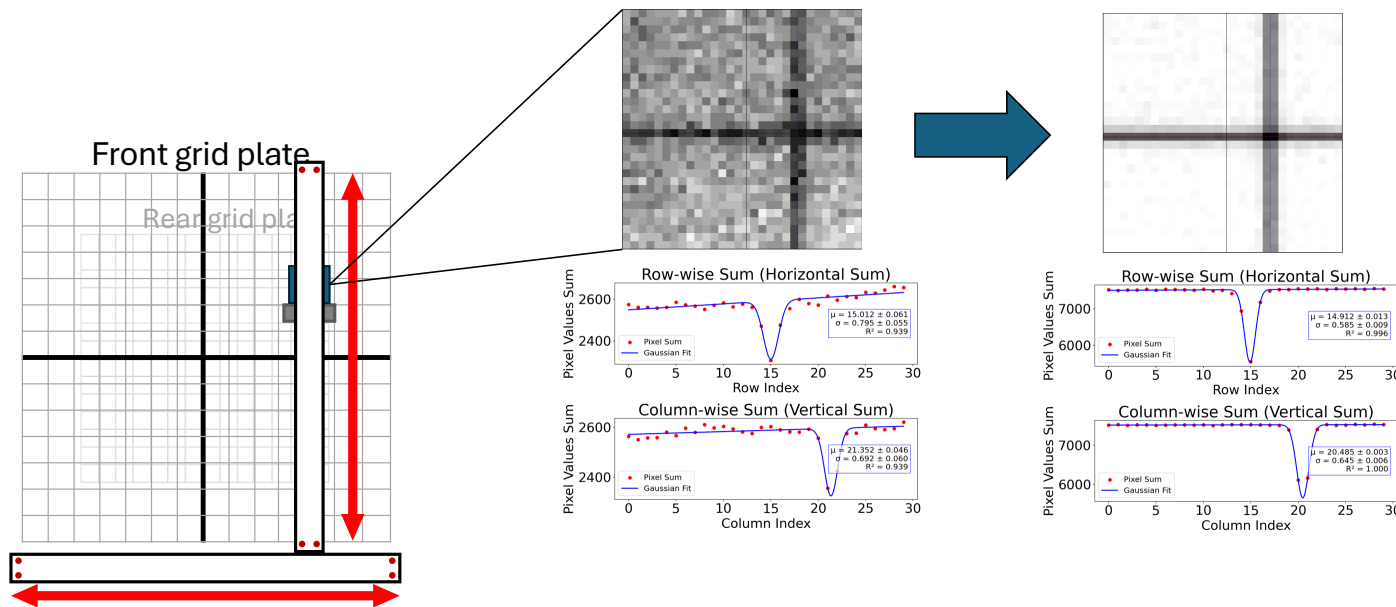


Y-Coordinate Mapping (Δy)



Error Term: Image Processing Error

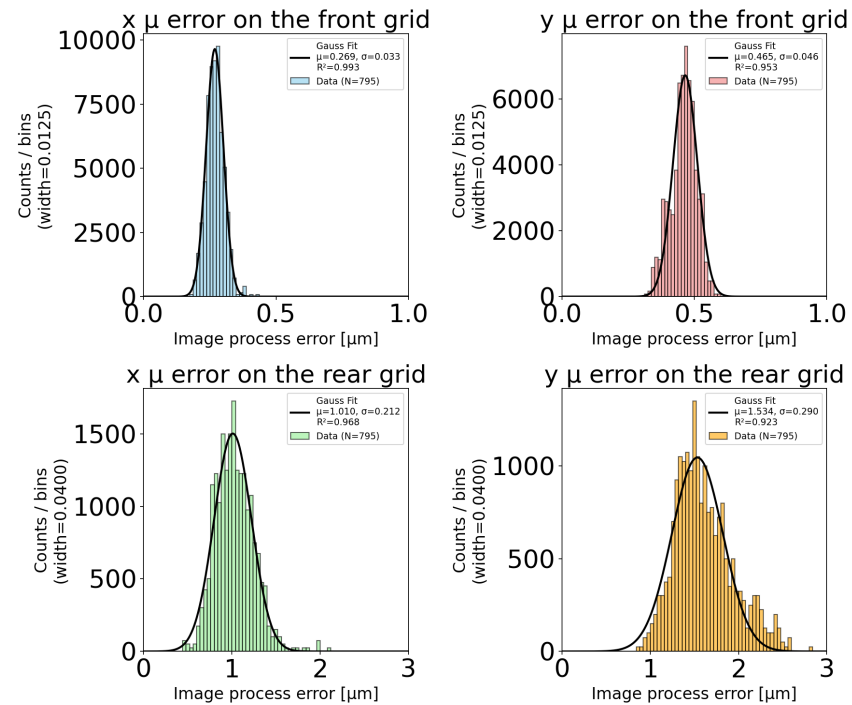
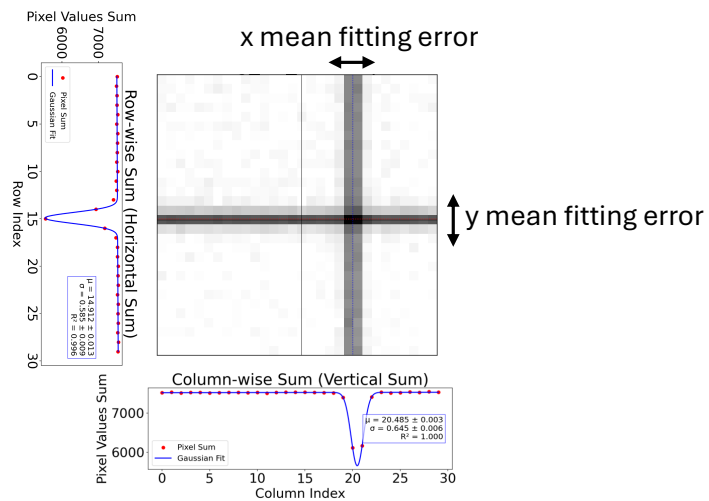
- Pixel sum Gaussian fitting affects coordinate values
- Estimating coordinate errors through the Gaussian mean value error



Fitting Error Factors

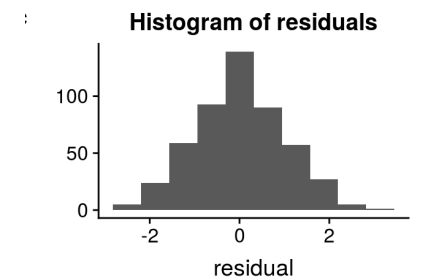
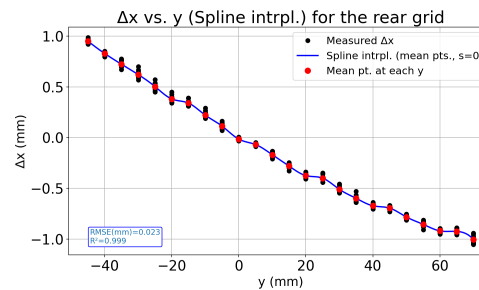
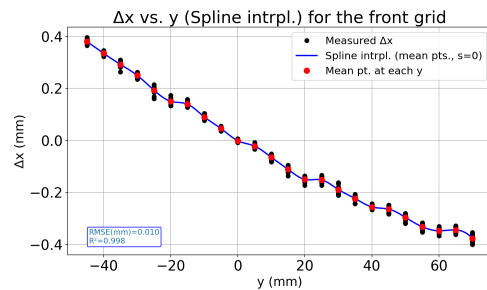
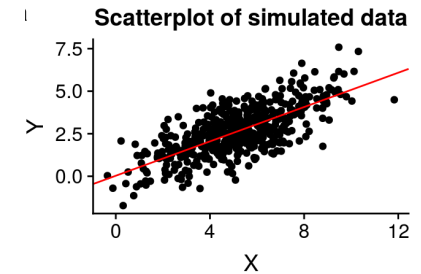
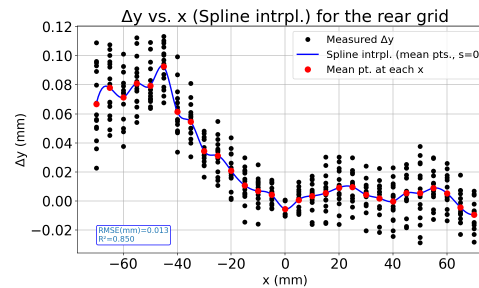
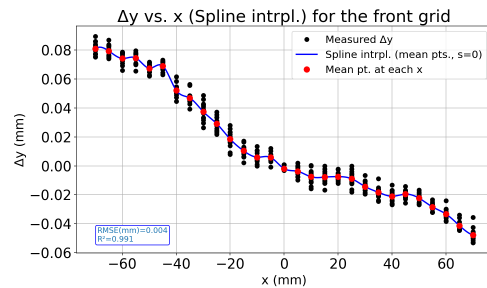
- Fitting initial value
- Linear + Gaussian
- Backlight
 - Uniform intensity
 - Remove shadow

Error Term: Image Processing Error

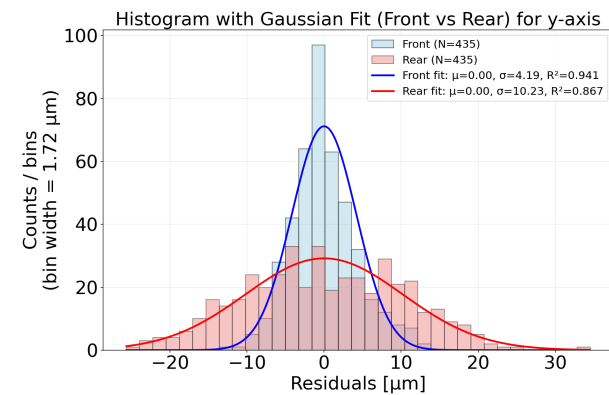
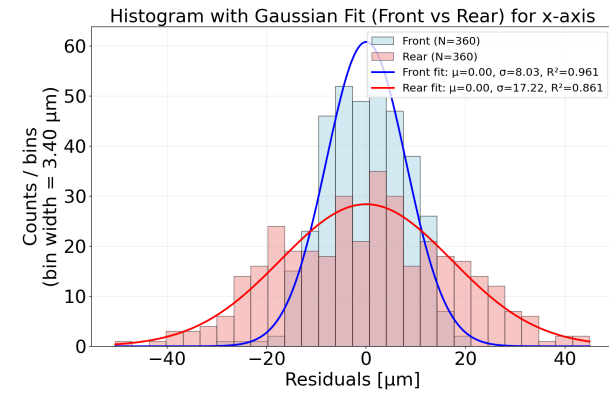
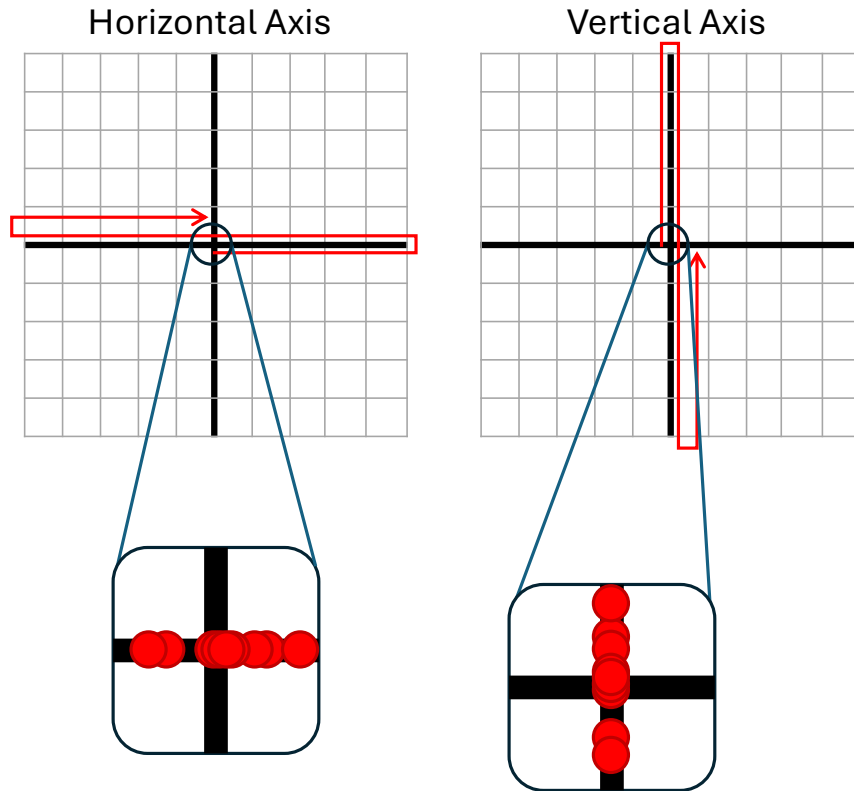


Error Term: Repeatability Error

- Motor reproducibility limit: coordinates are different each time even for the same position
- Residual: how much the measured value deviates from the mean



Error Term: Repeatability Error



Systematic Uncertainties

고려 사항 1: 앞/뒤 그리드의 에러 비율이 카메라와 각 그리드의 거리 비율과 다름

-> 그냥 큰 값 사용, 즉 rear grid의 에러 사용

-> 수평축, 수직축 둘 다 오차값이 수 마이크로미터 이내로 차이 남

고려 사항 2: 가우시안 그래프 피팅 자체에서 생기는 에러

-> 측정 횟수를 늘림

-> 히스토그램 막대 범위(bin) 조정 또는 R^2 을 극대화하도록 히스토그램을 그리기

고려 사항 3: image processing error 포함되어 있을 것

-> 반복측정도 이미지를 기반으로 하므로 이미지 자체의 에러가 내포되어 있다

-> 이미지 처리 오차를 반복 측정 오차와 함께 총 오차로 합치기

Systematic Uncertainties

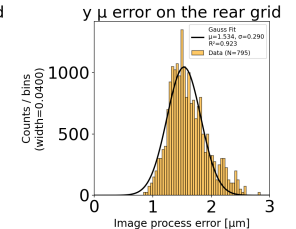
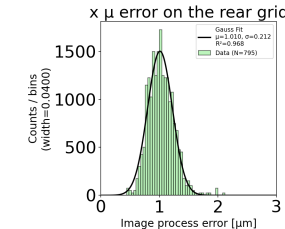
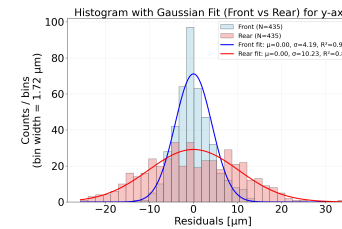
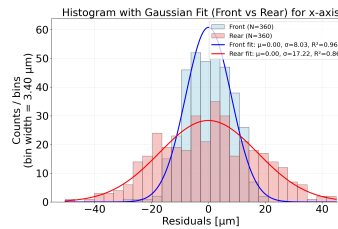
$$\vec{X}_{real} = \vec{X} + \Delta\vec{X} + \boxed{\vec{\delta}_{error}}$$

$\vec{X}_{real} = (x_{real}, y_{real})$: actual coordinates

$\vec{X} = (x, y)$: commanded coordinates

$\Delta\vec{X} = (\Delta x, \Delta y)$: deviation from grid line

$\vec{\delta}_{error} = (\delta_{error,x}, \delta_{error,y})$: systematic error



Error Type	Error Value (μm)
$\delta_{img,x}$	1.010
$\delta_{img,y}$	1.534
$\delta_{rep,x}$	17.22
$\delta_{rep,y}$	10.23

$$\blacktriangleright \vec{\delta}_{error} = \sqrt{\delta_{img}^2 + \delta_{rep}^2} = \begin{cases} \delta_{error,x} = 17.25 \mu m \\ \delta_{error,y} = 10.34 \mu m \end{cases}$$

THANK YOU