Inside your life !

대외비 2급

본질 집중
깊은 사고

새로운 시도
집요한 실행

정직과 신의

ToF 통합 Calibration

목 차

1. Indirect ToF의 기본 원리
2. Infineon(PMD) Calibration 장비
3. Sony Calibration 장비
4. ToF Calibration 통합화
5. Infineon Calibration 기술 소개
6. Sony Calibration 기술 소개
7. Calibration 차이점

2019. 04. 26

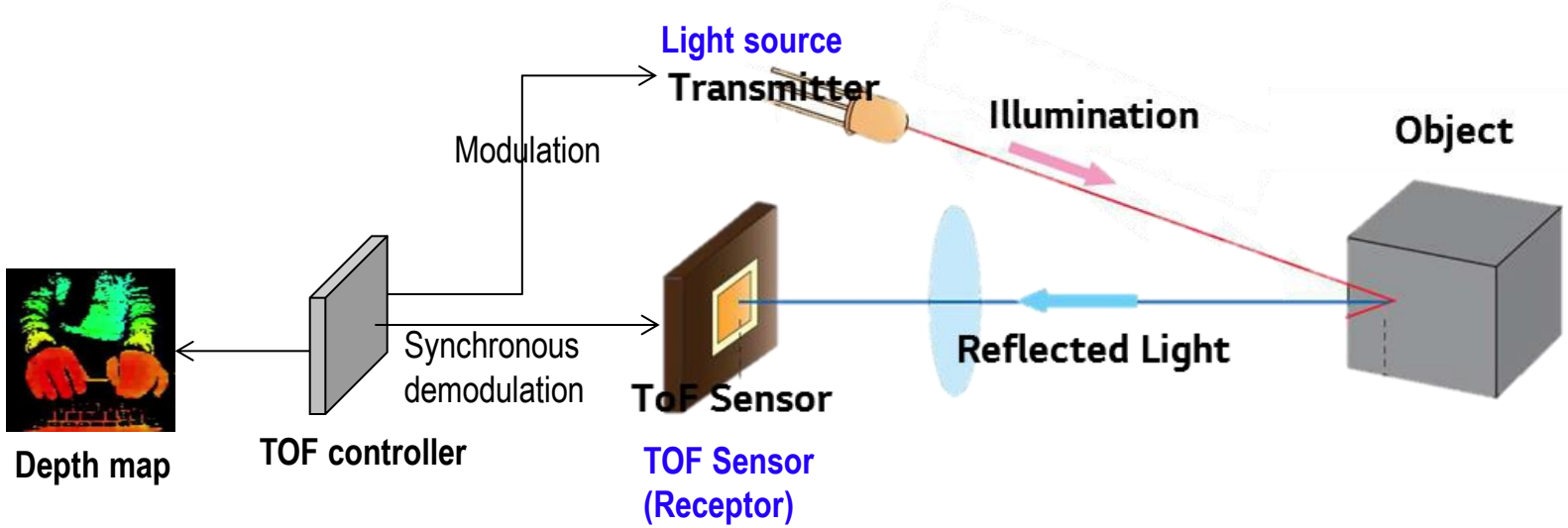
LG이노텍 / CTO

1. 개념

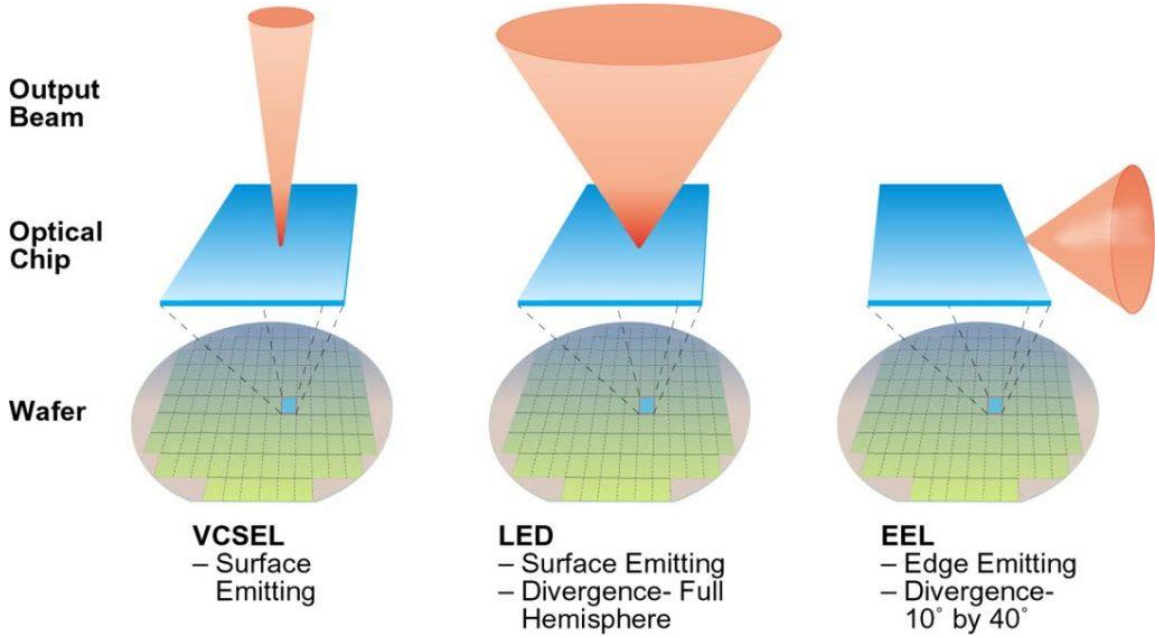
- Depth 인식을 하고자 하는 영역(3D Scene)으로 Light source (Laser) 에서 굉장히 빠른 간격으로 점멸 (Modulation)을 시키면서 빛을 쏘고,
- 수신부(TOF Sensor)에서는 Modulation 간격과 동기화 하여 Receptor들을 활성화 시키면서 되돌아오는 빛의 양을 인식하여 물체와의 거리 측정

2. 시스템 구성

핵심부품 : Light source(발광부), TOF Sensor(수광부)



3. Light source



VCSEL(vertical cavity surface emitting laser): LED에 비해 빛을 집중적으로 멀리 쏠 수 있는 장점

4. 인식 원리 (Indirect type)

● 인식거리는 속도 x 시간 측면에서 아래와 같이 계산함

$$d = \frac{1}{2} c\tau$$

c : Speed of Light, T : Flight time (Returning time)
(※T 은 Returning time이므로 ½로 계산)

● Indirect TOF에서는 직접적인 "T"를 알 수 없으므로,
Sinusoidal wave 라는 가정하에
송출신호와 수신신호 차이(Signal phase)를 토대로 계산

● 변조된 주파수의 범위는 10~100Mhz

● Signal phase와 Time of Flight의 관계는 아래와 같음

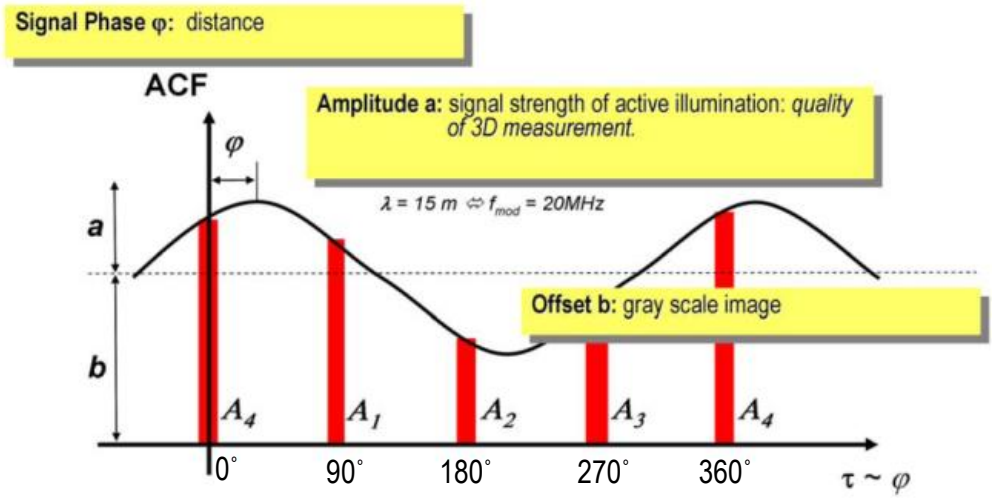
$$\phi = 2\pi f \tau \qquad \boldsymbol{d = \frac{1}{2f} c \frac{\emptyset}{2\pi}}$$

ϕ : Signal phase(위상차), f : modulation frequency

▪ TOF 측정 가능 범위

$$d = \frac{c}{2f}$$

f : Modulation Frequency — f = 80MHz → d = 1.875m
c : Speed of Light — f = 60MHz → d = 2.5m



"ϕ" : Signal phase, defined up to 2 π
"A" : Amplitude of the received signal, 물체의 반사율과 센서의 Sensitivity에 의해서 결정됨
Amplitude는 Light spread에 의해 $1/d^2$ 만큼 감소
"B" : Offset coefficient due to the ambient illumination.

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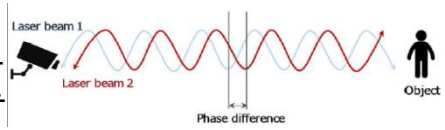
1. Indirect ToF의 기본 원리 (4/7)

저비용 가능한 기술
- D-ToF 에서 요구되는 기술 필요 없음
- 위상차에 의해 시간차/거리 추출 가능



자사의 모바일/차량 ToF 방식 ➔ 범용 calibration 기술/장비 구축 필요

Time of Flight

① Indirect ToF (I-TOF)

RF-modulated light sources with phase detectors

Phase difference method

Microsoft Kinect 2	Faro	Heptagon(MESA)	PMD/Infinion
Softkinetic(Sony)	ZF	Panasonic	Optex

Direct ToF (D-TOF)

② Pulse based Gate (Time-gating)

Range gated imagers

Measuring the TOF by using the semiconductor device structure in which detection and accumulation of carriers generated in the light changes depending on the arrival timing of the light.

Fraunhofer	SensL
TriDicam	Zecotek
STMicrotechnology	Caeleste/Brain vision

③ Pulse based Clock

Time-correlated single-photon counting (TCSPC)

The measurement method to measure TOF in direct time domain. It converts the electrical pulse generated through the avalanche effect into the change of time and to digital value by TDC.

ASC	Velodyne	IHI	STMicrotechnology
Toyota	Riegl	Toppcon	Nippon Signal
Princeton Lightwave	SICK	Hokuyo	Garmin(PulsedLight)
Harris	Renishaw	Konica Minolta	
Hexagon(SigmaSpace, Leica)		Mitsubishi	

④ Others

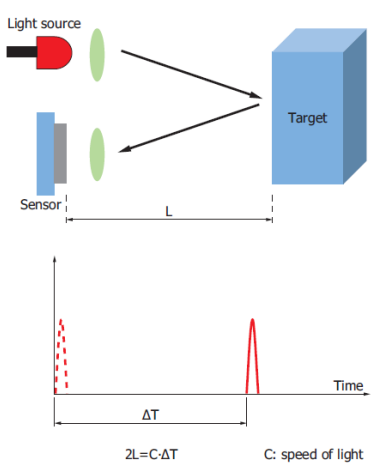
- Interferometer — Wavelength Scanning Interferometer: Leddartech
- Optical Phased Array — Optical Phased Array: Quanergy

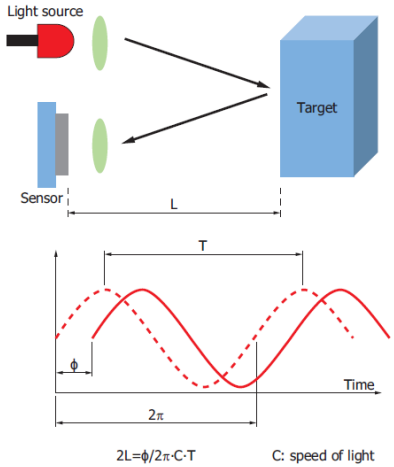
고비용이 요구되는 기술
- short pulsed light 생성 기술
- mm 해상도
- ps 단위의 time resolution

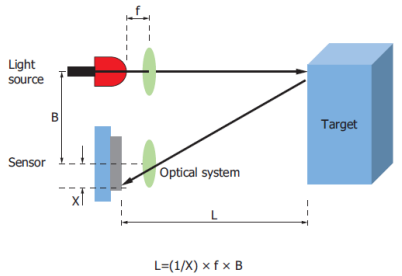
1. Indirect ToF의 기본 원리 (5/7)

구조광 방식

Parameter	Direct TOF	Indirect TOF	Triangulation
Measurement range	Long	Middle	Middle
Accuracy	Middle	High	High
Optical system size	Small	Small	Large
Readout circuit	Complex	Complex	Simple
Array	Suitable	Suitable	Unsuitable
Ambient light immunity	High	Middle	Low







4 Raw data

$Raw(x_0)$

$Raw(x_{90})$

$Raw(x_{180})$

$Raw(x_{270})$

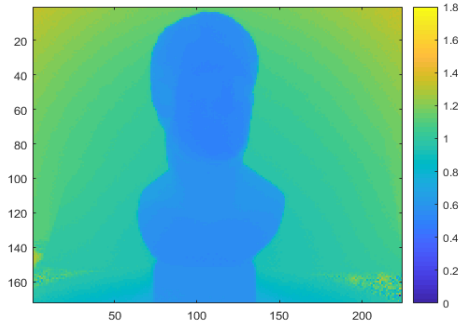
$$Amplitude = \frac{1}{2}\sqrt{(Raw(x_{90}) - Raw(x_{270}))^2 + (Raw(x_{180}) - Raw(x_0))^2}$$

$$Phase = \arctan\left(\frac{Raw(x_{90}) - Raw(x_{270})}{Raw(x_{180}) - Raw(x_0)}\right)$$

$$Depth = \frac{1}{2f} c \frac{Phase}{2\pi} \quad (c = speed\ of\ light)$$

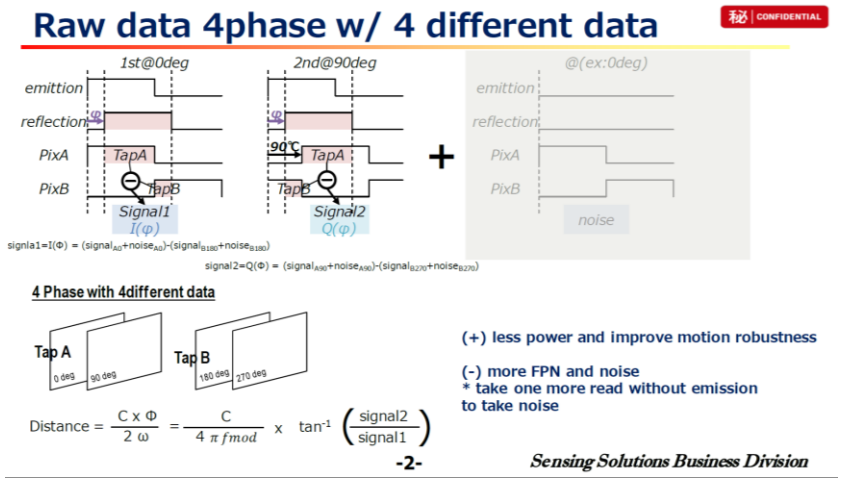
Amplitude Image

Depth Image
(gray ver.)

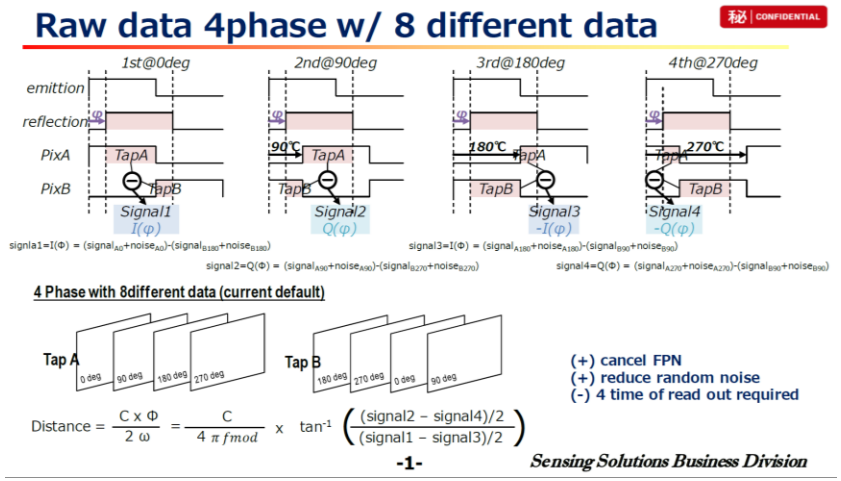


Depth Image
(color ver.)

PMD 와 Sony의 기본 phase data



Sony의 4 phase / 8 different data



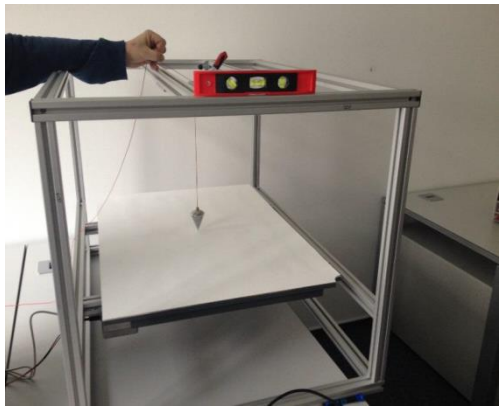
$$\text{Distance} = \frac{C \times \Phi}{2\,\omega} = \frac{C}{4\,\pi\, fmod} \times \tan^{-1}\left(\frac{signal2}{signal1}\right)$$

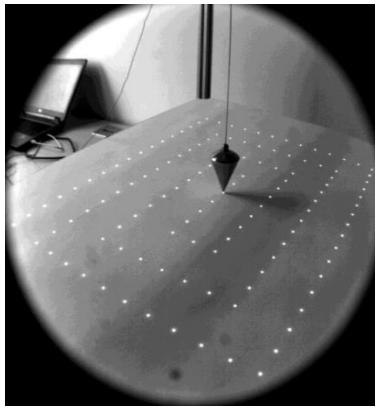
$$\text{Distance} = \frac{C \times \Phi}{2\,\omega} = \frac{C}{4\,\pi\, fmod} \times \tan^{-1}\left(\frac{(signal2 - signal4)/2}{(signal1 - signal3)/2}\right)$$

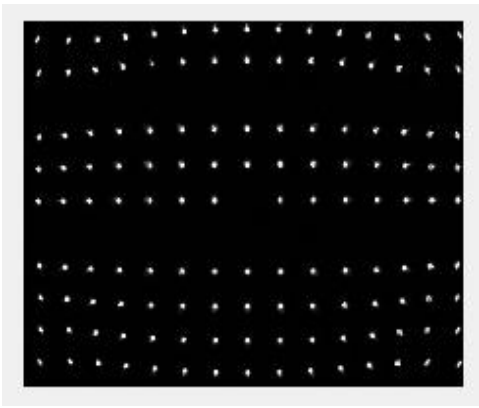
2. Infineon(PMD) Calibration 장비 (1/2)

1) LED box

- Lens Calibration
- FPN
- FPPN

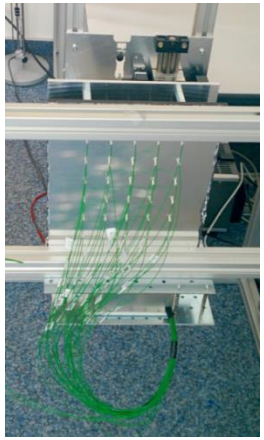


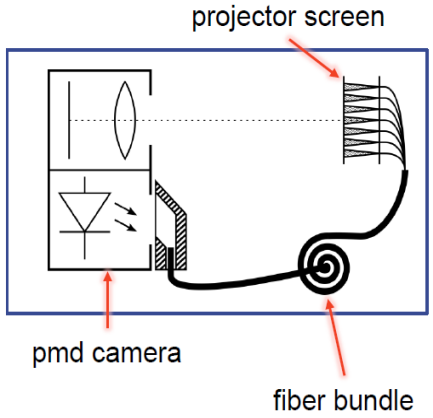


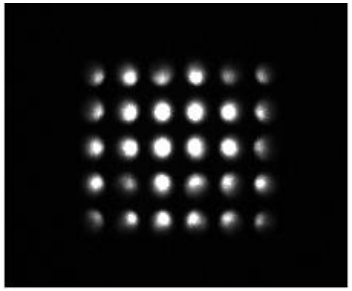


2) Fiber box

- Wiggling calibration (depth calibration)
- For mass production







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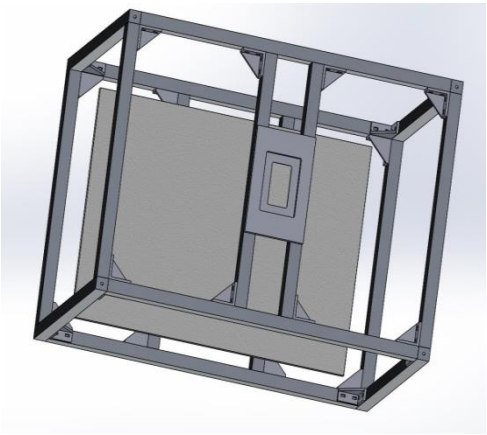
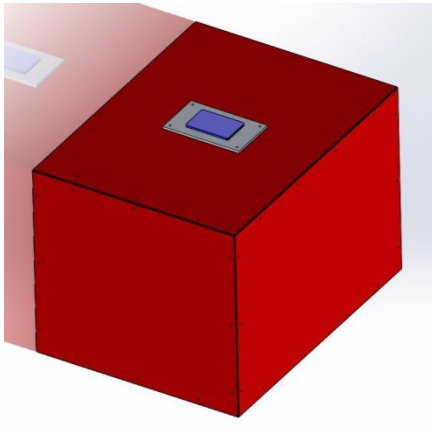
2. Infineon(PMD) Calibration 장비 (2/2)

3) Validation box

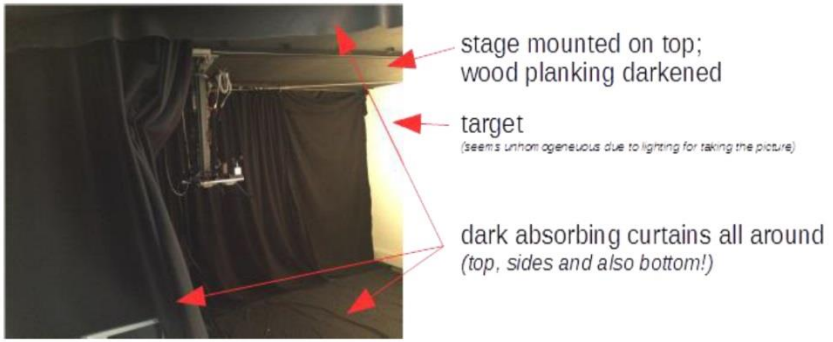
- Calibration output validation

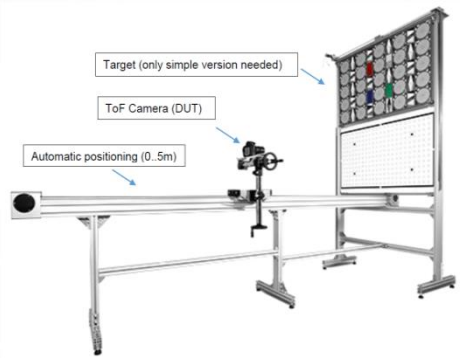




4) LTS (Linear translation stage)

- Wiggling calibration
  (depth calibration)
- For golden sample





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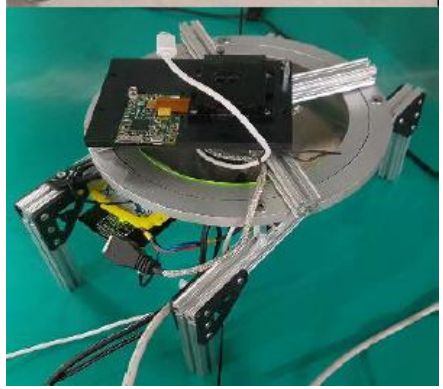
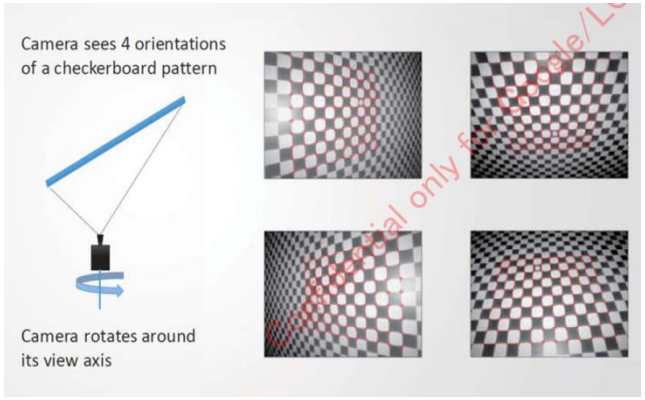
3. Sony Calibration 장비

1) Slated Chart

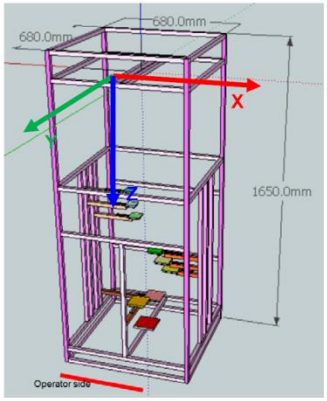
- Lens Calibration
- Gradient Error (FPPN과 동일)
- ~~FPN~~

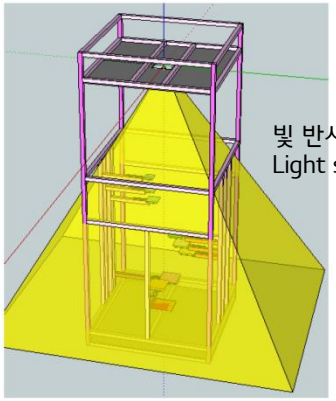




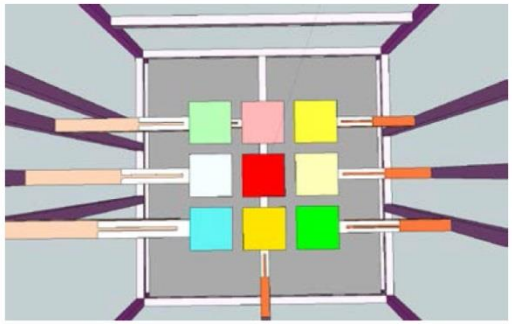
2) Cat Tree

- Cyclic Error





빛 반사 차단을 위해
Light shielding



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4. ToF Calibration 통합화 (~'18.7)

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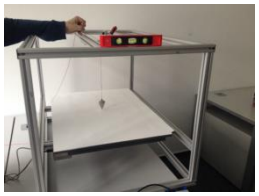
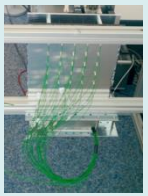
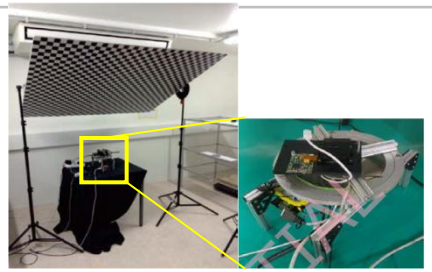
❑ 기존 (~'18.7) Infineon 2-box vs. Sony only Slated-chart

우 우위 동 동등 열 열위

Sensor	Calibration 장비	기술 완성도	자사의 숙련도	투자비 (MP) 300k/月 기준 4대 UPH 204	Tact-time 업체 제공 기준	Depth 정밀도
Infineon	 LED box • 2D calibration • 3D calibration  Fiber box • 3D calibration 양산성 Issue !! 삭제 검토 中 ➔ 성능 저하 예상	우 양산경험 有 /w Sunny Optics, Lite-on 2-box 개발 完 1-box 개발 中 (~'18.6)	열 Fiber Box 양산성 검토 미흡 ① 온/습도 유지 ② VCSEL과의 결합 ③ 주기적인 Fiber자체 calibration 필요	열 7.52 억원 LED chart와 module간의 정확한 alignment 유지를 위한 추가 장비 필요	- 2개 장비 - 1번 영상 획득 1개 module 동등 수준 예상 (NPI 장비로 분석 예정)	동 <1% @ 1m 절대적인 거리값 측정 가능
Sony	 Slated chart + Turn table • 2D calibration • 3D calibration	열 양산경험 無 개발 중 (~'18.6)	우 RGB, stereo 에서 이용하는 방식 SW처리를 통한 절대적인 위치 추출 가능 (예상)	우 7 억원 이하 ↓ (예상) 장비 관리를 위한 추가 장비가 필요없음	- 1개 장비 - 4번 영상 획득 4개 module 동시 (가능 여부 확인 필요)	동 <1% @ 1m 기울어진 chart로 다양한 거리값 측정 가능

❑ 검토 결과

- Infineon 장비도의 동합 가능성 ↓ (Sony 에서 black-box화하여 기술 제공 예상)
- Sony 장비도의 동합 가능성 ↑ (Infineon 기술 내재화 완료) (라이브러리 형태도 제공 예상)

✓ Sony 장비에 Infineon 기술을 통합하여 플랫폼화하는 방향으로 기술 검토 진행.

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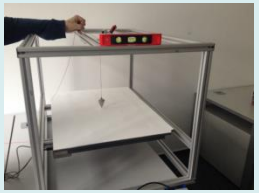
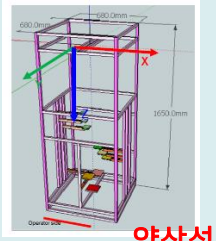
❑ 변경 ('18.8~) Infineon 1-box vs. Sony Slated-chart (/w Cat tree)

우 우위 동 동등 열 열위

Sensor	Calibration 장비	기술 완성도	자사의 숙련도	투자비 (MP) 300k/月 기준 4대 UPH 204	Tact-time 업체 제공 기준	Depth 정밀도
Infineon	LGE Alpha 향으로 MP 장비 Set-up  One box • iCM calibration • 2D calibration • 3D calibration	우 양산경험 有 /w Sunny Optics, Lite-on 2-box 개발 完 1-box 개발 中 (~'18.6)	모두 신규 장비	우 7 억원 이하 ↓ LED chart와 module간의 정확한 alignment 유지를 위한 추가 장비 필요	우 - 1개 장비 - 1번 영상 획득 1개 module	동 <1% @ 1m 절대적인 거리값 측정 가능
Sony	 Slated chart + Turn table • 2D calibration • Offset calibration  양산성 Issue !! Cat tree • Cyclic error	열 양산경험 無 개발 중 (~'18.6)		열 7 억원 이상 ↑ Cat tree 추가	열 - 2개 장비 - 4번 영상 획득 4개 module 동시 (가능 여부 확인 필요)	동 <1% @ 1m 기울어진 chart로 다양한 거리값 측정 가능

❑ 검토 결과

- Infineon 장비도의 동합 가능성 ↑ (Sony SW open 되어 기준 내재화 작업 中)
- Sony 장비도의 동합 가능성 ↓ (Infineon에서 black-box화하여 기술 제공)

✓ Infineon 장비에 Sony 기술을 통합하여 플랫폼화하는 방향으로 플랫폼화 기술 개발. (라이브러리 형태도 제공)

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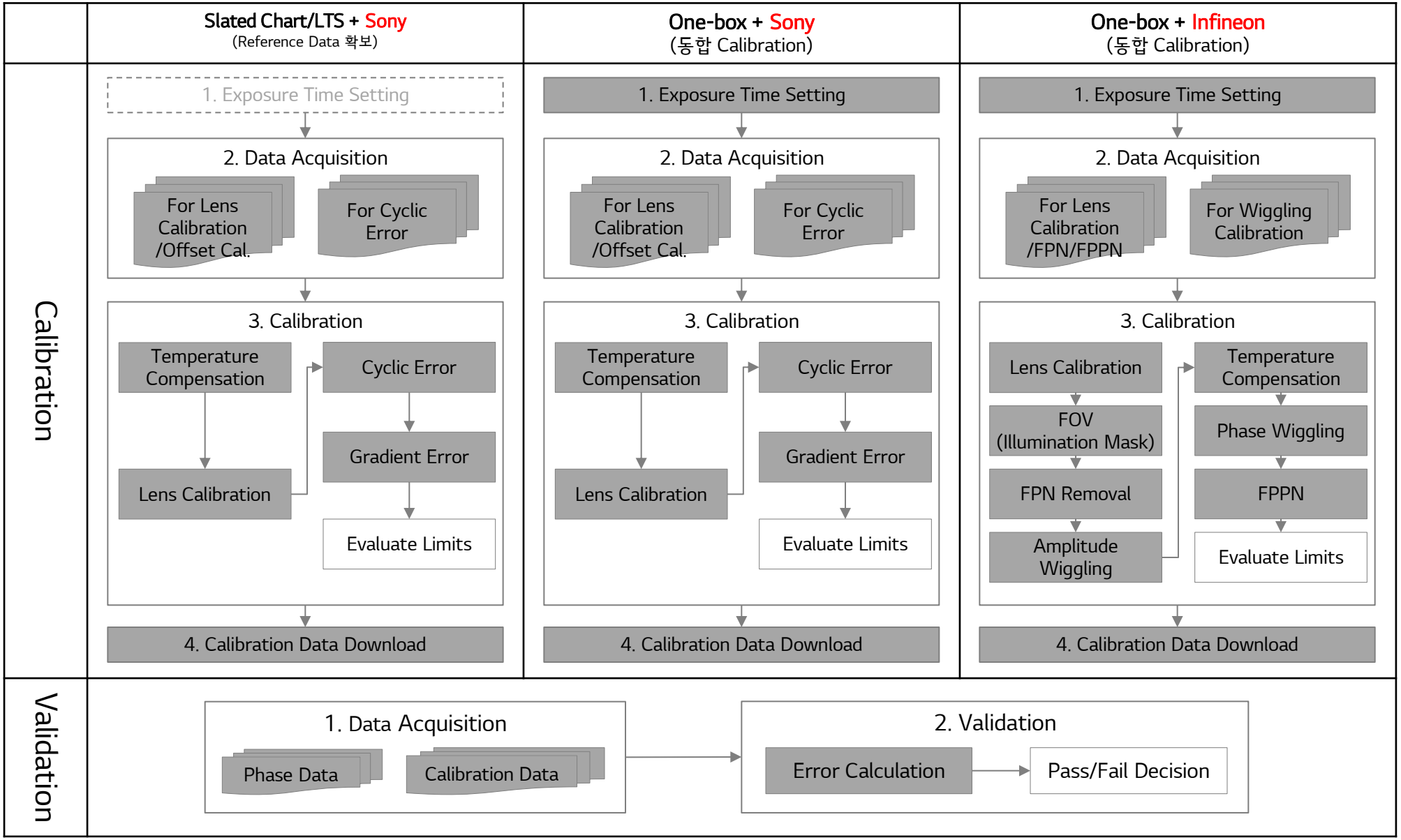
4. ToF Calibration 통합화 (~'18.11)

대외비 2급

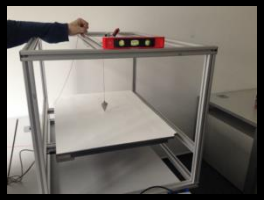
Not Started | In Progress | Done



LG이노텍

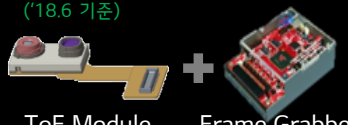
Platform 장비
+ Infineon 센서

Infineon 센서 Cal.-Val.



Calibration Box

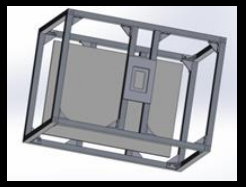
Alpha 向
('18.6 기준)



ToF Module + Frame Grabber

광동신

PC



Validation Box

[Calibration]

1. Data Acquisition
   - For Lens Calibration
   - For Fixed Pattern Noise
     One-box에부터 삭제
   - For Wiggling Calibration
     Fiber 정보 대신
     24 phase shift 정보

2. Calibration
   - Lens Calibration
   - FPN Removal
   - Wiggling Calibration
   - FPPN Calibration

3. Calibration Data Download

[Validation]

1. Data Acquisition

2. Validation
   - Error Calculation
   - Pass/Fail Decision

대외비 2급

[Calibration]

1. Data Acquisition
   - For Lens Calibration
   - For Wiggling Calibration

2. Calibration
   - Lens Calibration
   - FPN Removal
   - Wiggling Calibration
   - FPPN Calibration

3. Calibration Data Download

[Validation]

1. Data Acquisition

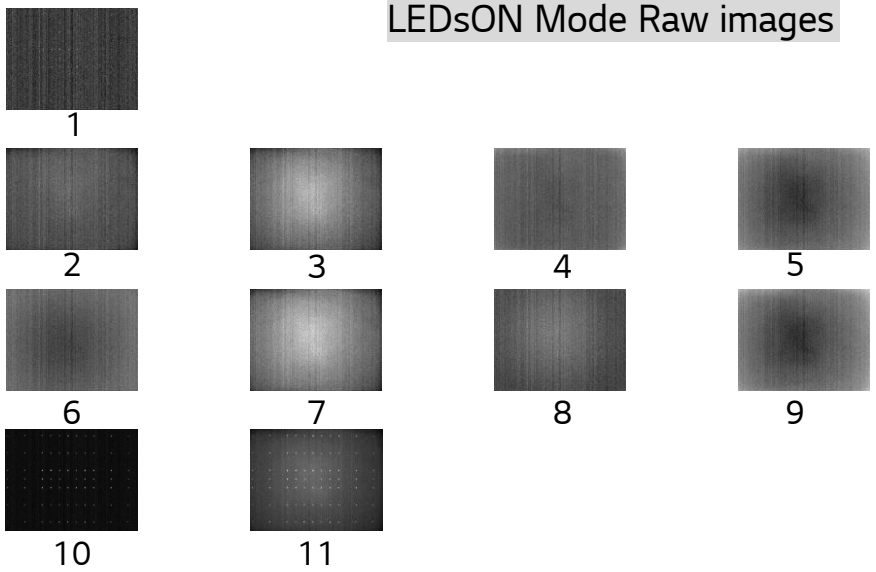
2. Validation
   - Error Calculation
   - Pass/Fail Decision

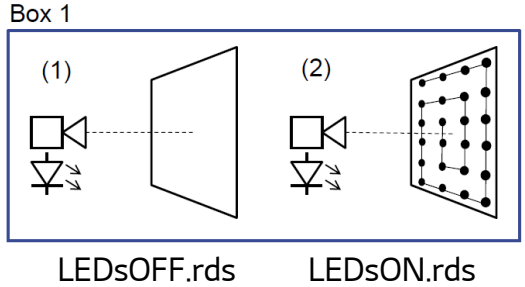
LEDsON.rds* / LEDsOFF.rds

Alpha向 PP0 SPL 기준

Sequence Type	Dummy	Modulated				Modulated				IlluOFF	IlluON
Raw image	1	2	3	4	5	6	7	8	9	10	11
	Gray Scale	0°	90°	180°	270°	0°	90°	180°	270°	Gray Scale	Gray Scale
Modulation Frequency [Hz]	60240000	80320000				60240000					
Exposure Time [μs]	100	1295				1295				1290	1295
Duty Cycle (Illumination)	0% (OFF)	25%				25%				0% (OFF)	25%

LEDsON Mode Raw images

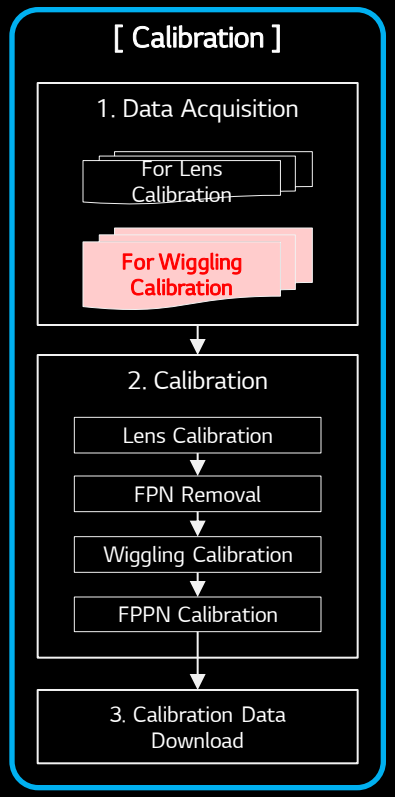


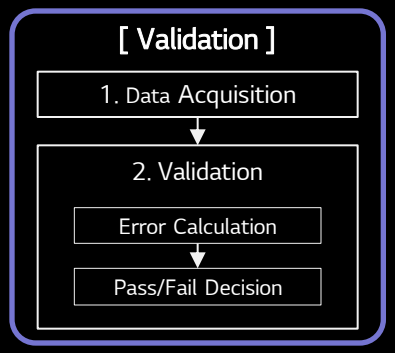


* RDS file format = calibration을 하기 위한 Raw data, Exposure time, Illumination temperature 등의 정보를 가진 input format

LG이노텍

대외비 2급



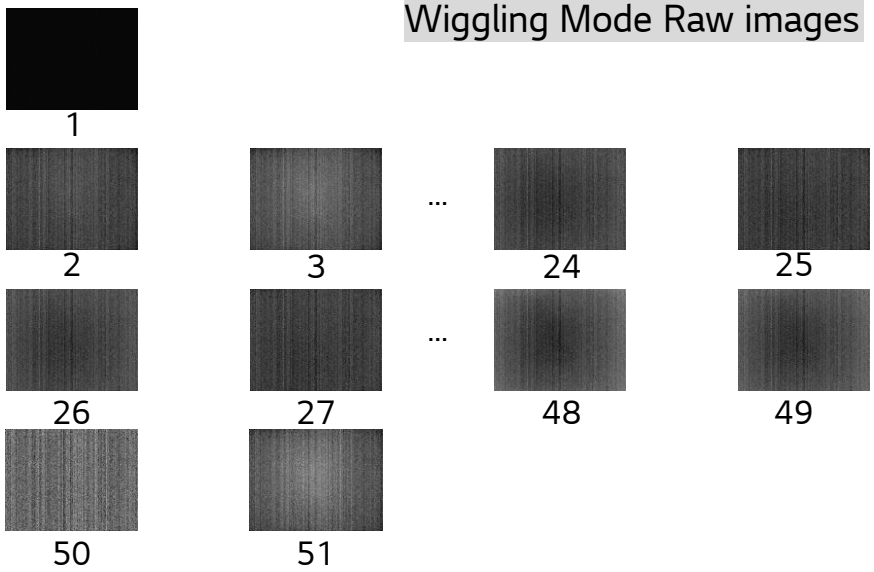


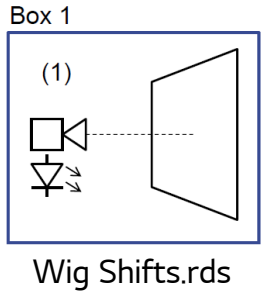
WigShifts.rds

Alpha向 PP0 SPL 기준

Sequence Type	Dummy	Modulated					Modulated					IlluOFF	IlluON
Raw image	1	2	3	...	24	25	26	27	...	48	49	50	51
	Gray Scale	0°	15°	...	330°	345°	0°	15°	...	330°	345°	Gray Scale	Gray Scale
Modulation Frequency [Hz]	60240000	80320000					60240000						
Exposure Time [μs]	100	600					600					110	300
Duty Cycle (Illumination)	0% (OFF)	25%					25%					0% (OFF)	25%

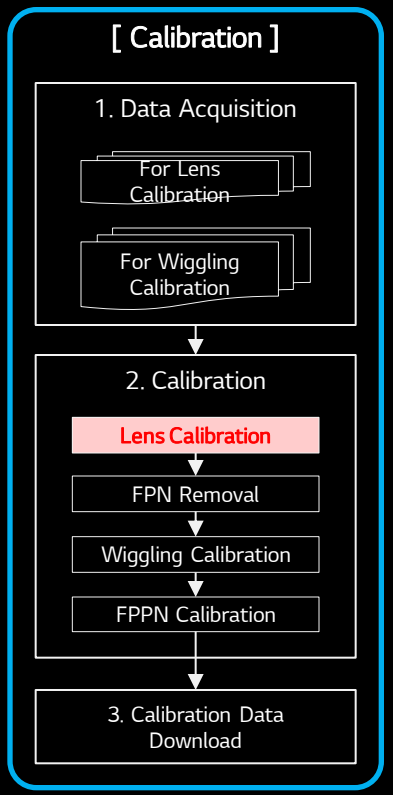
Wiggling Mode Raw images

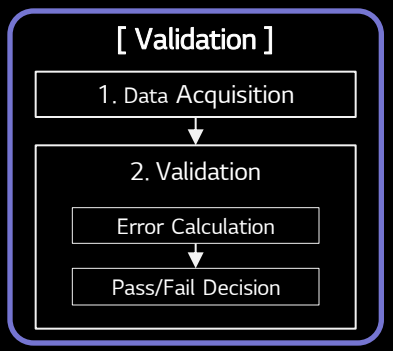




Wig Shifts.rds

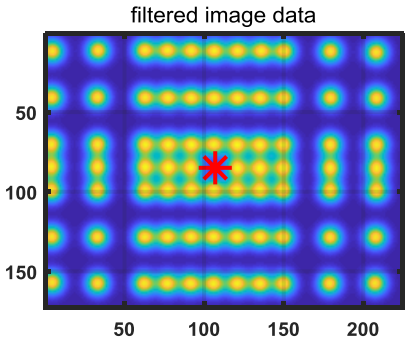
LG이노텍



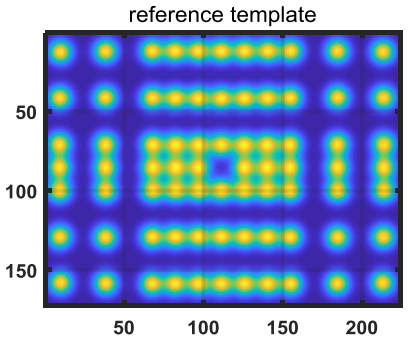


Lens Calibration

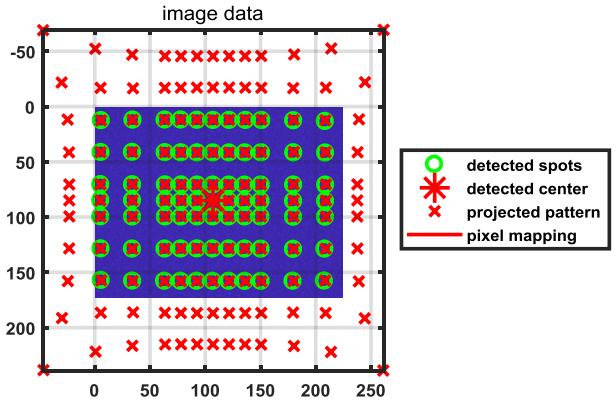
- 목적: 센서와 렌즈의 조립 공차 보상
- Input RDS: LEDsON.rds, LEDsOFF.rds
- Output: Lens parameter = [fx, fy, cx, cy, k1, k2, p1, p2, k3]



①

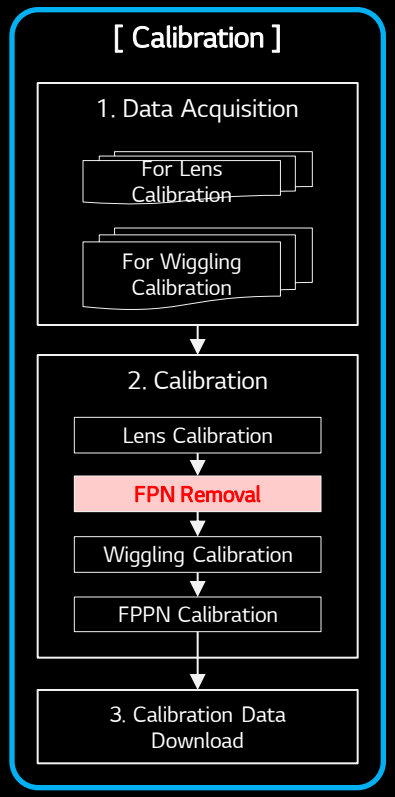


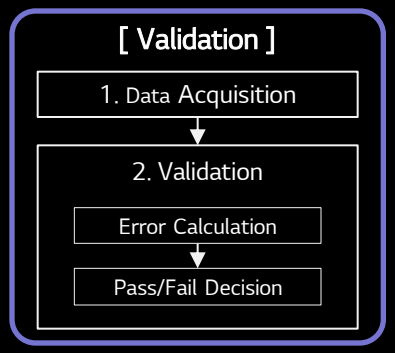
②



③

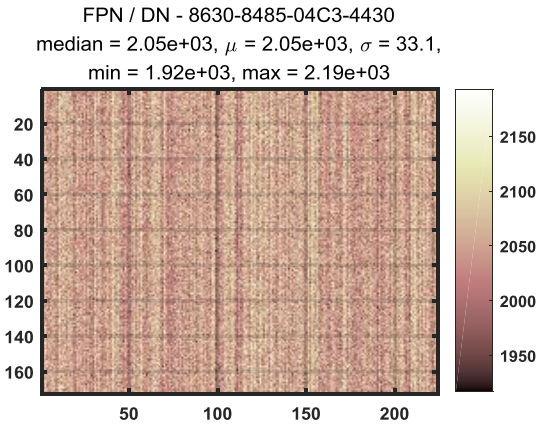
- ①: Filtered image data = 영상에서 검출 된 LED Pattern data
  (사용되는 영상 = LEDsON_Raw{10} – LEDsOFF_Raw{10})
- ②: Rerecence template = 실제 LED pattern의 위치 정보로 생성한 Reference data
- ③: ①과 ②의 Matching 결과
  ➔ LED pattern을 찾아서 센서와 렌즈 조립 오차 계산

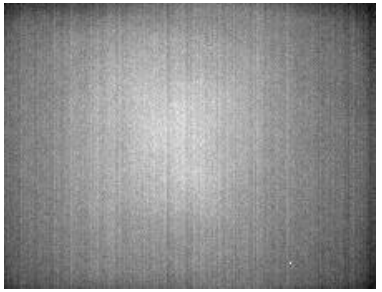




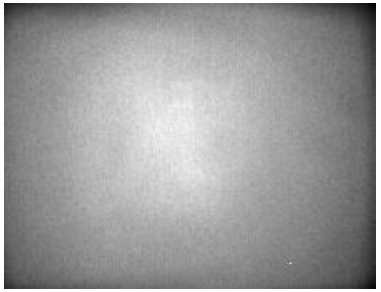
FPN(Fixed Pattern Noise) Removal

- 목적: 센서의 고정 노이즈 오차 계산
- Input RDS: LEDsOFF.rds
- Output: 224x172 크기의 FPN



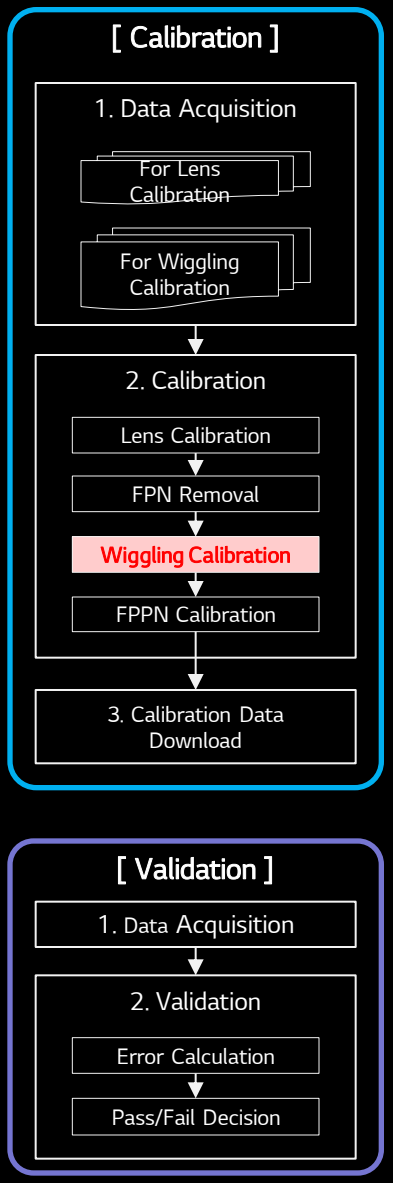


FPN 제거 전



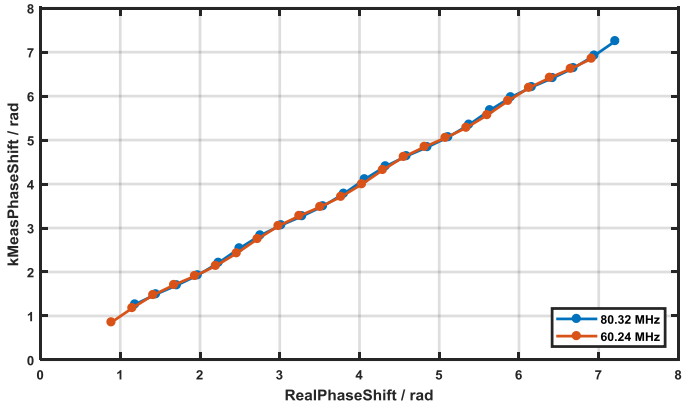
FPN 제거 후

- VCSEL의 영향을 최소화 하기 위하여 낮은 노출에서 offset image 획득
- 사용되는 영상: LEDsOFF_Raw{1} , LEDsOFF_Raw{10}
- FPN = LEDsOFF_Raw{10} – DarkCurrent xLEDsOFF_ExposureTime{10}
  DarkCurrent = (LEDsOFF_Raw{10} – LEDsOFF_Raw{1})
  / (LEDsOFF_ExposureTime{10} - LEDsOFF_ExposureTime{1})

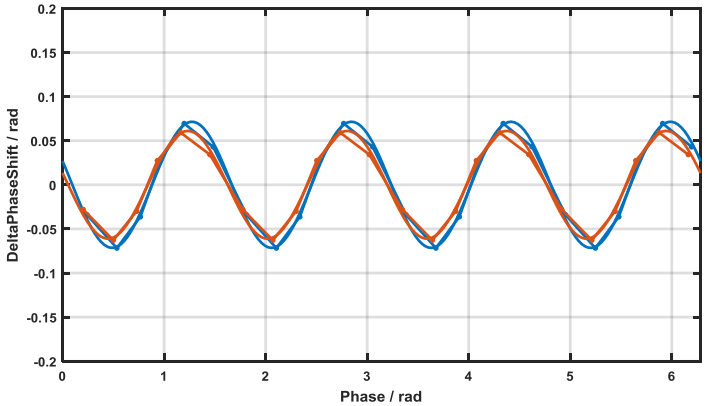


Wiggling Calibration

- 목적: 다양한 거리에 대한 거리 오차 계산
- Input RDS: WigShifts.rds
- Output: Modulation 별 fitting parameter



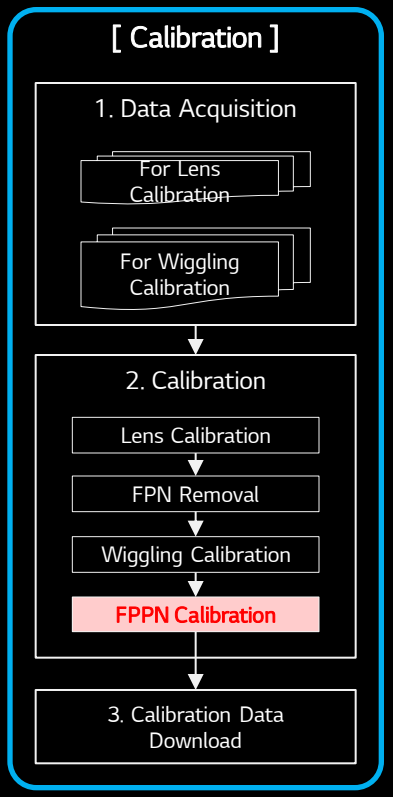
①

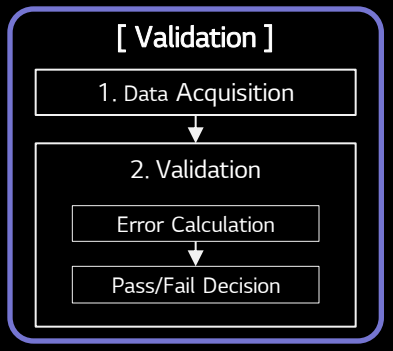


②

- ①: Real Phase와 Measured Phase에 대한 그래프
  - ➔ 가장 이상적인 모양은 y=x 형태
  - ➔ Real Phase와 Measured Phase의 차이 보상 필요
- ②: DeltaPhaseShift = Real Phase – Measured Phase
  - ➔ 다양한 거리에 대한 오차를 harmonic 함수*로 fitting
- 이때, 정확한 Real Distance가 중요하기 때문에 Box의 alignment가 필수

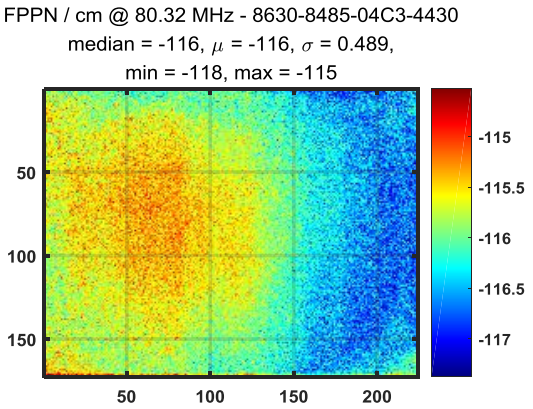
y=offset+A1*sin(1x+P1)+A2*sin(2x+P2)+A3*sin(4x+P3)+A4*sin(8x+P4)

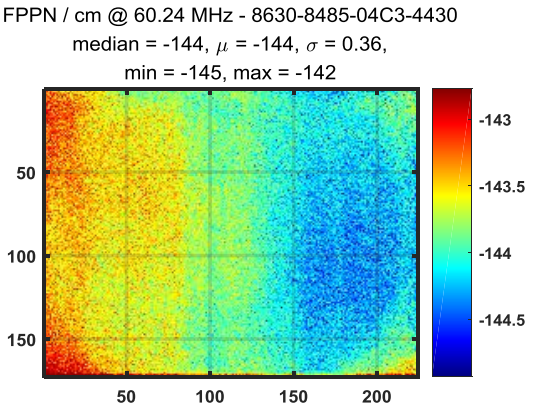




FPPN (Fixed Pattern Phase Noise) Calibration

- 목적: 센서의 픽셀 별 거리 오차 계산
- Input RDS: LEDsOFF.rds
- Output: Modulation 별 224x172 크기의 FPPN noise





- Flat한 평면의 Real Distance와 Measured Distance의 차를 이용하여 픽셀 별 오차 계산
- 이때, 정확한 Real Distance가 중요하기 때문에 Box의 alignment가 필수

[Calibration]

1. Data Acquisition
   - For Lens Calibration
   - For Wiggling Calibration

2. Calibration
   - Lens Calibration
   - FPN Removal
   - Wiggling Calibration
   - FPPN Calibration

3. Calibration Data Download

[Validation]

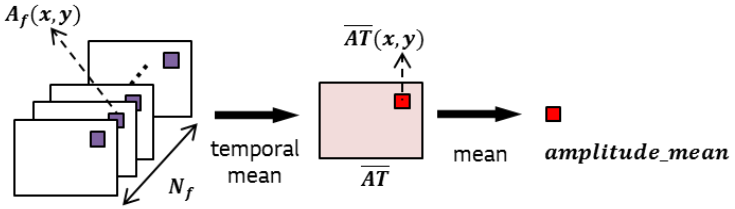
1. Data Acquisition

2. Validation
   - Error Calculation
   - Pass/Fail Decision

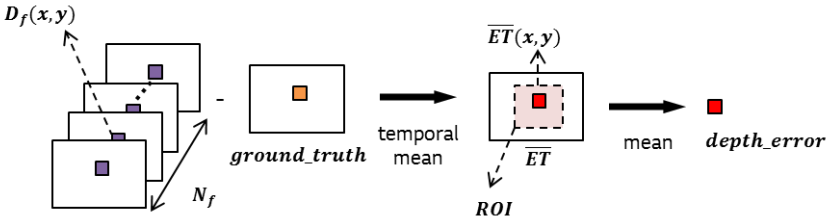
Error Calculation

- 목적: Calibration 적용 후 depth의 정량적 평가
- Input RDS: Validation.rds (LEDsOFF.rds와 유사하지만, box의 거리가 다름)
- Output: Amplitude Mean, Depth Error, Depth Noise 등 총 28개 항목

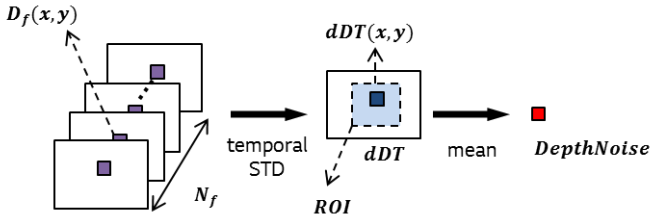
Amplitude Mean



Depth Error



Depth Noise



Raw Phase(80MHz, 60MHz)

↓

Wiggling Error Correction

↓

Illumination Temperature Compensation

↓ Phase to Distance

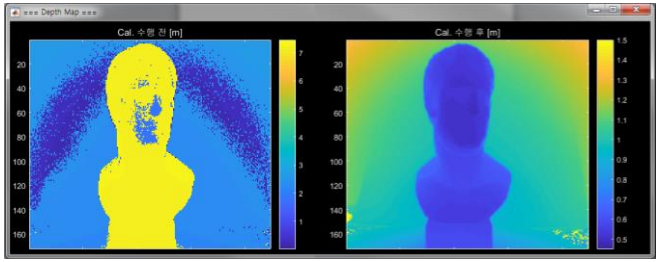
FPPN Compensation

↓

Combined 2Frequency Distance

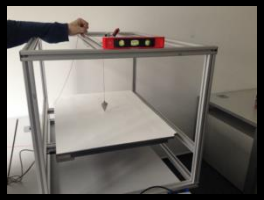
↓

Measured Distance



Platform 장비
+ Sony 센서

플랫폼 장비 – Sony 센서 Cal.-Val.



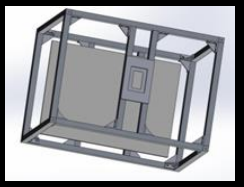
Calibration Box

ToF Module

Giant 向
('18.3 기준)

Frame Grabber

광동신



Validation Box

PC

[Calibration]

1. Data Acquisition

For Lens Calibration

For Cyclic Error

2. Calibration

Lens Calibration

Cyclic Error

Gradient Error

3. Calibration Data Download

[Validation]

1. Data Acquisition

2. Validation

Error Calculation

Pass/Fail Decision

[Calibration]

1. Data Acquisition
   - For Lens Calibration
   - For Cyclic Error

2. Calibration
   - Lens Calibration
   - Cyclic Error
   - Gradient Error

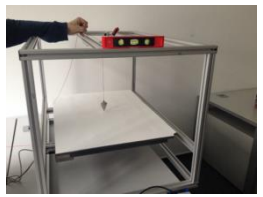
3. Calibration Data Download

[Validation]

1. Data Acquisition

2. Validation
   - Error Calculation
   - Pass/Fail Decision

Data Acquisition – For Lens calibration



One-box

Giant 向 ('18.3 기준)

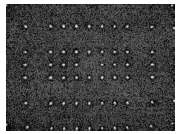
ToF Module

Frame Grabber

광동신

PC

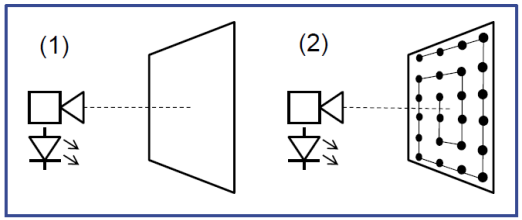
Data



Raw data – LED_ON_100.bin / LED_OFF_100.bin

Data	Tap A				Tap B			
Raw data	30°	120°	210°	300°	210°	300°	30°	120°
Modulation Frequency (Hz)	100000000							
Exposure Time [μs]	570							

Box 1



LED_OFF_100.bin LED_ON_100.bin

LG이노텍

[Calibration]

1. Data Acquisition
   - For Lens Calibration
   - For Cyclic Error

2. Calibration
   - Lens Calibration
   - Cyclic Error
   - Gradient Error

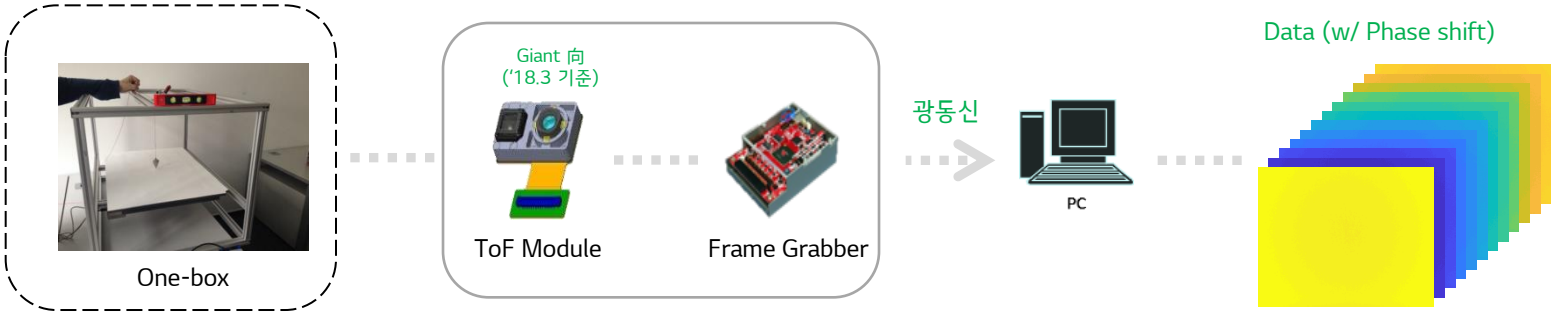
3. Calibration Data Download

[Validation]

1. Data Acquisition

2. Validation
   - Error Calculation
   - Pass/Fail Decision

Data Acquisition – For Cyclic Error

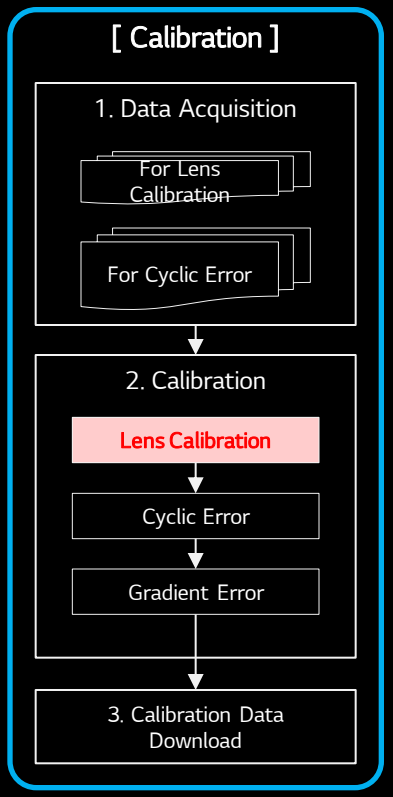


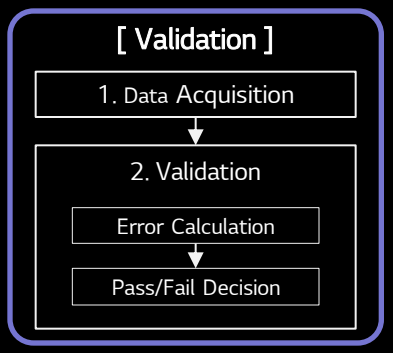
Raw data – CYCLIC_100_[deg].bin / CYCLIC_60_[deg].bin

Data	Tap A				Tap B			
Raw data_1	30°	120°	210°	300°	210°	300°	30°	120°
Raw data_2	60°	150°	240°	330°	240°	330°	60°	150°
...	...	...	...	...	...	...	...	...
Raw data_12	0°	90°	180°	270°	180°	270°	0°	90°
Modulation Frequency (Hz)	100000000							
Exposure Time [μs]	570							

Data	Tap A				Tap B			
Raw data_1	0°	90°	180°	270°	180°	270°	0°	90°
Raw data_2	18°	108°	198°	288°	198°	288°	18°	108°
...	...	...	...	...	...	...	...	...
Raw data_20	342°	72°	162°	252°	162°	252°	342°	72°
Modulation Frequency (Hz)	60000000							
Exposure Time [μs]	570							

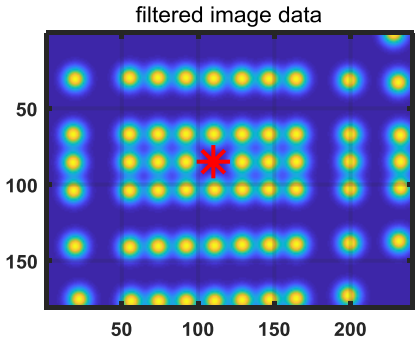
LG이노텍

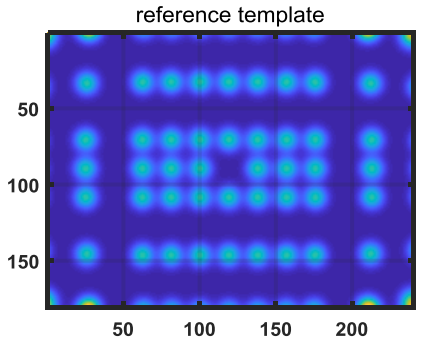


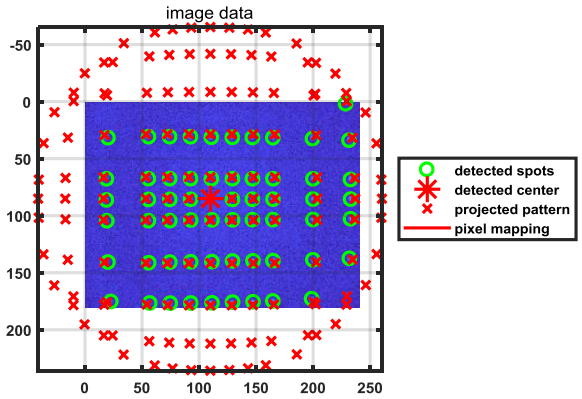


Lens Calibration

- 목적: 센서와 렌즈의 조립 공차 보상
- Input: LED_ON_100.bin, LED_OFF_100.bin
- Output: Lens parameter = [fx, fy, cx, cy, k1, k2]

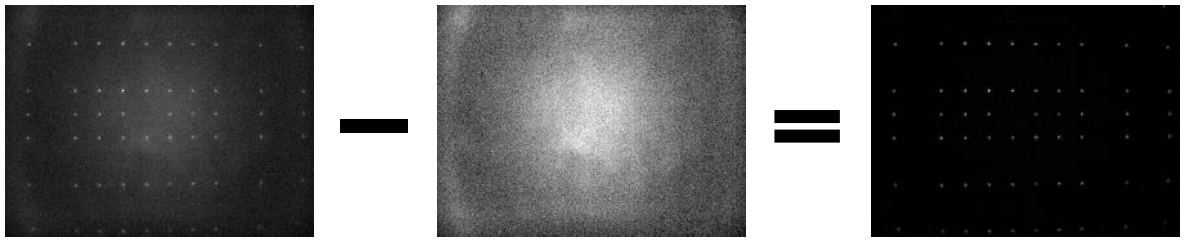




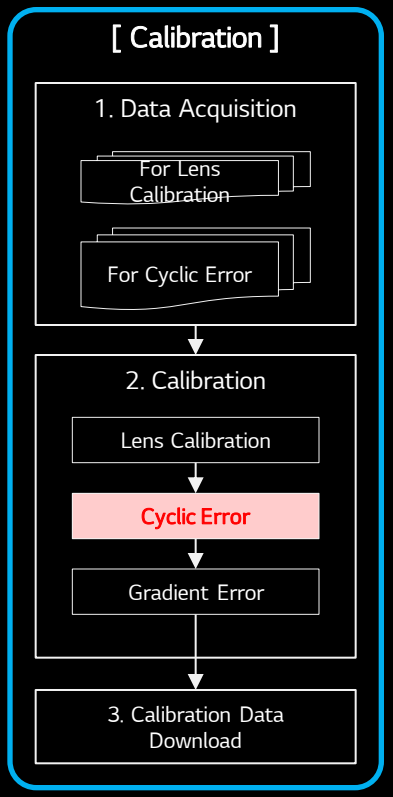


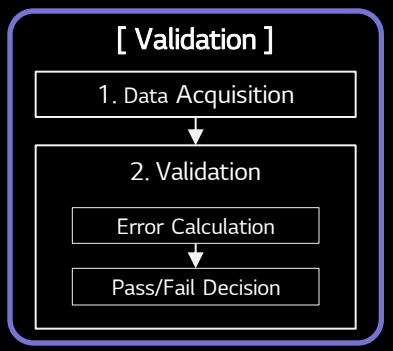
① ② ③

- ①: Filtered image data = 영상에서 검출 된 LED Pattern data
  (사용되는 영상 = LEDsON TapA(0) – LEDsOFF TapB(0))



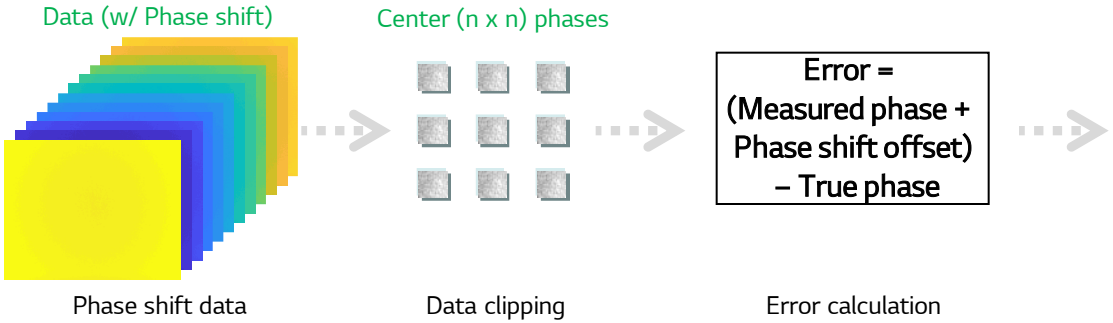
- ②: Rerecence template = 실제 LED pattern의 위치 정보로 생성한 Reference data
- ③: ①과 ②의 Matching 결과
  ➔ LED pattern을 찾아서 센서와 렌즈 조립 오차 계산





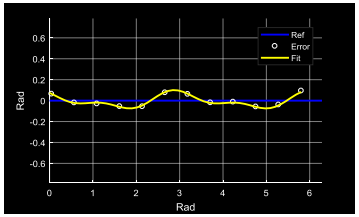
Cyclic Error

- 목적: 다양한 거리에 대한 거리 오차 계산
- Input: CYCLIC_100_[deg].bin / CYCLIC_60_[deg].bin
- Output: Modulation frequency 별 fitting parameter

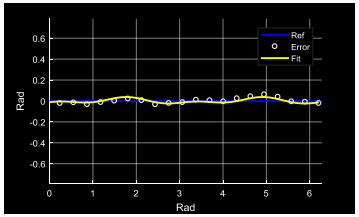


Phase shift data　　Data clipping　　Error calculation

100MHz



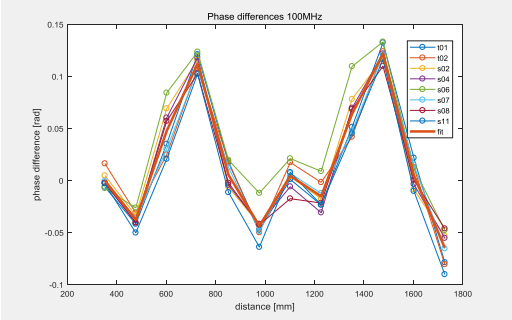
60MHz



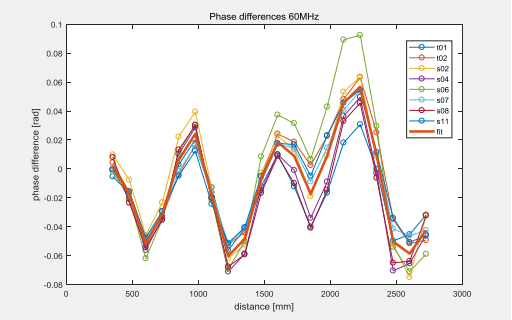
Error fitting

Phase Shift Offset

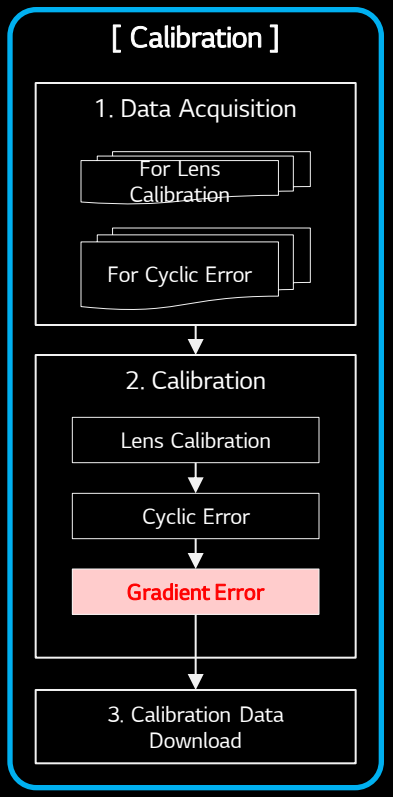
- Phase shift와 실제 거리에서 취득한 phase의 차이 (PP2 sample에서 발생)

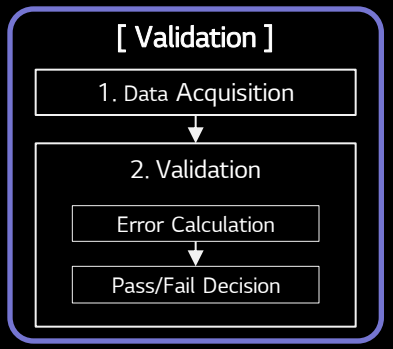


100MHz phase offset



60MHz phase offset



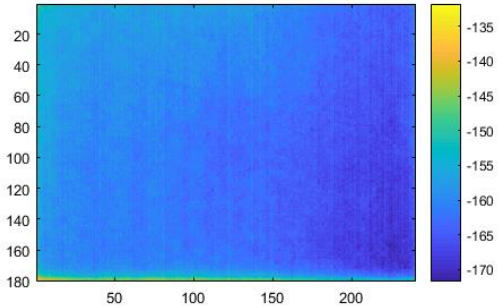


Gradient Error

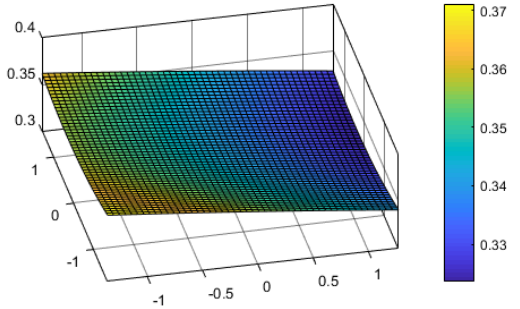
- 목적: 각 픽셀 별 거리 오차 계산
- Input: CYCLIC_100_30.bin / CYCLIC_60_0.bin
- Output: Modulation frequency 당 6 coefficients (p00, p10, p01, p20, p11, p02)

Difference
= Reference phase - Measured phase after CEC

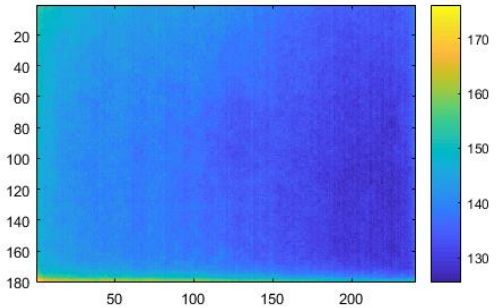
100MHz

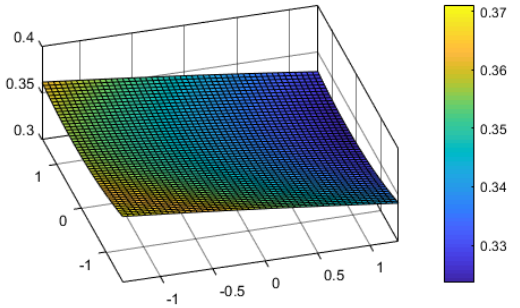


Poly fitting



60MHz





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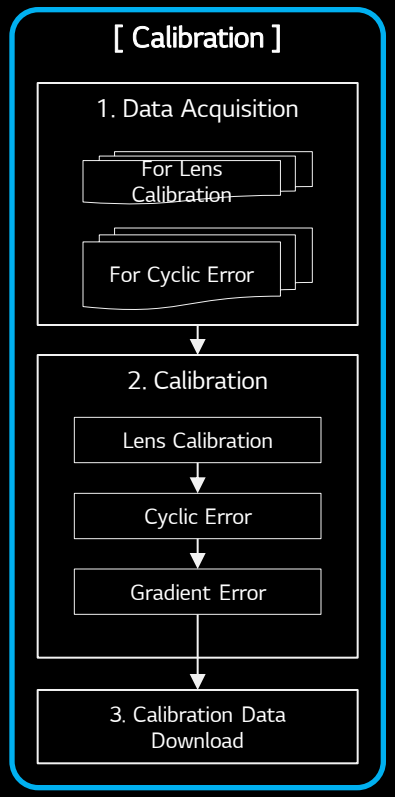
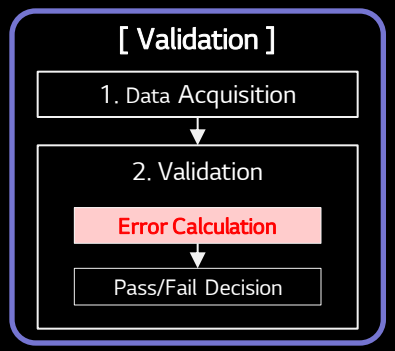
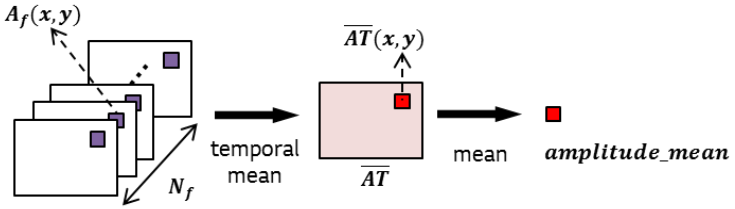




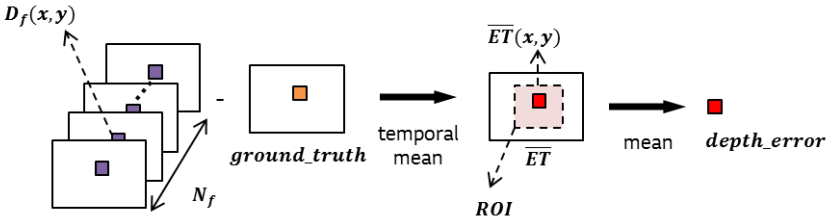
Error Calculation

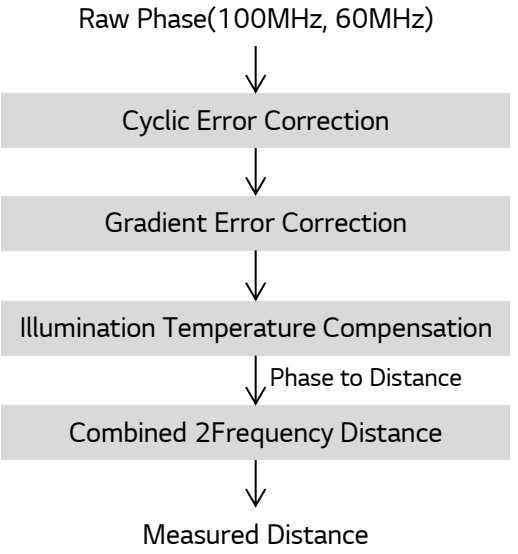
- 목적: Calibration Validation.rds적용 후 depth의 정량적 평가
- Input: VALDIATION_100.bin / VALIDATION_60.bin
- Output: Amplitude Mean, Depth Error, Depth Noise 등 총 28개 항목

Amplitude Mean

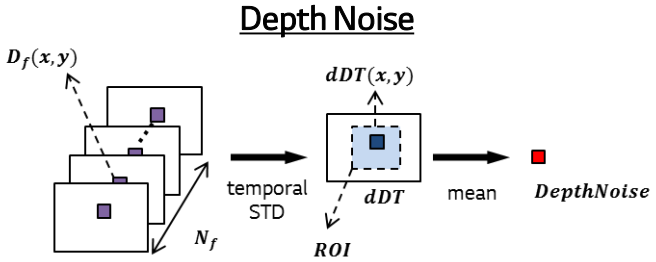


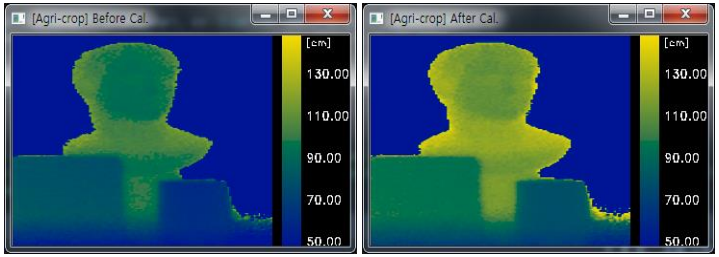
Depth Error





Depth Noise





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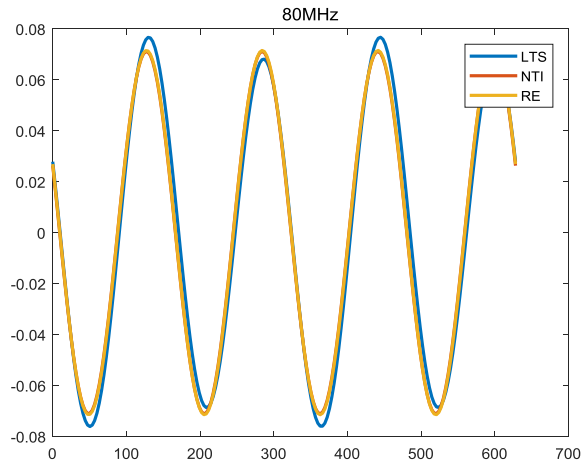
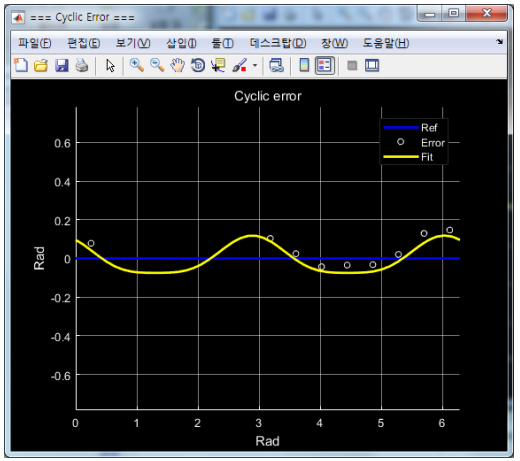
7. Calibration 의 차이점 (1/3)

<Infineon>

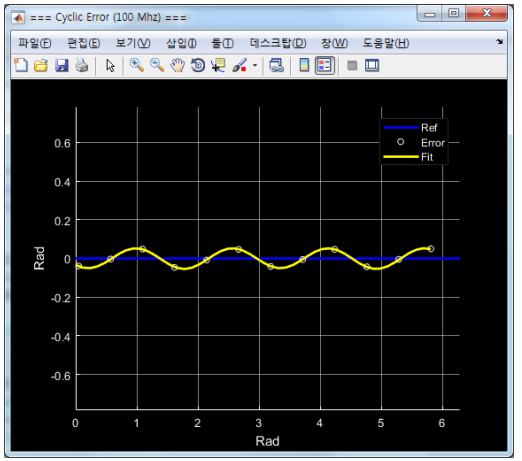


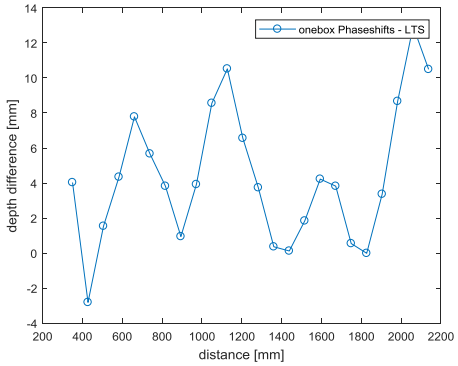
<Sony>

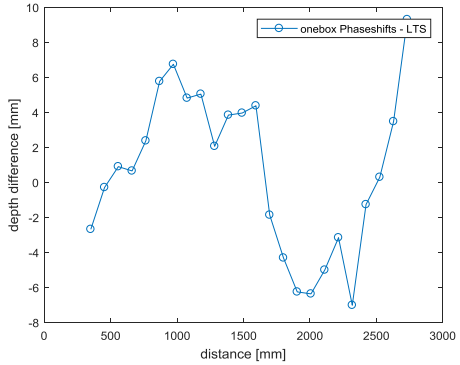
<LTS phase >

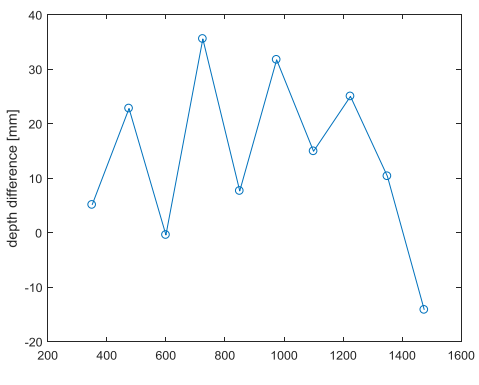


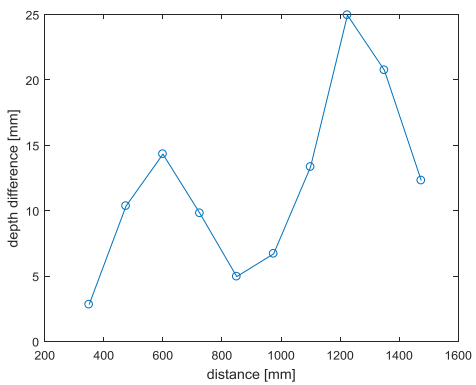
< OneBox phase shift >











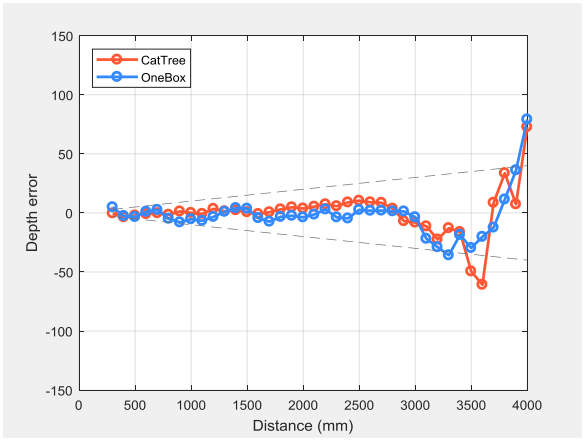
- One-box 도 Cyclic error correction은 핟 수 있기 위한 기본 가정
  - ✓ 주기 신호여야 함
  - ✓ 뭍리적인 거리 (LTS) 와 phase shift 도 계산된 거리 (One-box)가 유사한 형태여야 함

➢ Infineon(~1cm)에 비해 Sony(~4cm)의 Phase shift 구동 정확도가 떨어짐

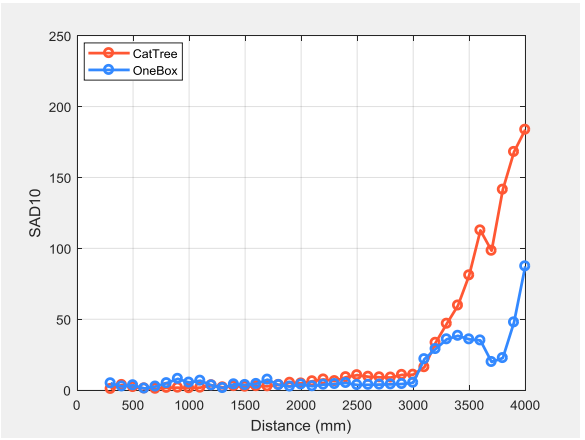
- One-Box의 Target 거리에 따른 최적의 기준 phase shift 가 있는 점을 확인
  - Cal.을 50cm에서 하려면, 100MHz: 30°, 60MHz: 0° phase shift 하여 사용
  - Cal.을 35cm에서 하려면, 100MHz: 60°, 60MHz: 18° phase shift 하여 사용

- Cat-tree 도 Calibration 한 결과 vs. One-box도 Calibration 한 결과
  - Depth Error: 동등 (근거리는 Cat-tree가 원거리는 One-box가 좋음)
  - Depth Noise: One-box가 더 좋음

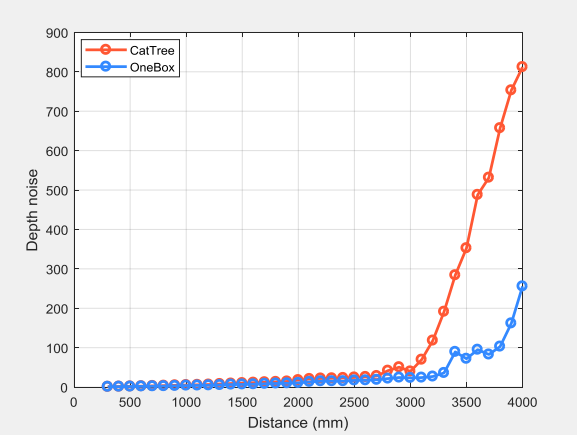
Depth Error



SAD10



Depth Noise

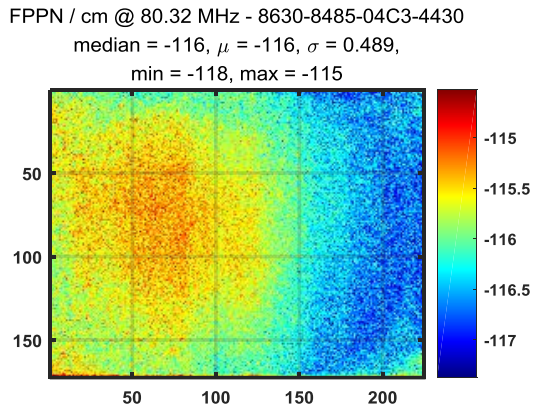


7. Calibration 의 차이점 (3/3)

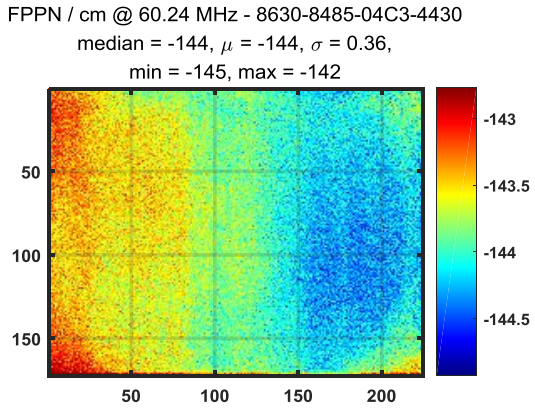
- Infineon 은 픽셀별 거리 오차가 랜덤하기 때문에 Fitting은 할 수 없음
  ➔ 해상도 만큼의 거리 오차 정보를 가지고 있어야 함
  ➔ Calibration data 용량의 차이가 큼
  Infineon : 120KB vs. Sony : 4KB

<Infineon>

80MHz



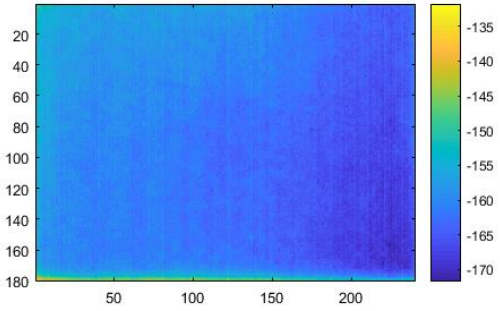
60MHz



<Sony>

Difference
= Reference phase - Measured phase after CEC

100MHz



60MHz