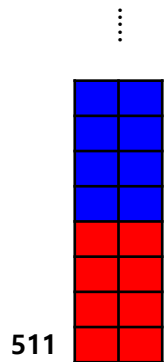# LiDAR Calibration
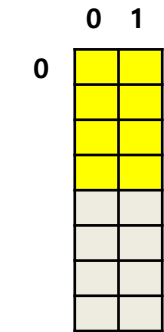
- GMAPD to Point Cloud

- Evaluation of LiDAR Calibration

- Presentation by Liam(NST test결과 공유 건)

- Appendix

Update : 21-12-02
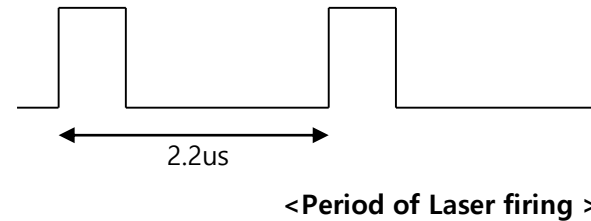
자율주행TDR

하주성 선임
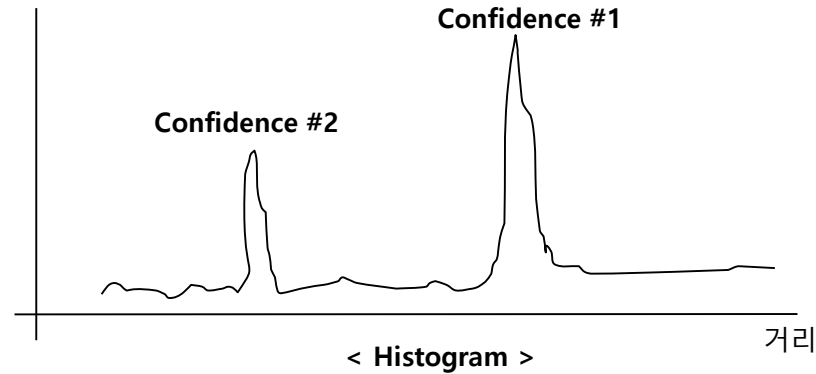
LG이노텍

대외비 2급

- GMAPD, Super Pixel and Point Cloud

0 1

0

⋮

511

MR : 4 x 2 grouping
LR : 6 x 2 grouping

MR : 512 x 2 → 128 x 1 vertical resolution
LR : 512 x 2 → 85 x 1

Confidence #1

Confidence #2

< Histogram >

거리

2.2us

<Period of Laser firing >

*30회 firing 하여 collecting한 data들의 통계로 confidence#1, #2를 구함
Confidence 1에 해당하는 거리를 return → LiDAR level에서는 이 거리만 사용

*Tcvr MR, 128개 resolution 중 1개 기준 거리 구하기
240(8 * **30**)개 data의 histogram으로 거리추정
(8: the number of pixels in a group, 30 : t0~t29)

LG이노텍

- LiDAR Calibration 평가(EOL Summary, Passrate)

  *Calibration room은 calibration 보다 evaluation에 더 초점을 맞춘 공간

각 chart마다 평가
(Reflectance / 거리)

L3-LGIT-0187 MR eol summary

|	POD	PFA	Range Bias(m)	Range Stdev(m)	Intensity Mean	# Pts Analyzed
100% 2m	1.0	0.0	-0.087	0.021	37.63	14849573
4% 10m	1.0	0.0	-0.078	0.03	5.126	974390
18% 10m	1.0	0.0	-0.115	0.021	10.306	993313
4% 20m	1.0	0.0	0.0	0.021	3.85	131281
18% 20m	1.0	0.0	-0.056	0.014	16.267	128465
100% 20m	1.0	0.0	-0.117	0.012	41.238	350809
74% 20m	1.0	0.0	-0.098	0.021	37.764	347061
4% 35m	1.0	0.0	0.007	0.031	1.448	95633
76% 35m	1.0	0.0	-0.102	0.01	13.317	74436
100% 35m	1.0	0.0	-0.109	0.009	15.055	74880
4% 48m	0.998	0.0	0.034	0.053	0.764	75769
75% 48m	1.0	0.0	-0.075	0.012	8.509	73453
100% 48m	1.0	0.0	-0.087	0.019	9.394	72357
20% 35m	1.0	0.0	-0.046	0.015	5.288	85871
20% 48m	1.0	0.0	-0.032	0.019	3.364	38897

- Point Cloud level의 평가

  - Point cloud의 검출/오검출
  - 거리 error 및 stdev

L3-LGIT-0187 MR EOL Pixel Passrate Summary

	POD Passrate%	PFA Passrate%	Range Bias Passrate%	Range Stdev Passrate%
100% 2m	1.0	1.0	1.0	1.0
4% 10m	1.0	1.0	1.0	1.0
18% 10m	1.0	1.0	1.0	1.0
4% 20m	1.0	1.0	1.0	1.0
18% 20m	1.0	1.0	1.0	1.0
100% 20m	1.0	1.0	1.0	1.0
74% 20m	1.0	1.0	1.0	1.0
4% 35m	1.0	1.0	1.0	1.0
76% 35m	1.0	1.0	1.0	1.0
100% 35m	1.0	1.0	1.0	1.0
4% 48m	0.992	1.0	1.0	1.0
75% 48m	1.0	1.0	1.0	1.0
100% 48m	1.0	1.0	1.0	1.0
20% 35m	1.0	1.0	1.0	1.0
20% 48m	1.0	1.0	1.0	1.0

- Pixel level 평가(> 90%, pass)

  - Tx/Rx overlap 및 Tx laser 상태에 영향 받는 항목
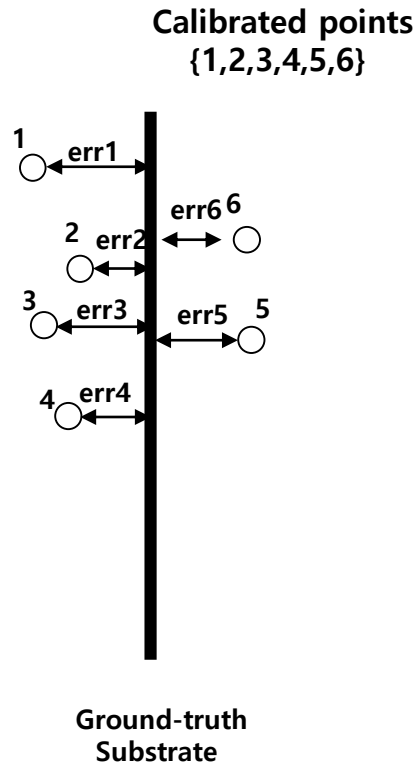 - Tcvr LR pixel 85개 중 83개 Spec In, 2개 out일 때 → 0.97(83/85)

overlap - @18m

Angle [deg]

Angle [deg]
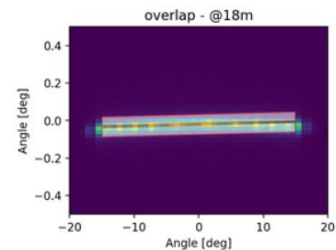
- POD,PFA

	True	**False**
Positive (point검출 성공)	1,2,3,5,6,7	4
Negative	Don't care	Don't care 8

- Detected points를 Positive로 분류.
  Probability of Detection : Ground-truth 기준, 일정 margin에 들어오면 True positive로 분류. 얼마나 detection을 잘했냐 이므로 높을 수록 좋은 값
  Probability False Alarm : margin 밖에 찍힌 점들은 False positive로 분류. 오탐에 대한 값이므로 낮을수록 좋은 값
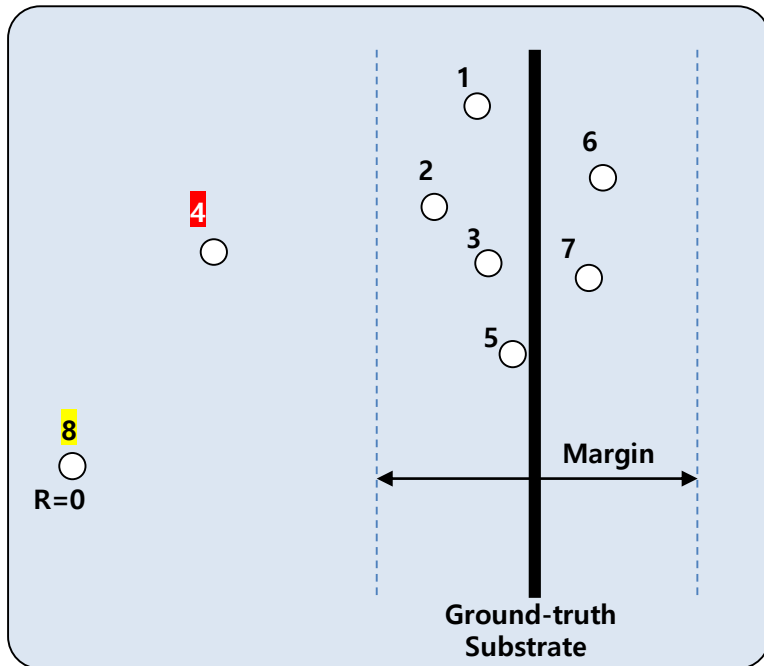
- False negative : 거리가 0으로 나오는 경우

- True negative : 예시) 아무 것도 없는 field scan했을 때

1

6

2

4

3

7

5

8
R=0

Margin

Ground-truth
Substrate

LG이노텍

Evaluation of LiDAR Calibration

- Range Bias

Calibrated points
{1,2,3,4,5,6}

Ground-truth
Substrate

- Range bias : {err1,…,err6} 의 평균 값

- Range bias Stdev : {err1,…,err6}의 standard deviation

*교정된 값으로 error의 평균 및 standard deviation을 구함

LG이노텍

- Metric Thresholds(Relaxed Criteria)

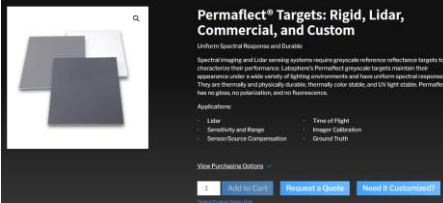| Metric	MR EOL Requirement	LR EOL Requirement
POD	95%	95%
Range Bias	±14cm	±24cm
Range Precision	7cm or .01% of range, whichever is larger.	13cm or .01% of range, whichever is larger.

- Metric Thresholds(from requirement document)

[EXTERNAL] Argo Sensor Head Product Specifications Rev 1.5(Mar. 2021 ver.)

Argo_Lidar_2020-AL_Perf_RQTs-45	Detection Range Bias - LR	The lidar shall report range with a bias of better than **±5.0 cm** across full detectable range and target reflectances as defined in requirement Detection Range-LR .
Argo_Lidar_2020-AL_Perf_RQTs-46	Detection Range Bias - MR	The lidar shall report range with a bias of better than ±5.0 cm across full detectable range and target reflectances as defined in requirement Detection Range-MR .
Argo_Lidar_2020-AL_Perf_RQTs-31	Detection Range - LR	The LR lidar shall detect objects at distances ranging from **20 m to 250 m.** All measurements assume a probability of detection of > 85% as defined in Probability of Valid Detection (Pd) All measurements assume a probability of false alarm of < 1% as defined in Probability of False Alarm (Pfa) 0.3% is the lowest detectable reflectance for any range less than 35 m The table below shows the range for an object with a given (lambertian) reflectance up to which the lidar meets the Pd requirement. Reflectance detectable range [m] **0.3 % 35** **2% 89** **5 % 141** **10% 200**
Argo_Lidar_2020-AL_Perf_RQTs-32	Detection Range - MR	The MR lidar shall detect objects at distances ranging from **2 m to 75 m**. All measurements assume a probability of detection of > 85% as defined in Probability of Valid Detection (Pd) All measurements assume a probability of false alarm of < 1% as defined in Probability of False Alarm (Pfa) 0.3% is the lowest detectable reflectance for any range less than 20 m The table below shows the range for an object with a given (lambertian) reflectance up to which the lidar meets the Pd requirement. Reflectance detectable range [m] **0.3% 20** **5% 60**

대외비 2급

- Calibration(Training) : Paju Site

- Evaluation : NST

Typical LR Aggregate Metrics

Permaflect® Targets: Rigid, Lidar, Commercial, and Custom

L3-LGIT-0136 LR eol summary

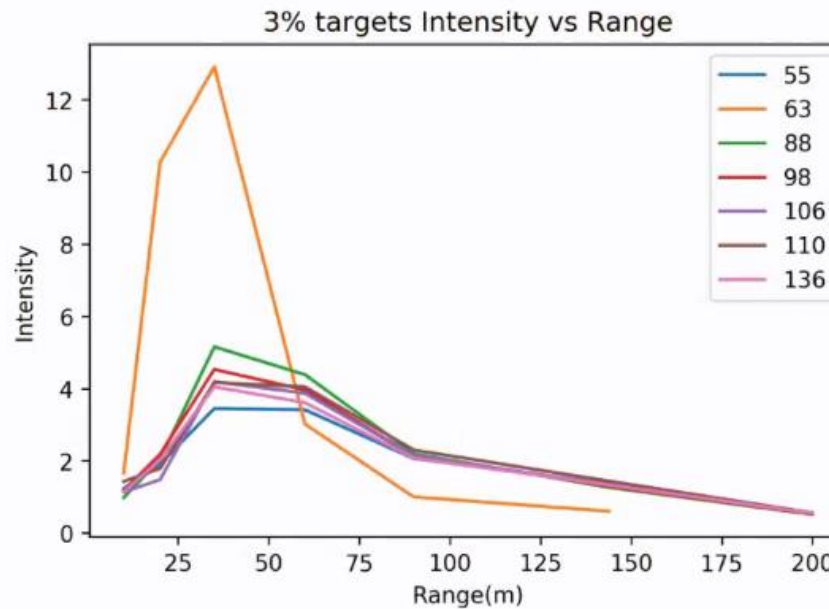|	POD	PFA	Range Bias(m)	Range Stdev(m)	Intensity Mean	# Pts Analyzed
3% Diffuse 200m	0.708	0.0	0.26	0.124	0.548	12764
High Reflectance Solar 200m	1.0	0.0	0.161	0.039	17.775	12178
10% Diffuse 200m	1.0	0.0	0.231	0.085	1.448	16260
5% Diffuse 141m	1.0	0.0	0.177	0.078	1.332	6892
Black Panel 102m	0.939	0.0	0.162	0.113	0.657	2941
High Reflectance Solar 60m	1.0	0.0	-0.039	0.06	28.783	193803
5% 60m	1.0	0.0	0.011	0.041	5.284	190269
Black Panel 20m	0.926	0.069	0.108	0.124	0.926	604428
Labsphere 5% 20m	1.0	0.0	0.0	0.049	5.754	829871
Labsphere 10% 20m	1.0	0.0	-0.044	0.035	8.949	826180
Labsphere 20% 20m	1.0	0.0	-0.034	0.04	16.274	834335
Labsphere 53% 20m	1.0	0.0	-0.043	0.04	24.233	833527
Labsphere 74% 20m	1.0	0.0	-0.056	0.051	26.128	847286
Labsphere 88% 20m	1.0	0.0	-0.051	0.064	27.849	843217
95% 48m	1.0	0.0	-0.058	0.056	27.314	379392
3% 48m	1.0	0.0	0.028	0.06	4.172	337165
10% 48m	1.0	0.0	-0.062	0.026	10.547	369013
20% 10m	1.0	0.0	-0.029	0.042	6.648	5048395
3% 10m	1.0	0.0	0.069	0.094	1.145	5716051
20% 20m	1.0	0.0	-0.054	0.035	11.752	1444392
3% 20m	1.0	0.0	0.055	0.068	2.029	1338060
3% 35m	1.0	0.0	-0.002	0.053	4.053	787300
3% 60m	1.0	0.0	0.046	0.075	3.61	212435
3% 90m	1.0	0.0	0.226	0.063	2.076	60428
Black Panel 4m	0.193	0.334	13.777	0.165	1.43	11406379

Typical LR
Pixel-Passrate

- Calibration(Training) : Paju Site

- Evaluation : NST

L3-LGIT-0136 LR EOL Pixel Passrate Summary

	POD Passrate%	PFA Passrate%	Range Bias Passrate%	Range Stdev Passrate%
3% Diffuse 200m	0.0	1.0	0.053	1.0
High Reflectance Solar 200m	1.0	1.0	1.0	1.0
10% Diffuse 200m	1.0	1.0	0.868	1.0
5% Diffuse 141m	1.0	1.0	1.0	1.0
Black Panel 102m	0.538	0.974	1.0	1.0
High Reflectance Solar 60m	1.0	1.0	1.0	1.0
5% 60m	1.0	1.0	1.0	1.0
Black Panel 20m	0.718	0.682	1.0	0.929
Labsphere 5% 20m	1.0	1.0	1.0	1.0
Labsphere 10% 20m	1.0	1.0	1.0	1.0
Labsphere 20% 20m	1.0	1.0	1.0	1.0
Labsphere 53% 20m	1.0	1.0	1.0	1.0
Labsphere 74% 20m	1.0	1.0	1.0	1.0
Labsphere 88% 20m	1.0	1.0	1.0	1.0
95% 48m	1.0	1.0	1.0	1.0
3% 48m	1.0	1.0	1.0	1.0
10% 48m	1.0	1.0	1.0	1.0
20% 10m	1.0	1.0	1.0	1.0
3% 10m	1.0	1.0	1.0	1.0
20% 20m	1.0	1.0	1.0	1.0
3% 20m	1.0	1.0	1.0	1.0
3% 35m	1.0	1.0	1.0	1.0
3% 60m	1.0	1.0	1.0	1.0
3% 90m	1.0	1.0	1.0	1.0
Black Panel 4m	0.0	0.0	0.0	0.027

Range Accuracy (Bias)
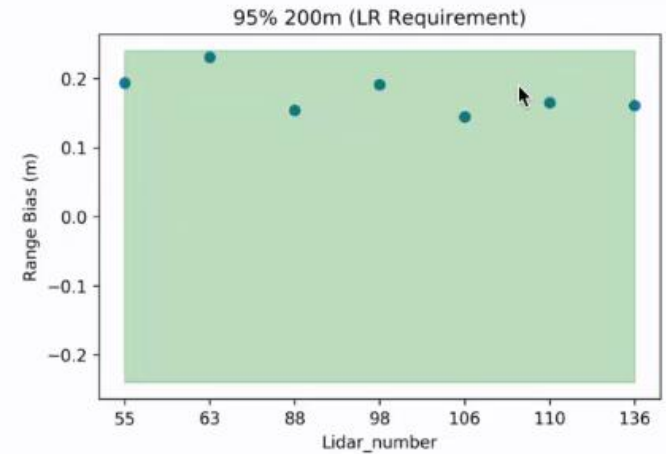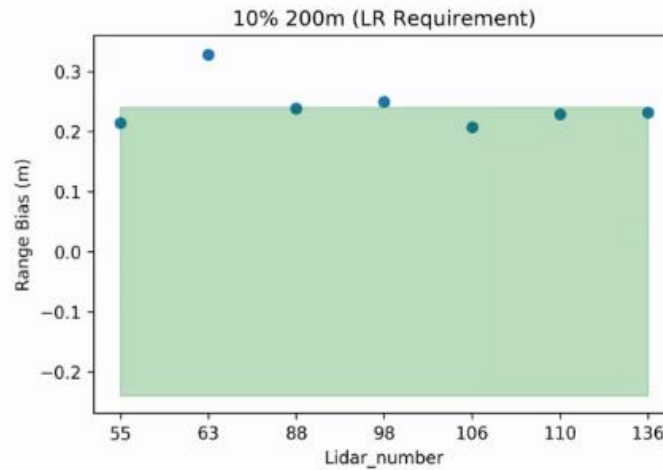
- Range accuracy on targets beyond 60m is significantly worse than anything observed at LGIT, **this is currently one of the biggest gaps in characterization**.
- Increased bias at longer range effects all targets, but it is mitigated by range walk on brighter targets.
- Despite failing range bias, these tcvrs have still been advanced to the fleet due to the fact that this issue likely effects all current tcvrs.
- Do we have a range-dependent range-error? Timing related? TBD.

Argo AI Secret   15
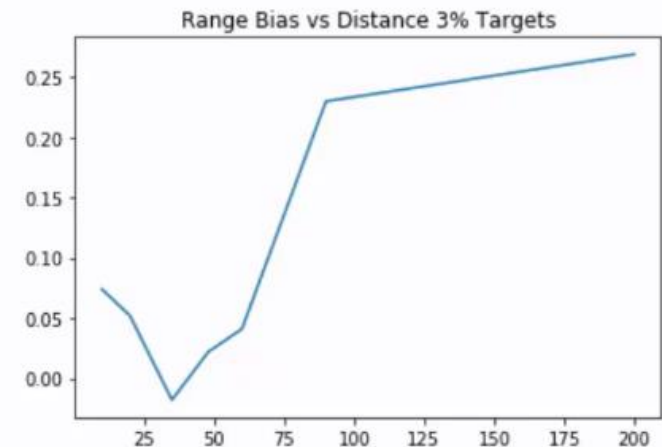
Final Notes

Main Takeaways:

6 out of the 7 lidars tested in New Stanton have passed, obviously we would like that number to be 7/7 , but we are at least on the right path. Suggestions I have to catch future failing LR units at the calibration station:

1. Identify why certain transceivers have unstable alignment.
2. Implement an upper intensity bound for LR tcvrs at the end of line evaluation.
3. Understand the cause of increasing range bias at longer ranges.

Analysis Coverage:

It should be noted that there are some inherent gaps in our current evaluation workflow which also need to be closed to have a thorough end of line test. These include:

- Evaluation of spectular targets, specifically the black panel.
- System (AV) driven pixel adjacency requirements instead of the current 90% pixel passrate.

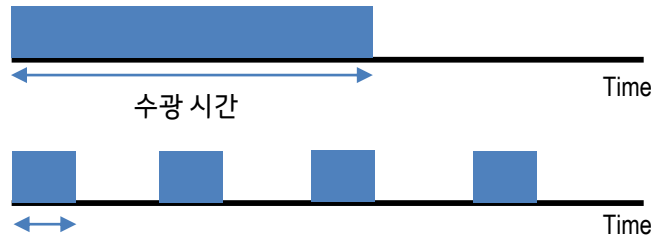Argo AI Secret   18

Appendix

- Features of Q3 FW, latest SW(21-10-29)

  Range Walk 해결 위한 DSP 관점의 update
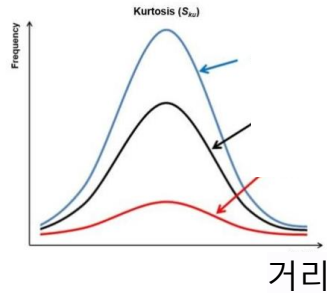
*신호특성
- Low reflectance obj : higher variance → fitting 및 center(거리) 찾기 어려움
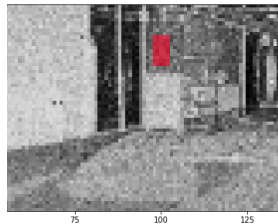- High reflectance obj : lower variance → Peaky해서 center찾기 좋음

FW Upgrade 및 최신 SW에 따른 수광 scheduling 방법

기존

Time

수광 시간

변경(Q3)

Time

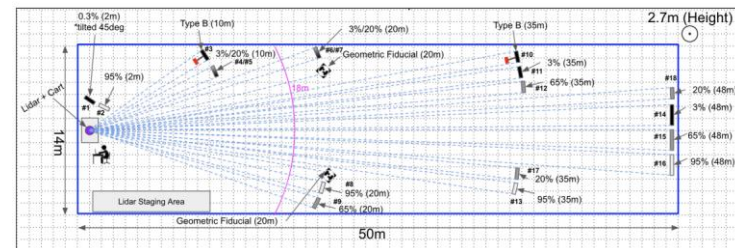- Calibration용 target (11/29 week, 2021 Release예정 SW)

<기존 : Only 3%/20m 하나 사용하여 calibration>

<변경 : Multiple charts 사용하여 calibration 예정>

LG이노텍