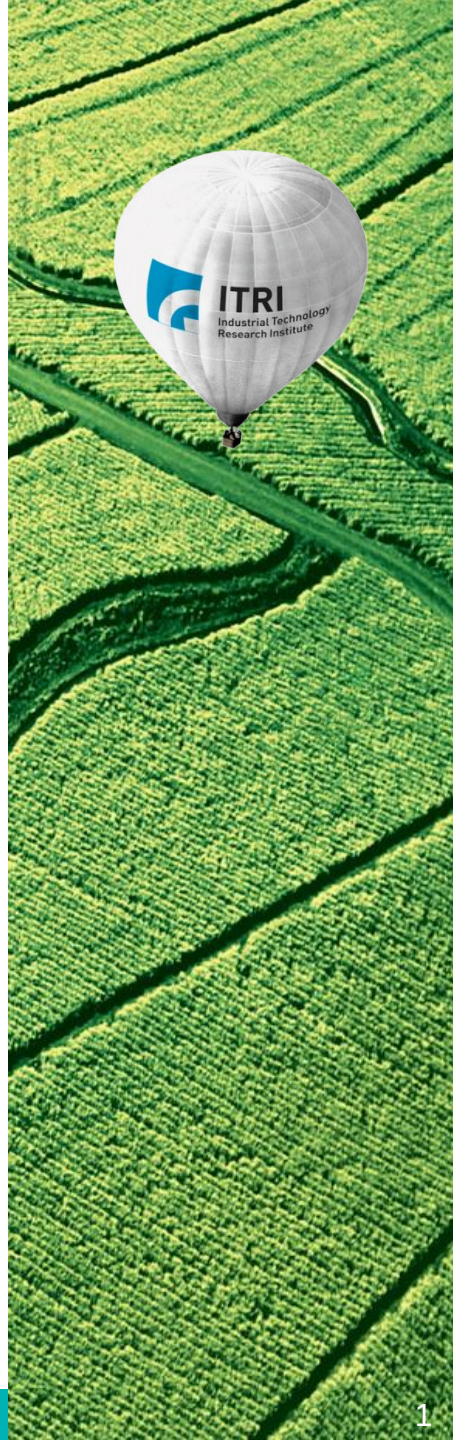
工業技術研究院

Industrial Technology
Research Institute



Accelerating production of HD maps in Taiwan

Results from research project「自駕車用高精地圖快速製圖策略研究案」sponsored by Ministry of Interior

Presenter: Victor Lu, R&D Manager

February 23, 2023

Background

- Guidelines and specifications for production of HD maps in Taiwan has been established by the Ministry of Interior (MOI).
- HD map produced at 17 locations (120 km), over the course of 3 years (2019 ~ 2021).
- Emerging applications in self-driving cars, smart transportation, smart cities increasingly require HD maps to have greater coverage and freshness.

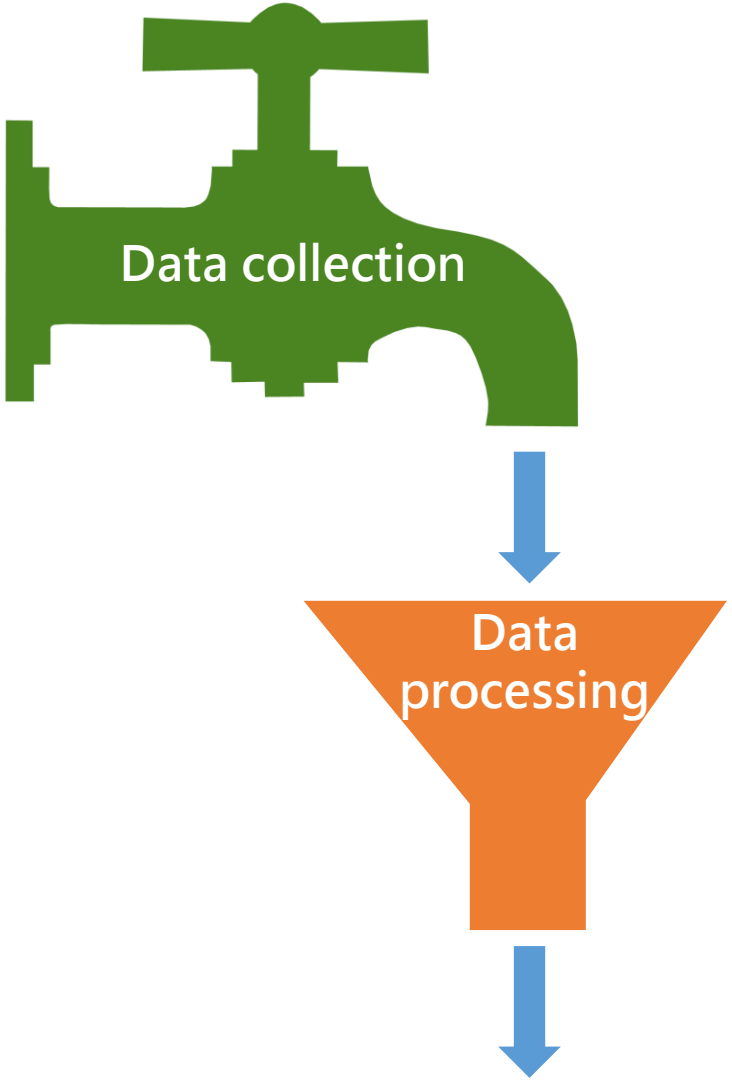
NCKU High Definition Maps Research Center

工業技術研究院
Industrial Technology Research Institute

Fast mapping = fast collection + processing of data

Mapping car

Surveyors



Raw sensor data

Lidar, camera, IMU, GNSS, control points

HD map

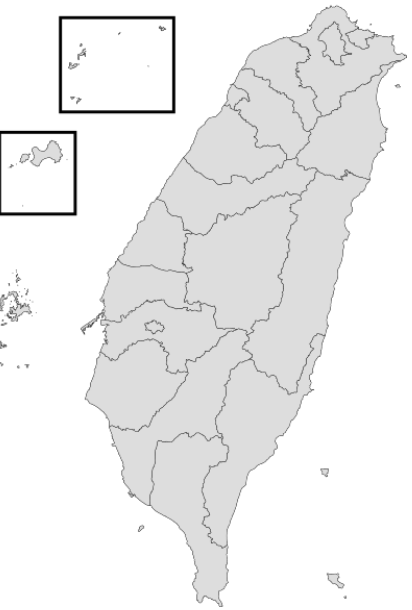
point cloud map, vector map

工業技術研究院
Industrial Technology Research Institute

Map freshness vs. map equipment cost

- Suppose 8 hour drive on urban roads can cover ~100 km
- Total road length in Taiwan[1] : 41,475km

Reigl VMX-2HA
$670K USD
($20M TWD)



1+ year	Monthly	Weekly	Daily
1 map car	15 map cars	60 map cars	420 map cars
$670K USD	$10M USD	$40M USD	$280M USD
$20M TWD	$0.3B NTD	$1.2B TWD	$8.4B TWD

[1] https://zh.wikipedia.org/wiki/臺灣公路

工業技術研究院
Industrial Technology Research Institute

ITRI HD map-making technology

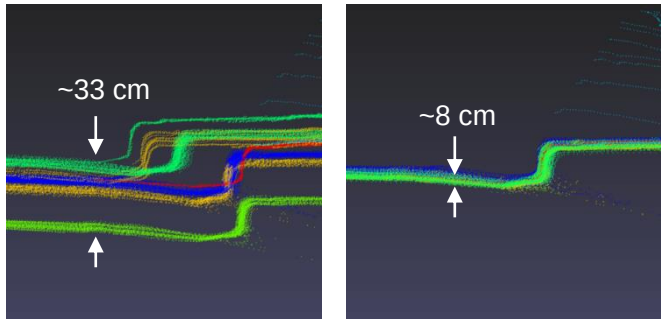
Low-cost HW

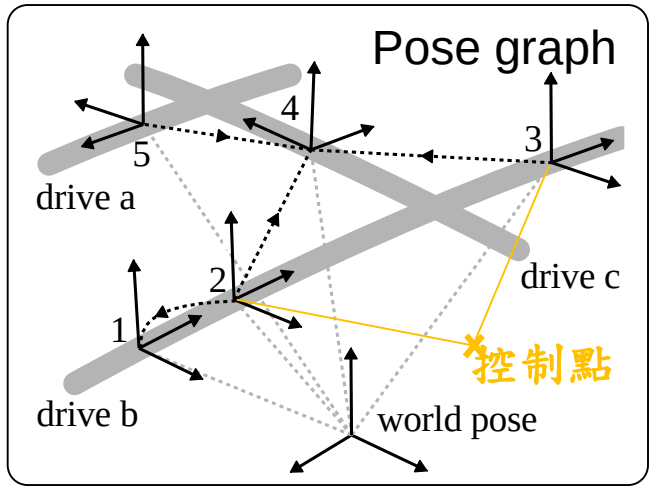
$67K USD

$2M NTD

Point cloud adjustment

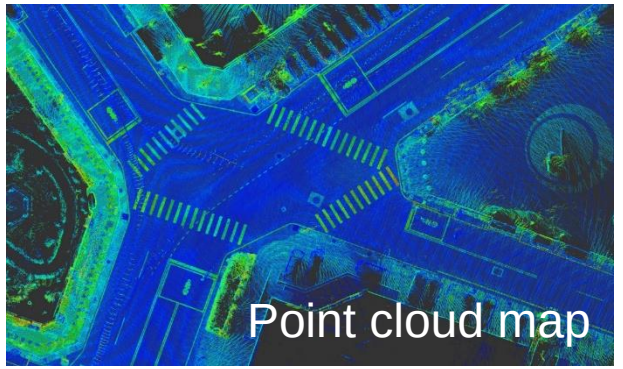
Compensate errors due to low-cost sensor HW, aligning multi-drive Lidar point cloud data

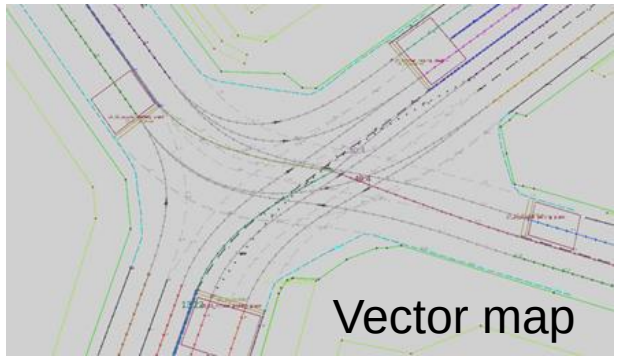




Efficient production of vector map data

Use semi-automated tools based on AI+3D algorithms





工業技術研究院
Industrial Technology Research Institute

Omit time-consuming control point measurements

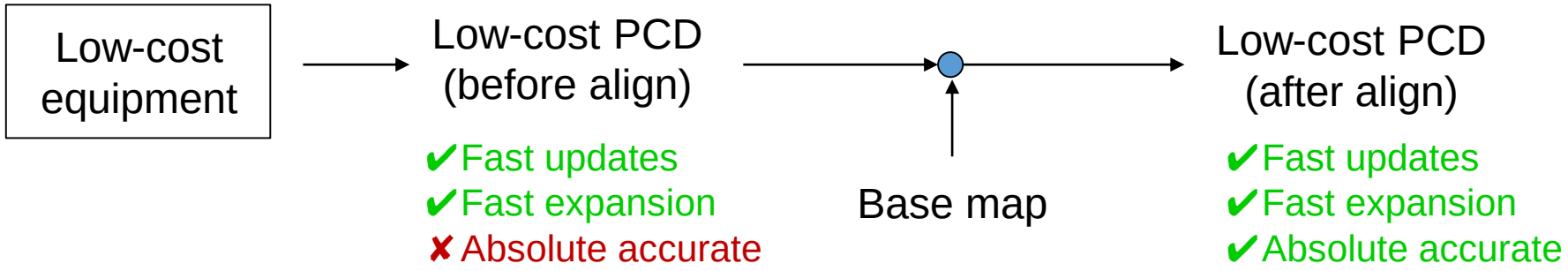
Absolute accuracy ~1m, relative accuracy < 10cm
If needed, absolute accuracy can be recovered by adding control point measurements at a later date.

Source: 詮華

工業技術研究院
Industrial Technology Research Institute

Low-cost updates by aligning to a base map

- Base map := map with cm-level absolute accuracy
  We currently use point cloud as base map,
  though other forms of base maps are also possible e.g. vector map
- Align low cost point cloud onto base map
  Leverage scan matching, point cloud adjustment methods
  (no need to manually select corresponding keypoints)
- Aligned point cloud will be both fresh and absolute accurate



工業技術研究院
Industrial Technology Research Institute

Main results

1. Quality validation of HD maps produced by ITRI low-cost method
   - Quality suitable for self-driving cars, pole maintenance
   - After aligning to base map, can satisfy MOI accuracy requirements
2. Vector map production workflow
   Semi-automated + application-oriented = large efficiency gains
   - Vector map layer: 54 days (surveying company) → 11 days (ITRI)
   - Pole data: 12 days (manual) → 1 day (semi-automated)
3. Framework for fast HD map production in Taiwan
   - Emerging low cost methods + existing methods (high cost HW, control points)
   - Coverage + Freshness + Accuracy

工業技術研究院
Industrial Technology Research Institute

Using ITRI low cost HD map

Self-driving car test in Taoyuan Airport

https://www.youtube.com/watch?v=hAPtT8EkYnw&t=132s

工業技術研究院
Industrial Technology Research Institute

Using ITRI low cost HD map

Self-driving truck test on highways of Melbourne AU

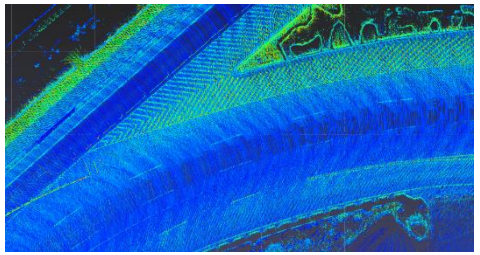
https://www.youtube.com/watch?v=Ox-bDbLq6lo

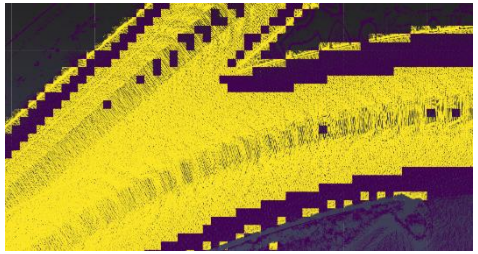
工業技術研究院
Industrial Technology
Research Institute

Ministry of Interior quality requirements on PCD

Density

>95% cells have density >2500pts/m²



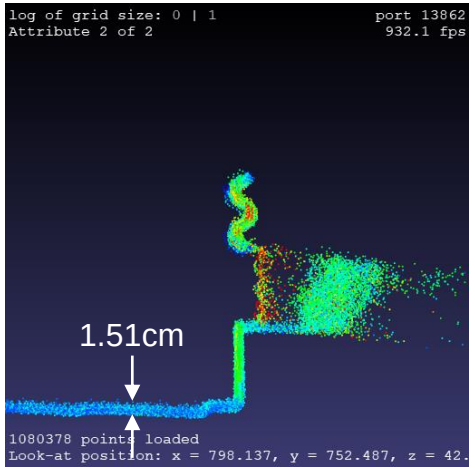


1m x 1m cells

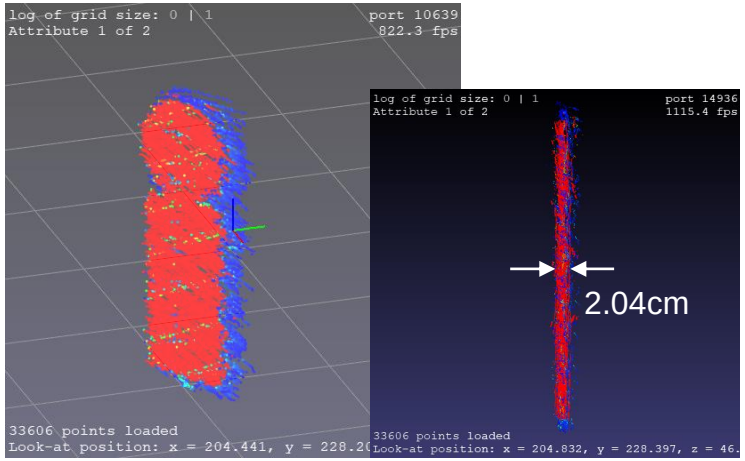
Relative Accuracy

"Thickness" of planar surfaces < 10 cm

Ground surfaces



Planar object surfaces



Absolute Accuracy

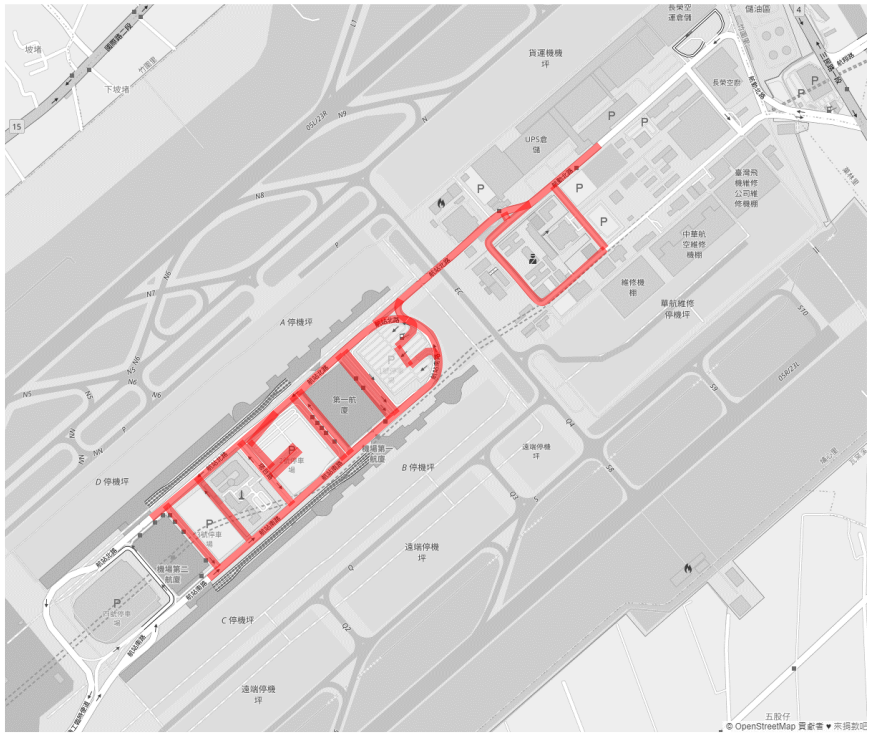
2D error < 20 cm
3D error < 30 cm

工業技術研究院
Industrial Technology Research Institute

Test site: Taoyuan airport

Coverage of low-cost map produced by ITRI system (~7.8km)

Coverage of base map produced by surveying company (~6.3km)



工業技術研究院
Industrial Technology Research Institute

MOI evaluation results

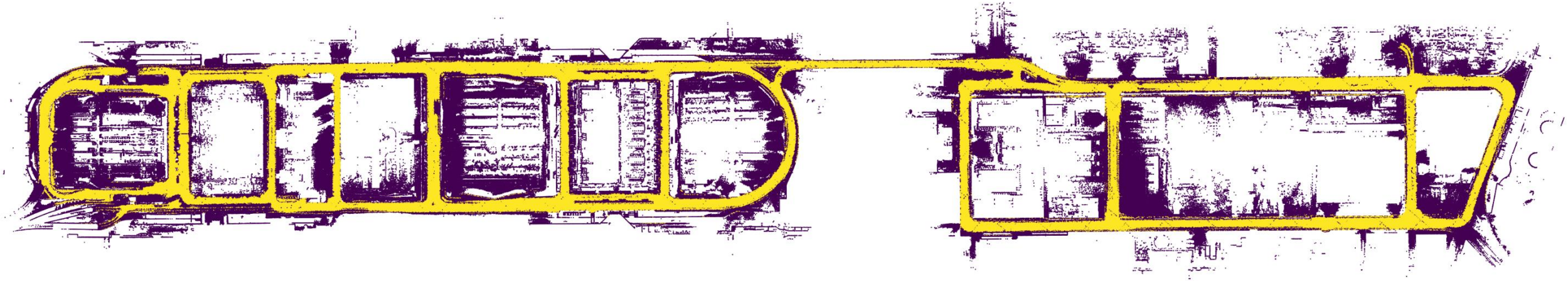
		ITRI		Base map	MOI spec.
		Before base map alignment	After base map alignment		
Point density		95.65%	95.65%	>95%	>95%
Relative accuracy	ground	2.6 cm*	2.2 cm	8.4 cm*	<10 cm
	object	20.0 cm*	7.8 cm	8.0 cm*	<10 cm
Absolute accuracy	2D	107.3 cm	11.76 cm	5.6 cm	<20 cm
	3D	114.9 cm	16.4 cm	11.8 cm	<30 cm

Meets MOI specifications
Does not meet MOI specifications
* Measurements provided by NCKU HD maps research center

All self-driving car and vector map results in this presentation use ITRI map **before** base map alignment.

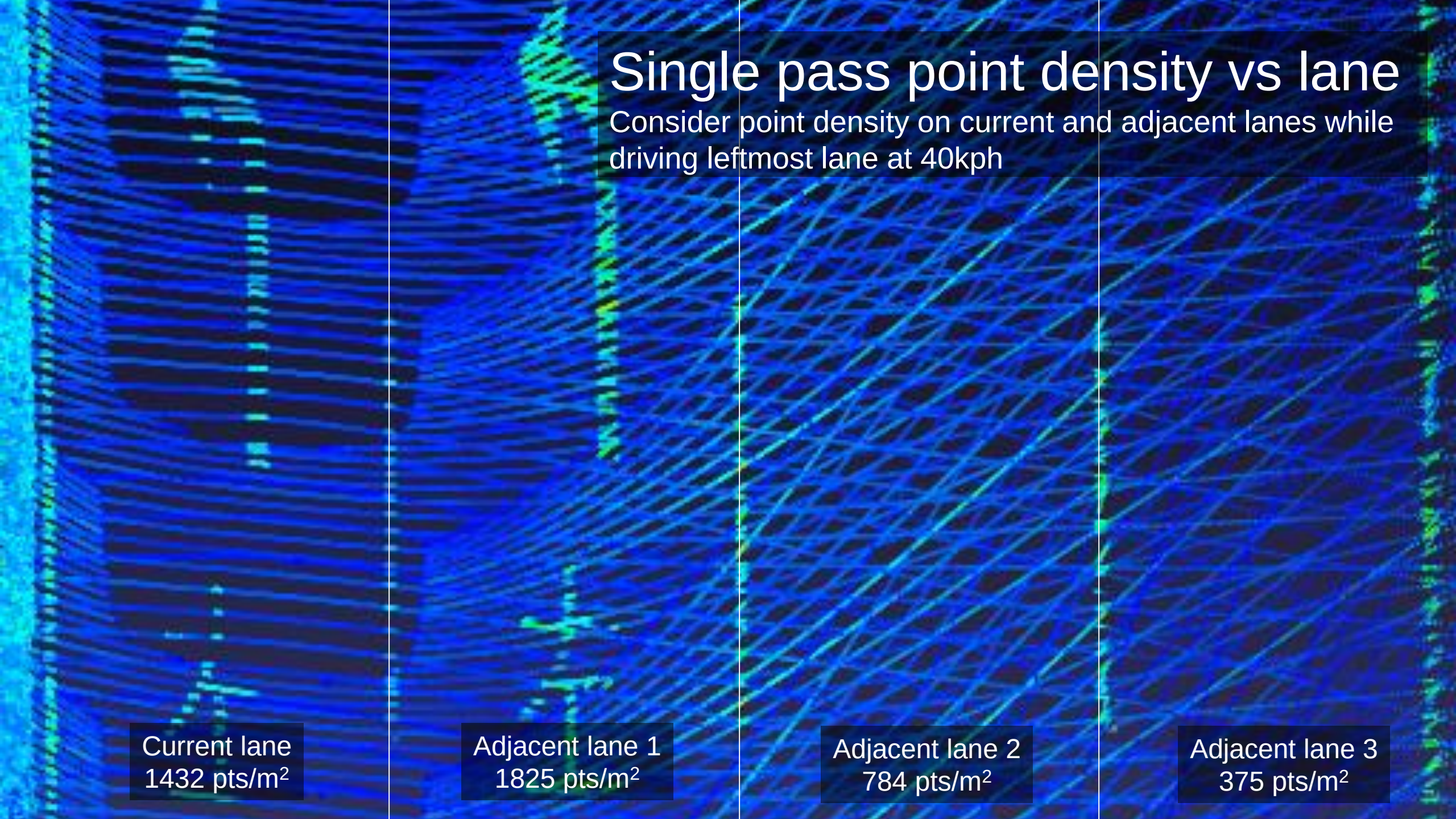
工業技術研究院
Industrial Technology Research Institute

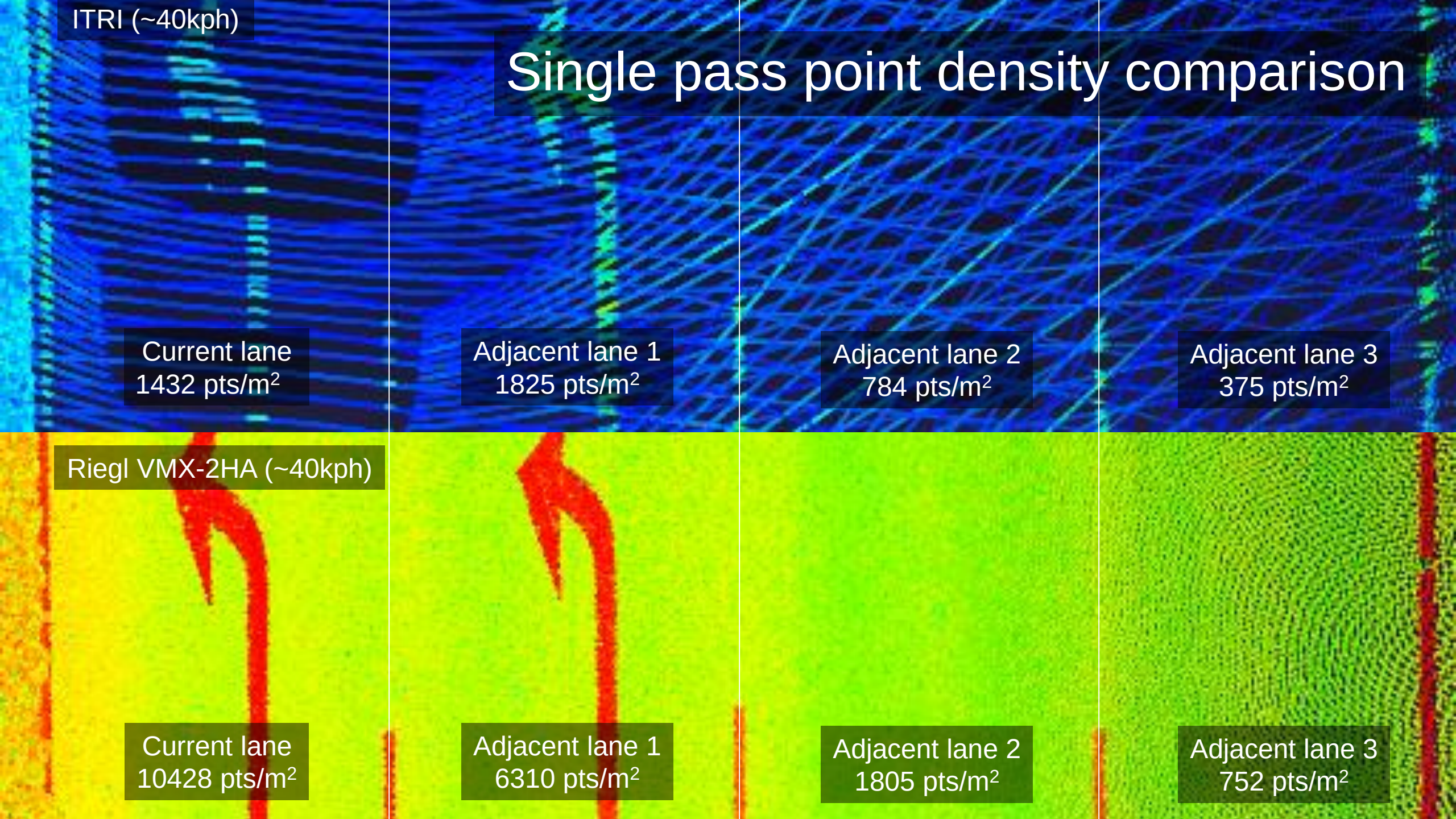
Point density visualization



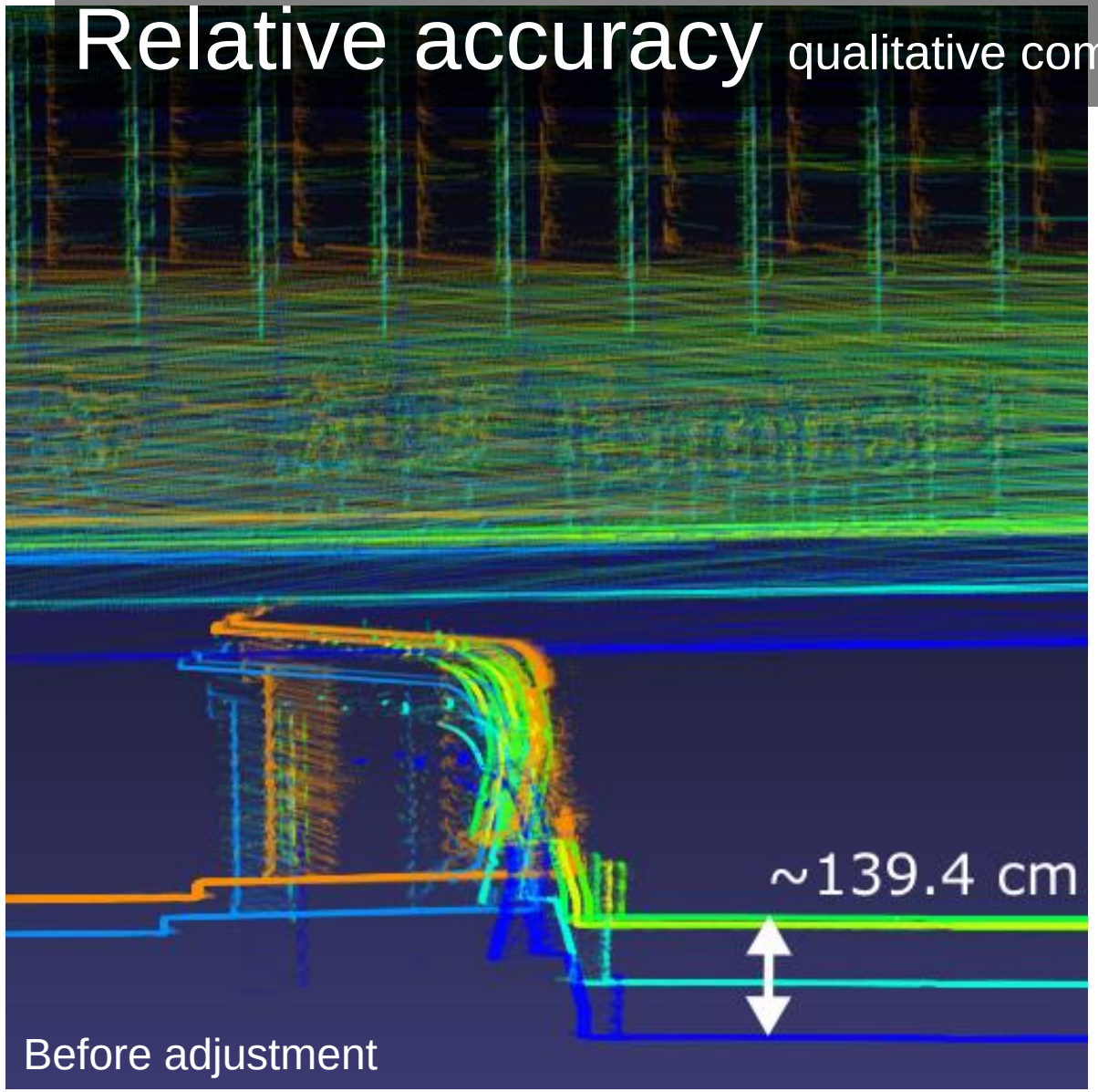
Yellow areas have point density > 2500pts/m^2

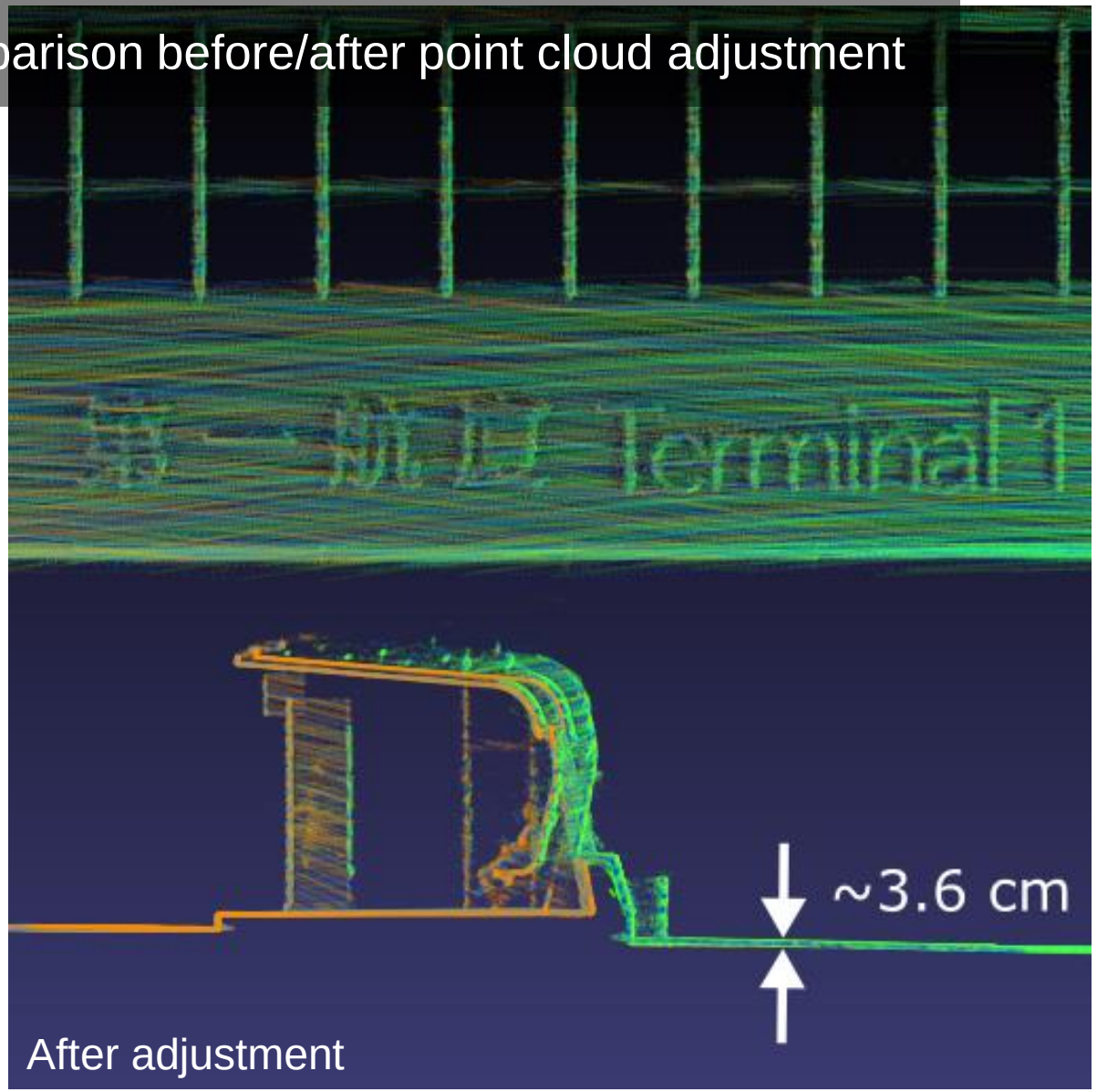
工業技術研究院
Industrial Technology Research Institute


Single pass point density vs lane
Consider point density on current and adjacent lanes while driving leftmost lane at 40kph
Current lane
1432 pts/m2
Adjacent lane 1
1825 pts/m2
Adjacent lane 2
784 pts/m2
Adjacent lane 3
375 pts/m2


ITRI (~40kph)
Single pass point density comparison
Current lane
1432 pts/m²
Adjacent lane 1
1825 pts/m²
Adjacent lane 2
784 pts/m²
Adjacent lane 3
375 pts/m²
Riegl VMX-2HA (~40kph)
Current lane
10428 pts/m²
Adjacent lane 1
6310 pts/m²
Adjacent lane 2
1805 pts/m²
Adjacent lane 3
752 pts/m²

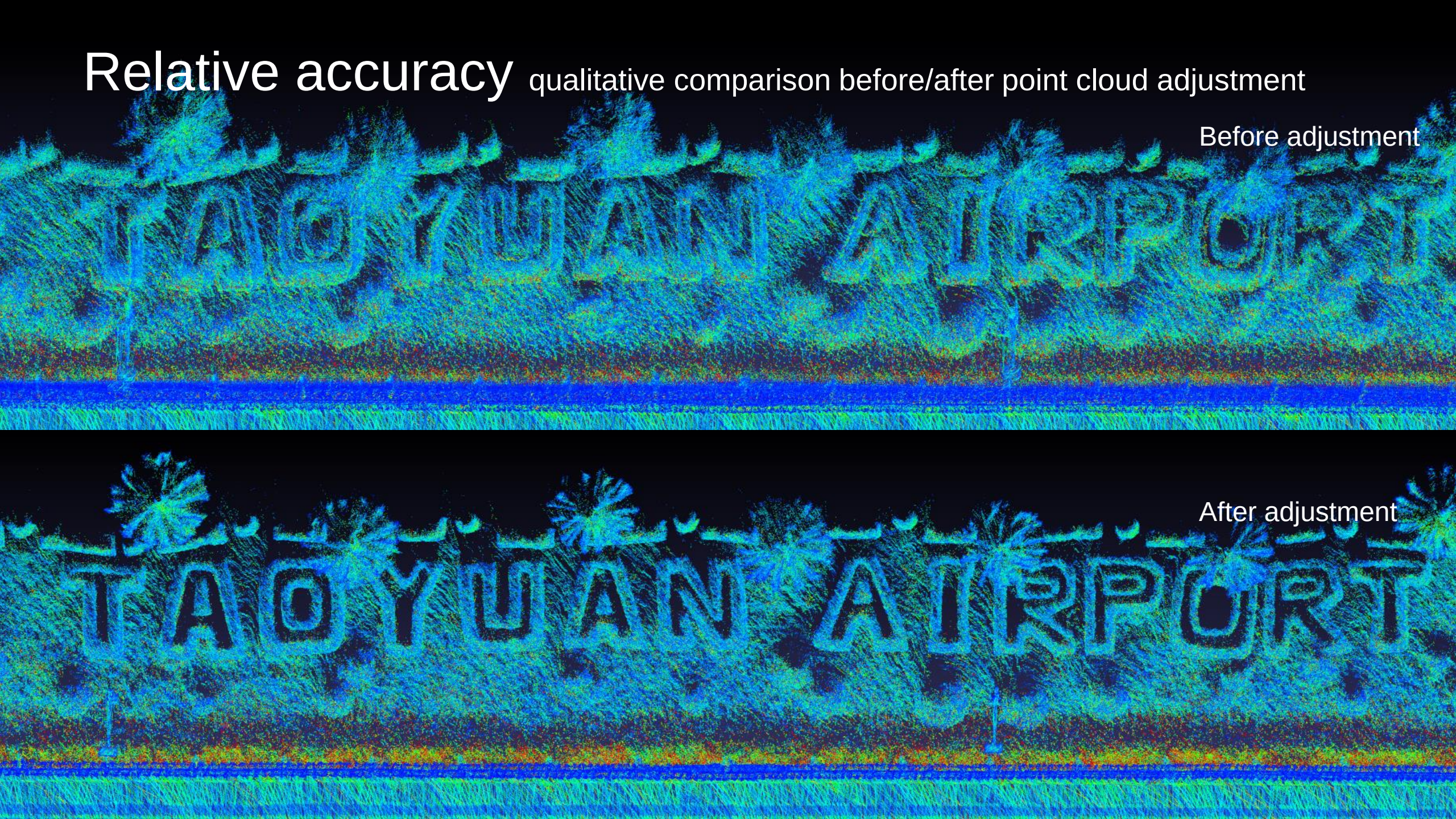
Relative accuracy qualitative comparison before/after point cloud adjustment





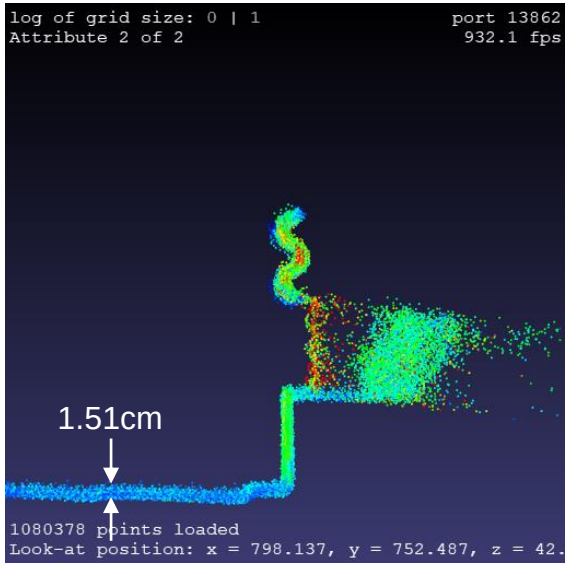
工業技術研究院
Industrial Technology Research Institute

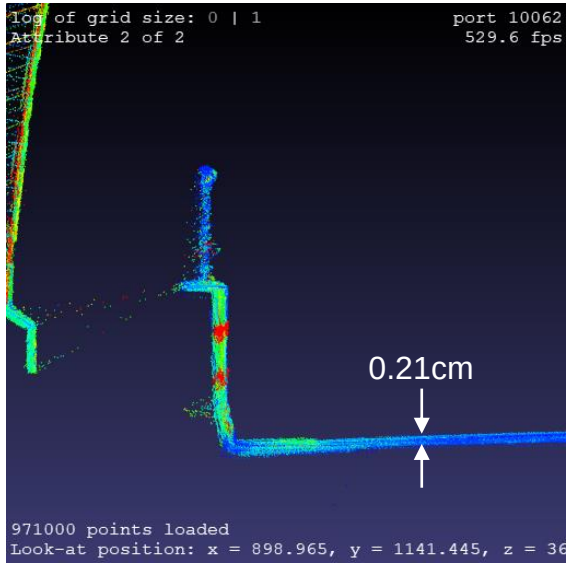
Relative accuracy qualitative comparison before/after point cloud adjustment

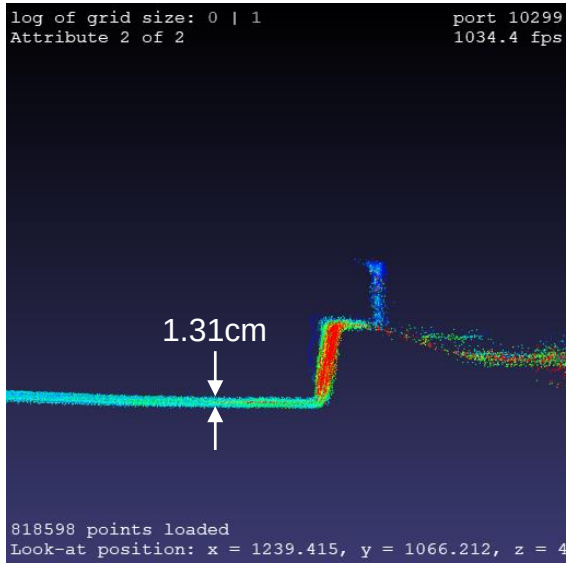


Relative accuracy: road surface cross sections

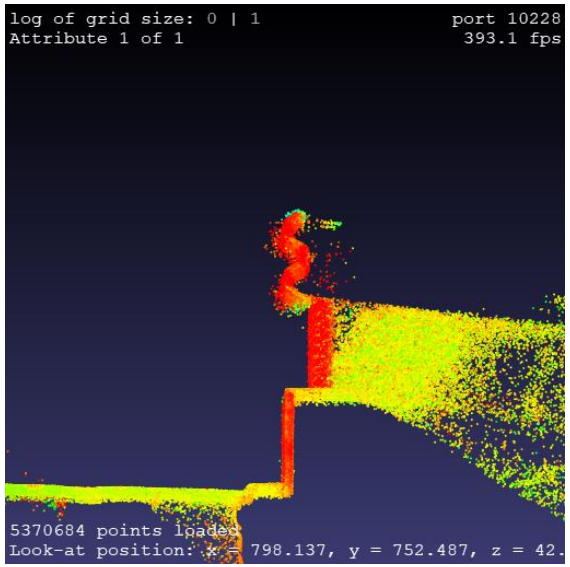
ITRI

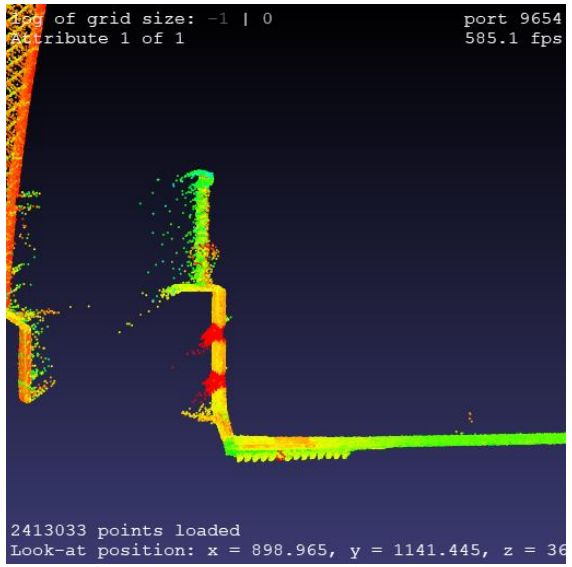


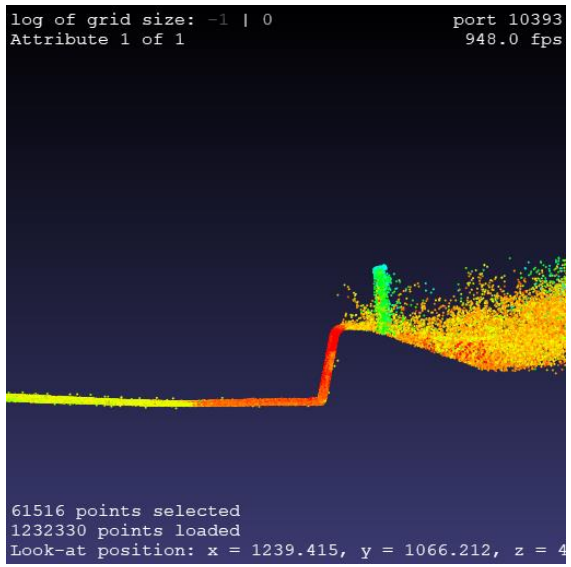




Riegl VMX-2HA



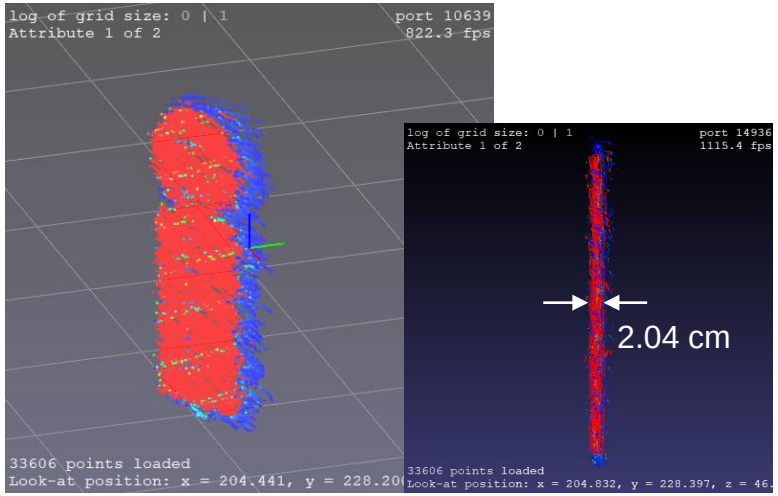


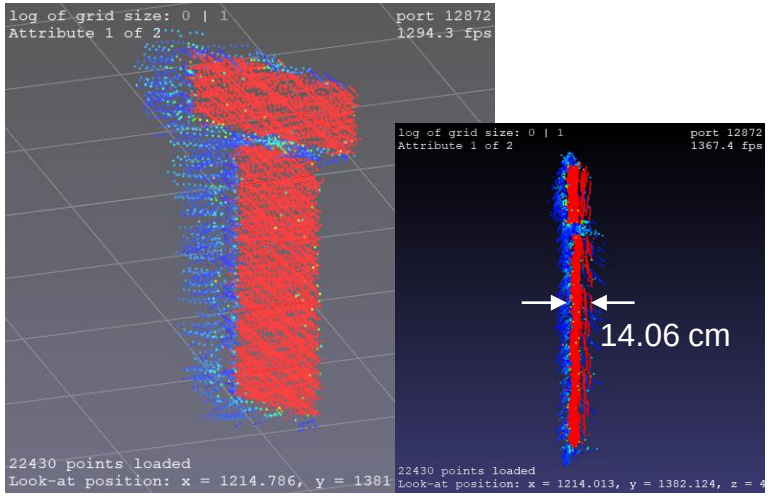


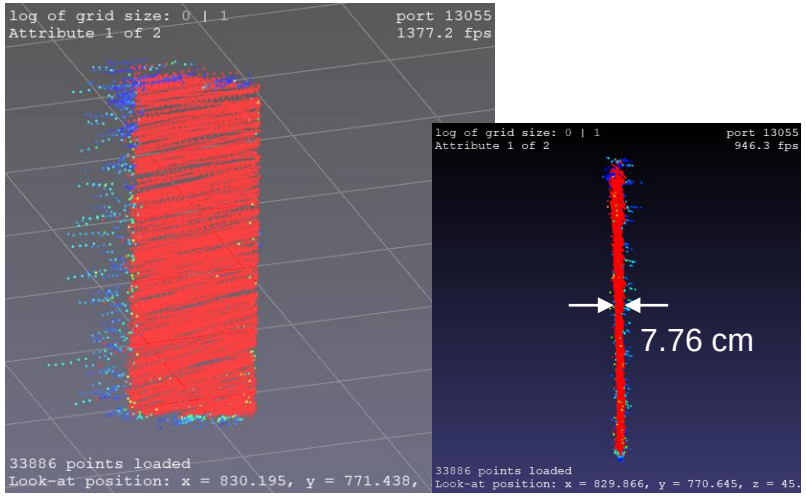
工業技術研究院
Industrial Technology Research Institute

Relative accuracy: traffic sign cross sections

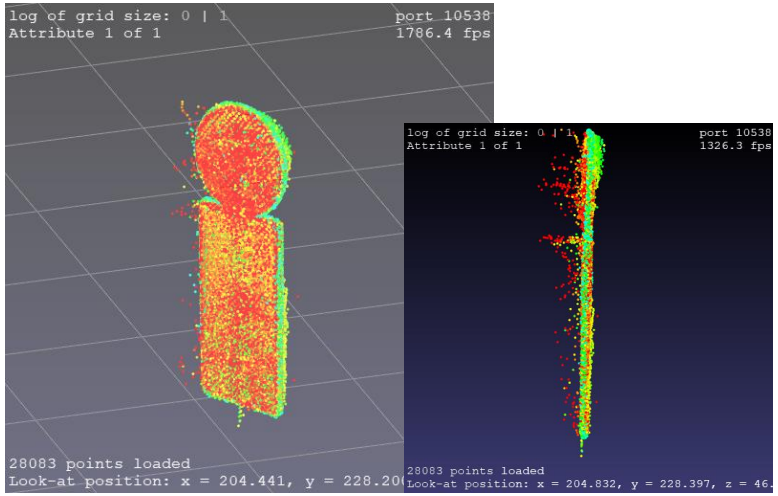
ITRI

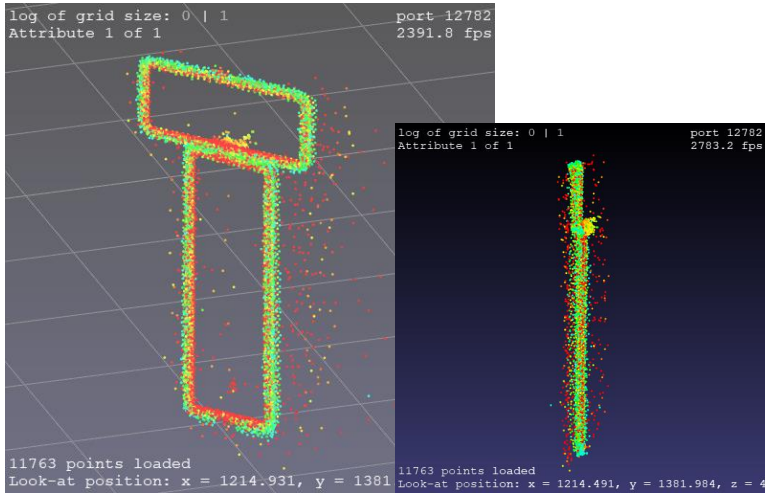


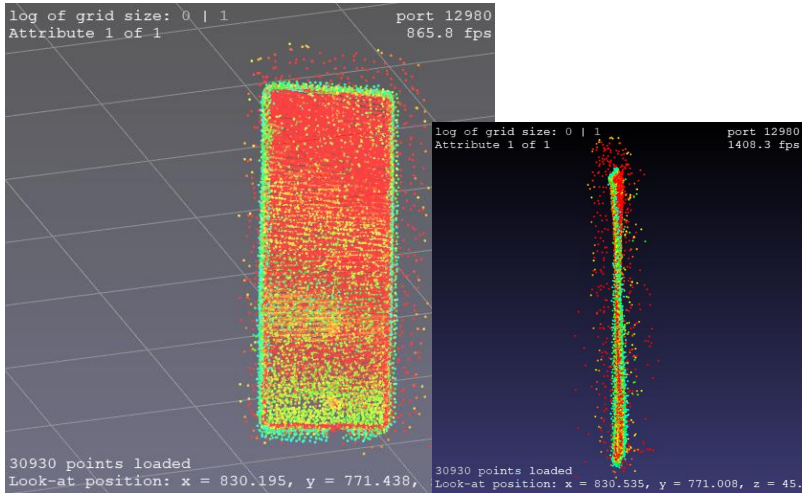




Riegl VMX-2HA







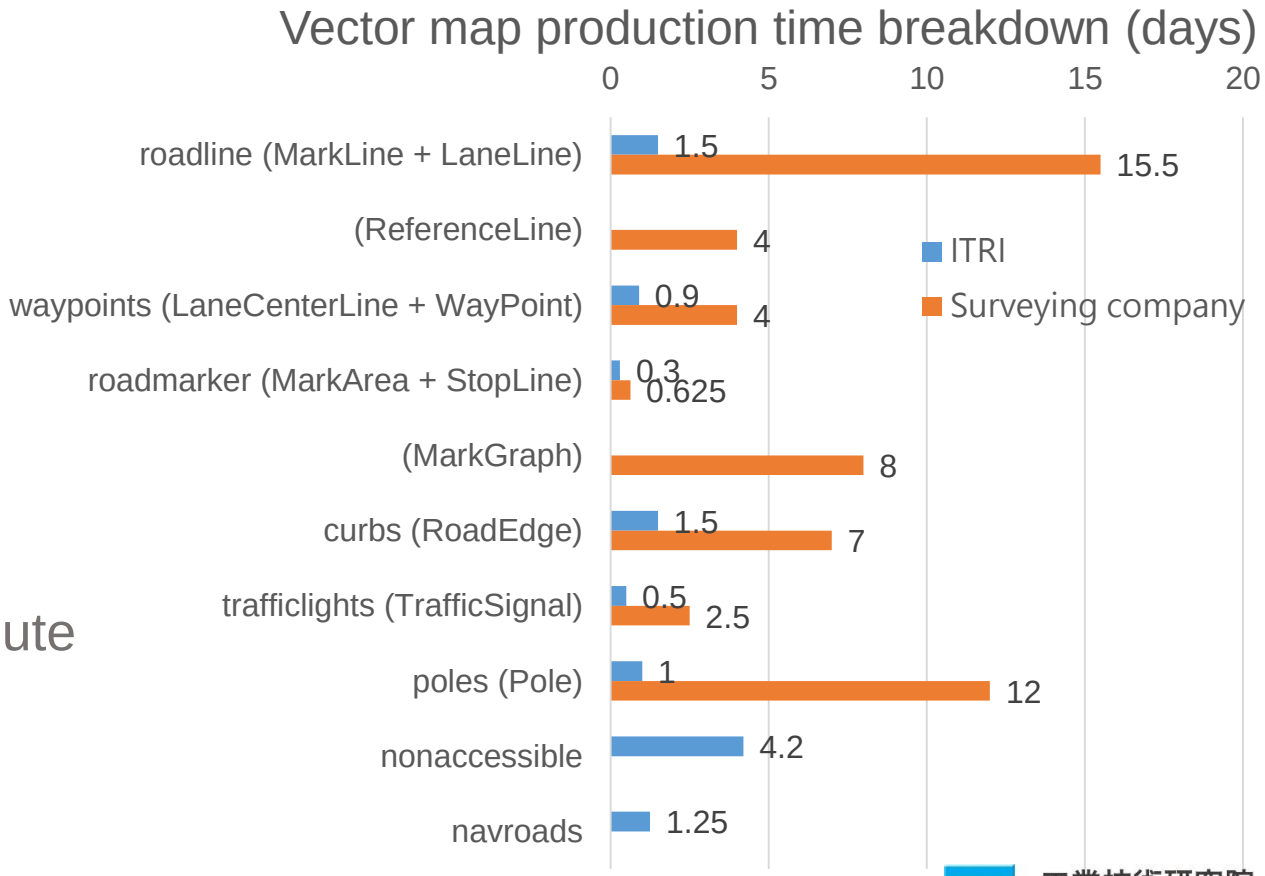
Comparison of vector map production efficiency

ITRI (11 day) vs. surveying company (54 days)

Sources of time difference:

- **Application-oriented workflow**
  (focused on self-driving car use case)
  - Use of simpler geometry
    e.g. represent traffic lights,
    road markings with rectangle
  - Focus on content related to planned operation
    e.g. omit waypoints outside of planned route

- **Semi-automated tools**
  Facilitate creation of 3d object models



工業技術研究院
Industrial Technology Research Institute

Semi-automated semantic map making: Poles

Semi-automated process (1 day)

1. Fully automated detection + fitting (3 hrs)
2. Remove false positives (5 hrs)
3. Add false negatives (3 hrs)

All manual process (12 days)

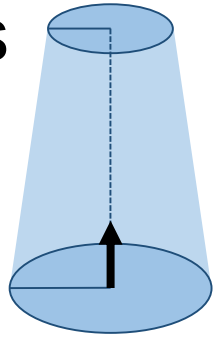
Results

- Total # of auto-produced poles: 1154
- # of false positives removed: 607
- # of false negatives added: 1206
  (875 of which were warning posts)

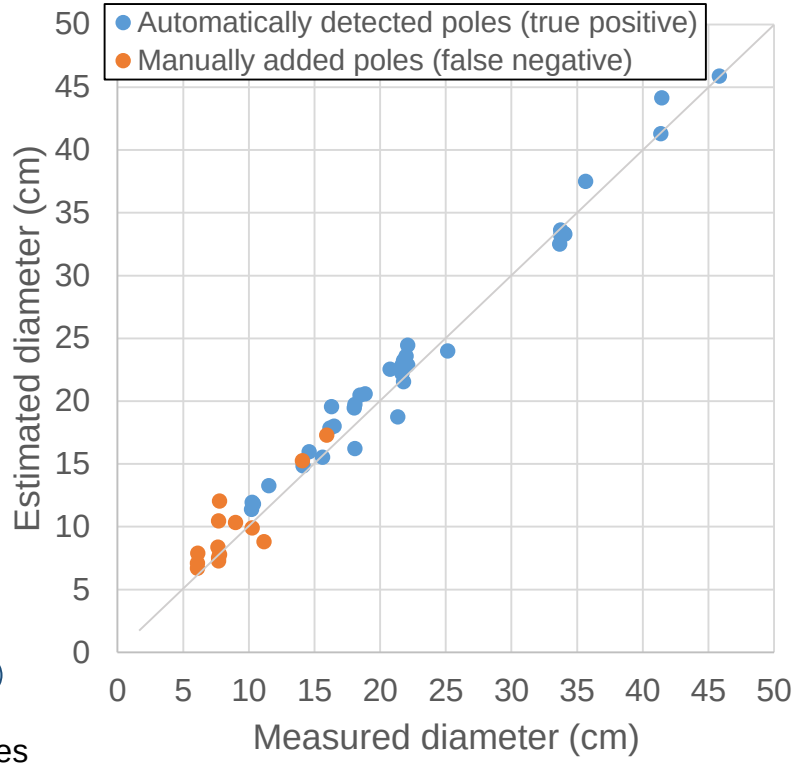
Accuracy of ITRI pole models

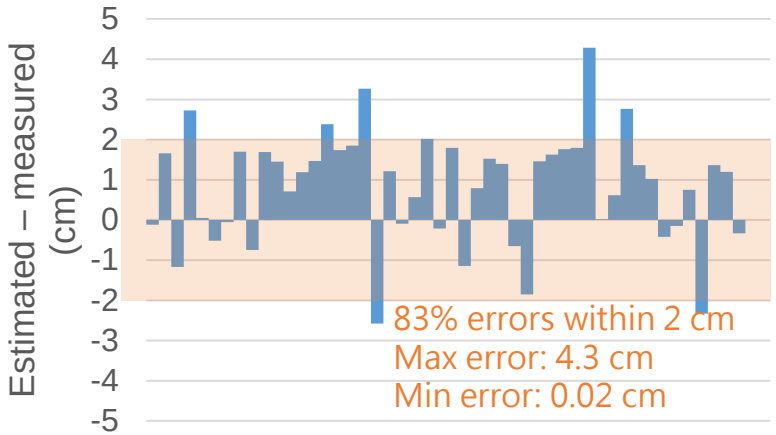
Compared pole model diameters against against measured diameter of 48 poles

- Average error: 1.3 cm
- 83% of errors were within 2 cm
- Poles with diameters > 15 cm achieved 97% detection recall



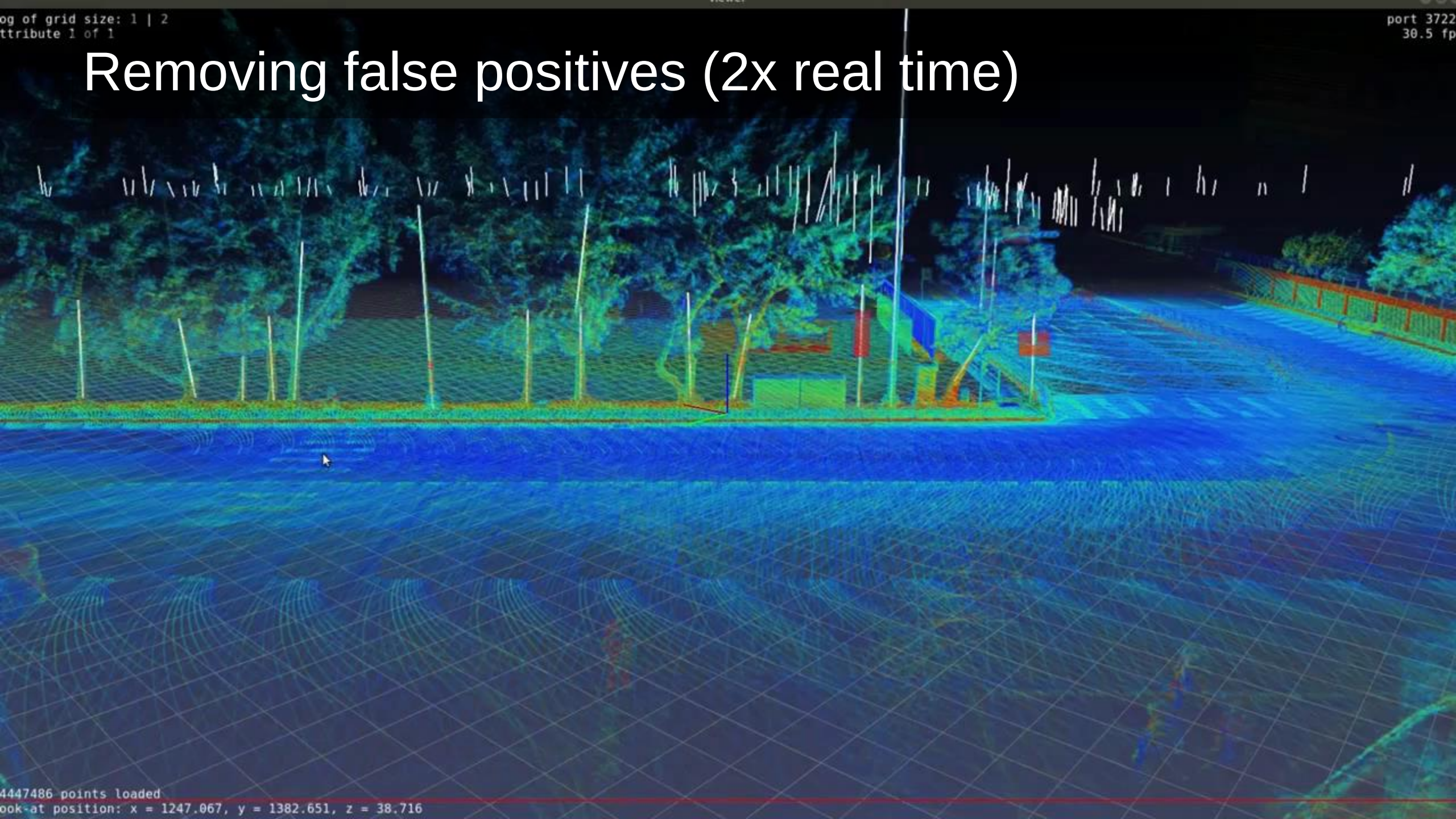
We represent poles using a truncated cone model





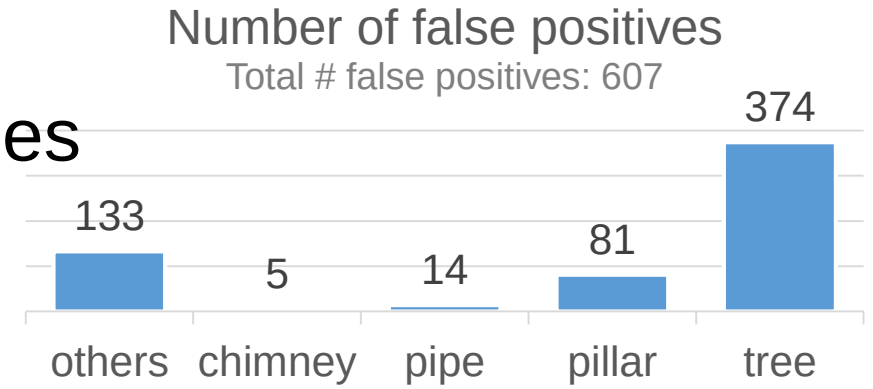
工業技術研究院
Industrial Technology Research Institute

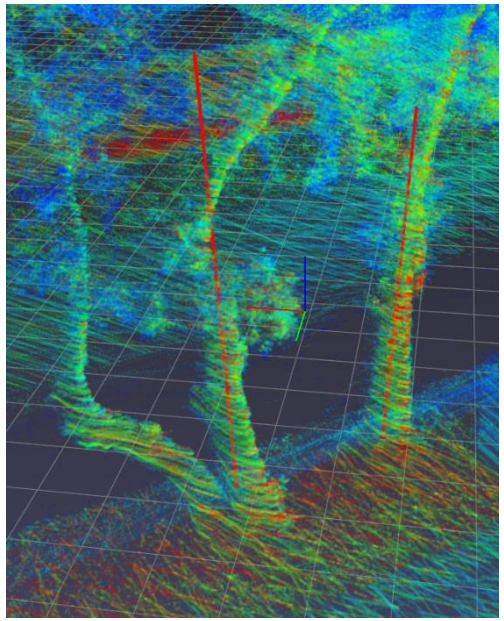
Removing false positives (2x real time)

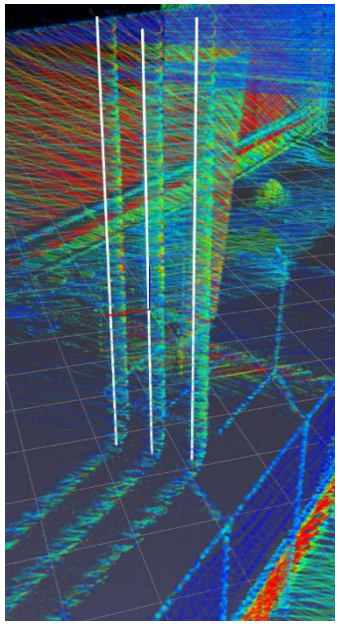


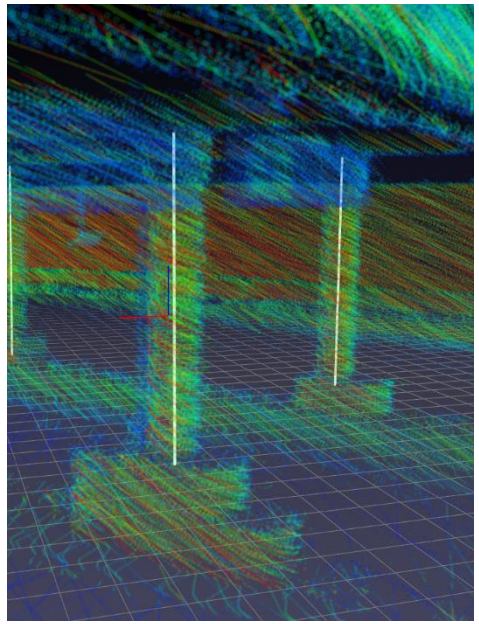
Example false positives

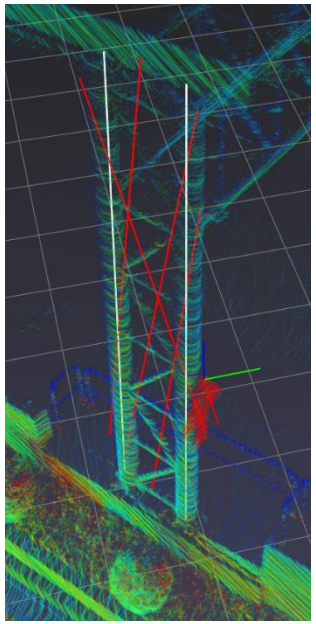
- Many false positives have potential other uses
  - E.g. tree inventory is useful for managing carbon footprint
  - If treating these false positives as true positives our method achieves 88.5% detection precision.

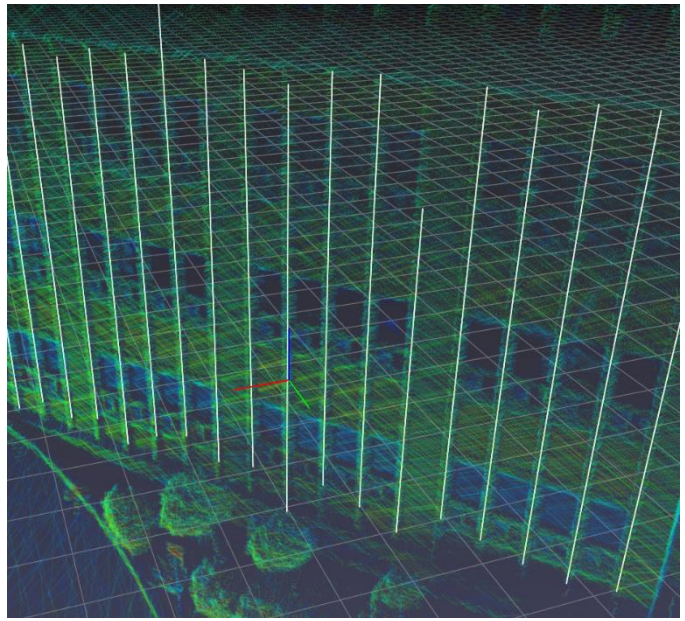



Tree trunk/branches


Pipes


Pillars


Others


Others

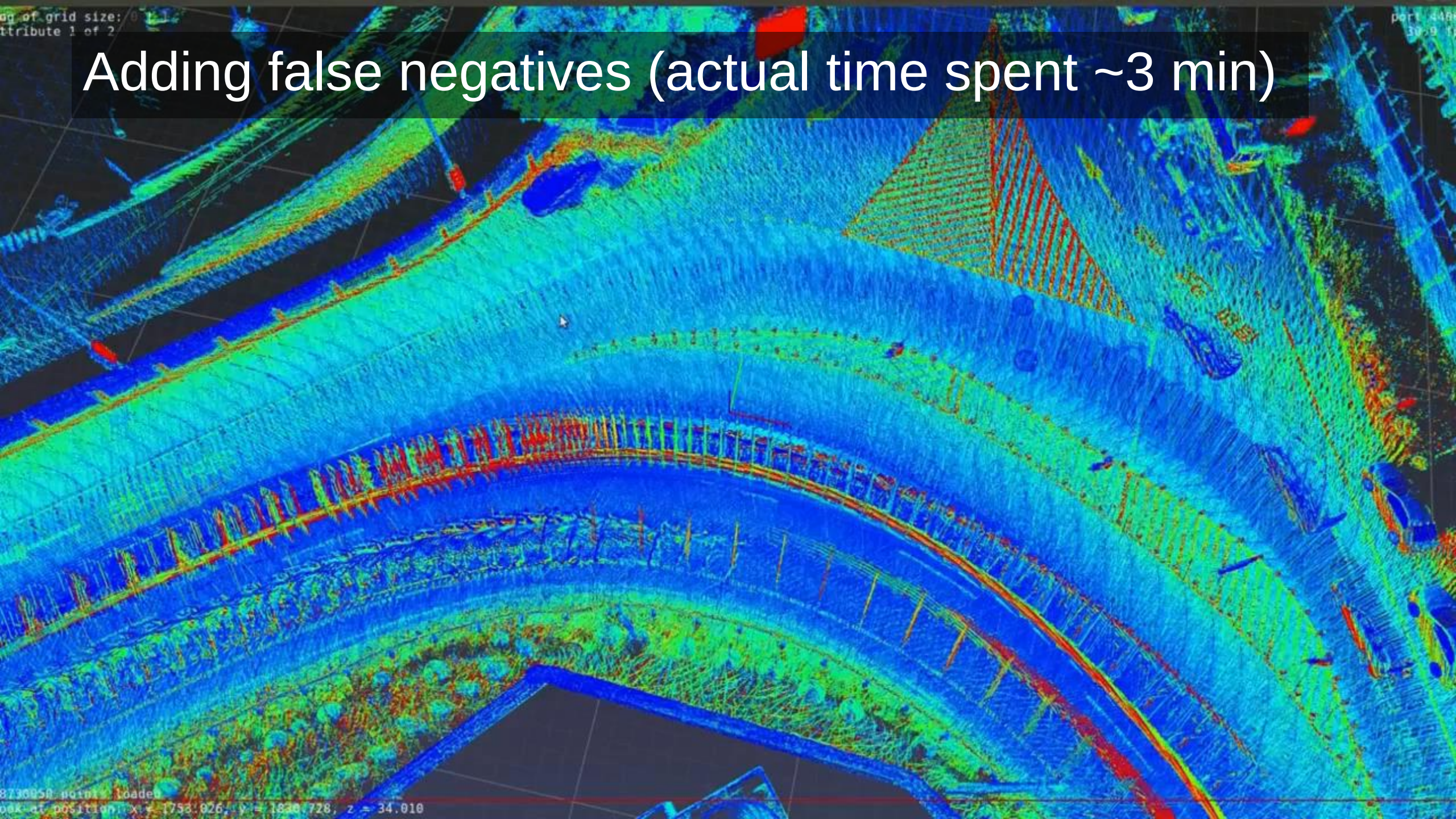
工業技術研究院
Industrial Technology Research Institute

Example false negatives (mostly short and thin poles)

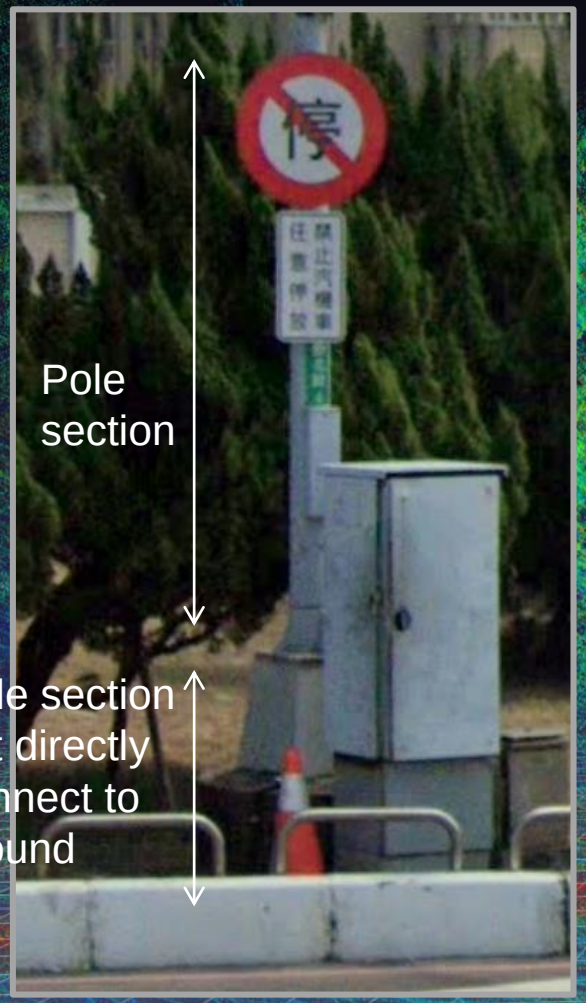
Left image source: Google StreetView

工業技術研究院
Industrial Technology Research Institute

Adding false negatives (actual time spent ~3 min)

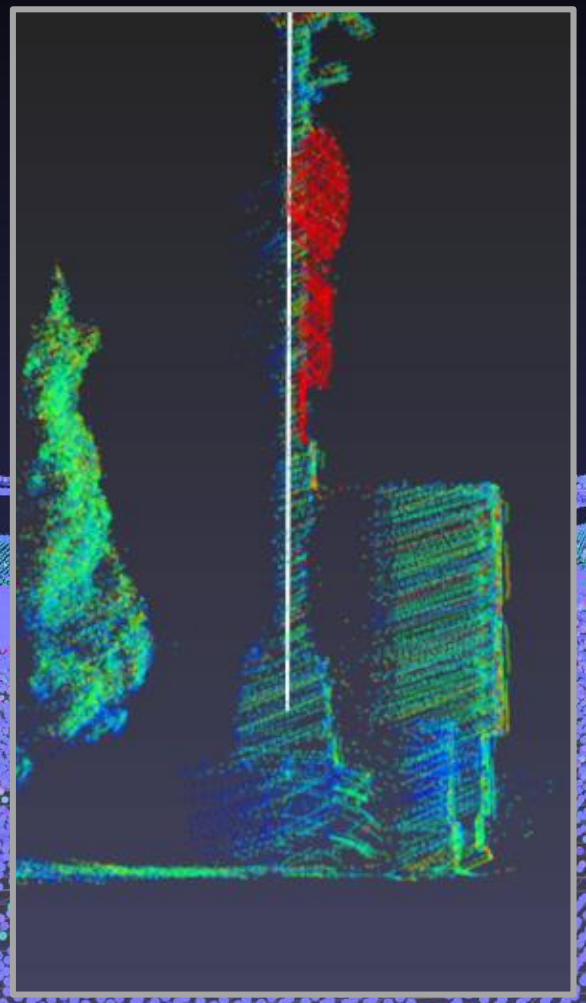


Estimating pole base position



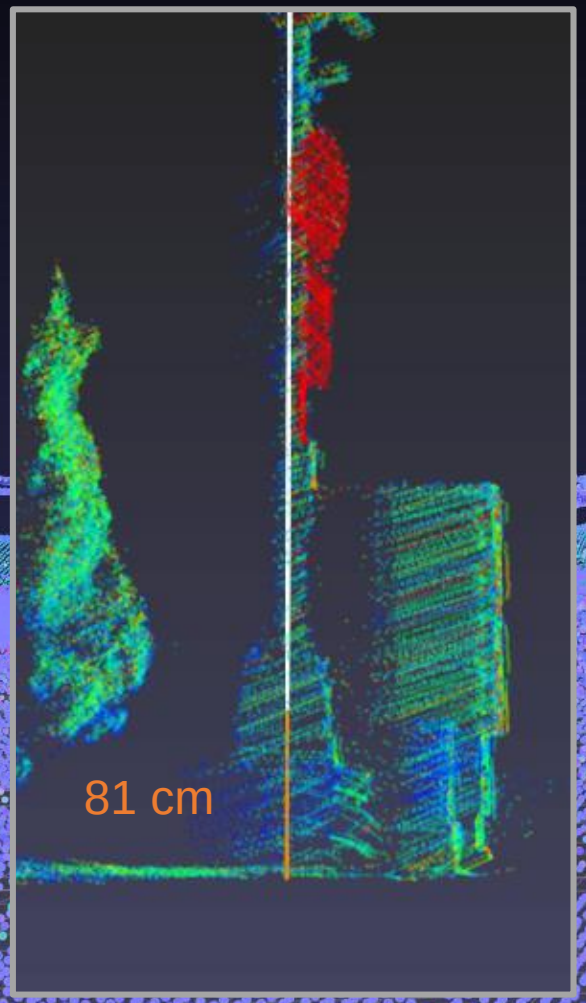
Estimating pole base position

Remove non-ground points



Estimating pole base position

Extend to closest ground point



Framework for fast HD map production in Taiwan

Rapidly expand coverage of low cost map, fostering new use cases and value creation

e.g. self-driving cars, pole maintenance

Low cost map
✔Freshness
✔Relative accuracy
✘Absolute accuracy

✔Freshness
✔Rel. accuracy
✔Abs. accuracy

High cost map
(base map)
✘Freshness
✔Relative accuracy
✔Absolute accuracy

Gradually grow coverage of base map coverage, enabling low cost maps to gain absolute accuracy via alignment.

- Low cost equipment
- Omit control point measurements

Low cost map aligned to high cost map, yielding map that is both fresh and accurate

- High cost equipment
- Time-consuming control point measurements