Terrestrial **Laser Scanning**
Hand-held **Laser Scanning**
Mobile **Laser Scanning**
UAV **Laser Scanning**
Airborne **Laser Scanner**

รองศาสตราจารย์ ดร. ไพศาล สันติธรรมนนท์

คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

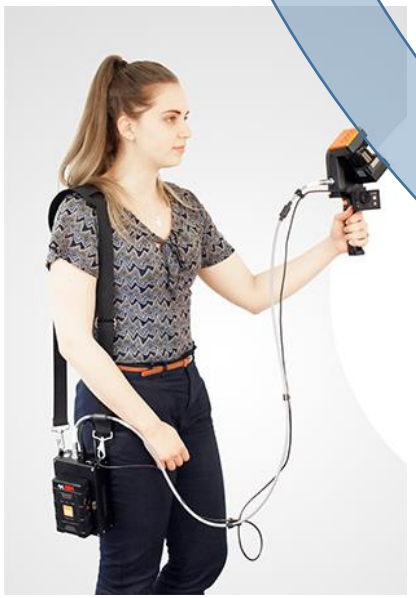
…X…. Mobile Mapping System

- Hand-held ….
- Wearable …
- Back-pack …
- Portable …
- Cart-based …
- Vehicle-based

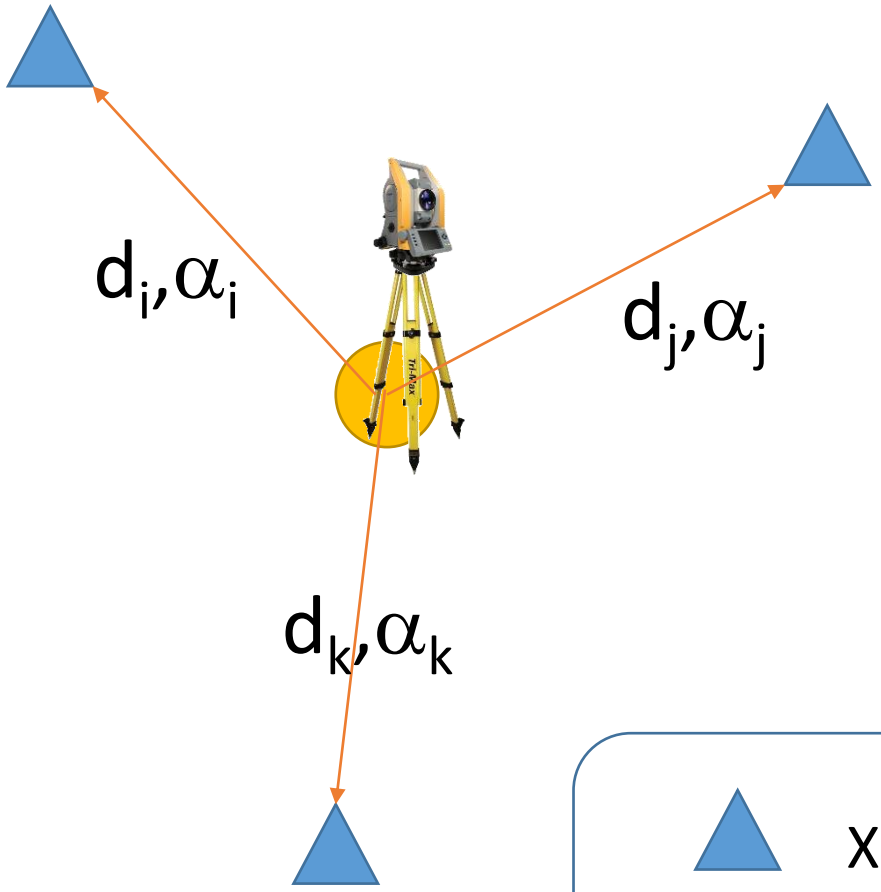
Autonomous Vehicle (AV)

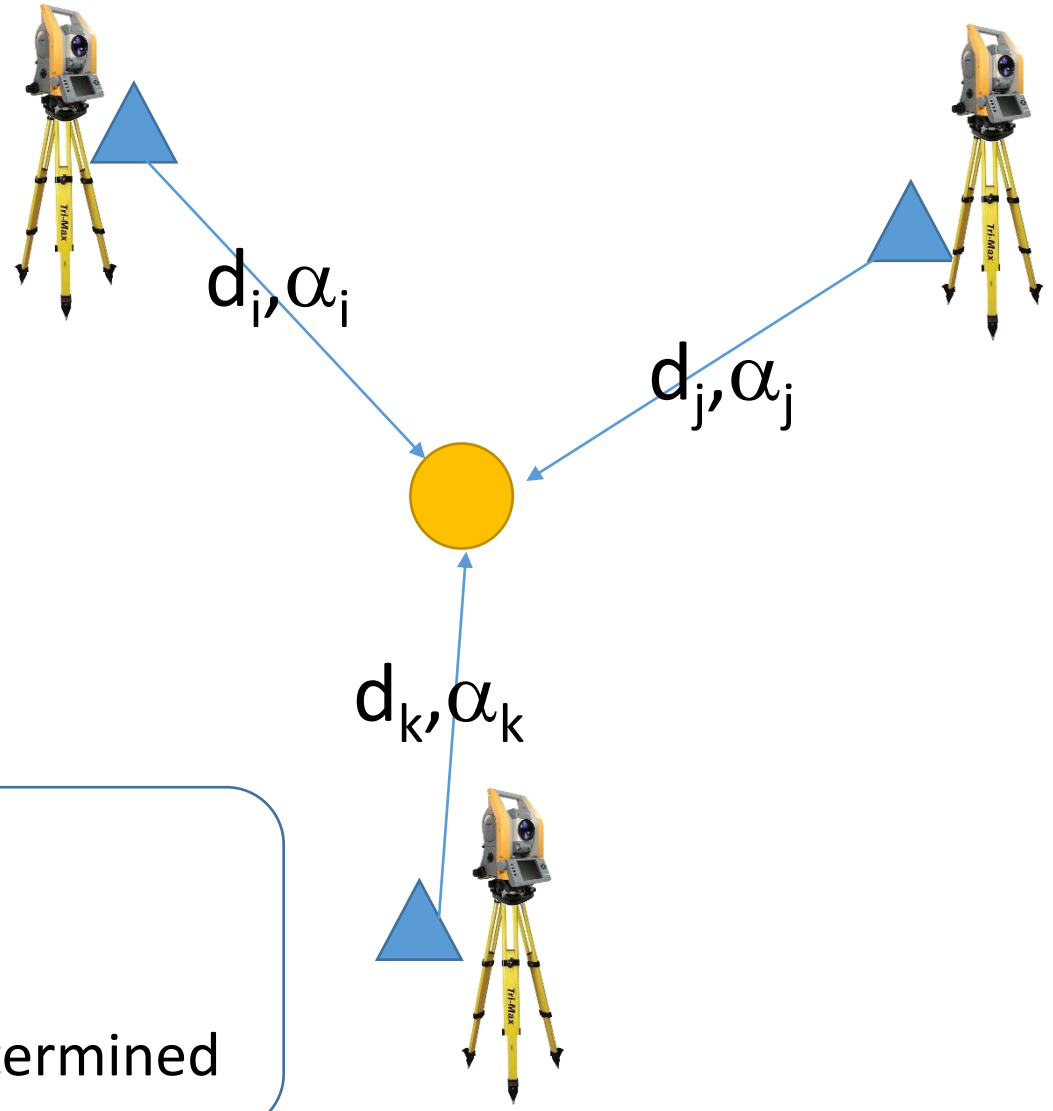
Evolution of ‘Mobile’

- Hz = 1 จุดต่อวินาที
- RTS = 1000 Hz+…
- TLS = 100 KHz+ ….
- ALS = 1 MHz+…



Resection Problem & Intersection Problem

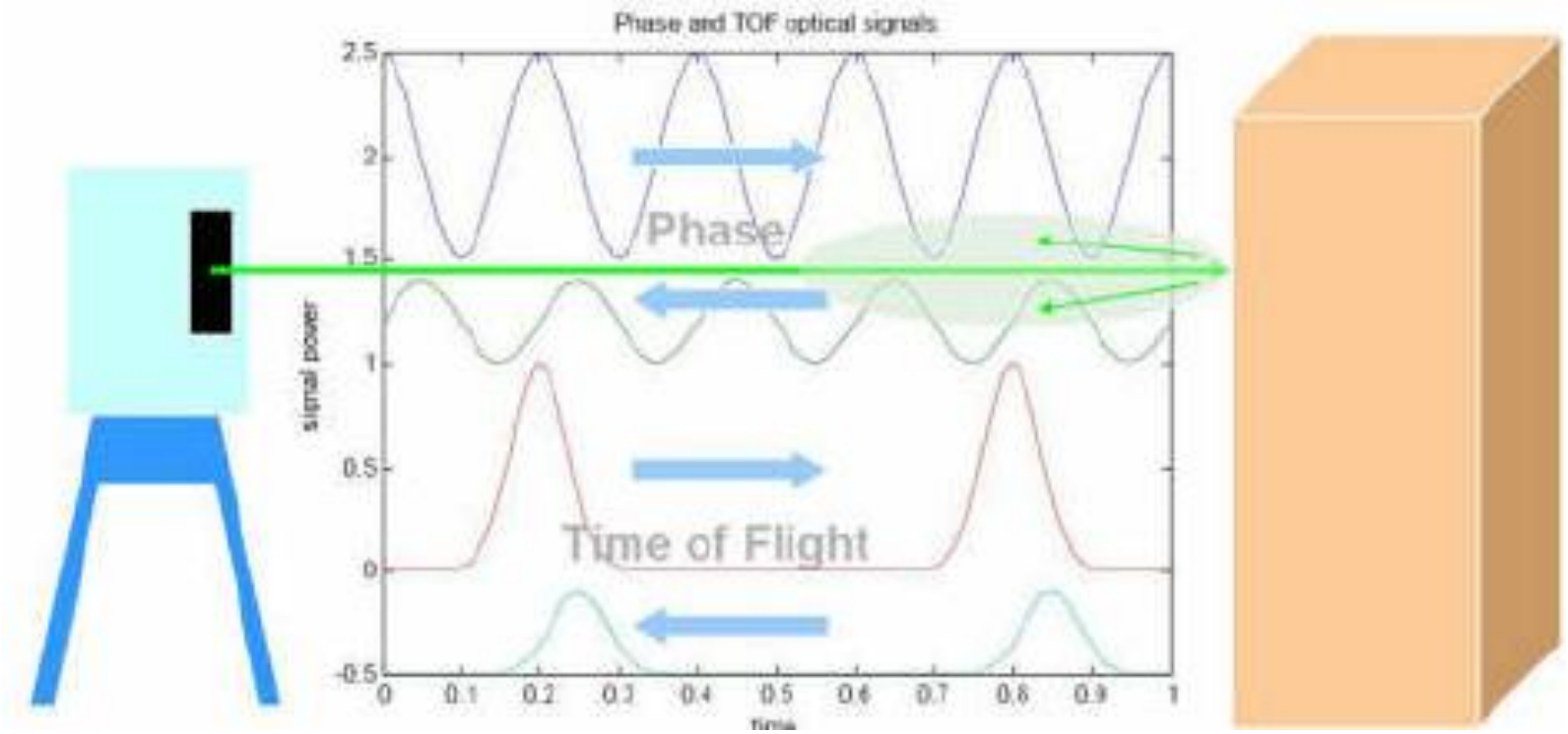




X,Y,Z : known

X,Y,Z : to be determined

Time-of-Flight (TOF) Measurement (TLS) speed of light ~ 300,000 km/second



- Phase Measurement (Total Station)

A

B

C

D

E

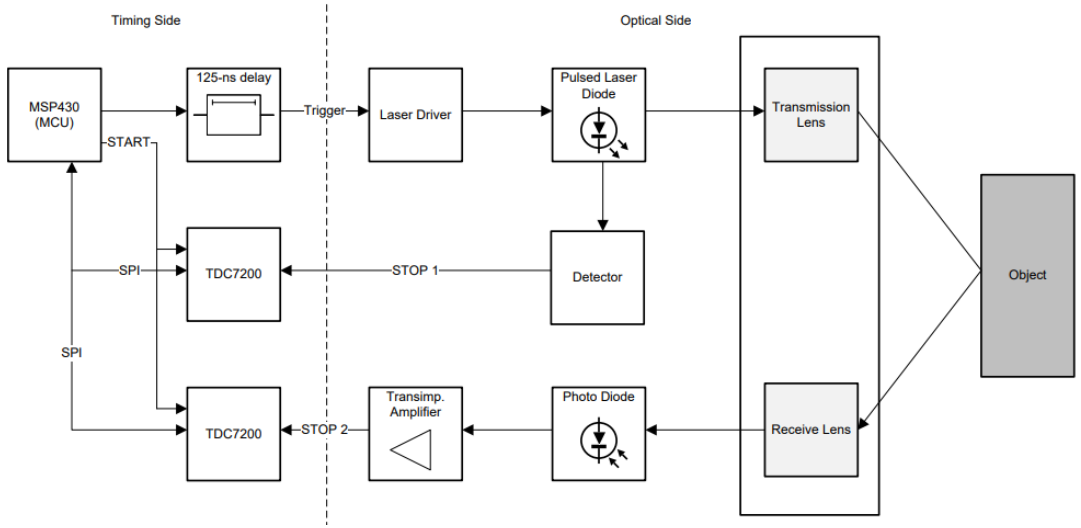
F

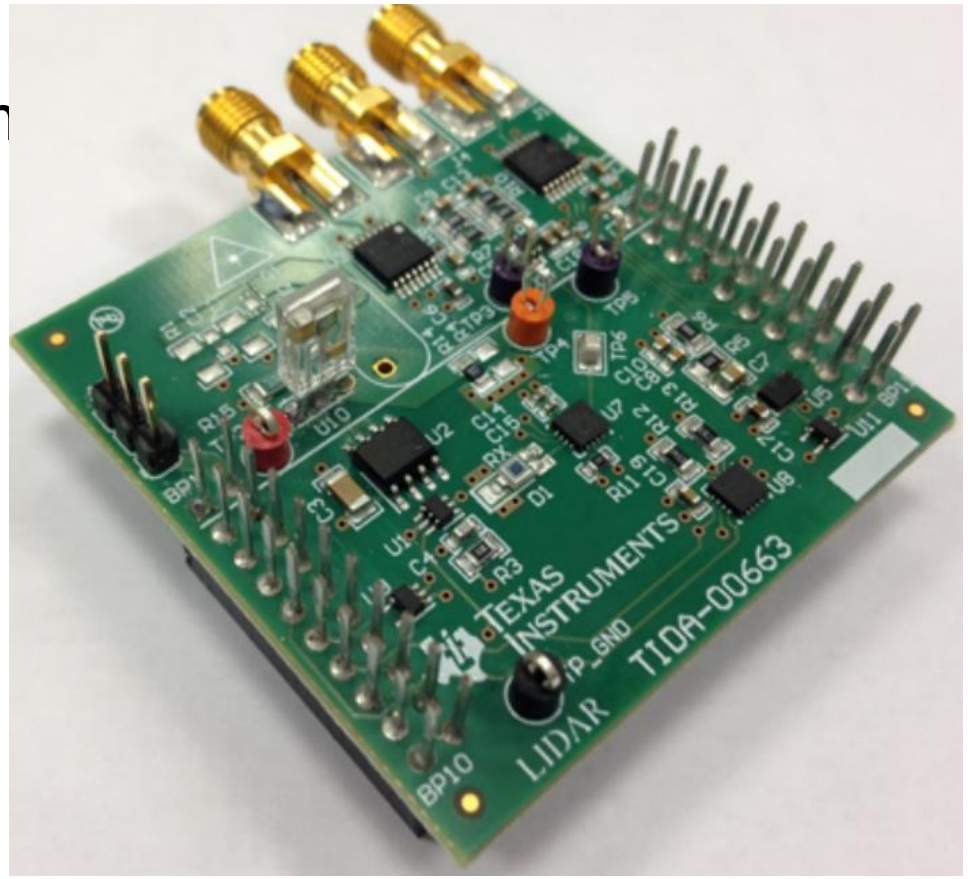
Time of Flight distance sensor

- ToF resolution 55 ps
- 55 picoseconds * the speed of light =1.6 cm

Features

- LIDAR Pulsed Time of Flight (ToF) Measurement
- Distance Resolution at System Level < 1 cm
- TDC Resolution of 1.65 cm and White Noise of 1.05-cm RMS
-





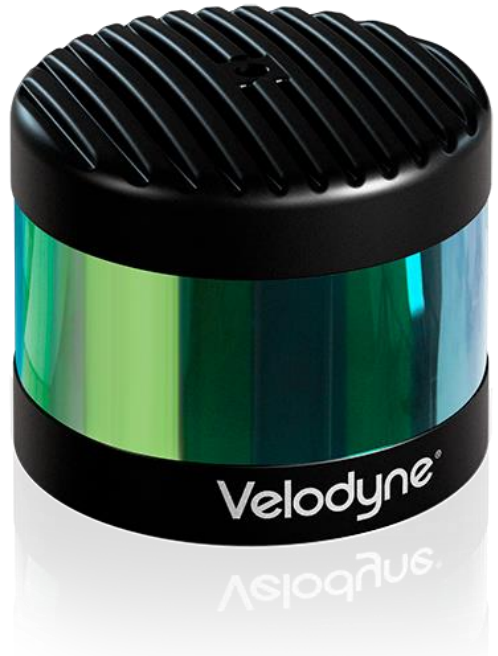
Velodyne LiDAR Opens Megafactory in San Jose for Large-Scale Production of 3D LiDAR Sensors

- Founded in 1983 by David S. Hall, Velodyne Acoustics Inc.
- 2005, HDL-64 Solid-State Hybrid LiDAR sensor
- The compact, lightweight HDL-32E sensor is available for applications including UAVs,
- the VLP-16 LiDAR Puck is a 16-channel LiDAR sensor that is both substantially smaller and dramatically less expensive than previous generation sensors.


Velodyne
Velodyne
Velodyne

New Velodyn Lidar

- ULTRA Puck™ VLP-32C
  - 32 Channel Range 200 m , dual return
  - 1.2 Million Point
  - FOV 360 x (+15/-25) deg
- VLS-128
  - 32 Channel Range 300 m , 4 returns
  - 9.6 Million Point
  - FOV 360 x (+15/-25) deg

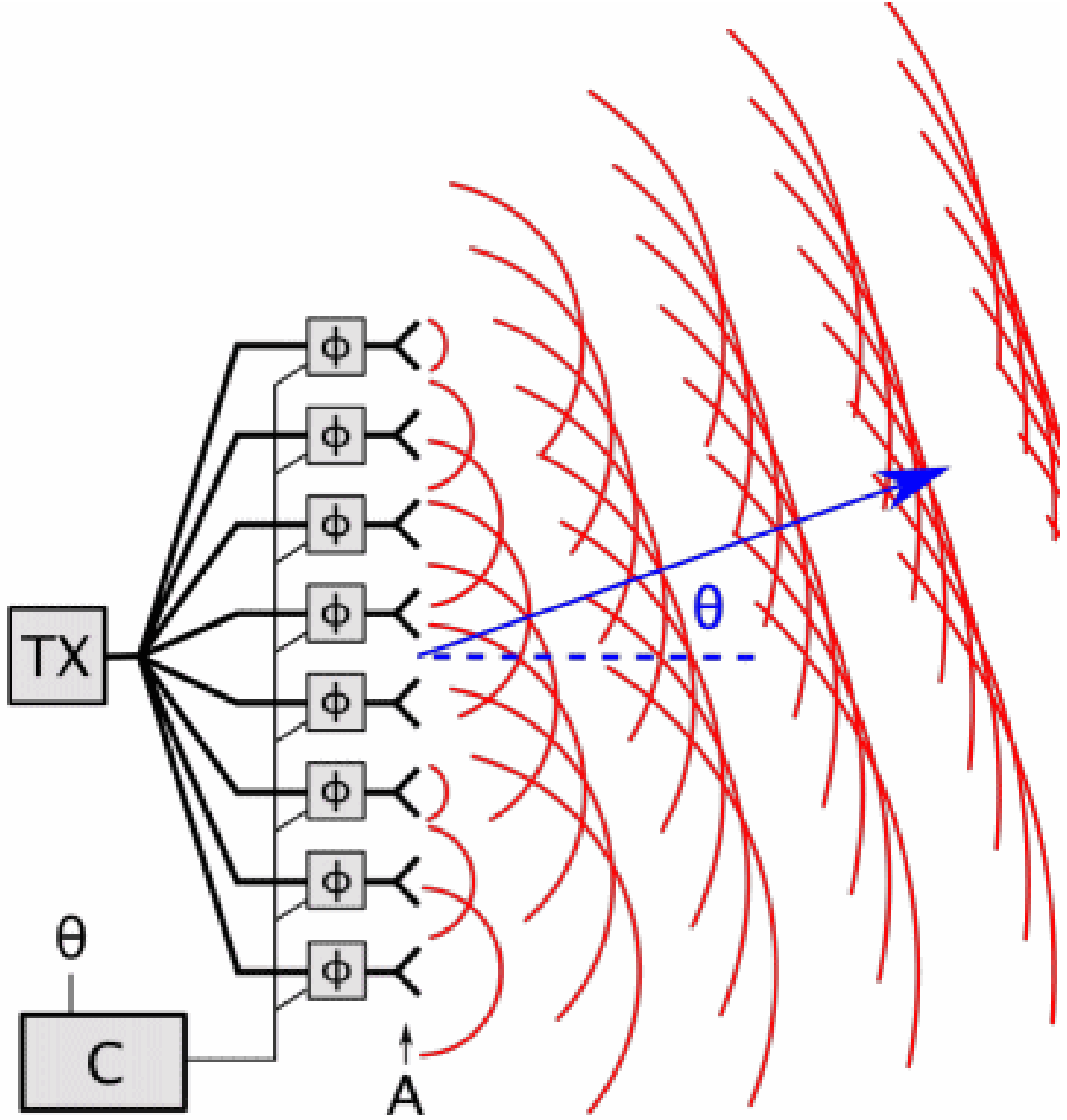


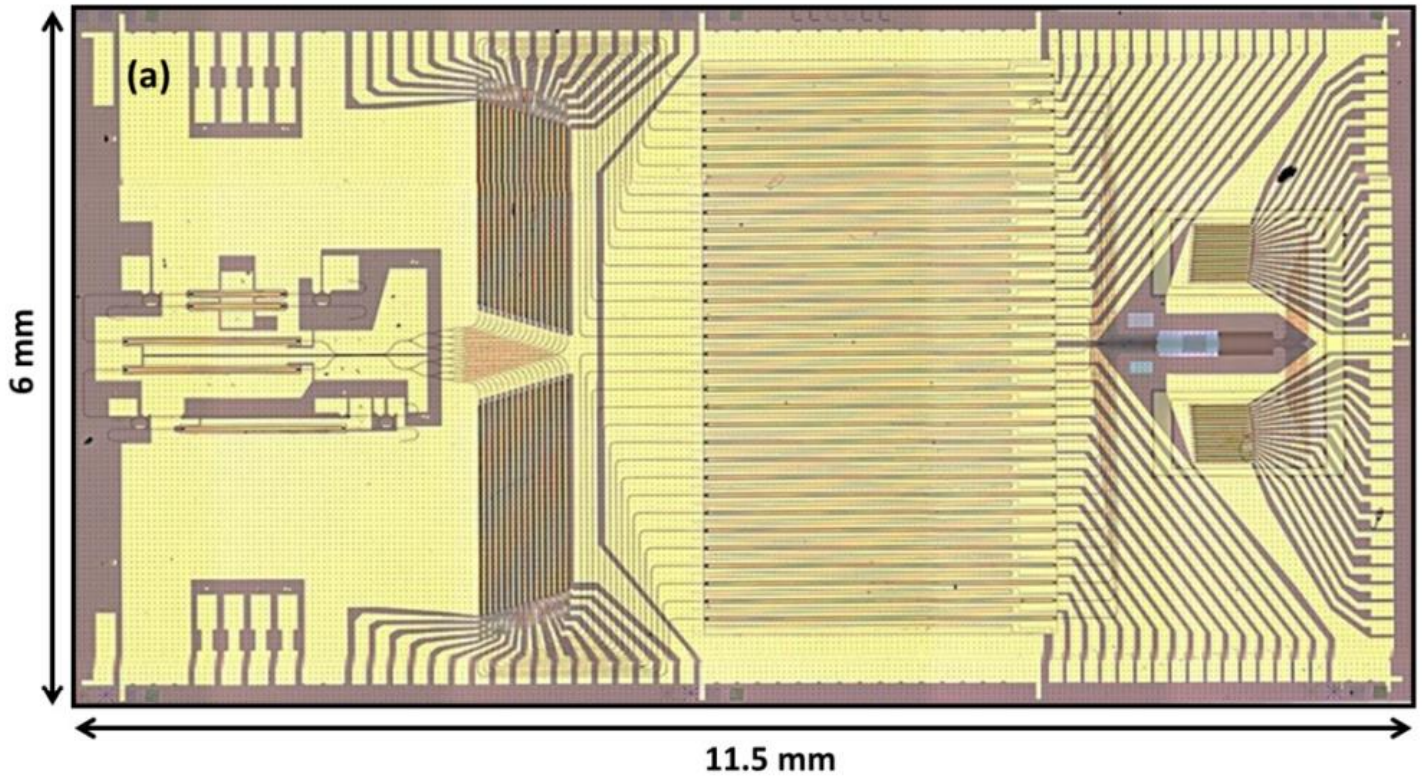
Ouster Solid-state Lidar

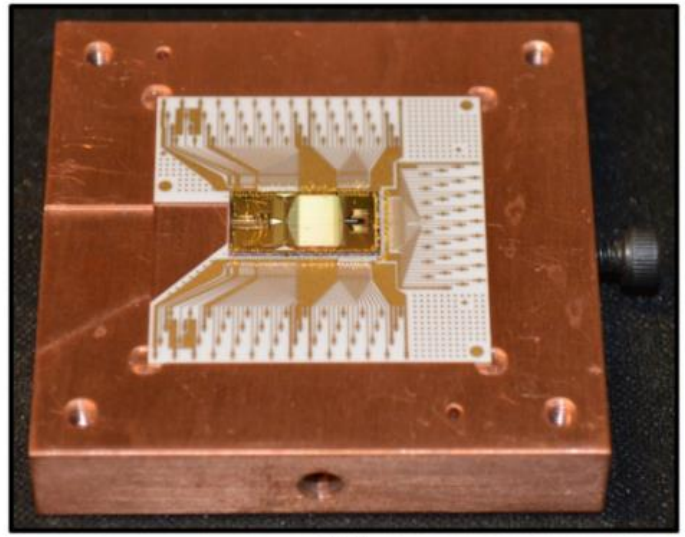
- 3.5 k USD 16 channel and
- OS-1 12 k USD 64 channel
- Range 120 m (80%)
- Range 50 m (10%)
- Precision 3 cm avg.
- Rotation rate 10-20 Hz
- 1.3 M.Pnt per sec.

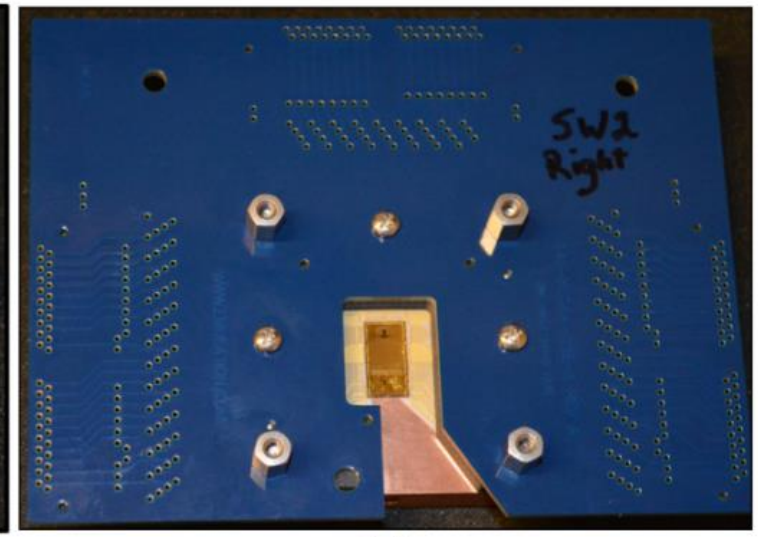
$24,000

Solid-state Lidar

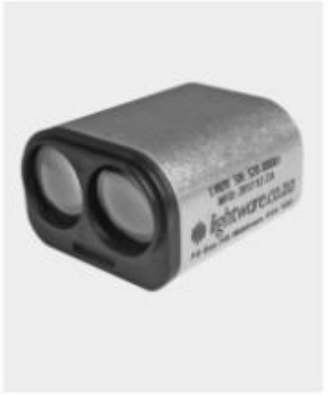



(a)
6 mm
11.5 mm




SW1
Right

LightWare Lidar / Range Finder



LW20/C (100 m)
$319.00 USD

SF11/C (120 m)
$249.00 USD

SF11/B (50 m)
$249.00 USD

SF40/C (100 m)
$999.00 USD

SF20/C (100 m)
$299.00 USD

SF30/C (100 m)
$399.00 USD

LW20/B (50 m)
$299.00 USD

SF20/B (50 m)
$279.00 USD

SF30/B (50 m)
$349.00 USD

LW20/SER/X (100 m)
$199.00 USD

Simultaneous localization and mapping (SLAM)

- Given a series of sensor observations t, the SLAM problem is to compute an estimate of the agent's location and a map of the environment. All quantities are usually probabilistic, so the objective is to compute

$$P(m_t, x_t | o_{1:t})$$

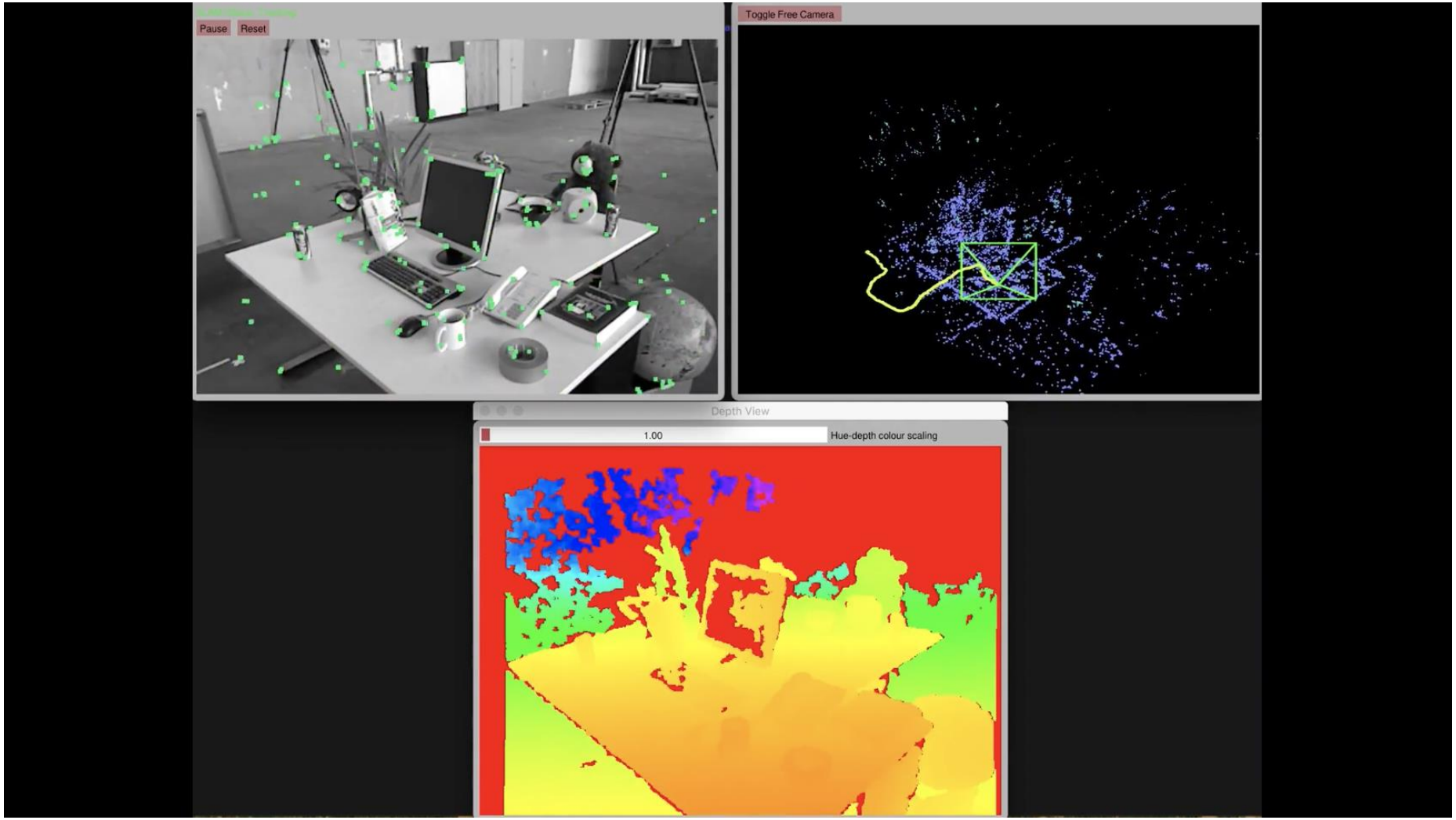
SLAM History

- A seminal work in SLAM is the research of R.C. Smith and P. Cheeseman on the representation and estimation of spatial uncertainty in 1986.[21][22]
- Other pioneering work in this field was conducted by the research group of Hugh F. Durrant-Whyte in the early 1990s.[23]
- The self-driving STANLEY and JUNIOR cars, led by Sebastian Thrun, won the DARPA Grand Challenge and came second in the DARPA Urban Challenge in the 2000s,
- Self-driving cars by Google and others have now received licenses to drive on public roads in some US states.

SLAM Methodologies

- EKF SLAM
- FastSLAM 1.0
- FastSLAM 2.0
- L-SLAM[1] (Matlab code)
- GraphSLAM
- Occupancy Grid SLAM[2]
- DP-SLAM
- Parallel Tracking and Mapping (PTAM)[3]
- OpenVSLAM
  - Parallel Tracking and Mapping (PTAM)[3]
  - LSD-SLAM[4] (available as open-source)
  - S-PTAM[5] (available as open-source)
  - ORB-SLAM[6] (available as open-source)
  - ORB-SLAM2 (available as open-source)
  - MonoSLAM
  - CoSLAM[7]
  - SeqSlam[8]
  - iSAM (Incremental Smoothing and Mapping)[9]

Surface-from-Motion (SfM) SLAM



OpenSLAM

Give your algorithm to the community

What is OpenSLAM.org?

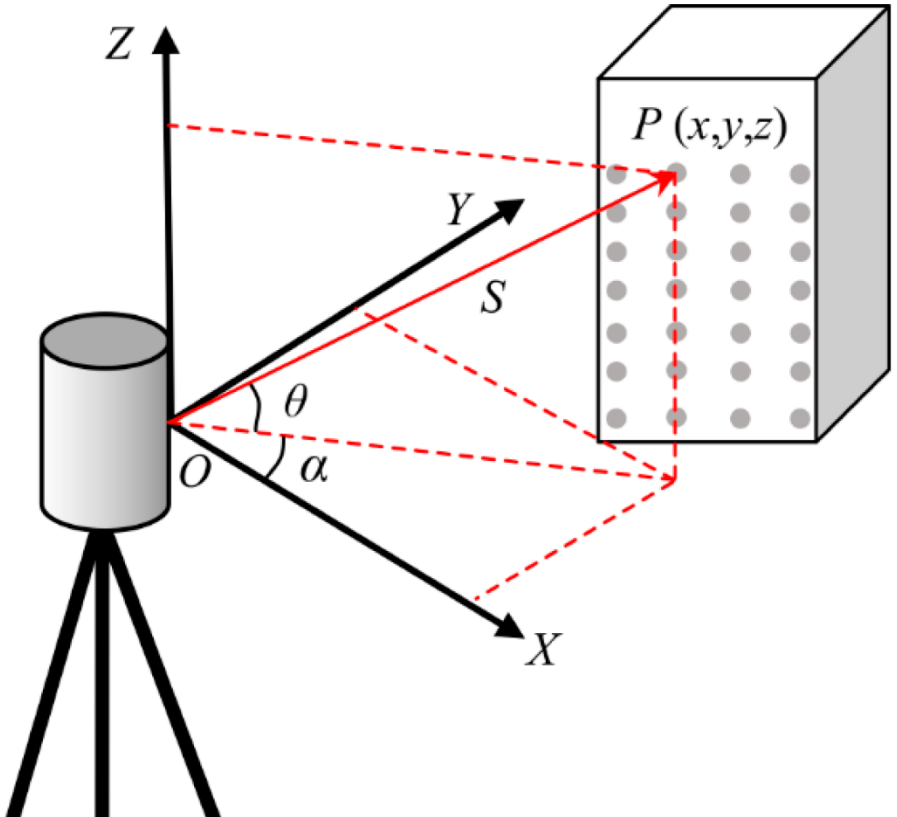
The simultaneous localization and mapping (SLAM) problem has been intensively studied in the robotics community in the past. Different techniques have been proposed but only a few of them are available as implementations to the community. The goal of OpenSLAM.org is to provide a platform for SLAM researchers which gives them the possibility to publish their algorithms. OpenSLAM.org was established in 2006 and in 2018, it has been moved to github.

The OpenSLAM Team
Cyrill Stachniss, Udo Frese, Giorgio Grisetti

Terrestrial Laser Scanner

หลักการของเลเซอร์สแกนเนอร์ตั้งพื้น (TLS)

- ใช้การวัดระยะทางด้วย Light Detection and Ranging (LiDAR)
- ใช้หลักการวัดระยะทางจากที่ตั้งไปยังวัตถุ ด้วยความถี่สูง 50 kHz … 1 MHz
- มีปริซึมหมุนรอบแนวดิ่ง หักเหลำแสงเลเซอร์กระจายในแนวดิ่ง
- ด้วยความเร็ว 10 … 10,000 deg/sec
- เครื่องมือหมุนในแนวราบด้วยความเร็ว 10…60 deg / sec
- ข้อมูลที่บันทึกได้ คือ Point Cloud (X,Y,Z)
- และอาจมีข้อมูลเพิ่มเติม
  - RGB, Intensity, GPS time, n-returns



Leica Laser Scanner

- BLK360
  - 360,000 laser scan pts/se
  - Range 60 m
  - 3D accuracy : 6mm@10m / 7mm@20m
- **Leica RTC360 3D Laser Scanner**
  - Speed : 2 min full dome
  - Resolution : 6mm@120m
  - FOV 360 x 300 deg.
  - Range: 130 m
  - Density: 2 mil.pnts./second

Leica ScanStation P50/P40/P30

Leica ScanStation Comparison

Which 3D laser scanner is right for me?

	ScanStation P50	ScanStation P40	ScanStation P30
DISTANCE MEASUREMENT SYSTEM			
Maximum range	> 1 km	270 m	120 m
Maximum scan rate	1 Mio Pts/sec	1 Mio Pts/sec	1 Mio Pts/sec
Selectable sensitivity levels	✔	✔	✗
Resolution settings	User definable	User definable	0.8 mm to 50 mm at 10 m
Laser class	1	1	1

Trimble 3D Laser Scanner

- Trimble TX8
  - Range 120 m
  - Range Acc 2mm.
  - FOV 360 x 317 deg

Scan Parameters	Preview	Level 1	Level 2	Level 3
Max range	120 m	120 m	120 m	120 m
Scan duration (minutes)[3]	01:00	02:00	03:00	10:00
Point spacing at 10 m	15.1 mm	———	———	———
Point spacing at 30 m	———	22.6 mm	11.3 mm	5.7 mm
Point spacing at 300 m	———	———	———	———
Mirror rotating speed	60 rps	60 rps	60 rps	30 rps
Number of points	8.7 Mpts	34 Mpts	138 Mpts	555 Mpts

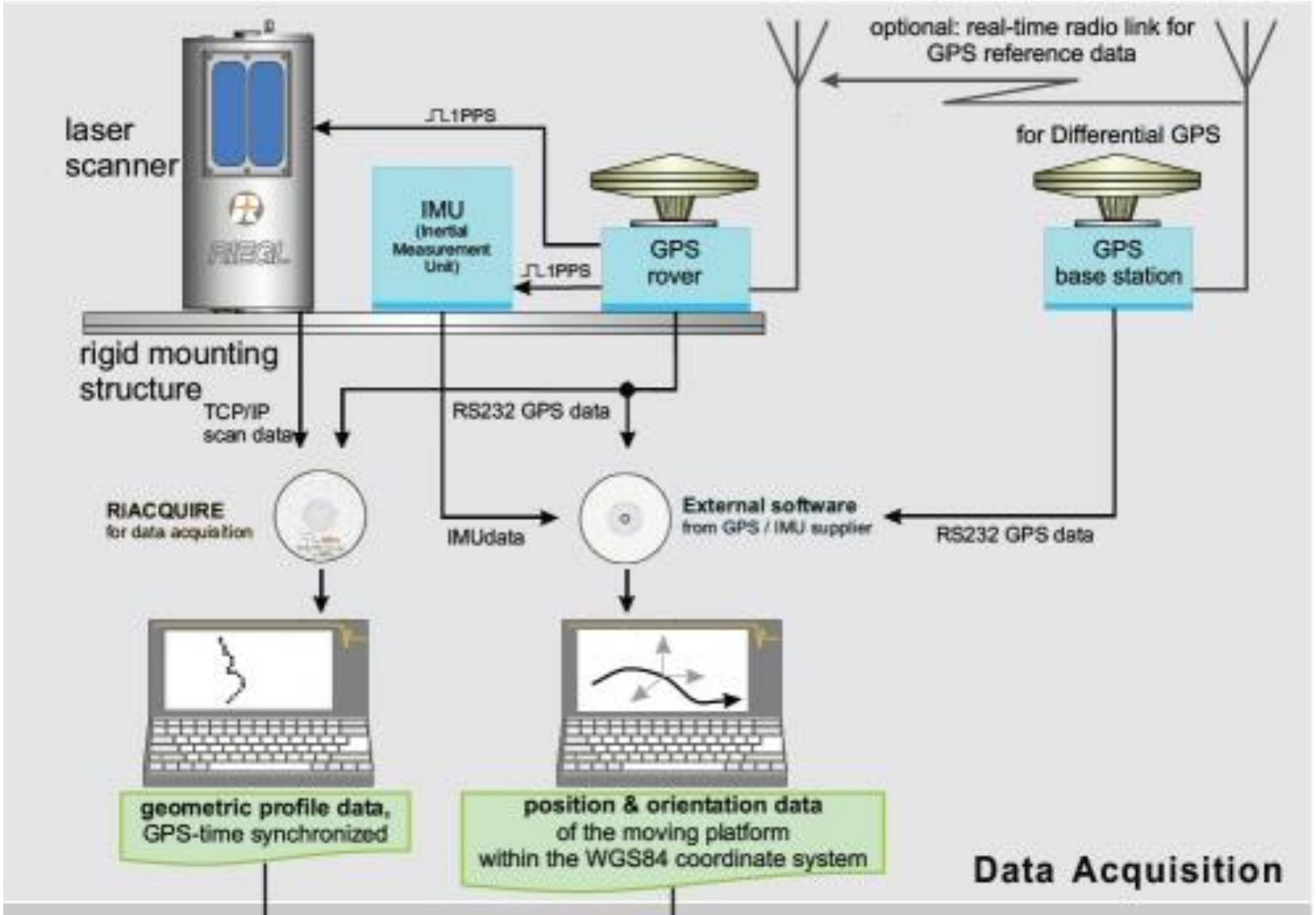
Trimble SX10

- Trimble SX10 Scanning Total Station

Scanning principle	Band scanning using rotating prism in telescope
Measurement rate	26.6 kHz
Point spacing	6.25 mm, 12.5 mm, 25 mm or 50 mm @ 50 m
Field-of-view	360° x 300°
Coarse scan; full dome - 360° x 300° (horizontal angle x vertical angle) Density: 1 mrad, 50 mm spacing @ 50 m	Scan time: 12 minutes
Standard scan; area scan - 90° x 45° (horizontal angle x vertical angle) Density: 0.5 mrad, 25 mm spacing @ 50 m	Scan time: 6 minutes

Mobile Laser Scanning

Mobile Laser Scan System



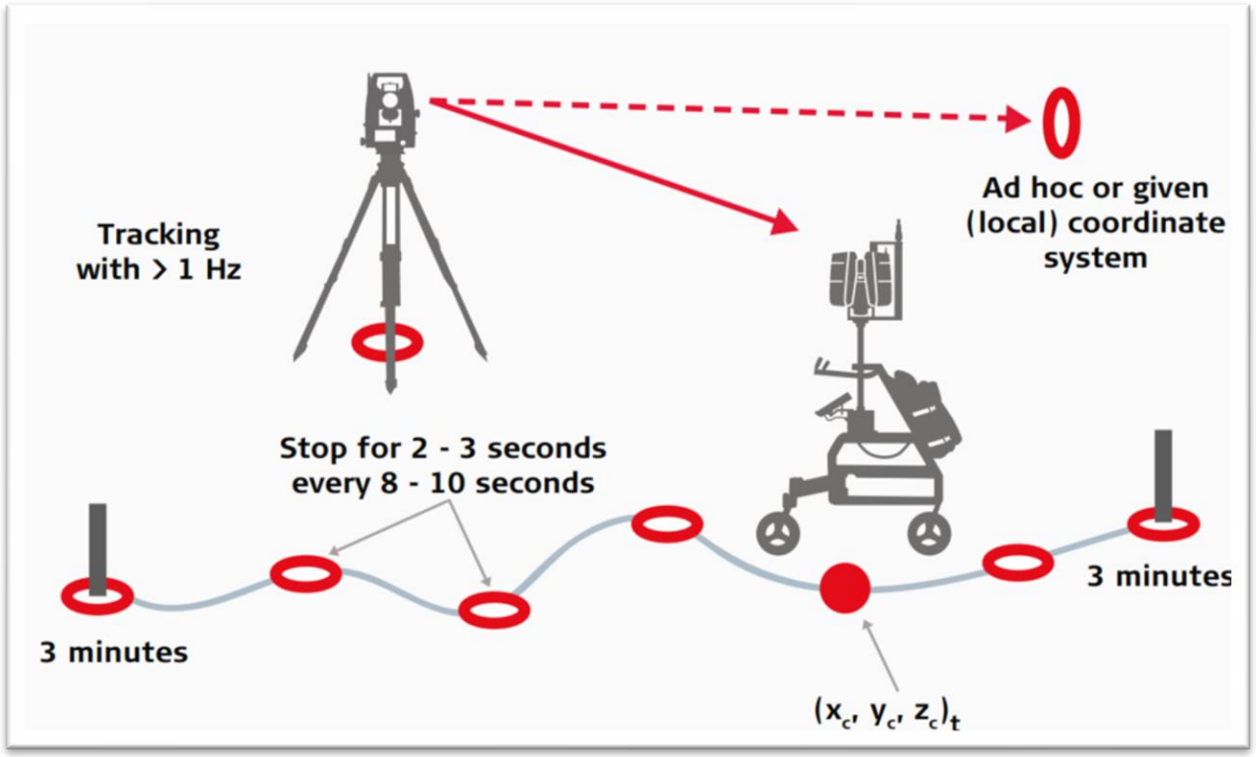
Leica ProScan

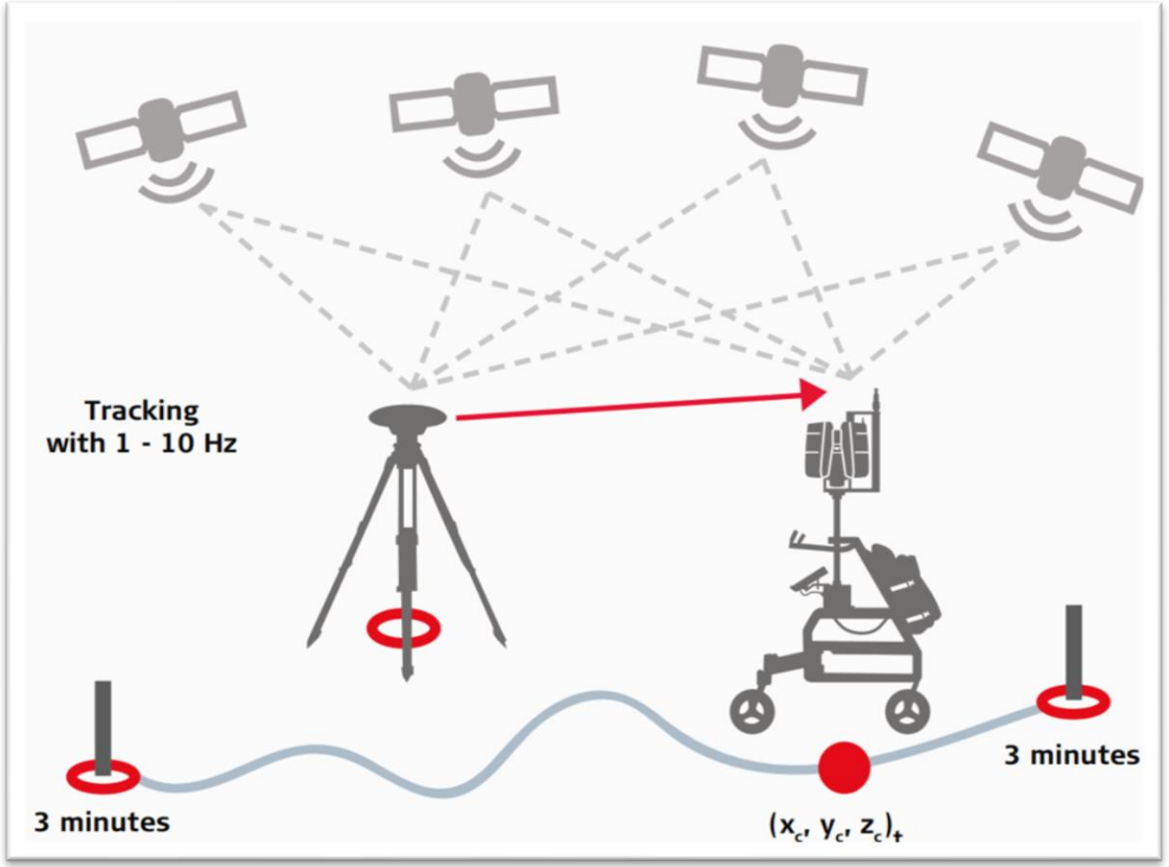
- G-Series (GNSS)
- Hor.acc : 20-30 mm
- Ver.acc : 30-50 mm

- T-Series (TPS)
- Hor.acc : 10-20 mm
- Ver.acc : 5-10 mm

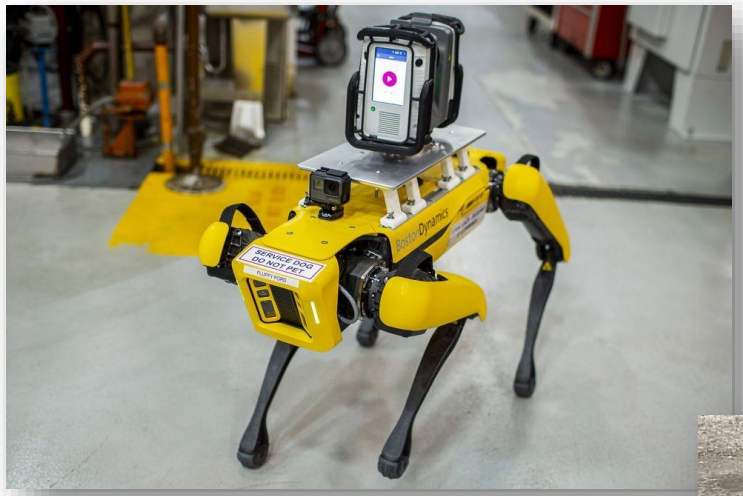
- Roll-Pitch acc: 0.0025°
- Heaing acc: 0.0075°

ScanPro Tracking Process





TLS on SpotMini (BostonDynamics)



Mobile Mapping System

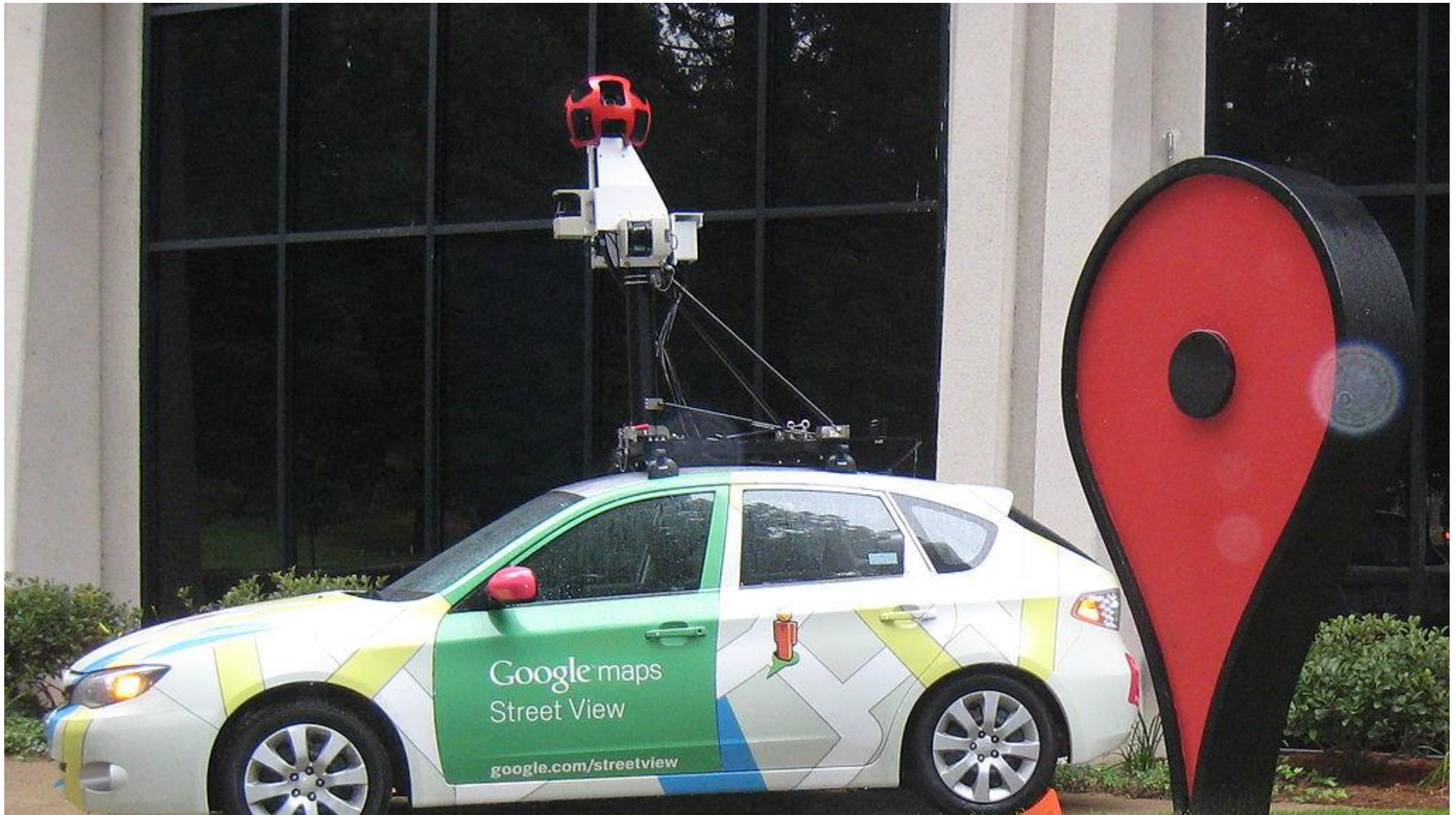
Omni Spherical Camera Ladybug 5

- Now with FLIR company
- Resolution 2048 x 2464
- MegaPixel 30 MP (5MPx6)
- CMOS Sony IMX64
- Interface USB 3.1

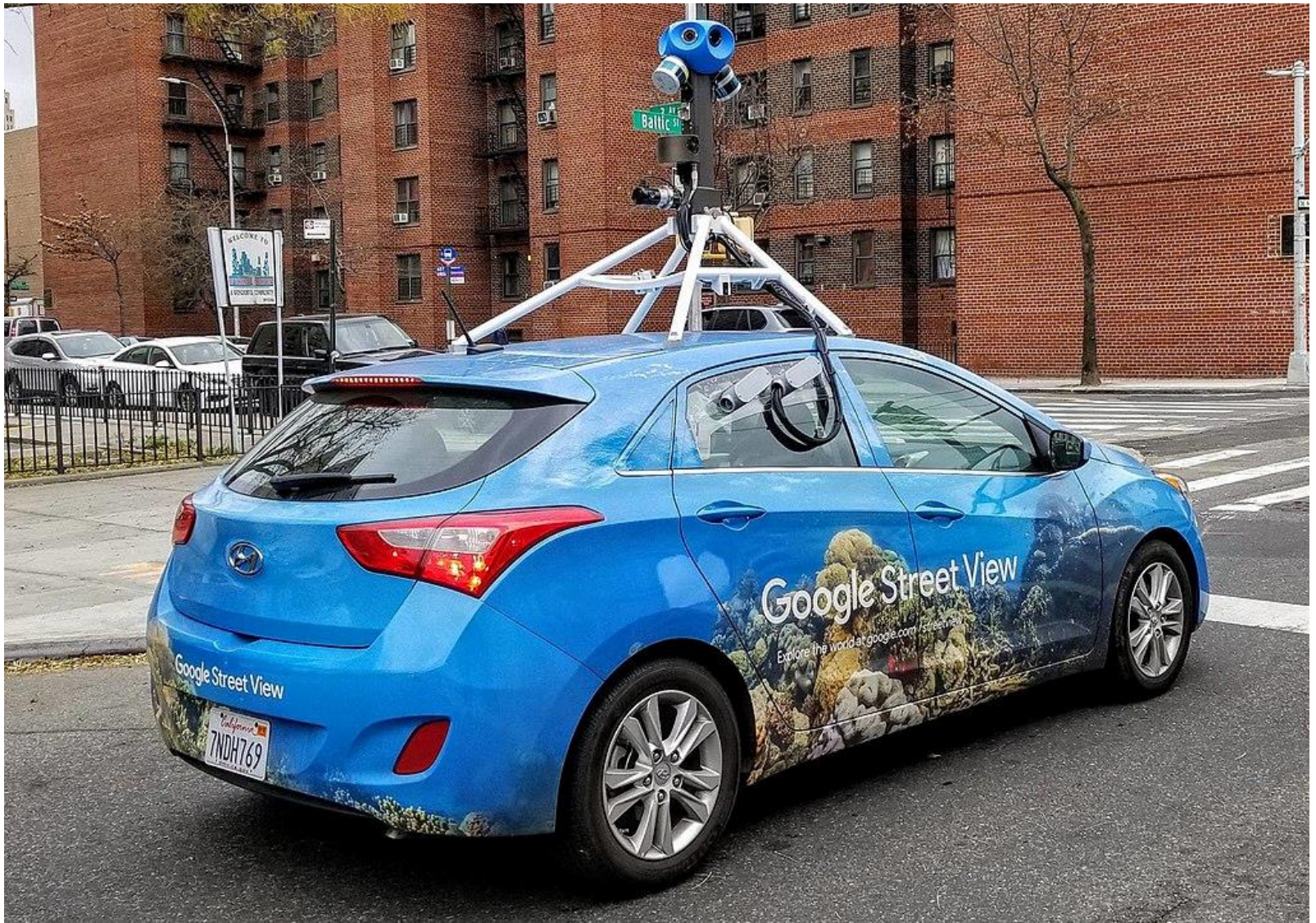
Panorama Image for multi-camera

Google Street View ：R2 Model

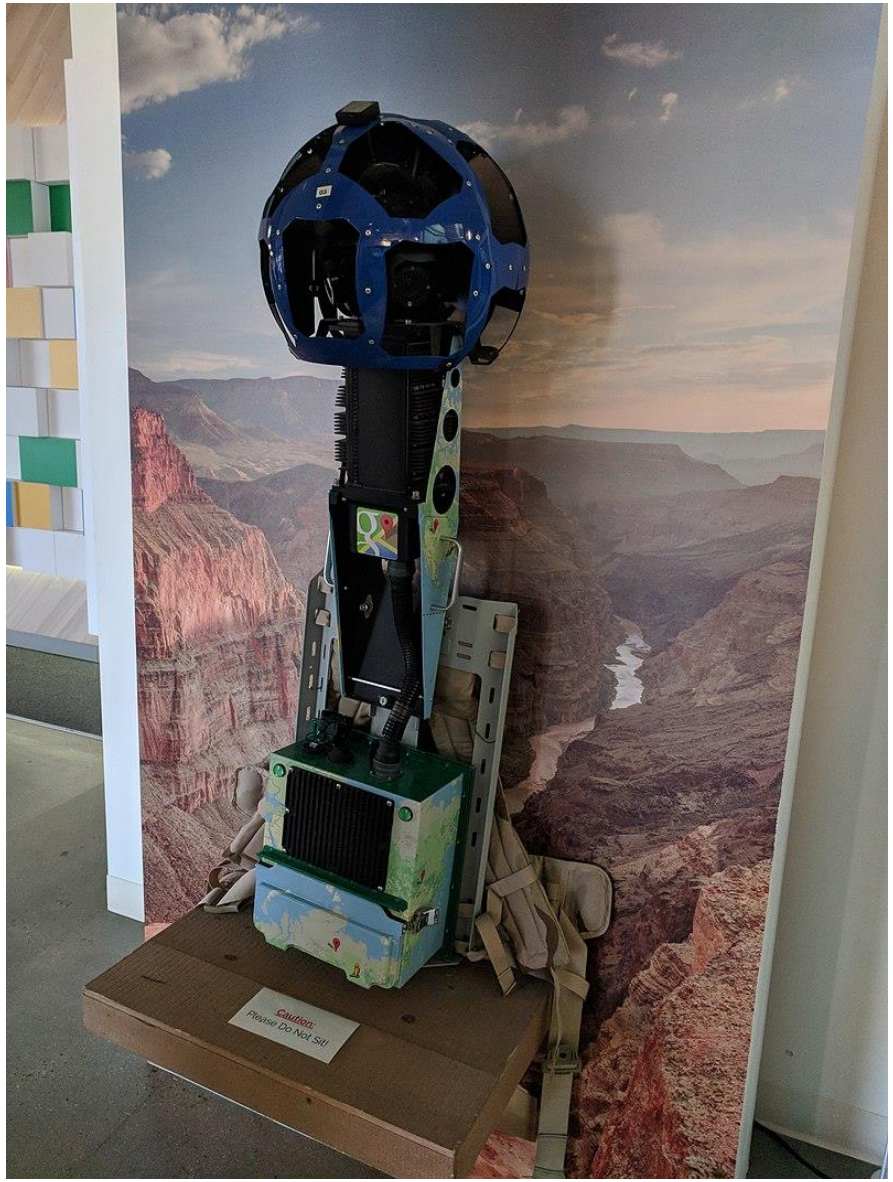
Google Street View ：R5 Model



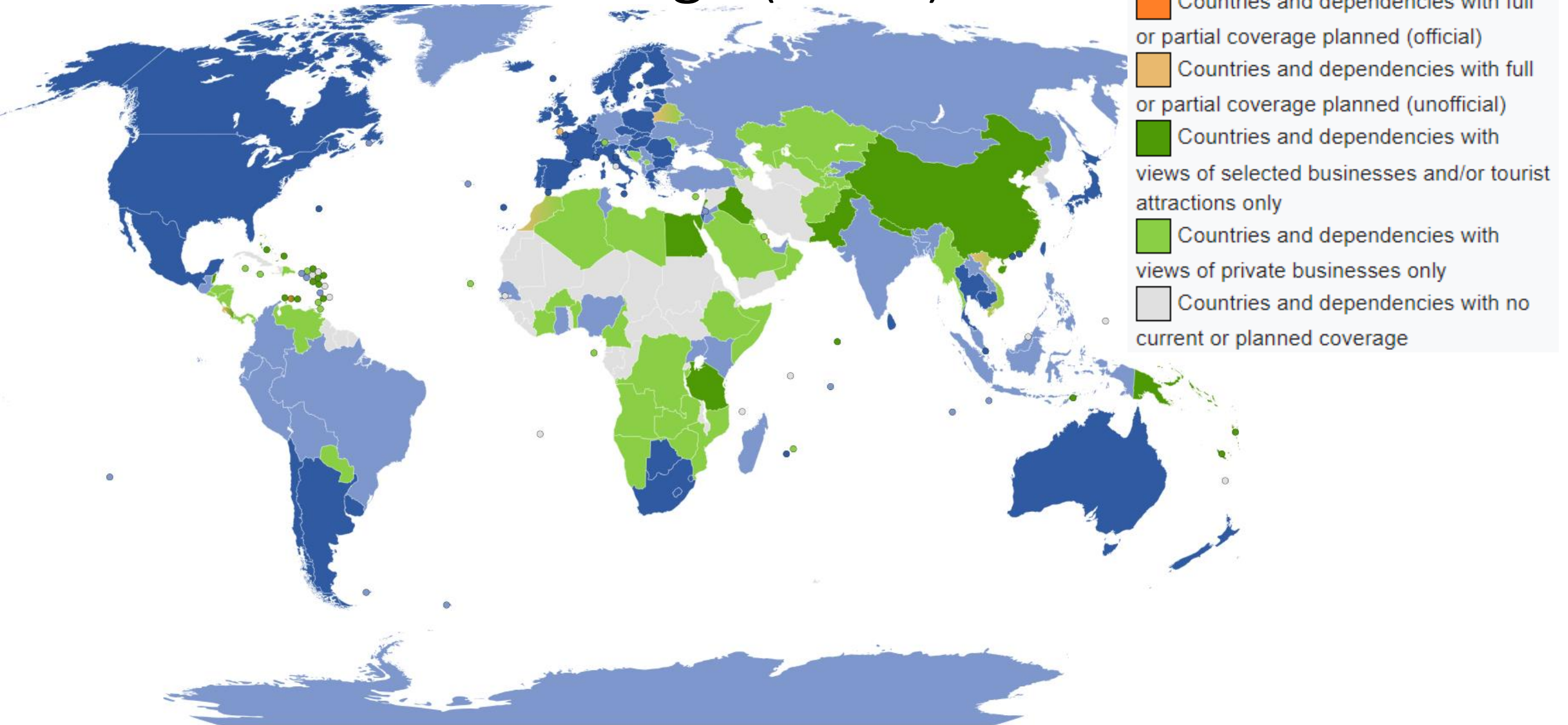
Google Street View ：2017 Model



Street View Backpack



Street View Coverage (2018)



Mappillary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Mapillary.com
Blog
Sign up
Help
About Mapillary
Manifesto
Open positions
Press
Status
Legal summary
Terms and conditions
Privacy policy
Cookies
Sign in
or
Sign up
VIOFO A119S
image by poramet for Here

Trimble MX9

LadyBug 3 / 5 / 5+

Teledyne Optech MMS

Maverick

Portable, ultra-light, multi-platform mobile solution for asset mapping

Lynx HS300

Survey-grade accuracy with a single or double, light-weight lidar/camera installation options

Teledyne Optech MMS

Lynx HS600

Premium mobile mapping solution for exceptional accuracy, and unmatched data resolution.

Lynx Cameras

Co-located, simultaneous and georeferenced imaging to enhance lidar data

TOPCON IP-S3

- 226-channel GNSS Tracking
- IMU : GYRO 1deg/hour
- Acceleration bias : 7.5 mg
- Laser Scanner : 700,000 pts/sec
- Range 100 m (70m typical)
- Acc. 50 mm at 10 m
- 10 mm on road surface
- 6 x CCD @ 8000x4000 pixels

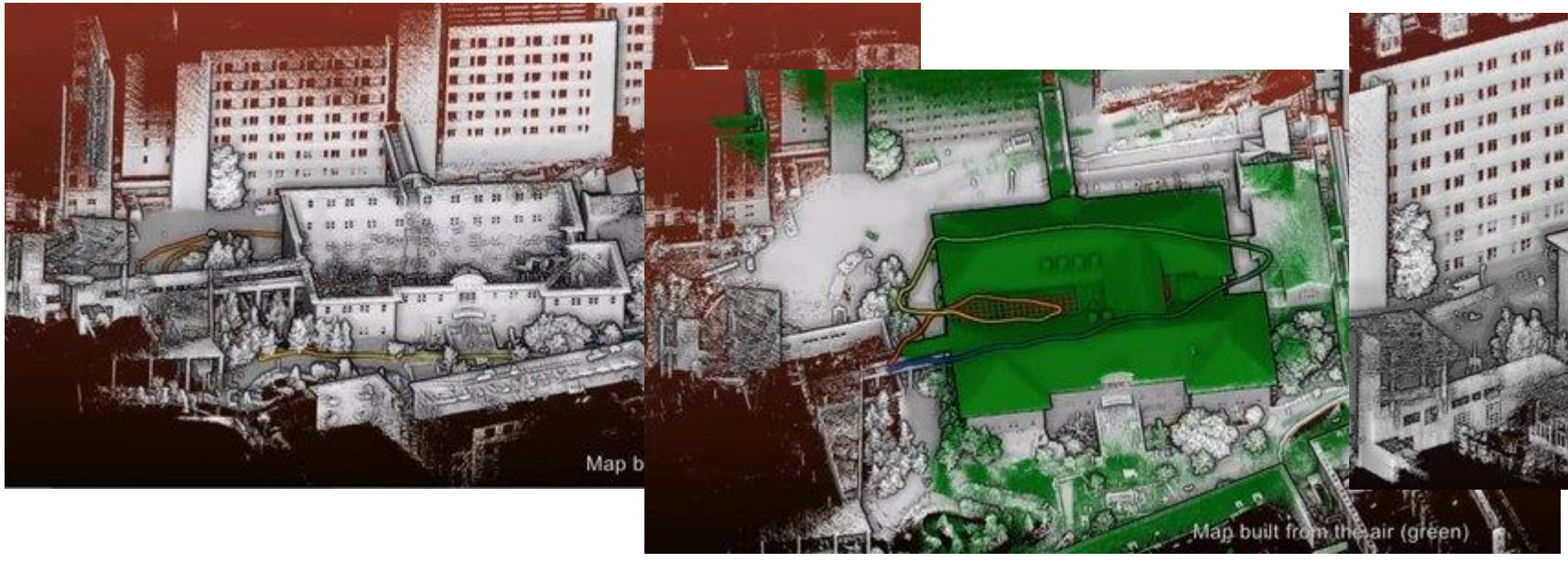
Outdoor SLAM MMS

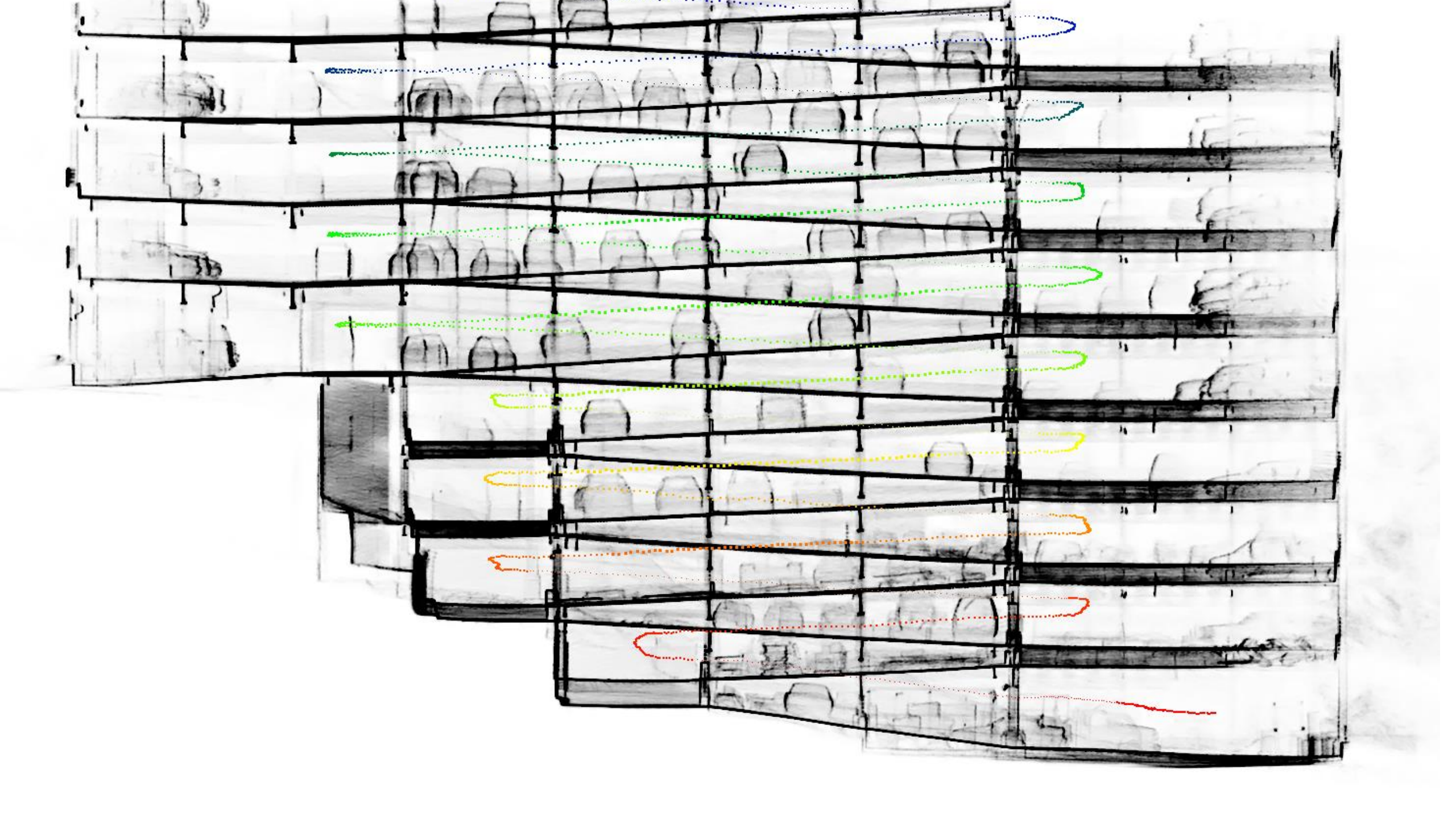
KAARTA MMS

- Pittsburg-based startup Kaarta is building hardware devices for architects and engineers to create quick scans of rooms.
- 700 (1.54lb) gram package (without lidar)
- Laser scanner: adapts to Velodyne VLP-16,
- MEMS IMU: 6DOF solid state
- i7 dual core processor
- Input: Power 12-19 VDC
- Output: HDMI, 4 USB 3.0, Thunderbolt 3, I
- Includes 9.7” iPad 32MB


Step 1: Mapping from the ground


Step 2: Mapping from the air


Map b
Map built from the air (green)
Final merged m



LiBackpack 50

- Integrating LiDAR with SLAM (simulta
  technology

HERON GEXCEL

HERON® AC-2

6 kg weight, for fast and professional 3D survey of indoor/outdoor big areas.

HERON® MS-2

11 kg weight in a rugged configuration for difficult conditions.

HERON® *COLOR*

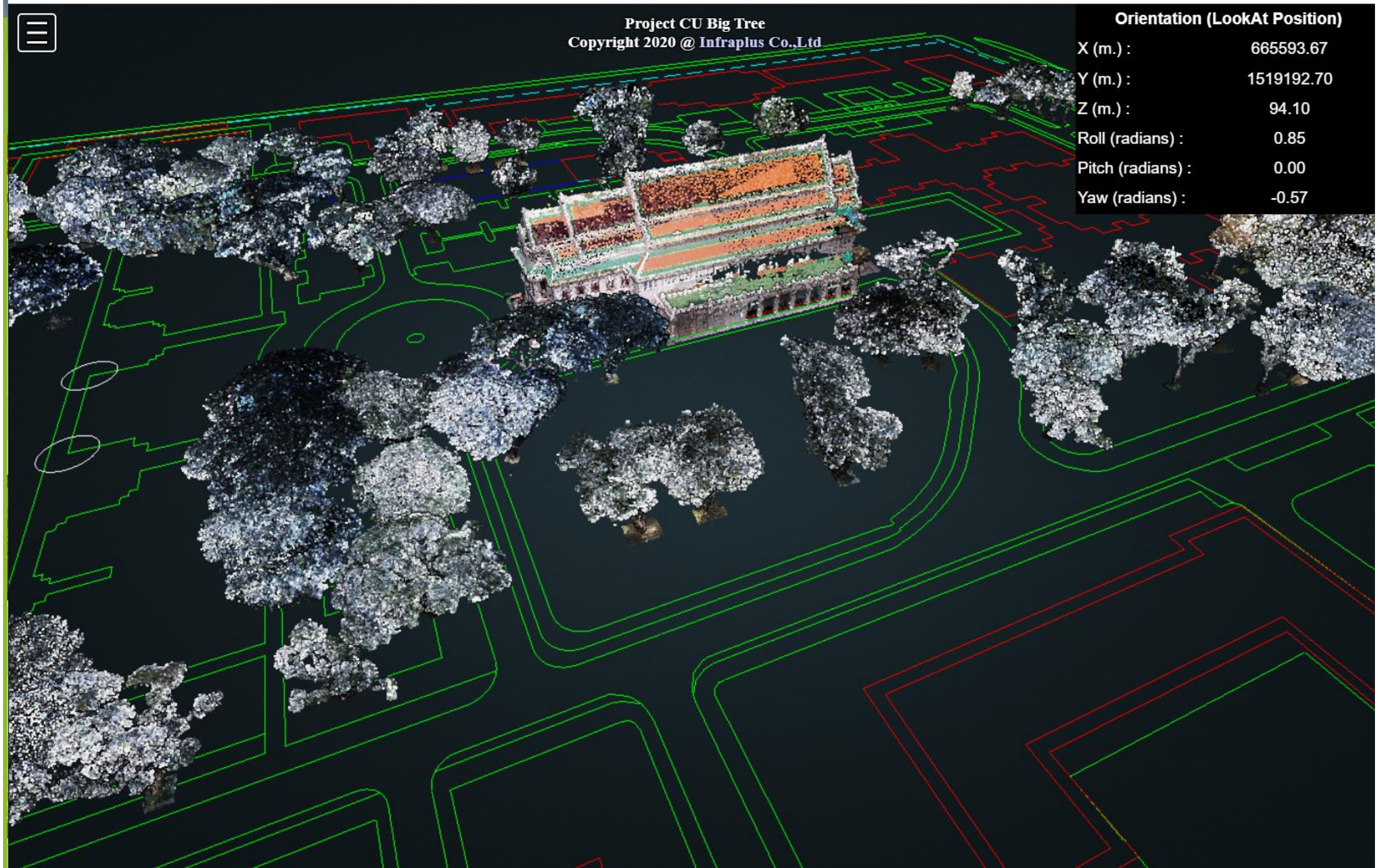
Hi-Res panoramic camera integration for facility management and more.

HERON® LITE

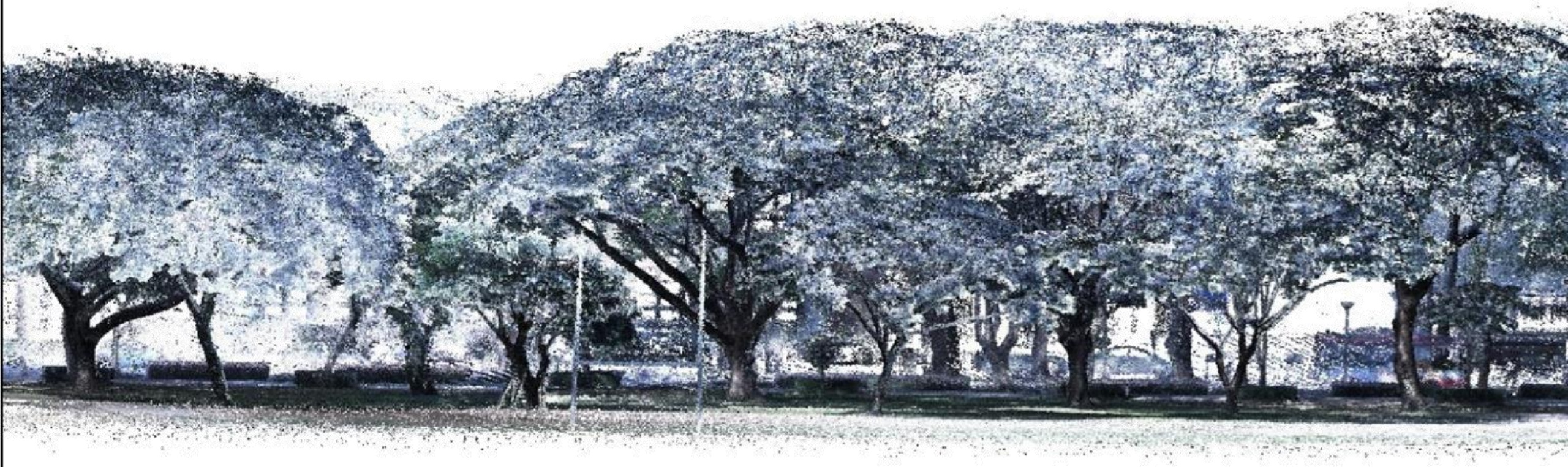
The professional, versatile and affordable handheld model.

Paracosm PX-80

- Relative Acc : 2-3 cm
- Max.frame Rate : 50 fps
- FOV: 250deg x 360deg
- PointCloud : 300,000 pts/sec
- Range : 80 m


Project CU Big Tree
Copyright 2020 @ Infraplus Co.,Ltd
Orientation (LookAt Position)
X (m.) : 665593.67
Y (m.) : 1519192.70
Z (m.) : 94.10
Roll (radians) : 0.85
Pitch (radians) : 0.00
Yaw (radians) : -0.57

โครงการสำรวจต้นไม้ด้วย Hand-held Laser Scanners



Cart-based Mobile Mapping System

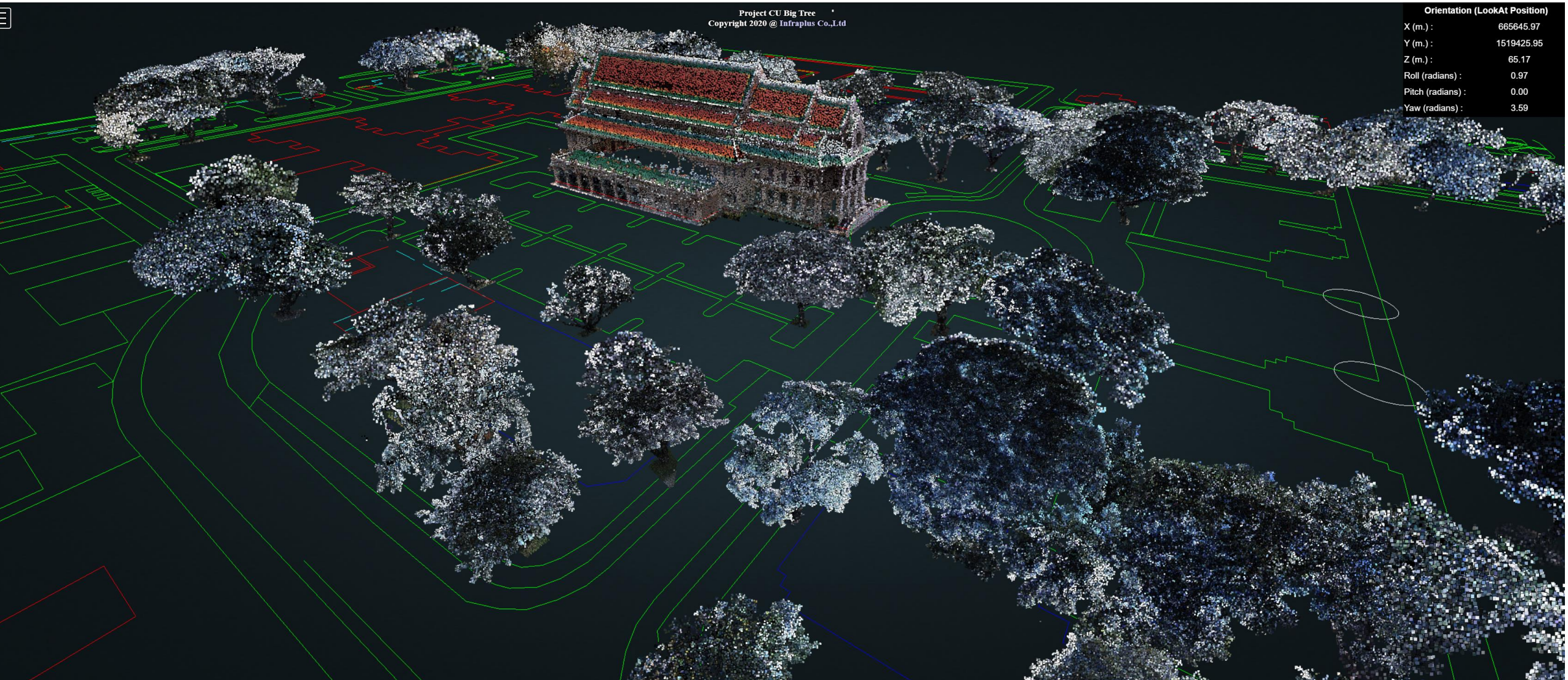
Applanix TIMMS : Indoor Mapping

- Omni Camera : Ladybug 3

การประยุกต์ใช้งาน TLS / HLS

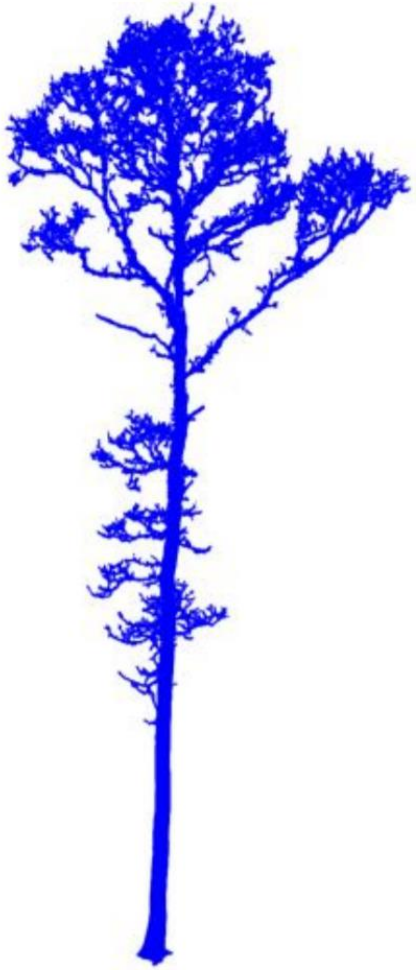
https://cu-pointcloud.web.app/main

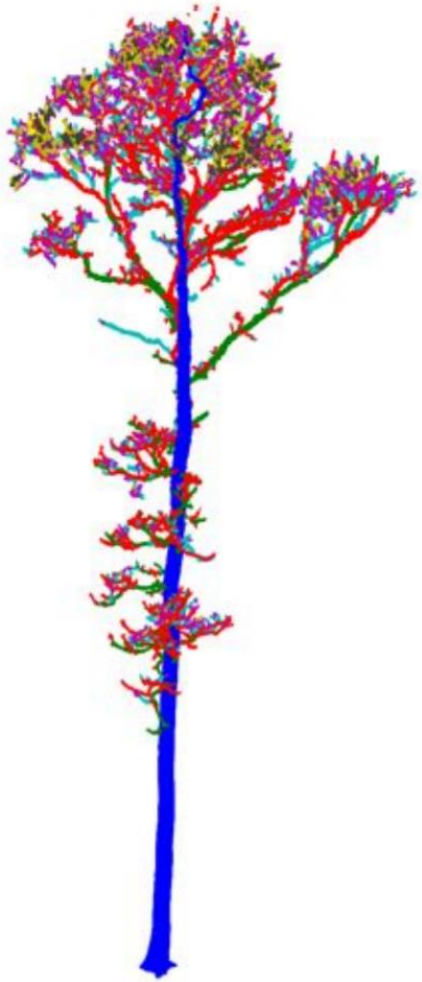
การบริหารจัดการต้นไม้ขนาดใหญ่ในมหาวิทยาลัย (CU-BigTree 2020 : TLS + HLS)

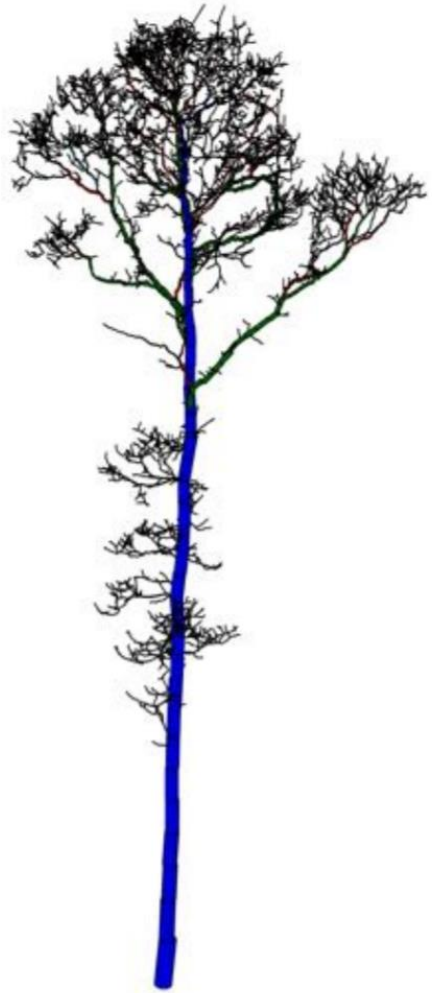


PMCU Smart City (2020-2022) UAV-P/ PC

TreeQSM: How it works?





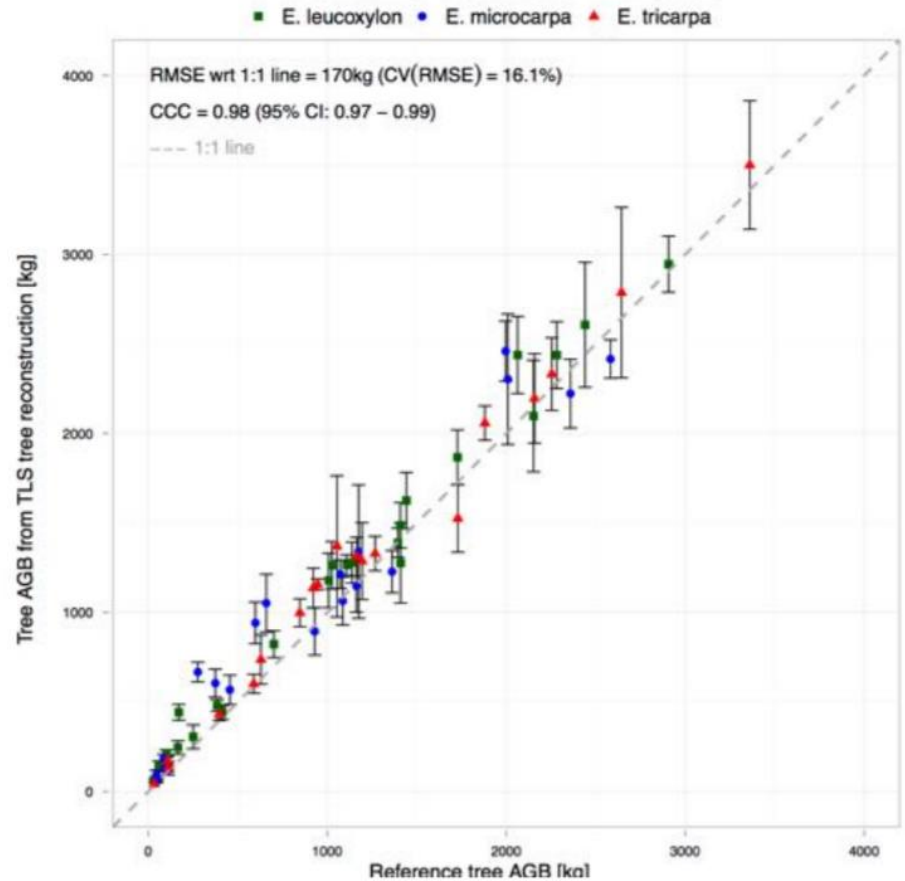


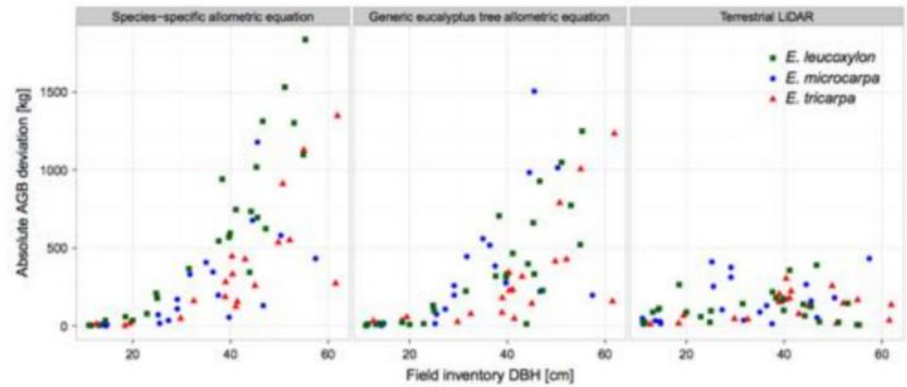
Input: point cloud, parameters —> **Branch-segmented point cloud** —> **Cylindrical QSM**

xyz-data **Topology, branching structure** **Geometry, volumes**

Above-ground volume and biomass

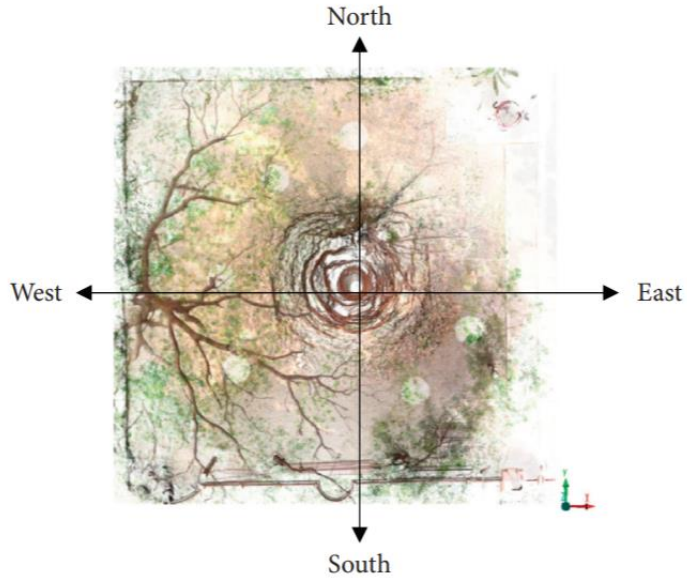
- Lidar+QSM gives volume + wood density = biomass
  - Calders et al. (2015). Non-destructive estimates of above-ground biomass using terrestrial laser scanning. Methods in Ecology and Evolution.
  - Raumonen et al. 2015: “Massive-scale tree modelling from TLS data”. ISPRS Annals.
  - Hackenberg et al. (2015). SimpleTree - an efficient open source tool to build tree models from TLS clouds. Forests.
  - Kunz et al. (2017): Comparison of wood volume estimates of young trees from terrestrial laser scan data. iForest.
  - Gonzalez de Tanago Menaca et al. 2018: ”Estimation of above-ground biomass of large tropical trees with Terrestrial LiDAR”. Methods in Ecology and Evolution.
- Generally under 10% error in biomass
- Accuracy/error independent of tree size
- For big trees allometry can give large (30-50%) errors
- This conference: Eric Casella: “Sensitivity analysis of an automated processing chain and uncertainty in the prediction of tree above ground biomass from TLS data”.
- This conference: Alvaro Lau: “Tropical tree biomass equations from terrestrial LiDAR”.





An Alternative Method for Long-Term Monitoring of Thai Historic Pagodas Based on Terrestrial Laser Scanning Data:

- A Case Study of Wat Krachee in Ayutthaya
- Peerasit Mahasuwanchai ,1 Chainarong Athisakul ,1 Phasu Sairuamyat ,1 Weerachart Tangchirapat ,1 Sutat Leelataviwat ,1 and Somchai Chucheepsakul 1



(a)

(b)

(c)

(d)

(e)

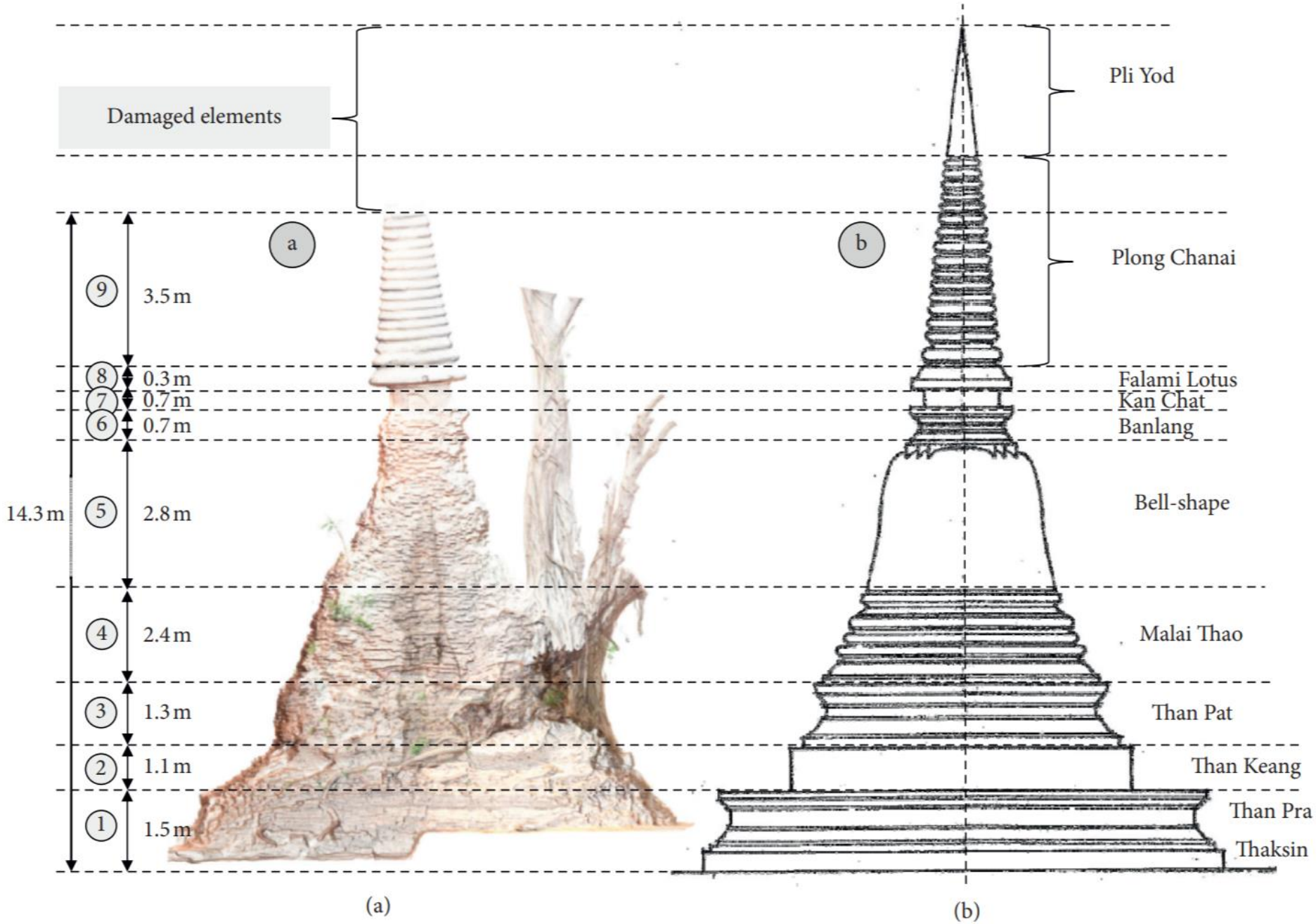


FIGURE 16: The comparison elements of the Wat Krachee pagoda. (a) 3D point cloud model. (b) Assumption model [29].

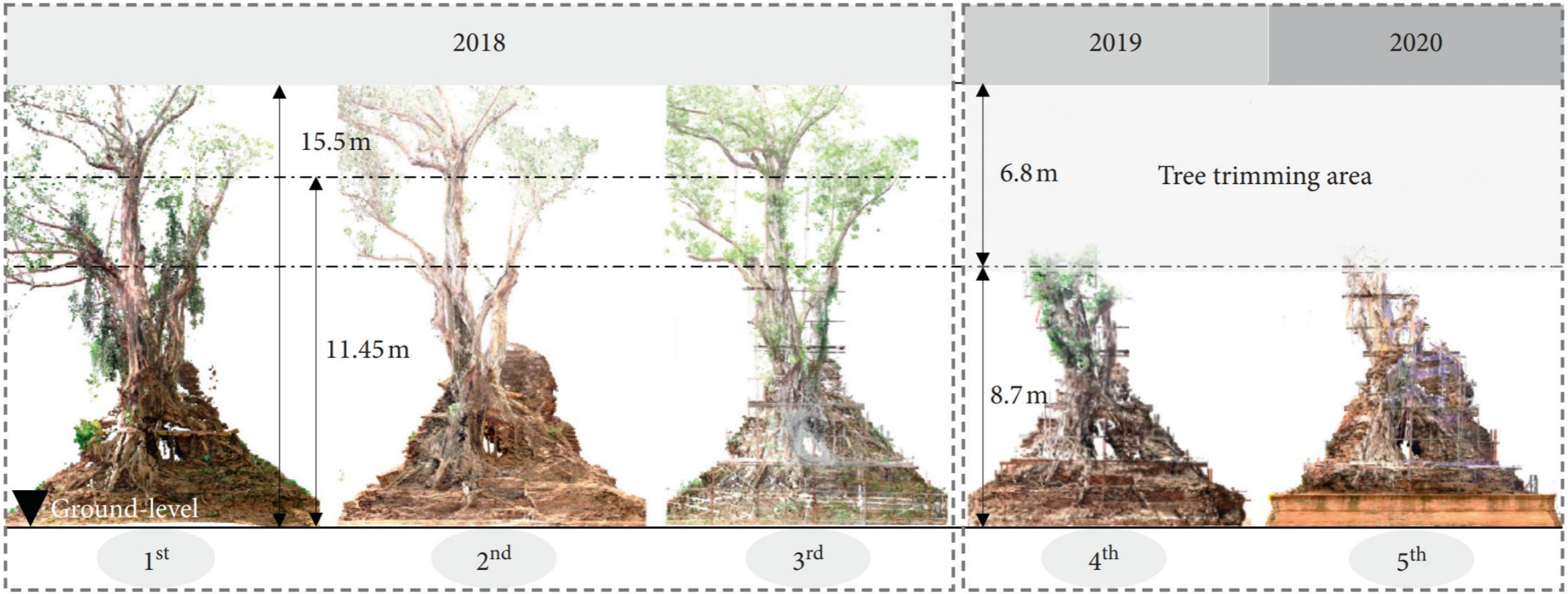
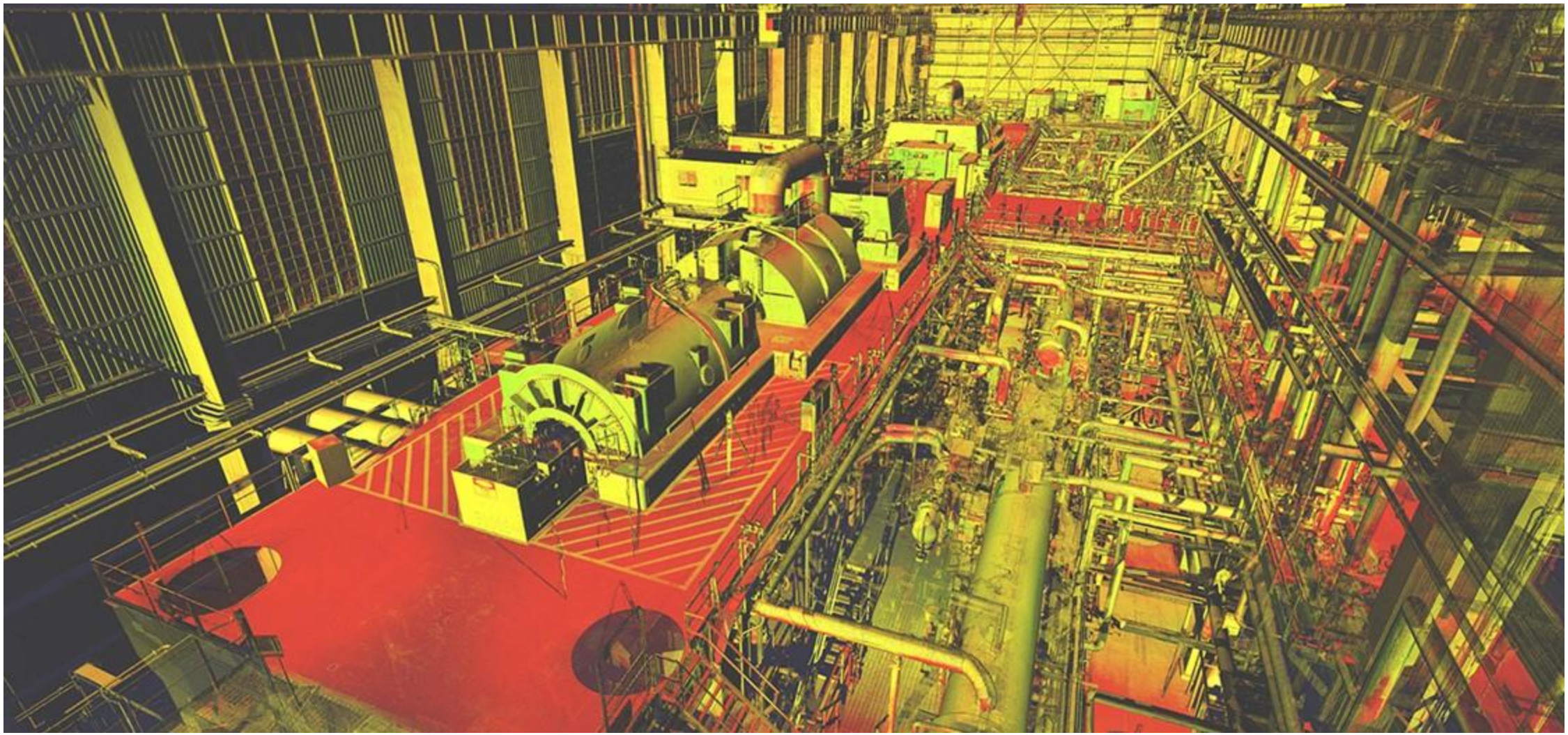


FIGURE 20: The changing of the trees surrounding the Wat Krachee.


z
y
x




QK4 Land Survey Department

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