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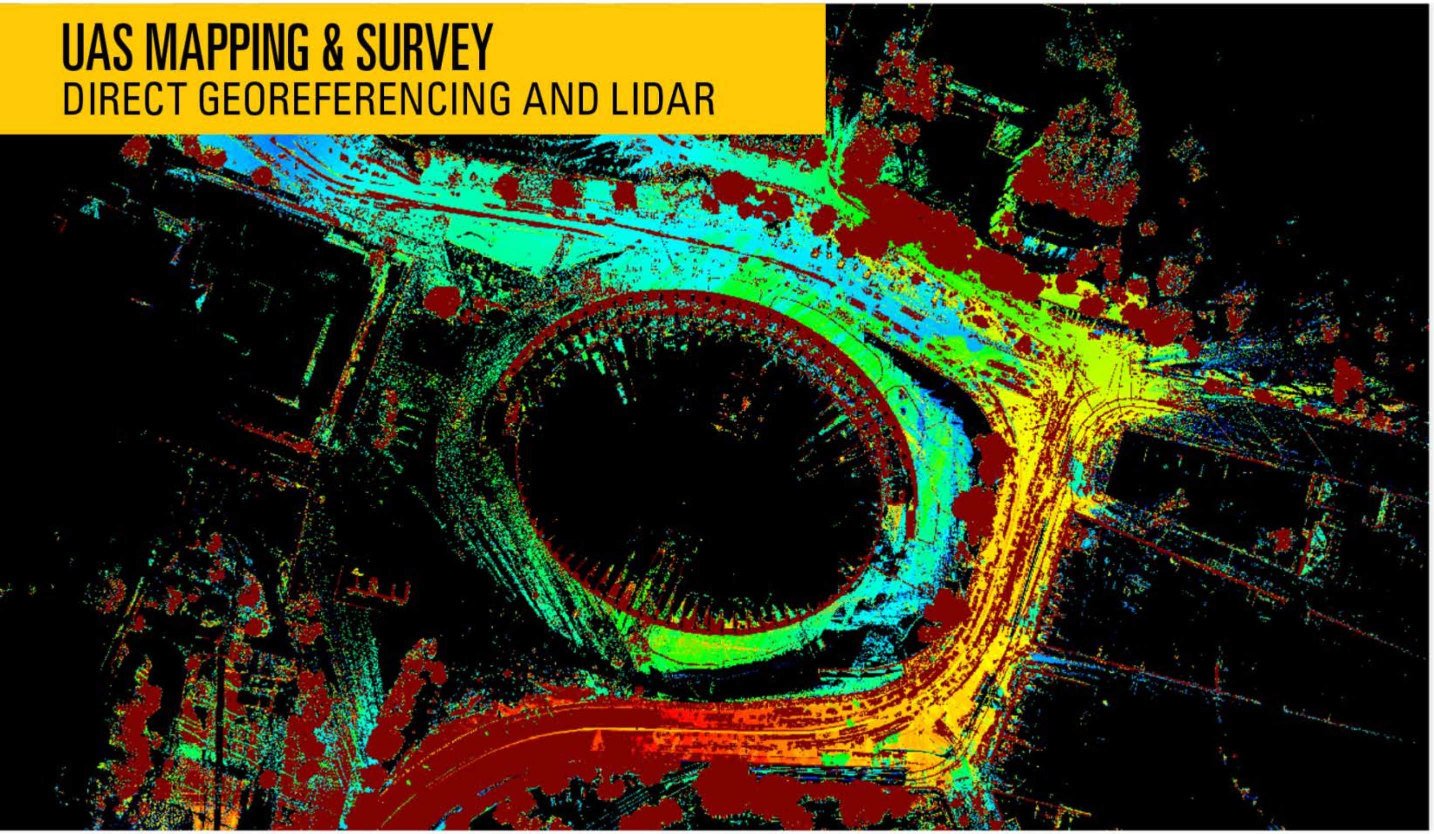
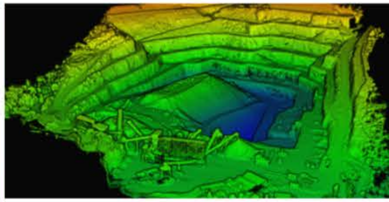
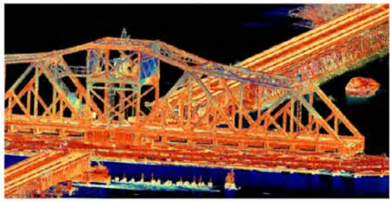
UAS MAPPING & SURVEY
DIRECT GEOREFERENCING AND LIDAR







Wednesday, April 19, 2017

10 a.m. PDT • 11 a.m. MDT • Noon CDT • 1 EDT

InsideGNSS applanix inside unmanned systems

WELCOME TO
UAS Mapping & Survey - Direct Georeferencing and LiDAR

Lewis Graham
CTO
GeoCue Corporation

Pierre Chaponnière
Application Engineer
YellowScan

James van Rens
CEO
***RIEGL* USA**

Co-Moderator: Lori Dearman, Sr. Webinar Producer

Who's In the Audience?

A diverse audience of over 600 professionals registered from 58 countries representing the following industries:

- **43%** Professional User
- **14%** System Integrator
- **11%** Product/Application Designer
- **9 %** GNSS equipment manufacturer
- **23%** Other

Richard Fischer
Publisher
Inside GNSS and Inside Unmanned Systems

Welcome from *Applanix*

Joe Hutton, MASc
P.Eng, Director
Inertial Technology and
Airborne Products

James Poss, Maj Gen (ret), USAF
CEO
ISR Ideas

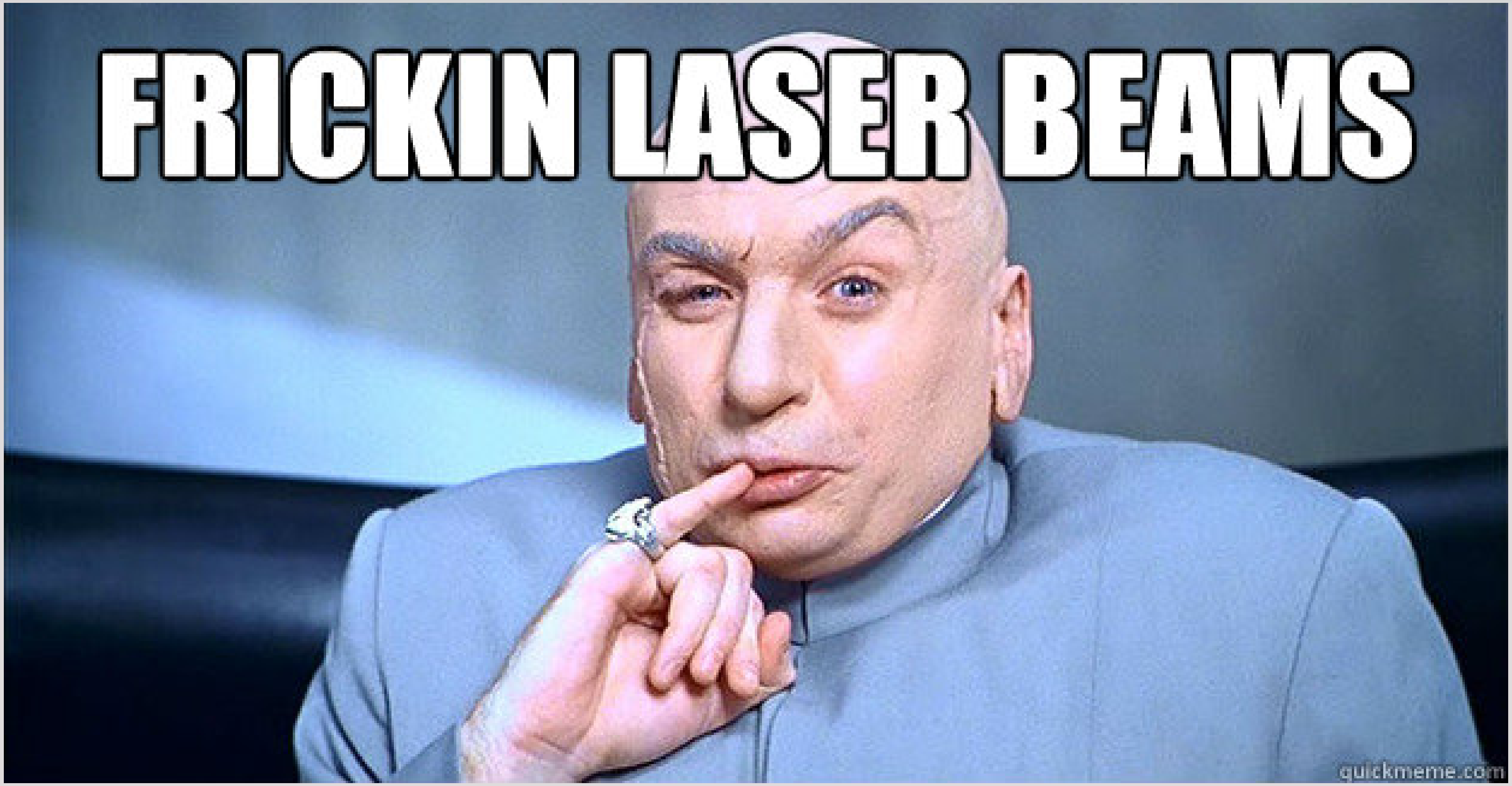
Poll #1

Can you really use LIDAR in small UAVs
(Please select one)

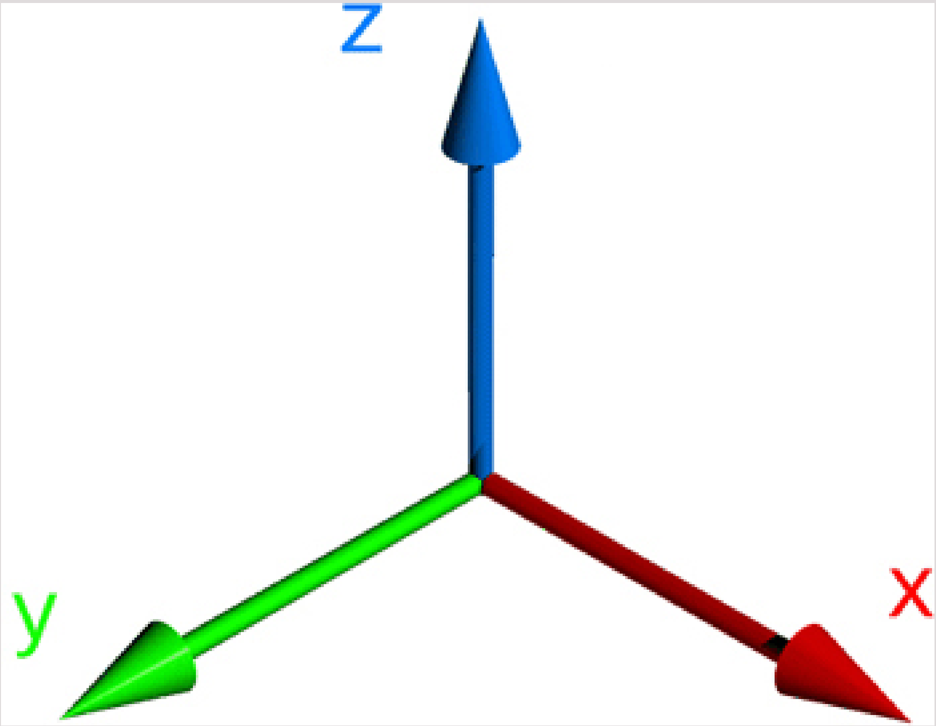
- ***No the tech isn't there yet.***
- ***Yes, but there are a lot of problems in application.***
- ***Are you crazy, of course you can!***

Drones with Frickin' Laser Beams?

James Poss, Maj Gen (ret), USAF
CEO
ISR Ideas



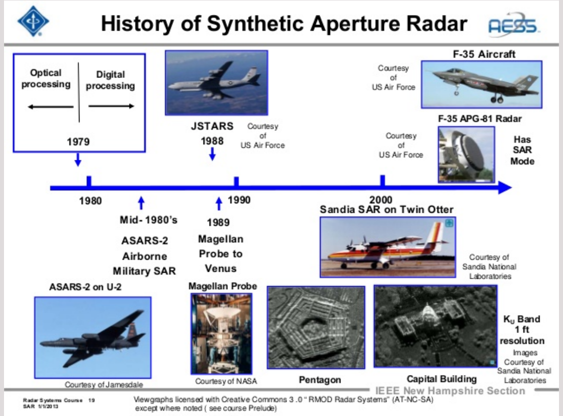
SHOULD Dr. Evil have asked for drones instead of sharks?



It's all about the "Z."

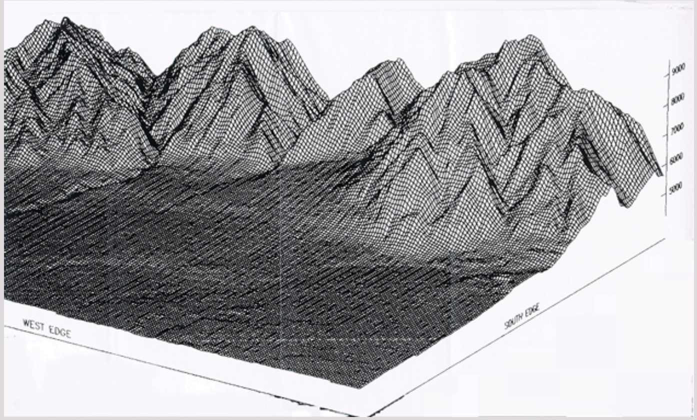
The Story of Z

- Late 1970's: USAF commits to cruise missiles, needs precision navigation, precision maps to support
  - Invents GPS to solve navigation problem
  - Precision mapping equally tough problem: how to turn 2D imagery into 3D? Tried:
    - Electro optical stereo imagery
    - Synthetic Aperture Radar



Problems with Optical and Radar

- Electro Optical issues:
  - Requires stereo imagery
    - Double coverage required
    - Difficult to process
    - Deriving “Z” coordinate requires extensive training
- Radar issues:
  - Easier to process, derive “Z” coordinate, not as accurate as stereo EO
- Yields Digital Terrain Models
  - Good enough for cruise missiles, laser guided munitions

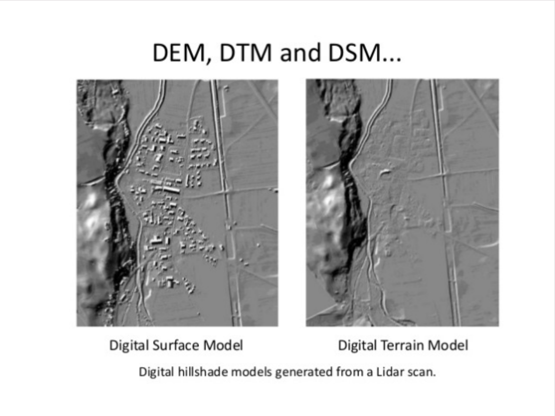


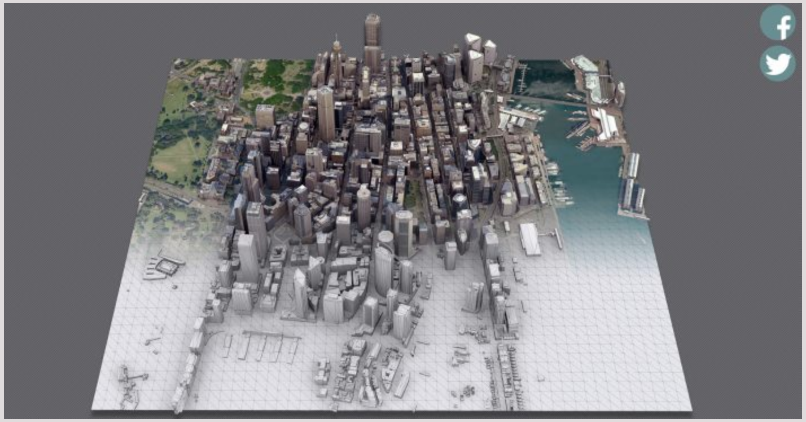
The Problem of GPS Weapons

- Laser guided munitions:
  - Dropped in pairs on single target, pilot guides in bomb
    - Pilot needs X, Y coordinates, laser compensates for Z
- GPS guided missions:
  - Simultaneous drops only limited by aircraft payload
  - Need EXTREMELY precise X, Y and particularly Z targeting coordinates
    - Mistake in Z coordinate = bomb drops way short (or long)

Enter the Laser

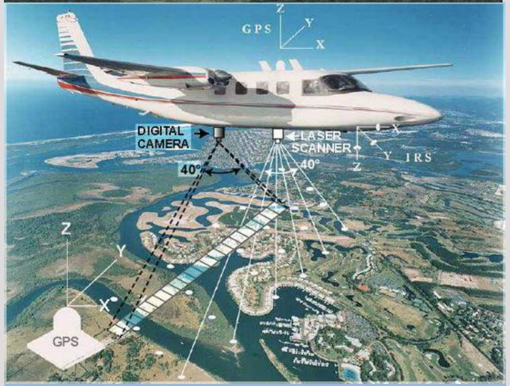
- LIDAR advantages
  - LIDAR easily solves digital terrain elevation problem:
    - Z accuracy before = 3 ft
    - Z accuracy with LIDAR = 3 cm
  - Much easier to process terrain models
    - Can just "skin" LIDAR with EO
- LIDAR disadvantages
  - Weather can impact collection
  - Tremendous storage requirements





Realistic for Drones?

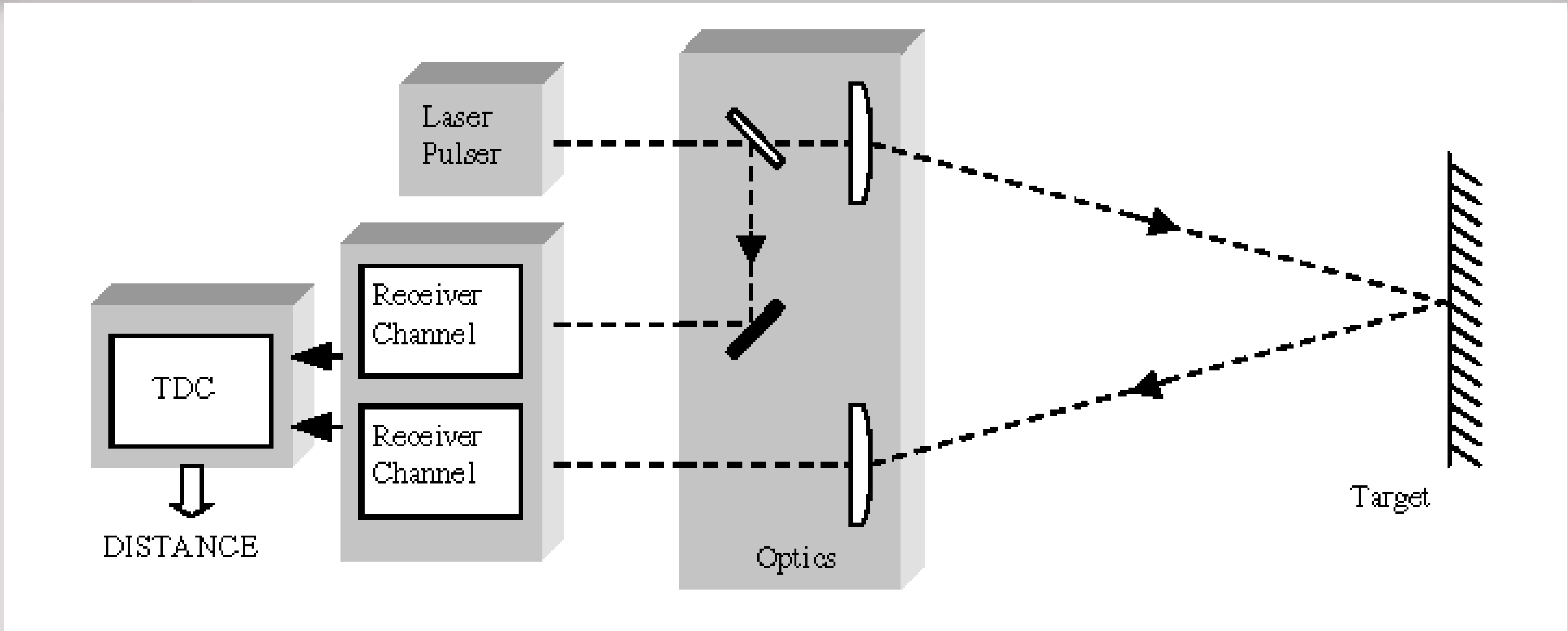
- LIDAR works well on manned aircraft, but is it realistic for FAA Part 107 drones?
- Can LIDAR:
  - Fit within the size, weight and power restrictions of a less-than-55lb drone?
  - Gather enough data if flown below 400 ft at less than 100 mph within visual line of sight of its remote pilot?



An Overview of LIDAR

Lewis Graham
CTO
GeoCue Corporation

A time of flight rangefinder

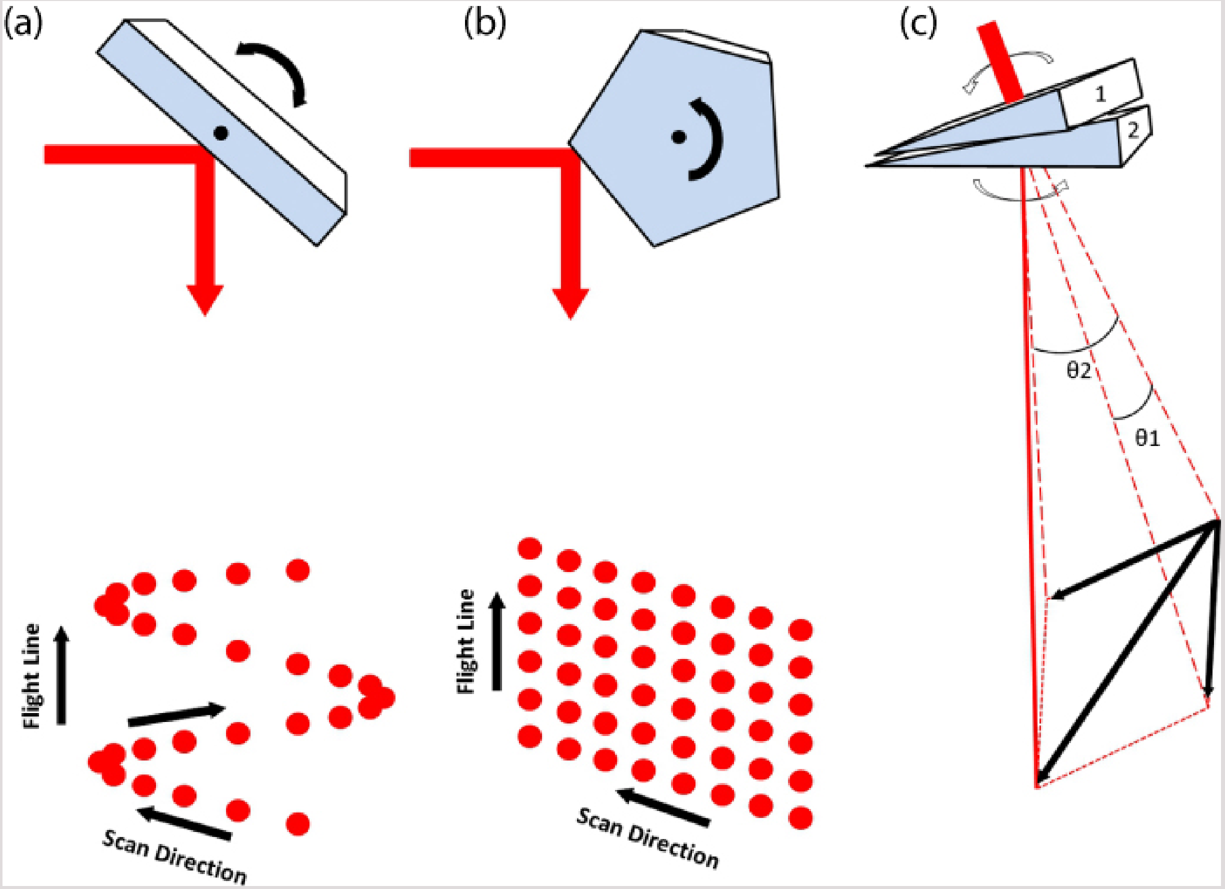


- The speed of light (c), in a vacuum, is a constant regardless of the speed of the emitting platform (an astonishing fact!!)
- We simply measure the time it takes a pulse to make a round trip:

  $$D = c \times t/2$$

- Light travels ~30 cm (~ 1 foot) in 1 nanosecond (10^{-9} sec) so it is all about excellent timing!

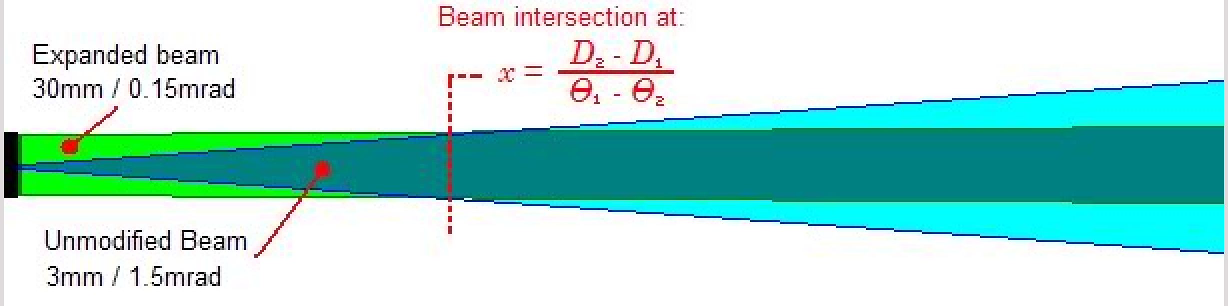
“Sweeping” extends coverage



Why LASER?

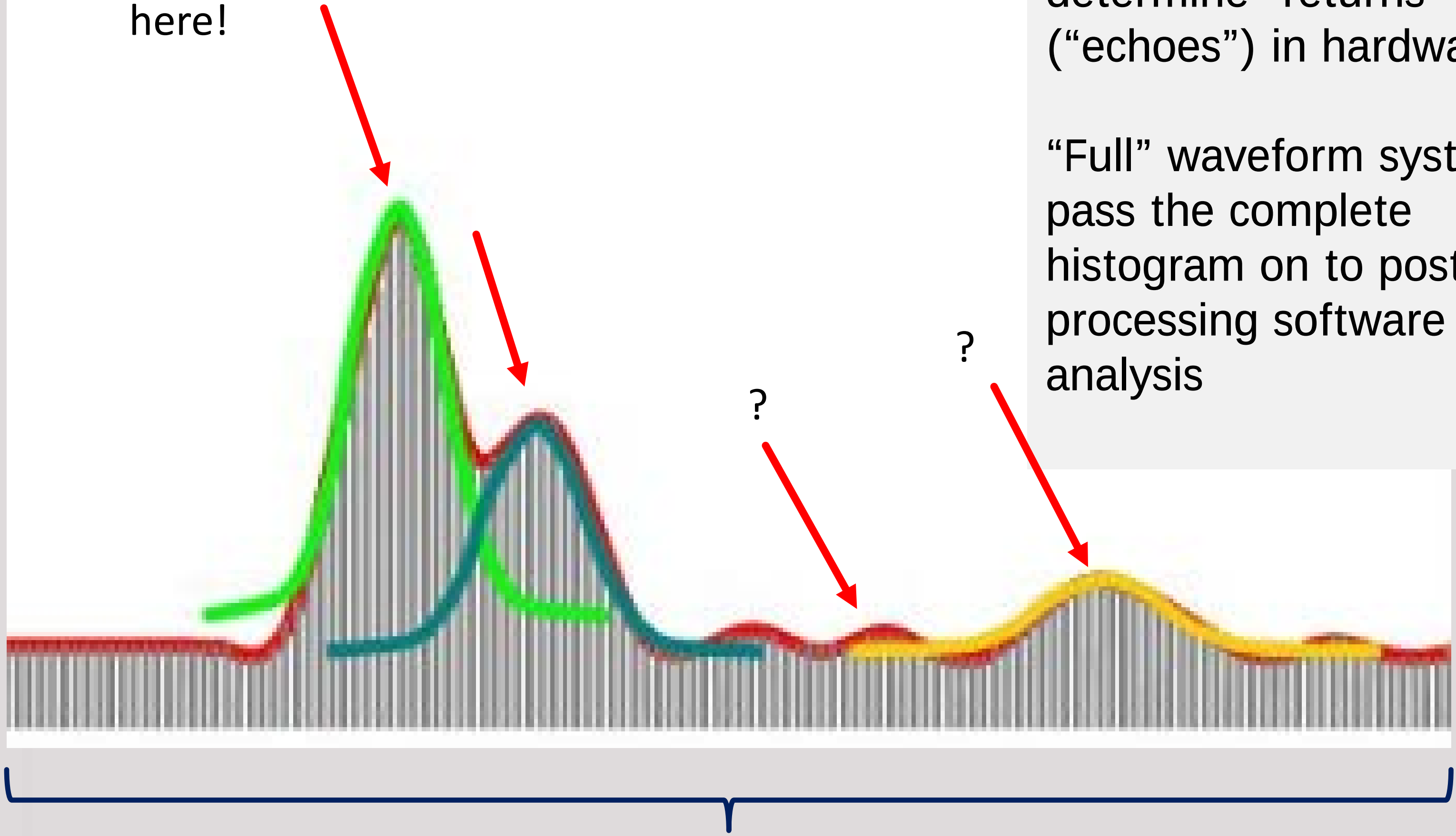
Spatially Coherent – low beam divergence → small spot on the ground → high spatial resolution

Temporally Coherent – short pulses (recall 1 nanosecond is 30 cm!) → high range resolution



LASER return waveform

Looks like something is here!

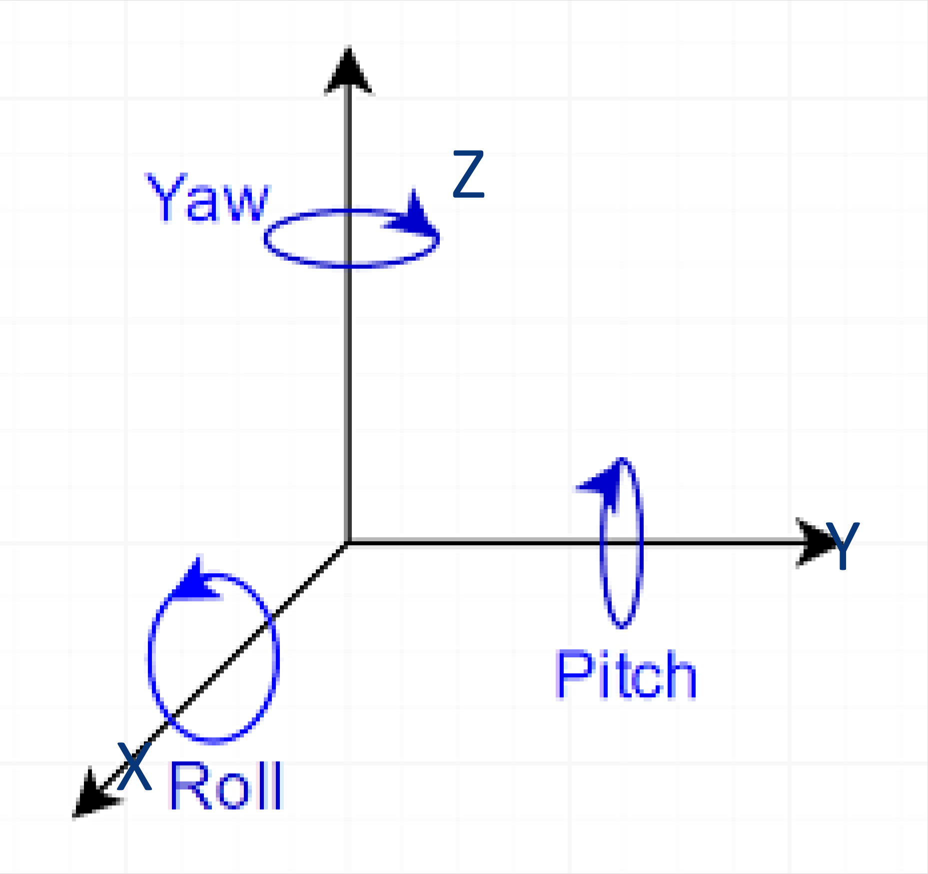


Return Energy Histogram

Discrete systems determine "returns" ("echoes") in hardware

"Full" waveform systems pass the complete histogram on to post-processing software for analysis

Position and Orientation

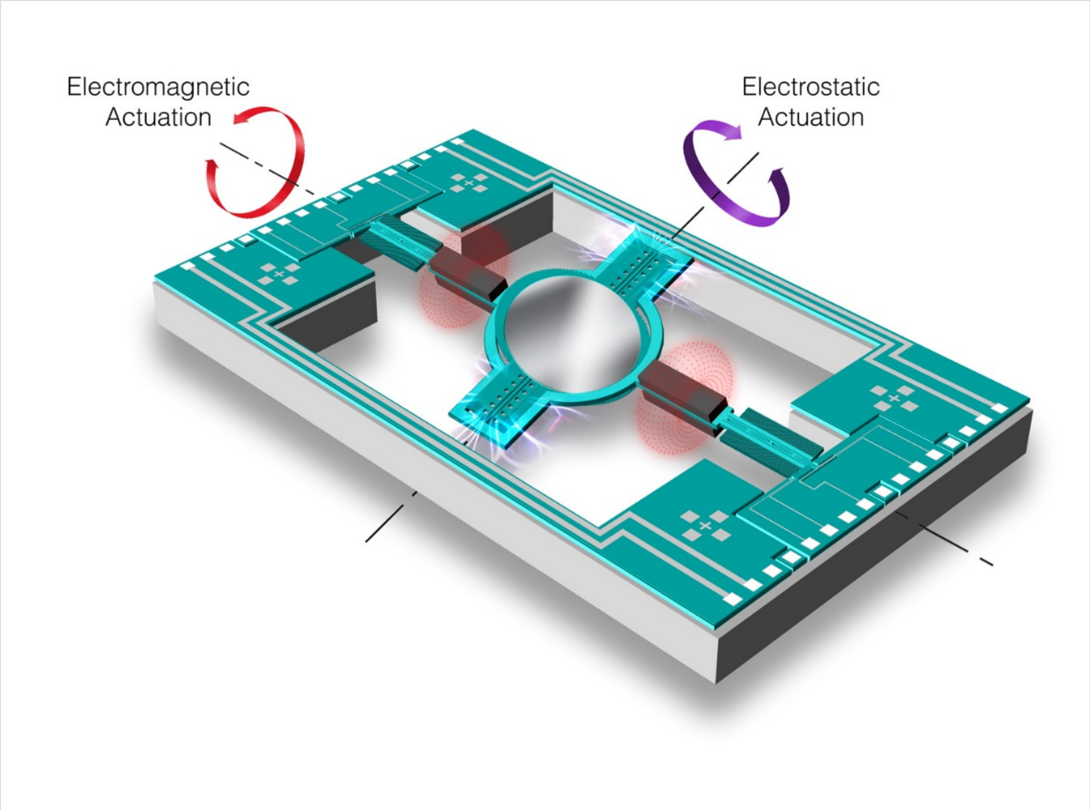


We have to know where the laser is located (Position – X, Y, Z) and which way it is pointed (Orientation – Pitch, Yaw, Roll)

Position → Global Navigation Satellite System (GNSS)
Orientation → Inertial Measurement Unit (IMU)

Applanix Position and Orientation System (POS)

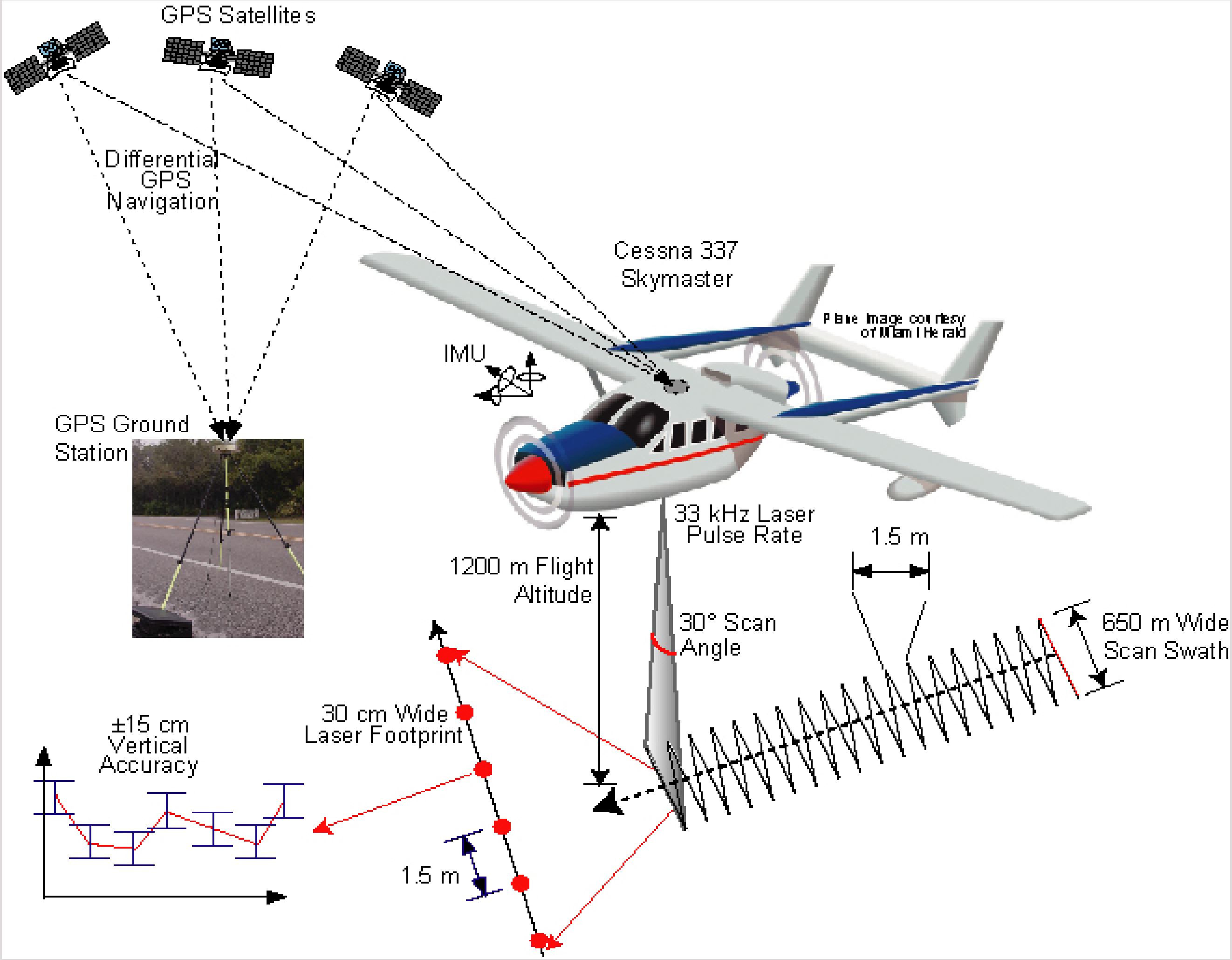
Scanner Position



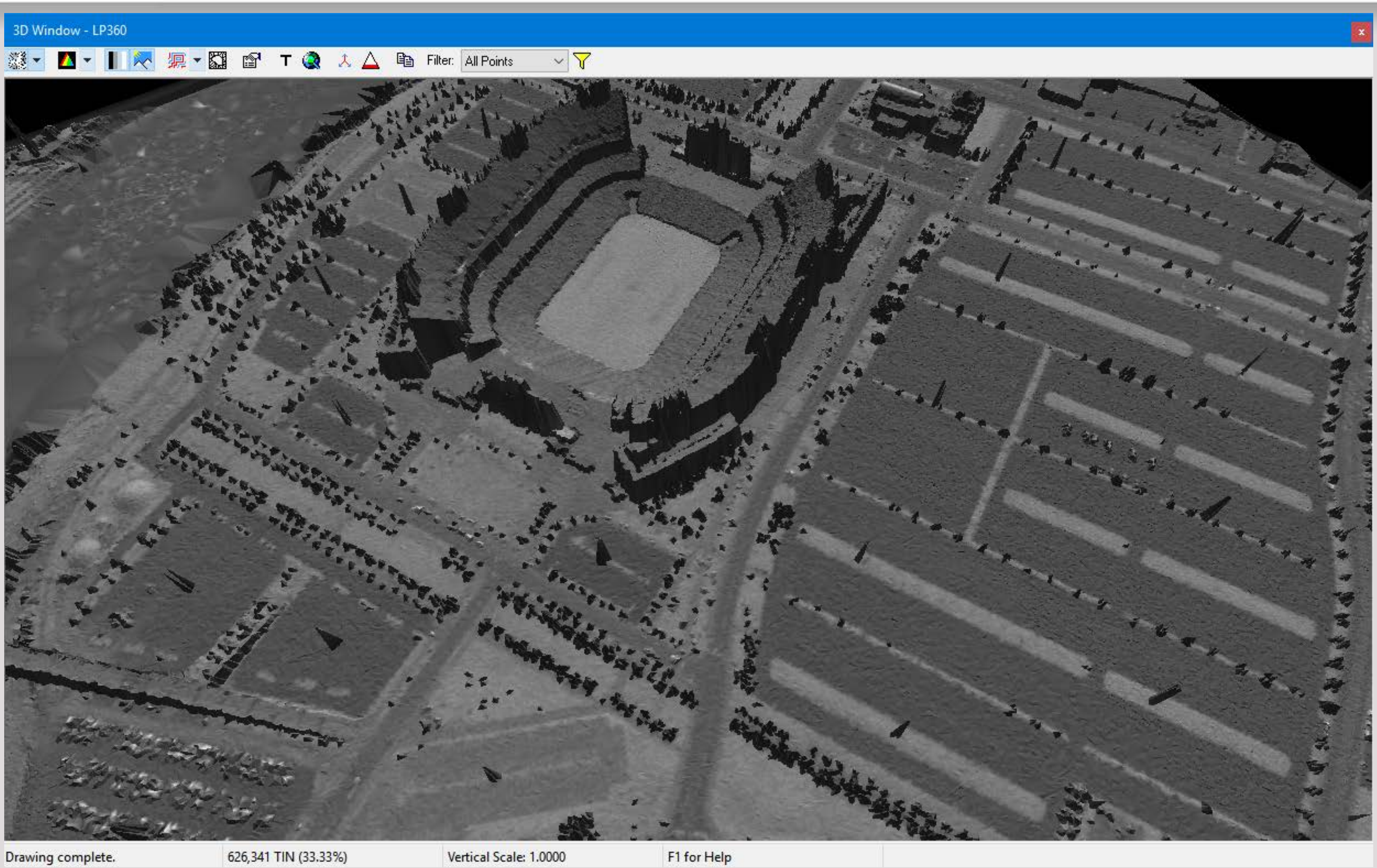
Scanning lasers sweep out a swath using a rotating mirror or prism

We must superimpose the exact position of the mirror on the position and orientation to determine where the ray will point in object space

An Airborne Laser Scanning System



Laser Imaging, Detection and Ranging (LIDAR)



A LIDAR “image” rendered by visualizing laser return power

Davidson County, TN – Courtesy USDA

A Classified LIDAR Project

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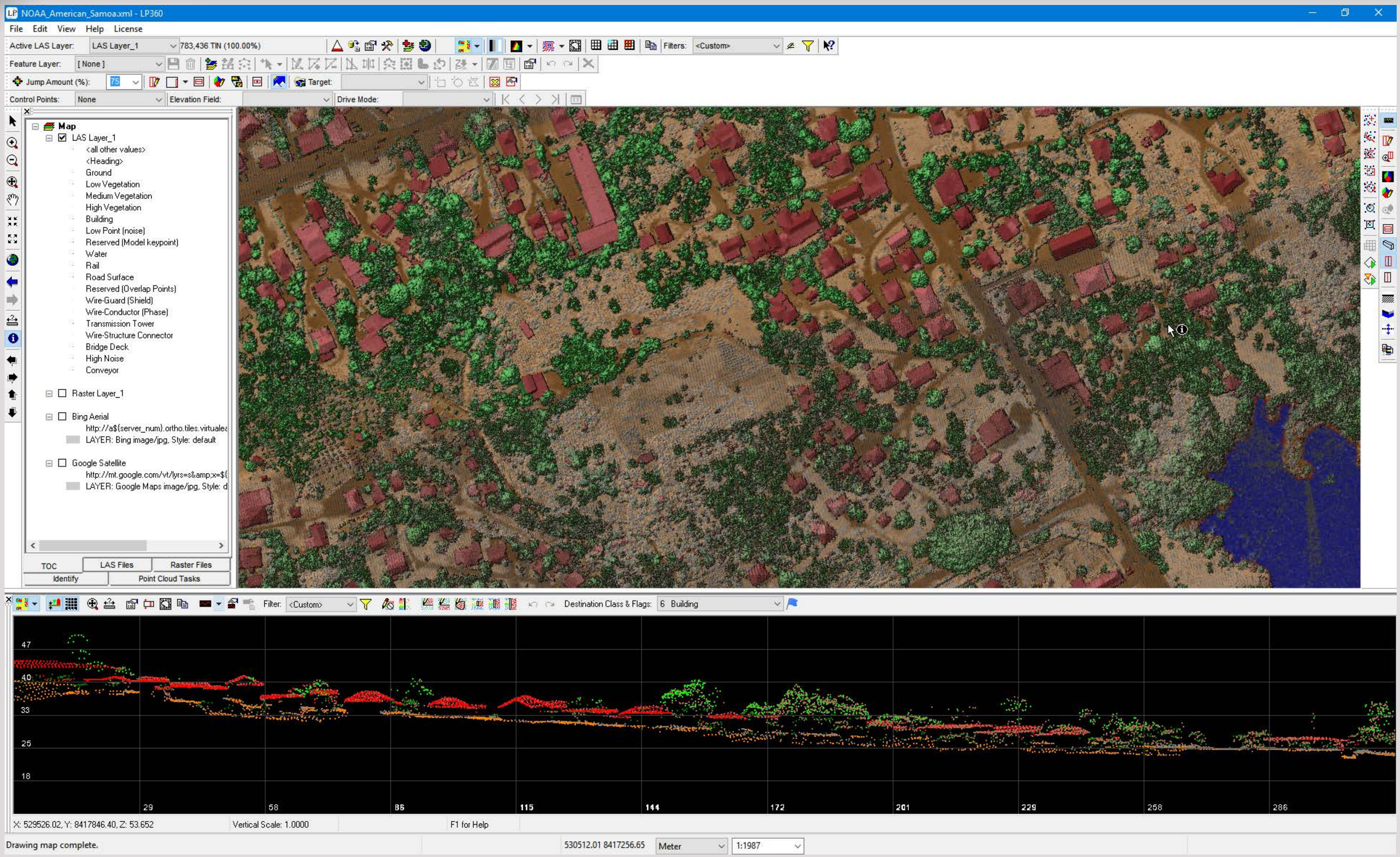
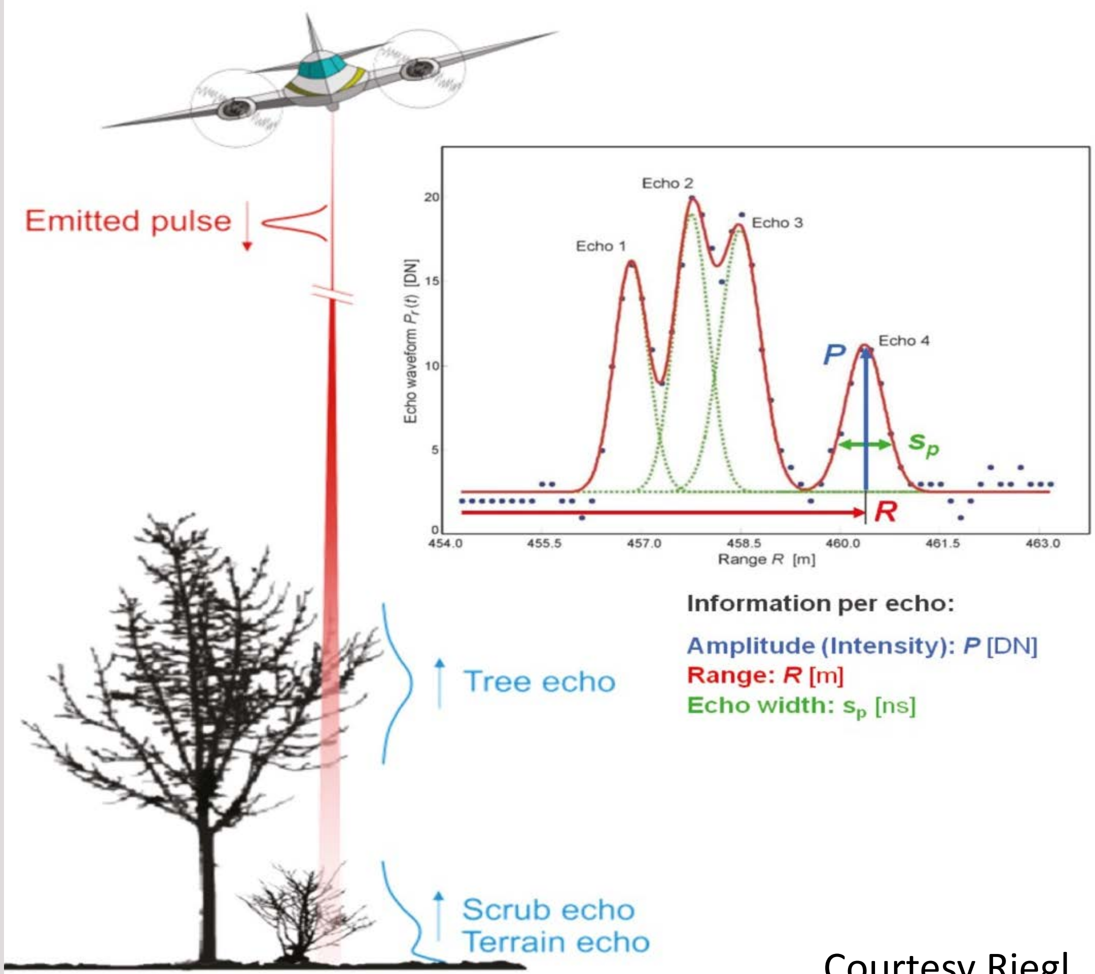


American Samoa – Courtesy NOAA

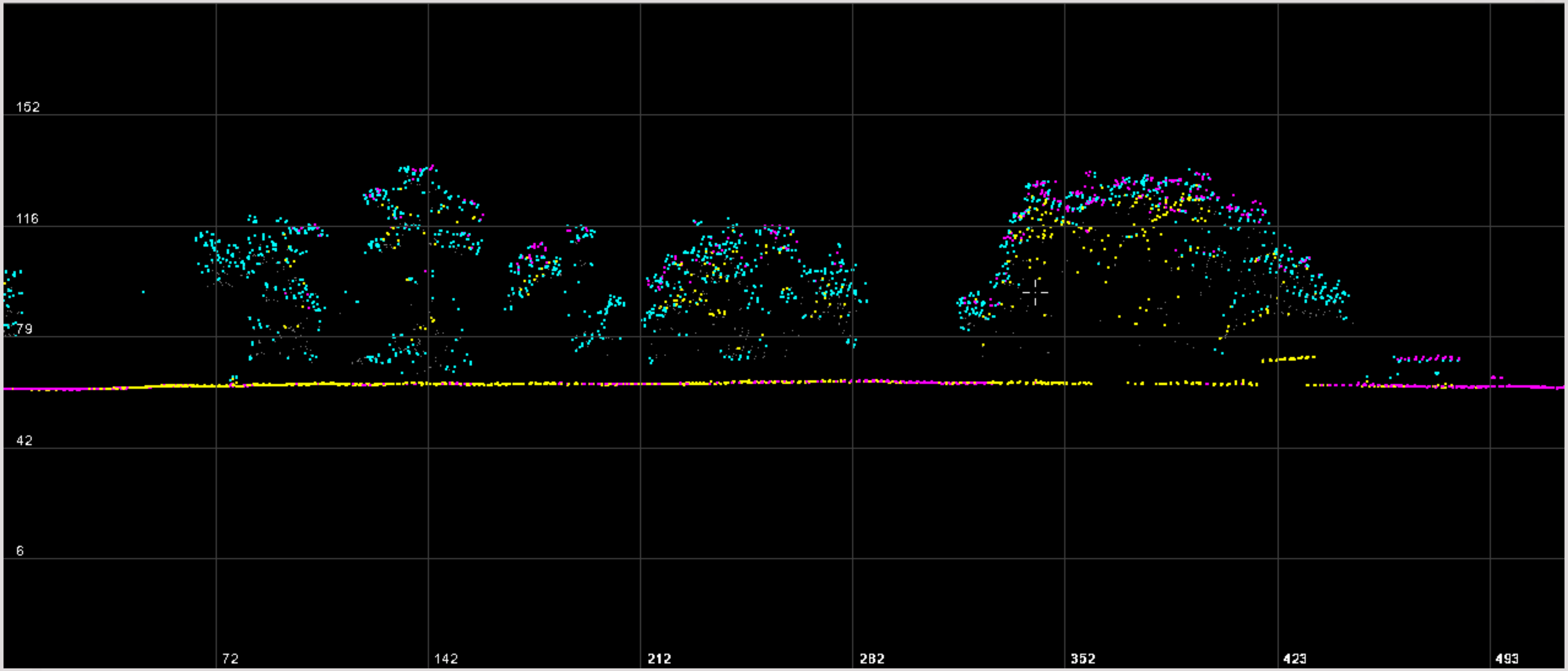
Modern LIDARs can detect Multiple Returns (echoes) & Waveform



Courtesy Riegl

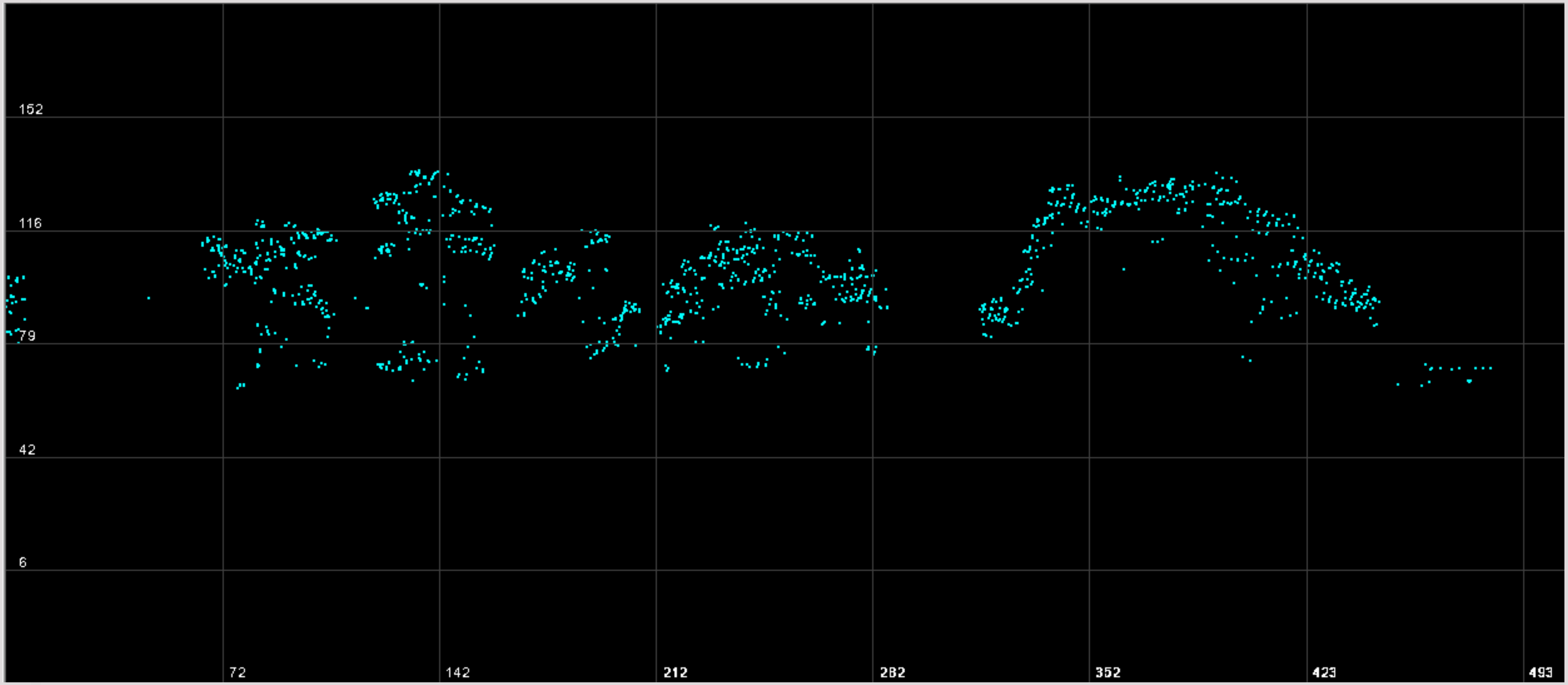
Multiple return (echo) detection, whether in hardware or post-process analytic software, is invaluable for classification algorithms

Multi-return

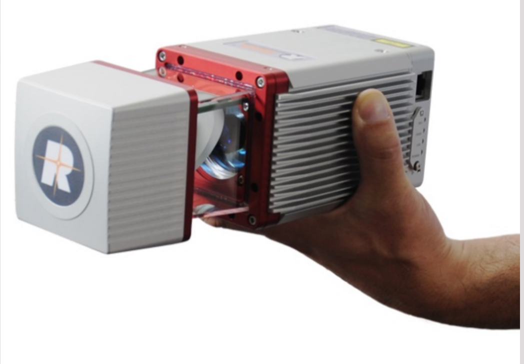


Bushnell, Florida – Courtesy SWFWMD, Riegl

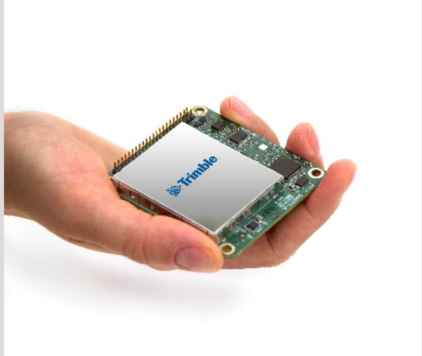
First of Multiple Returns



Miniaturization changes everything!



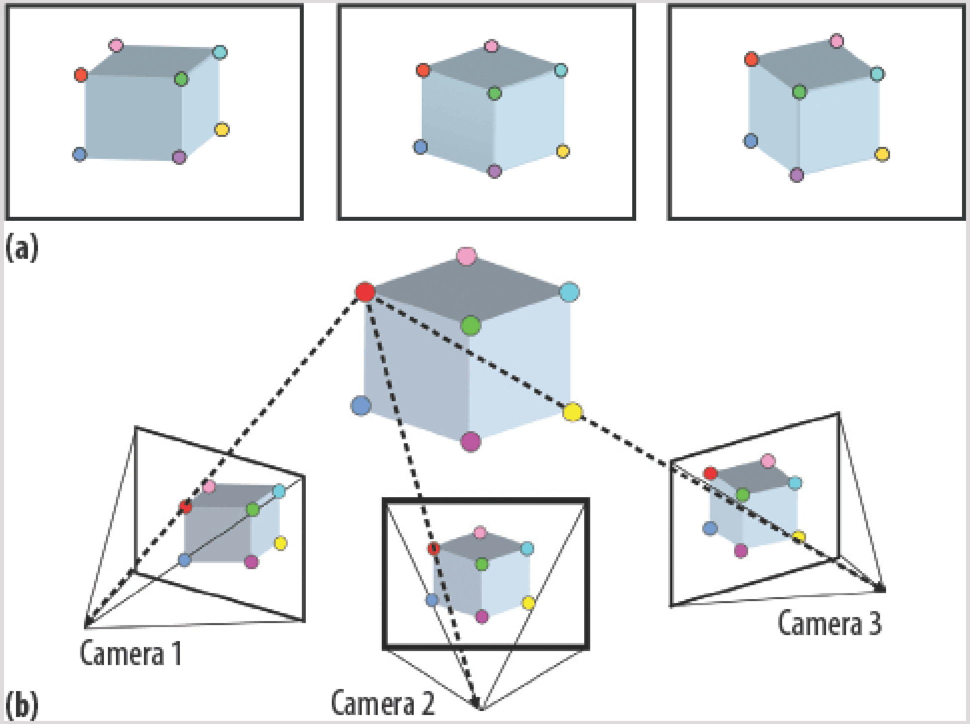
Riegl miniVUX – 5 returns, 250 m range
1.55 kg



Applanix APX-15 UAV POS
0.060 kg (60 g)

DJI M600 – Payload capacity of 6 kg – easily supports full LIDAR system + a camera!

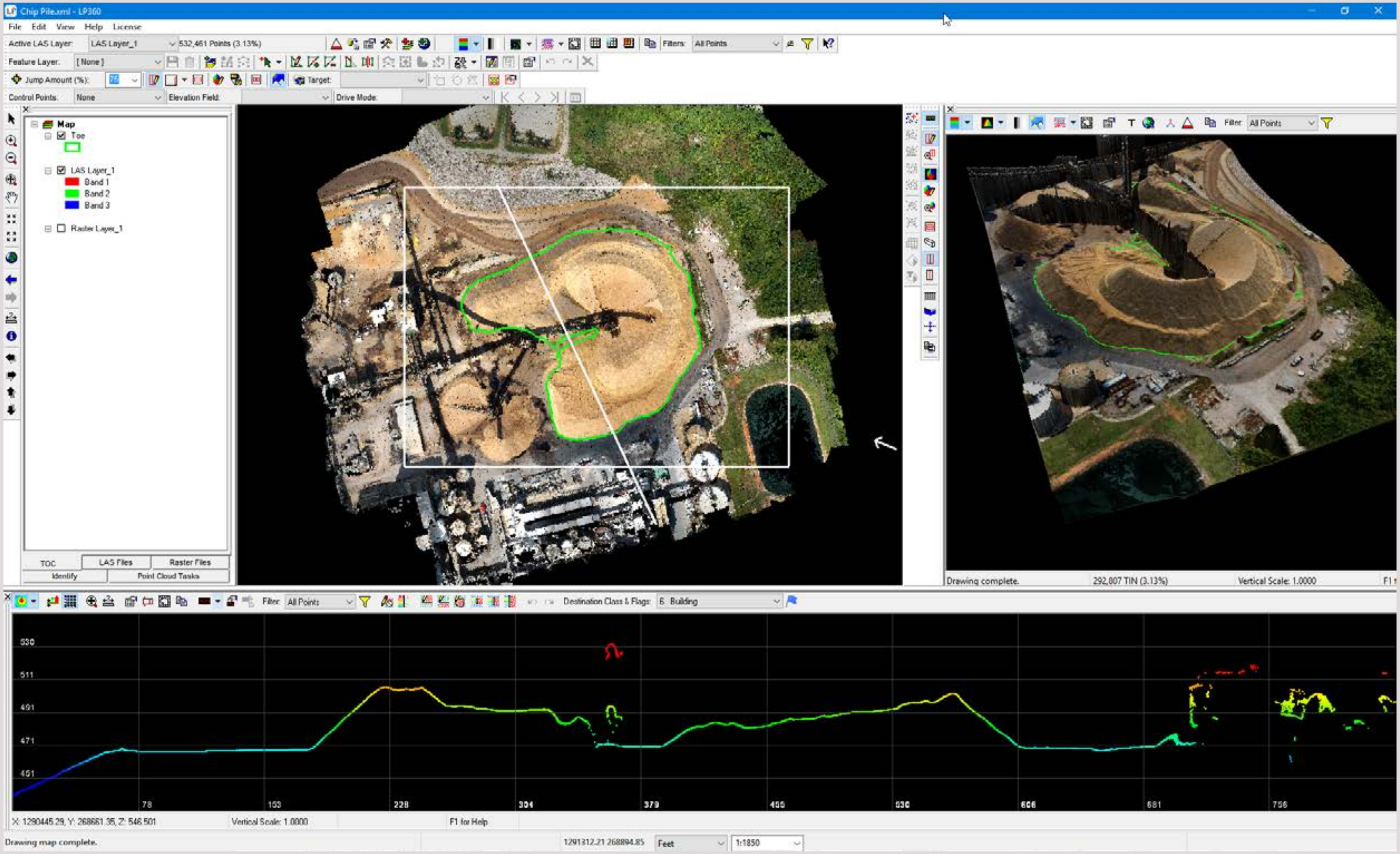
Structure from Motion (SfM)



When a camera sees the same Object spot from multiple positions (the 'motion'), a 3D surface can be reconstructed (the 'structure')

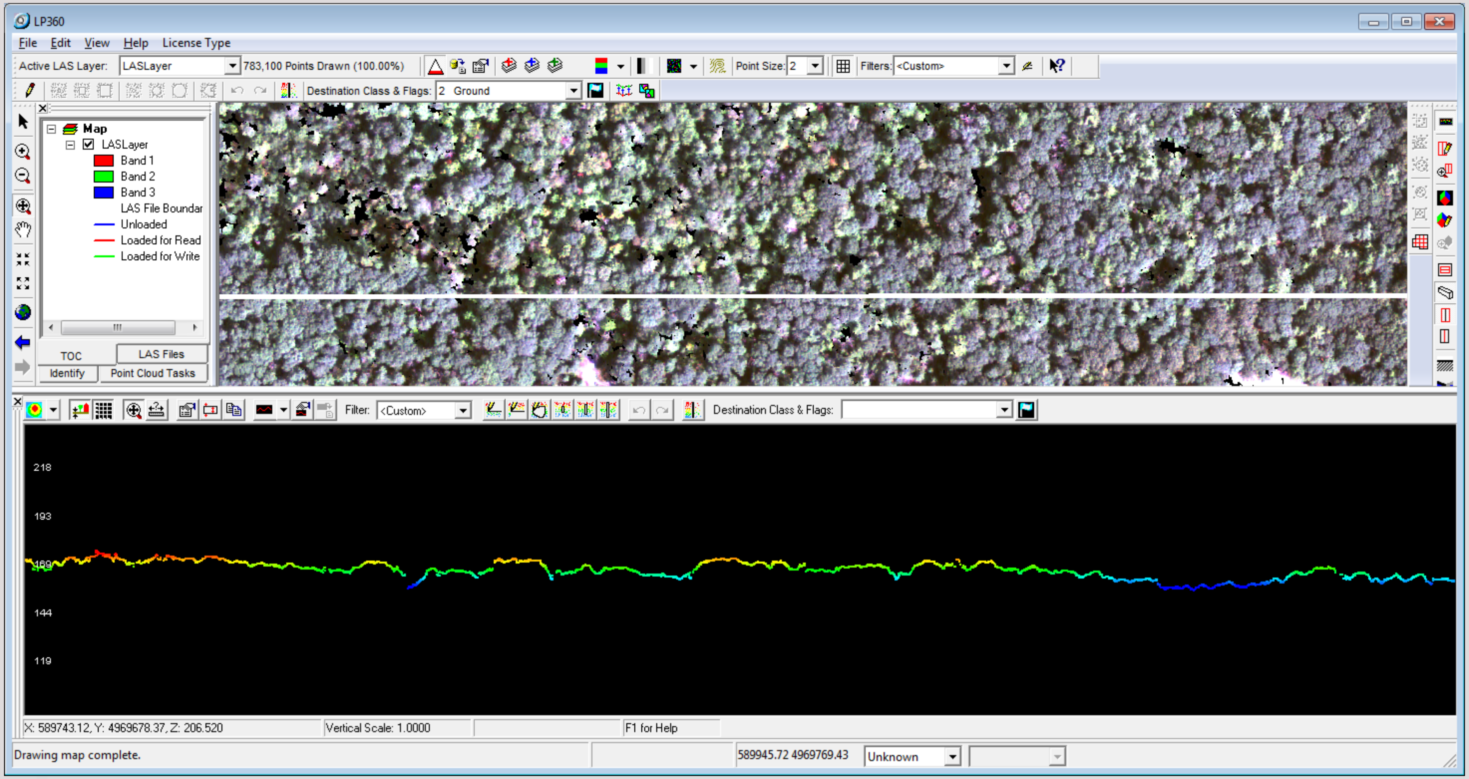
SfM allows us to build 3D point cloud models from multiple 2D images

A UAV Collected SfM Cloud



Data courtesy Packaging Corp. of America, AirGon LLC

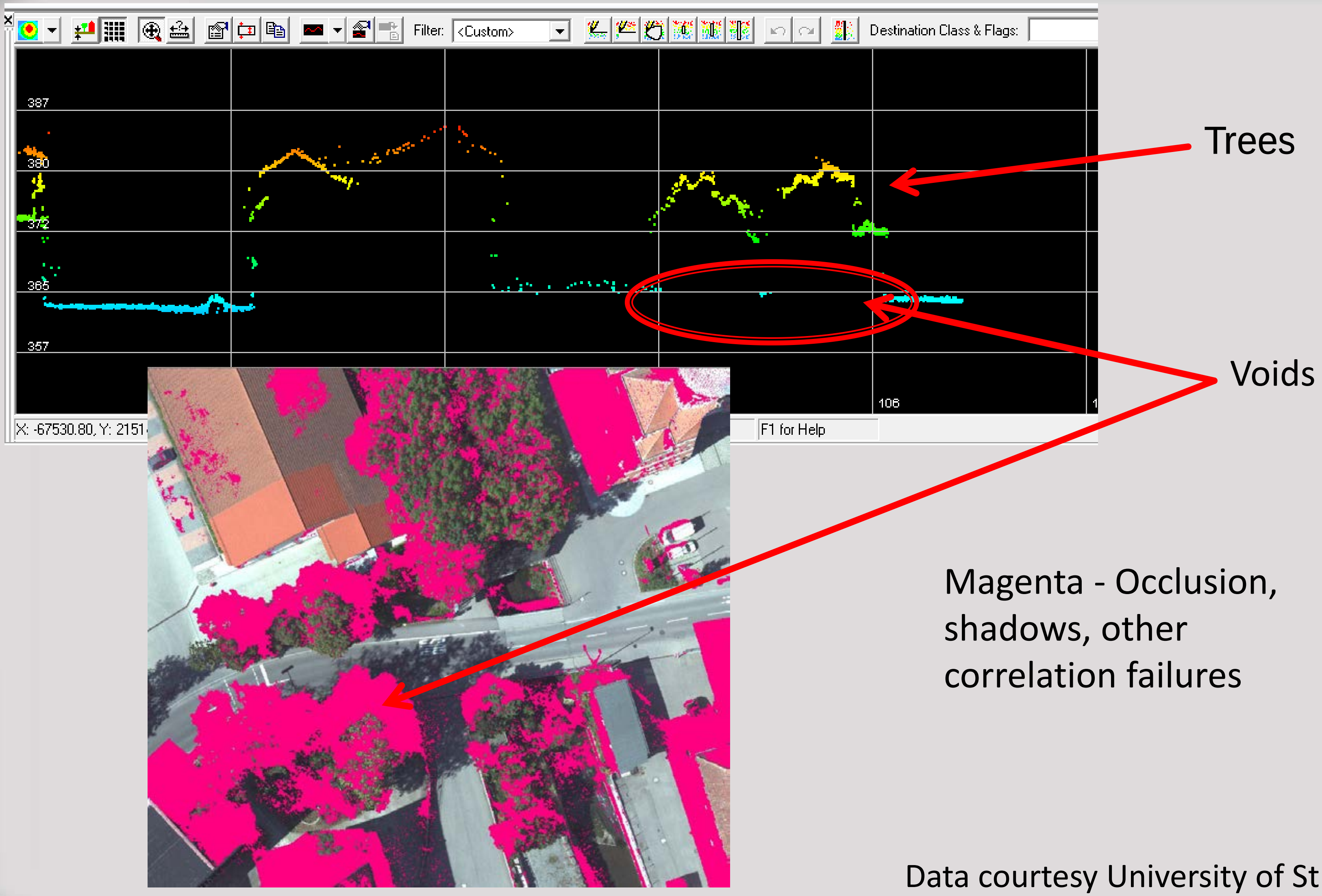
SfM Models are Surface only



Forested area

Zero penetration to ground

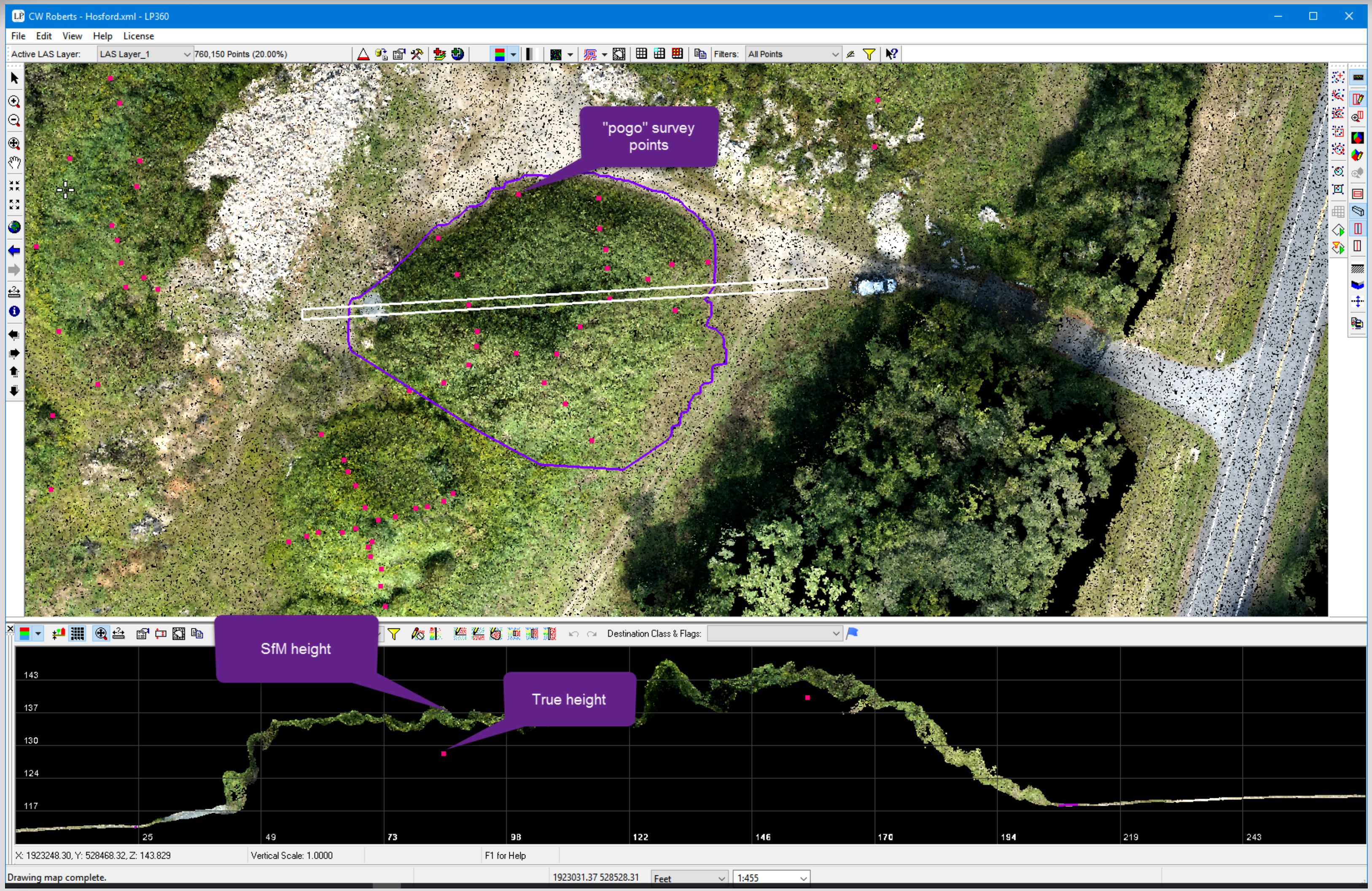
Voids occur in 1 image areas



Magenta - Occlusion, shadows, other correlation failures

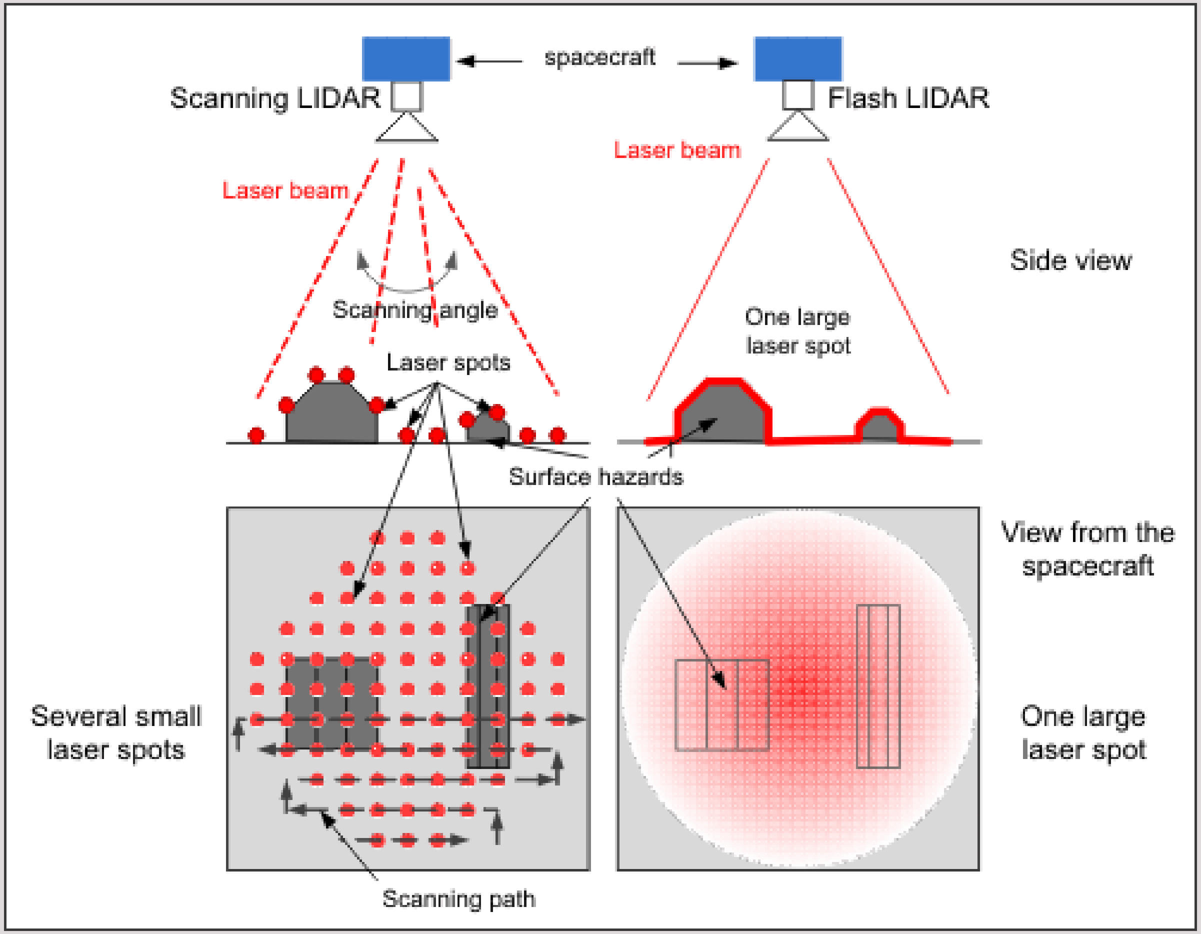
Data courtesy University of Stuttgart

Where SfM fails…

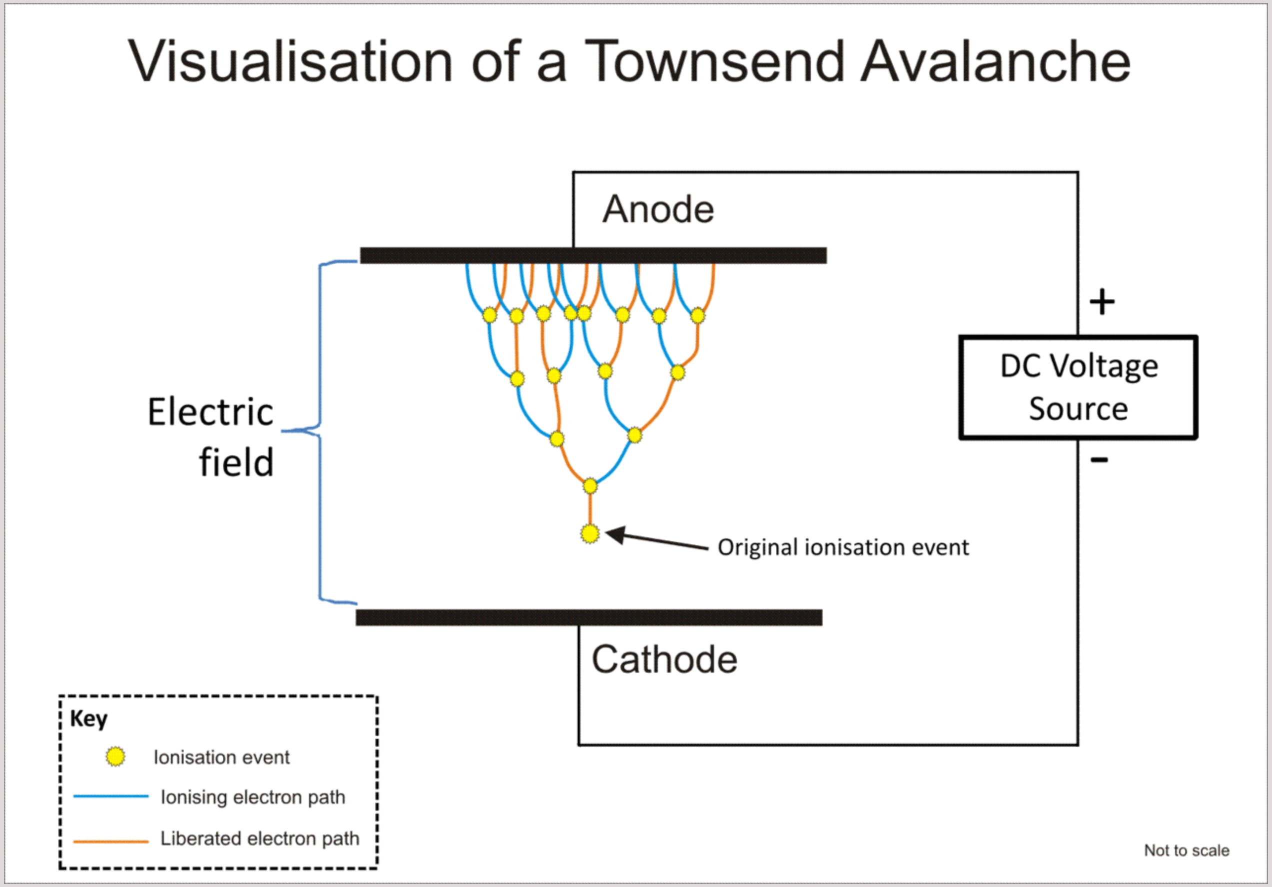


Data courtesy CW Roberts, AirGon LLC

Focal Plane Array (Flash) LIDAR

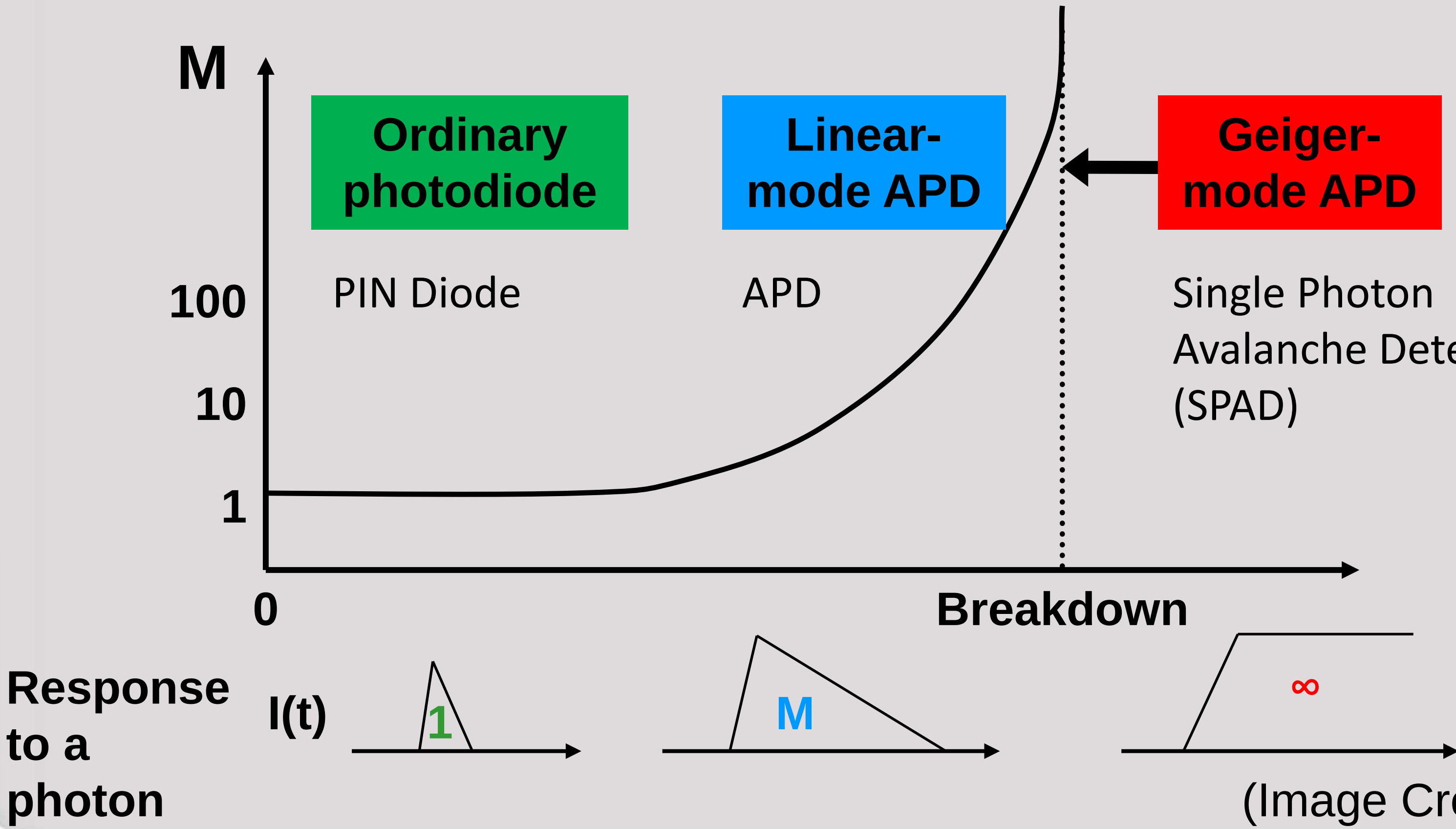


Secondary Ionization
(John Townsend – 1897)



Linear-mode vs. Geiger-mode

- APDs can be operated in linear-mode or Geiger-mode
- Geiger-mode provides much more sensitivity
- Linear-mode can produce intensity images



(Image Credit: D.F Figer.)

LIDAR Summary

- Only a single ray is required to model a 3D object point
  - Huge advantage over any other technique such as photogrammetry
- Modern scanning LIDAR systems offer very high resolution, range precision and accuracy
- Largest contributor to high accuracy is a very high quality Position and Orientation System (POS)
- Miniaturization of laser scanners and POS has enabled deployment of very high accuracy systems on low altitude drones
- Avalanche mode (Geiger) sensors are on the verge of entering the main-stream
  - Noise is a huge problem that has yet to be solved
- Focal Plane Array (FPA) linear mode scanners will probably be the market leading technology for short range systems within five years

Ask the Experts – Part 1

Lewis Graham
CTO
GeoCue Corporation

Pierre Chaponnière
Application Engineer
YellowScan

James van Rens
CEO
RIEGL USA

Poll #2

What's your favorite LIDAR platform?
(Select one)

- *Large manned aircraft (I need the Size Weight and Power (SWAP) and coverage)*
- *Small UAS (I'll deal with the smaller SWAP less coverage for greater detail for lower cost)*
- *Ground vehicle (I don't need the overhead coverage, I'm just street mapping)*
- *Backpack (I need to go inside buildings!)*

From Big Data to Information

High Precision ***RIEGL*** Waveform-LiDAR and GNSS Integration

James van Rens
CEO
***RIEGL* USA**

RIEGL – Applanix Partnership Benefits

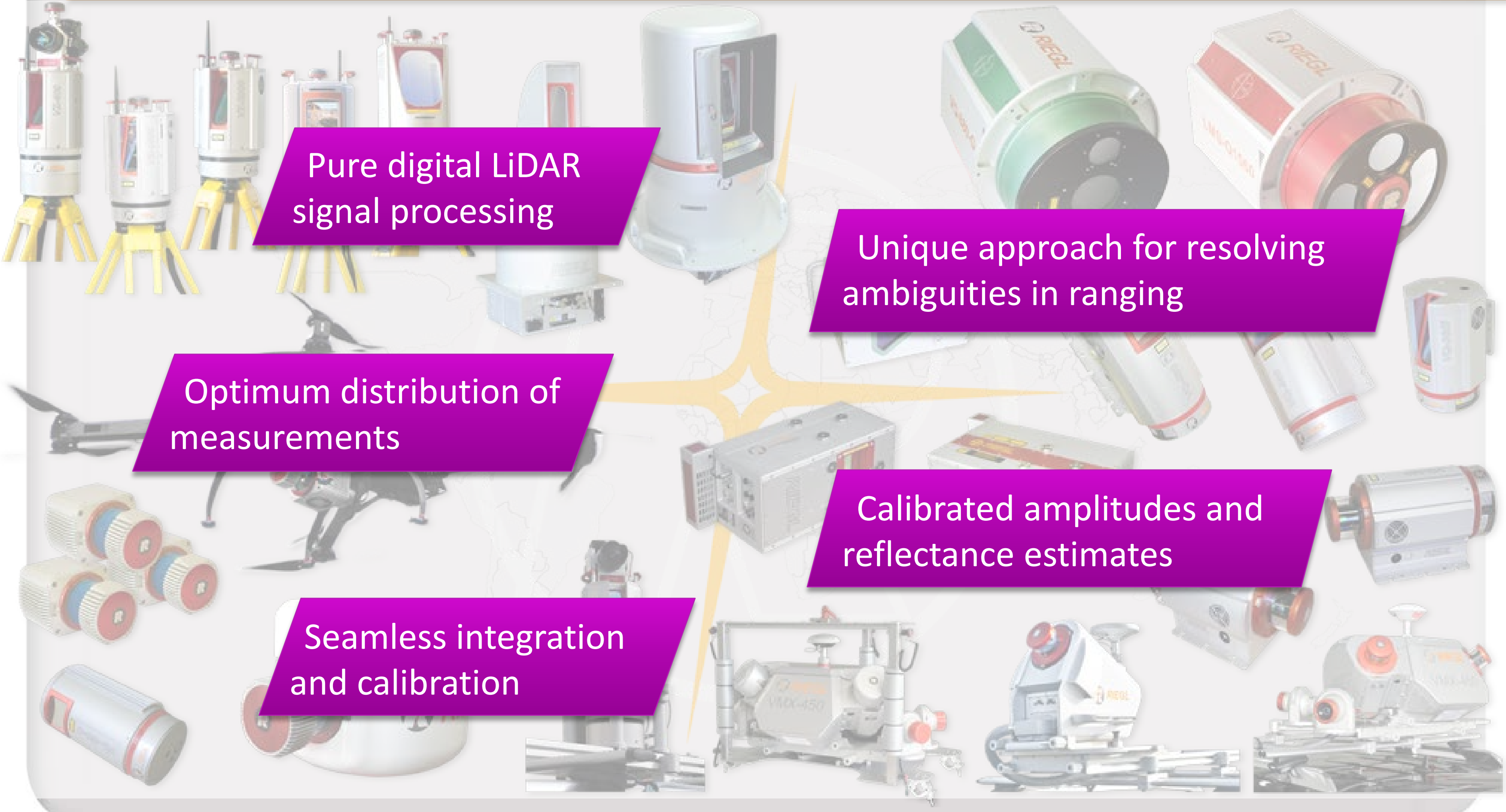
GNSS is the enabling technology for kinematic LiDAR

High precision *RIEGL* Waveform-LiDAR requires survey-grade position accuracy for all platforms

RIEGL RiPrecision software adjusts GNSS/INS Trajectories

Tightly coupled integration of GNSS and LiDAR provides the basis for seamless integration for other sensors

RIEGL's Core Technologies



- Pure digital LiDAR signal processing
- Optimum distribution of measurements
- Seamless integration and calibration
- Unique approach for resolving ambiguities in ranging
- Calibrated amplitudes and reflectance estimates

RIEGL Waveform-LiDAR needs survey-grade GNSS accuracy to be able to deliver

- High ranging accuracy
- Low range noise / high precision
- Highest multi-target resolution
- Precise distribution of measurements
- Valuable pulse shape information for cleaning up point clouds, assisting classification, filtering
- Key to advanced MTA techniques
- Solid basis for radiometric measurements

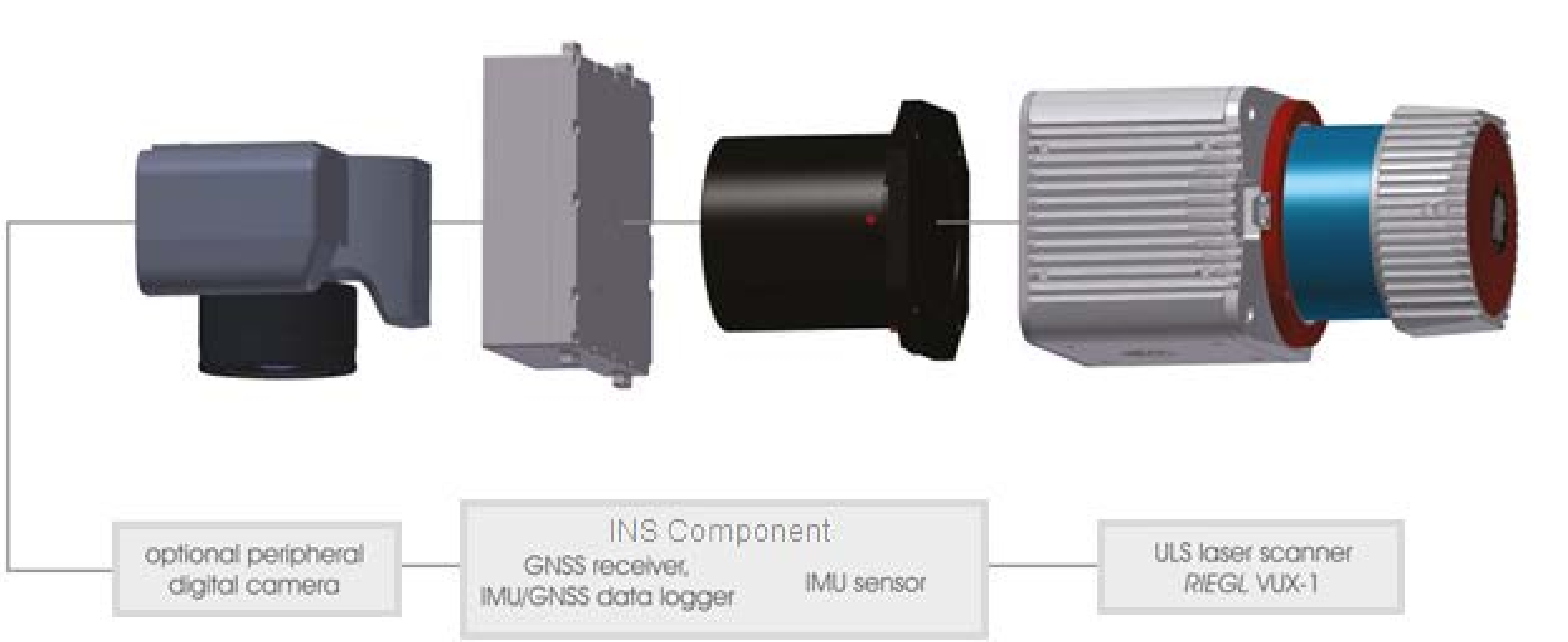
Precision Discussion

- Precision 10 mm typ
- Relative accuracy 15 mm typ
- Absolute accuracy 25 mm typ
- Spatial resolution 15 cm typically (AGL 600 m)

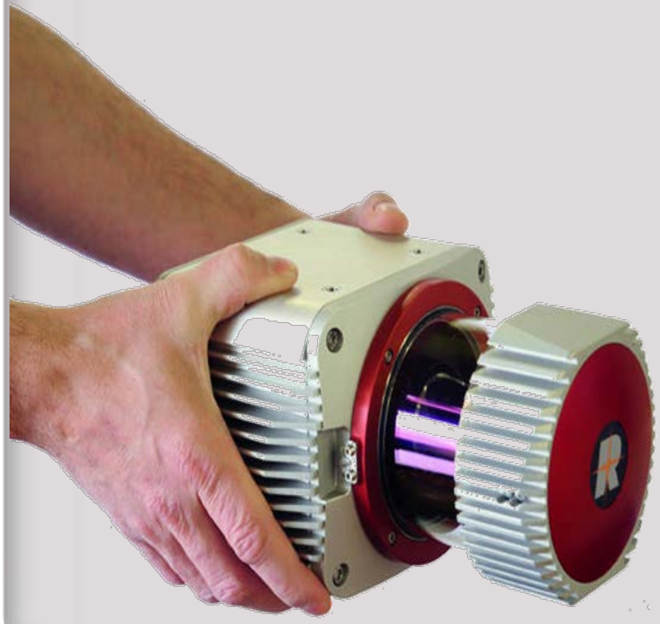
LiDAR Platforms

FAA Part 107 Compliant LiDAR UAV

Typical integration of components for survey grade UAV LiDAR



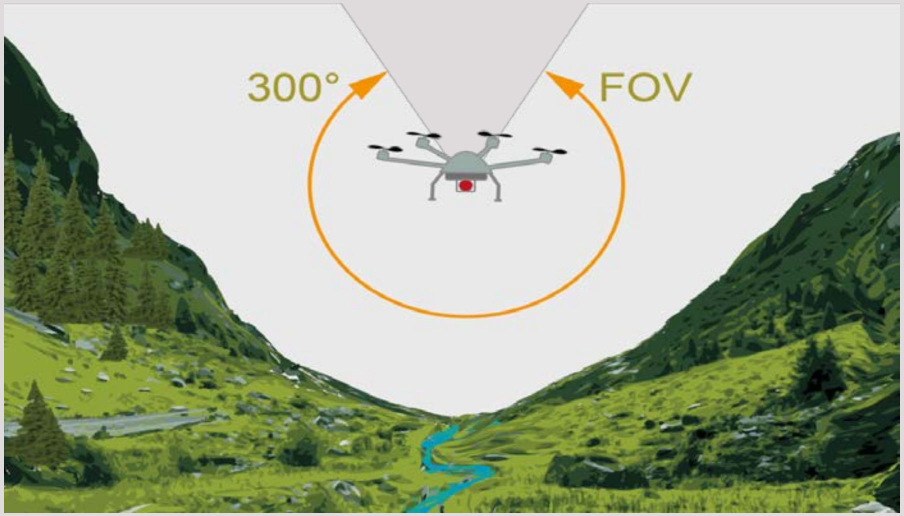
- ***RIEGL* miniVUX-1UAV**
  - 242 x 99 x 85 mm
  - 1.55 kg (without cooling fans)
  - 1.60 kg (with cooling fans)



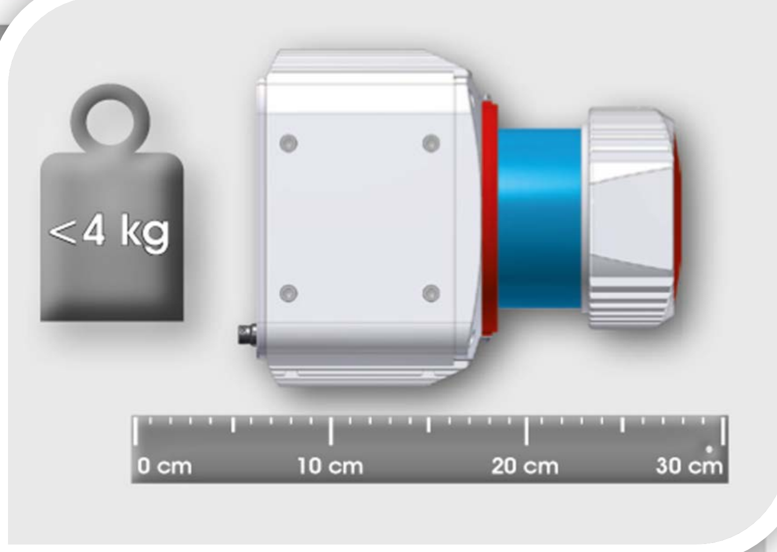
- ***RIEGL* VUX-1UAV/HA/LR**
  - 227 x 180 x 125 mm
  - 3.60 kg (without cooling fans)
  - 3.85 kg (with cooling fans)

RIEGL's Surveying Grade LiDAR Drone Stats

- 220 degree Field of View which means effective at low altitudes
- 30 minute flight time – 60 acres:
  - 4.5 GB LiDAR Data
  - 14.2 GB Image Data
  - 1 GB LAS files
- Computer: Quad Core, SSHD, 16 gig RAM. High End NVIDIA Graphics card



PART 107 Rules



Less than 55 pounds weight

Daylight and twilight operation

400 ft. maximum altitude above ground

87 Knots(100 mph) maximum speed

Class G airspace

External loads allowed; cameras, LiDAR, Amazon stuff

Pilot Certification is required

You Self Certify the Drone

Must perform preflight visual and operation checks

UAS must be registered

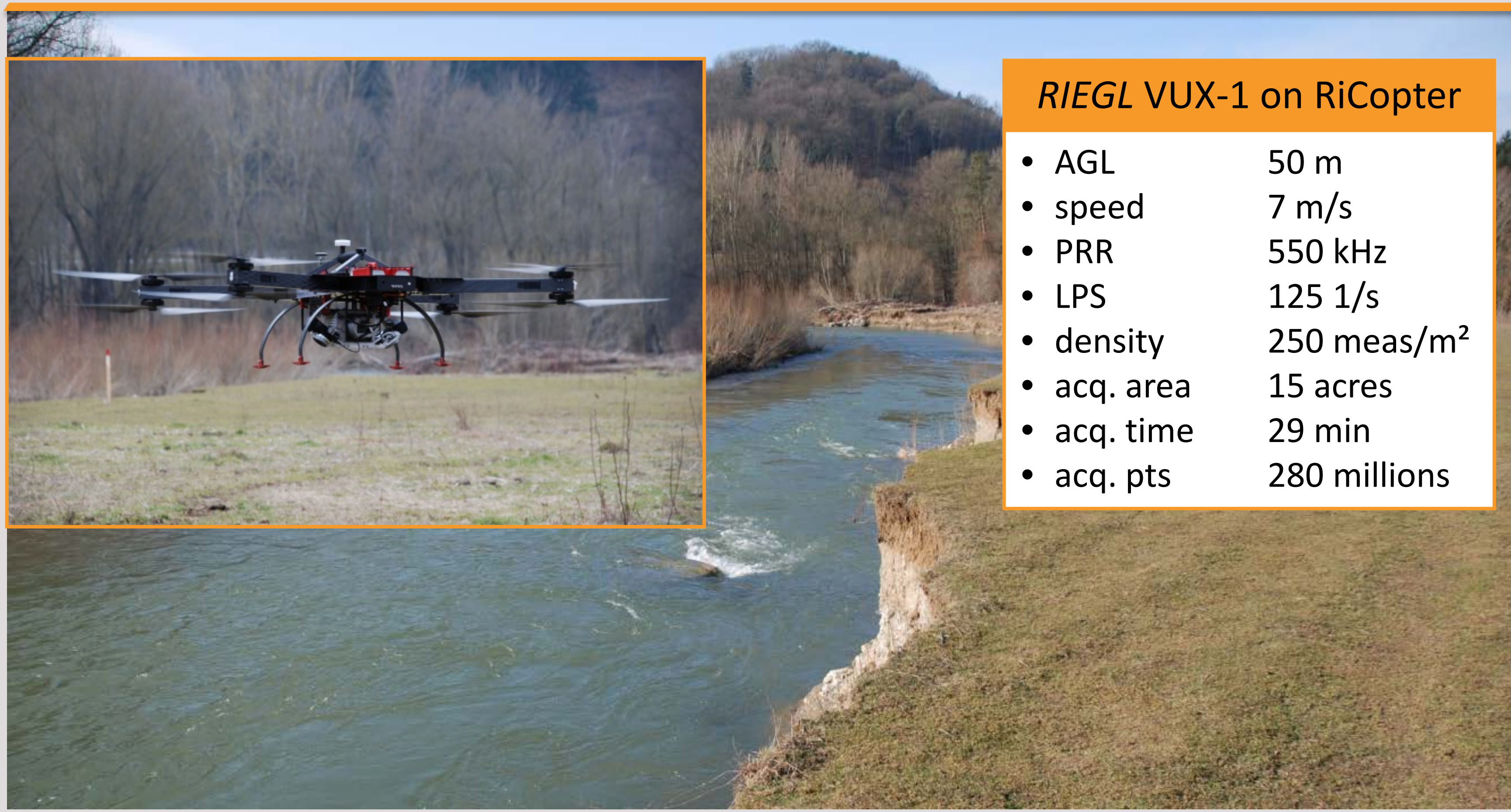
You are responsible for compliance to all laws

You must keep an aircraft log

You must report to the FAA any loss of at least $500

Michigan Highway Bridge Project

GNSS & Distribution of Measurements



RIEGL VUX-1 on RiCopter

• AGL	50 m
• speed	7 m/s
• PRR	550 kHz
• LPS	125 1/s
• density	250 meas/m²
• acq. area	15 acres
• acq. time	29 min
• acq. pts	280 millions

Distribution of Measurements: UAV Data Collect

RIEGL VUX-1 on RiCopter

- AGL 50 m
- speed 7 m/s
- PRR 550 kHz
- LPS 125
- density 250 meas/m²
- acq. area 15 acres
- acq. time 29 min
- acq. pts 280 millions

Sample Data

- area 720 m²
- tree height 35 m
- points 4.6 millions

Seamless GNSS Integrations and Calibration for…

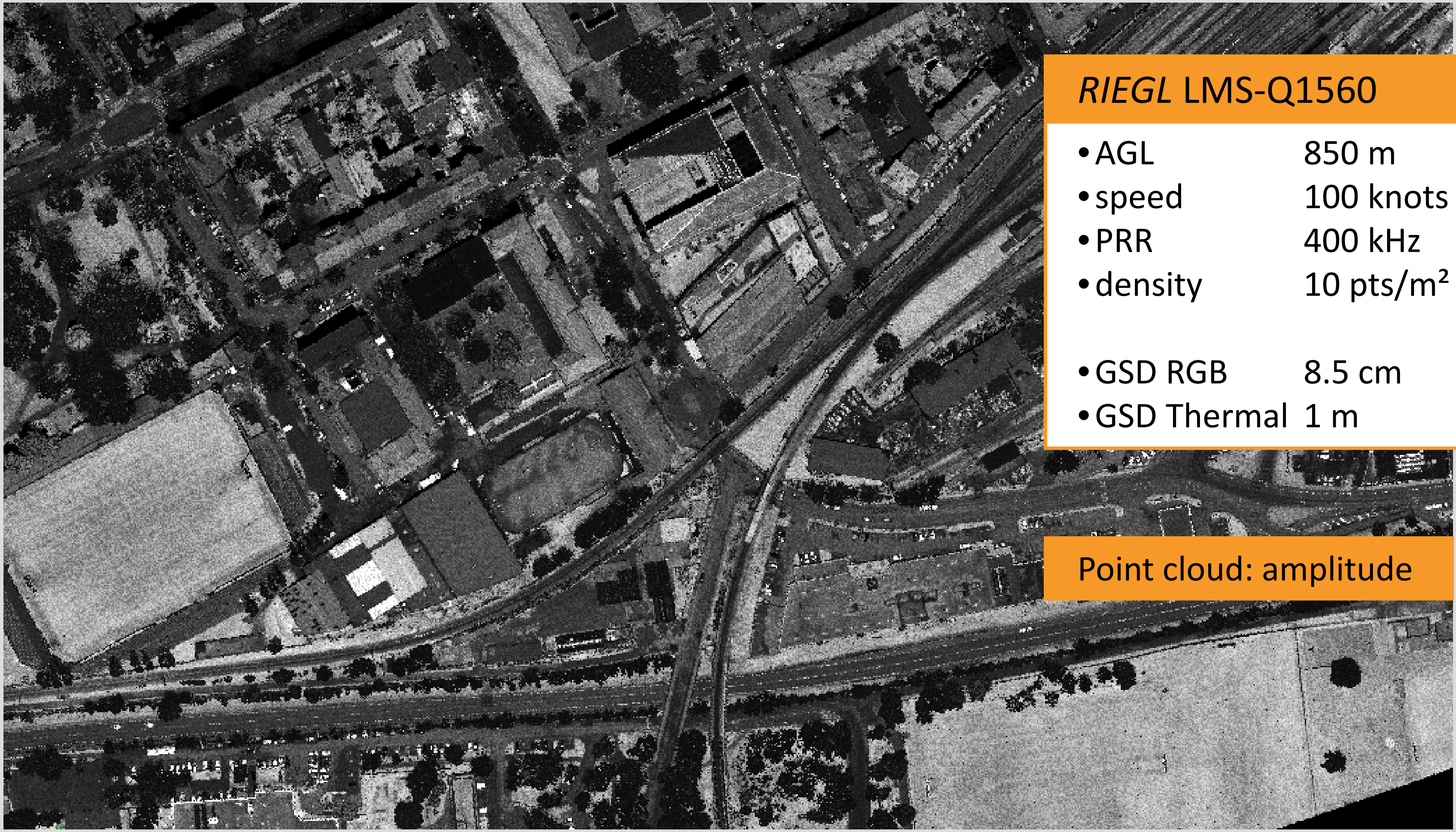
- Integrating *RIEGL* LIDAR engines with IMU/GNSS navigation solutions
  - precise time stamping for synchronization

- Integrating cameras with LiDAR scanners
  - power supply, trigger output, exposure input, data interface USB, GigE Vision
  - high-end consumer-grade cameras, thermal cameras, industrial cameras, FLIR's
  - precise time stamping essential (same 4 port interface)
  - *RIEGL* hardware and software for triggering, time stamping, image storage, preview generation

- Software for system integration for kinematic *RIEGL* LiDAR systems: RiACQUIRE

- Software for calibration / calibration verification: RiPROCESS

Seamless Integration and Calibration



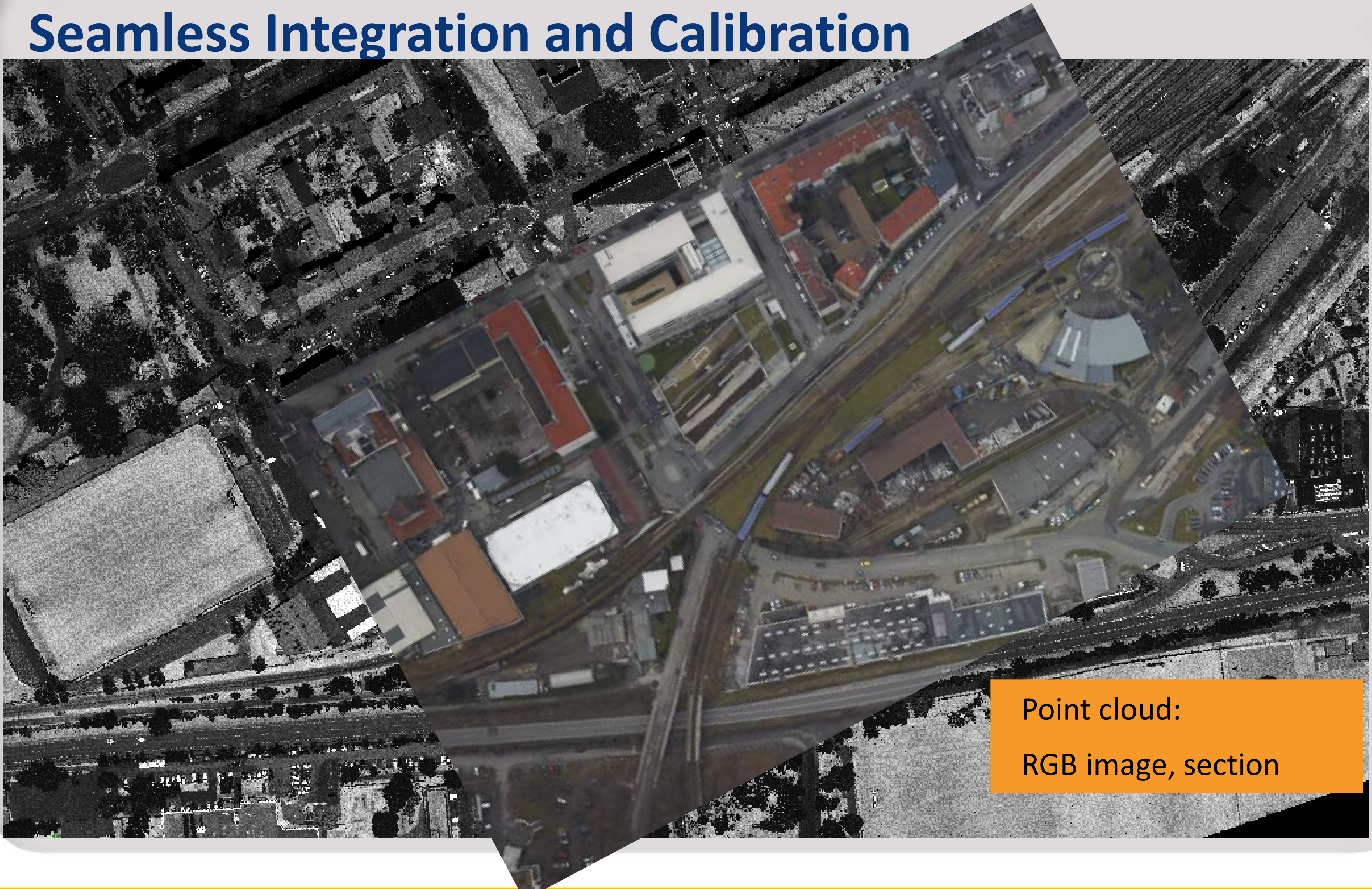
RIEGL LMS-Q1560

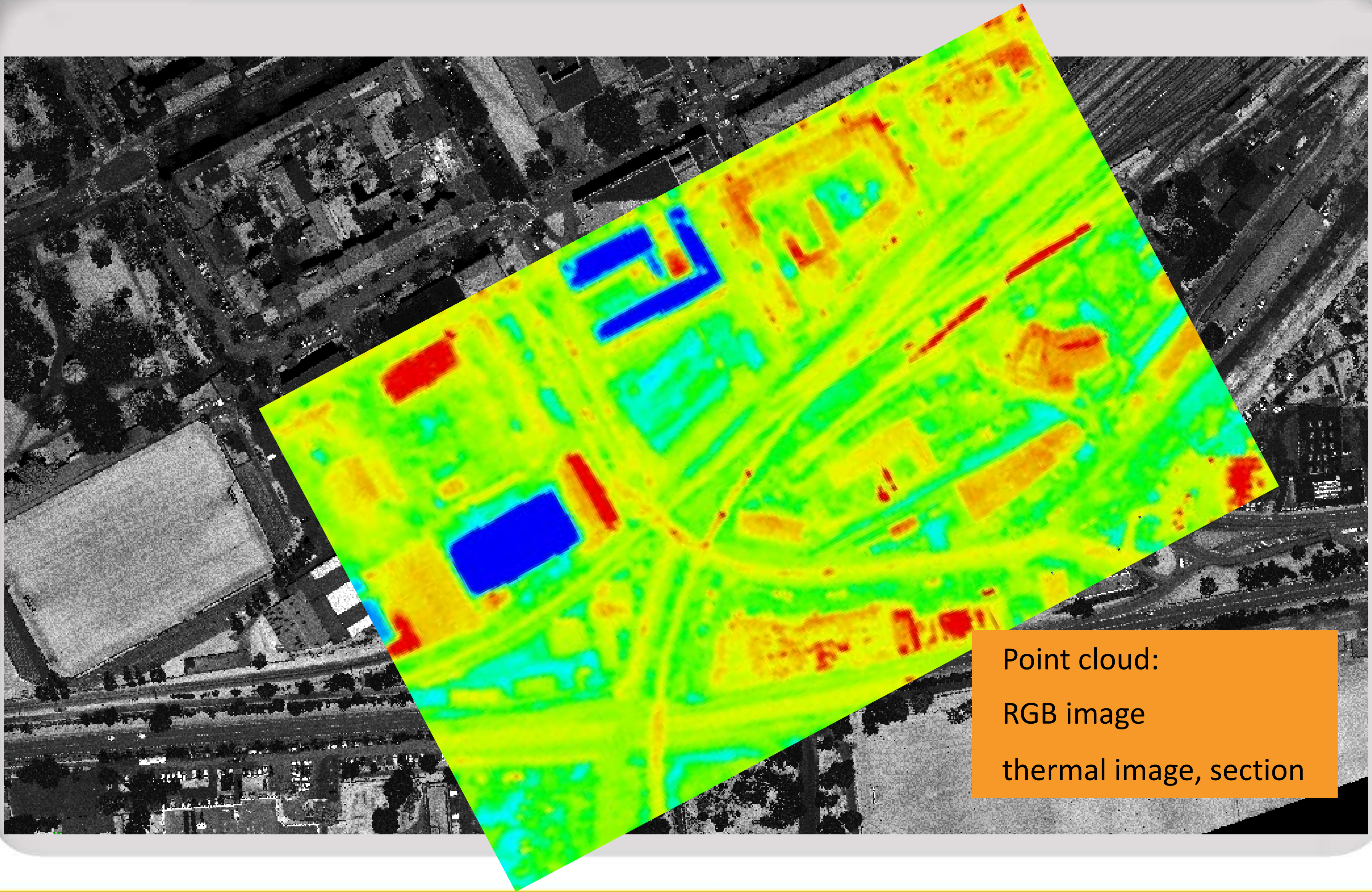
- AGL 850 m
- speed 100 knots
- PRR 400 kHz
- density 10 pts/m²

- GSD RGB 8.5 cm
- GSD Thermal 1 m

Point cloud: amplitude

Seamless Integration and Calibration



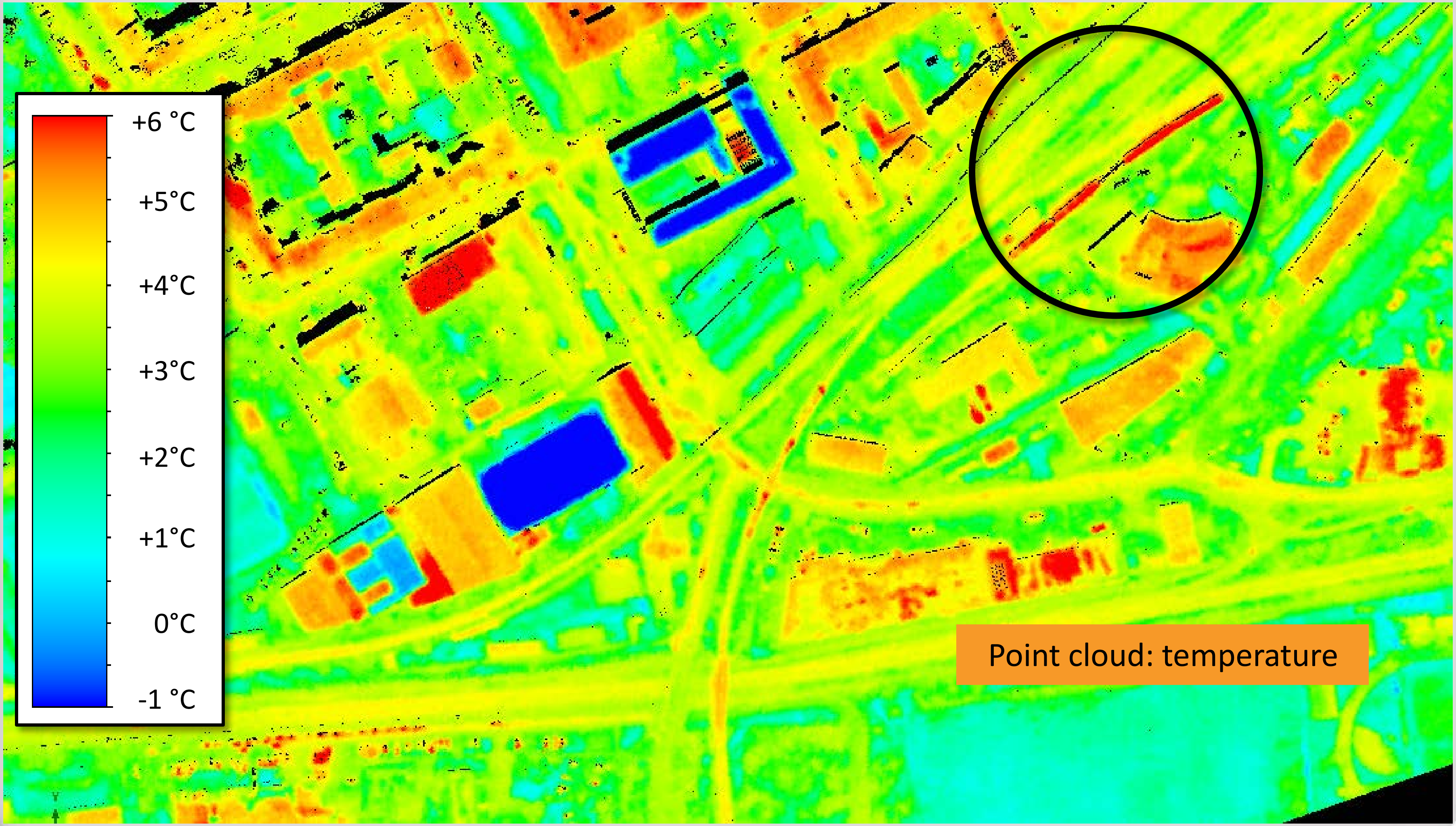


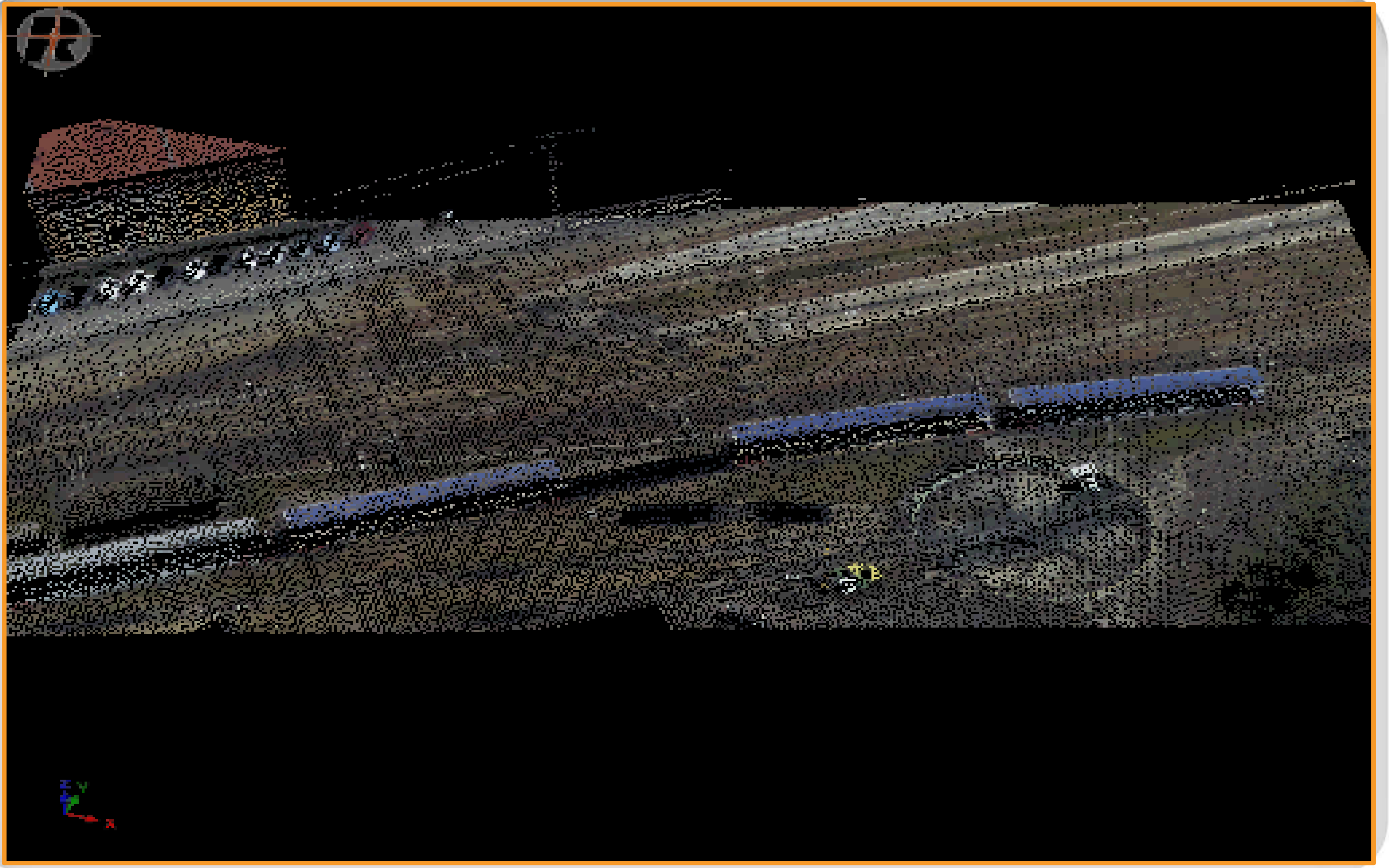
Point cloud:

RGB image

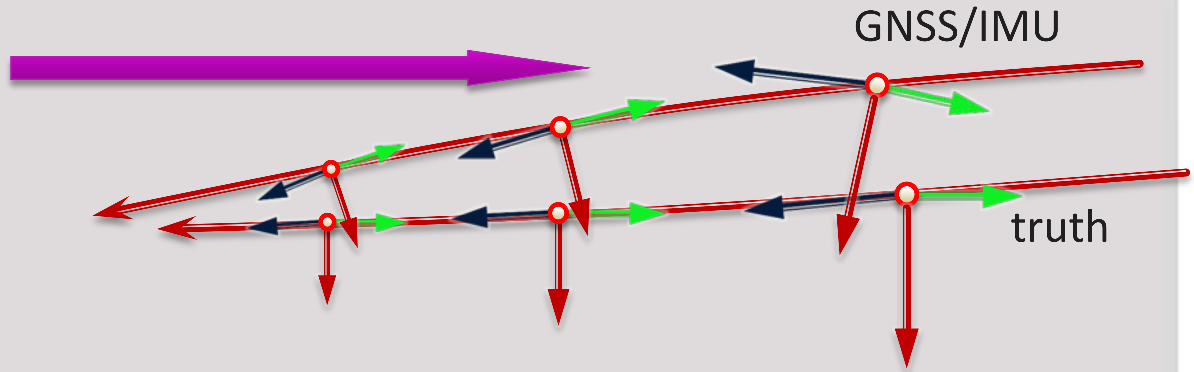
thermal image, section


Point cloud: RGB color


+6 °C
+5°C
+4°C
+3°C
+2°C
+1°C
0°C
-1 °C
Point cloud: temperature



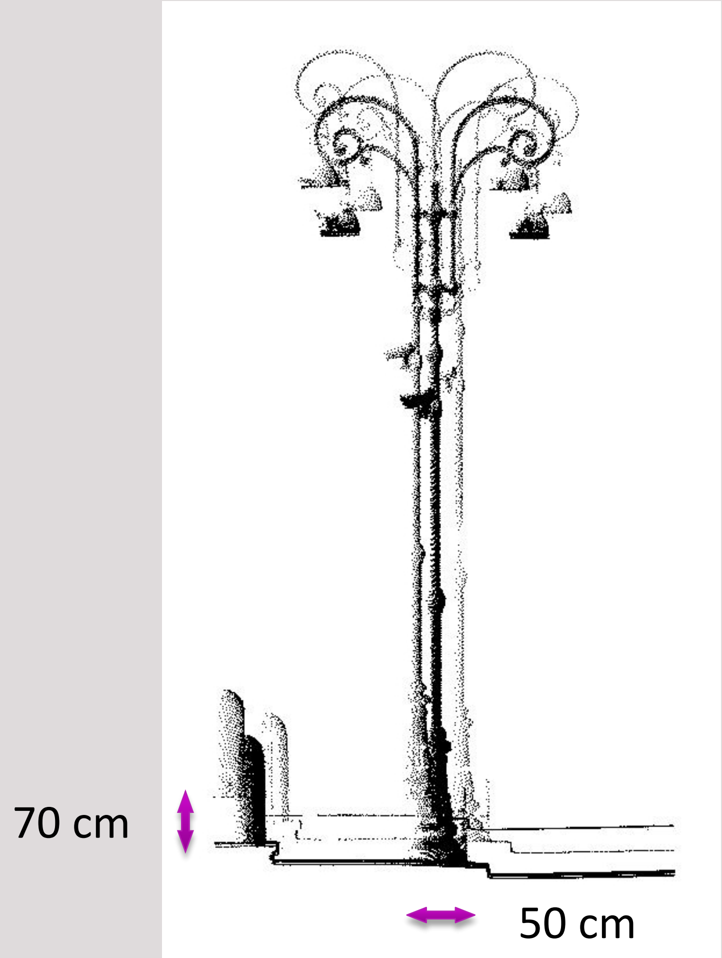
RiPrecision Adjustment of GNSS Trajectory



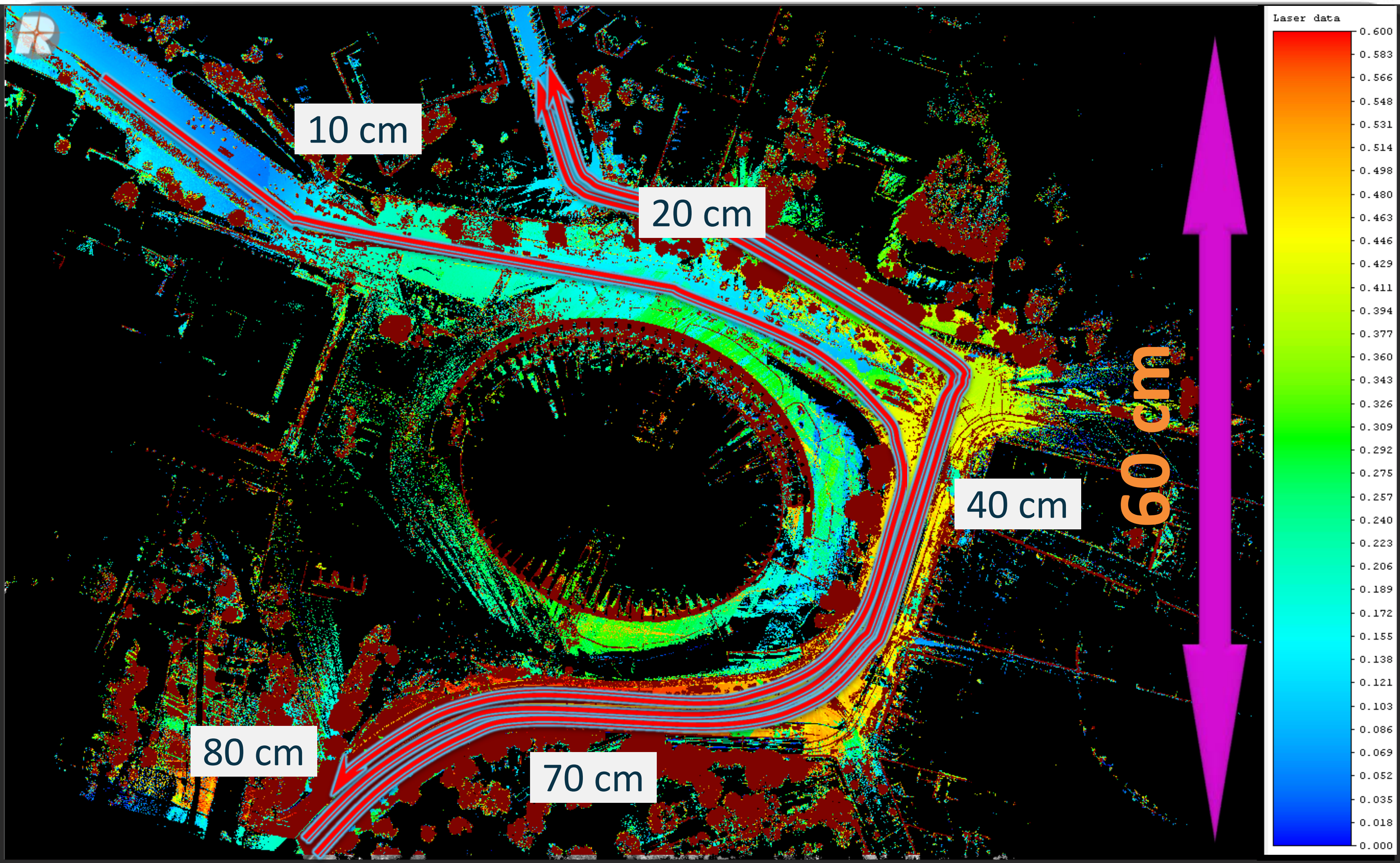
Laser Scanners	System Calibration	Platform Trajectory
Scanner coordinate systems	Lever arms and orientation	From GNSS/IMU
Highly accurate and precise	Highly accurate and precise	GPS denied low accuracy
~ Some mm	~ mm ~ mdeg	~ Some cm — m ~ Several mdeg

Point Clouds from Kinematic Laser Scanning

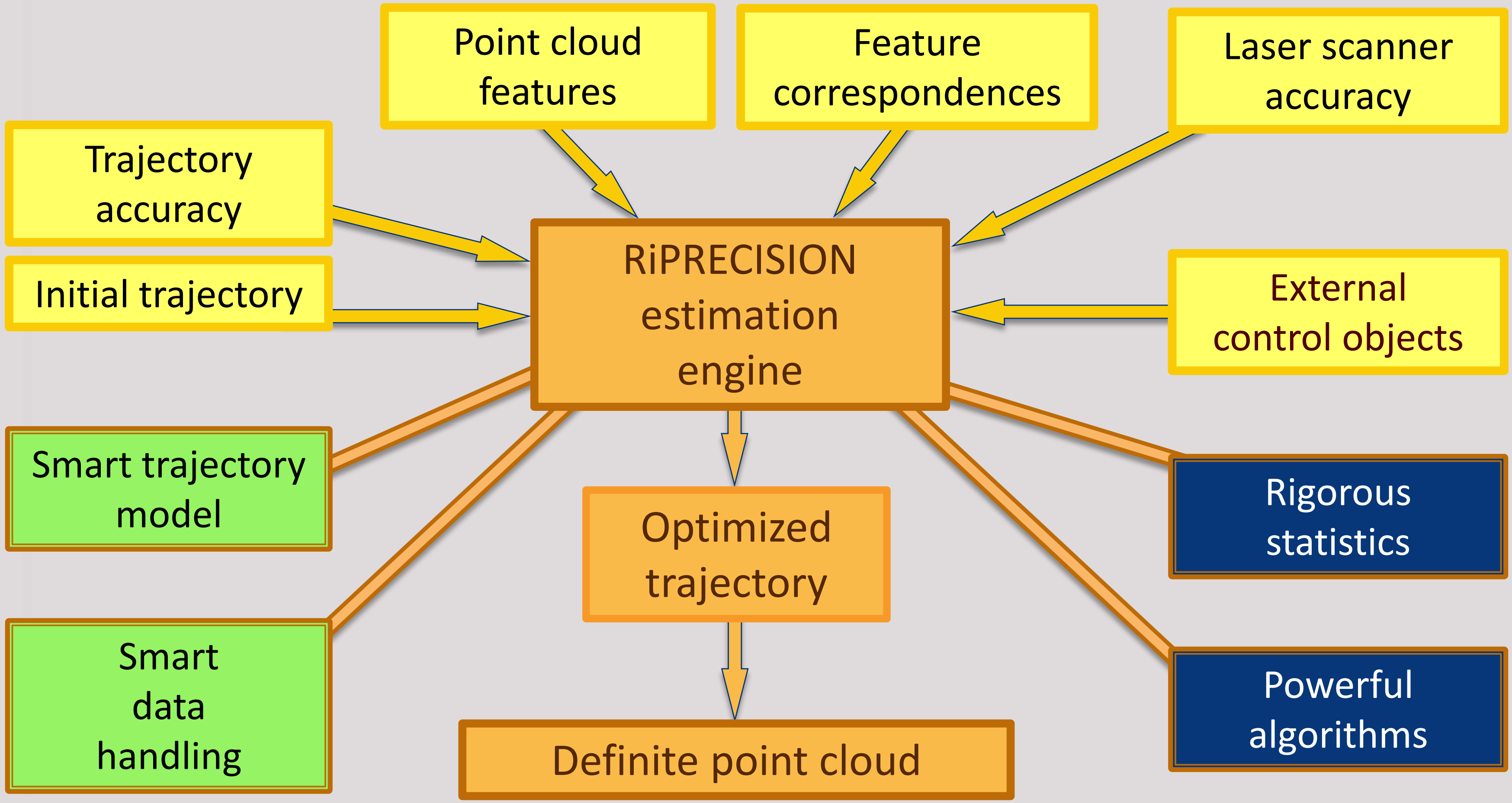
- Precise laser scanner data
- Deviations between different passes
- …12 scans (6 passes with 2 scanners)
  - 70 cm vertical separation
  - 50 cm horizontal separation

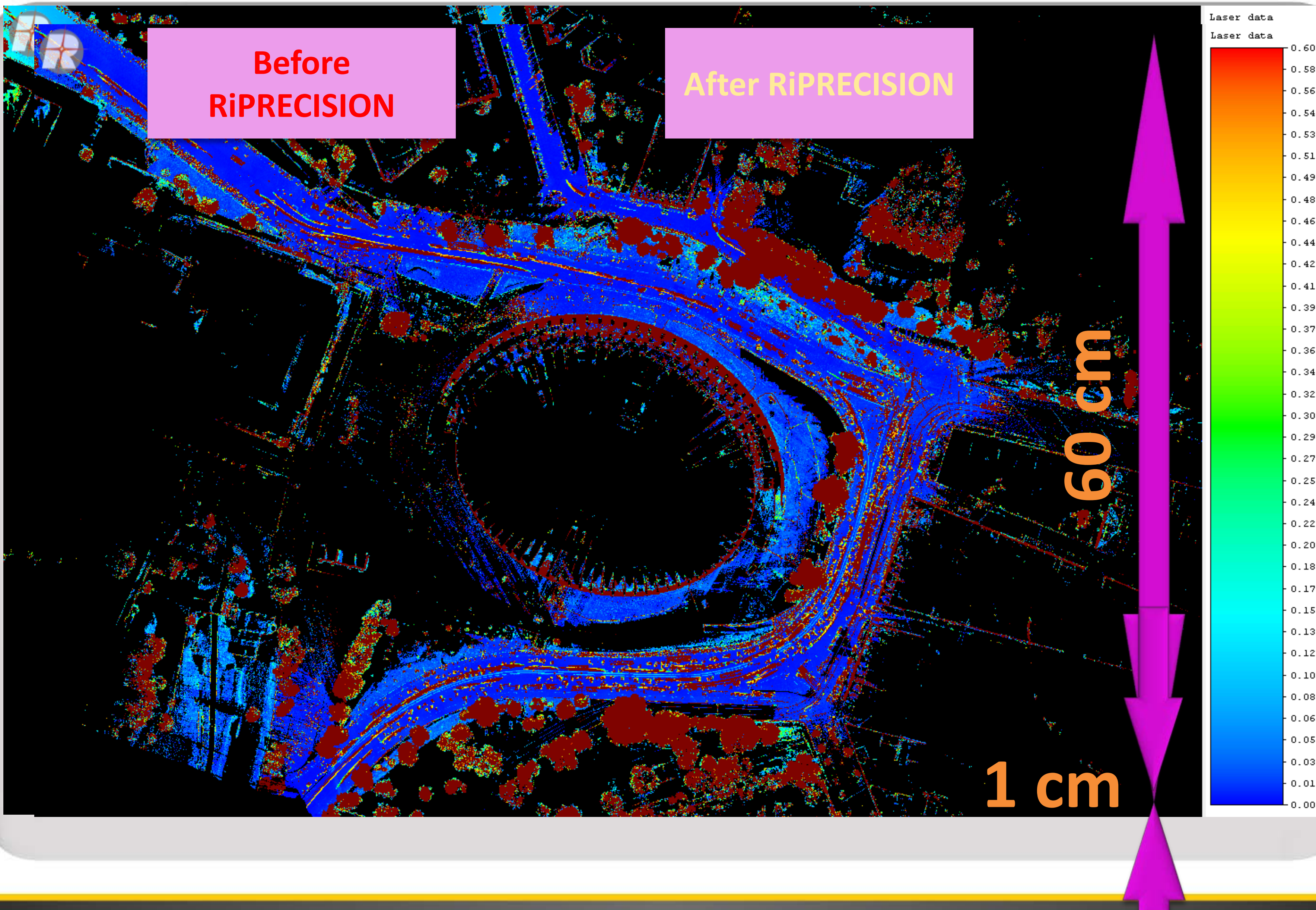


Effects on the Point Cloud



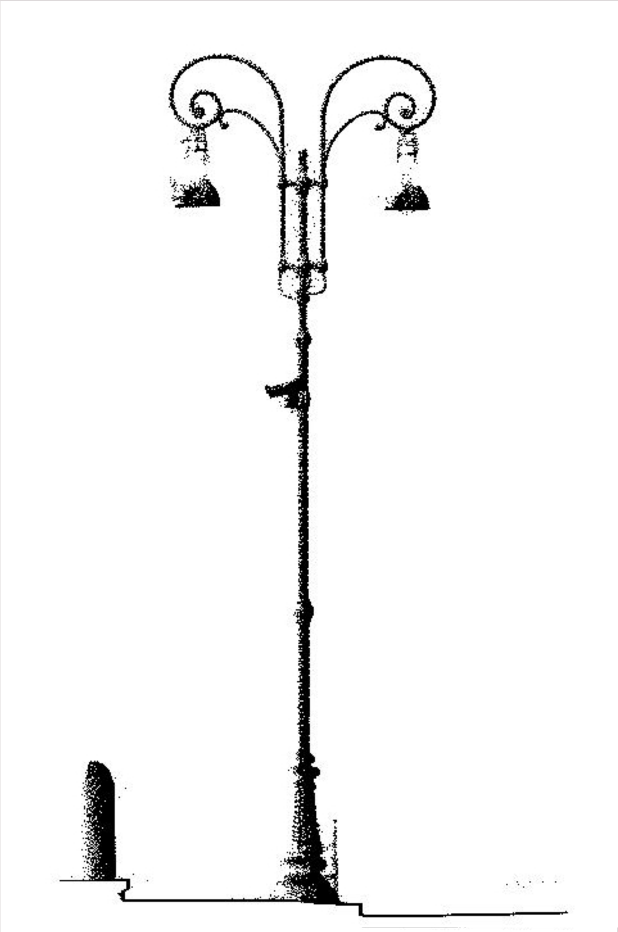
RiPRECISION –Working Principles



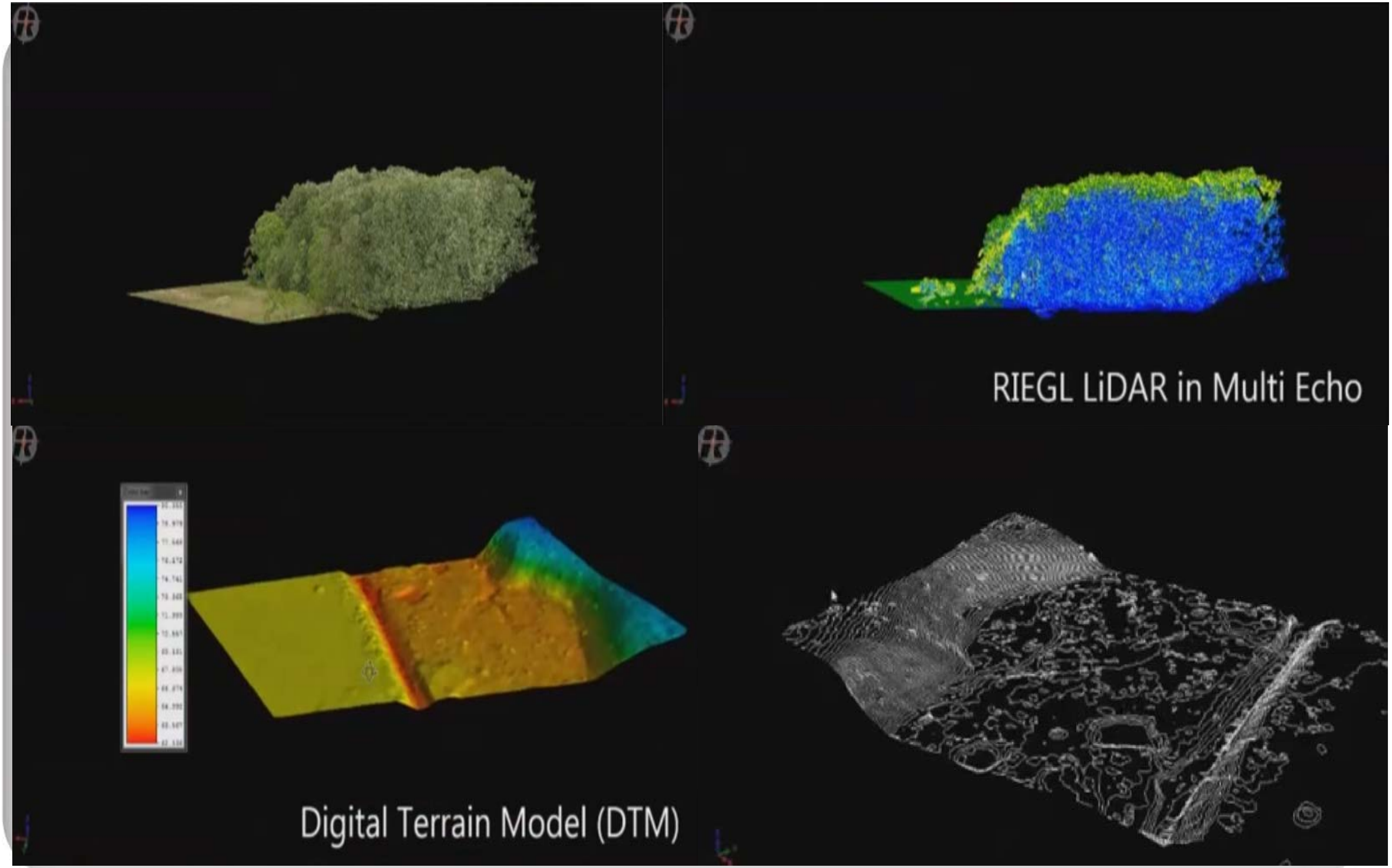

Before RiPRECISION
After RiPRECISION
60 cm
1 cm
Laser data
Laser data
0.600
0.583
0.566
0.548
0.531
0.514
0.498
0.480
0.463
0.446
0.429
0.411
0.394
0.377
0.360
0.343
0.326
0.309
0.292
0.275
0.257
0.240
0.223
0.206
0.189
0.172
0.155
0.138
0.121
0.103
0.086
0.069
0.052
0.035
0.018
0.000

RiPRECISION Details—Street Lamp

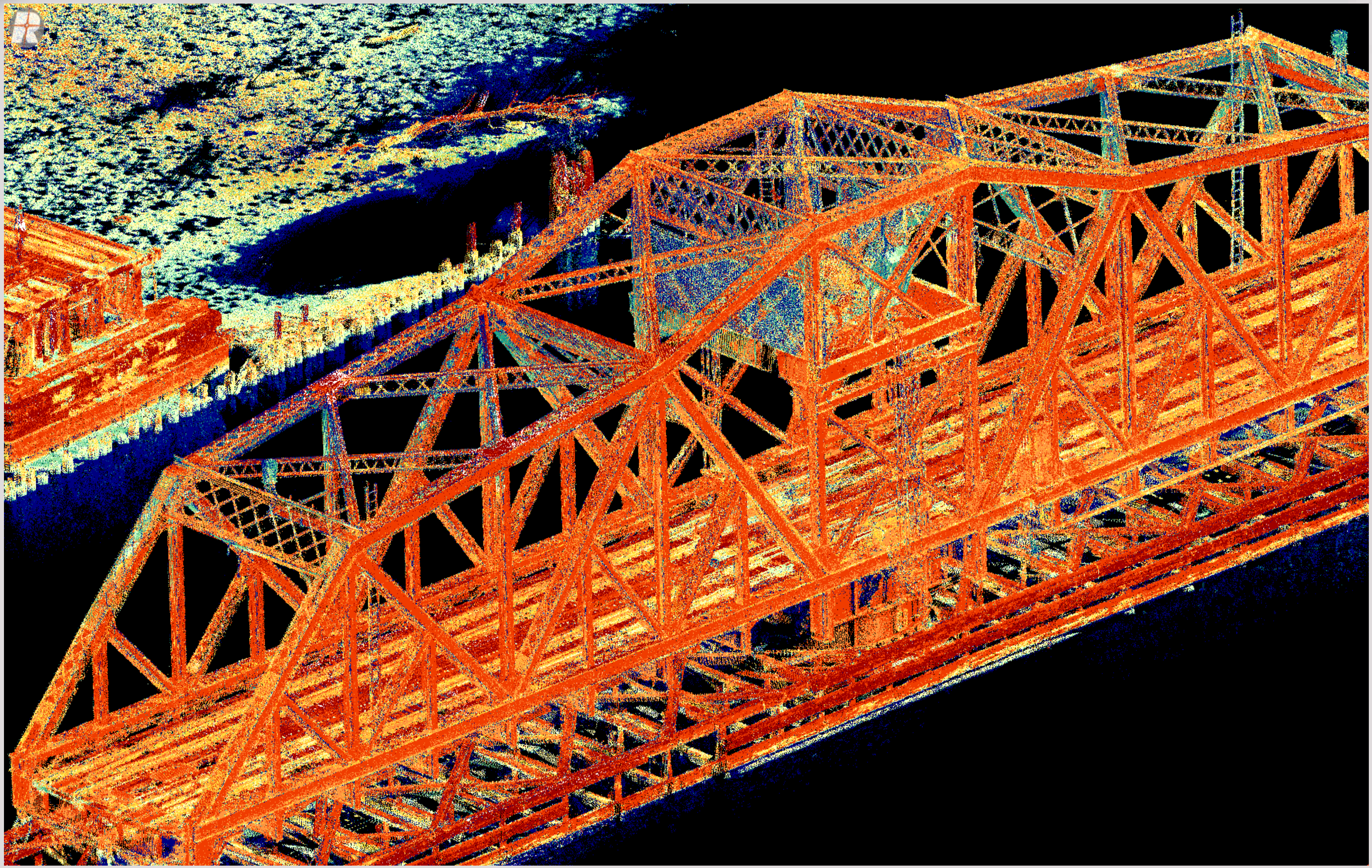
Before RiPRECISION



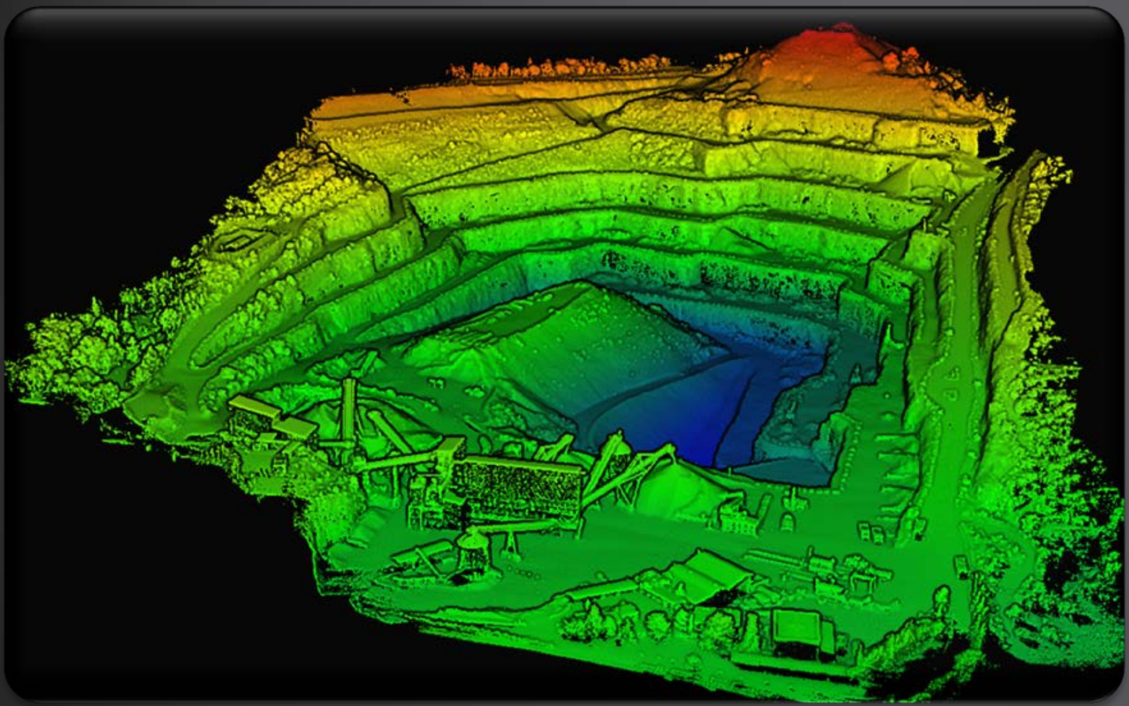
After RiPRECISION


RIEGL LiDAR in Multi Echo
Digital Terrain Model (DTM)

FROM BIG DATA TO INFORMATION



Benefits of Direct Georeferencing for simultaneous LiDAR / photogrammetry systems versus traditional Aerial Triangulation. Example of a quarry site in France.



Pierre Chaponniere
Application Engineer
YellowScan

YellowScan – lightweight LiDAR manufacturer

YellowScan designs and develops ultra compact and light weight LiDAR systems

We come from :

- Research & surveying background – tight & strong collaboration with academic research
- 12 years of operation experience in the field
- Prototyping phase for YellowScan's first LiDAR solution started in 2012

We provide LiDAR systems :

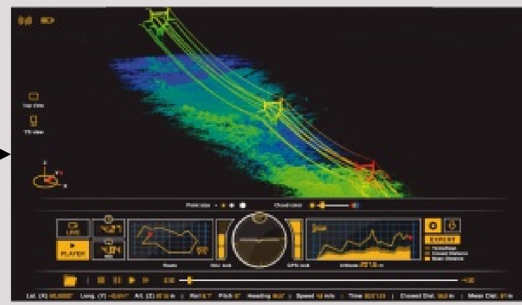
- Highly integrated, lightweight & easy-to-use : everything's included
- Robust & Versatile: Operated on dozens unmanned aircrafts worldwide
- Global support & LiDAR expertise



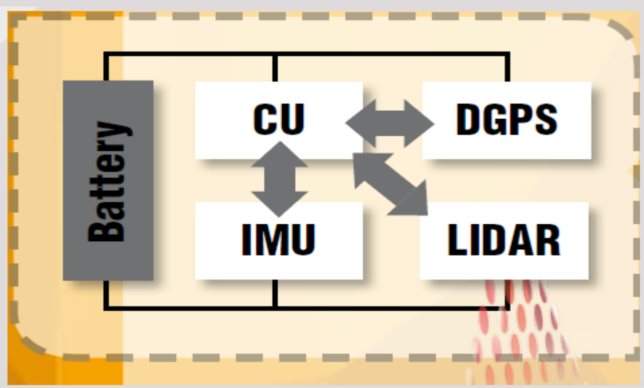

YellowScan LiDAR systems

FAA Part 107 compliant ? ….you're left with 52.8 lbs to organize a flying rig!

- Ultra light systems : only 2.2 lbs for the Surveyor (all in, batt. incl.)
- Self powered and autonomous
- Ready to use
- DG ready systems and photogrammetric DG-enabling devices
- Real time monitoring



YellowScan Mapper

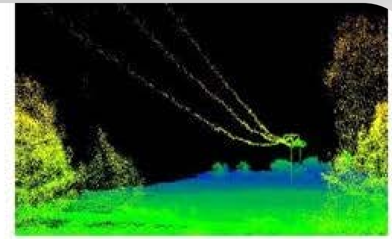


YellowScan Surveyor

YellowScan applications

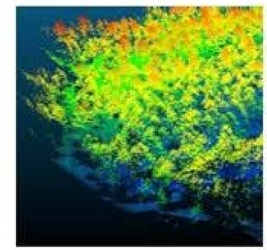
Power Lines

ERDF SNCF



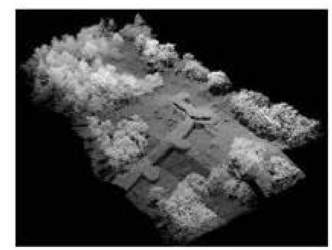
Forestry

Office National des Forêts carbomap FPInnovations



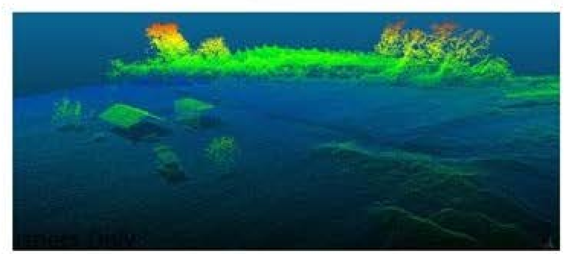
Archeology

Inrap cnrs

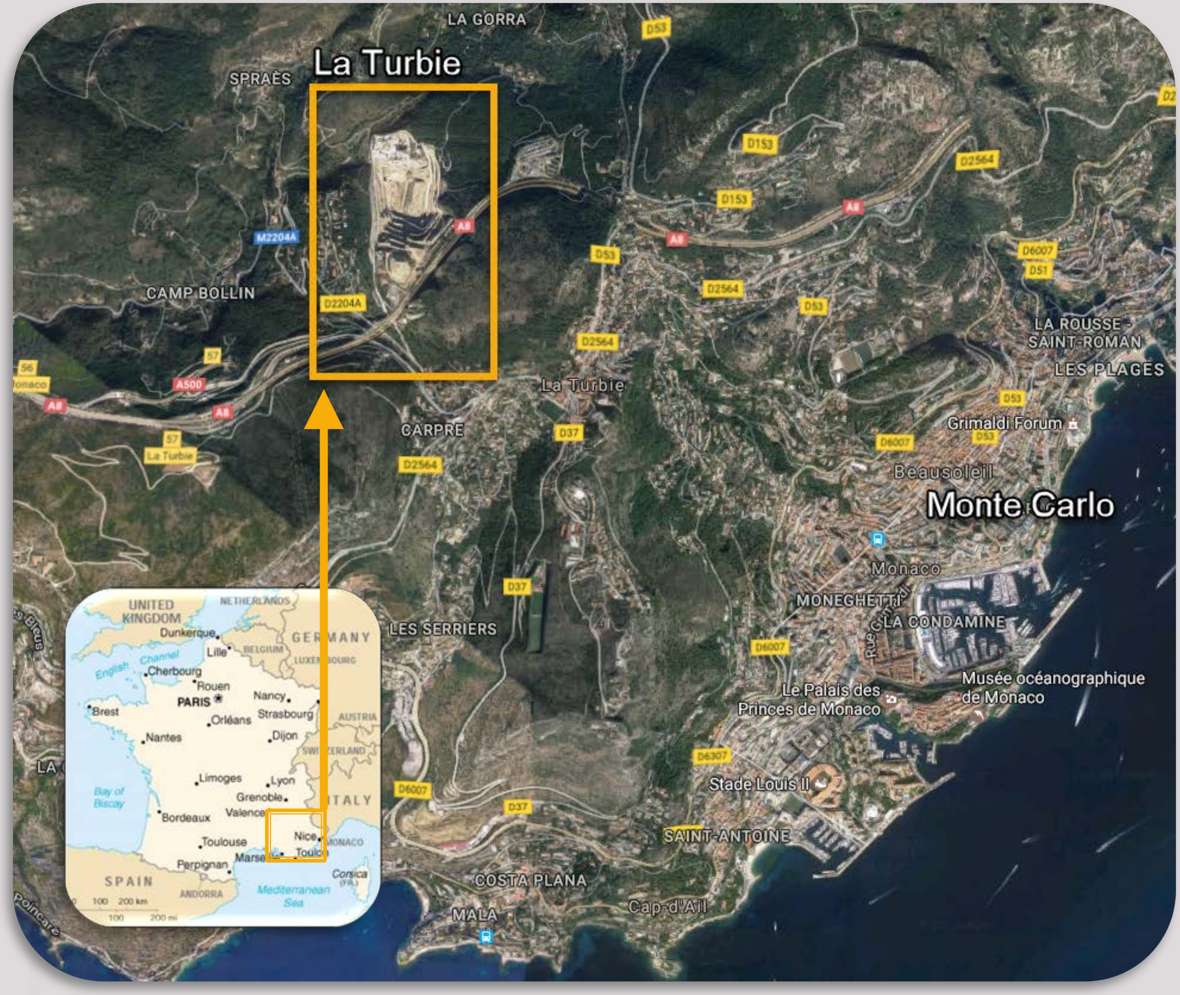


Civil Engineering, Mining

COLAS EUROVIA suez SITA



Test site – Quarry in France



Operator's need :

- Quarterly maps
- Infrastructure planning
- Volumetric calculations

Specificity

- 140m deep pit
- 25ha

Surveying techniques used at La Turbie

Terrestrial LiDAR System (TLS)

Trimble TX5 scanner

Up to 976kHz frequency
Up to 120m range, 11lbs

Photogrammetry (AT process)

DJI Inspire

16 Mpx X5 camera: FC550
4608 x 3456, f: 15

Dual LiDAR / photogrammetry (DG system)

YellowScan Surveyor

PPK mode, 2.2lbs
24 Mpx Sony A6000 :
6000 x 4000, f: 18

Operational considerations

Terrestrial LiDAR System (TLS)

- Calibration of the scanner
- Setup & survey checkerboard - RTK GPS and theodolite used
- Reflective sphere targets to move between scans

Photogrammetry (AT process)

- Flight @ 100m AGL
- Install & survey 7 GCPs

Dual LiDAR / photogrammetry (DG system)

- Base station setup
- Adaptative flight plan height @ 40m AGL

Timing

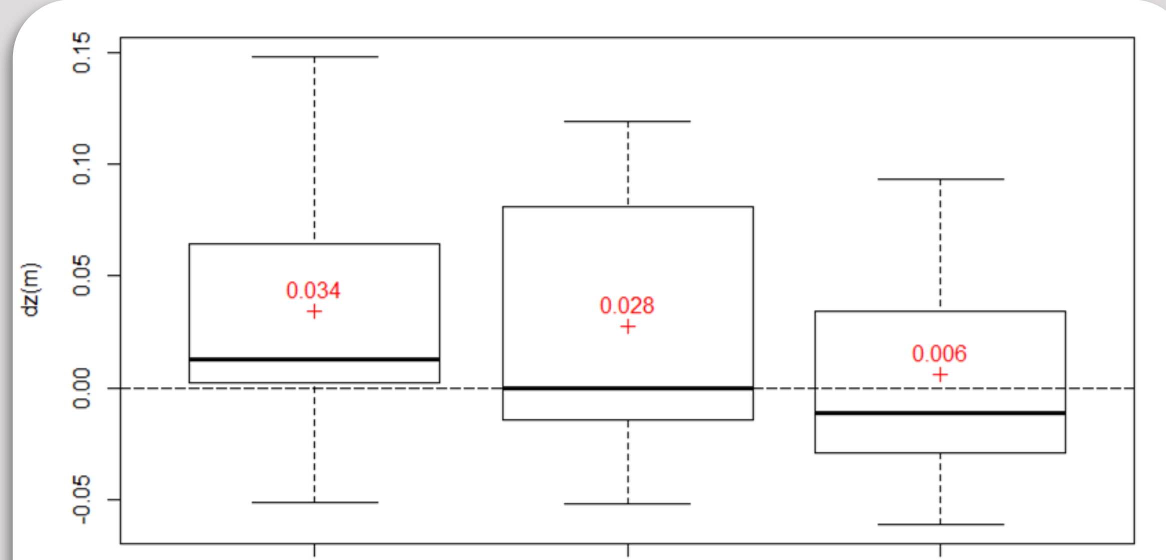
	Terrestrial LiDAR System (TLS)	Photogrammetry (AT process)	Dual LiDAR / photogrammetry (DG system)
Field survey	**6h** Covered 22 stations Surface covered ~**1ha**	**6h** 10x10min flights + preparation Surface covered ~ **25ha**	**2h** 4 x 10min flights + preparation Surface covered ~ **25ha**
	➔ 2Gb scan data	➔ 6Gb (900 images .tif)	➔ 4.1Gb scan data + 6.7Gb (669 images .tif)
Manual processing	**+2h** –sphere and checkerboard seach & alignement	**+0h** - Automated process	**+0.5h** - PPK process **+1h** - Line matching + classification **+2h** - DG images and ortho generation
Machine processing	**+1h** – export process	16 Mpx camera **+12h** - AT, GCP, dense cloud 24 Mpx camera (from LiDAR survey) **+40h** – AT, GCP, dense cloud	**+2h** – matching & classification process
Products	➤ 0.1ha/h **TLS** **2Gb las, unclassified,** **GSD = 1cm**	➤ 0.5ha/h **YS AT 24Mpx** **10Gb las, unclassified** **GSD = 2cm** ➤ 1.4ha/h **DJI AT 16Mpx** **0.6Gb las, unclassified,** **GSD = 10cm**	➤ 3.3ha/h **YS-DG** **2.7Gb las, colorized DG & classified,** **GSD = 5cm**

Absolute accuracy assessement

7 installed target points used for photogrammetric AT process

+ 27 ground truth points collected during the mission using RTK GPS on bare earth

Control report assessment : 1/Point cloud meshing at direct vicinity of validation point, 2/Validation point to mesh vertical distance measurement



TLS
(no validation points available)

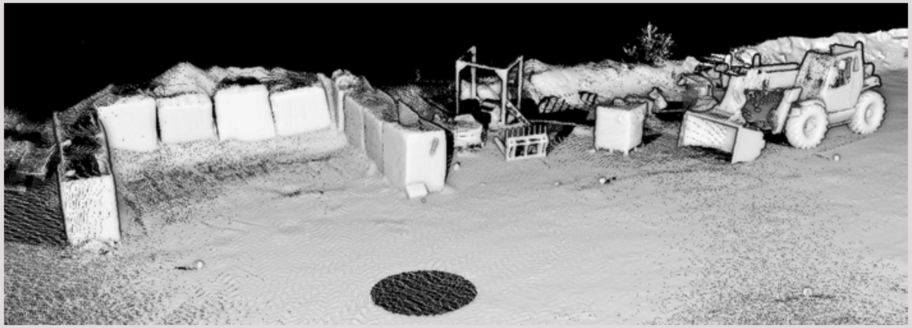
YS AT 24Mpx
AT GCP excluded
27 validation points
RMSEz = 61mm

DJI AT 16Mpx
AT GCP excluded
27 validation points
RMSEz = 62mm

YS-DG
27 validation points
RMSEz = 45mm

Accuracy assessement – cloud to cloud

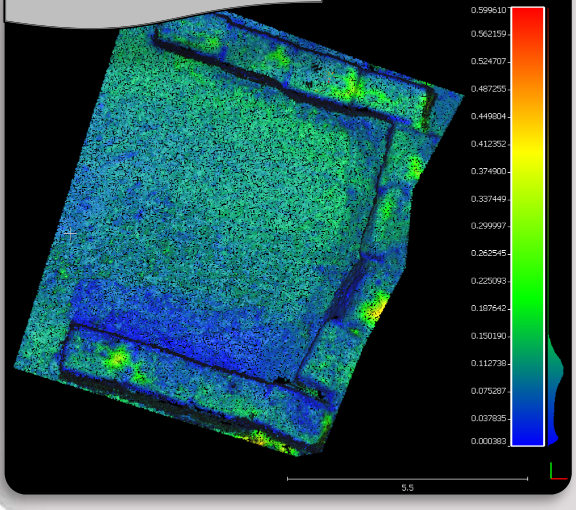
Cloud selection representative of sharp slope changes



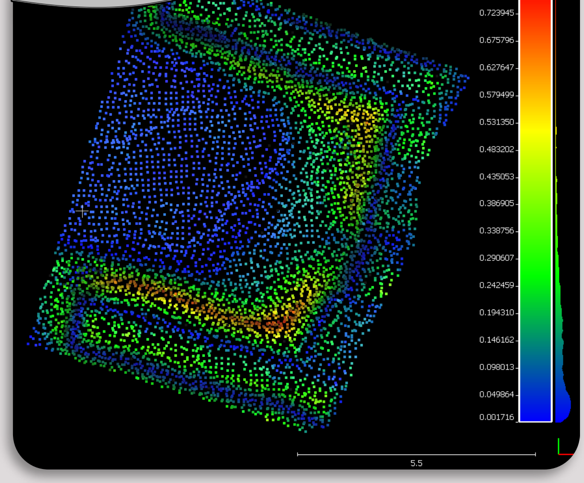
TLS

Used as reference

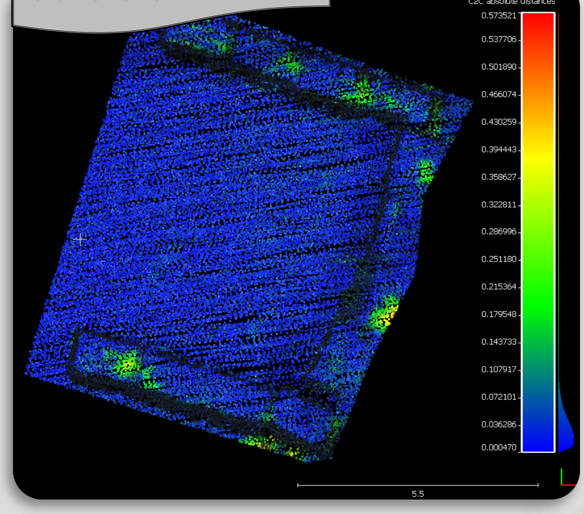
YS AT 24Mpx
Mean distance = 84mm
Std deviation = 47mm



DJI AT 16Mpx
Mean distance = 175mm
Std deviation = 148mm

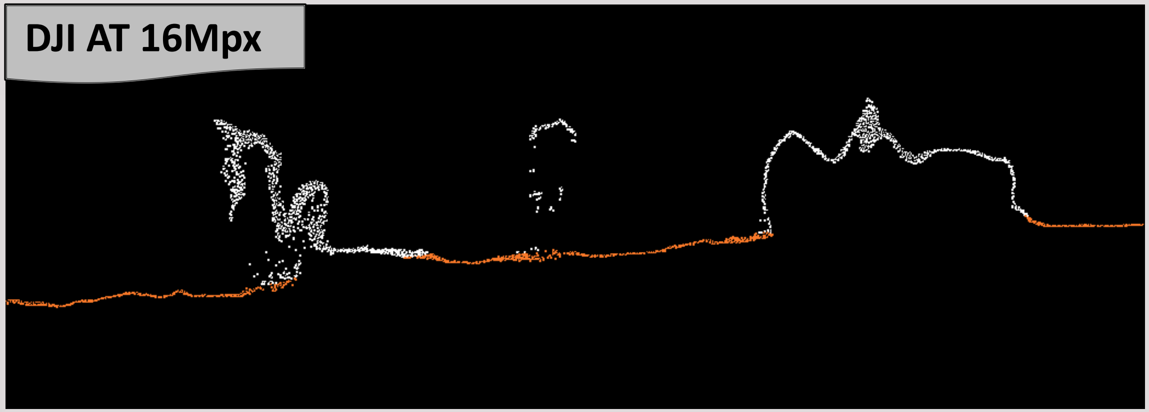


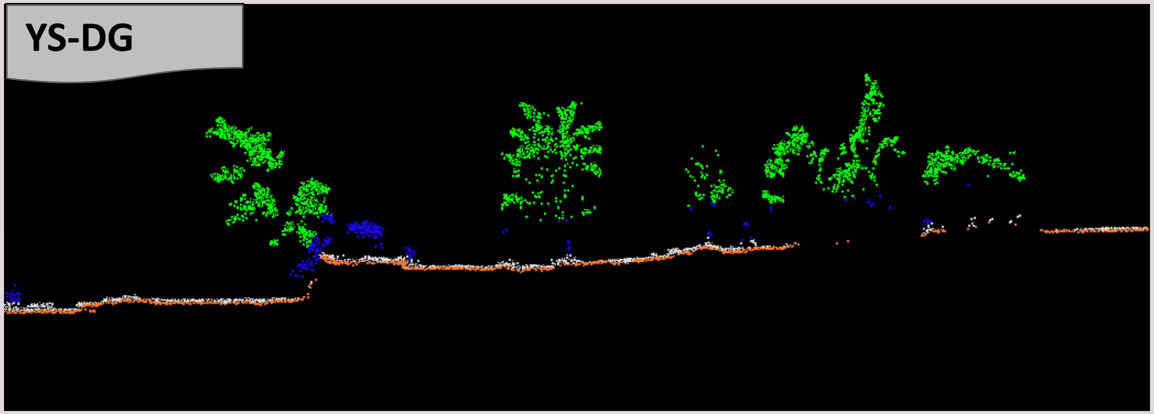
YS-DG
Mean distance = 42mm
Std deviation = 41mm



Qualitative comparison

Vegetation penetration





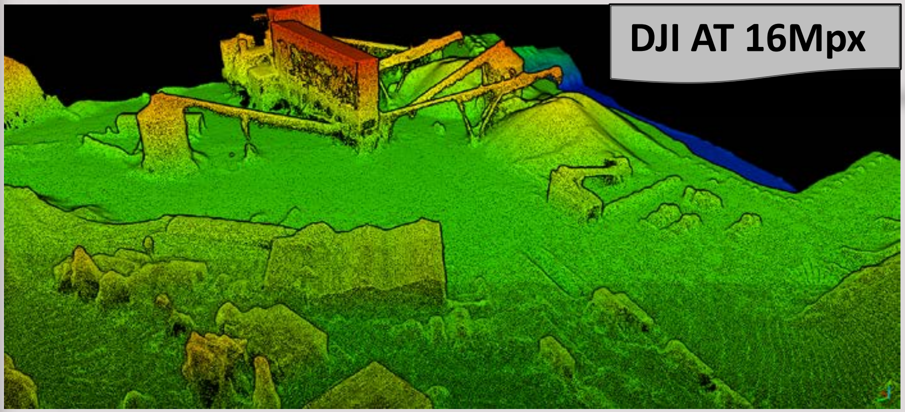
20cm cross section view at same extent & scale

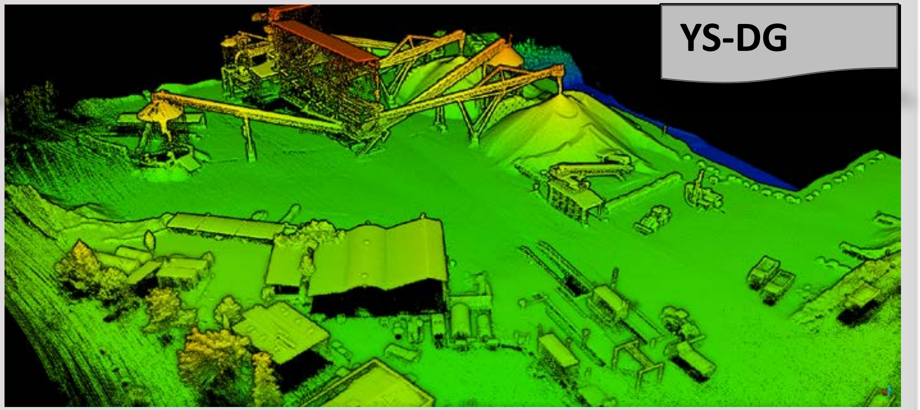
Qualitative comparison

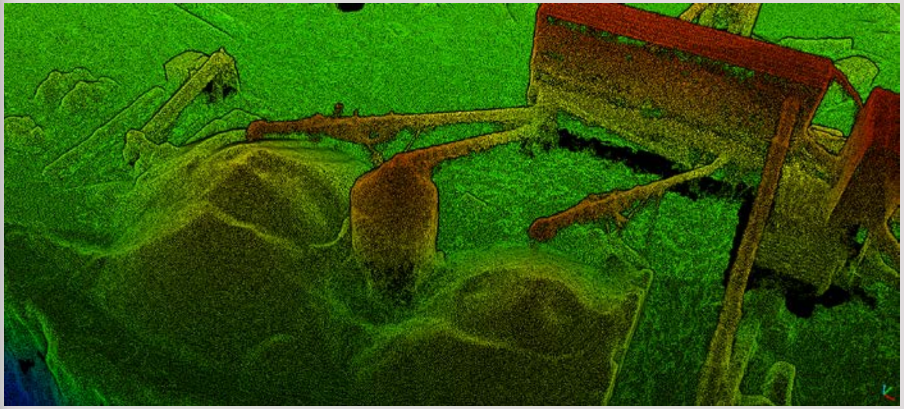
InsideGNSS applanix inside unmanned systems

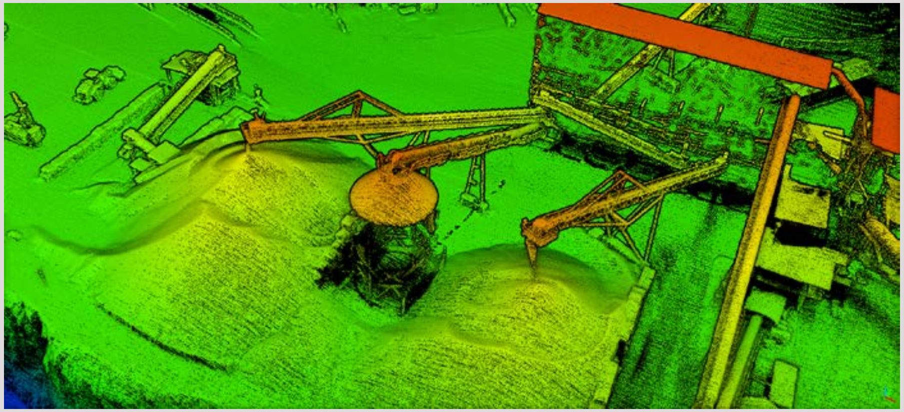
Infrastructure mapping

Quarry offices and conveyors – same extent & scale









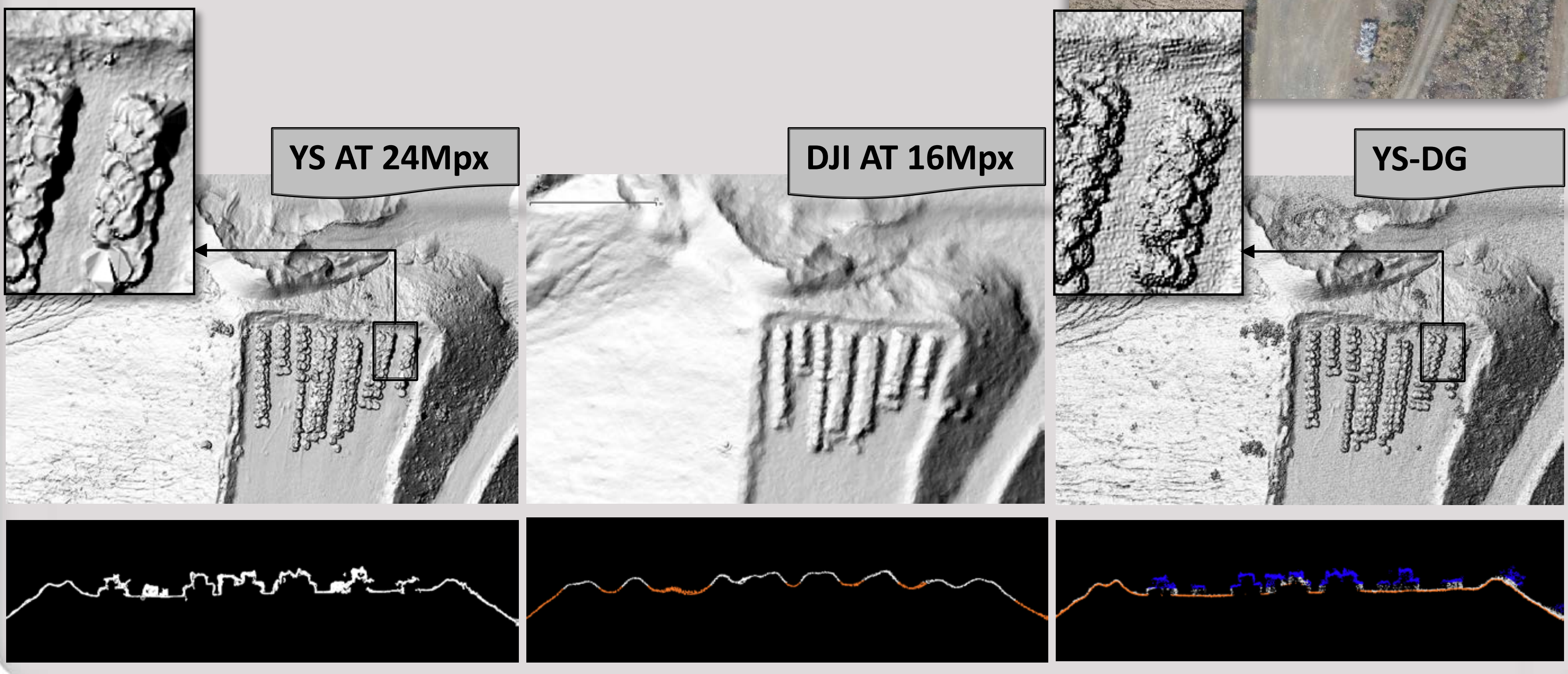
Qualitative comparison

Sharp slope changes – bulk bag storage

Hillshade (top) and 20cm cross section views of the products

Photogrammetric resolution is key

But shadows remain an issue



Conclusion

In summary

	TLS	YS AT 24Mpx	DJI AT 16Mpx	YS DG
Production rate	0.1 ha/h	0.5 ha/h	1.4 ha/h	3.3 ha/h
GSD	10mm	20mm	100mm	50mm
Accuracy - GCP	na	61mm	62mm	45mm
Accuracy - extent	reference	47mm	148mm	41mm
Key points	• Tedious setup • Need GCPs • Low coverage • Shadow issues ++	• Quick to deploy • Adapt AGL • Less overlap • Need GCPs…AT :(• Long computing time • Shadow issues	• Quick to deploy • Easy flight plan • High overlap • Need GCPs…AT :(• Shadow issues • Draping effect	• Quick to deploy • Adapt AGL • 1 GCP (base) DG ! • Active light • Below vegetation • Accurate • Reliable The one tool every surveyor needs !

Conclusion

What benefits for simultaneous LiDAR / photo DG solutions vs AT photogrammetry ?

- Faster survey time (less flight lines needed), faster processing time
- Reduction / elimination of need to survey GCPs in the field

Other benefits inherent from remote sensing surveys

- Safer operations, no disturbance, no operation down time
- Faster data collection
- Wider field of view

More benefits inherent from LiDAR surveys

- Faster survey, faster data process
- Active light captures ground points under vegetation and not affected by sunlight
- Not impacted by image correlation issues (homogenous surfaces like snow, sand)
- Ability to capture fine infrastructures or objects (power lines, conveyors…)

YellowScan

Visit us & register @
www.yellowscan.fr

Next Steps

Visit **www.insidegnss.com/webinars** for:

- PDF of Presentations

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Poll #3

Are you ready to invest in LIDAR?

(Please select one)

- Right now- tech is mature!
- Within a year.
- 1-3 years from now.
- Beyond 3 years.

Ask the Experts – Part 2

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CEO
***RIEGL* USA**

Pierre Chaponnière
Application Engineer
YellowScan

Lewis Graham
CTO
GeoCue Corporation

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Applanix @ www.applanix.com