LIDAR Workshop
IPSRS – Commission 1

2-Jul-2007, Ljubliana, Slovenia

Arthur Rohrbach, Leica Geosystems, Switzerland

- when it has to be right

Presentation topics

1. **Basics of Airborne LIDAR Sensing Technology**
2. **Typical Applications** (for Airborne LIDAR Technology)
3. **System Components** (of Airborne LIDAR Scanners)
4. **Performance Parameters** (for Airborne LIDAR Missions)
5. **Operational Workflow** (for Airborne LIDAR Operations)
6. **Costs Parameters** (for Airborne LIDAR Operations)
7. **Practical Examples / Application Cases / Planning**
8. **Dual Airborne Sensor & LIDAR Scanner Systems**
9. **Outlook / Trends**

Topic - 1

Basics of Airborne

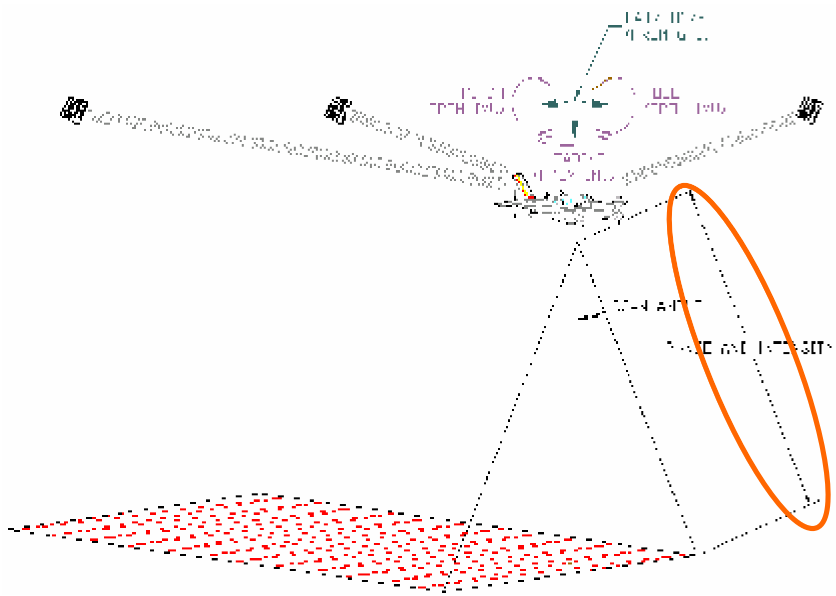
LIDAR

Sensing Technology

Typical LIDAR technology implementation

Develop lat/lon/el of points on ground based on:

- Aircraft position (lat/long/H)
- Aircraft orientation (roll/pitch/heading)
- Scan angle
- Round-trip propagation time of laser pulse
- Atmospherics



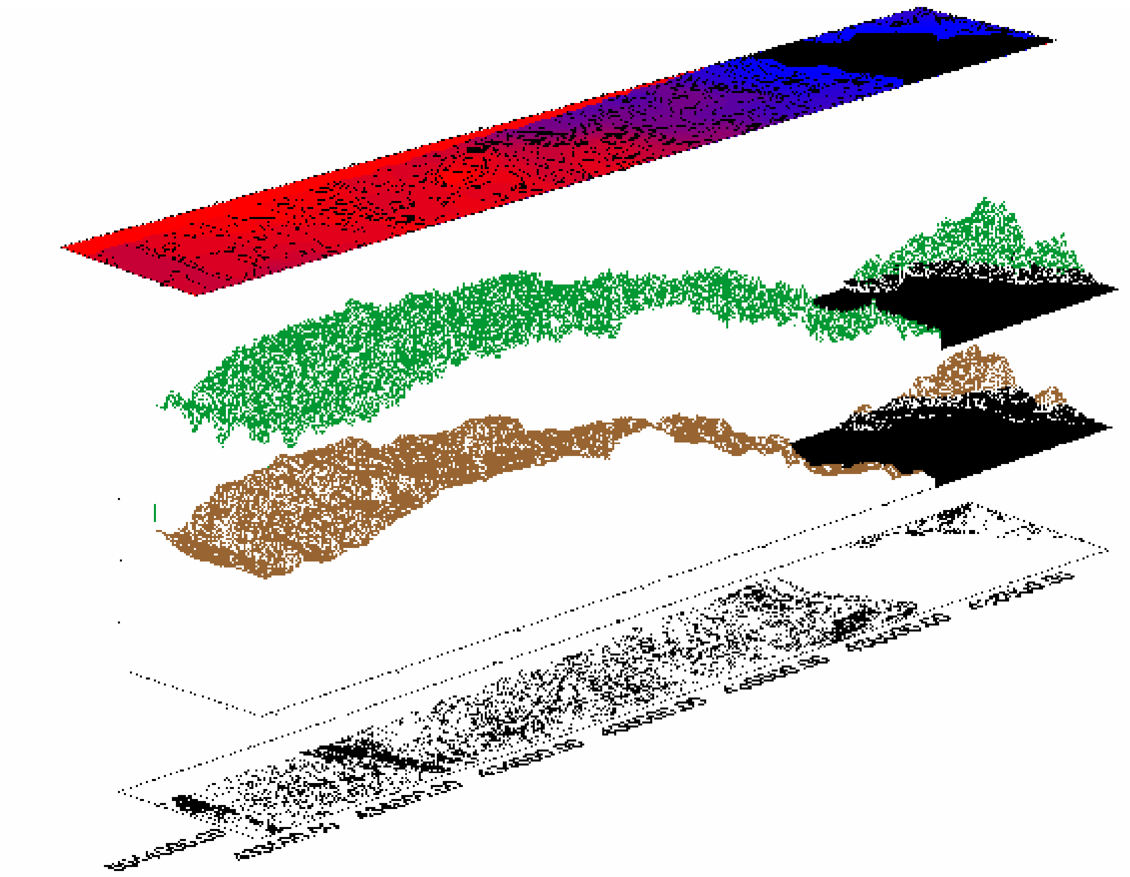
Raw data recorded in air (System) & on ground (DGPS base station)

Recorded data post-processed on ground

Multiple-return intensity concerns attributes of the range measurement

- Time or distance
- Intensity

Basic Lidar Data "Layers"



Surface Mapping

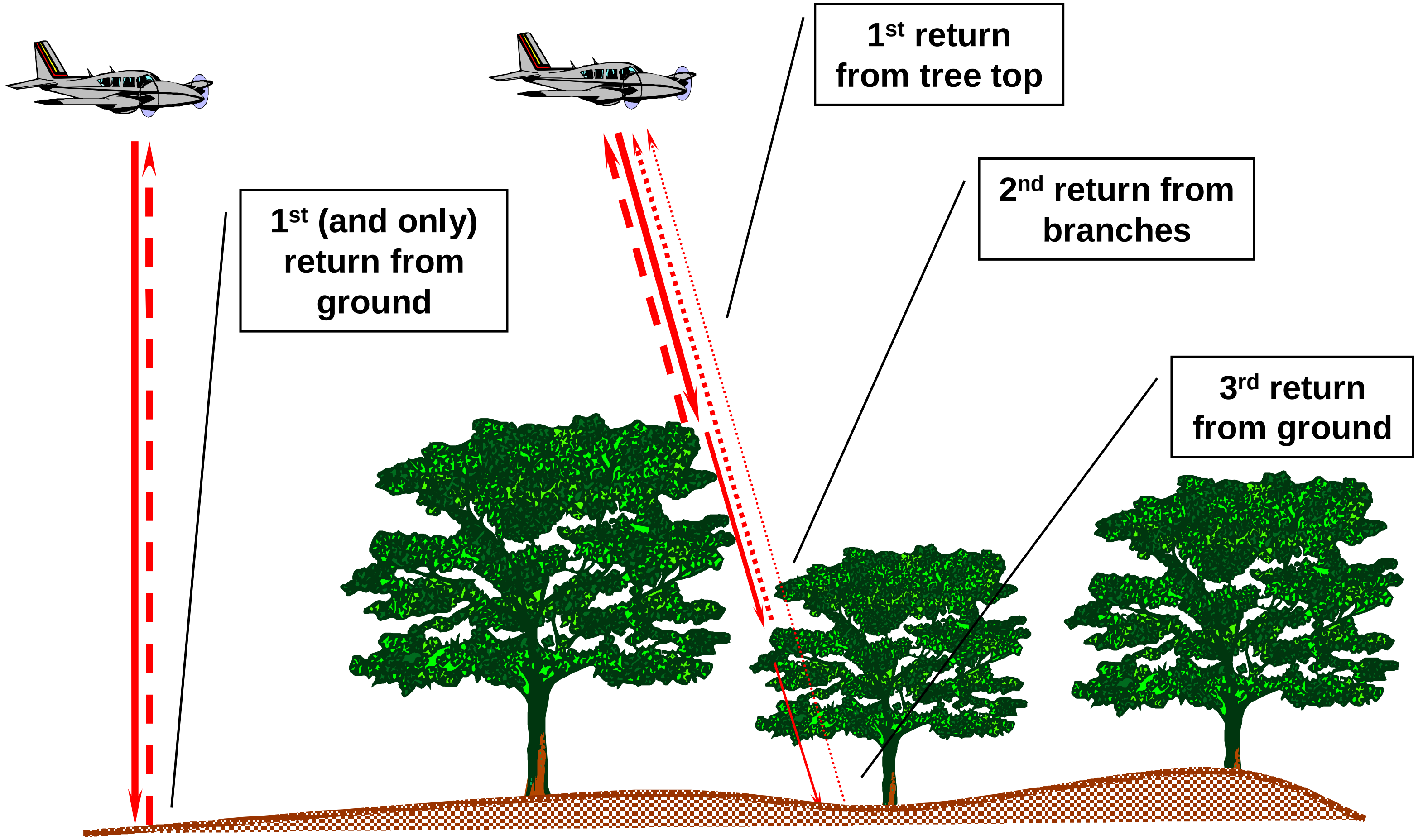
Vegetation Classification

Ground Classification

Laser Point Data

Fundamentals of multiple-return technology

example for 1- and 3-return scenarios

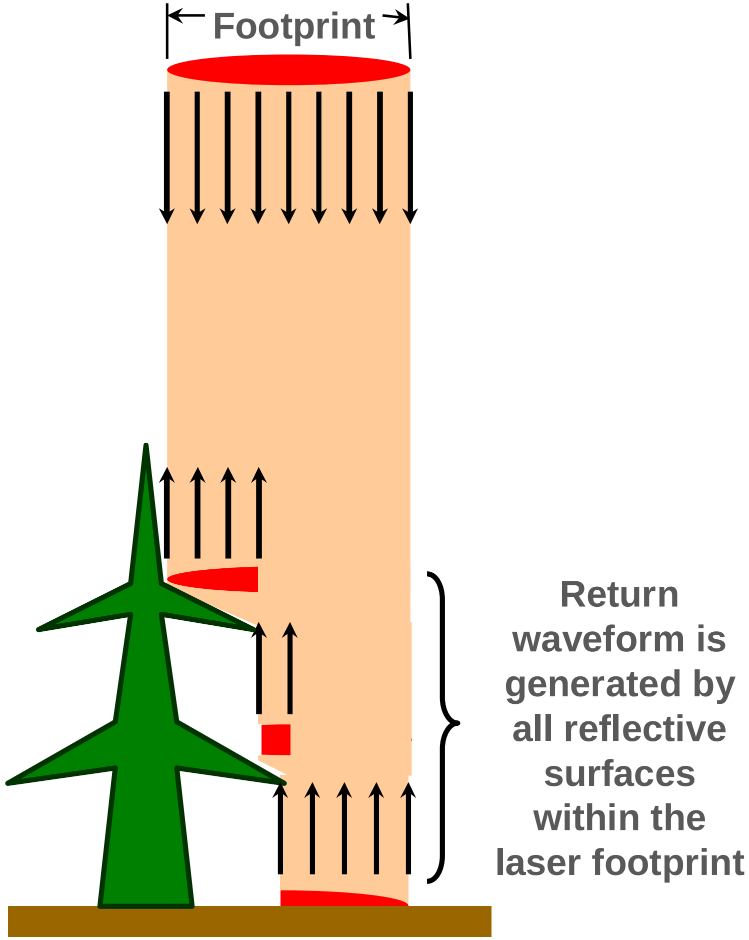


Concept of multi-return intensity measurement

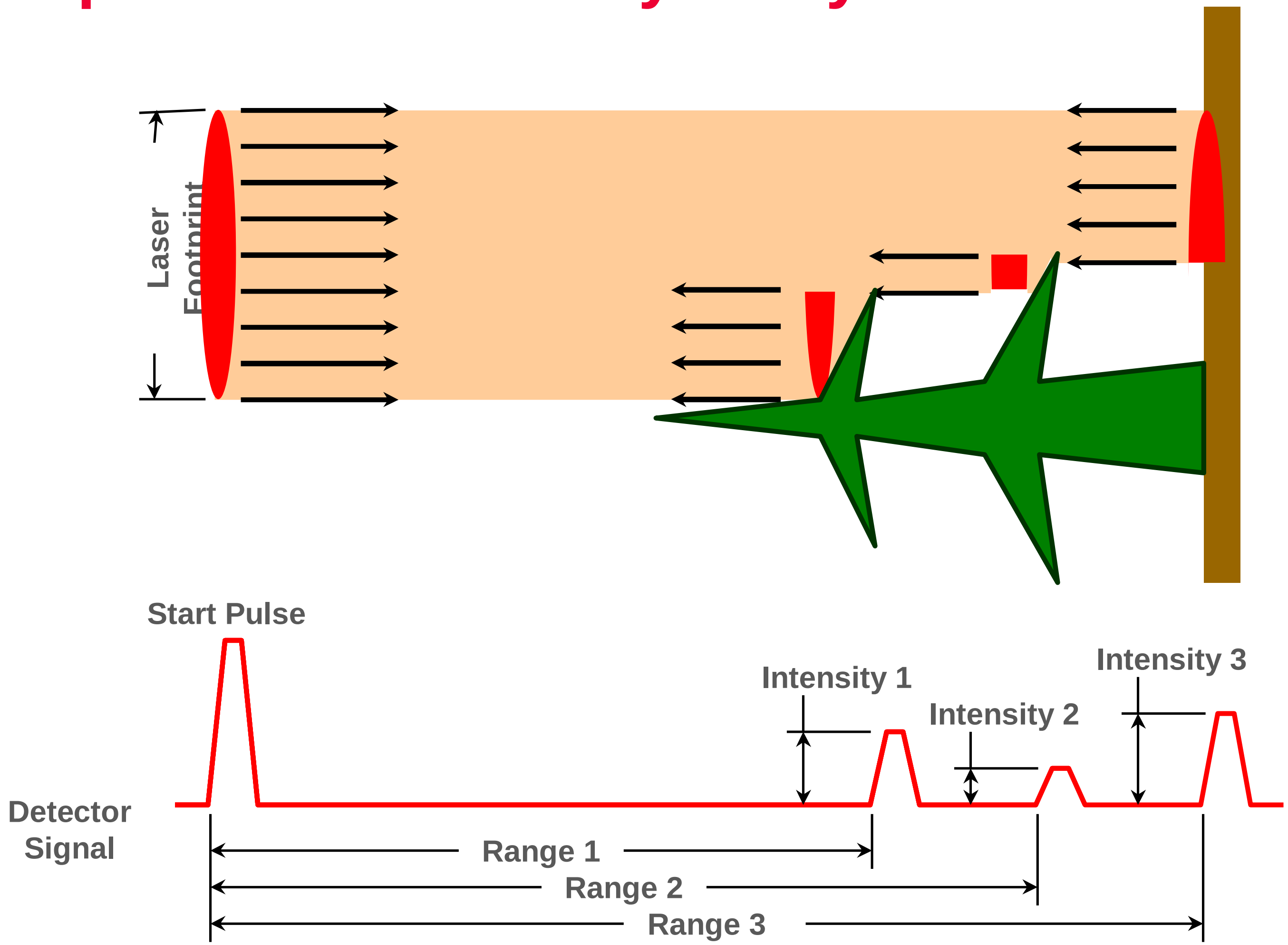
Multiple return intensity measurement is a natural extension of the measurement process

Systems featuring 1-5 return intensity measurement are available

Multiple ranges and associated intensities are generated as the laser pulse hits various levels in the forest canopy



Multiple-return intensity analysis

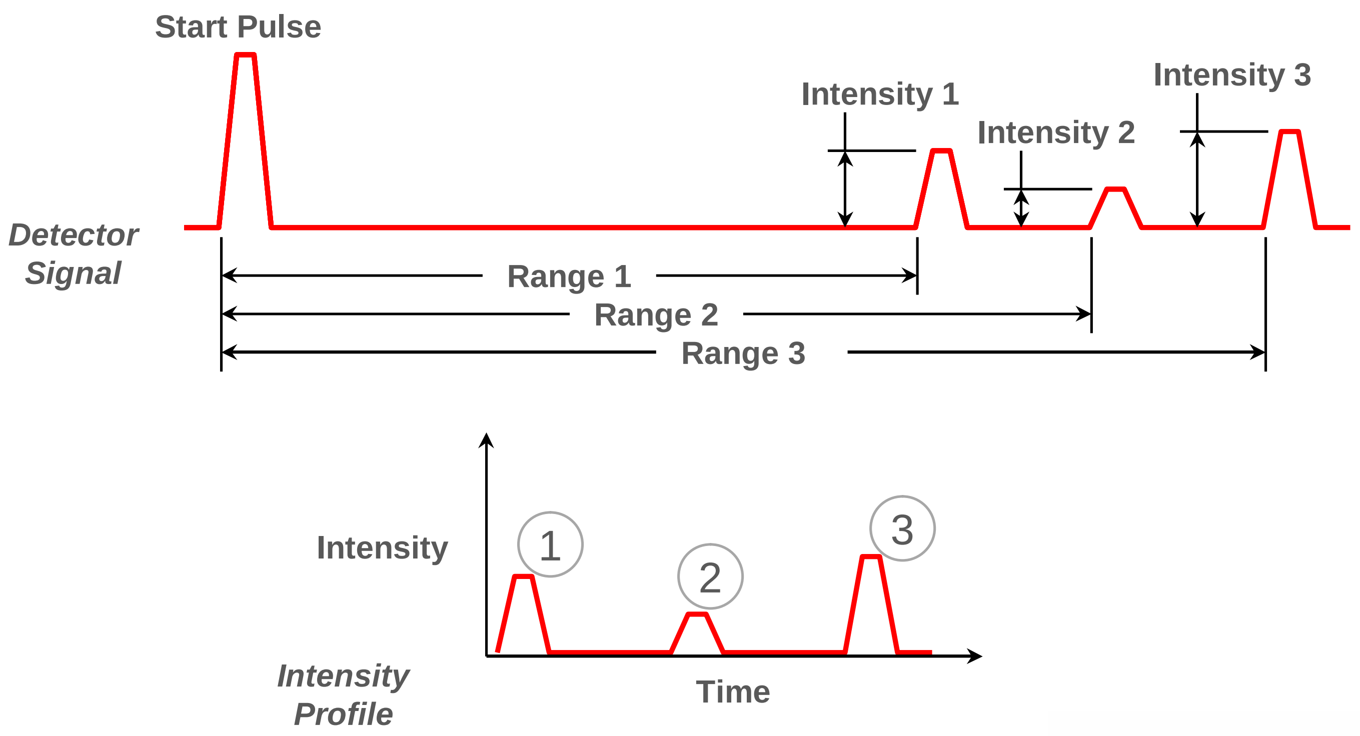


Increases the possibility of classifying otherwise ambiguous data by looking at the relationship between intensity and time variables, simultaneously

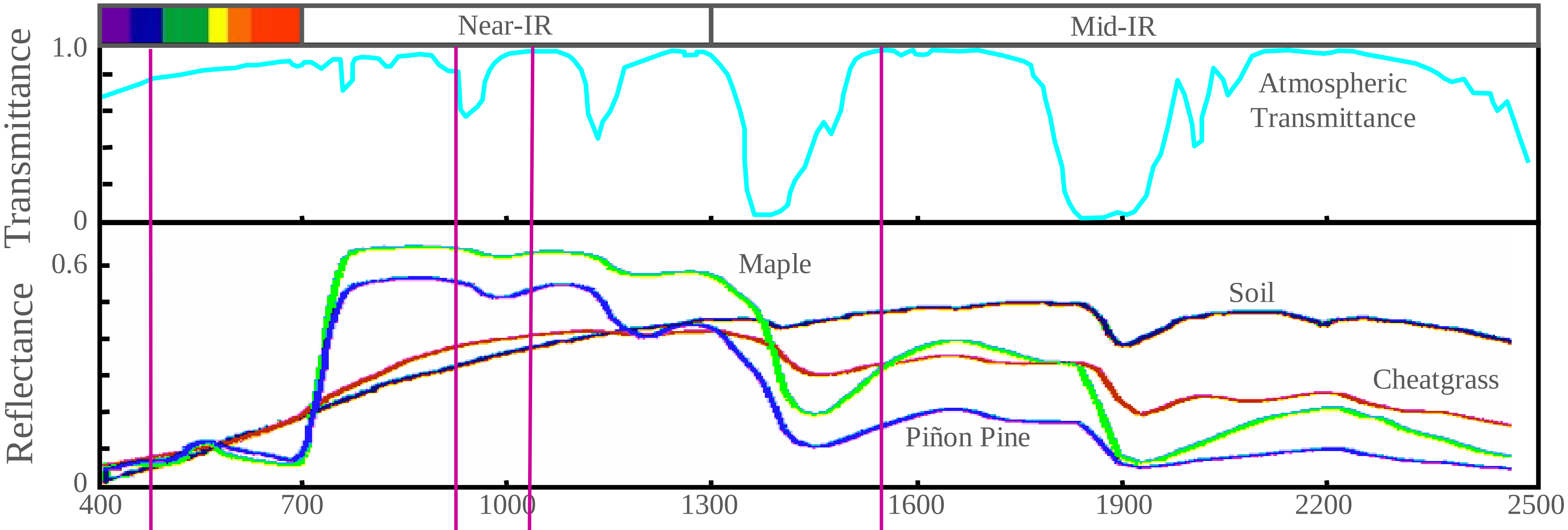
Multiple return intensity measurement methodology

Each return can be considered to represent a single pulse at a given range from the airborne vehicle

Each return pulse’s width and intensity can be plotted, referenced to some fixed point, say the start of the first return



Wavelengths of LiDAR Sensors



900 nm

FLI-MAP I/II

1047/1057/1064 nm

Optech ALTM
Leica ALS
Topeye
Riegl

1540 nm

TopoSys I/II

532 nm

LADS / SHOALS / Hawkeye Bathymetric Systems

Topic - 2

Typical Applications

(for Airborne LIDAR Technology)

Summary of applications

broad categories of applications

Modeling

Visualization

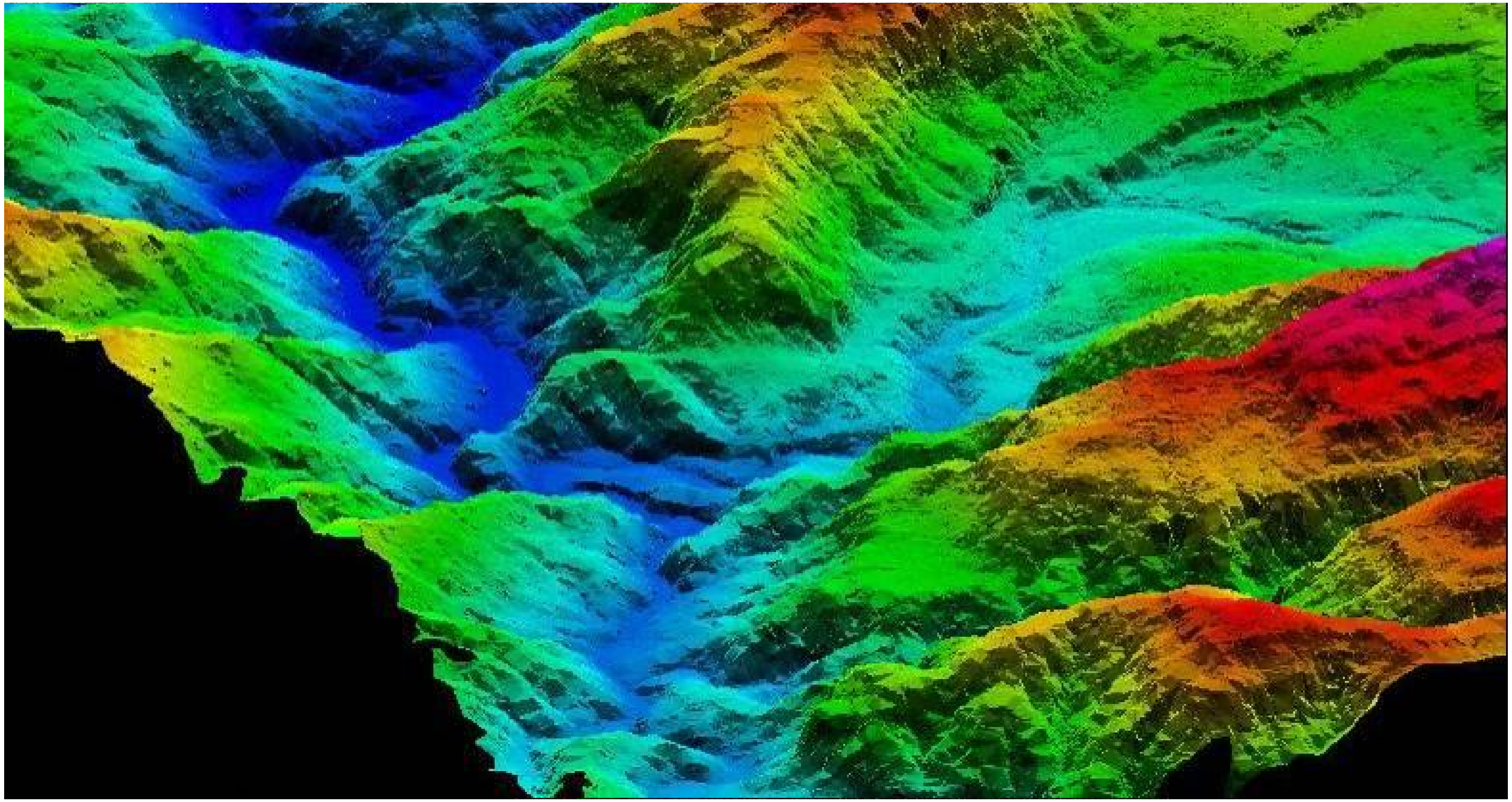
Change detection

Applications are limited only by

- **Sensor spatial resolution**
  (typically to 10 points/m2 with 250+ m swath in fixed-wing aircraft)
- **Accuracy**
  (typically 5-15 cm)

Forestry

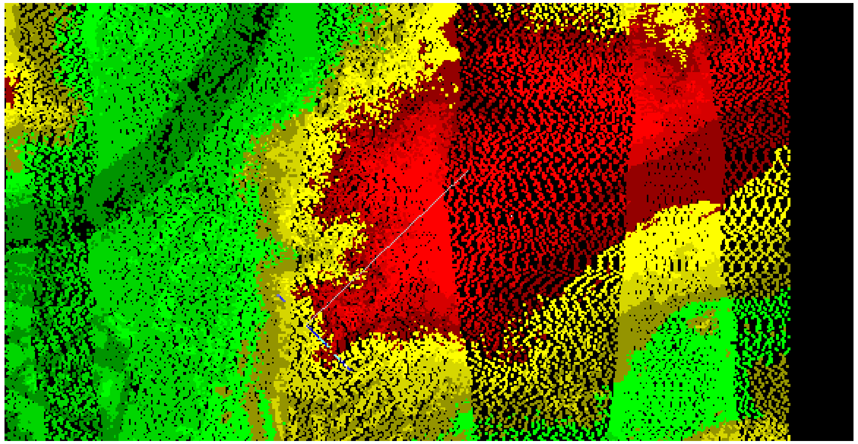
accurate ground profiling during leaf-on conditions



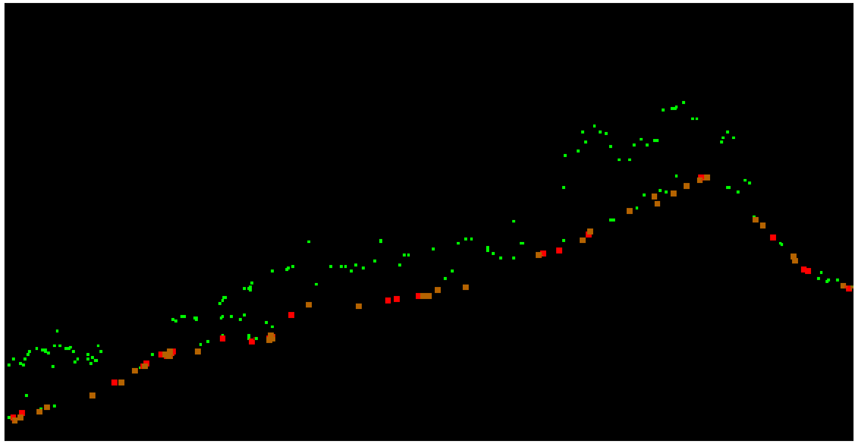
Forestry

tree height and biomass estimation

Top View – Color Coded by elevation

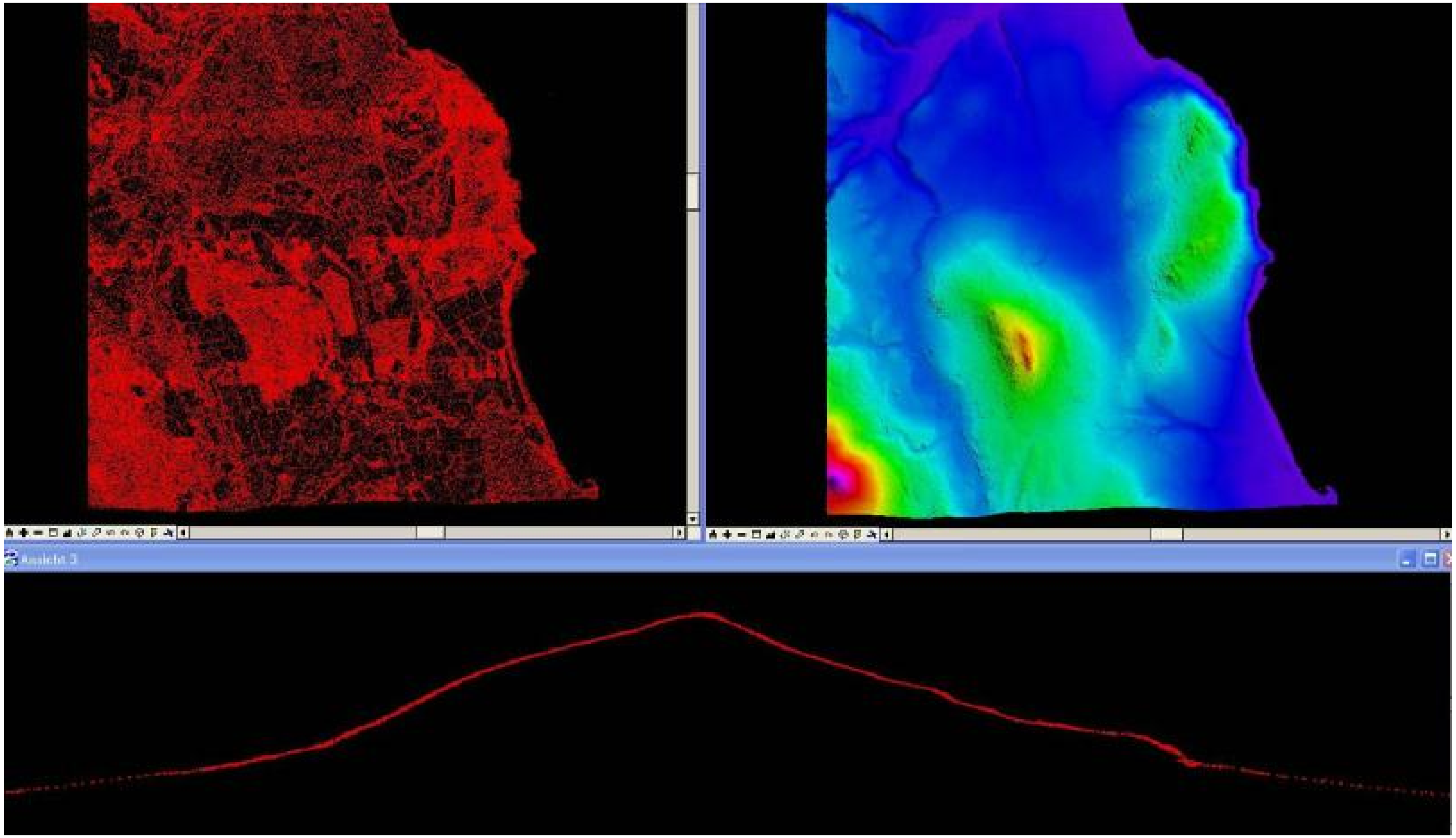


Section view color coded by class



- **Brown = Ground**
- **Green = Vegetation**
- **Red = Model Key Points**

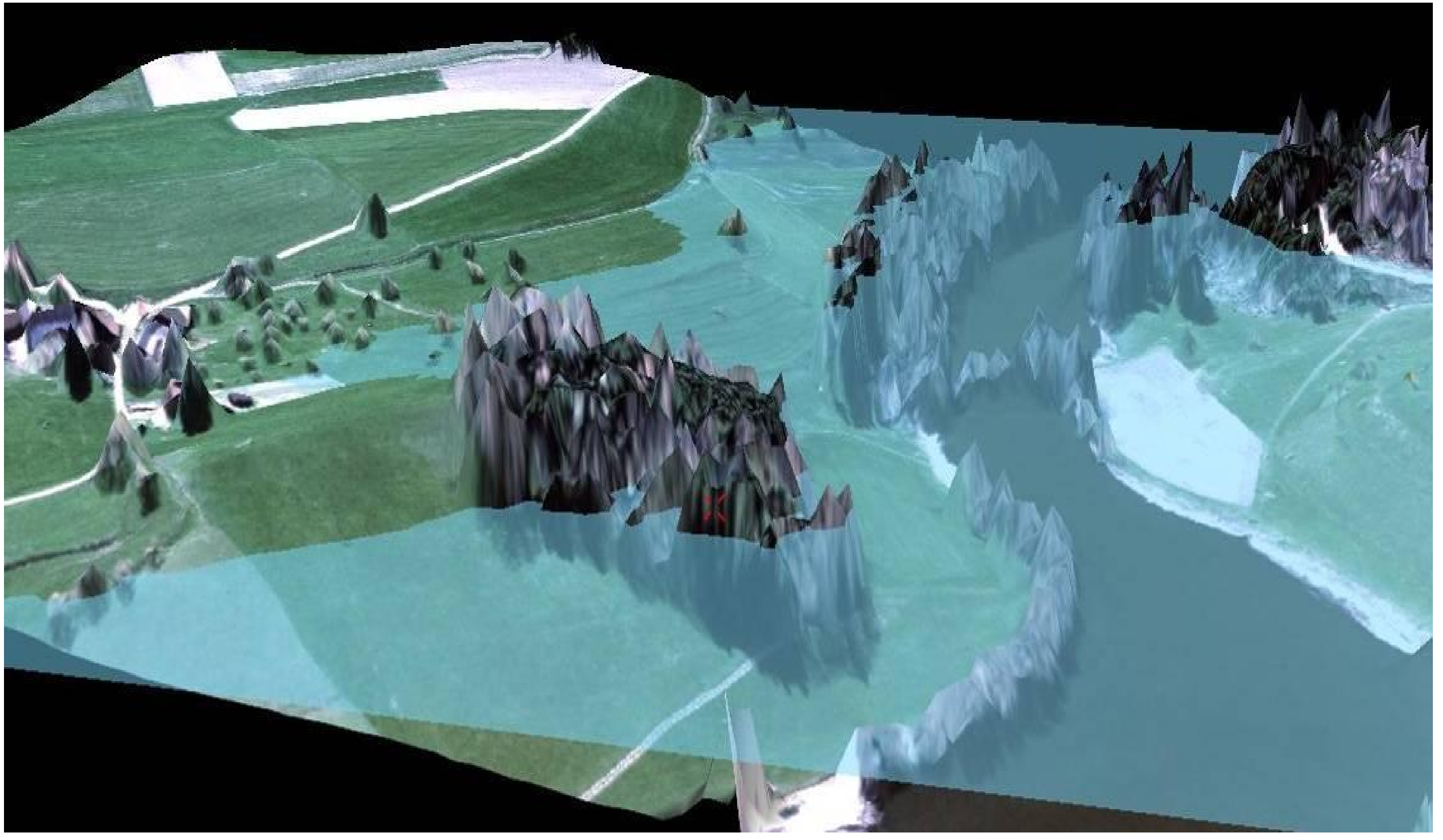
Hydrology
coastal engineering



Hydrology
erosion studies

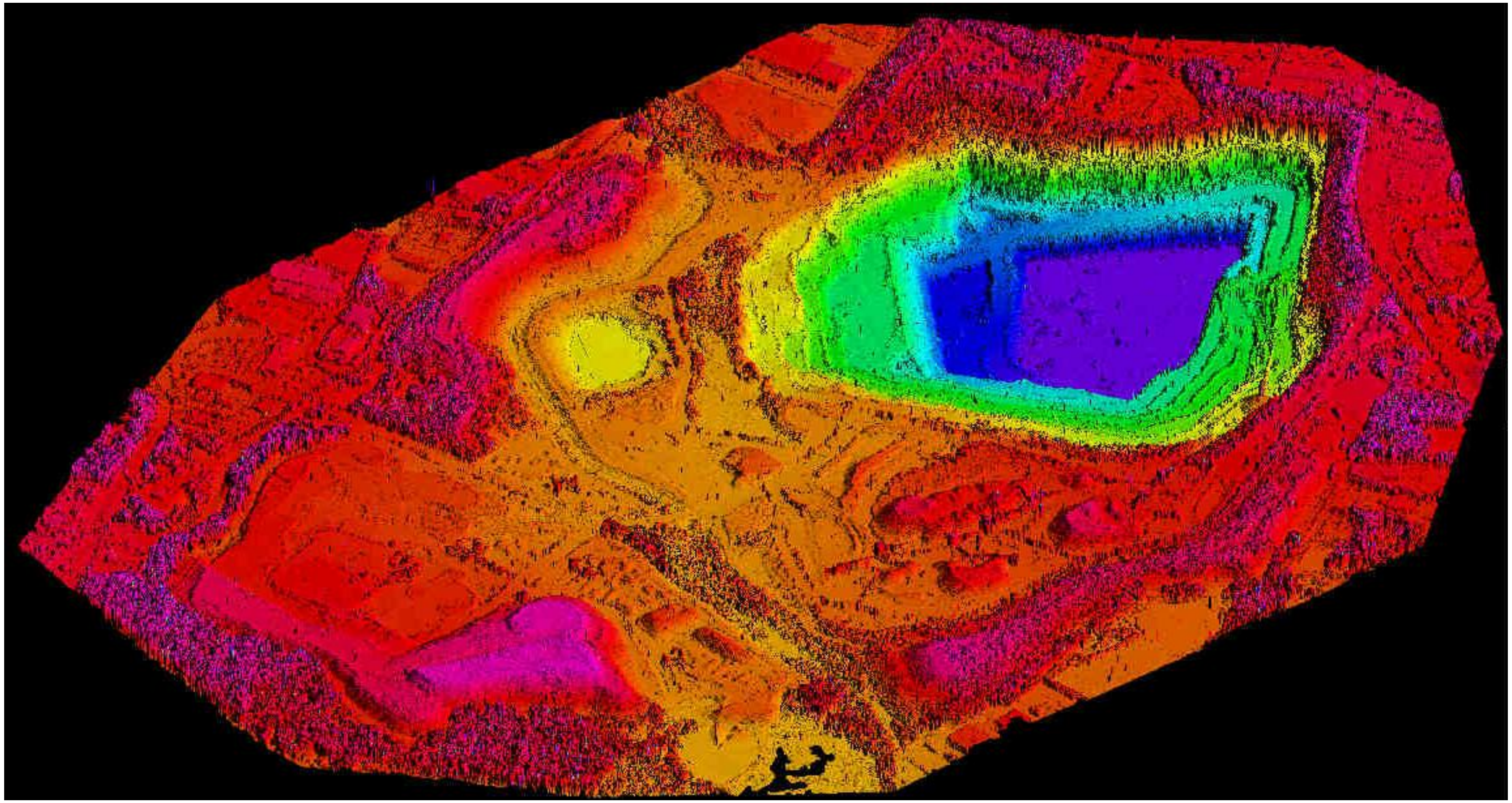
Hydrology

flood plain mapping and simulation



Mining and construction

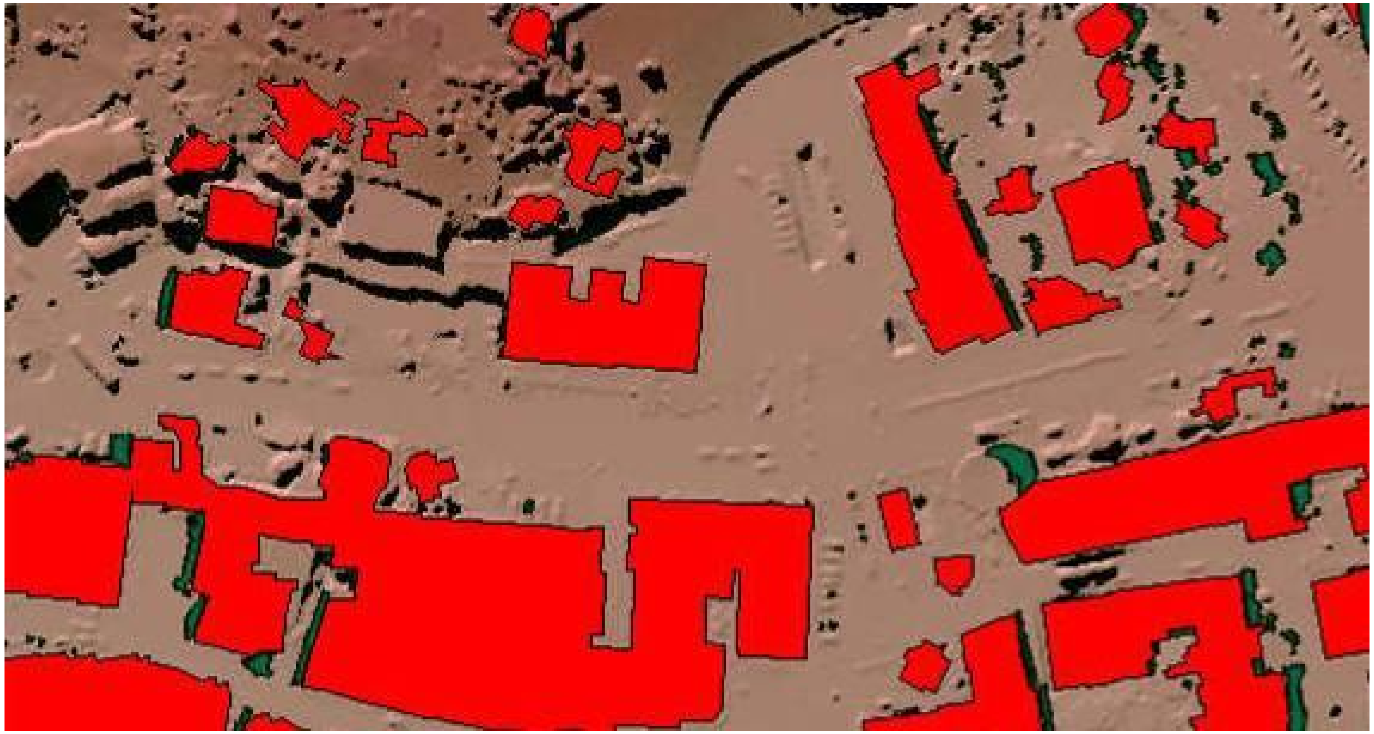
accurate volumetric calculations



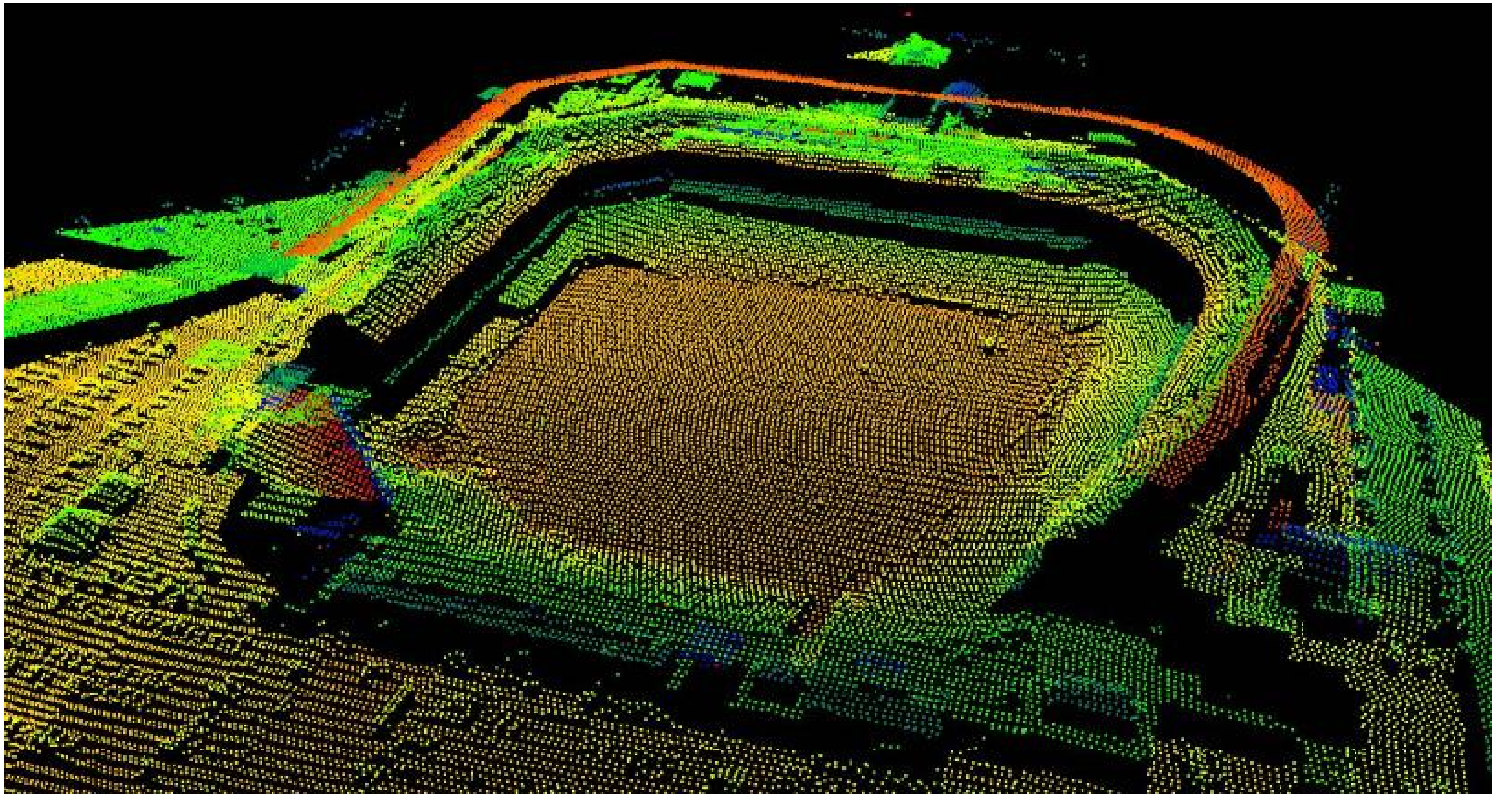
Urban modeling
building extraction

Urban modeling

building extraction

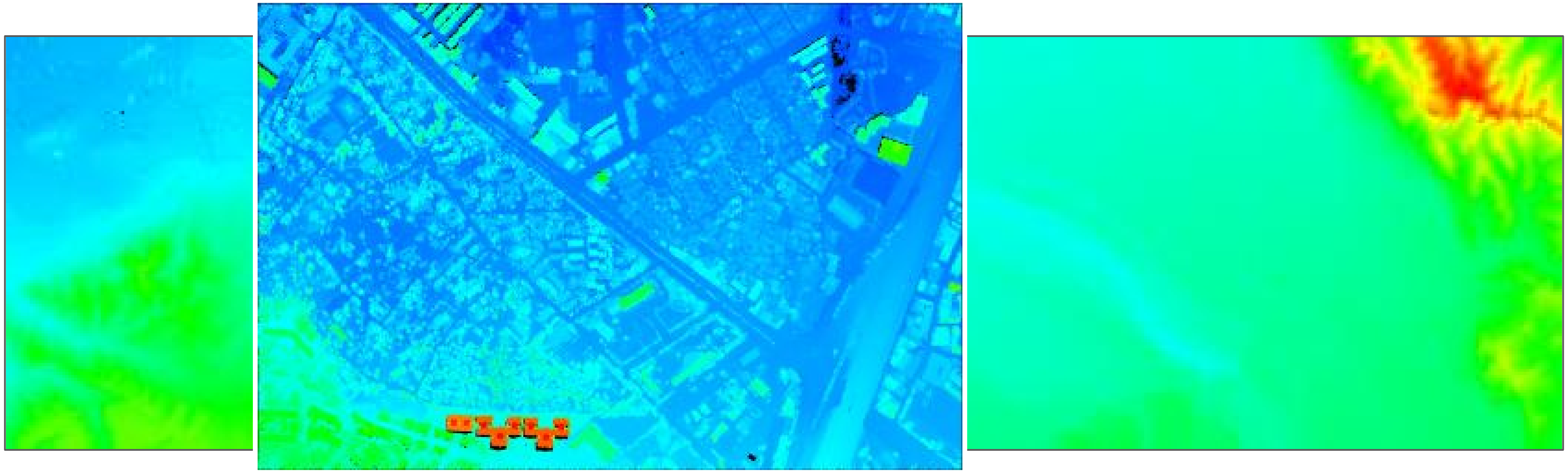


Urban modeling
detailed “as-built” data



Urban modeling

large areas with high level of detail

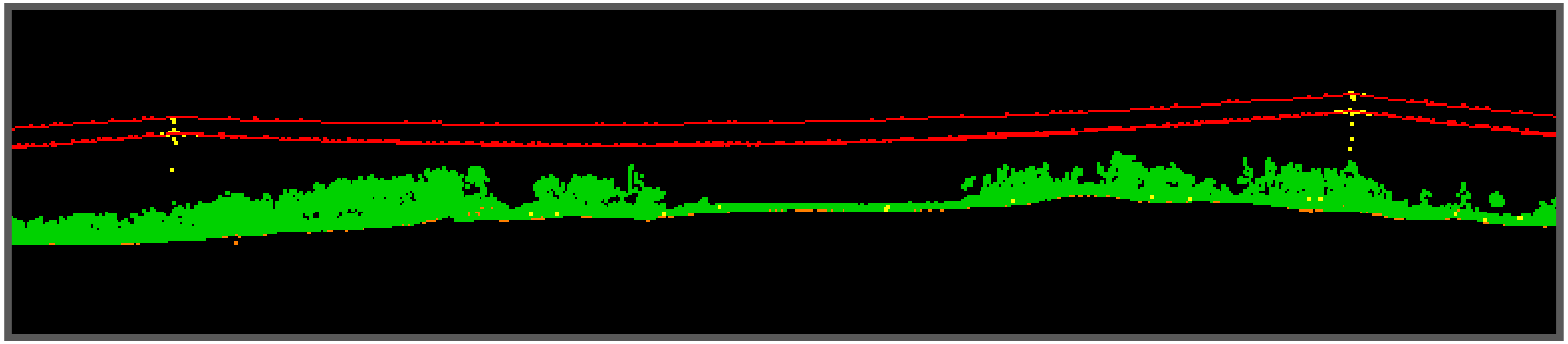


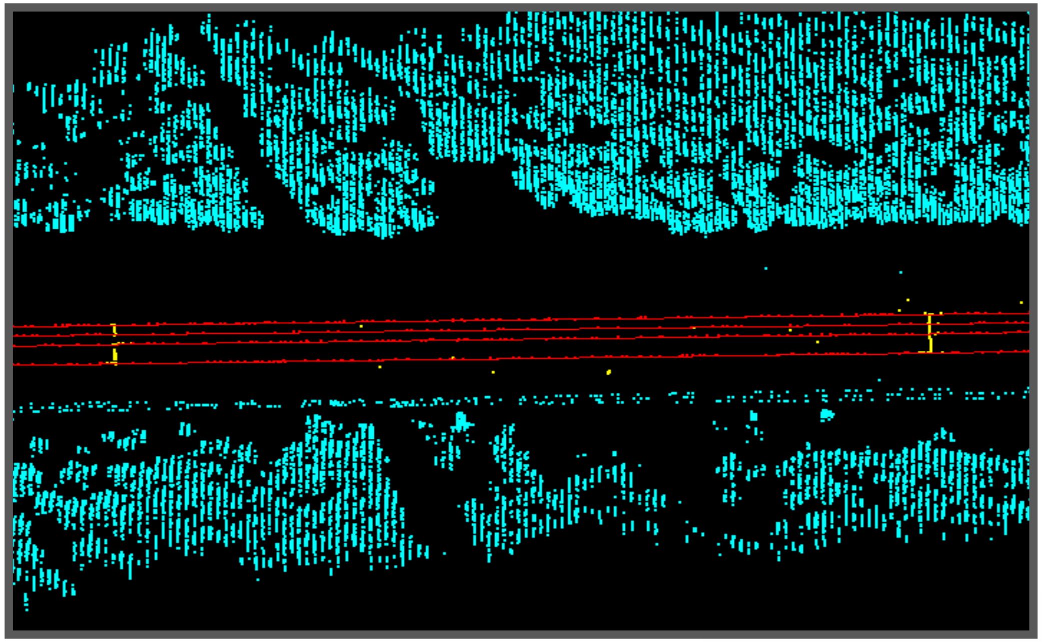
Flight parameters: altitude: 800m AGL, FOV: 35 degrees, scan rate: 29.4 Hz, pulse rate: 38 kHz, line spacing: 250m, number of lines: 18

Data parameters: area = 11.7 X 5 km (58.5 km2), number of points = 103 million, average density = 1.7 pts m2

Corridor mapping

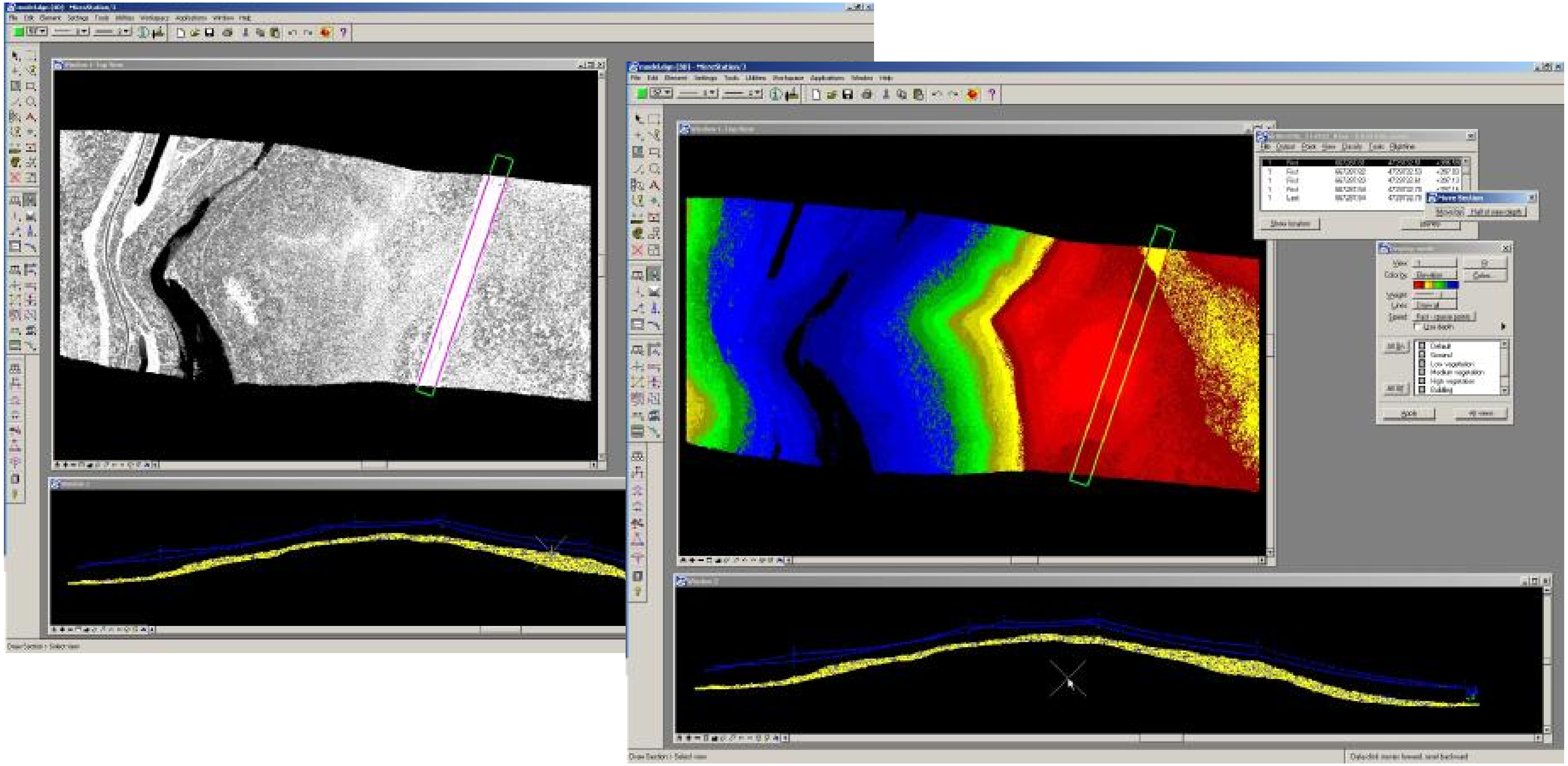
power line position and vegetation clearance



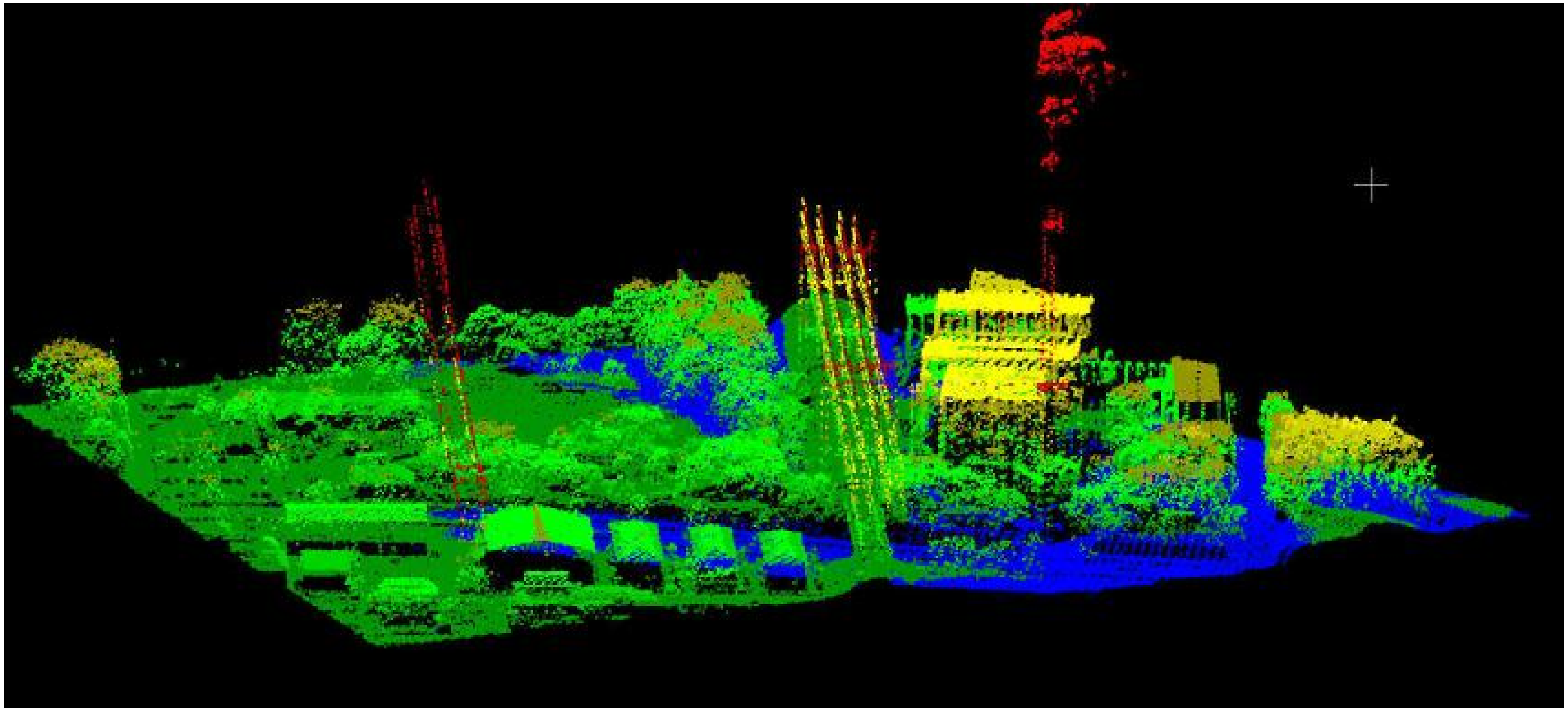


Corridor mapping

power line position and vegetation clearance

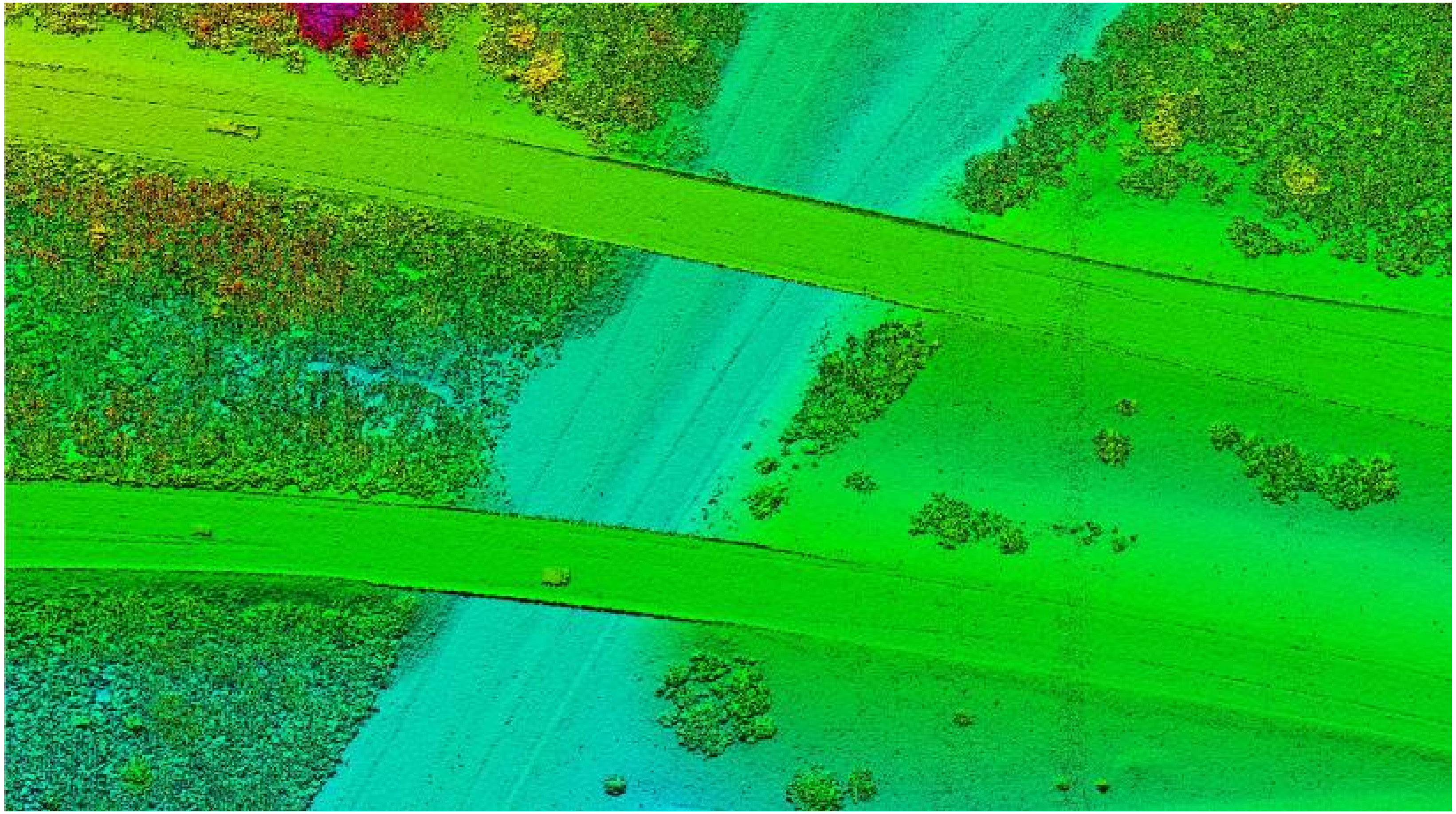


Power line and infrastructure condition



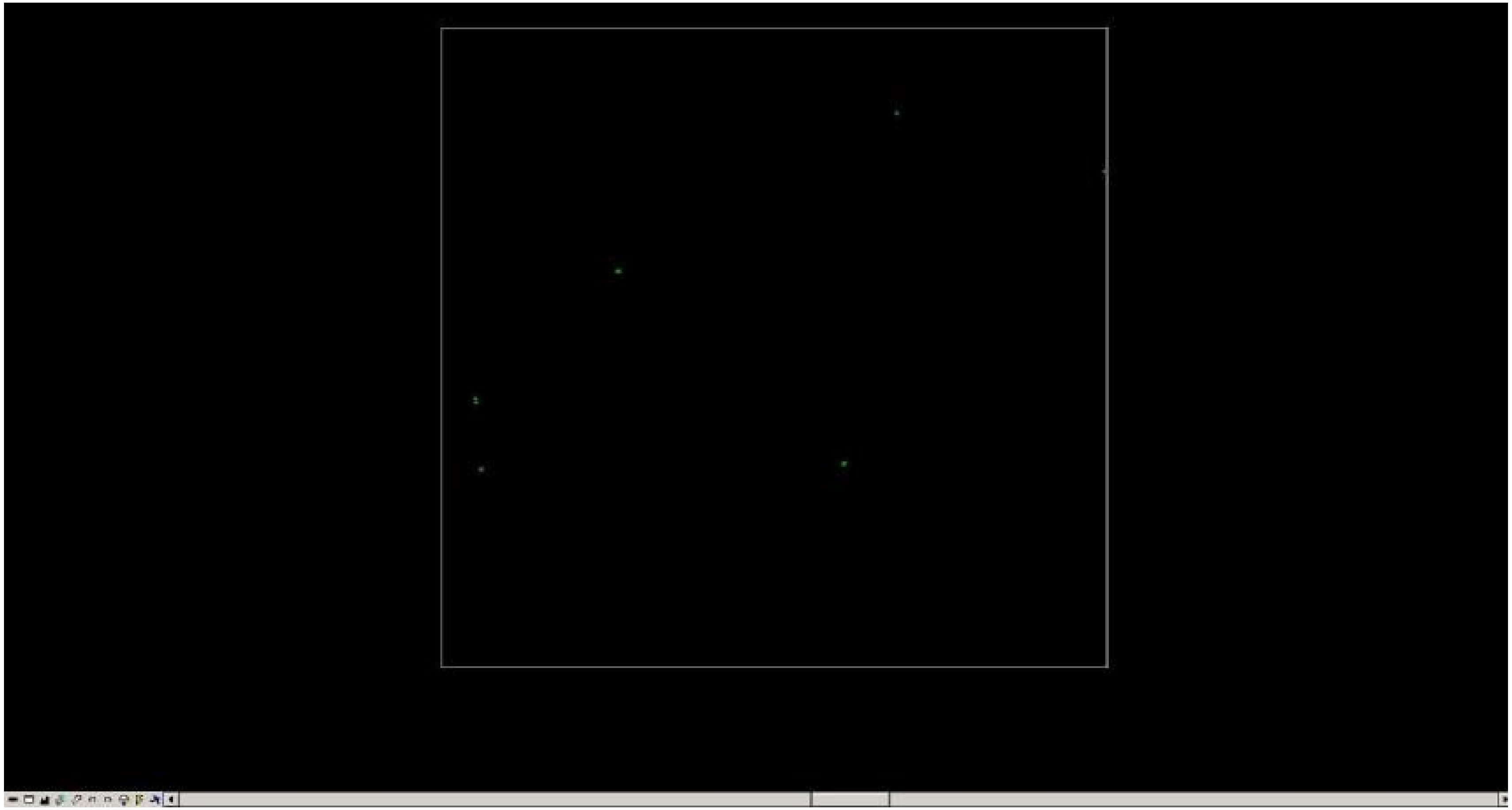
Corridor mapping

highway corridor mapping



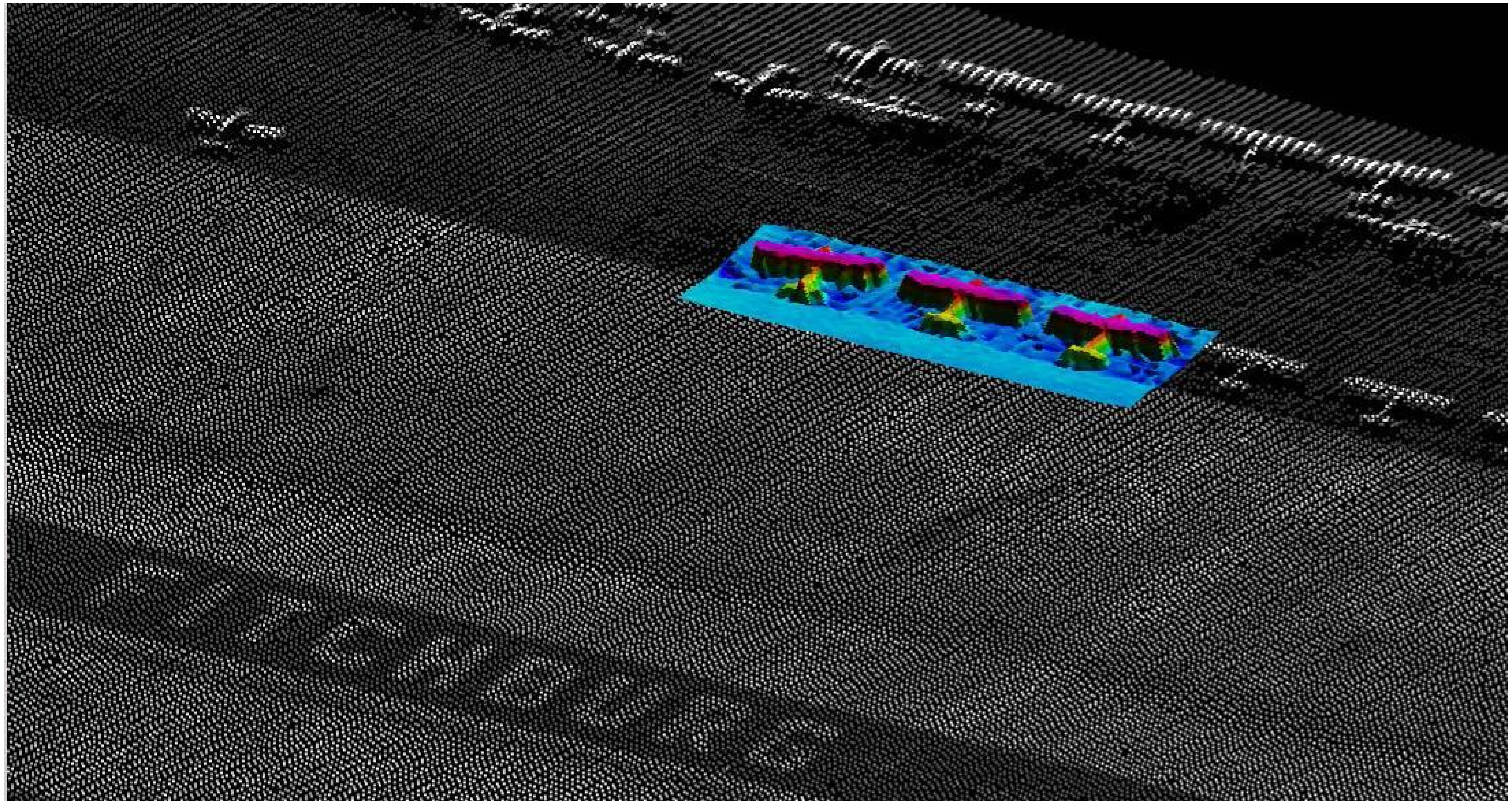
Airspace intrusion detection

comparing bare earth + DSM



Data fusion

surface and intensity data



Topic - 3

Main System Components

(of Airborne LIDAR Scanners)

Complete Airborne LIDAR Scanner *(Leica ALS50-II)*

including System Control & Flight Navigation Guidance

Data Sensing <> Scanner Head *(Leica ALS50-II)*

New generation system provides greater point density, while increasing accuracy

In virtually all scenarios, ALS50-II with MPiA out-performs competing products

The ALS50-II provides a greater FOV and greater roll compensation range than competing products

The ALS50-II Scanner fits in small places like helicopter pods

Data Sensing <> Scanner Head *(Leica ALS50-II)*

Installation in Helicopter Pod

Data Control & Storage *(Leica ALS50-II)*

3 Highly-flexible auxiliary sensor ports (included)

- **Cameras**
- **Thermal sensors**
- **Hyperspectral sensors**
- **Other external sensors / systems Accesses common GPS/IMU data**

Dedicated flight management system port (included)

- **Interface to a variety of external FMS hardware**
- **Potential for use as 4th sensor port**

System Control & Navigation *(Leica ALS50-II)*

Airborne-qualified operator interface – no laptops

Highly integrated flight management

Modularity with minimal external cabling

Single-drive recording of GPS/IMU and scanner data

All controls operated via GUI

- **Shutter**
- **Laser output regulation**
- **AGC settings**

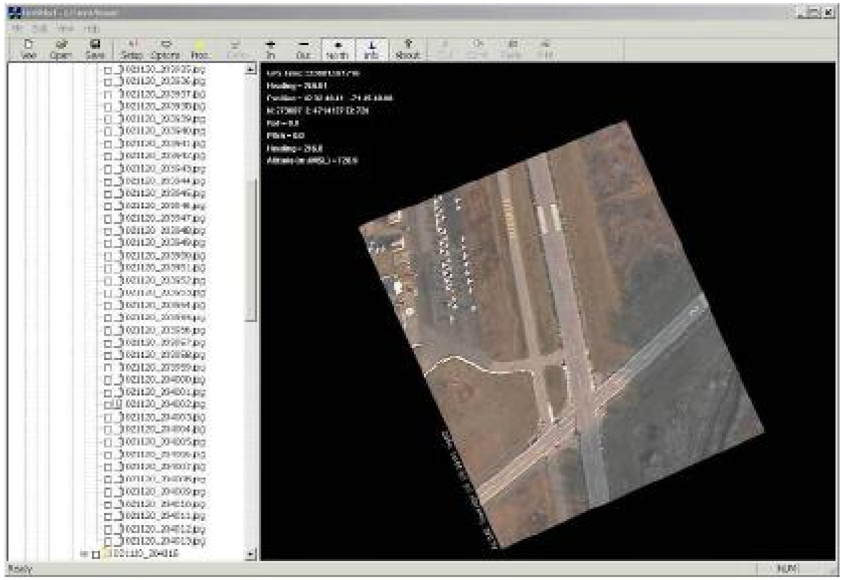
Real-time digital camera *(Leica ALS50-II)*

enhances editing

Real-time imagery to check for clouds / haze in line of sight

JPEG images recorded at preset interval for post flight terrain / cover verification

Images time-indexed and contain all georeferencing data



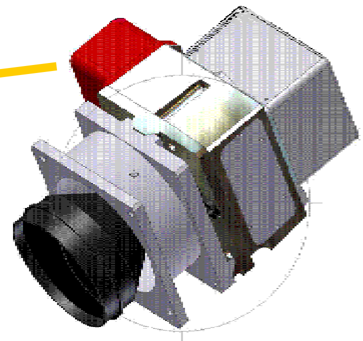
Mid-Format Camera System *(Leica MidiPix 39MPx)*

product configuration

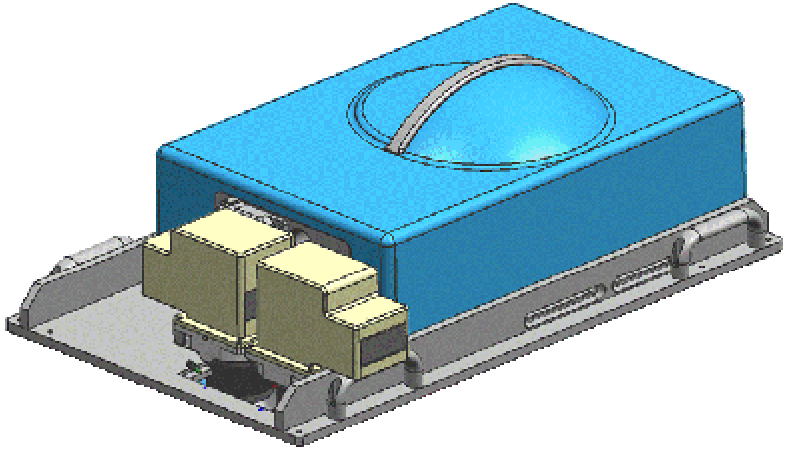
CH39 Camera Head (39 MP)

Lens (35, 60 or 100 mm)

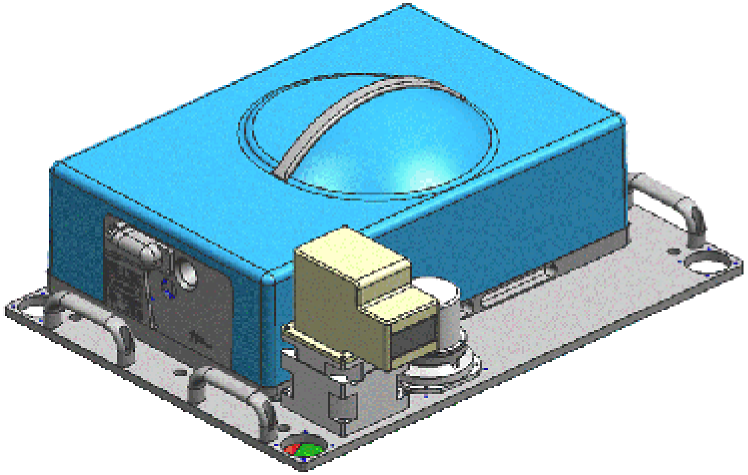
CC105 Camera Controller



Digital Frame Camera Head
typical installations



Front-mount, dual CH39, non-isolated



Side-mount, CH39 + thermal sensor, isolated

Topic - 4

Performance Parameters

(for Airborne LIDAR Missions)

Key performance parameters

- Performance of Optical System
- Accuracy of Components
- Performance of Laser
- Multiple Pulse capability (MPiA)
- Performance of IMU
- Performance of GPS
- Multiple Pulse capability (MPiA)
- Robustness / Calibration stability of system components

Large Optical Aperture

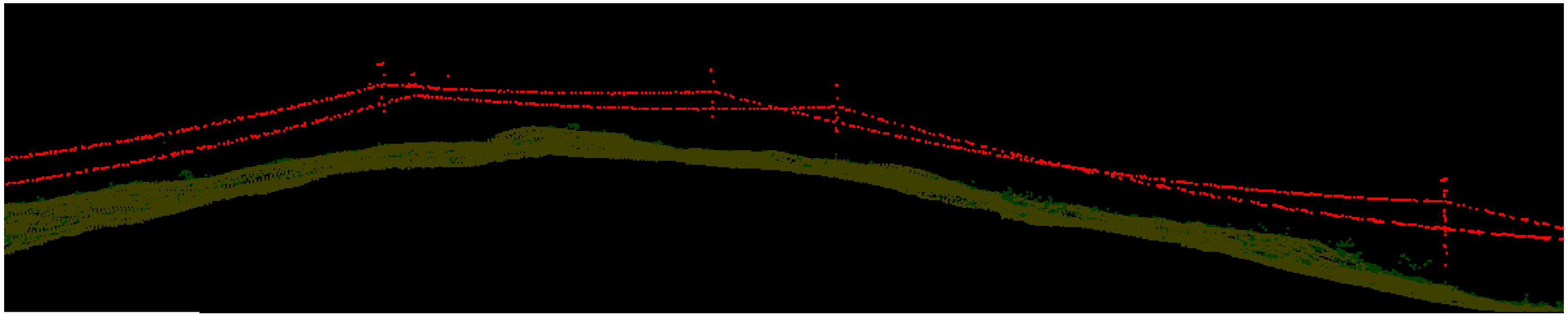
To “see” more

Detect smaller targets at higher altitude (e.g., power line profiling)

Fewer “drop outs” on low-reflectivity terrain features (e.g., asphalt pavement)

Fly in less-desirable atmospheric conditions (e.g., haze/smoke)

Preserves performance, *even at today’s high pulse rates*



Robust components

To assure continuous high performance

Laser features consistent pulse shape over wide range of pulse rates for high range accuracy/low range jitter

High-accuracy scan angle encoder preserves planimetric accuracy as altitude increases

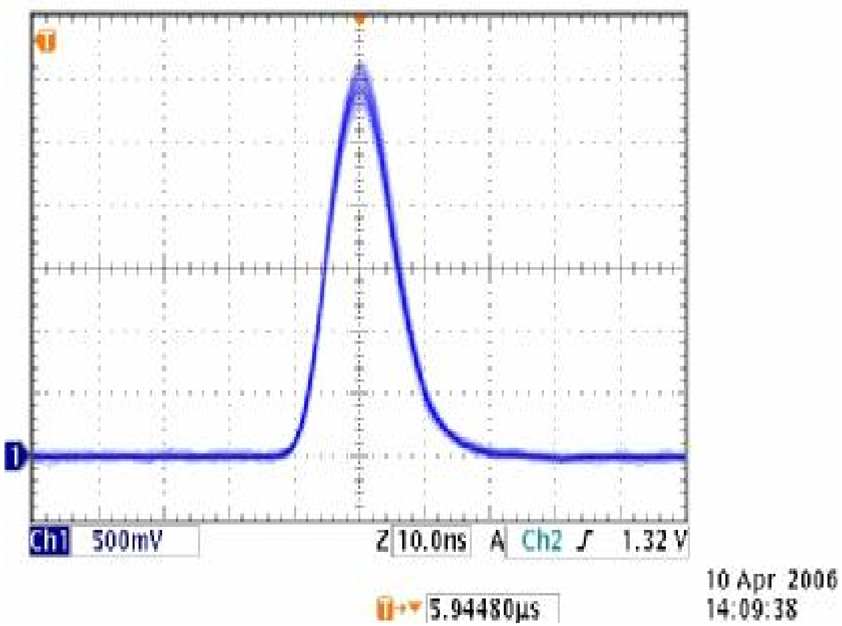
Powerful galvanometer scanner

- **Allows use of large-aperture optics**
- **Scans fast at any given FOV, allowing:**
  - Small along-track spacing in fixed wing aircraft
  - Balanced along-track and cross-track (very important when using high pulse rates and/or higher-speed aircraft)
- **Allows widest available FOV and greatest roll compensation range**

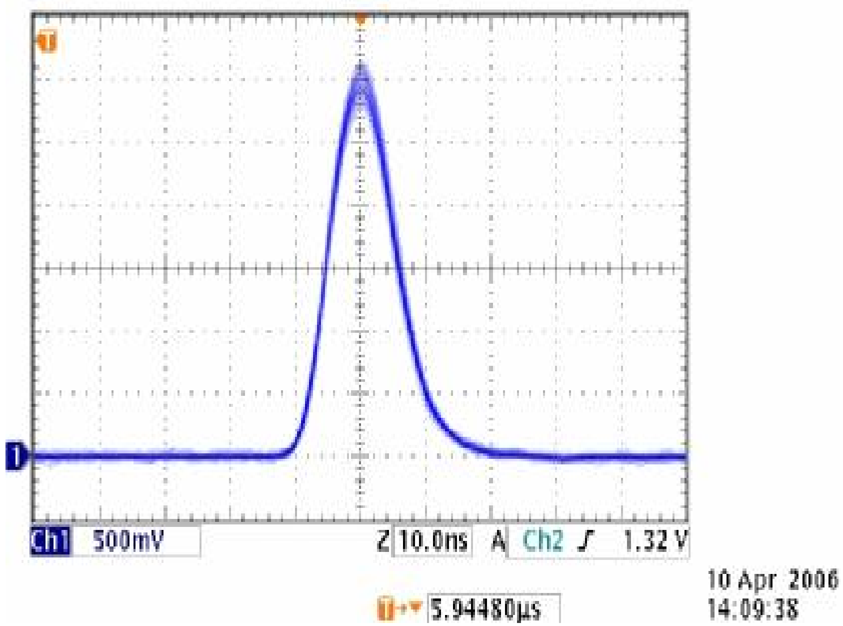
High Laser Performance

To ensure clean pulses even at high pulse rates

Typical laser pulse



ALS50-II laser pulse

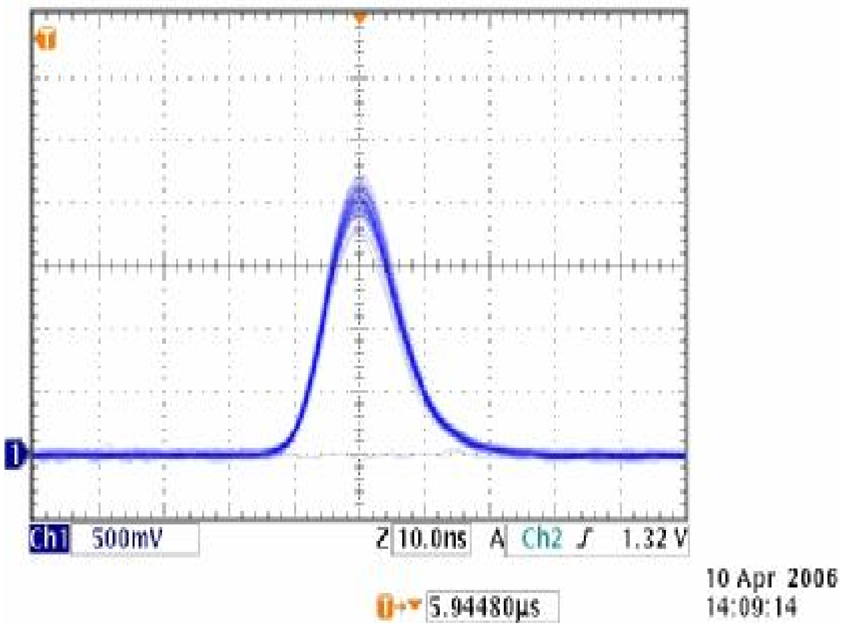


33 kHz

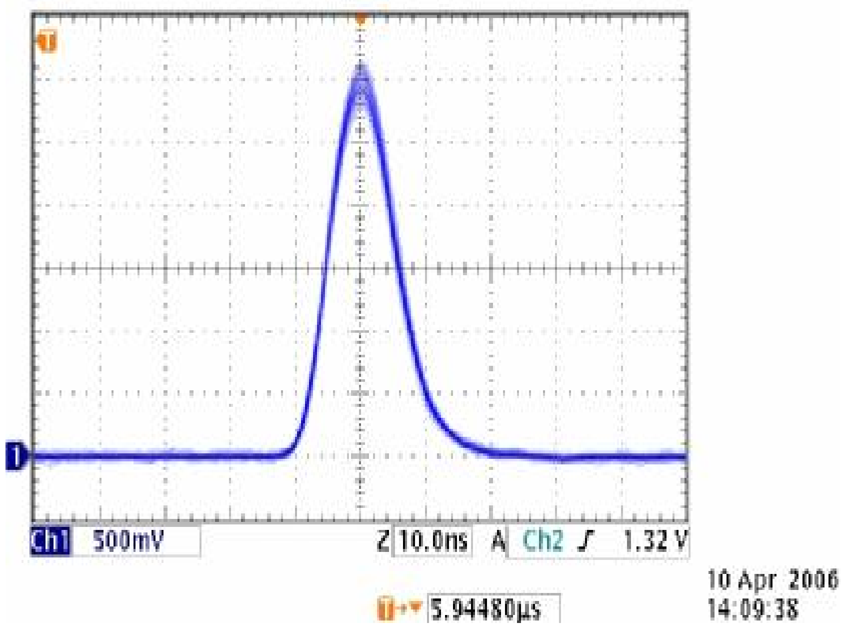
High Laser Performance

To ensure clean pulses even at high pulse rates

Typical laser pulse



ALS50-II laser pulse

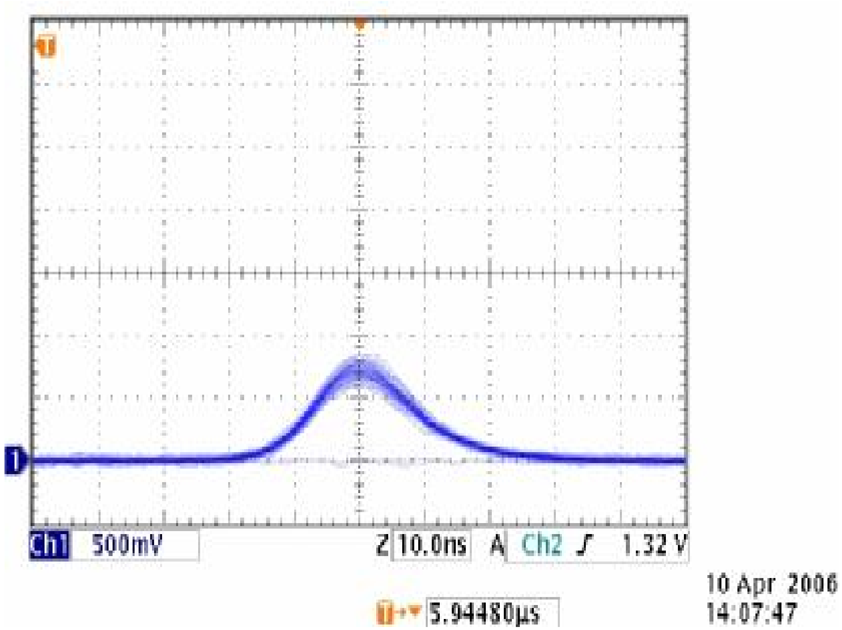


50 kHz

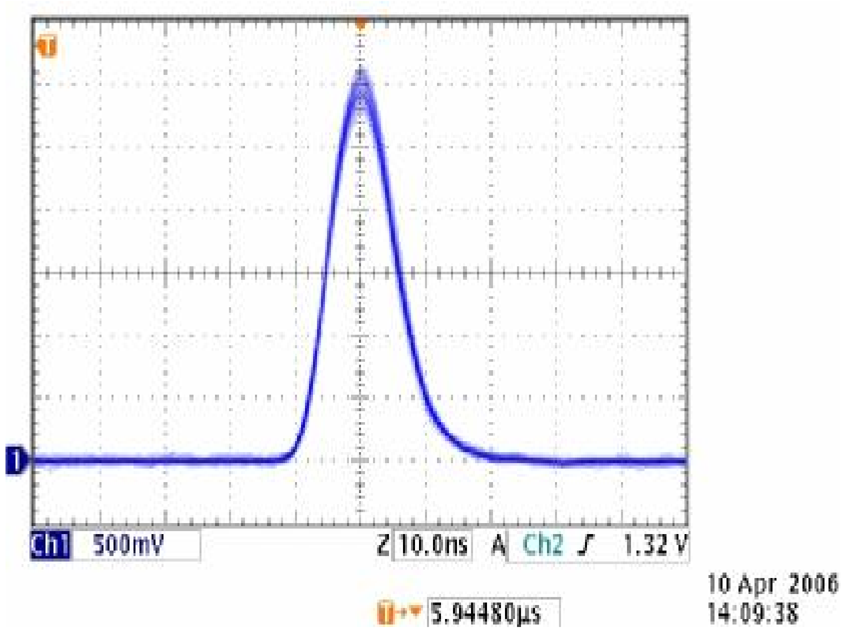
High Laser Performance

To ensure clean pulses even at high pulse rates

Typical laser pulse



ALS50-II laser pulse

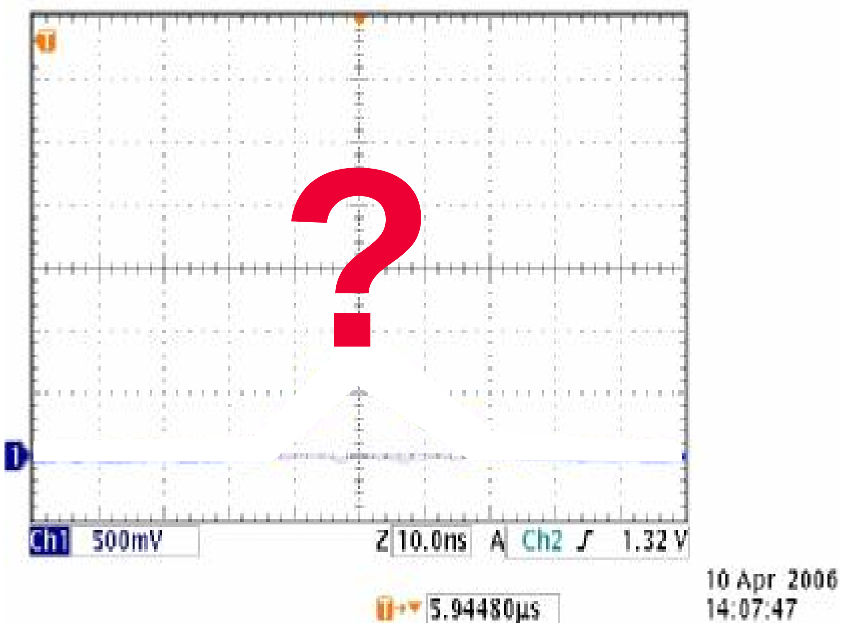


100 kHz

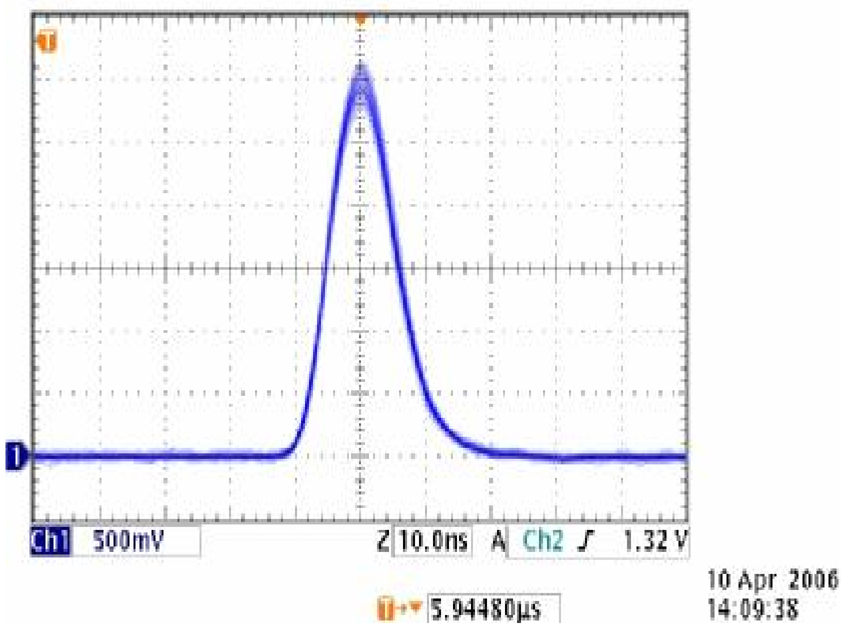
High Laser Performance

To ensure clean pulses even at high pulse rates

Typical laser pulse



ALS50-II laser pulse



150 kHz

MPiA – Multiple Pulse in the Air technology

significant advancement in range measurement

> 1st Press release, 5-Oct-06: MPiA technology (Leica ALS50-II)

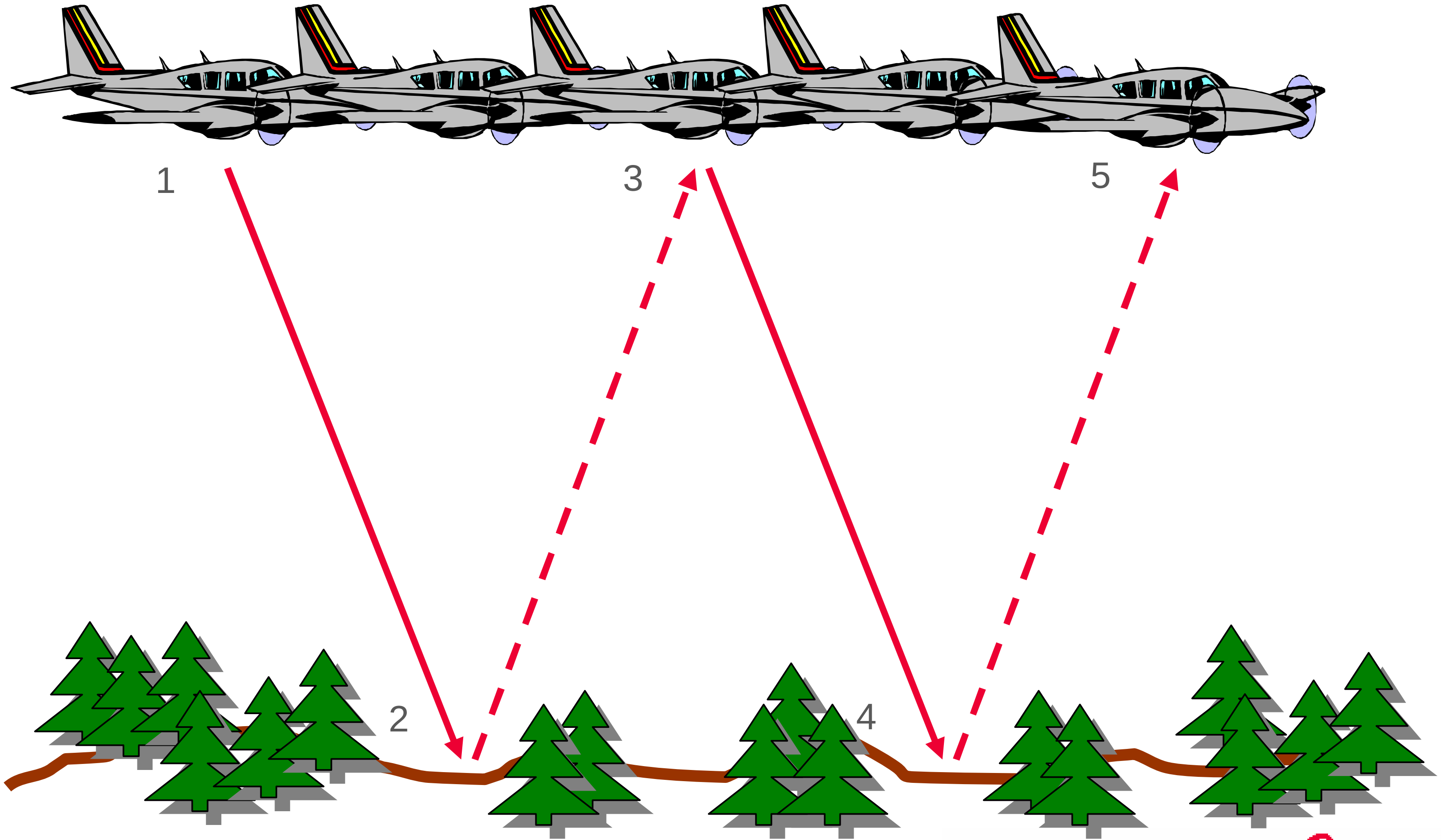
- § Allows rangefinding system to operate at double the pulse rate of current systems at any given altitude
- § - Uncomplicated upgrade path for existing systems (Leica ALS50)

> Significant performance benefits:

- § Double the data density at current swath
- § Double the swath at current density
- § Data acquisition cost savings approaching 50%

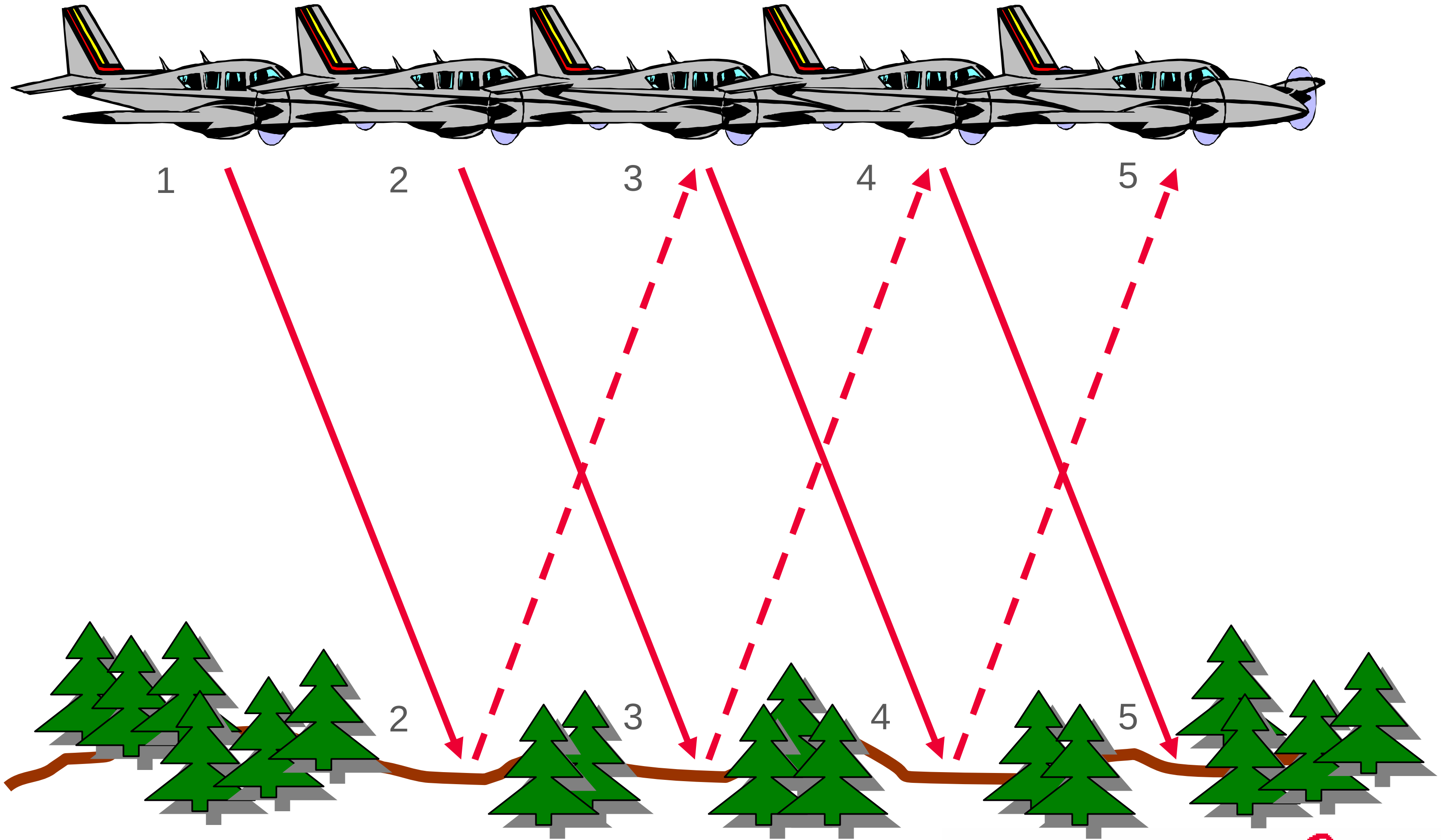
Fundamentals of MPiA technology

single-pulse technology limits pulse rate



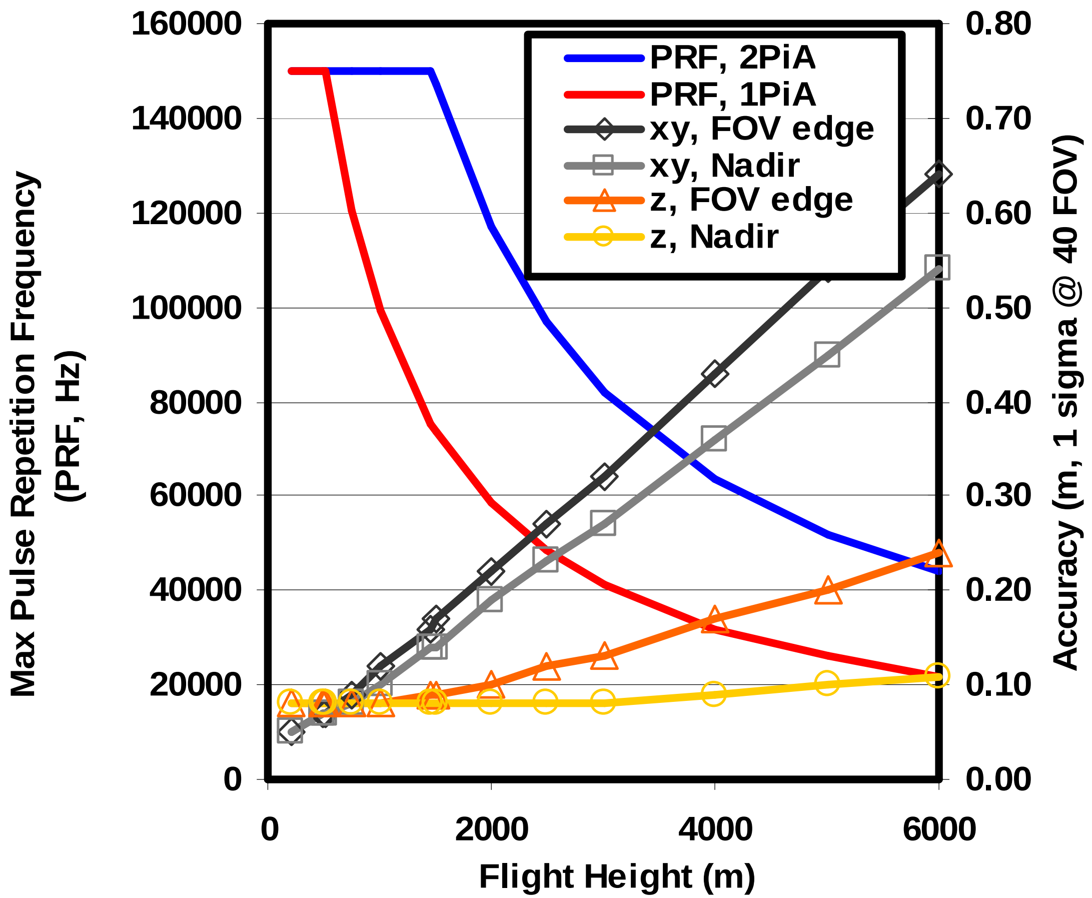
Fundamentals of MPiA technology

MPiA allows doubling of pulse rate



Gain in Pulse Rate & Accuracy (Leica ALS50-II-MPiA)

Assuming a 5 cm GPS error

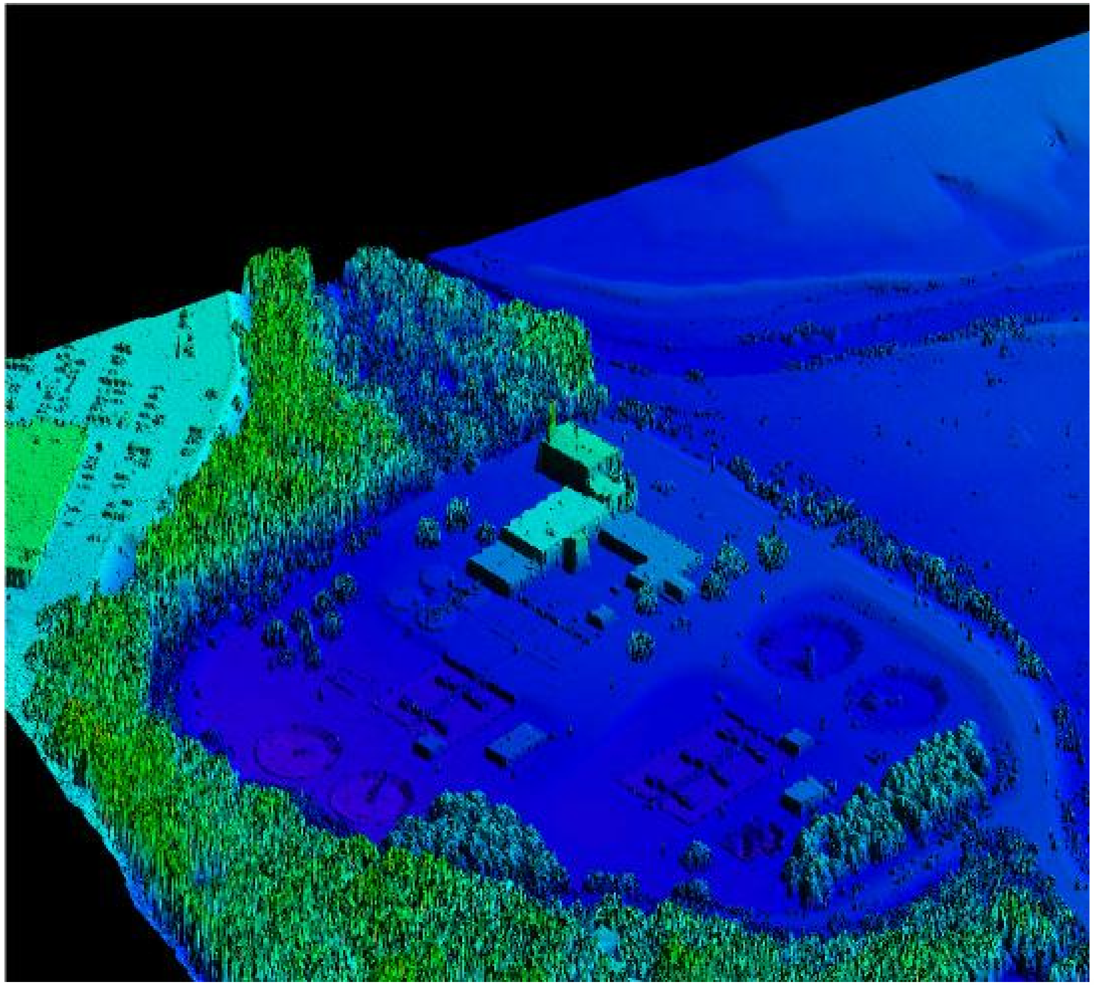


MPiA intensity image (Leica ALS50-II)

2.5 points/m^2 with 1000 m swath

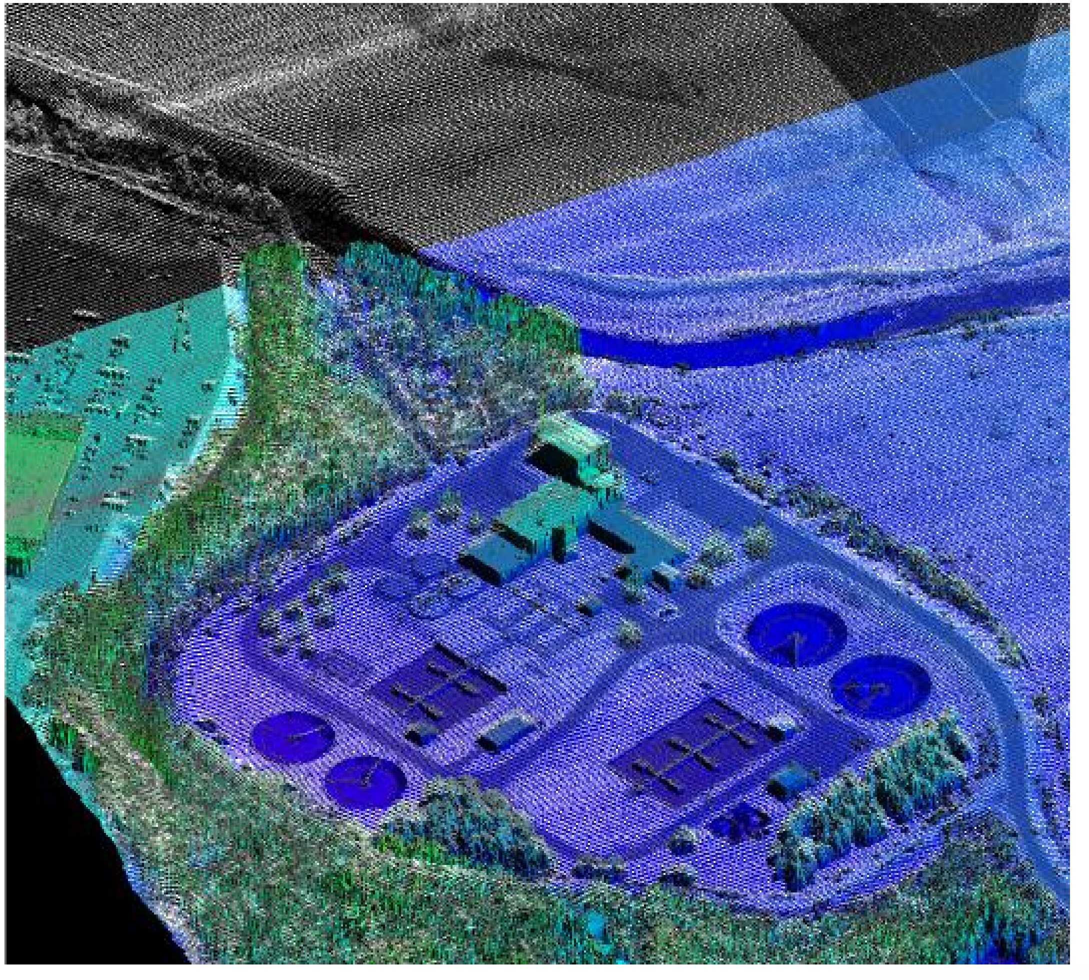
MPiA surface model (Leica ALS50-II)

low range noise for smoother surface models



MPiA intensity & surface model (Leica ALS50-II)

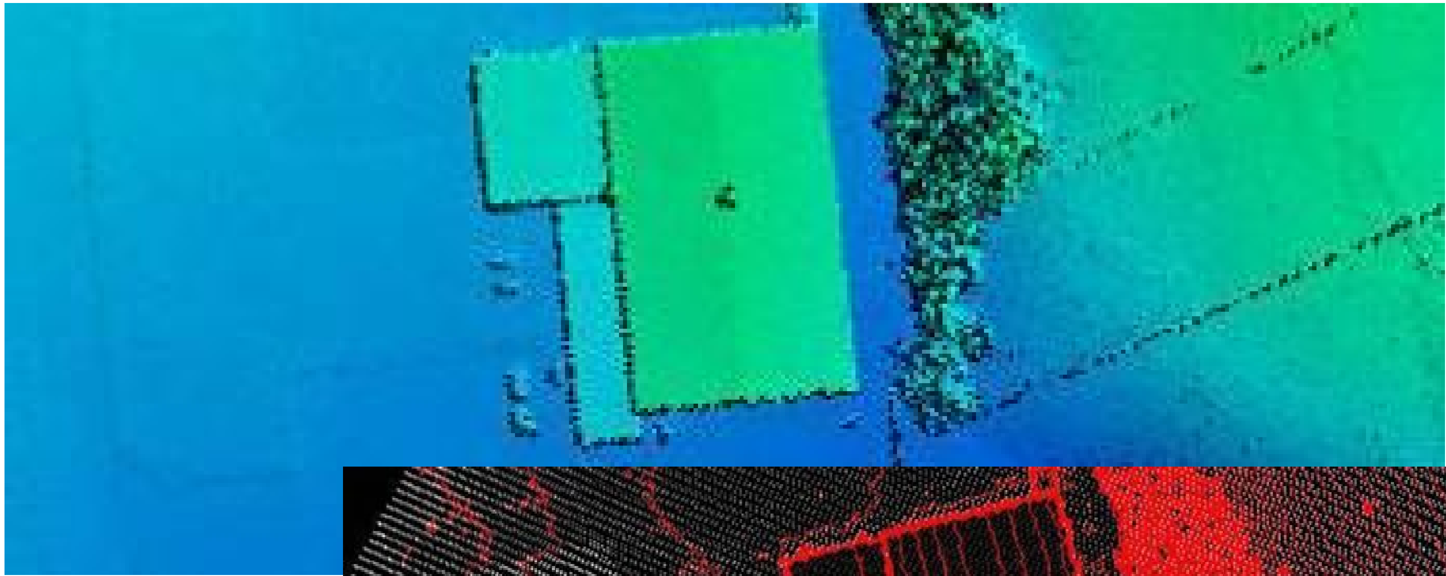
Combined result from data @ 150 kHz pulse rate from 1250 m AGL

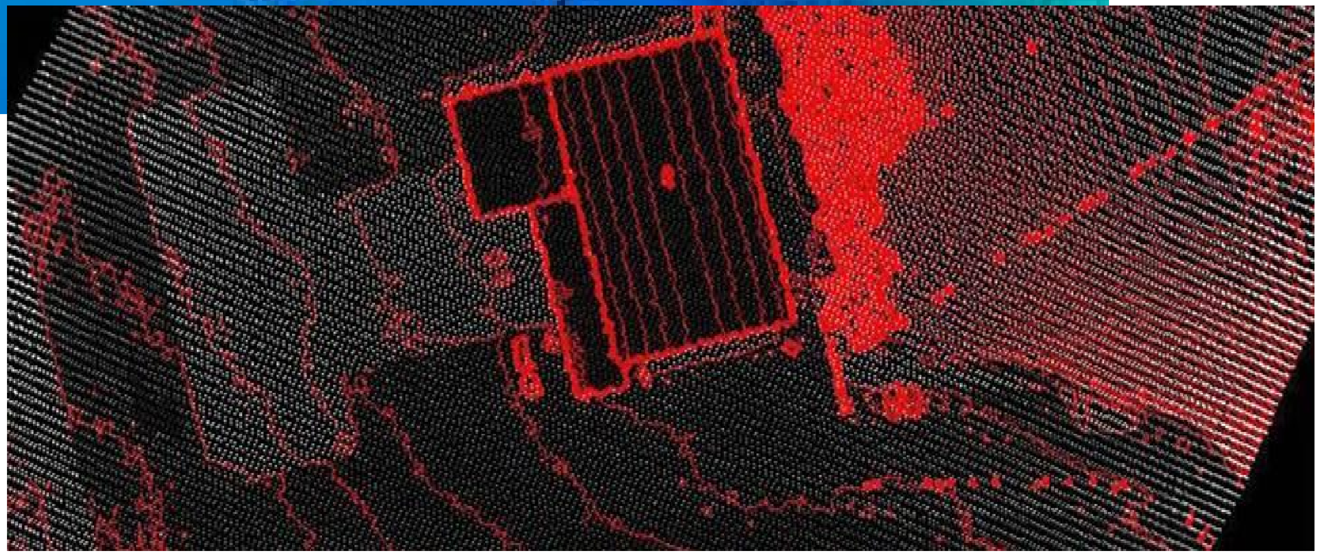


MPiA intensity image

2.5 points/m^2 with 1000 m swath

Ultra-high point density with superior accuracy





from an 125-knot aircraft!

Topic - 5

Operational Workflow

(for Airborne LIDAR Operations)

Airborne LIDAR Workflow - General comments

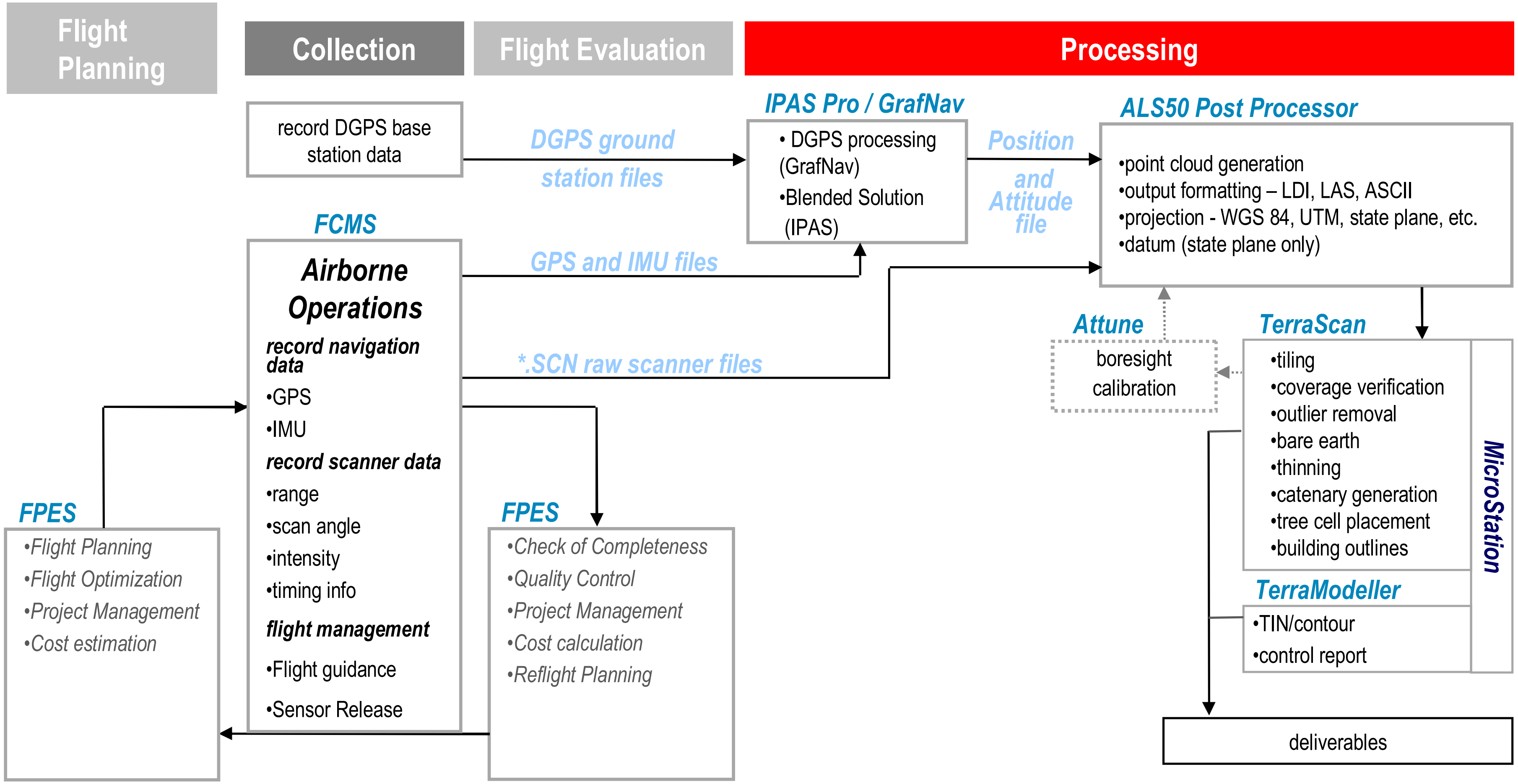
Workflow costs often follow a "5 – 10 - 85" pattern

- **5% of costs for job / mission planning**
- **10% of costs for data acquisition**
- **85% of costs for data processing**

The "85%" figure can vary substantially depending on nature final of deliverables

- **Raw point cloud versus bare earth model**
- **Feature collection required (building outlines, breaklines, etc.)**
- **Level of quality checking**

“Point cloud-based” workflow (Leica ALS50)
based on TerraScan/TerraModeler



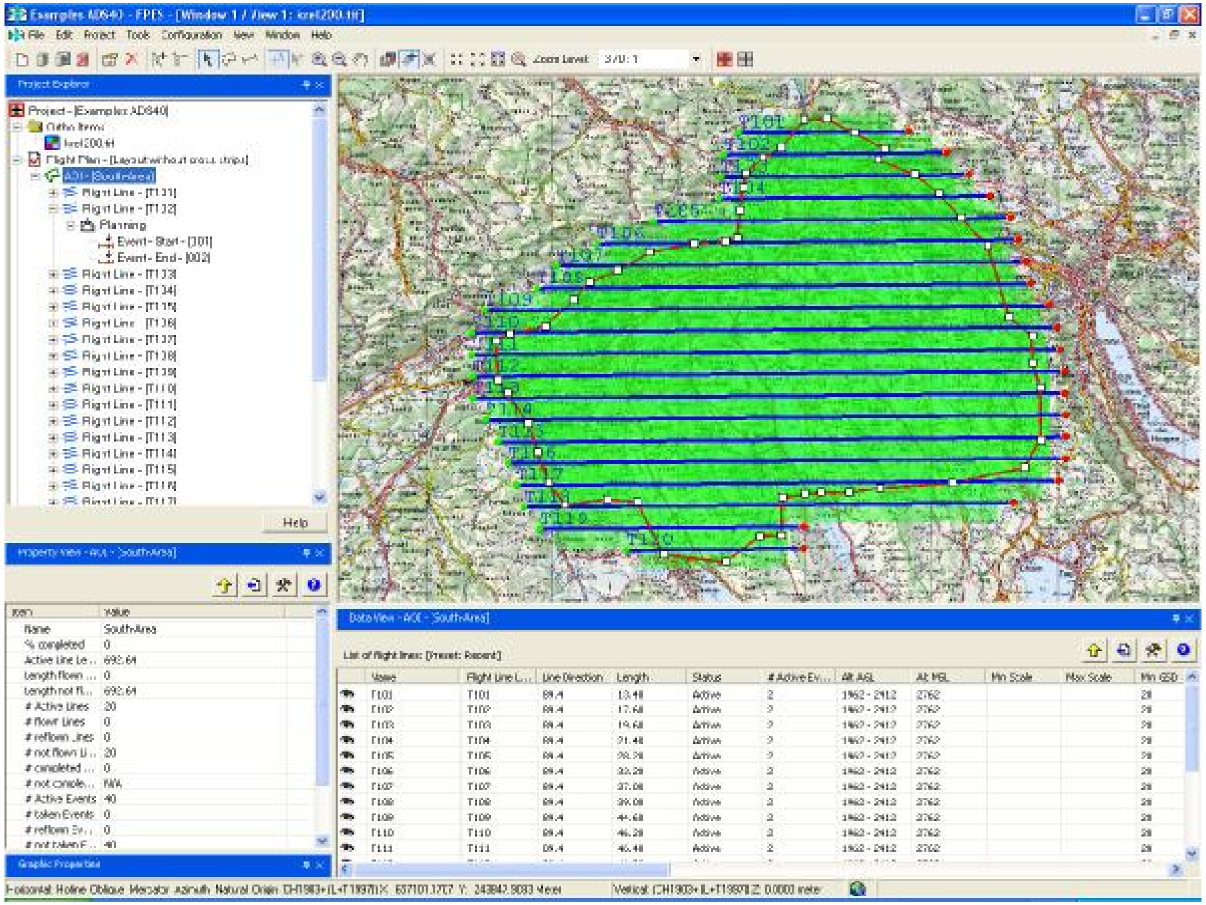
Flight Planning & Evaluation Software (Leica FPES)

Project Explorer

Shows the project in a tree-like directory

Property view

Display of summarized data



Graphic view

Data view

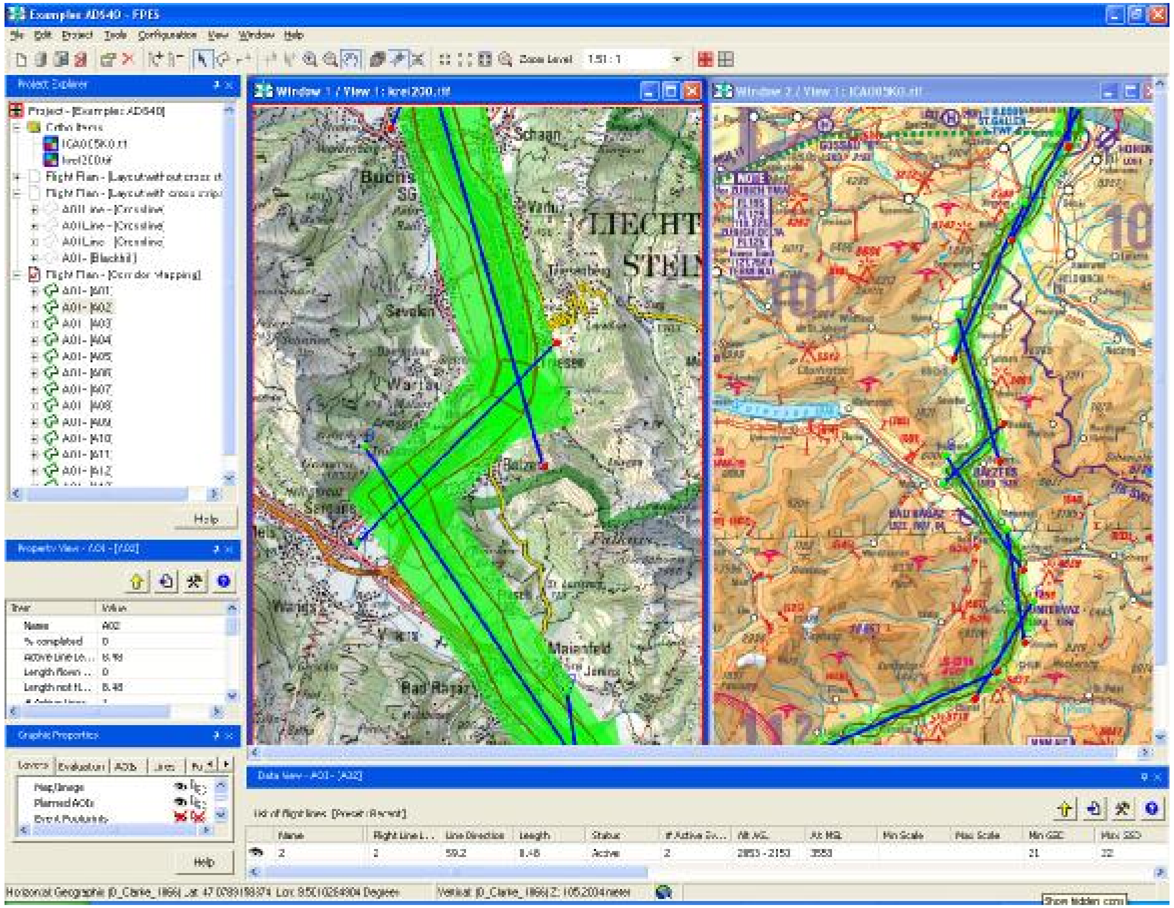
Display of detailed data

Flight Planning & Evaluation Software (Leica FPES)

Multiple windows for different maps

Maps can have

- § Different Datum
- § Different zoom level



Example

- § Topographic map
- § Airspace map

Flight Planning & Evaluation Software (Leica FPES)

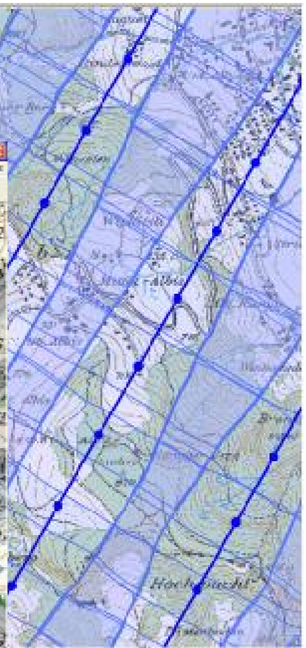
Footprints on DTM

Footprint planning

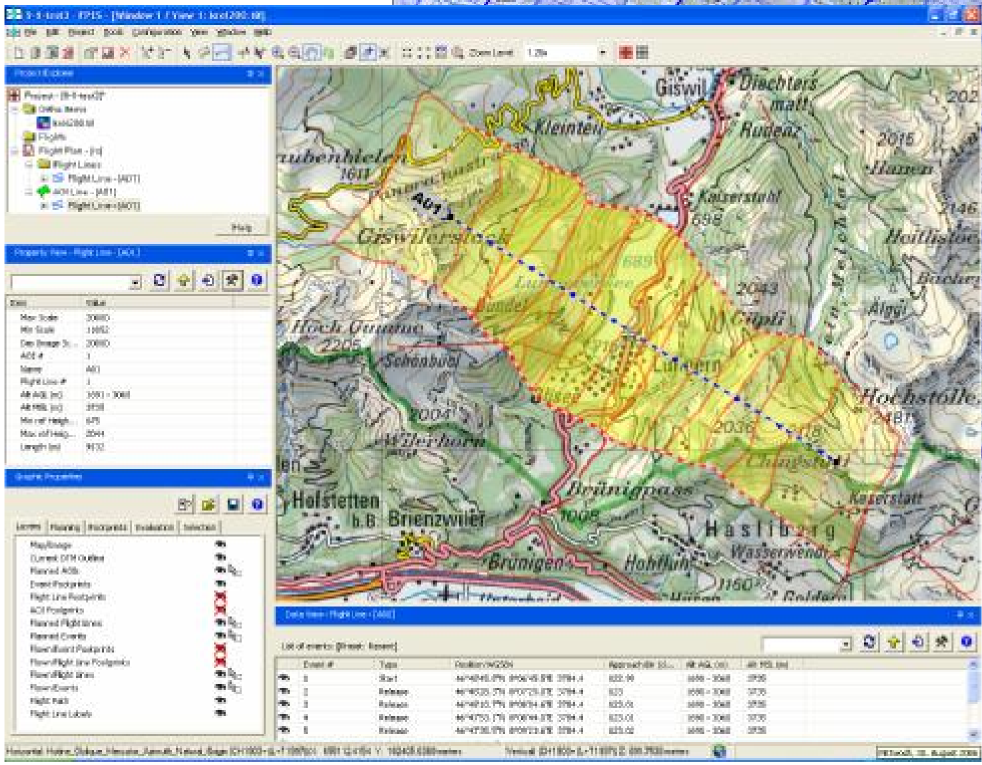
- AOI
- Flight line
- Event (Photo)

Footprint flight

- Flight Line
- Event (Photo)



AOI, hilly terrain

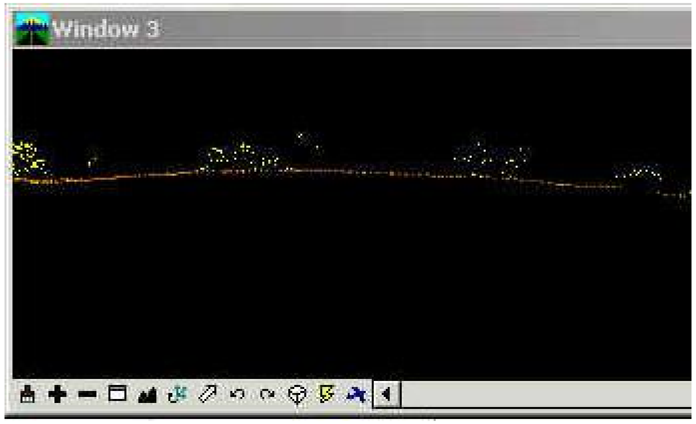


Single line, mountainous terrain

TerraSolid Processing Software

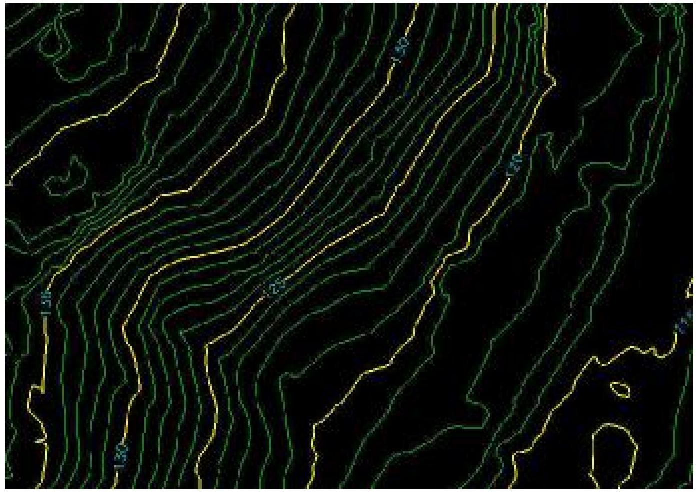
TerraScan

- Automatic and manual classification of laser data (ground, vegetation, …) the key to all lidar data processing
- Thinning of point cloud
- 2D and 3D viewing of laser points



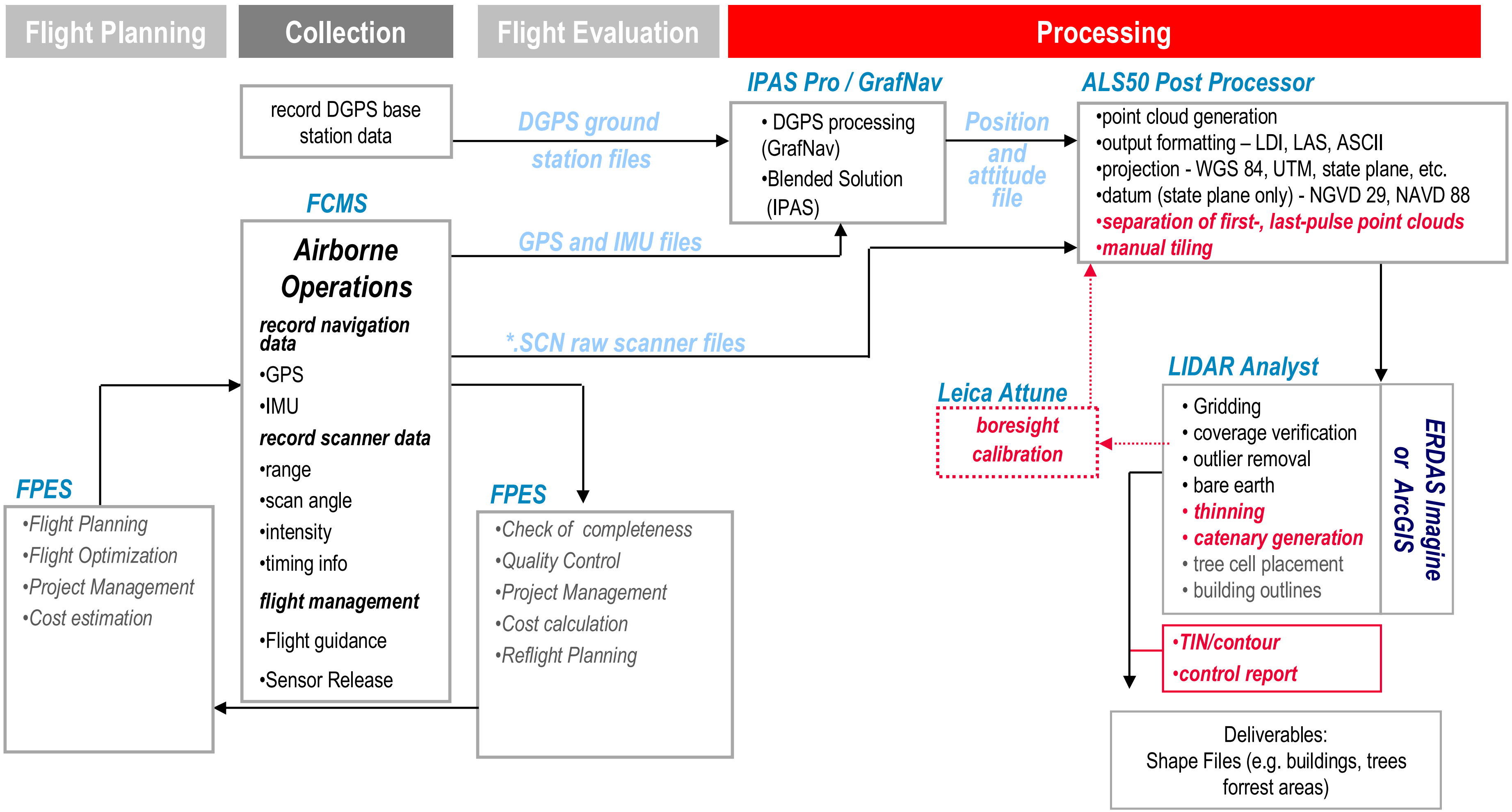
TerraModeller

- TIN/Contour generation
- Import or manually add break lines
- Cut/Fill calculations
- Interface with PRO600 for feature extraction

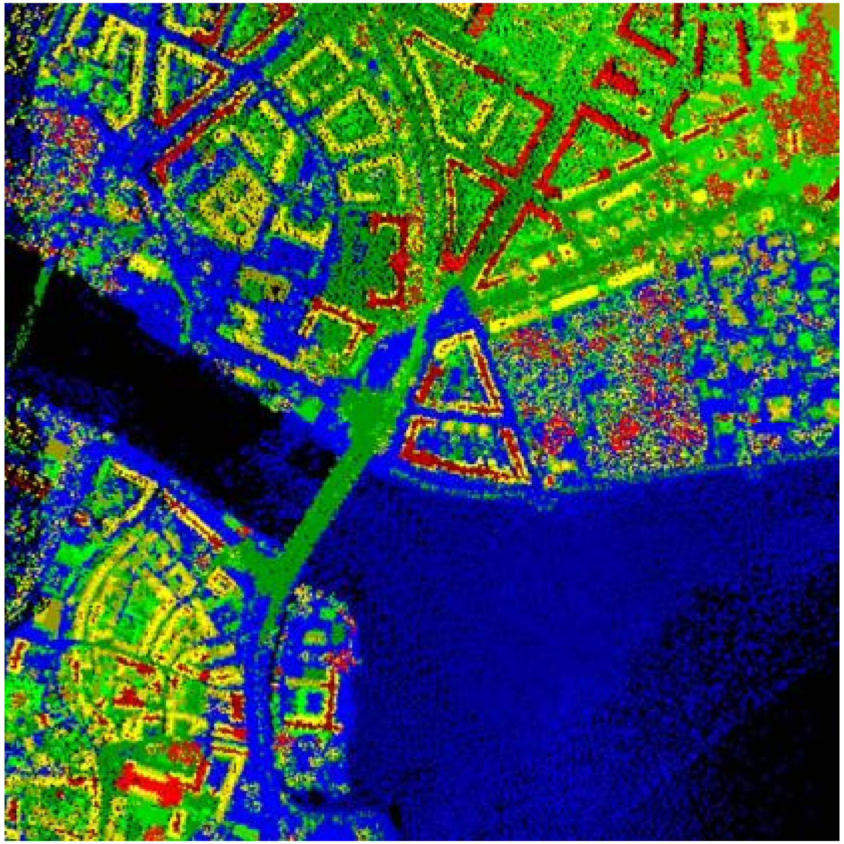


“Grid-Based” workflow (Leica ALS50)

based on VLS LIDAR Analyst



Starting point
point cloud block loaded



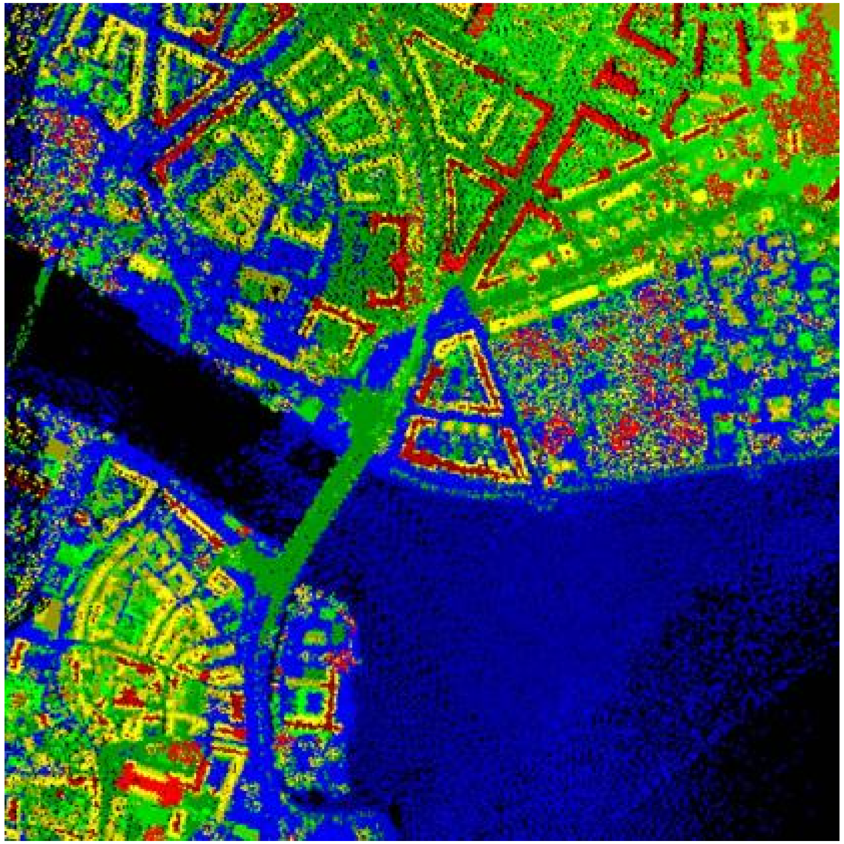
All returns shown

Ortho point cloud view

Color coded by elevation

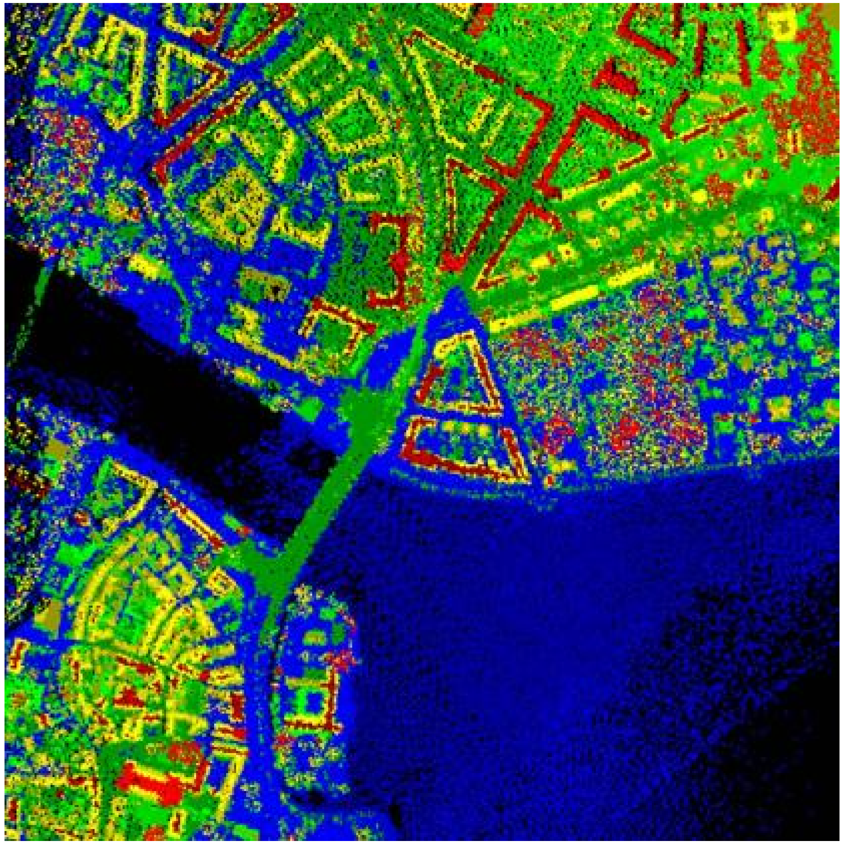
Comparison of rendered 1st returns to point cloud

point cloud gridded



Comparison of rendered last returns to point cloud

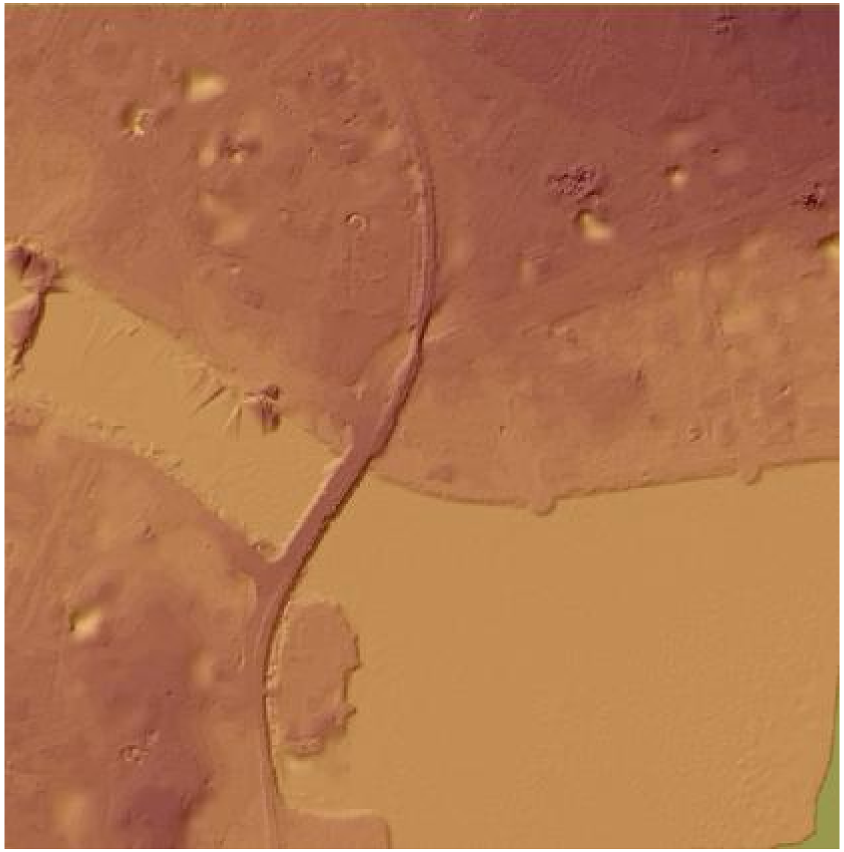
point cloud | gridded



Bare earth extraction

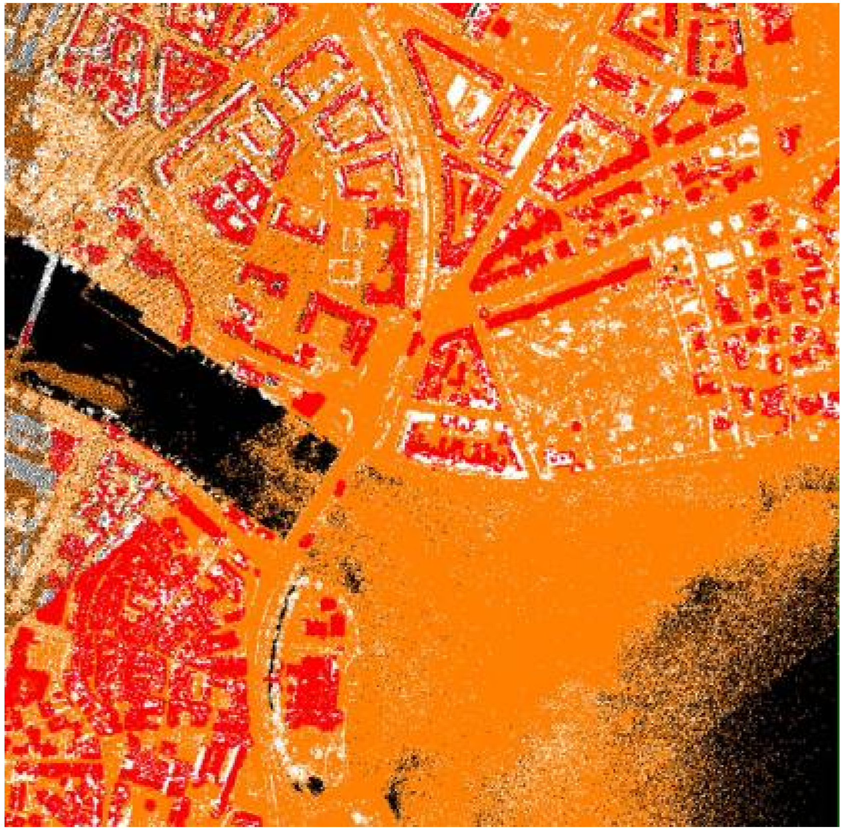
point cloud

gridded

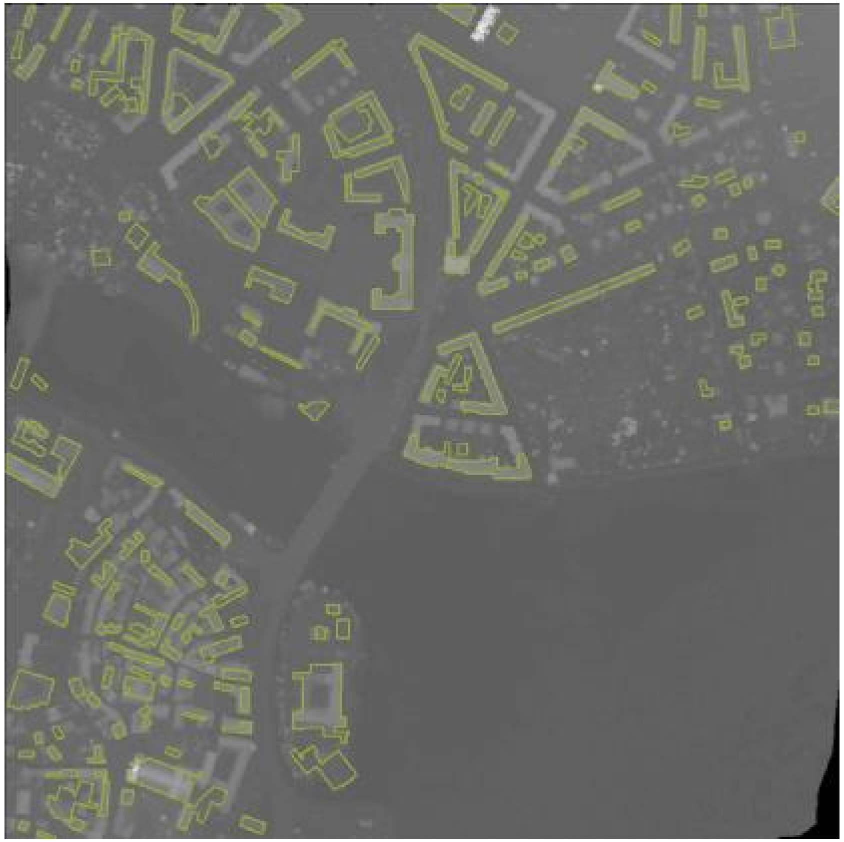


Building extraction

point cloud

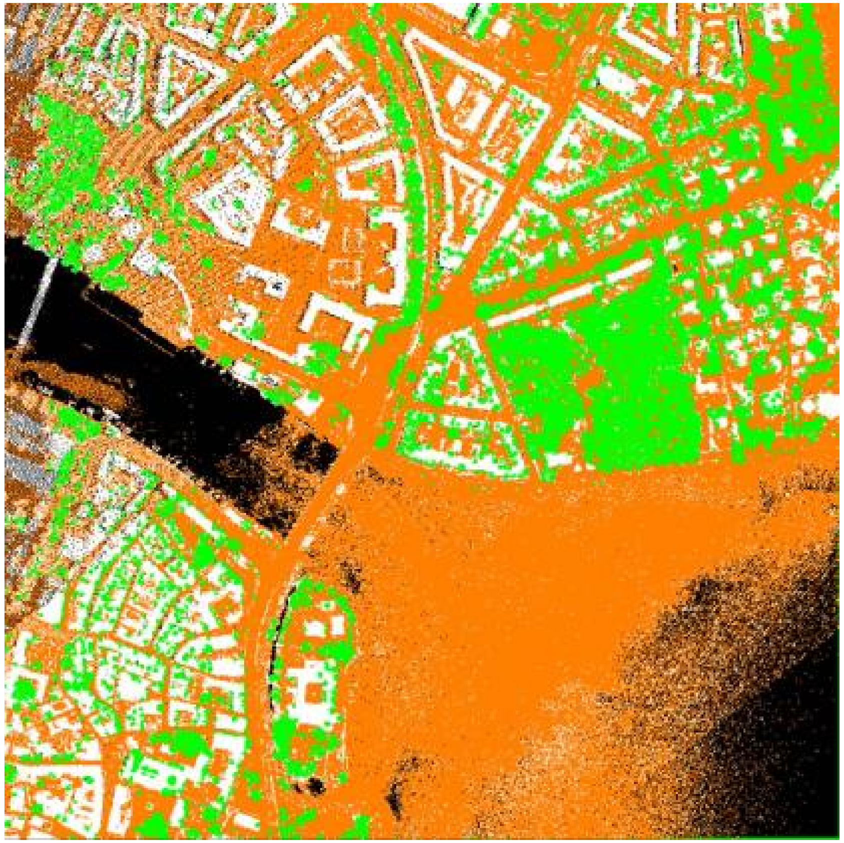


gridded



Tree extraction

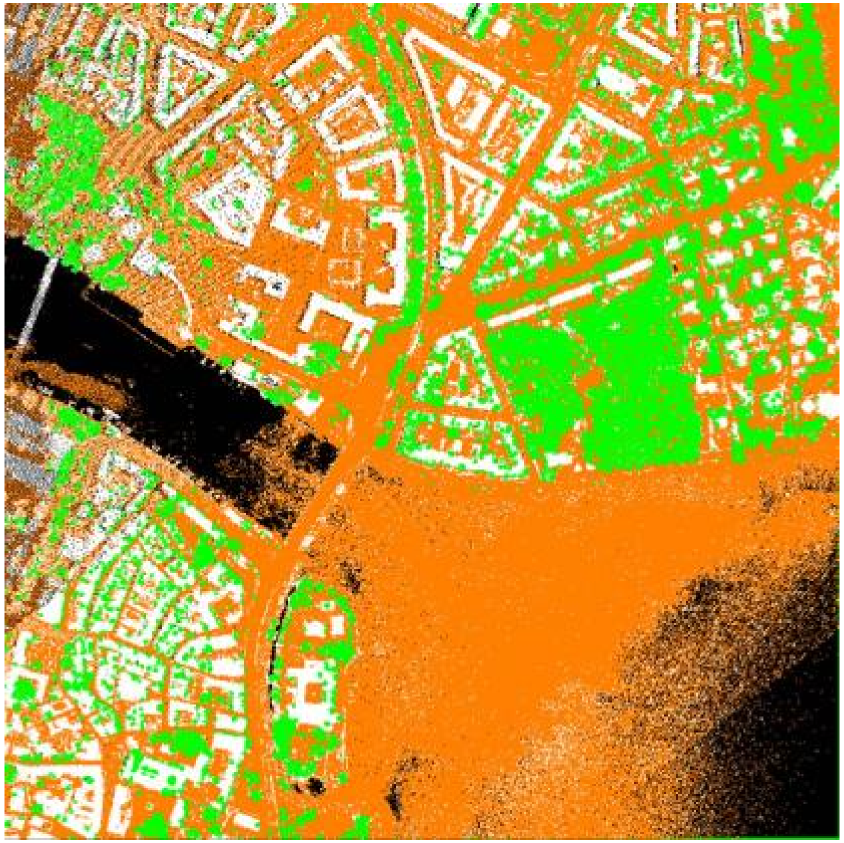
point cloud



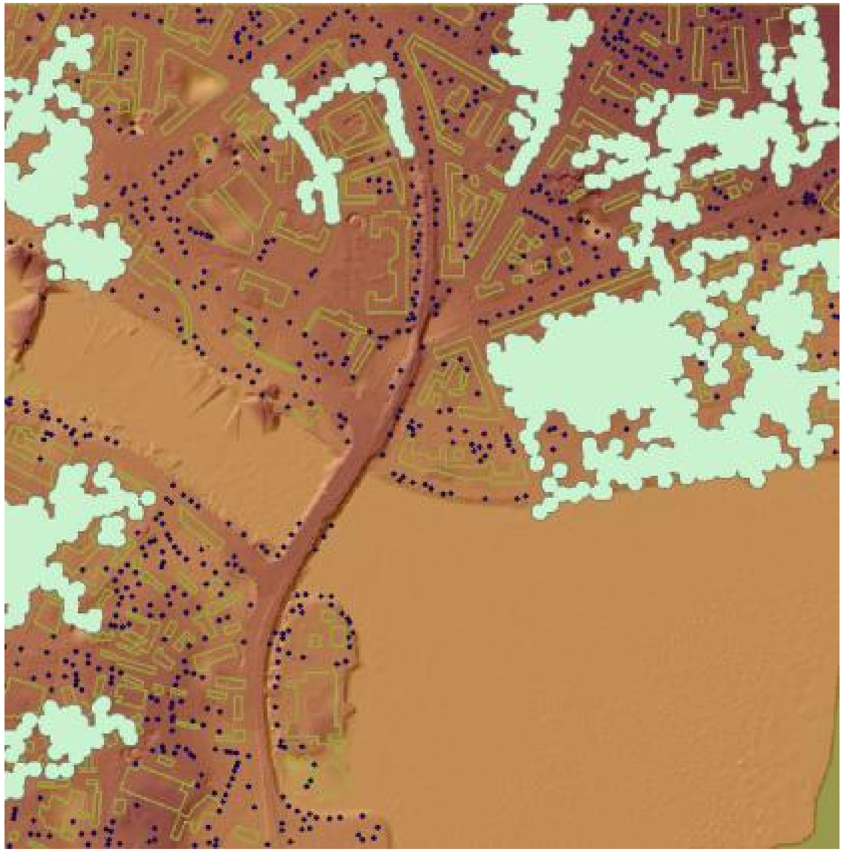
gridded

Forest extraction

point cloud

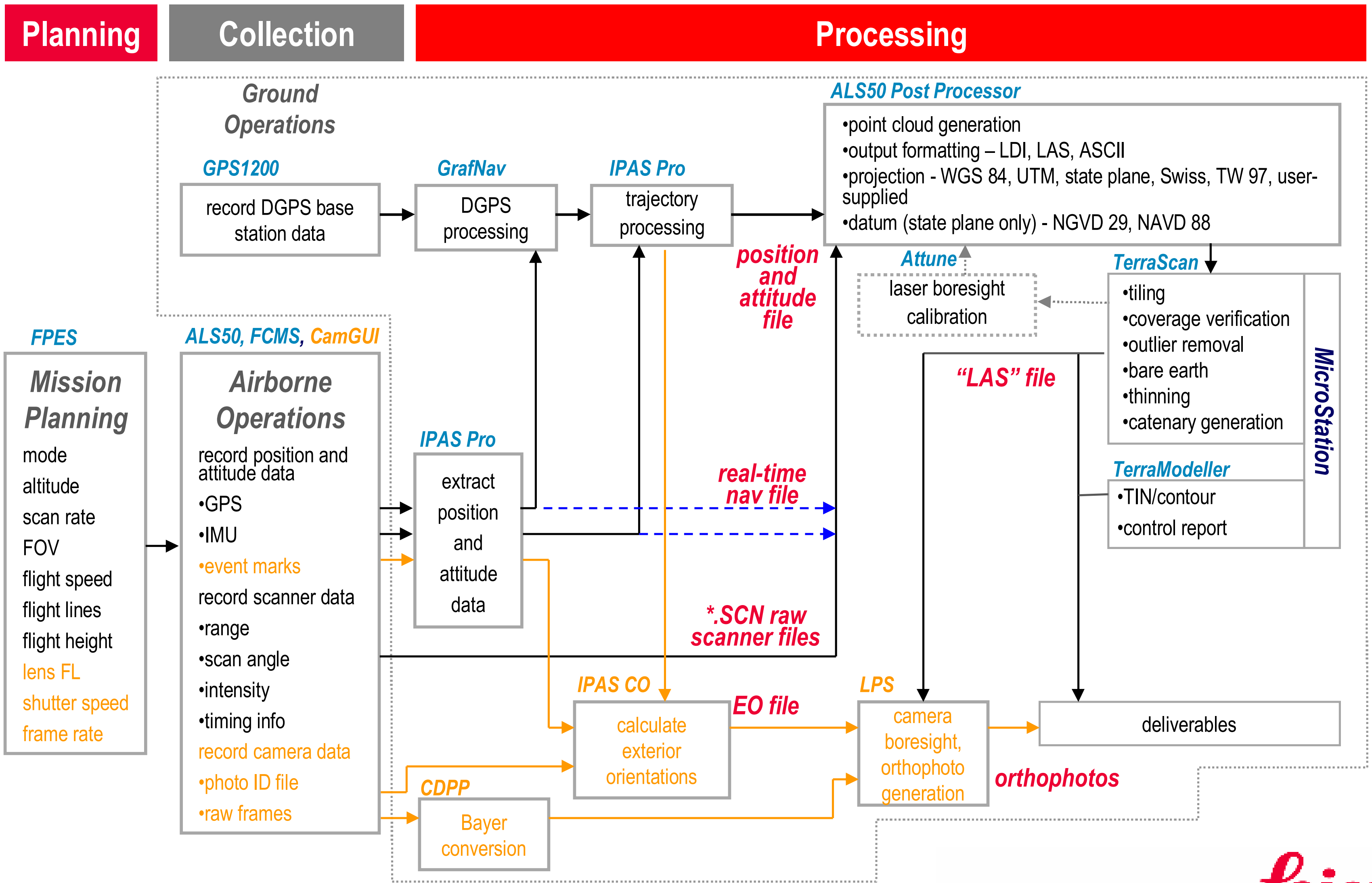


gridded



LIDAR Processing Workflow (Leica ALS50 – MidiPix 39MPx)

additional digital camera workflow items in amber



Topic - 7

Practical Examples / Planning

of

Airborne LIDAR Applications

Application Cases

A. Corridor Mapping (power line, pipeline, road, railway)

B. Forestry Mapping / Monitoring (Resource Mngt)

C. Hydrology / River bed Mapping (Flood Modelling)

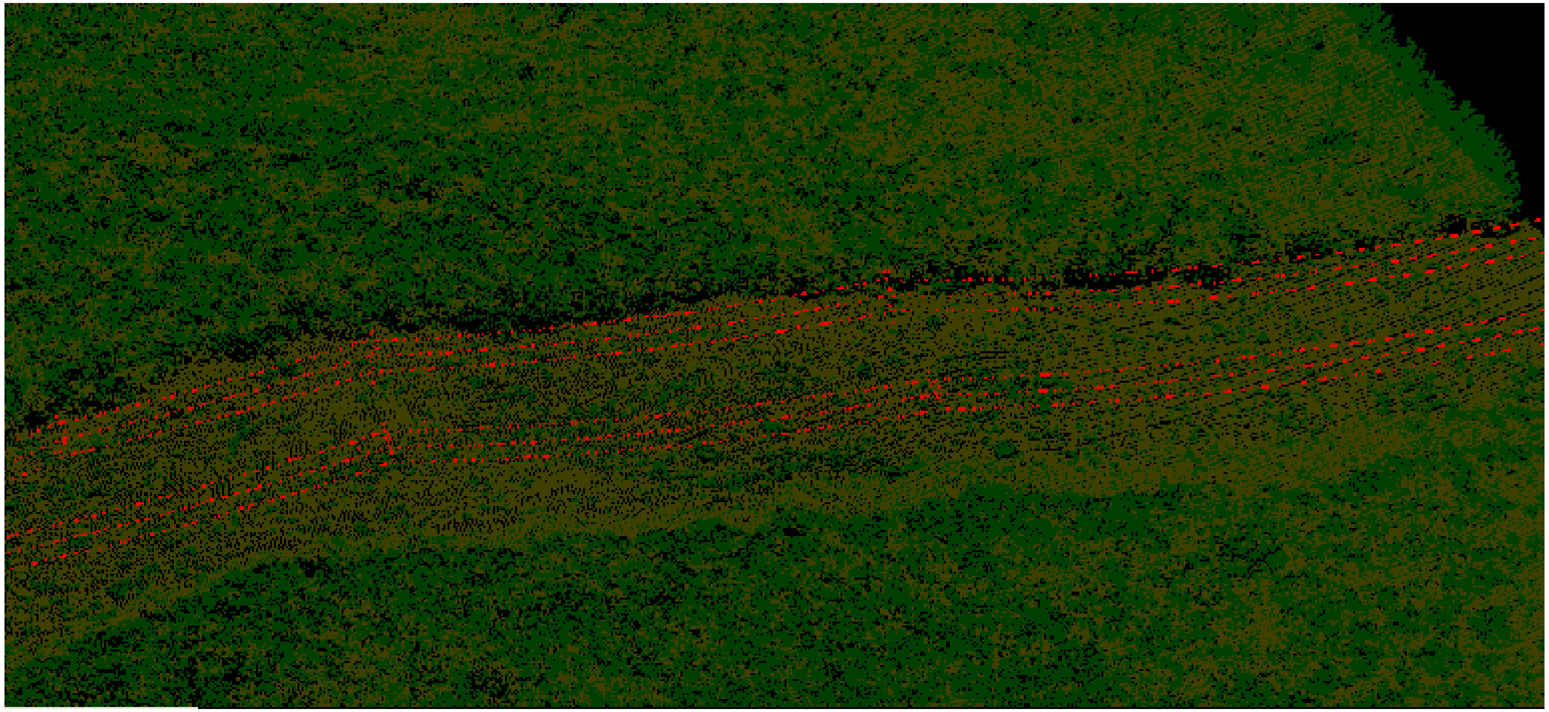
D. City Mapping (3D-Modelling, Telecom)

E. Costal Mapping (Erosion / Change Detection)

F. Basic DEM / DSM Generation (Key Reference for Orthophoto Mapping)

A. Corridor Mapping - 1
(power lines)

power line position and vegetation clearance



Microsoft Excel - 070702a_Aeroplan-Std-Powerline-300.xls

	A	B	C	D		S	
9							BLACK
10	*Commanded FOV (full angle)*	*degrees*	20.00				
14	Terrain Elevation AMSL (minimum in survey area)	meters	40.00	131.23	feet		
16	Terrain Elevation AMSL (maximum in survey area)	meters	100.00	328.08	feet		
18	Nominal Flying Height Above Minimum Terrain Elevation	meters	300.00	984.24	feet		
20	Nominal Flying Altitude AMSL	meters	340.00	1115.47	feet		
22	Airspeed	knots	40.00	20.58	meters/sec	67.51	feet/sec
24	Range/Intensity Mode (1, 2, 3, 4)		4.00				
25	Max Laser Pulse Rate	Hz	150000.00				
26	Laser Pulse Rate Used	Hz	150000.00	**7.50**	watts avg		
28	System Controller Firmware (<V2.07, V2.07+)		V2.07+				
29	Laser Power Class (3=3W, 4=4W, LC50, XHR)		LC50				
30	Receiver Aperture Stop (45, 60, 65, 75, LM, ALS50)	degrees	ALS50				
31	Scan Rate	Hz	33.00				
32	Max Scan Rate (ALS50 Phase II only)	Hz	63.82				
37							
38	**Resulting Scan Pattern**						
39							
40	*Full Swath Width (nominal flying height above lowest terrain elevation)*	*meters*	*105.80*	*347.10*	*feet*		
41	Max Cross Track Spacing (occurs @ nadir)	meters	0.08	0.25	feet		
42	Max Along Track Spacing (occurs @ FOV edge)	meters	0.62	2.05	feet		
43	Cross Track / Along Track Ratio		0.12				
44	Illuminated Footprint Diameter (@ 1/e^2 energy)	meters	0.08	0.26	feet		
45	Point Density (average)	pts/meter^2	68.90	6.40	pts/ft^2		
46	Point Density (@ nadir)	pts/meter^2	41.54				
47	Area / Point (average)	meters^2	0.01	0.16	ft^2		
48	Average Point Spacing	meters	0.12	0.40	ft		
91							
92	**Resulting Accuracy Estimates (1 sigma)**						
93							
94	Assumed GPS Error	meters	0.03				
95			Nadir	FOV Edge			
96	Estimated Cross-Track Error	meters	0.04	0.04			
97	Estimated Along-Track Error	meters	0.04	0.04			
98	Estimated Height Error	meters	0.06	0.06			
99							
100	Estimated Cross-Track Error	feet	0.14	0.14			
101	Estimated Along-Track Error	feet	0.13	0.13			
102	Estimated Height Error	feet	0.21	0.21			
103							
104	**ALS Data Storage Requirements**						
105							
106	Raw Data - IPAS GPS/IMU	GB/hour	0.10				
107	Raw Data - ALS .scn files	GB/hour	16.09				
108	Post Processed LAS file (max returns @ 20 bytes/return)	GB/hour	40.23				
109	Post Processed LAS file (max returns+GPS time @ 28 bytes/return)	GB/hour	56.33				
110	Allocation for Working Copies (2x factor)	GB/hour	145.04				
111	Total Workstation Disk Space Required (ALS)	GB/hour	217.56				
112							

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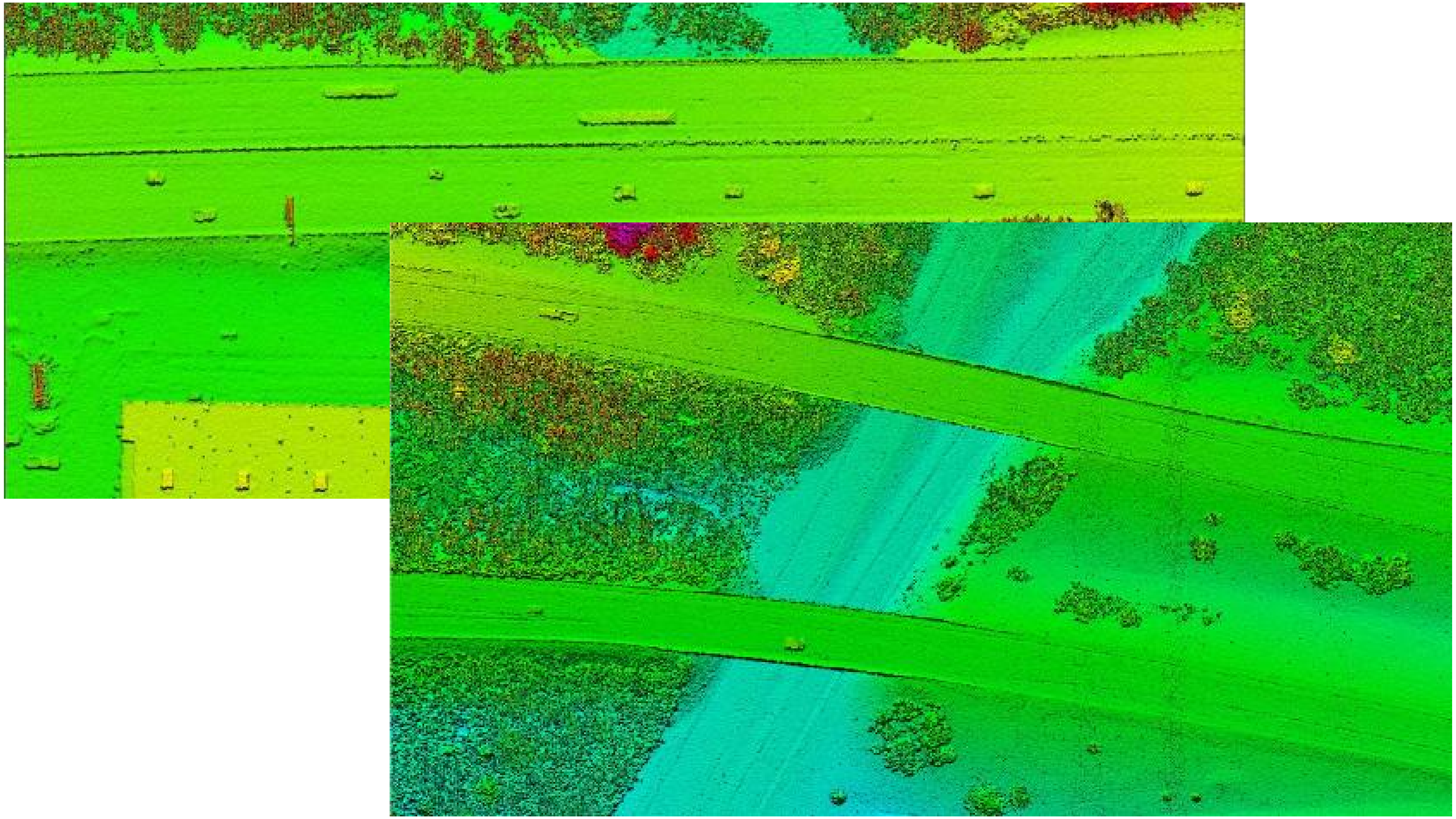
A. Corridor Mapping - 2

(roads, railways)



Microsoft Excel - 070702a_Aeroplan-Std-Powerline-300.xls

File Edit View Insert Format Tools Data Window Help

SET_ATTEN...

	A	B	C	D	E	S	T
9							BLACK
10	*Commanded FOV (full angle)*	*degrees*	20.00				
14	Terrain Elevation AMSL (minimum in survey area)	meters	40.00	131.23 feet			
16	Terrain Elevation AMSL (maximum in survey area)	meters	100.00	328.08 feet			
18	Nominal Flying Height Above Minimum Terrain Elevation	meters	300.00	984.24 feet			
20	Nominal Flying Altitude AMSL	meters	340.00	1115.47 feet			
22	Airspeed	knots	40.00	20.58 meters/sec		67.51 feet/sec	
24	Range/Intensity Mode (1, 2, 3, 4)		4.00				
25	Max Laser Pulse Rate	Hz	150000.00				
26	Laser Pulse Rate Used	Hz	150000.00	**7.50** watts avg			
28	System Controller Firmware (<V2.07, V2.07+)		V2.07+				
29	Laser Power Class (3=3W, 4=4W, LC50, XHR)		LC50				
30	Receiver Aperture Stop (45, 60, 65, 75, LM, ALS50)	degrees	ALS50				
31	Scan Rate	Hz	33.00				
32	Max Scan Rate (ALS50 Phase II only)	Hz	63.82				
37							
38	***Resulting Scan Pattern***						
39							
40	*Full Swath Width (nominal flying height above lowest terrain elevation)*	*meters*	*105.80*	*347.10 feet*			
41	Max Cross Track Spacing (occurs @ nadir)	meters	0.08	0.25 feet			
42	Max Along Track Spacing (occurs @ FOV edge)	meters	0.62	2.05 feet			
43	Cross Track / Along Track Ratio		0.12				
44	Illuminated Footprint Diameter (@ 1.e^2 energy)	meters	0.08	0.26 feet			
45	Point Density (average)	pts/meter^2	68.90	6.40 pts/ft^2			
46	Point Density (@ nadir)	pts/meter^2	41.54				
47	Area / Point (average)	meters^2	0.01	0.16 ft^2			
48	Average Point Spacing	meters	0.12	0.40 ft			

	A	B	C	D
91				
92	***Resulting Accuracy Estimates (1 sigma)***			
93				
94	Assumed GPS Error	meters	0.03	
95			Nadir	FOV Edge
96	Estimated Cross-Track Error	meters	0.04	0.04
97	Estimated Along-Track Error	meters	0.04	0.04
98	Estimated Height Error	meters	0.06	0.06
99				
100	Estimated Cross-Track Error	feet	0.14	0.14
101	Estimated Along-Track Error	feet	0.13	0.13
102	Estimated Height Error	feet	0.21	0.21
103				
104	***ALS Data Storage Requirements***			
105				
106	Raw Data - IPAS GPS/IMU	GB/hour	0.10	
107	Raw Data - ALS .scn files	GB/hour	16.09	
108	Post Processed LAS file (max returns @ 20 bytes/return)	GB/hour	40.23	
109	Post Processed LAS file (max returns+GPS time @ 28 bytes/return)	GB/hour	56.33	
110	Allocation for Working Copies (2x factor)	GB/hour	145.04	
111	Total Workstation Disk Space Required (ALS)	GB/hour	217.56	
112				

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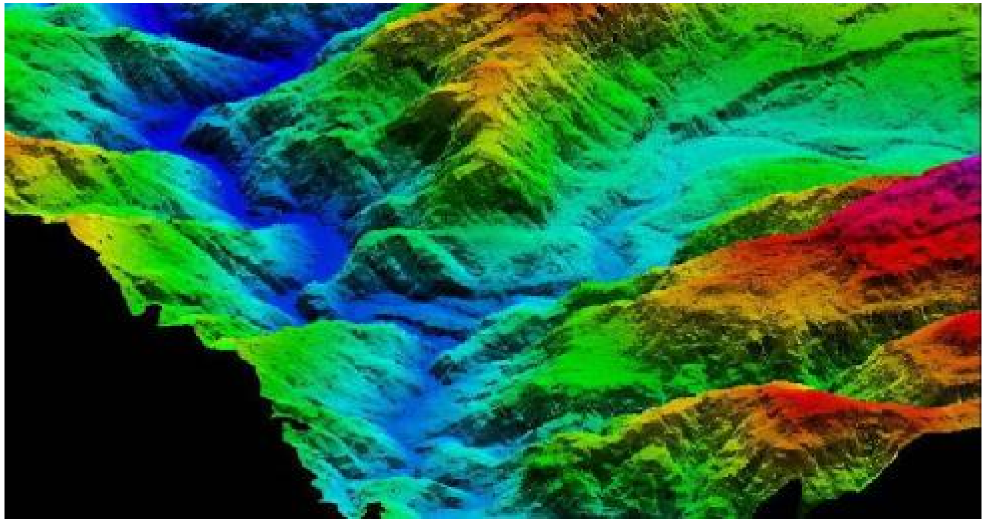
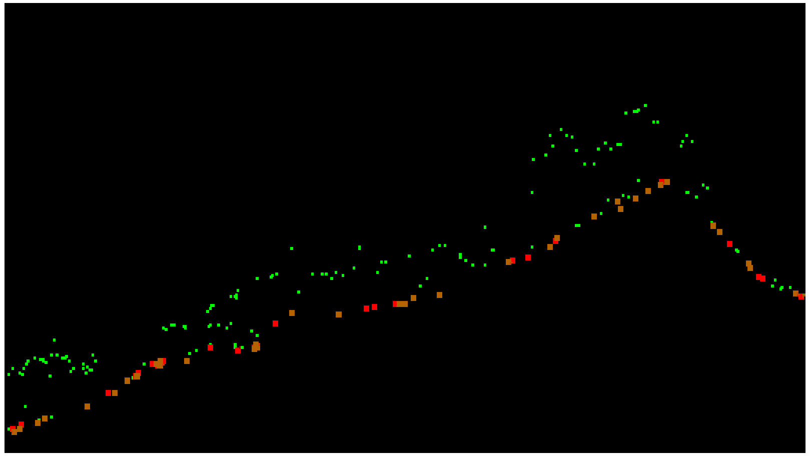
Start | C:\Data\A0_1_... | Microsoft Powe... | Microsoft Exc... | Aeroplan-Powe... | 81% | 11:37

2. Forestry Mapping / Monitoring
(Resource Management)





Microsoft Excel - 070703b_Aeroplan-MPiA-Forestry-1500.xls

GREEN BOLD ITALIC
BLACK

Row	A	B	C	D	E	S
8	***Scanner Setup***					
9						
10	***Commanded FOV (full angle)***	***degrees***	35.00			
14	Terrain Elevation AMSL (minimum in survey area)	meters	0.00	0.00	feet	
16	Terrain Elevation AMSL (maximum in survey area)	meters	0.00	0.00	feet	
18	Nominal Flying Height Above Minimum Terrain Elevation	meters	1500.00	4921.20	feet	
20	Nominal Flying Altitude AMSL	meters	1500.00	4921.20	feet	
22	Airspeed	knots	140.00	72.02	meters/sec	236.29 feet/sec
24	Range/Intensity Mode (1, 2, 3, 4)		4.00			
25	Max Laser Pulse Rate	Hz	72600.00			
26	Laser Pulse Rate Used	Hz	145200.00	**7.50**	watts avg	
28	System Controller Firmware (<V2.07, V2.07+)		V2.07+			
29	Laser Power Class (3=3W, 4=4W, LC50, XHR)		LC50			
30	Receiver Aperture Stop (45, 60, 65, 75, LM, ALS50)	degrees	ALS50			
31	Scan Rate	Hz				
32	Max Scan Rate (ALS50 Phase II only)	Hz	48.27			
37						
38	***Resulting Scan Pattern***					
39						
40	***Full Swath Width (nominal flying height above lowest terrain elevation)***	***meters***	***945.90***	***3103.30***	***feet***	
41	Max Cross Track Spacing (occurs @ nadir)	meters	0.00	0.00	feet	
42	Max Along Track Spacing (occurs @ FOV edge)	meters	#DIV/0!	#DIV/0!	feet	
43	Cross Track / Along Track Ratio		#DIV/0!			
44	Illuminated Footprint Diameter (@ 1.e^2 energy)	meters	0.34	1.13	feet	
45	Point Density (average)	pts/meter^2	#DIV/0!	#DIV/0!	pts/ft^2	
46	Point Density (@ nadir)	pts/meter^2	#DIV/0!			
47	Area / Point (average)	meters^2	#DIV/0!	#DIV/0!	ft^2	
48	Average Point Spacing	meters	#DIV/0!	#DIV/0!	ft	
91						
92	***Resulting Accuracy Estimates (1 sigma)***					
93						
94	Assumed GPS Error	meters	0.05			
95			Nadir	FOV Edge		
96	Estimated Cross-Track Error	meters	0.15	0.16		
97	Estimated Along-Track Error	meters	0.14	0.16		
98	Estimated Height Error	meters	0.07	0.09		
99						
100	Estimated Cross-Track Error	feet	0.49	0.54		
101	Estimated Along-Track Error	feet	0.47	0.52		
102	Estimated Height Error	feet	0.24	0.29		
103						
104	***ALS Data Storage Requirements***					
105						
106	Raw Data - IPAS GPS/IMU	GB/hour	0.10			
107	Raw Data - ALS .scn files	GB/hour	15.58			
108	Post Processed LAS file (max returns @ 20 bytes/return)	GB/hour	38.95			
109	Post Processed LAS file (max returns+GPS time @ 28 bytes/return)	GB/hour	54.52			
110	Allocation for Working Copies (2x factor)	GB/hour	140.40			
111	Total Workstation Disk Space Required (ALS)	GB/hour	210.61			

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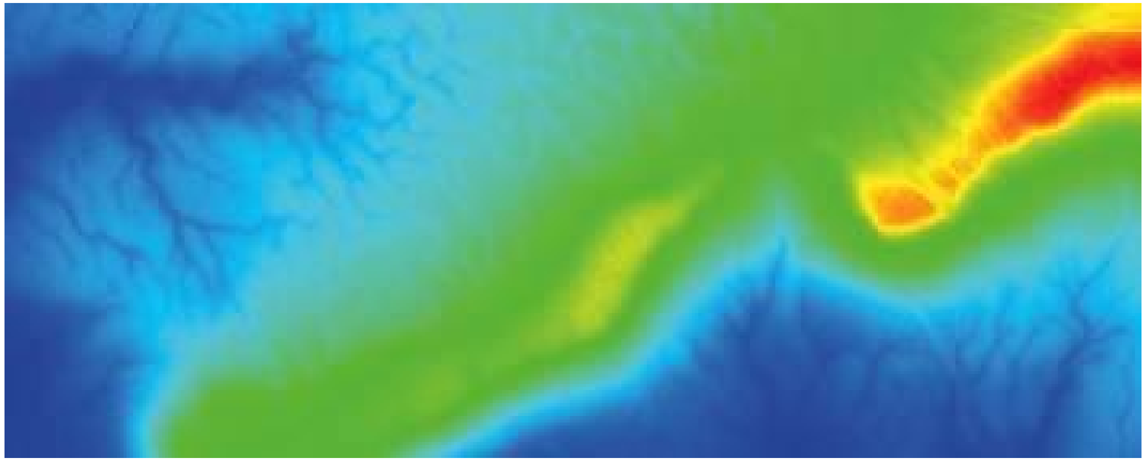
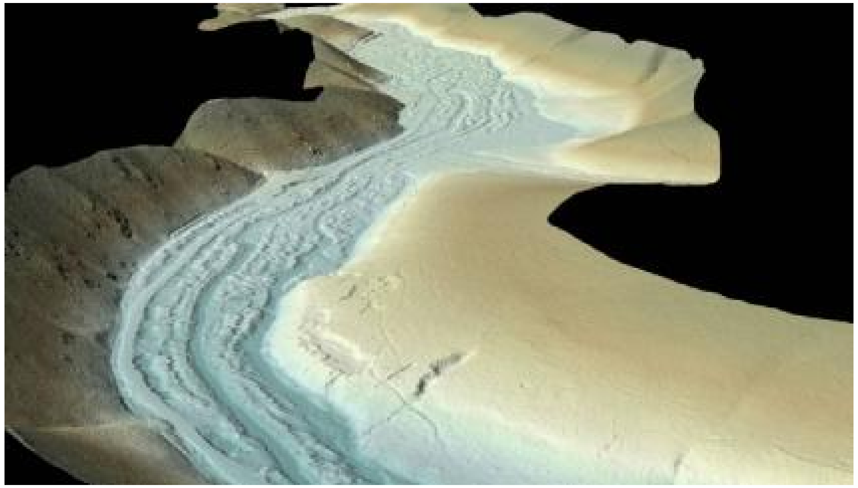
3. Hydrology / River bed Mapping

(Flood Modelling)





Microsoft Excel - 070703c_Aeroplan-River-800.xls

C94 — 0.03

Row	A	B	C	D		E
8	***Scanner Setup***					
9						
10	*Commanded FOV (full angle)*	*degrees*	28.00			
14	Terrain Elevation AMSL (minimum in survey area)	meters	0.00	0.00	feet	
16	Terrain Elevation AMSL (maximum in survey area)	meters	100.00	328.08	feet	
18	Nominal Flying Height Above Minimum Terrain Elevation	meters	800.00	2624.64	feet	
20	Nominal Flying Altitude AMSL	meters	800.00	2624.64	feet	
22	Airspeed	knots	80.00	41.16	meters/sec	135.02 feet/sec
24	Range/Intensity Mode (1, 2, 3, 4)		4.00			
25	Max Laser Pulse Rate	Hz	115800.00			
26	Laser Pulse Rate Used	Hz	115800.00	**7.29**	watts avg	
28	System Controller Firmware (<V2.07, V2.07+)		V2.07+			
29	Laser Power Class (3=3W, 4=4W, LC50, XHR)		LC50			
30	Receiver Aperture Stop (45, 60, 65, 75, LM, ALS50)	degrees	ALS50			
31	Scan Rate	Hz	53.97			
32	Max Scan Rate (ALS50 Phase II only)	Hz	53.97			
37						
38	***Resulting Scan Pattern***					
39						
40	*Full Swath Width (nominal flying height above lowest terrain elevation)*	*meters*	*398.92*	*1308.79*	*feet*	
41	Max Cross Track Spacing (occurs @ nadir)	meters	0.59	1.92	feet	
42	Max Along Track Spacing (occurs @ FOV edge)	meters	0.76	2.50	feet	
43	Cross Track / Along Track Ratio		0.77			
44	Illuminated Footprint Diameter (@ 1.e^2 energy)	meters	0.19	0.62	feet	
45	Point Density (average)	pts/meter^2	7.05	0.66	pts/ft^2	
46	Point Density (@ nadir)	pts/meter^2	4.47			
47	Area / Point (average)	meters^2	0.14	1.53	ft^2	
48	Average Point Spacing	meters	0.38	1.24	ft	
91						
92	***Resulting Accuracy Estimates (1 sigma)***					
93						
94	Assumed GPS Error	meters	0.03			
95			Nadir	FOV Edge		
96	Estimated Cross-Track Error	meters	0.08	0.09		
97	Estimated Along-Track Error	meters	0.08	0.08		
98	Estimated Height Error	meters	0.06	0.07		
99						
100	Estimated Cross-Track Error	feet	0.27	0.28		
101	Estimated Along-Track Error	feet	0.25	0.27		
102	Estimated Height Error	feet	0.21	0.22		
103						
104	***ALS Data Storage Requirements***					
105						
106	Raw Data - IPAS GPS/IMU	GB/hour	0.10			
107	Raw Data - ALS .scn files	GB/hour	12.42			
108	Post Processed LAS file (max returns @ 20 bytes/return)	GB/hour	31.06			
109	Post Processed LAS file (max returns+GPS time @ 28 bytes/return)	GB/hour	43.48			
110	Allocation for Working Copies (2x factor)	GB/hour	112.02			
111	Total Workstation Disk Space Required (ALS)	GB/hour	168.02			

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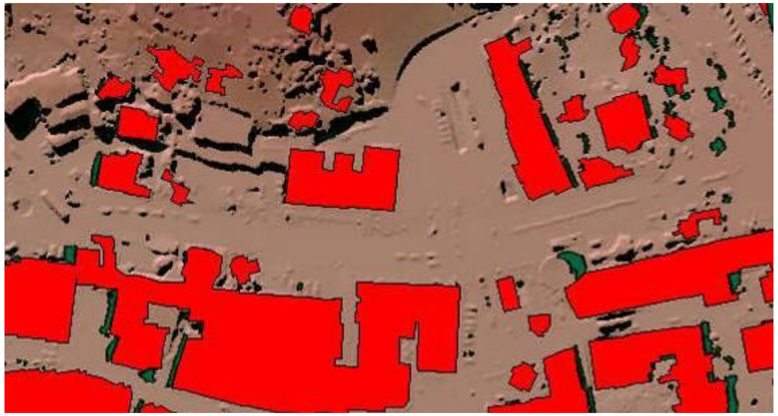
4. City Mapping
(3D-Modelling, Telecom)



Microsoft Excel - 070702_Aeroplan-Std-City.xls

Row	A	B	C	D	S	T
9						BLACK
10	*Commanded FOV (full angle)*	*degrees*	20.00			
14	Terrain Elevation AMSL (minimum in survey area)	meters	0.00	0.00 feet		
16	Terrain Elevation AMSL (maximum in survey area)	meters	100.00	328.08 feet		
18	Nominal Flying Height Above Minimum Terrain Elevation	meters	900.00	2952.72 feet		
20	Nominal Flying Altitude AMSL	meters	900.00	2952.72 feet		
22	Airspeed	knots	80.00	41.16 meters/sec	135.02 feet/sec	
24	Range/Intensity Mode (1, 2, 3, 4)		4.00			
25	Max Laser Pulse Rate	Hz	107800.00			
26	Laser Pulse Rate Used	Hz	107800.00	**6.89** watts avg		
28	System Controller Firmware (<V2.07, V2.07+)		V2.07+			
29	Laser Power Class (3=3W, 4=4W, LC50, XHR)		LC50			
30	Receiver Aperture Stop (45, 60, 65, 75, LM, ALS50)	degrees	ALS50			
31	Scan Rate	Hz	62.26			
32	Max Scan Rate (ALS50 Phase II only)	Hz	63.82			
37						
38	***Resulting Scan Pattern***					
39						
40	*Full Swath Width (nominal flying height above lowest terrain elevation)*	*meters*	*317.39*	*1041.29 feet*		
41	Max Cross Track Spacing (occurs @ nadir)	meters	0.58	1.91 feet		
42	Max Along Track Spacing (occurs @ FOV edge)	meters	0.66	2.17 feet		
43	Cross Track / Along Track Ratio		0.88			
44	Illuminated Footprint Diameter (@ 1.e^2 energy)	meters	0.21	0.69 feet		
45	Point Density (average)	pts/meter^2	8.25	0.77 pts/ft^2		
46	Point Density (@ nadir)	pts/meter^2	5.19			
47	Area / Point (average)	meters^2	0.12	1.30 ft^2		
48	Average Point Spacing	meters	0.35	1.14 ft		
91						
92	***Resulting Accuracy Estimates (1 sigma)***					
93						
94	Assumed GPS Error	meters	0.03			
95			Nadir	FOV Edge		
96	Estimated Cross-Track Error	meters	0.09	0.09		
97	Estimated Along-Track Error	meters	0.09	0.09		
98	Estimated Height Error	meters	0.09	0.09		
99						
100	Estimated Cross-Track Error	feet	0.30	0.30		
101	Estimated Along-Track Error	feet	0.28	0.29		
102	Estimated Height Error	feet	0.28	0.29		
103						
104	***ALS Data Storage Requirements***					
105						
106	Raw Data - PAS GPS/IMU	GB/hour	0.10			
107	Raw Data - ALS .scn files	GB/hour	11.57			
108	Post Processed LAS file (max returns @ 20 bytes/return)	GB/hour	28.91			
109	Post Processed LAS file (max returns+GPS time @ 28 bytes/return)	GB/hour	40.48			
110	Allocation for Working Copies (2x factor)	GB/hour	104.29			
111	Total Workstation Disk Space Required (ALS)	GB/hour	156.44			
112						

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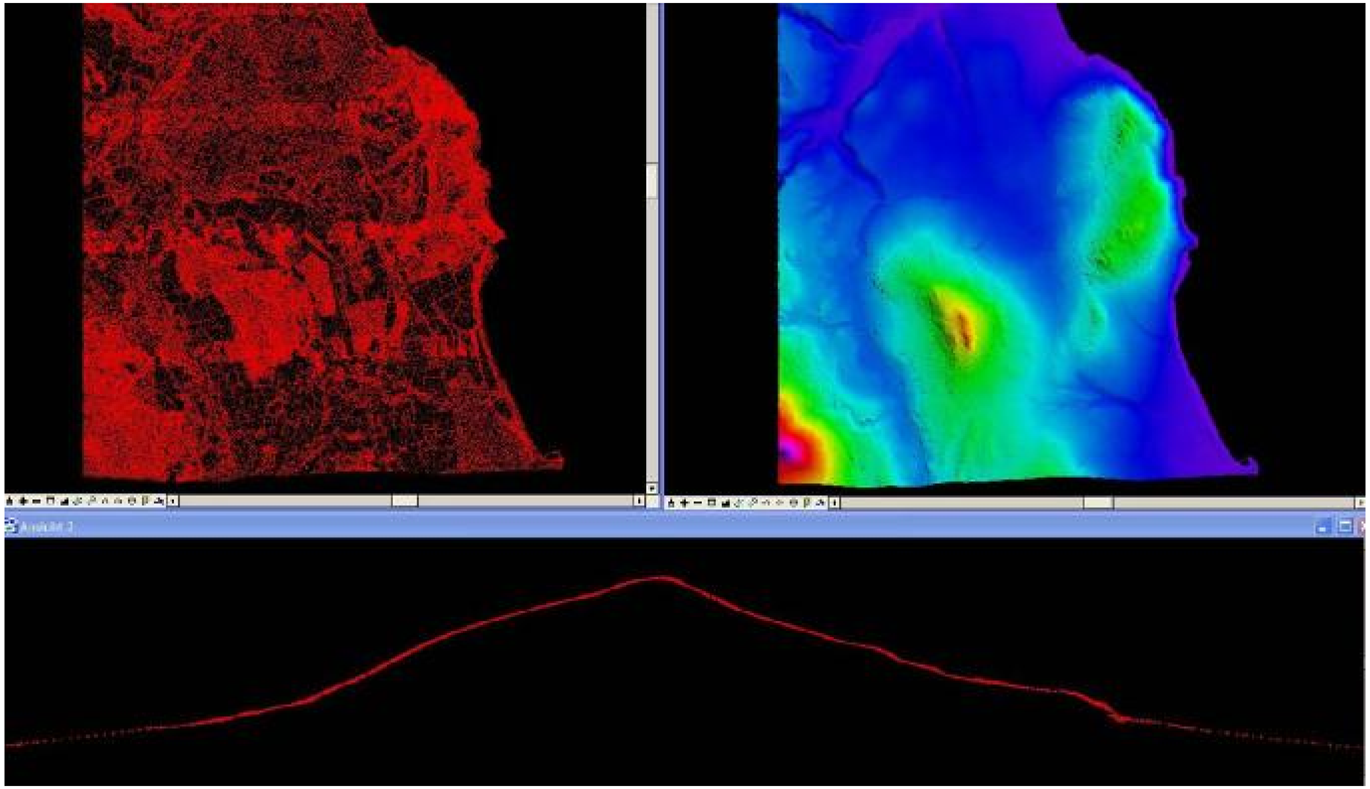
5. Costal Mapping

(Erosion / Change Detection)



Microsoft Excel - 070703e_Aeroplan-MPIA-Coast-2000.xls

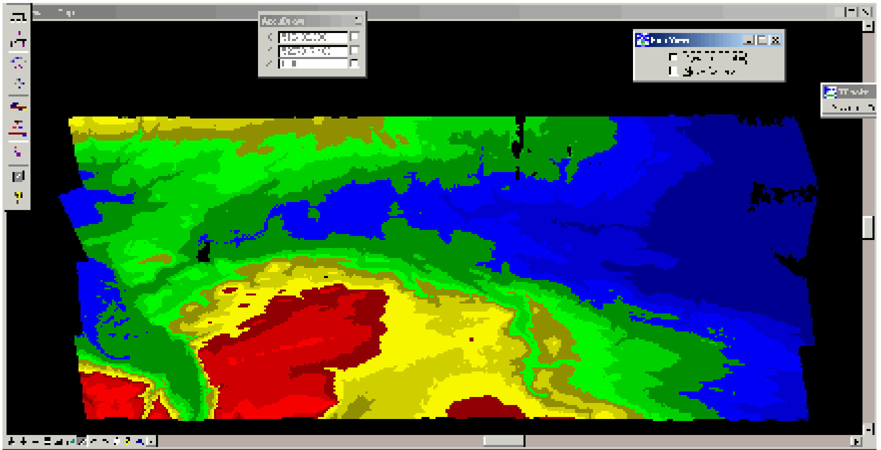
Row	A	B	C	D			
8	***Scanner Setup***						
9							
10	*Commanded FOV (full angle)*	degrees	45.00				
14	Terrain Elevation AMSL (minimum in survey area)	meters	0.00	0.00	feet		
16	Terrain Elevation AMSL (maximum in survey area)	meters	0.00	0.00	feet		
18	Nominal Flying Height Above Minimum Terrain Elevation	meters	2000.00	6561.60	feet		
20	Nominal Flying Altitude AMSL	meters	2000.00	6561.60	feet		
22	Airspeed	knots	140.00	72.02	meters/sec	236.29	feet/sec
24	Range/Intensity Mode (1, 2, 3, 4)		4.00				
25	Max Laser Pulse Rate	Hz	56300.00				
26	Laser Pulse Rate Used	Hz	112600.00	**7.13**	watts avg		
28	System Controller Firmware (<V2.07, V2.07+)		V2.07+				
29	Laser Power Class (3=3W, 4=4W, LC50, XHR)		LC50				
30	Receiver Aperture Stop (45, 60, 65, 75, LM, ALS50)	degrees	ALS50				
31	Scan Rate	Hz	40.30				
32	Max Scan Rate (ALS50 Phase II only)	Hz	42.46				
37							
38	***Resulting Scan Pattern***						
39							
40	*Full Swath Width (nominal flying height above lowest terrain elevation)*	*meters*	*1656.85*	*5435.81*	*feet*		
41	Max Cross Track Spacing (occurs @ nadir)	meters	1.79	5.87	feet		
42	Max Along Track Spacing (occurs @ FOV edge)	meters	1.79	5.86	feet		
43	Cross Track / Along Track Ratio		1.00				
44	Illuminated Footprint Diameter (@ 1.e^2 energy)	meters	0.45	1.49	feet		
45	Point Density (average)	pts/meter^2	0.94	0.09	pts/ft^2		
46	Point Density (@ nadir)	pts/meter^2	0.63				
47	Area / Point (average)	meters^2	1.06	11.41	ft^2		
48	Average Point Spacing	meters	1.03	3.38	ft		
91							
92	***Resulting Accuracy Estimates (1 sigma)***						
93							
94	Assumed GPS Error	meters	0.05				
95			Nadir	FOV Edge			
96	Estimated Cross-Track Error	meters	0.20	0.23			
97	Estimated Along-Track Error	meters	0.19	0.22			
98	Estimated Height Error	meters	0.08	0.11			
99							
100	Estimated Cross-Track Error	feet	0.64	0.74			
101	Estimated Along-Track Error	feet	0.61	0.72			
102	Estimated Height Error	feet	0.25	0.36			
103							
104	***ALS Data Storage Requirements***						
105							
106	Raw Data - IPAS GPS/IMU	GB/hour	0.10				
107	Raw Data - ALS .scn files	GB/hour	12.08				
108	Post Processed LAS file (max returns @ 20 bytes/return)	GB/hour	30.20				
109	Post Processed LAS file (max returns+GPS time @ 28 bytes/return)	GB/hour	42.28				
110	Allocation for Working Copies (2x factor)	GB/hour	108.93				
111	Total Workstation Disk Space Required (ALS)	GB/hour	163.39				

GREEN BOLD ITALIC
BLACK

ALS MISSION PLANNING / ALS JOB COSTING / USER SHEET 1 / USER SHEET 2 / USER SHEET 3 / RELEASE NOTES

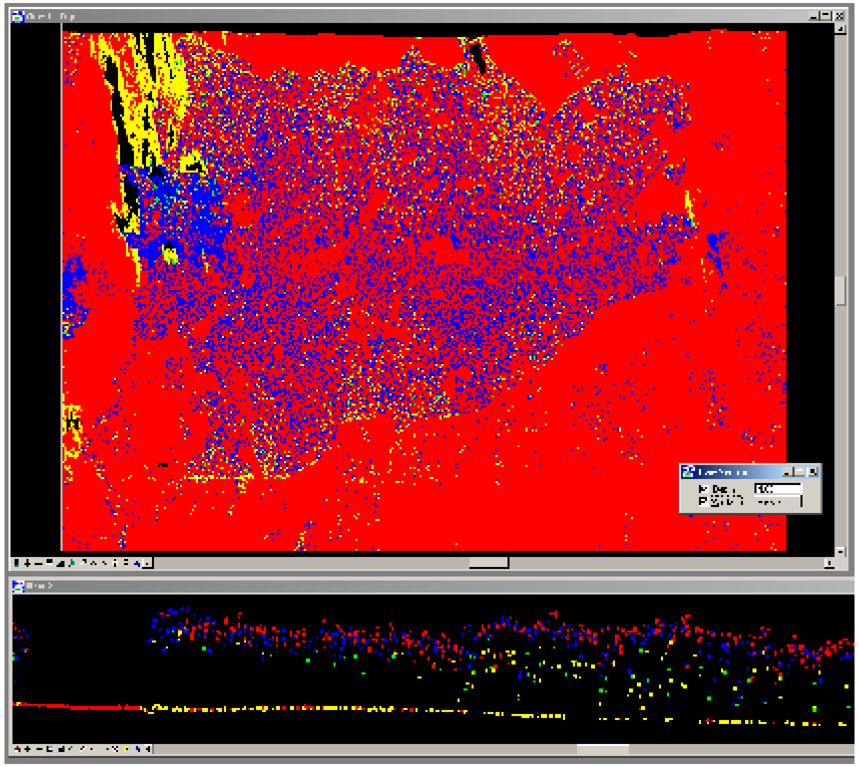
6. Basic DEM / DSM Generation

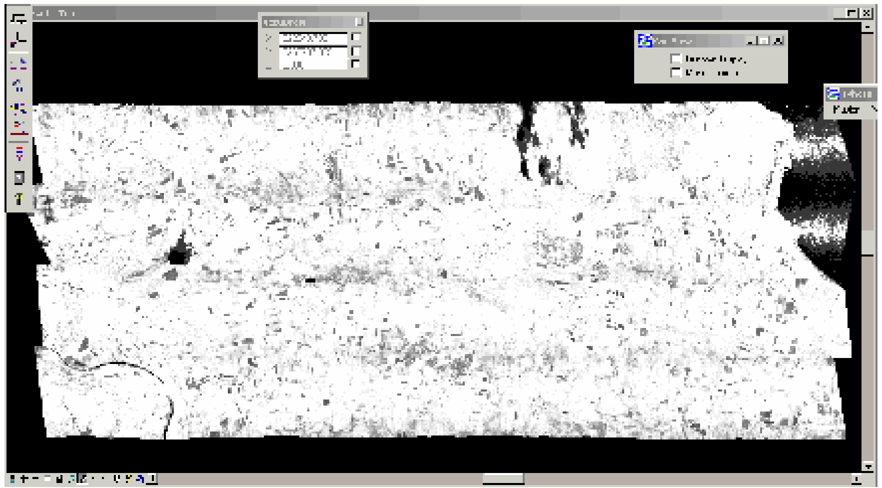
(Key Reference for Orthophoto Mapping)



< by color elevation

by echo v





< by intensity (grey scale)

Microsoft Excel - 070703f1_Aeroplan-MPiA-DTM-4000.xls

Row	A	B	C	D		E/S	T
8	Scanner Setup						GREEN BOLD ITALIC
9							BLACK
10	*Commanded FOV (full angle)*	*degrees*	55.00				
14	Terrain Elevation AMSL (minimum in survey area)	meters	0.00	0.00	feet		
16	Terrain Elevation AMSL (maximum in survey area)	meters	0.00	0.00	feet		
18	Nominal Flying Height Above Minimum Terrain Elevation	meters	4000.00	13123.20	feet		
20	Nominal Flying Altitude AMSL	meters	4000.00	13123.20	feet		
22	Airspeed	knots	150.00	77.17	meters/sec	253.17	feet/sec
24	Range/Intensity Mode (1, 2, 3, 4)		4.00				
25	Max Laser Pulse Rate	Hz	29800.00				
26	Laser Pulse Rate Used	Hz	59600.00	**4.55**	watts avg		
28	System Controller Firmware (<V2.07, V2.07+)		V2.07+				
29	Laser Power Class (3=3W, 4=4W, LC50, XHR)		LC50				
30	Receiver Aperture Stop (45, 60, 65, 75, LM, ALS50)	degrees	ALS50				
31	Scan Rate	Hz	19.50				
32	Max Scan Rate (ALS50 Phase II only)	Hz	38.56				
37							
38	Resulting Scan Pattern						
39							
40	*Full Swath Width (nominal flying height above lowest terrain elevation)*	*meters*	*4164.54*	*13663.01*	*feet*		
41	Max Cross Track Spacing (occurs @ nadir)	meters	3.97	13.03	feet		
42	Max Along Track Spacing (occurs @ FOV edge)	meters	3.96	12.98	feet		
43	Cross Track / Along Track Ratio		1.00				
44	Illuminated Footprint Diameter (@ 1/e^2 energy)	meters	0.89	2.93	feet		
45	Point Density (average)	pts/meter^2	0.19	0.02	pts/ft^2		
46	Point Density (@ nadir)	pts/meter^2	0.13				
47	Area / Point (average)	meters^2	5.39	58.04	ft^2		
48	Average Point Spacing	meters	2.32	7.62	ft		
91							
92	Resulting Accuracy Estimates (1 sigma)						
93							
94	Assumed GPS Error	meters	0.05				
95			Nadir	FOV Edge			
96	Estimated Cross-Track Error	meters	0.38	0.48			
97	Estimated Along-Track Error	meters	0.36	0.46			
98	Estimated Height Error	meters	0.72	0.84			
99							
100	Estimated Cross-Track Error	feet	1.25	1.58			
101	Estimated Along-Track Error	feet	1.19	1.52			
102	Estimated Height Error	feet	2.36	2.74			
103							
104	ALS Data Storage Requirements						
105							
106	Raw Data - IPAS GPS/IMU	GB/hour	0.10				
107	Raw Data - ALS .scn files	GB/hour	6.39				
108	Post Processed LAS file (max returns @ 20 bytes/return)	GB/hour	15.99				
109	Post Processed LAS file (max returns+GPS time @ 28 bytes/return)	GB/hour	22.38				
110	Allocation for Working Copies (2x factor)	GB/hour	57.75				
111	Total Workstation Disk Space Required (ALS)	GB/hour	86.62				

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Topic - 8

Dual Airborne Sensor Systems

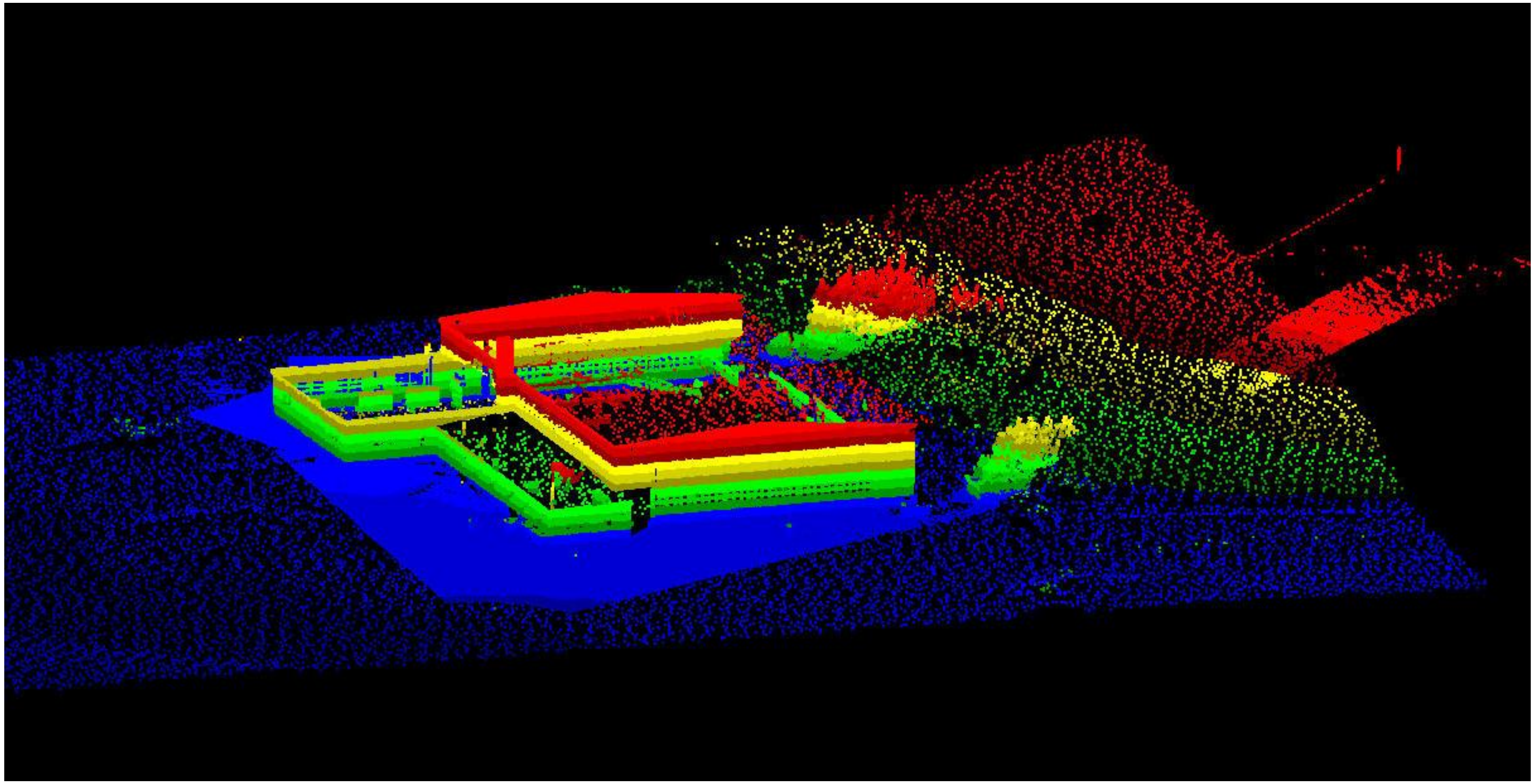
(ADS40 & ALS50)

Dual LIDAR Scanner Systems

(Airborne ALS50-II & Terrestrial HDS)

Dual - LIDAR - Systems
(Airborne & Ground based)

LIDAR Data Fusion



Dual - Airborne Sensing - Systems

(Digital Sensor & LIDAR Scanner)

Topic - 9

Outlook / Trends
in Digital Elevation Modeling

from an airborne LIDAR perspective

3 factors that will change how we use DEM data

system performance, processing efficiency, data delivery

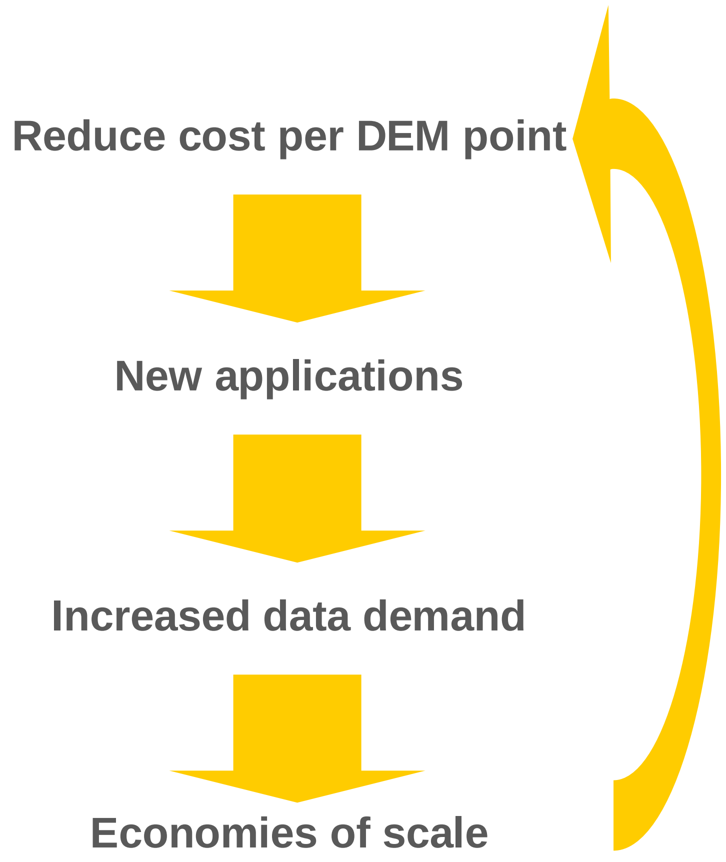
System performance

- Affects “suitability for purpose”
- Affects data acquisition cost

Processing efficiency will continue to be a major driver in cost per DEM point

Data delivery – the big enabler

- Easy access
- Broader market



System performance trends

point density is up…

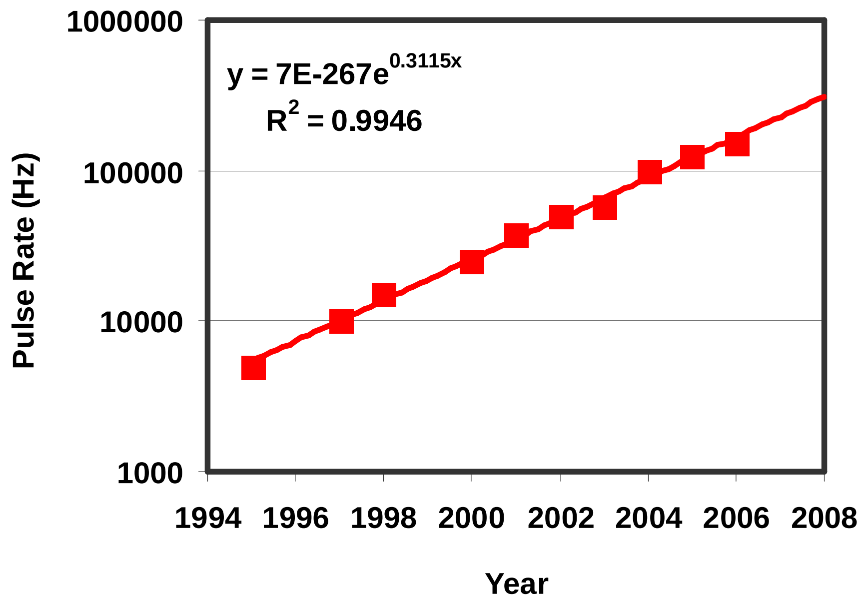
Over the past 10 years:

- **System pulse rates have increased 30x**
- **Point spacing has decreased 5.5X**

Major breakthroughs, such as Multiple Pulses in Air (MPiA) and enhanced laser technologies will continue to push data acquisition efficiency upward

How much detail is enough?

When does mapping become surveillance?



System performance trends

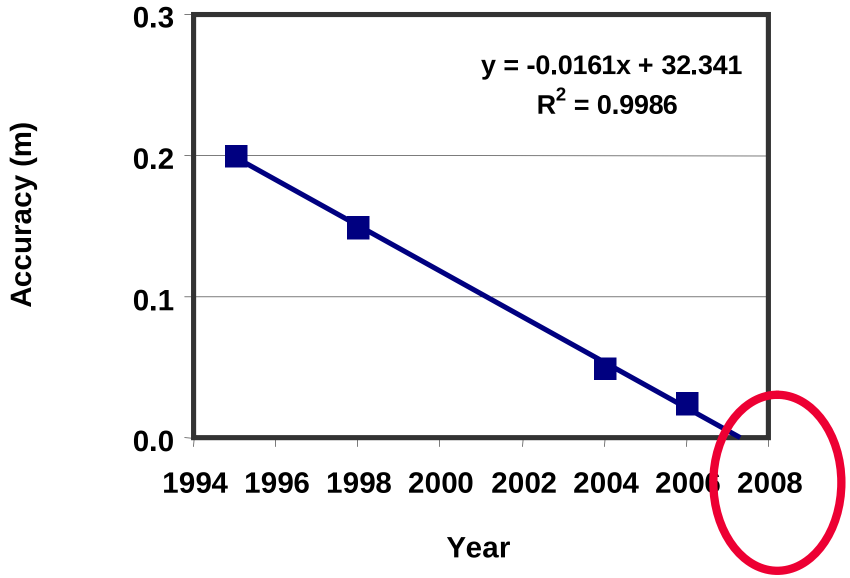
error is down

Improvements in technology have steadily reduced error

- **Ranging errors**
- **GPS errors improved, but are now the dominant error source at low altitude**

Error levels are keeping pace with increased data density

BEWARE EXTRAPOLATION!!!



Processing efficiency

what trend?

Processing has continued to take roughly the same time per flight hour

Gains have been mostly due to increased computing power

Big opportunity for improvement

After 10 years of LIDAR development, there are finally multiple 3rd-party competitors for filtering / editing SW

- **VLS**
- **Q Coherent**
- **TerraSolid**

Data delivery

is it an image? or is it a surface? who delivers it?

Constraints on data delivery

- **2D presentation versus 3D data**
- **Data transmission method**

Specialized firms will likely be the innovators

- **"owners" of data users in our industry (e.g., ESRI, Oracle)**
- **"owners" of data users in other markets (e.g., Google, Microsoft)**

Conclusions

Cost per DEM point continues to decrease

Quality of DEM data continues to increase (at least for now)

Opportunities for standardization, establishing "best practices" exist, particularly in the areas of

- § GPS planning standards (SV quantity, PDOP, base station practices)
- § Point density requirements derived from mapping standards
- § Quality Control methodologies and/or reporting

Increases in processing efficiency are a big opportunity

New data delivery methods could enable data use in broader markets


Thank you
HB-GII