Producing UAS-Derived Products for Transportation Projects: Challenges and Opportunities

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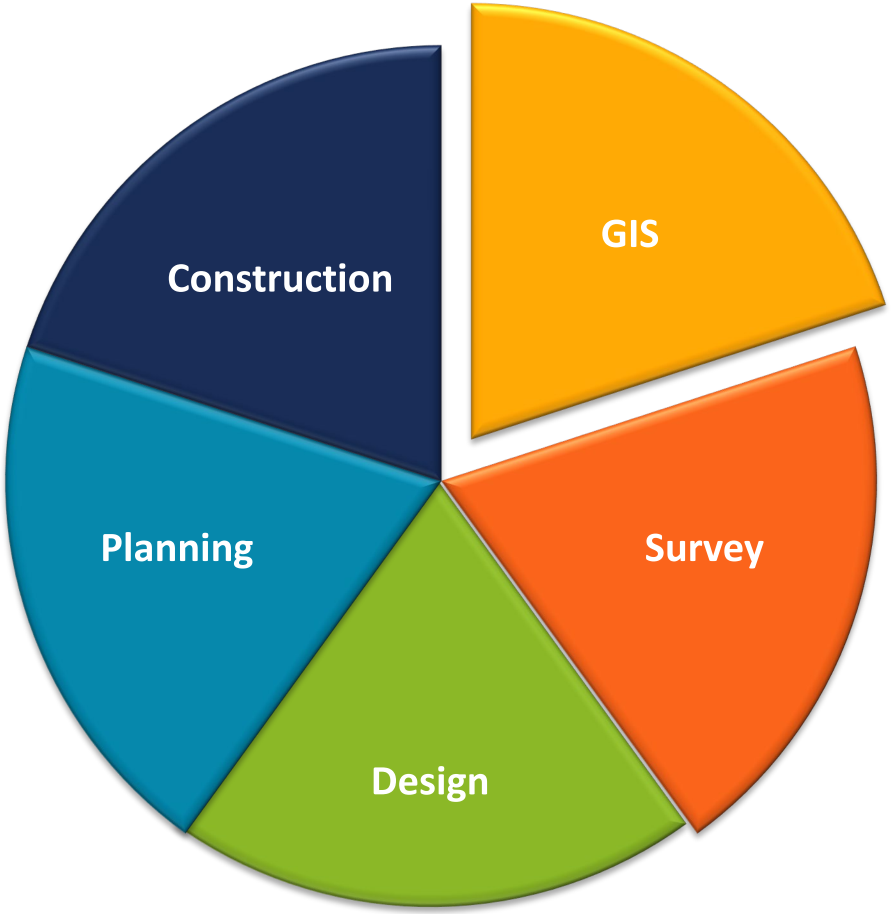
WOOLPERT
ARCHITECTURE | ENGINEERING | GEOSPATIAL

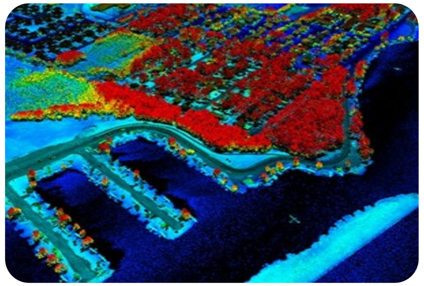
About Woolpert

- Established in 1911
- Over 850 Professionals
- 25 Offices
    - Dayton - Headquarters

Woolpert Business



Geospatial Services

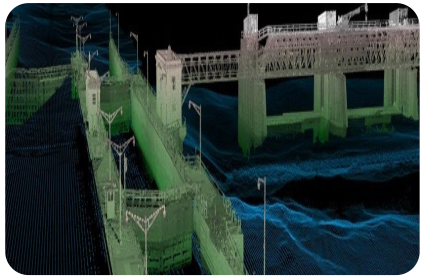

Aerial Mapping


Mobile Lidar


Terrestrial Lidar


Surveying


GIS


Bathymetry


UAS Operations

3D Modeling: Imagery or Lidar?

Characteristics of Data from Mobile Mapping System

- High Density
  - 2,000 pts/m2 to 6,000 pts/m2
- High Accuracy
  - Accuracy ≅ 1.8 cm (one sigma) → 0.06 ft.
- Expensive to acquire and to process

Characteristics of Data from UAS

- High Density
  - Few hundreds to 2,000+ pts/m2
- Lower Accuracy
  - Accuracy ≅ 3.0 to 6.0 cm (one sigma) → 0.1 to 0.2 ft.
- Low cost to acquire and to process

Mobile Mapping Lidar

Mobile Mapping System Technology (MMS)

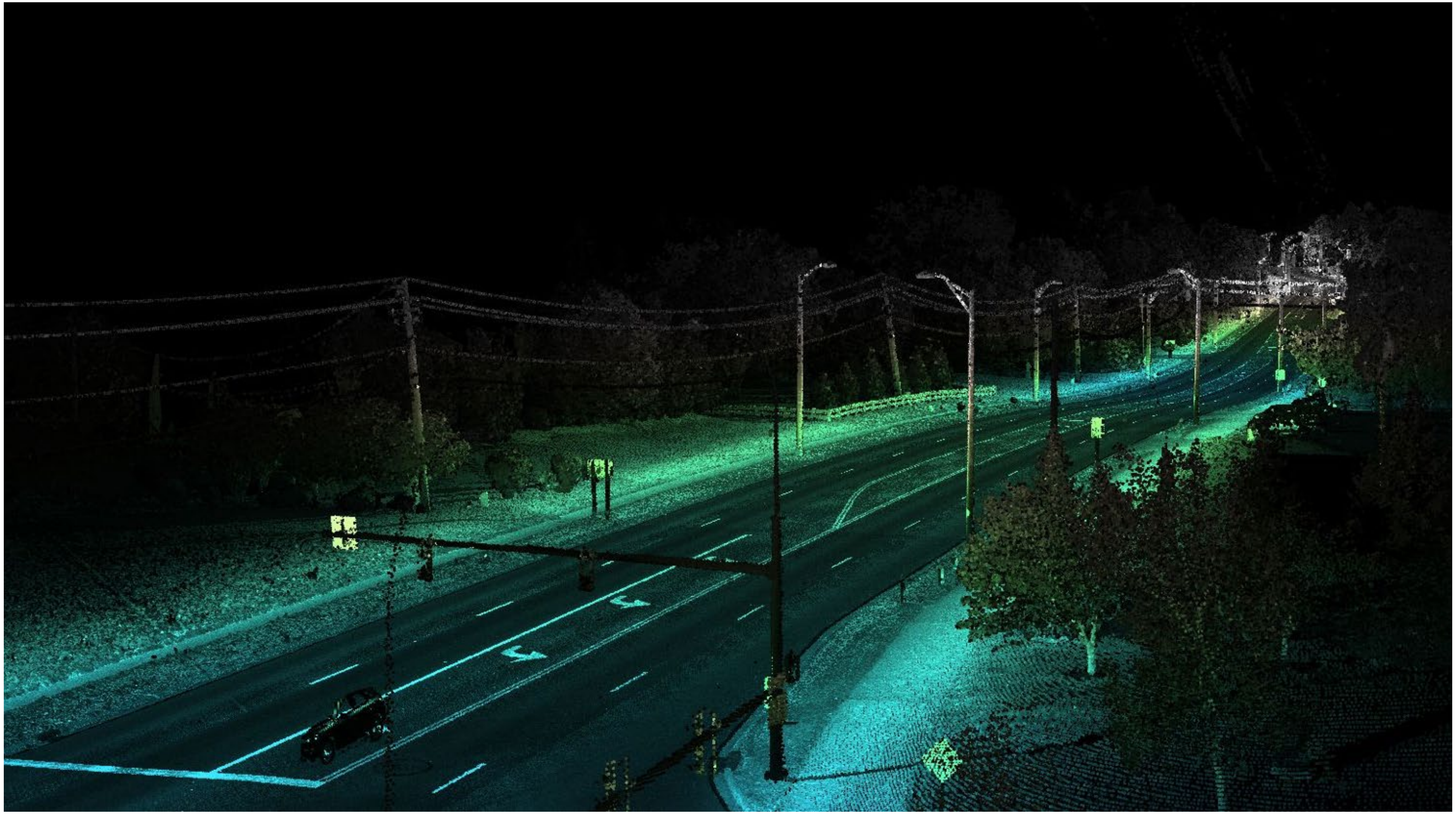
1,000,000 points per second (2,000 pts/m^2 to 6,000 pts/m^2) Accuracy≅1.8 cm

Anatomy of MMS

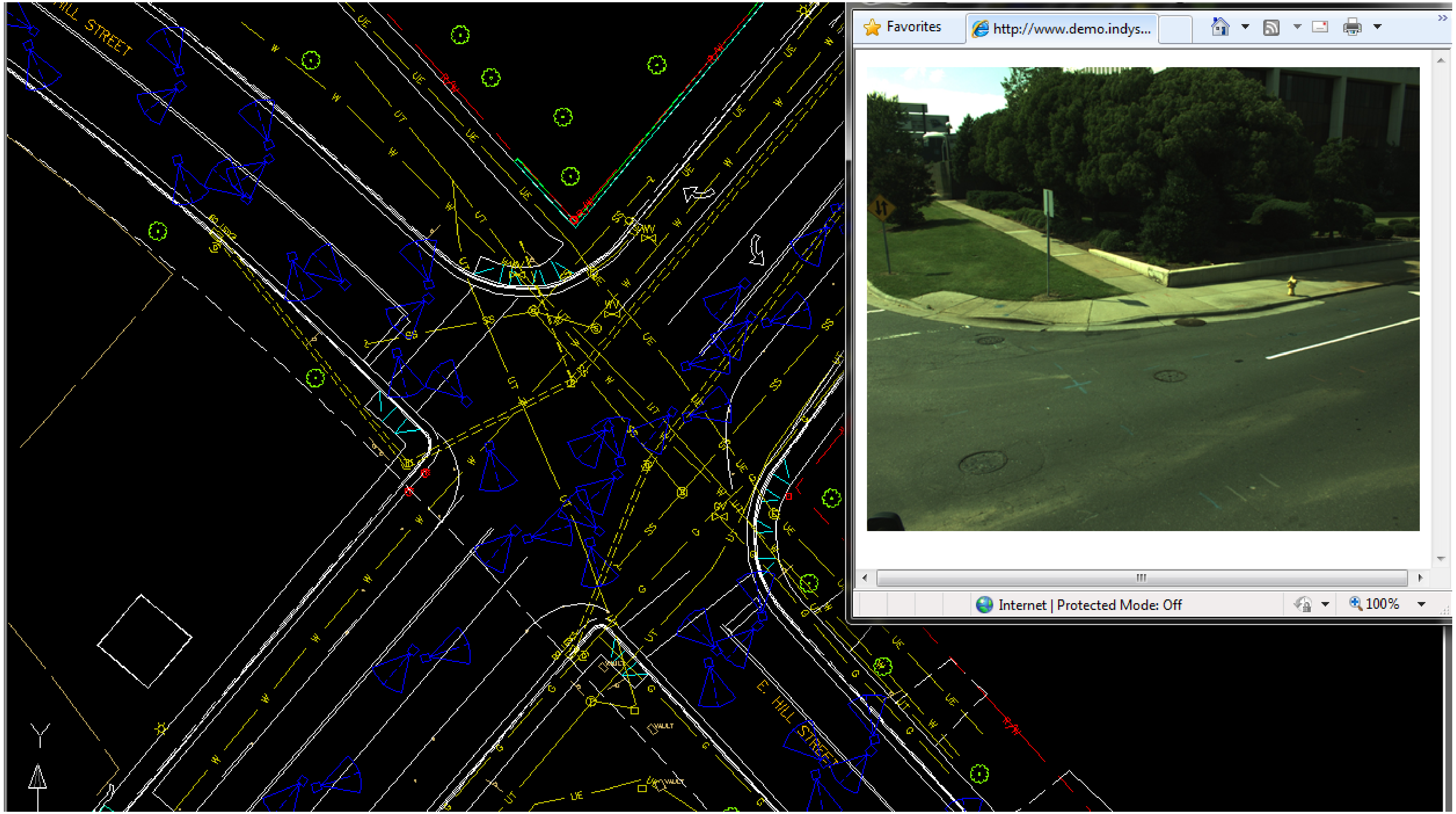
Optech Lynx M1 Mobile Mapping Sy

- **Dual LiDAR Sensors**
  - 1,000,000 points per second (2,000 pts/m^2 to 6,000 pts/
  - 200 meter range
- **4 integrated cameras**
  - 2-3 frames per second
  - 5 MP color cameras
- **Real-time point cloud viewing**
- **Collection at highway speeds**

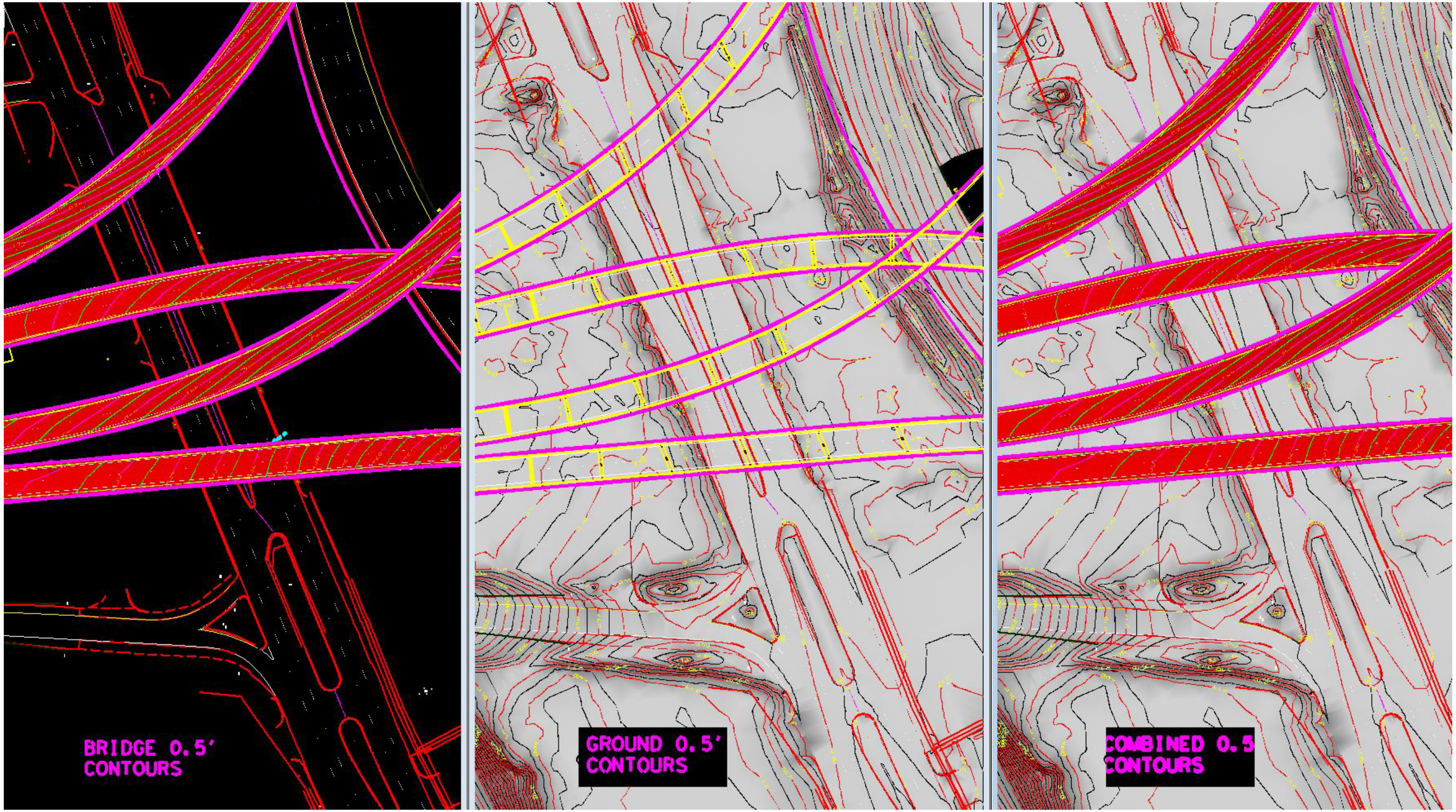
MMS for Roads Assets Management



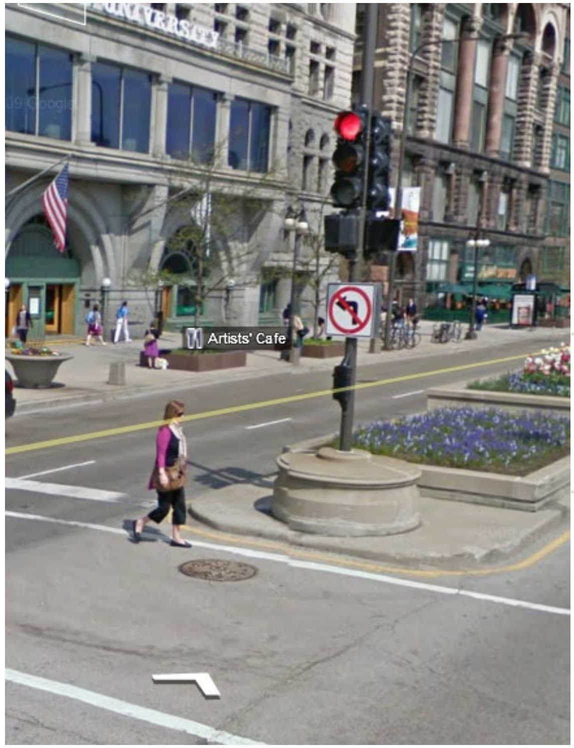
MMS for Design Survey

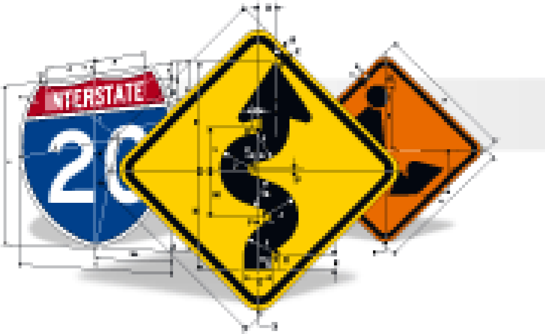


MMS for Design Survey



Woolpert's Smart Feature Extraction Tool





- Imagery (Visual Information)
  - Sign Color
  - Sign Text
  - Condition
    - Functional
    - Needs Attention
    - Needs Replacement

- LiDAR (Spatial Information)
  - Sign Position/Location
  - Sign Dimensions
  - Cardinal Direction
  - Mounting Type

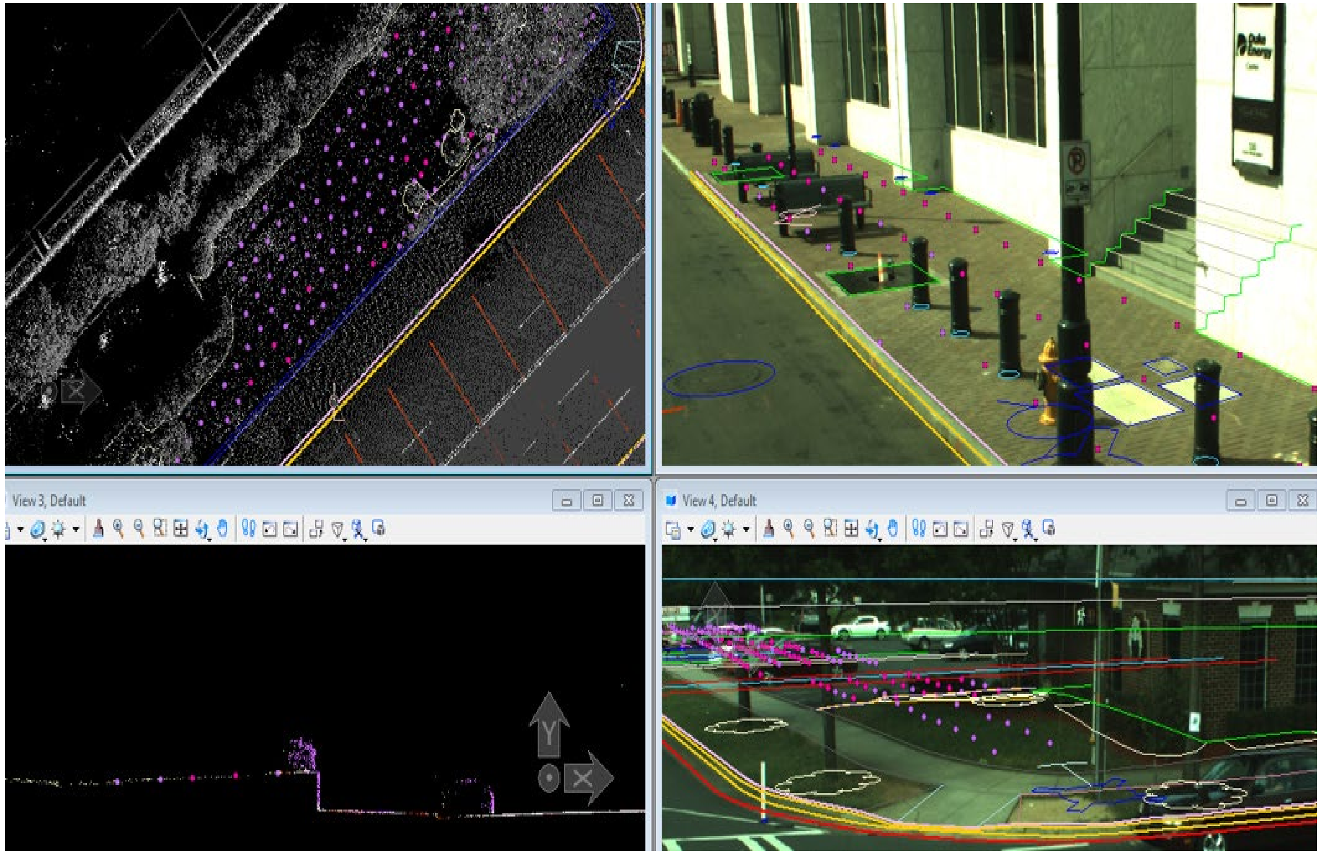
MMS for Curb and Sidewalk Assessment

MMS for Road Safety Audit Surveys
A proactive approach

- Road Crossfalls
  - Slope calculations
  - Road radius of curvature
  - Superelevation measurements
- Horizontal & vertical line of sight analysis
  - "Viewshed" analysis
  - Lateral & vertical clearances
- Others
  - Monitoring
  - Change detection
  - Missing signs
  - 4D Modeling

Leveraging MMS Data with Other Departments

- Utilities
- Paint stripes
- Guardrails
- Fire hydrants
- City furniture
- Parking meters
- ADA ramps
- Engineering design



How Accurate is the MMS Survey?

Two ranges of accuracies depending on needs

- **Planning/Mapping Level Accuracy**
  - No ground control (≅0.2’) with Good satellite visibility
  - No ground control (≅1.0’) with Poor satellite visibility
- **Design Level Accuracy**
  - Done with benefit of ground control
    - ≅0.06’ using Mobile Mapping System (1σ)

Understanding UAS Mapping Operations

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Types of UAS

- Fixed Wing
  - The main advantages are large area coverage, ease of operation, heavier load, high flexibility, and stability
  - The main disadvantages of a fixed wing UAV include limitations in takeoff and landing
- Rotary
  - Rotary blade UAVs can perform vertical takeoff and landing and fly in every direction (horizontal and vertical) with the ability to hover over a fixed position
  - They are most commonly used in large scale mapping with large overlaps. They offer ease of operation, high flexibility and stability.
  - They can provide nadir images with minimum crab angle.
  - They can fly at lower altitudes and can be programmed to fly autonomously along pre-programmed waypoints with the ability to acquire oblique imagery.
  - Some disadvantages include a short battery life (10-25 min in general) and smaller payload. Image translation and rotational component might exist.
- Hybrid
  - Uses a tilt rotor as the main driver and has the advantages of fixed and rotary blade systems

Camera Quality

- Camera systems have tremendous impacts on the achieved photogrammetric accuracy. Since almost every camera system used with UAS is a non-metric camera, it is highly recommended to use a camera with firm lens elements that maintains its calibration.

- The magnitude of the camera lens distortion is very large in small and mobile cameras.

- Many consumer grade cameras have image stabilization features to detect and correct camera movement during image acquisition by moving the camera lens elements.

- In a UAS environment, the stability of camera calibration is a prerequisite for precise photogrammetric mapping.

- It is recommended to disable image stabilization in UAV photography.

- UAS camera shutter plays an important role on mapping accuracies

Image Blur

- Image blur is usually caused by the UAVs motion.
- This in turn degrades the quality of the acquired imagery.
- Images with high image blur would detect less matching features using image correlation and can reduce the accuracy of a bundle solution.
- Multi-copters can minimize image blur if they hover during the image exposure.
- Image blur can be minimized also by having high exposure rate with short exposure time (1/2000 seconds).

GPS/IMU Camera Positioning and Orientation

- Single frequency GPS Receiver L1 – **Meters accuracy**
- Dual frequency GPS Receiver L1, L2 - **Few centimeters accuracy**
- Real Time Kinematic GPS (RTK) – **Few centimeters accuracy**
- Post Processed Kinematic GPS (PPK) – **Few centimeters accuracy**

Camera Orientation Determination:

- Inertial Measurement Unit (IMU) – Low grade IMU for UAS

RTK versus no-RTK GPS

RTK UAS:

- With the RTK's and GSD of 1.5 cm:
  - Relative accuracy of 1-3x GSD
  - Absolute horizontal/vertical accuracy of down to 3/5 cm (without GCPs)**

No-RTK UAS:

- No GCPs: Depends on the accuracy of the GPS/IMU, usually 1 to 3 meters.
- With GCPs as good or better than the results from RTK UAS.

** Based on a claim by Sensfly.com using their eBee RTK.

Camera Positioning

- Camera positioning has a large impact on the block accuracy.

- It can be encoded in the image EXIF header or saved in a separate file.

- Many UAVs use a single frequency L1 to establish positioning, which is not enough to achieve mapping accuracy since single frequency GPS systems' precision is in meters level not in the order of centimeters.

- New UAVs have on board receiver for GNSS L1 and L2 signals, with corrections sent from the master station to achieve the desired accuracy.

- The rationale for producing RTK-enabled UAVs is to minimize GCPs needed.

Flight Planning

- Flight height
- Forward and side lap
- Flight direction
- GSD
- Ground points
  - Size and shape
  - Control points
  - Number
  - Distribution
  - Check points

Flight Planning Best Practices

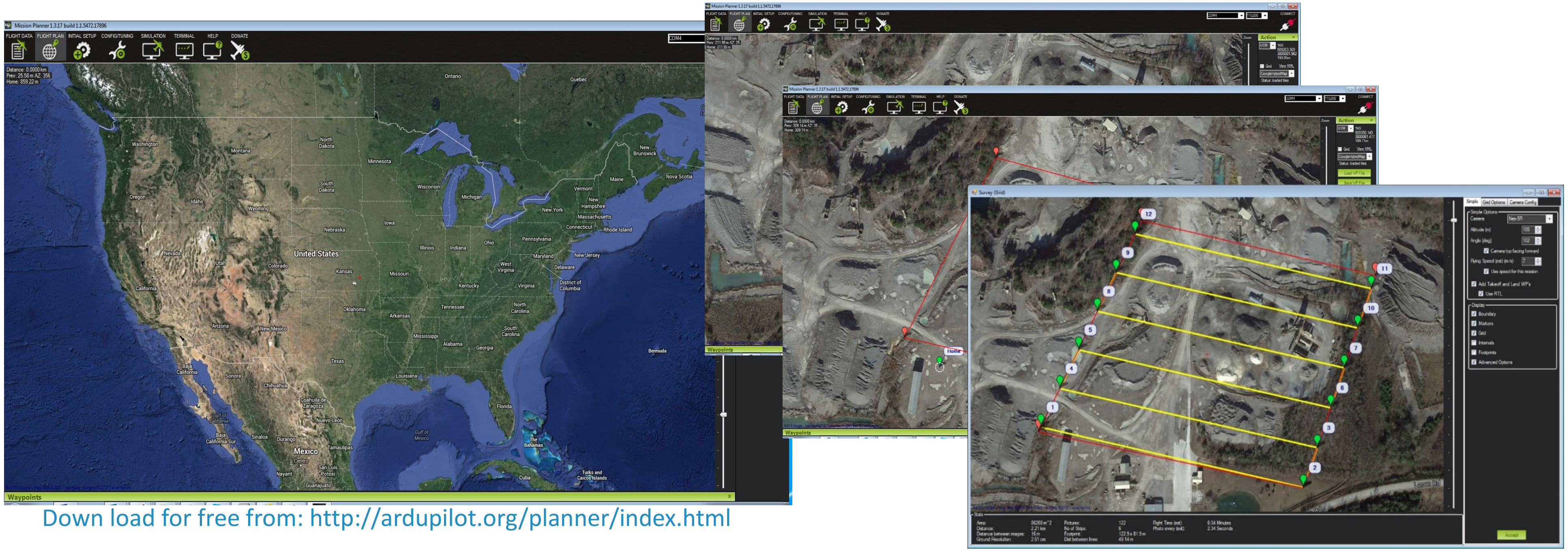
- Flight patterns are optimized for minimizing flight time, wind direction and topography.
- Flight patterns can be vertical, oblique and circular .
- Flights in opposite directions can contribute to a better estimation of the principal point when self-calibration is applied in the block adjustment.
- It is advisable to add extra frames at the end of each flight line since poor image quality results during turn-about.
- The benefit of cross strips to the block is not clear. Some references claim it can reduce the number of GCPs and strengthen the bundle solution. Others claim it did not have an impact .
- To take advantage of using structure from motion (SfM) algorithms, the forward overlap must be increased. Overlap (> 80% along strips and 70% across strips) will provide better accuracy, and reduce image mismatches.

Flight Planning Best Practices

- Lowering the flight altitude demands a longer acquisition time and may increase image shadow effect.
- Adding images with different altitudes (20% higher) may improve the block accuracy , which will contribute to better focal length estimation when self-calibration is being used.
- For corridor mapping the accuracy will depend on the number and distribution of the GCPs and the accuracy of the directly measured camera positions using GNSS.
- Measurements of camera angles using an Inertial Measurement Unit (IMU) may contribute to the accuracy.
- Use dedicated flight planning tools.
- Plan on using processing software that provides camera calibration capability and handles GPS issues.

Recommended Free Flight Planning Software

(Mission Planner by Ardupilot)



Down load for free from: http://ardupilot.org/planner/index.html

Ground Control Points (GCPs)

Ground Control Points (GCPs)

- Ground control points are a must to achieve the accuracy required.
- Current direct geo-referencing technology and algorithms do not provide such accuracy.
- The number of GCPs and their distribution depends on project size and accuracy requirements.
- It is recommended that the image size of the GCPs is 6 to 10 pixels
- GCPs are surveyed in most cases with GNSS surveys using RTK mode. Horizontal accuracy of 1-2 cm and vertical accuracy of 2-3 cm can be achieved
- Accuracy of check points should be at least three times better than that of the target validation results. This goes with ASPRS standards.
- Terrestrial laser scanning has been used as ground truth with an accuracy of 2 to 4mm and GSD as low as 1.5 mm.

Processing Software

- The structure from Motion (SfM) is widely used because it provides greater flexibility and high quality results.
- The major software used by the industry are:
  - Photoscan by AgiSoft
  - Pix4D. Photoscan
  - SimActive – Correlator 3D
- The user in principle has very little control over the data processing.
- It is another example of a black box approach
- They show increasing robustness and visually appealing 3D models.
- But they do not provide a thorough statistical analysis of results, but a mean re-projection and the RMS from check points are given in the report.

Strength and Weakness of UAS-based Photogrammetry

Strength:

- High Resolution Imagery
- Low Altitude
- Excessive Overlap and Image Redundancy
- Capable Processing Software

Weakness:

- Small Size Projects
- Low Cost Non Metric Cameras
- Inaccurate IMU

Camera on board small Unmanned Aerial System (UAS)

Mostly consumer grade cameras:

Sony

Panasonic

Cannon

Nikon

GoPRO

Fixed Wings UAS

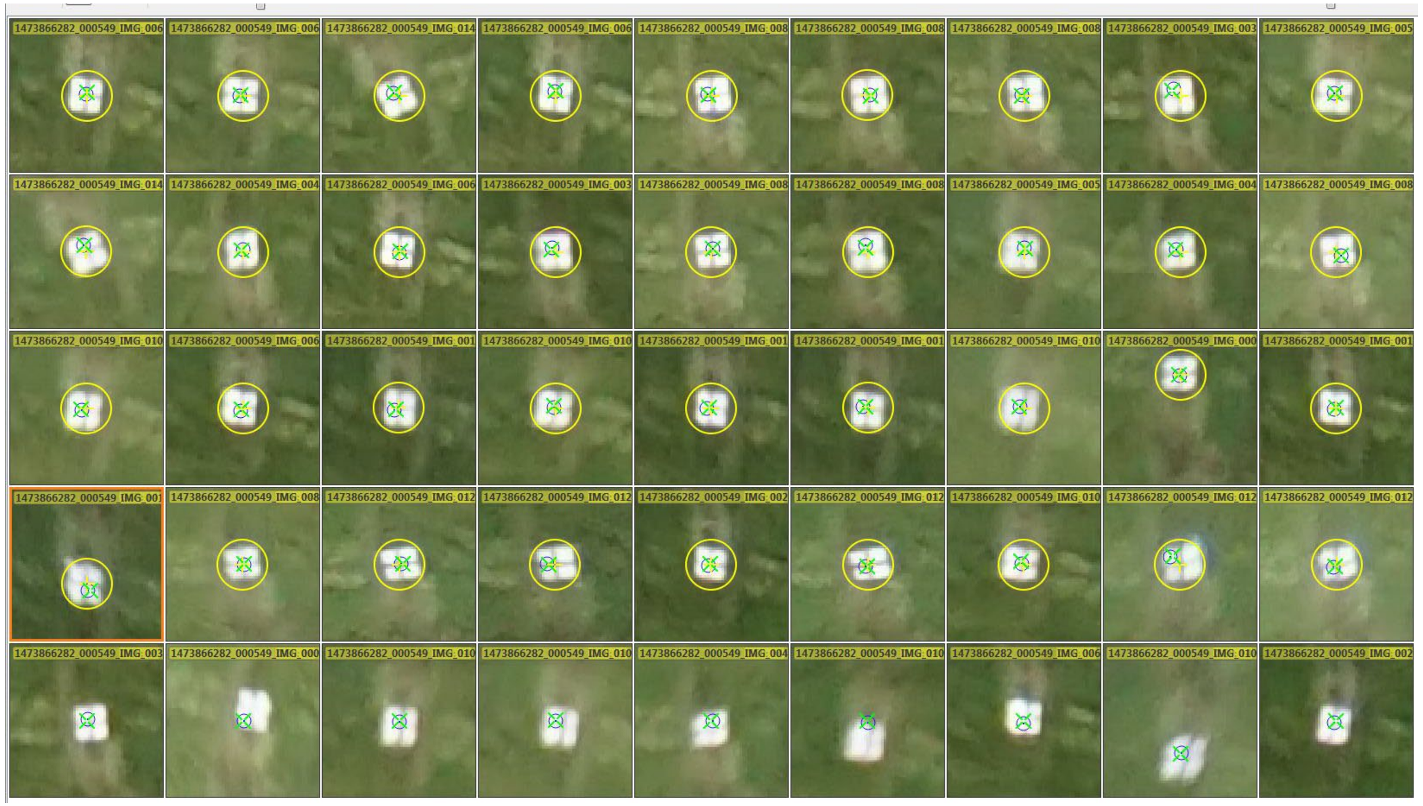
Rotary UAS

UAS Strength: High Resolution Imagery

Low altitude minimizes attitude errors on products and increase details

UAS Strength: Image Redundancy

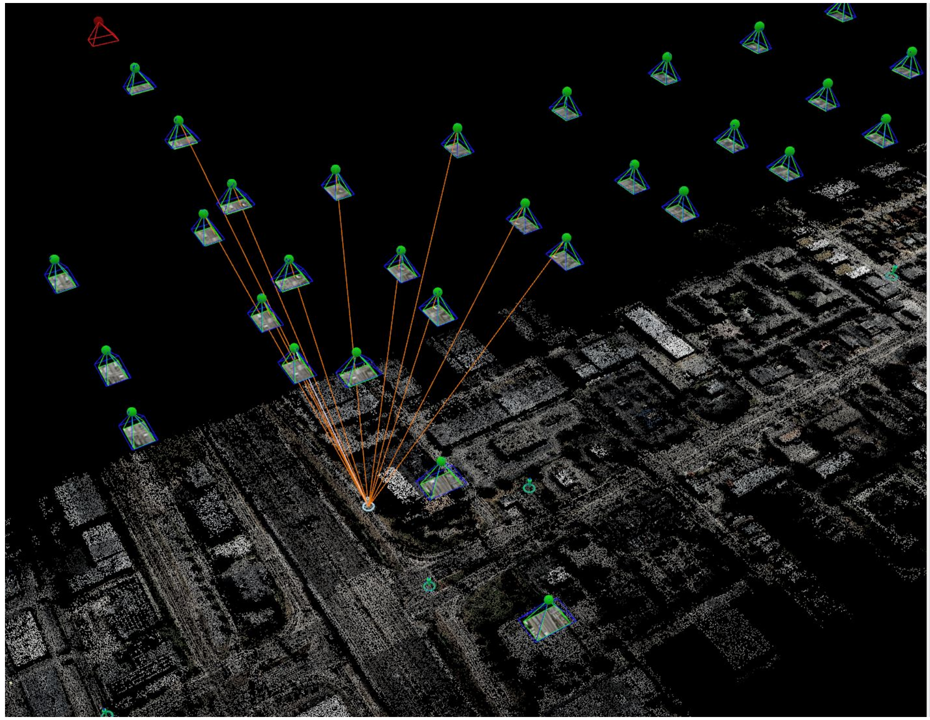
Digital Imagery and Increased overlap

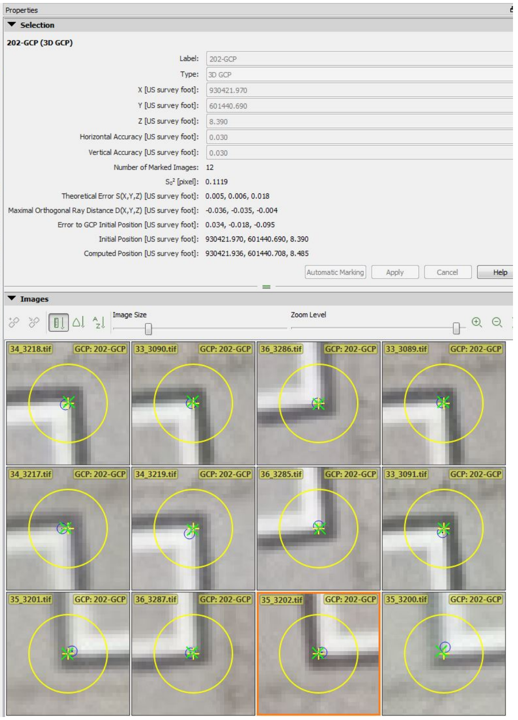


GCP shows in 45 images

UAS Strength: Image Redundancy

Digital Multi-Rays Photogrammetry



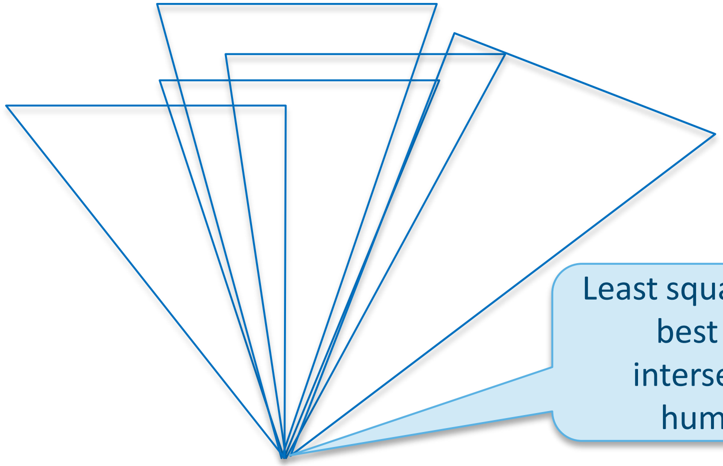


Properties

Selection

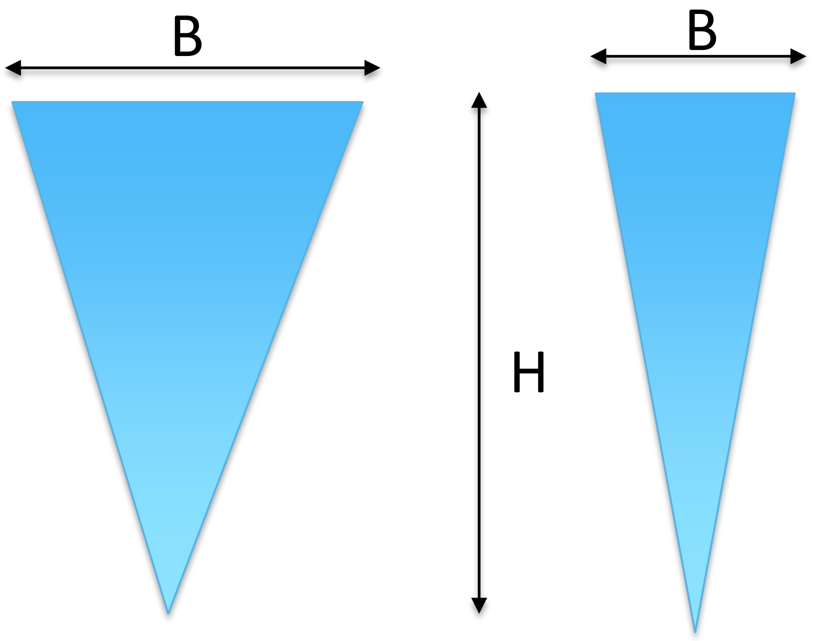
202-GCP (3D GCP)

Label: 202-GCP
Type: 3D GCP
X [US survey foot]: 930421.970
Y [US survey foot]: 601440.690
Z [US survey foot]: 8.390
Horizontal Accuracy [US survey foot]: 0.030
Vertical Accuracy [US survey foot]: 0.030
Number of Marked Images: 12
S_0^2 [pixel]: 0.1119
Theoretical Error S(X,Y,Z) [US survey foot]: 0.005, 0.006, 0.018
Maximal Orthogonal Ray Distance D(X,Y,Z) [US survey foot]: -0.036, -0.035, -0.004
Error to GCP Initial Position [US survey foot]: 0.034, -0.018, -0.095
Initial Position [US survey foot]: 930421.970, 601440.690, 8.390
Computed Position [US survey foot]: 930421.936, 601440.708, 8.485

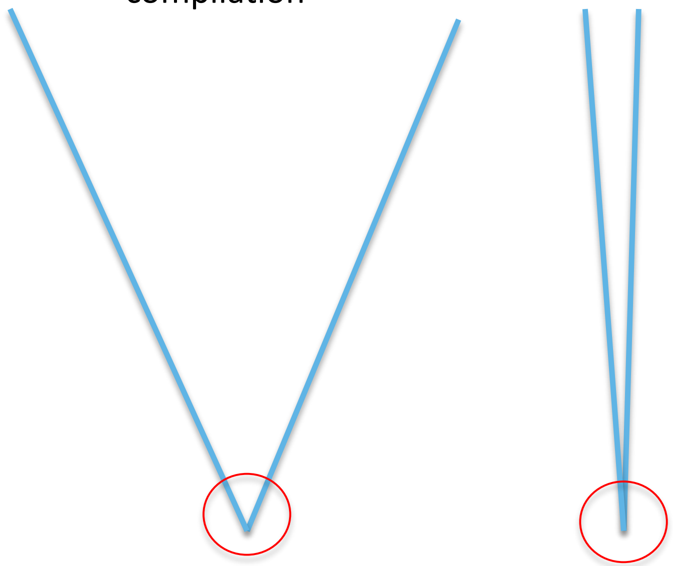


Least squares finds the best point of intersection not human eyes

How about B/H Ratio?


Traditional Stereo Geometry

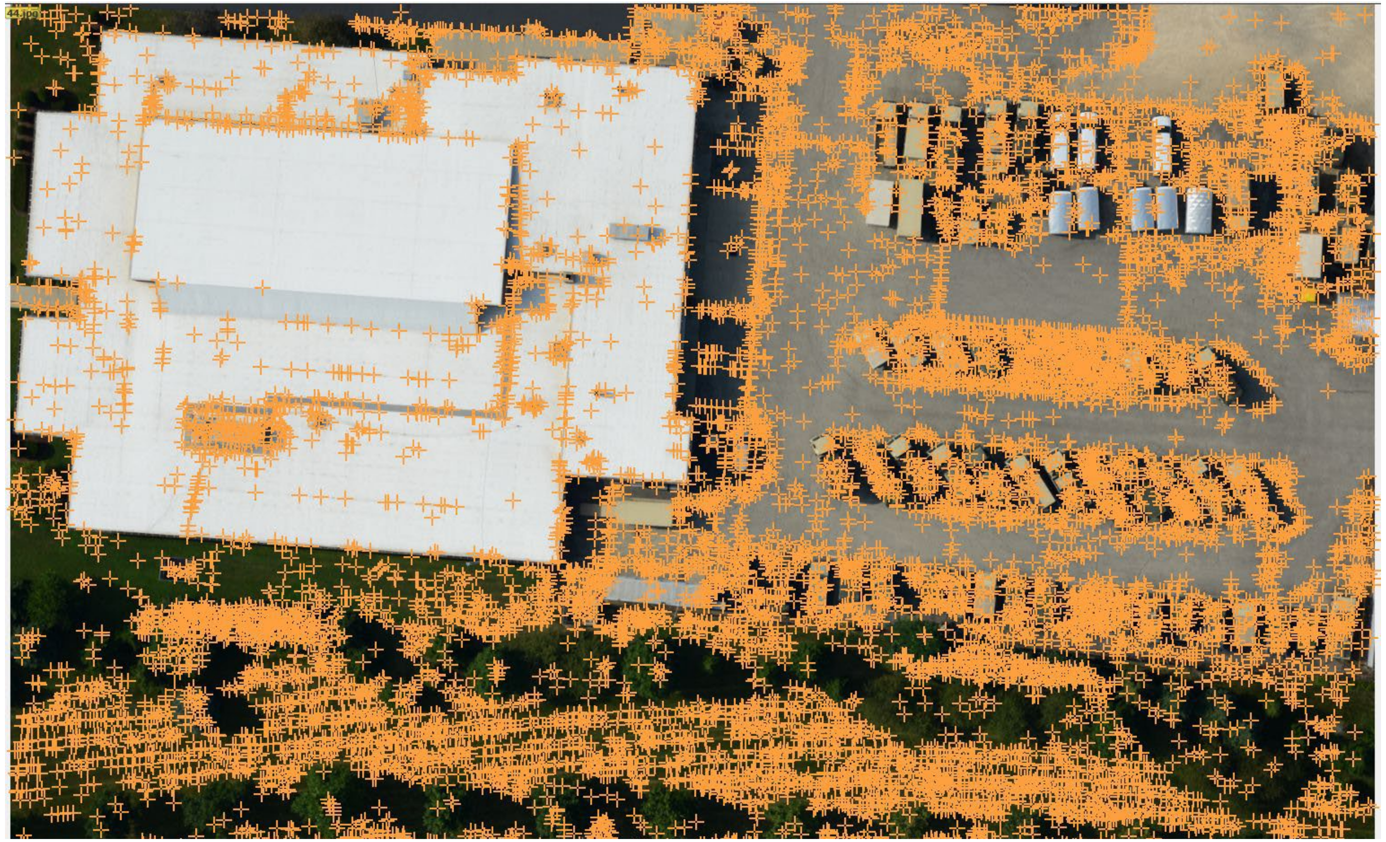
Today's Stereo Geometry


Traditional Stereo Geometry
Intersection at a point
Good for manual stereo compilation

ok for digital correlation

UAS Strength: Capable Software

Plenty of tie points results in a strong geometrical fidelity



UAS Strength: Capable Software

It handles camera self calibration and structure from motion

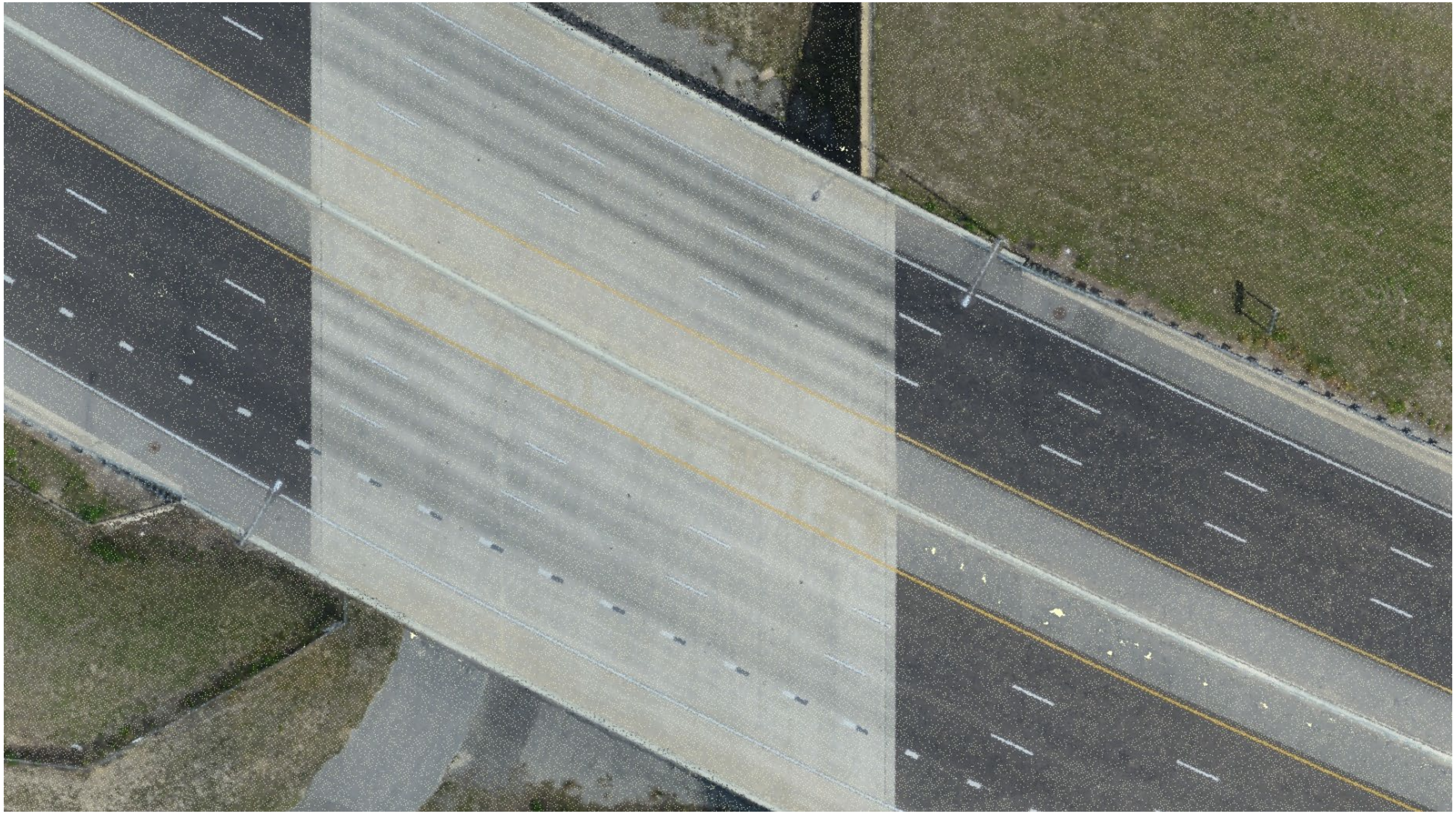
Platform used: Woolpert Kespry UAS

What the Geospatial Community Expect from UAS

- **High Resolution Imagery:**
  a) Orth-rectified
  b) High Resolution
  c) Accurate
- **Digital Terrain Data:**
  a) Dense points cloud
  b) RGB colorized points cloud
  c) Accurate
- **Sites and Bridges Inspection:**
  a) Maneuverability
  b) Safe Operation

Demand #1: High Resolution Imagery

UAS Standard Deliverables

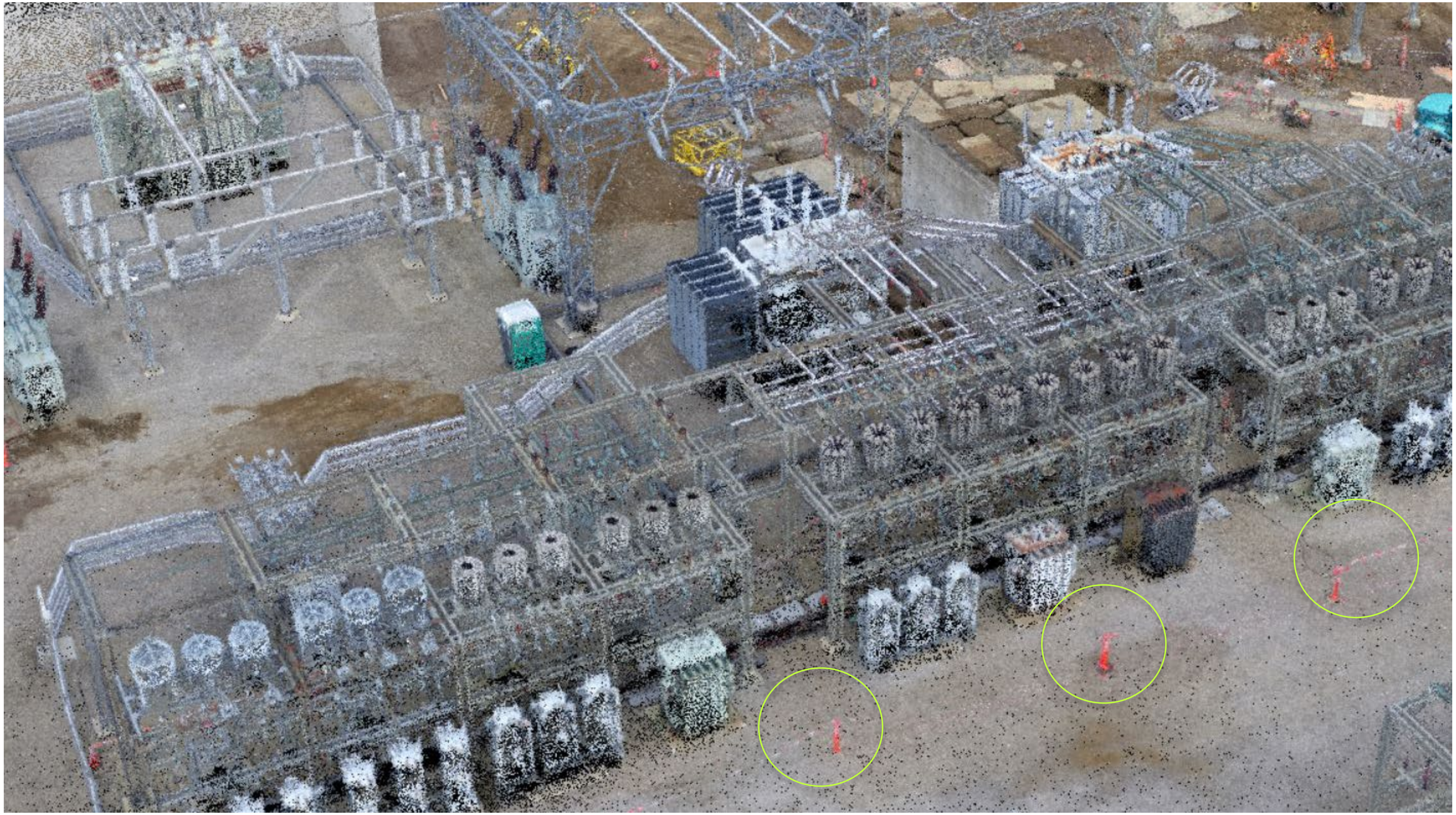


UAS Standard Deliverables

UAS Standard Deliverables

Bypass Construction project
2-cm Orthos Details

Power Station by UAS: >2000 pts/m2



Power Station by UAS: >2000 pts/m2

Demand #2: Can UAS Products be Accurate?

Woolpert UAS Assets

Fixed Wings UAS

PLATRFORMS:

Platform	Manufacturer	Model
Phantom 2	DJI	Phantom 2 Vision+
Inspire 1 Pro	DJI	Inspire 1 Pro
Inspire 1 #2	DJI	Inspire 1
Phantom 3 Pro	DJI	Phantom 3 Professional
INSPIRE 2 - WOOLPERT 1	DJI	INSPIRE 2
INSPIRE 2 - WOOLPERT 2	DJI	INSPIRE 2
NOVA III	Altavian	NOVA III
Kespry	Kespry	Kespry 2S

Rotary UAS

UAS Accuracy Evaluation – Project 1

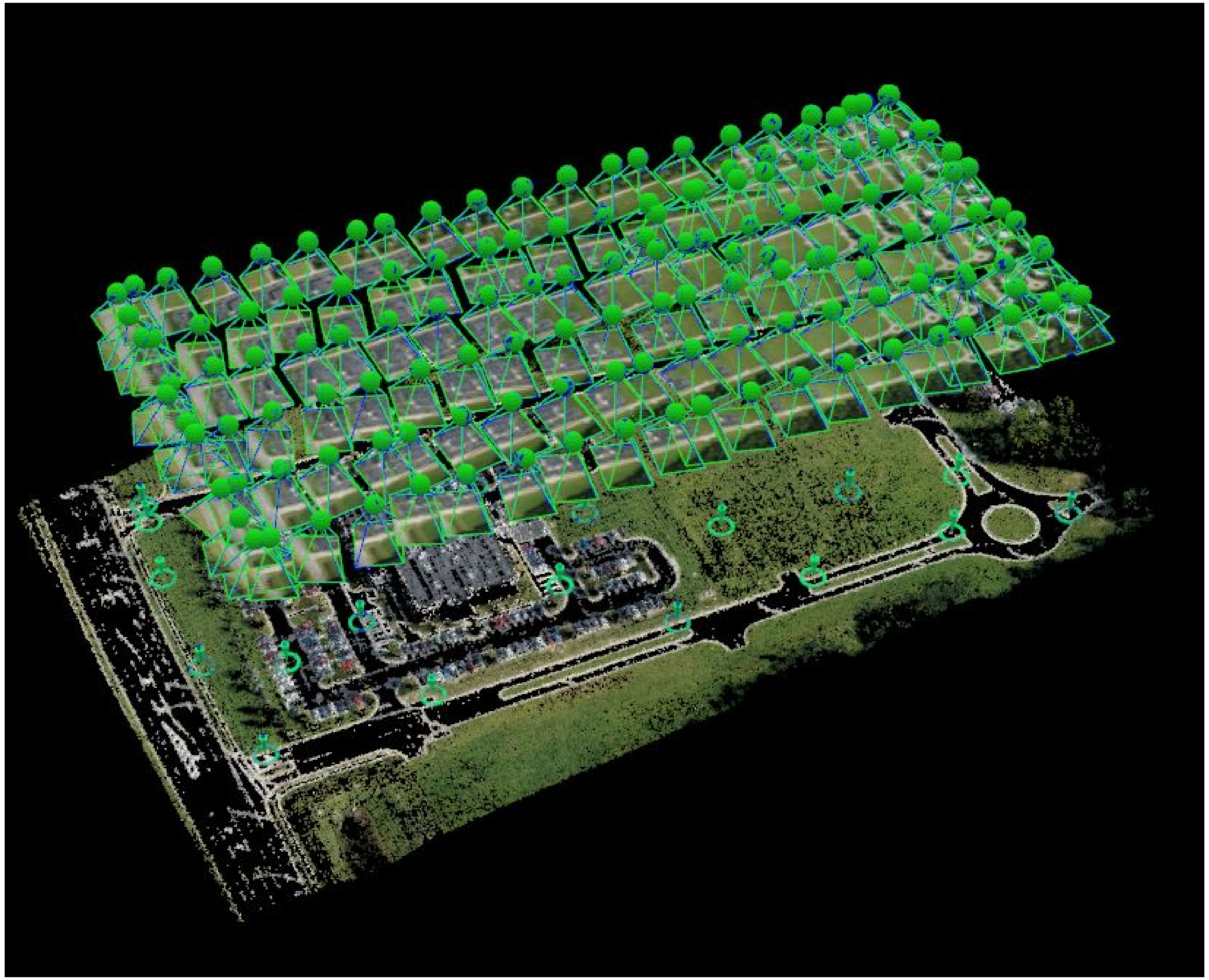
The Testing Site:

- 11 acre site
- Contained roadways and was relatively unobstructed

Woolpert's Control Field – Dayton, Ohio

UAS Accuracy Evaluation – Project 1

Flight Design



Accuracy Verification

- Two surveys
- 49 control/check points

Accuracy verification: Control Layout Scenarios

How Accurate are the UAS-derived Products?

Imagery GSD = 2.7 cm Altitude 350 ft. AGL

Accuracy Term	Processing Scenario						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Number of Control Points	29	0	4	5	7	9	13
Number of Check Points	**20**	**49**	**45**	**44**	**42**	**40**	**36**
RMSE E (ft.)	0.22	2.34	0.16	0.18	0.17	0.18	0.18
RMSE N (ft.)	**0.18**	**1.40**	**0.14**	**0.14**	**0.14**	**0.14**	**0.15**
Horizontal Radial RMSE N,E (ft.)	0.29	2.73	0.21	0.23	0.22	0.23	0.24
Vertical **RMSE Elev. (ft.)**	**0.32**	**1.62**	**1.35**	**0.32**	**0.23**	**0.25**	**0.29**
Horizontal Accuracy at 95% (ft.)	0.49	4.72	0.36	0.4[illegible]	0.39	0.39	0.41
Vertical Accuracy at 95% (ft.)	**0.62**	**3.17**	**2.[illegible]**	**0.63**	**0.45**	**0.49**	**0.57**

Can we obtain < 0.2 ft. vertical accuracy?

Perhaps: fly lower, use RTK/PPK GPS

UAS: Can we meet DOTs Vertical Accuracy Specs ?

Radial RMSE N,E (ft.)	0.29	2.73	0.21	0.23	0.22	0.23	0.24
RMSE Elev. (ft.)	**0.32**	**1.62**	**1.35**	**0.32**	**0.23**	**0.25**	**0.29**

Ohio DOT Specifications

DTM Accuracy Class	Recommended Use	Maximum Allowable Average Dz (feet)	Maximum Allowable RMSE (feet)
Class A	Paved areas	± 0.07	0.16
Class B	Vegetated areas outside of pavement that are maintained at a minimum biannual frequency (i.e.: farm fields, residential yards, roadside R/W, etcetera)	± 0.25	0.32
Class C	Vegetated areas that are not maintained	± 0.50	0.5
Class D	Areas where vertical accuracy is not critical or warranted (i.e.: planning engineering projects)	± 1.00	1.00

UAS: Can we meet DOTs Horizontal Accuracy Specs ?

Radial RMSE N,E (ft.)	0.29	~~2.73~~	0.21	0.23	0.22	0.23	0.24
RMSE Elev. (ft.)	**0.32**	**1.62**	**1.35**	**0.32**	**0.23**	[illegible]	**0.29**

Ohio DOT Specifications

Planimetric Accuracy Class	Recommended Use	Maximum Allowable RMSE (ft)
Class I	Projects that require Class I planimetric features listed in Appendix A to be identified and mapped (ie: design engineering projects)	0.3
Class II	Projects that require Class II planimetric features listed in Appendix A to be identified and mapped (ie: planning studies)	1.0

Accuracy Evaluation – Project 2

Corridor Environment using **RENAISSANCE**™

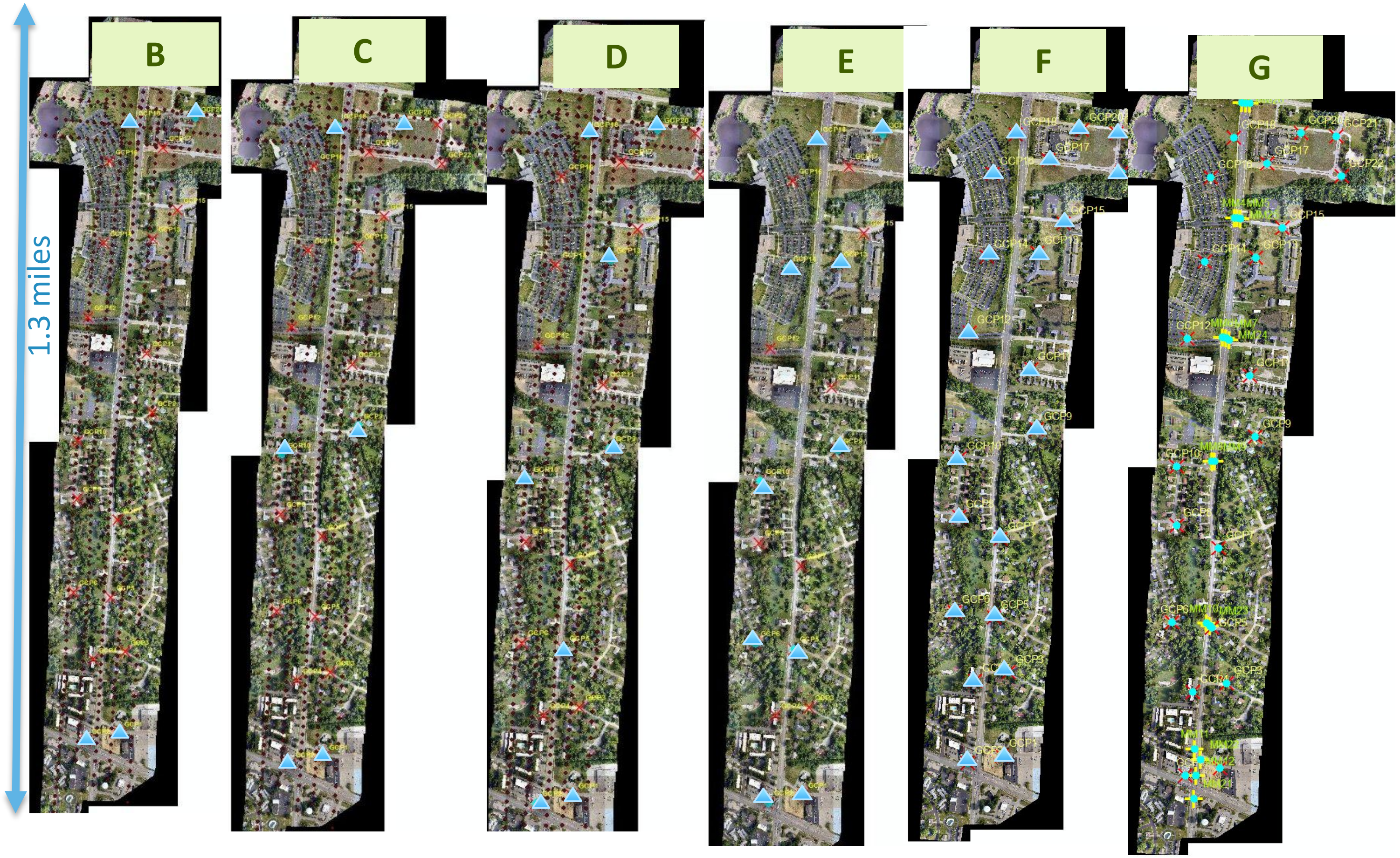
RENAISSANCE™

Driven by Affordability

- Consumer Grade Camera
- Single-Engine Aircraft
- Pilot-Only Operation
- Computer-Vision Processing

- **Nikon D800E**
  - 7360 x 4912 pixels (36 megapixels)
  - 36mm x 24mm CMOS
  - 85mm lens
  - Up to 2cm resolution
  - Up to 2 frames per second
  - 60% - 70% sidelap
  - 70% - 80% forward lap

UAS Accuracy Evaluation – Project 2



How Accurate are the Renaissance-derived Products?

Accuracy Term	Processing Scenario						
	A	B	C	D	E	F	G
Number of Control Points	0	4	6	8	10	21	38
Number of Check Points	**38**	**34**	**32**	**30**	**28**	**17**	**0**
RMSE E (ft.)	4.47	0.23	0.16	0.18	0.13	0.05	0.05
RMSE N (ft.)	**1.89**	**0.26**	**0.20**	**0.14**	**0.14**	**0.07**	**0.05**
Horizontal Radial RMSE N,E (ft.)	4.86	0.35	0.26	0.23	0.19	0.08	0.06
Vertical **RMSE Elev. (ft.)**	**13.51**	**0.54**	**0.71**	**0.40**	**0.35**	**0.26**	**0.17**
Horizontal Accuracy at 95% (ft.)	8.40	0.60	0.45	0.39	0.34	0.14	0.11
Vertical Accuracy at 95% (ft.)	**26.49**	**1.05**	**1.40**	**0.78**	**0.69**	**0.52**	**0.34**

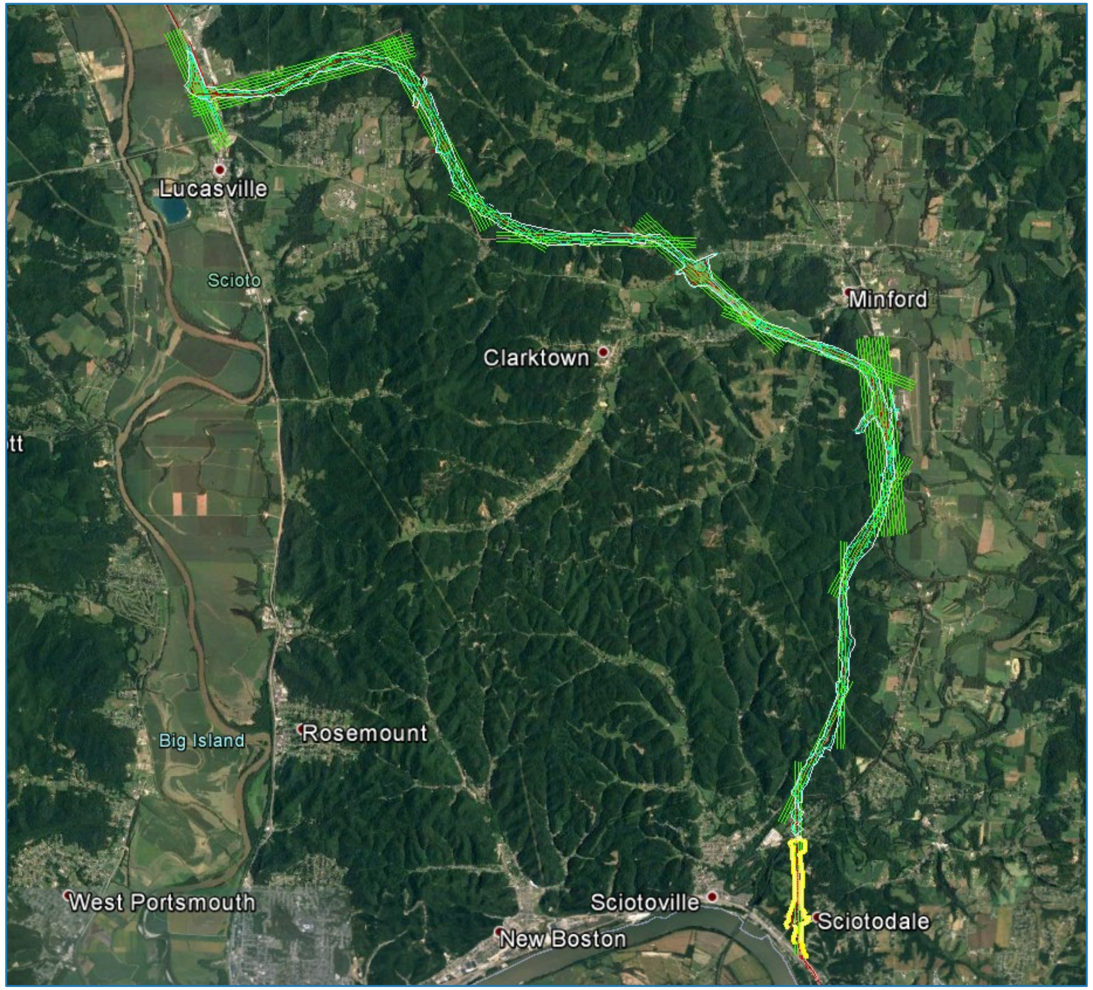
The winner: Pair of GCPs every 500 to 700 ft. along the route

Accuracy Evaluation – Project 3

19 Miles of Portsmouth Bypass, OH

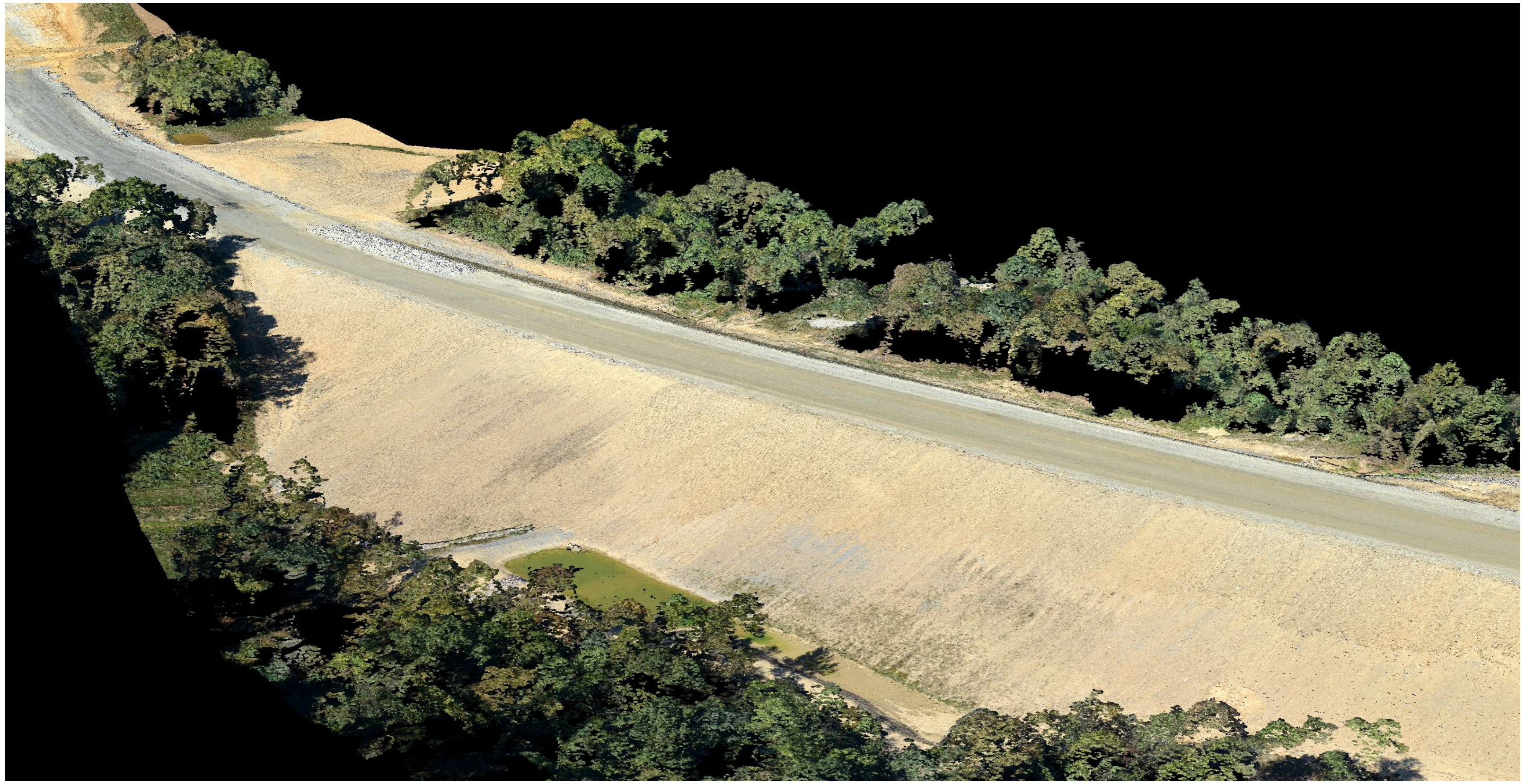
- Joint venture effort to develop a 16 mi, 4 lane, limited access highway bypass
- Collected with our Surrogate UAS platform
- Project area was too complex to rely on standard UAS:
  - Dynamic construction
  - Limited visibility
  - Size of project

We deployed the **RENAISSANCE**™



Ortho-rectified Imagery GSD = 2-cm

3-D Terrain Model



3-D Terrain Model

Portsmouth Bypass Project:
Client Testimony on Accuracy

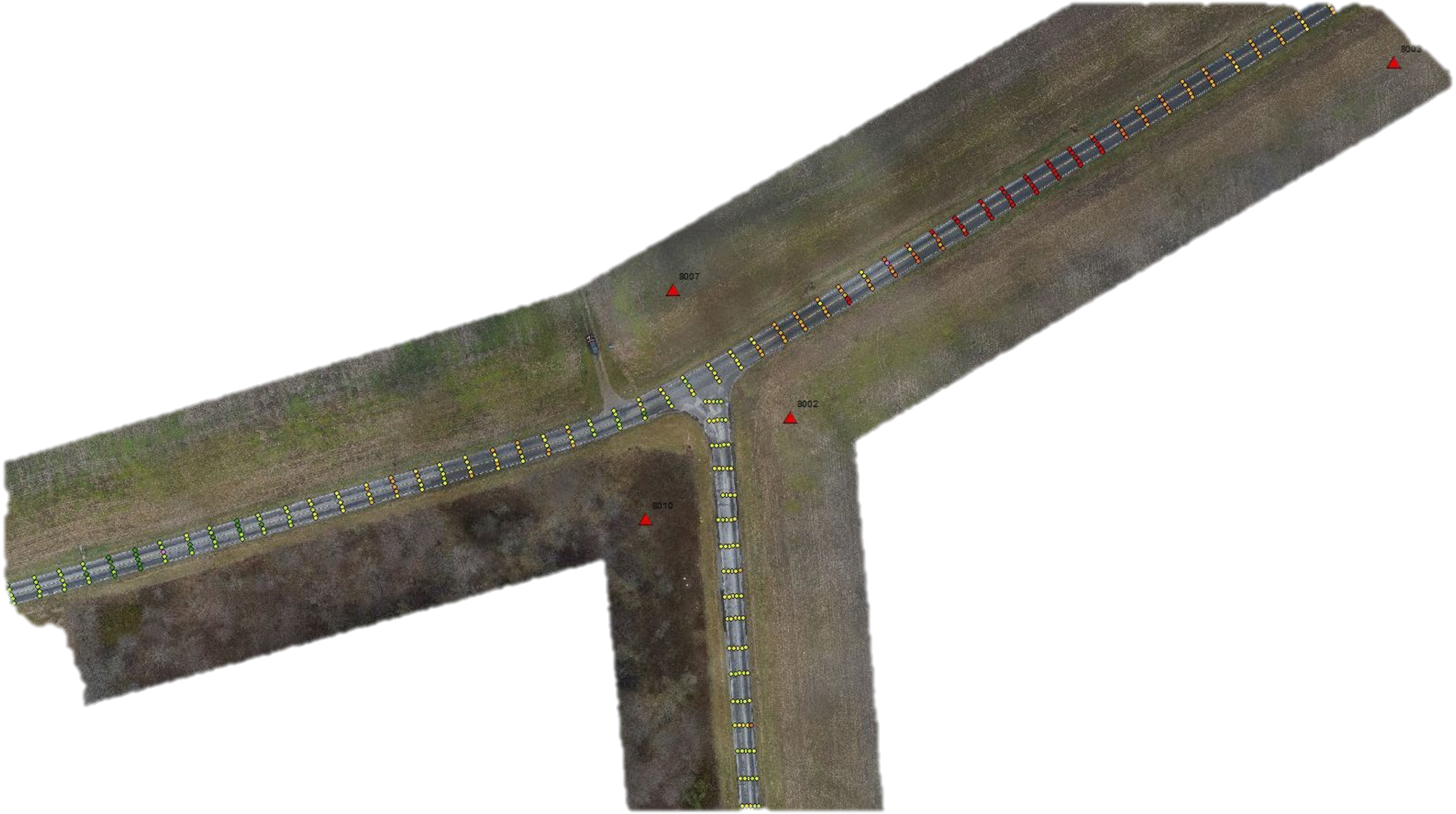
"The conventional topo matched up well with the Dec flight, **+/-0.2ft.**"

"Everyone on our end was pleased with the data provided from the Dec flight."

"Tell your crew I appreciate all their work and efforts"

UAS Accuracy Evaluation – Project 4

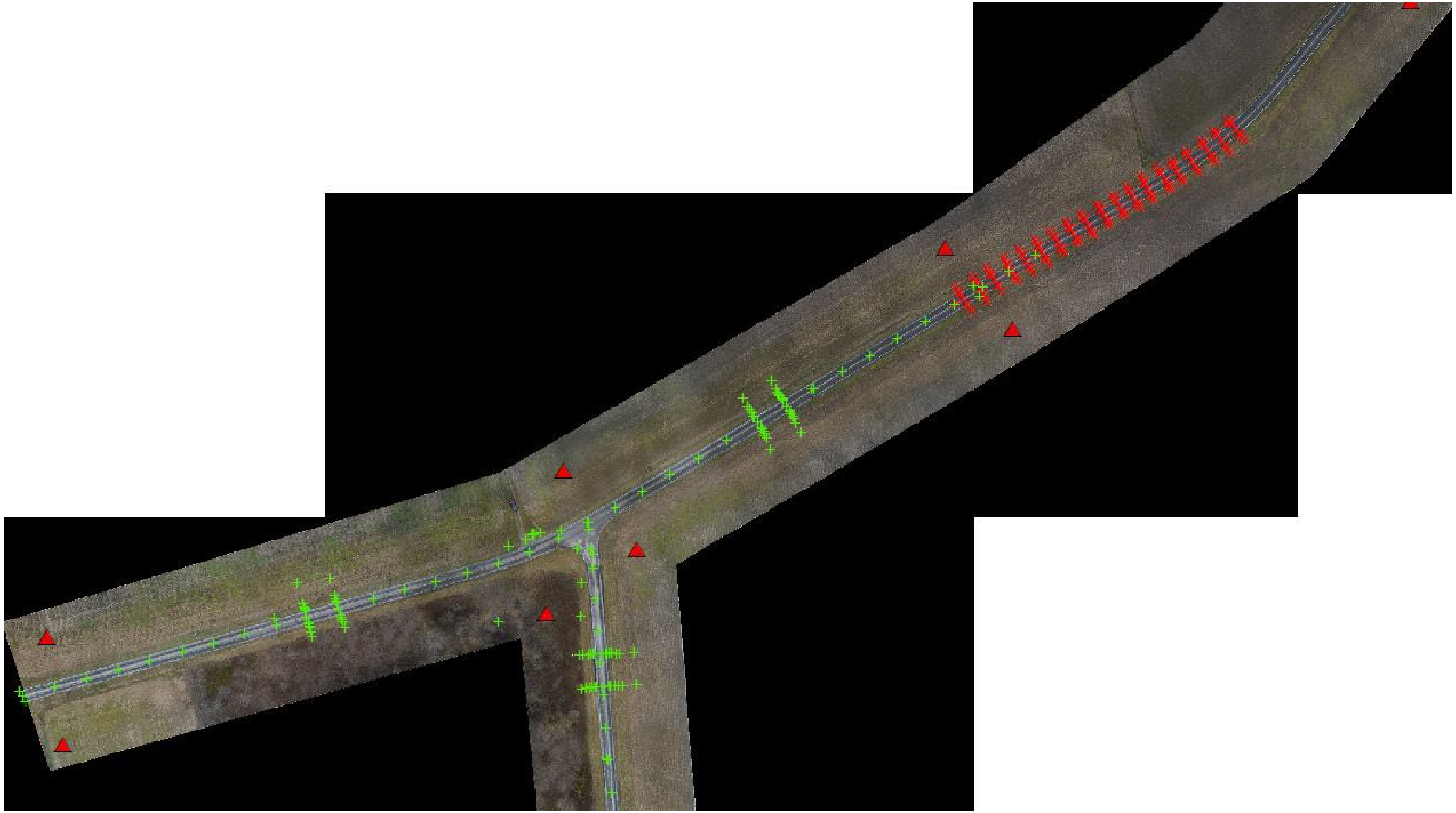
Intersection of Petersburg and Overman Roads, Ohio



Altitude = 100’ AGL

Altitude = 300’ AGL

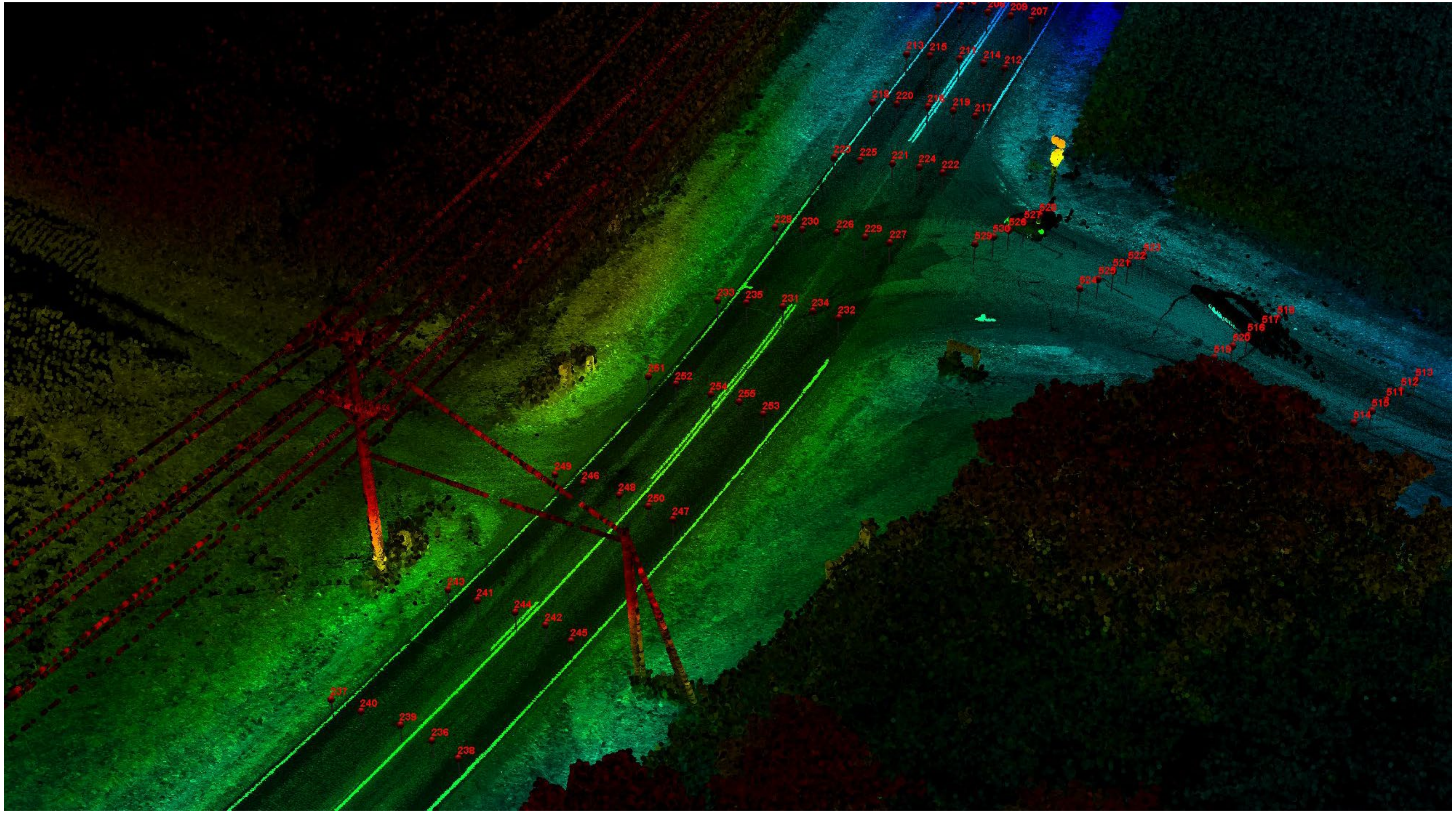
2013 and 2017 Check Points



Green – 2013

Red - 2017

Mobile Mapping (MMS) Data



Check points with MMS Data

Created five points along a cross section of the road every 25 ft.

Accuracy Evaluation According to 2013 Ground Controls

lidar DSM accuracy according to 2013 controls

Number of Check Points	**79**	
Mean Error	0.023 ft.	0.007 m
Standard Deviation (StDEV)	**0.037 ft.**	**0.011 m**
Root Mean Squares Error (RMSEz)	0.043 ft.	0.013 m
NSSDA Vert Accuracy at 95% Confidence Level	**0.085 ft.**	**0.026 m**

100 ft. DSM Accuracy according to 2013 check points

Number of Check Points	**73**	
Mean Error	0.085 ft.	0.026 m
Standard Deviation (StDEV)	**0.130 ft.**	**0.040 m**
Root Mean Squares Error (RMSEz)	0.154 ft.	0.047 m
NSSDA Vert Accuracy at 95% Confidence Level	**0.302 ft.**	**0.092 m**

300 ft. DSM Accuracy according to 2013 check points

Number of Check Points	**73**	
Mean Error	0.067 ft.	0.020 m
Standard Deviation (StDEV)	**0.290 ft.**	**0.088 m**
Root Mean Squares Error (RMSEz)	0.296 ft.	0.090 m
NSSDA Vert Accuracy at 95% Confidence Level	**0.579 ft.**	**0.177 m**

Comparing UAS Data MMS lidar Data

Lidar DSM Versus UAS DSM

Number of Check Points	**528**	**509**	**509**
	DSM300 - DSM100	**DSM300 - lidar**	**DSM100 - lidar**
Mean Error	-0.058 ft.	0.030 ft.	0.080 ft.
Standard Deviation (StDEV)	**0.327 ft.**	**0.247 ft.**	**0.124 ft.**
Root Mean Squares Error (RMSEz)	0.332 ft.	0.249 ft.	0.147 ft.
NSSDA Vert Accuracy at 95% Confidence Level	**0.651 ft.**	**0.488 ft.**	**0.289 ft.**

What does ASPRS standards mean for UAS products?

Required accuracy for the products:

Ortho Accuracy: 4 cm (RMSEx or y)
DSM Accuracy: 4 cm (RMSEz)

ASPRS Standards Requires:

$RMSE_x$, $RMSE_y$ or $RMSE_z$ (ground control)= ¼ * $RMSE_{x(Map)}$, $RMSE_{y(Map)}$ or $RMSE_{z(DEM)}$

Ground Control for AT accuracy = 1 cm (RMSEx,y,z)
Check points for QC accuracy = 1.33 cm

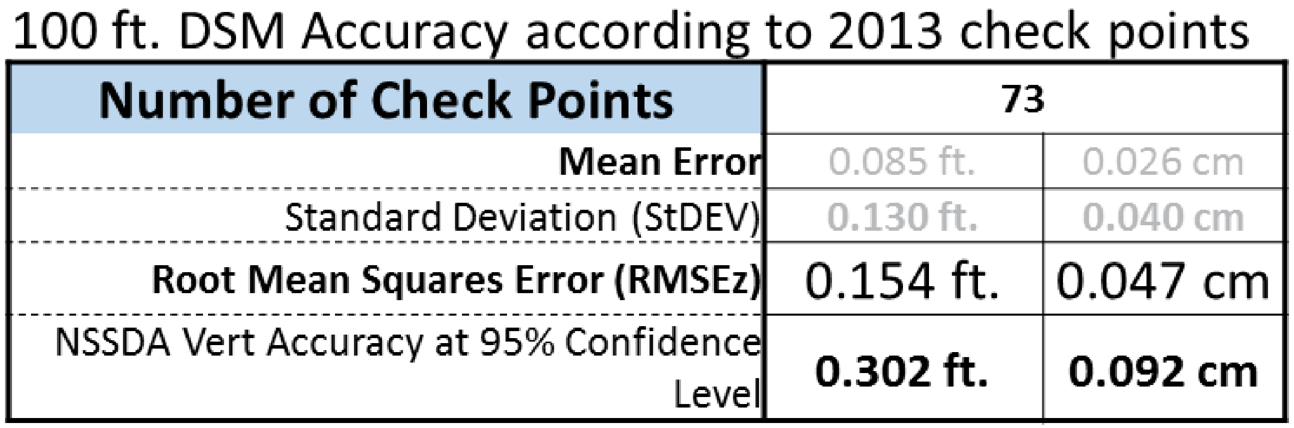
The Problem: People are claiming they can deliver 1-cm accuracy

The Question: Did you survey your controls to **0.25 cm accuracy**?

Ask surveyors about what it takes to get this type of vertical accuracy. No GPS survey supports 0.25 cm accuracy

Fact: *Usually control points are surveyed to 2 cm accuracy which support ortho accuracy of 8-cm*

Accuracy Reporting According to ASPRS Standard



100 ft. DSM Accuracy according to 2013 check points

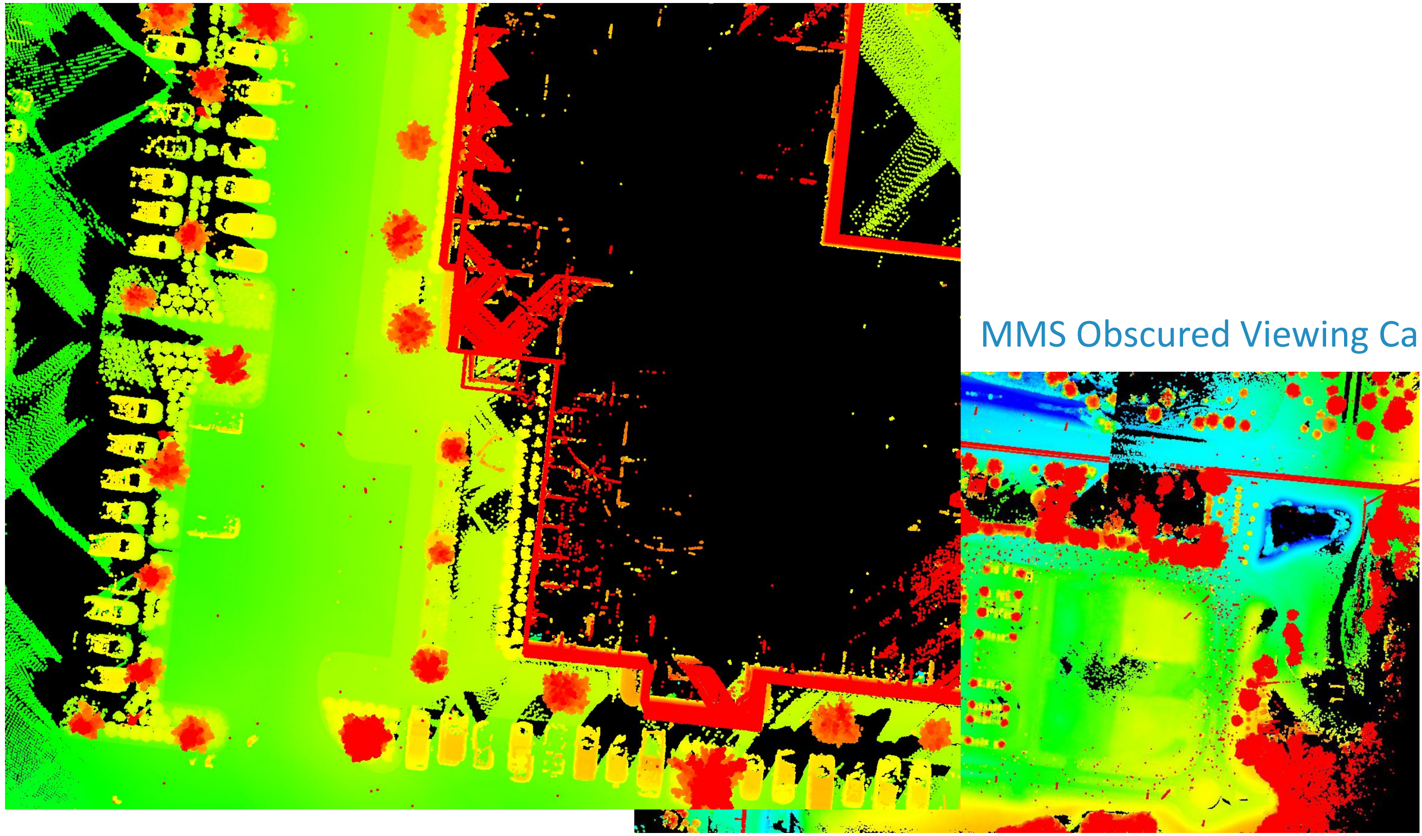
Number of Check Points	**73**	
Mean Error	0.085 ft.	0.026 cm
Standard Deviation (StDEV)	0.130 ft.	0.040 cm
Root Mean Squares Error (RMSEz)	0.154 ft.	0.047 cm
NSSDA Vert Accuracy at 95% Confidence Level	**0.302 ft.**	**0.092 cm**

Independent Vertical Accuracy Testing Statement:

“This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 4.7-cm, equating to +/- 9.2 cm at 95% confidence level. Actual VVA accuracy was found to be +/- N/A cm at the 95th percentile.”

Imagery-base Points Cloud versus Lidar: Data Quality Comparative Analysis

UAS versus MMS: Data Coverage

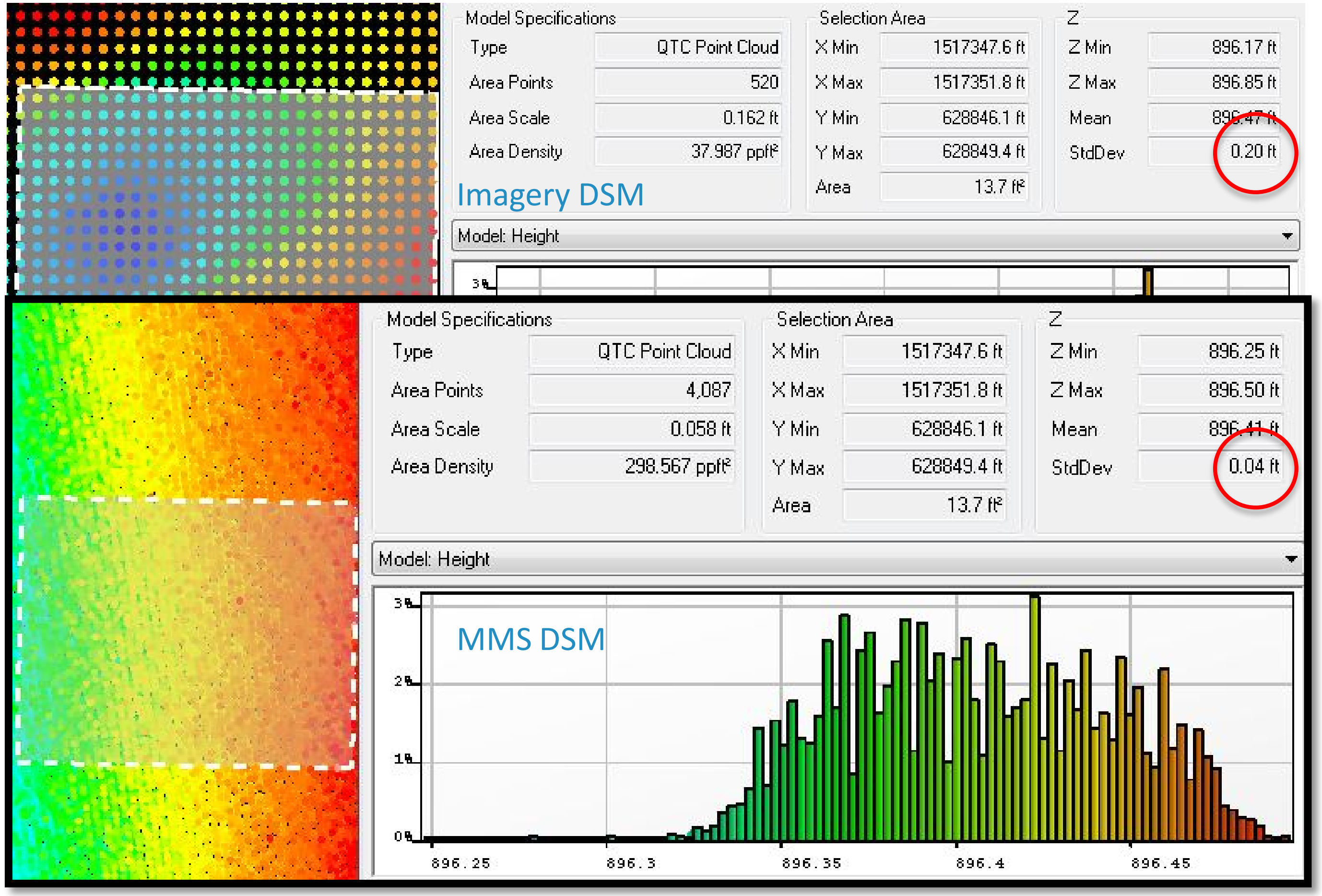


MMS Obscured Viewing Capability

UAS versus MMS: RGB Colorization

UAS ortho is perfectly co-registered with point clouds resulting in perfect RGB values

UAS versus MMS: Data Smoothness



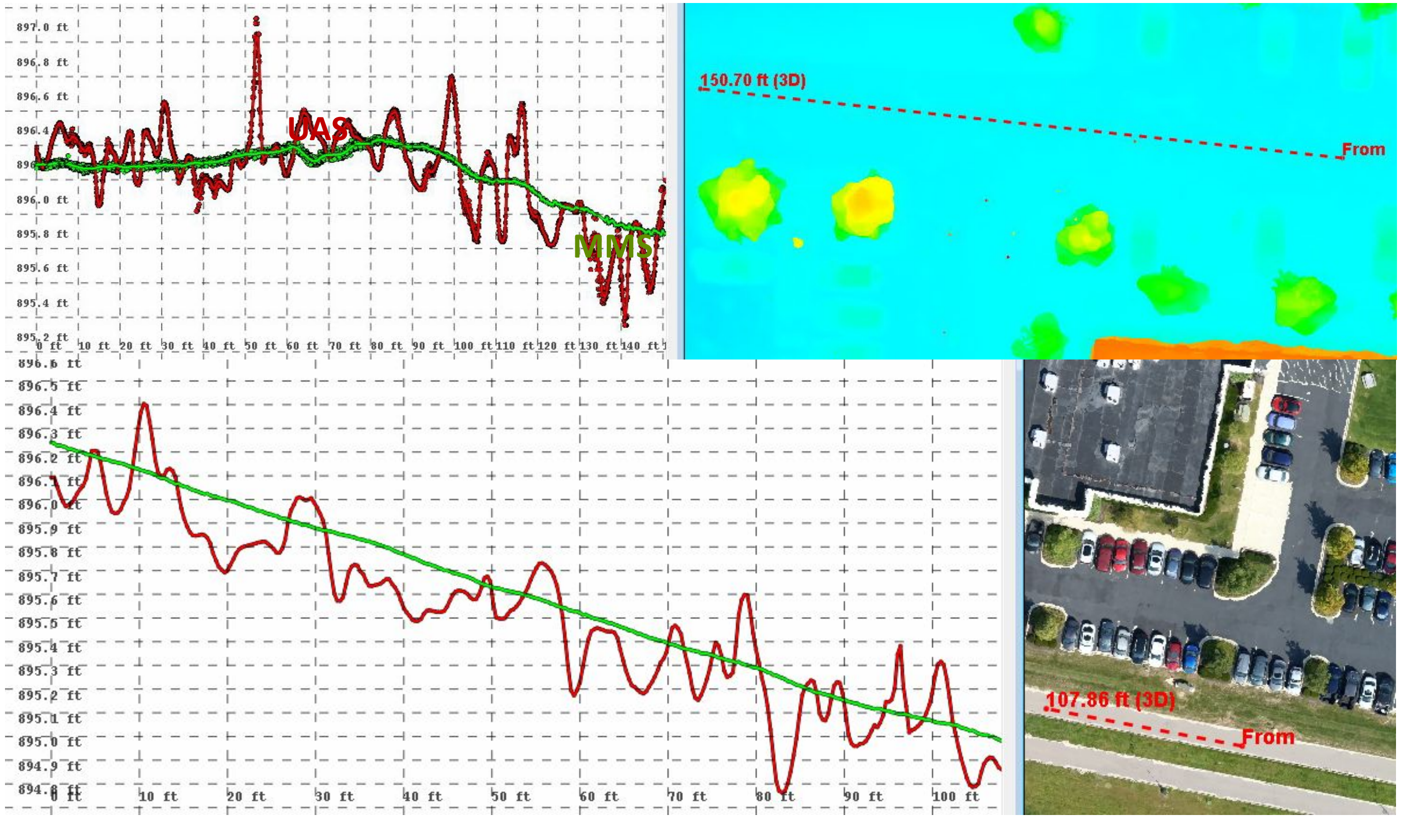
Imagery DSM

Model Specifications		Selection Area		Z	
Type	QTC Point Cloud	X Min	1517347.6 ft	Z Min	896.17 ft
Area Points	520	X Max	1517351.8 ft	Z Max	896.85 ft
Area Scale	0.162 ft	Y Min	628846.1 ft	Mean	896.47 ft
Area Density	37.987 ppft²	Y Max	628849.4 ft	StdDev	0.20 ft
		Area	13.7 ft²		

MMS DSM

Model Specifications		Selection Area		Z	
Type	QTC Point Cloud	X Min	1517347.6 ft	Z Min	896.25 ft
Area Points	4,087	X Max	1517351.8 ft	Z Max	896.50 ft
Area Scale	0.058 ft	Y Min	628846.1 ft	Mean	896.41 ft
Area Density	298.567 ppft²	Y Max	628849.4 ft	StdDev	0.04 ft
		Area	13.7 ft²		

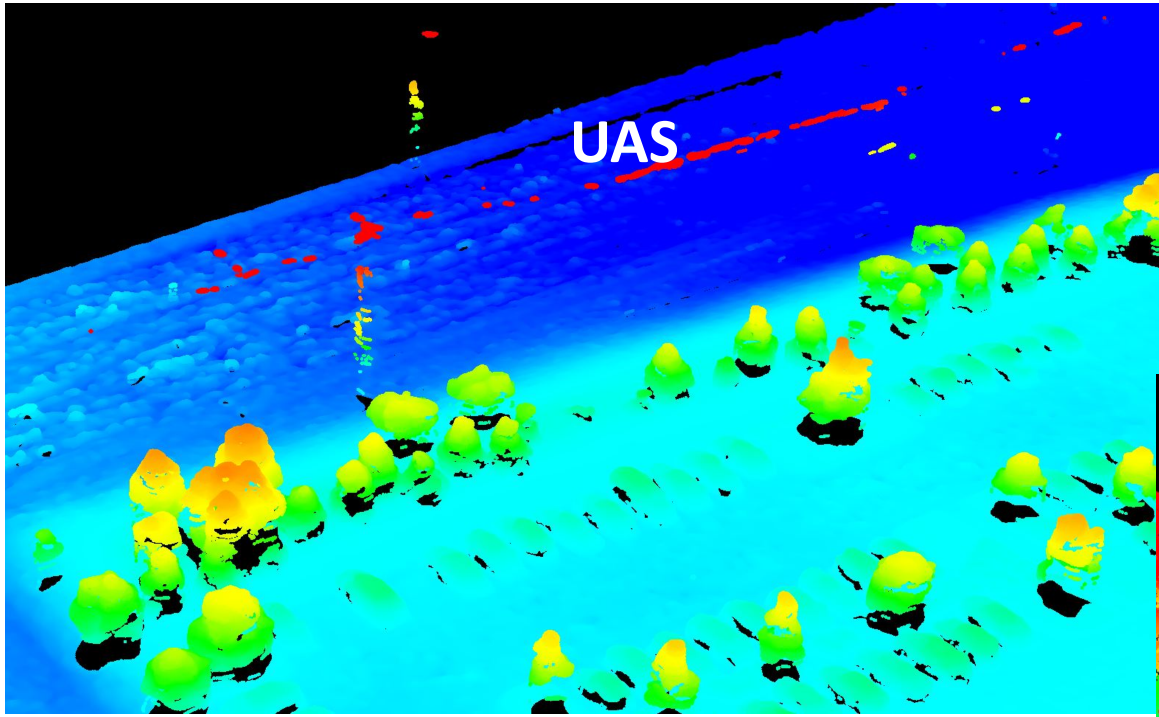
UAS versus MMS: Data Smoothness



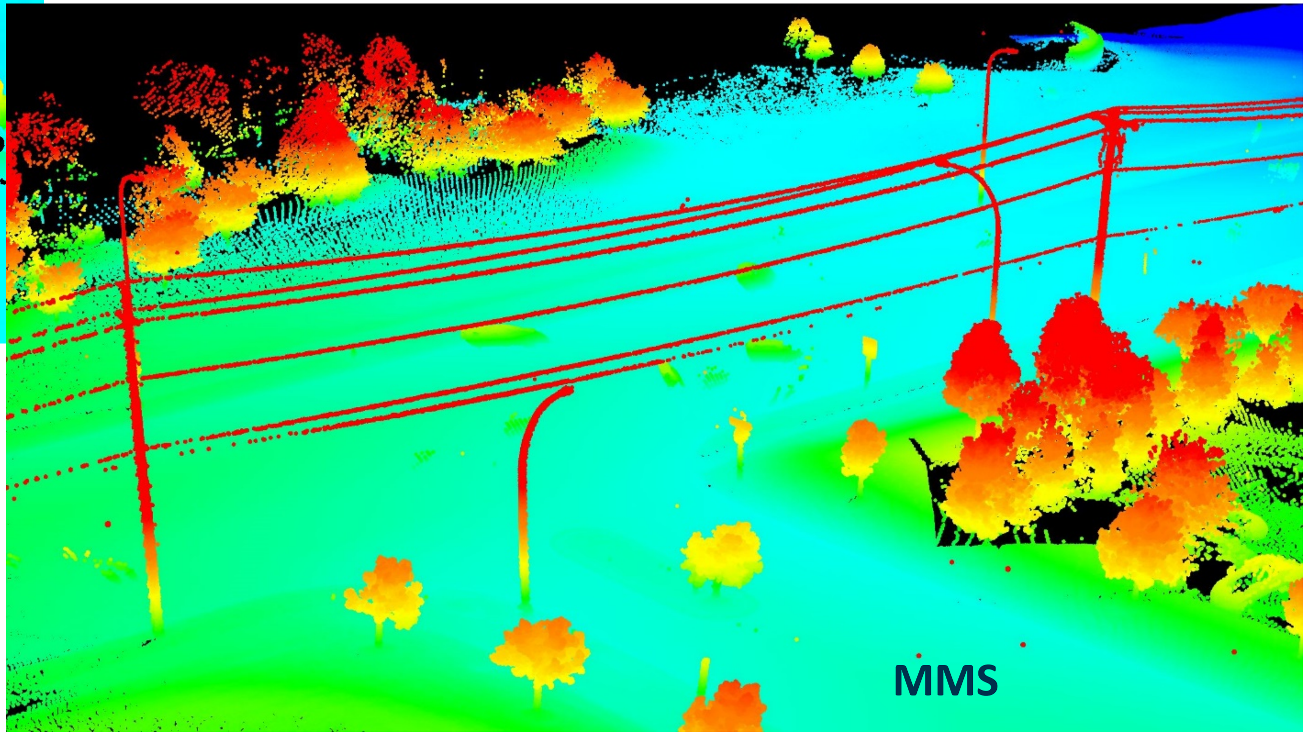
UAS versus MMS: Features Mapping

MMS: The ever proven technology for the road survey

UAS versus MMS: Features Mapping



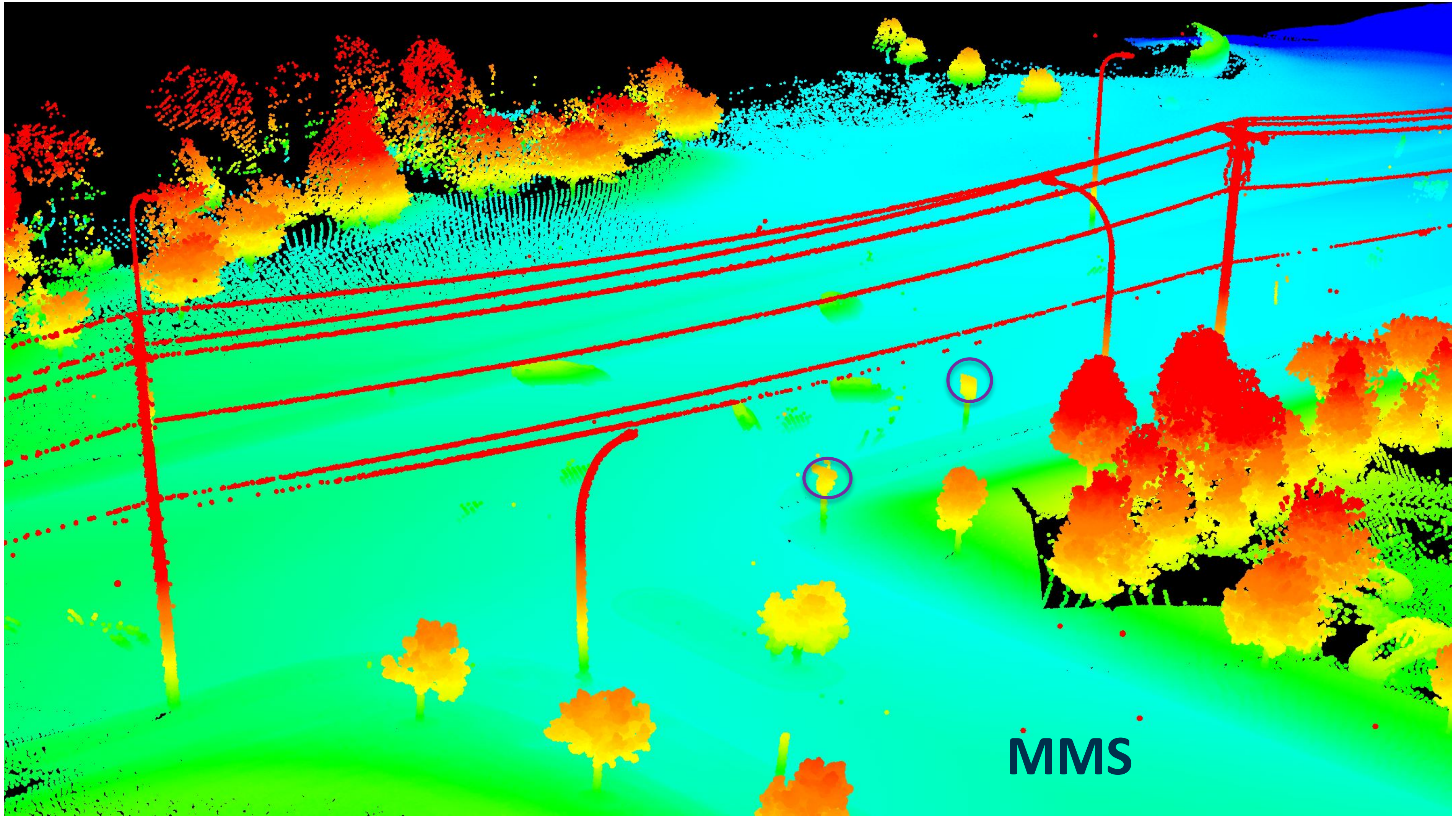
Power Lines
Power Poles



UAS products may catch up with the MMS products accuracy but not necessarily the 3D features details

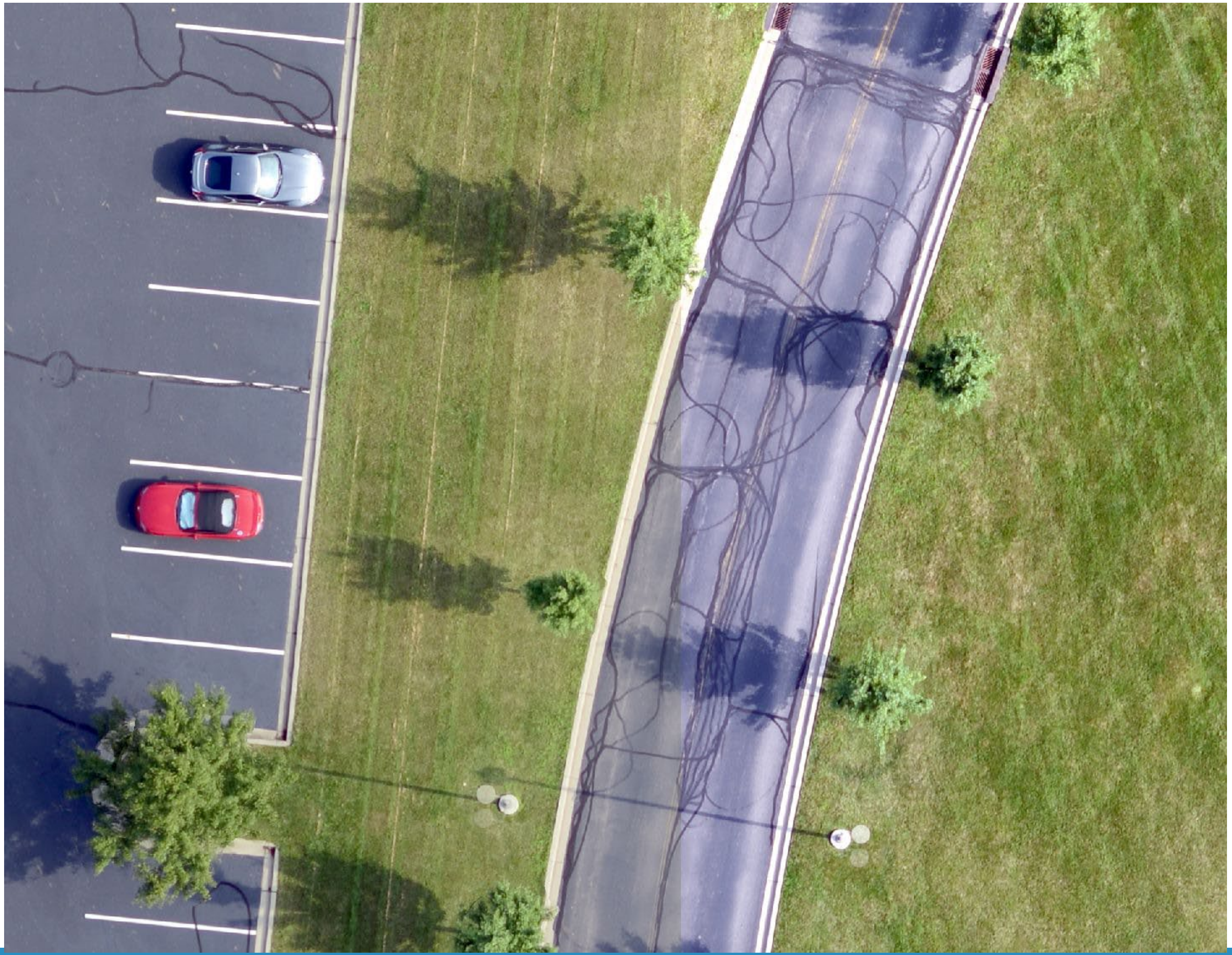
UAS versus MMS: Features Mapping

Roads Signs Only in MMS Data



UAS versus MMS: Features Mapping

2D Features Mapping is superior with UAS/Renaissance Imagery



Final Remarks

a. 3D products may not match the quality and accuracy of products generated from MMS, but it comes very close

b. UAS can provide an alternative to manned aircraft for mapping small projects

c. Products accuracy can further be enhanced by adding more ground control and RTK/PPK UAS

d. UAS ortho-rectified imagery provides best 2D details for mapping

Final Remarks

e. UAS products are good for certain specifications but not all

f. UAS derived products can be used to augment MMS products as long the final products accuracy is stamped within the UAS products accuracy

g. Accuracy can further be enhanced by adding more ground control and RTK/PPK UAS

h. For transportation projects, a hybrid solution of UAS and manned aircraft is the best approach to cover the entire ROW

Thank you!

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