The New Hybrid Product Approach: Aligning Project Specifications with UAS Photogrammetry & Lidar

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WOOLPERT

ARCHITECTURE | ENGINEERING | GEOSPATIAL

Agenda

1. The state of Lidar technologies
2. The state of digital imagery
3. The hybrid approach to 3D data generation
    - Step-by-step to the hybrid approach
    - Proof of concept for PennDOT for section 35 of SR80
4. Concluding remarks and discussions

The state of Lidar technologies

A word about the state of Lidar

- Manufacturers continue their innovations
- Lidar market is still strong with high demand for higher density and better quality lidar data
- Lidar becomes an integral part of roads planning, design, and construction activities
- UAS-based Lidar has a unique niche in the market

The state of Digital Imagery

New Generation of Digital Cameras bring giant Capabilities

Now come the drones

SwellPro Spash Drone

Sensfly Albris

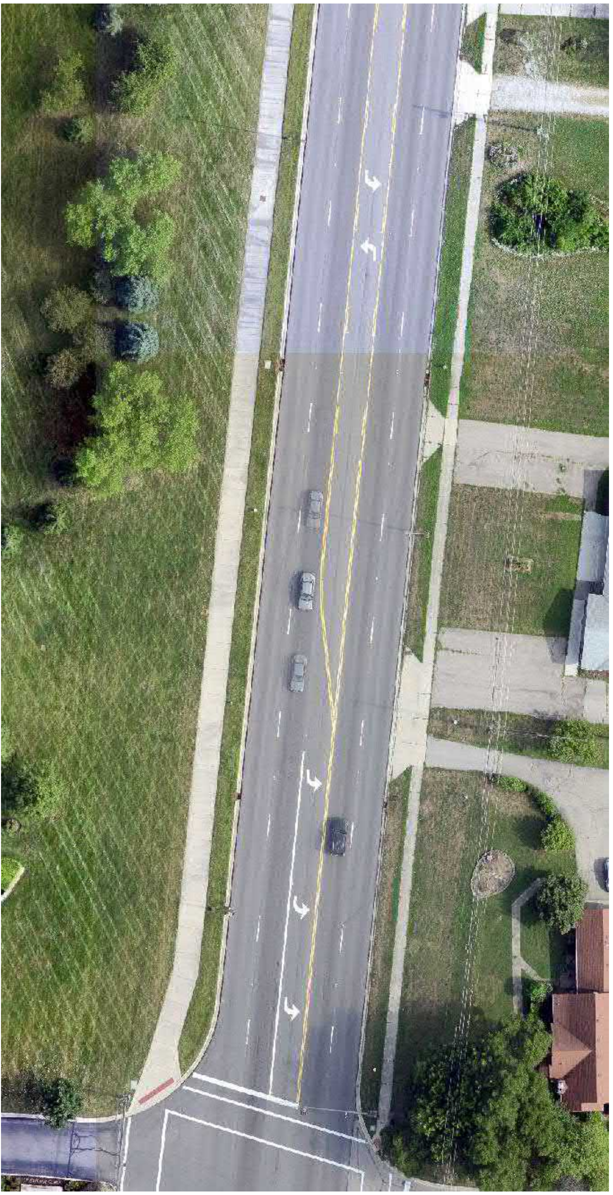
DJI Inspire

Sensfly eBee X RTK

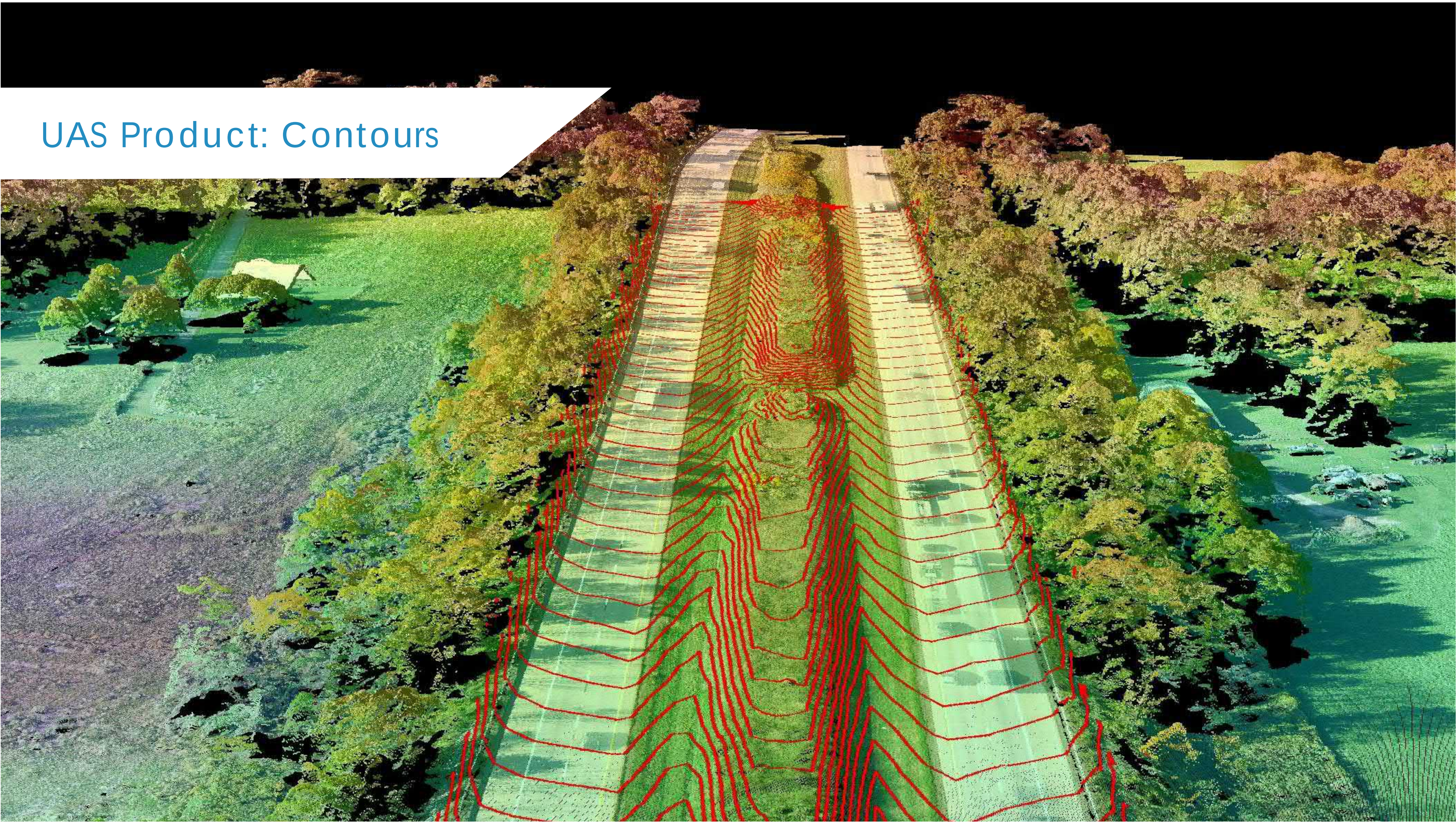
What can you get from UAS-based consumer grade cameras?

UAS Product: Points Cloud

UAS Product: Ortho Mosaic



UAS Product: Contours



The lesson learned about Geospatial data acquisition technologies..

- Every data acquisition technology has its own weakness and so as strength
- Building on the strength of each technology opens new opportunities when different technologies are used together

The by-product from different technologies is….

The Hybrid Digital Terrain Model

What is the hybrid DTM?

- Is a new product derived from multiple DTM acquisition technologies
- It is a product that was planned and budgeted during the project phase, i.e., not as after thought
- It is a product with defined quality and positional accuracy
- It is a product that meets the project specifications and saves time and money

The Hybrid DTM utilizes the best of all worlds:

Aerial Lidar + MMS + UAS

Aerial Lidar:

Points Density: up to 30 pts/m^2

Accuracy(v) RMSE = 6 to 15 cm

MMS:

Points Density: 2,000 to 6,000 pts/m^2

Accuracy(v) RMSE = 1.5 cm

UAS:

Points Density: 40 to 1000 pts/m^2

Accuracy(v) RMSE = 5 to 15 cm

Project zones and their requirements

- **Zone A:** Central Region of the Right-of-Way
  - highest accuracy level
- **Zone B:** Edges of the ROW
  - Medium accuracy level
- **Zone C:** Extended Project Basin
  - Lowest accuracy level

The Hybrid DSM Approach

What do you need to do?

Step I- Accuracy Verification

Aerial Lidar: Existing Statewide Lidar

Number of Check Points	197	
Mean Error	0.47 ft.	14.39 cm
Standard Deviation (StDEV)	0.16 ft.	4.90 cm
Root Mean Squares Error (RMSEz)	0.50 ft.	15.19 cm
NSSDA Vert Accuracy at 95% Confidence Level	0.98 ft.	29.79 cm

Land-based Lidar: The MMS Data

Accuracy Validation

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

Photogrammetric: UAS Data

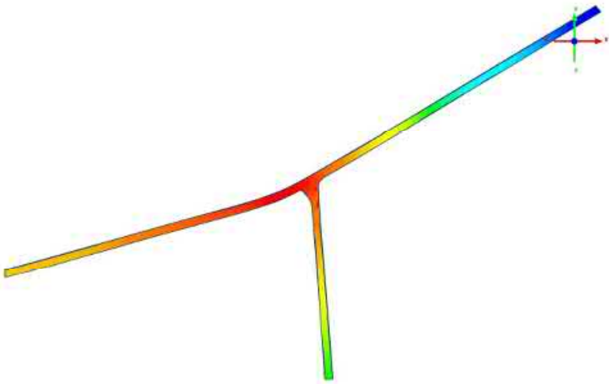
Number of Check Points	73	
Mean Error	0.085 ft.	0.026 cm
Standard Deviation (StDEV)	0.130 ft.	0.040 cm
Root Mean Squares Error (RMSEz)	0.154 ft.	0.047 cm
NSSDA Vert Accuracy at 95% Confidence Level	0.302 ft.	0.092 cm

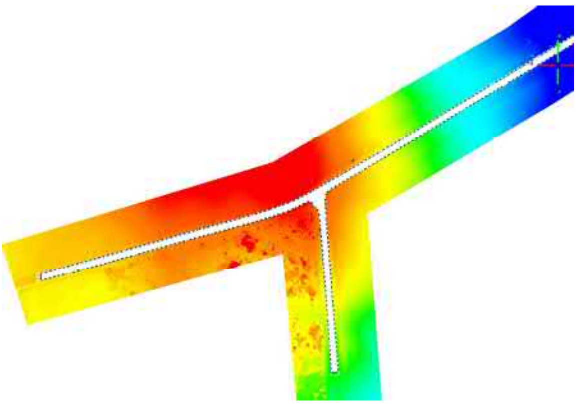
II. Data Preparation

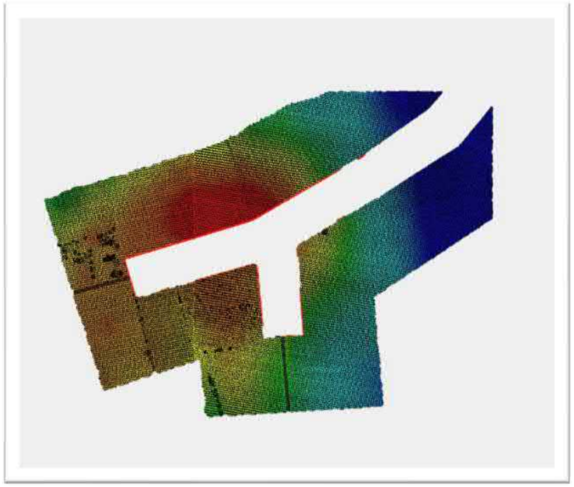
Data needs to be prepared for data fusion:

- Data reformatting necessary
- Reprojection if necessary
- Clipping and cropping

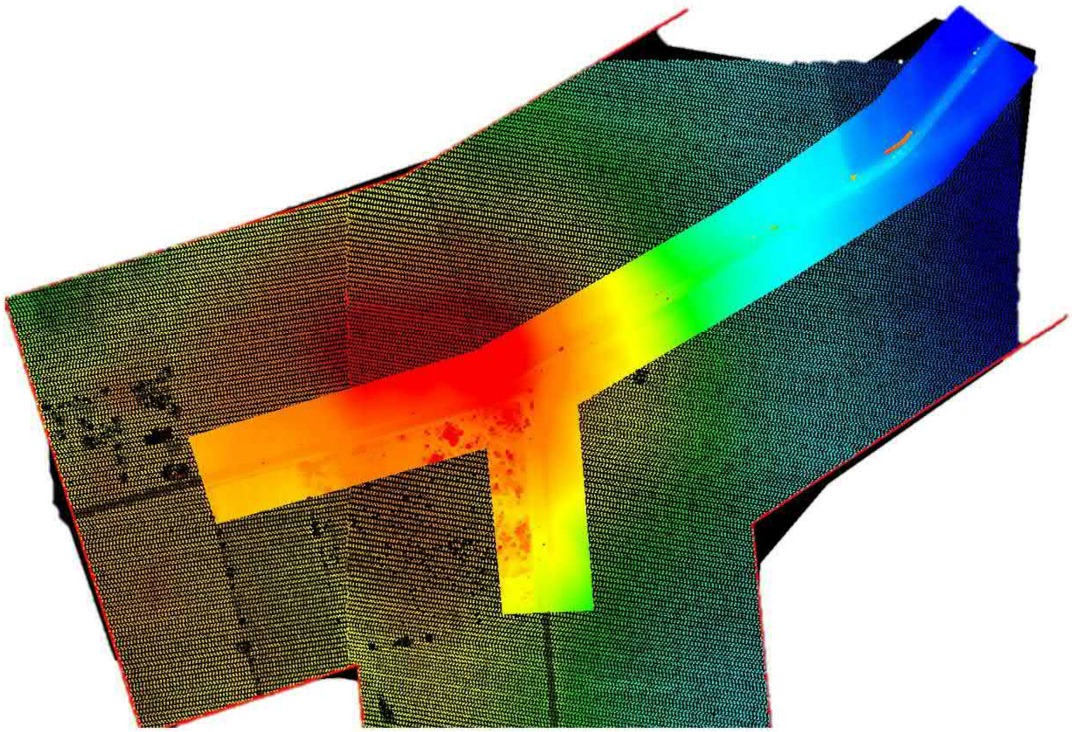
Clipping good data







Preparing the Three Datasets



Merging the Three Datasets

III. Products Development and Final Deliverables

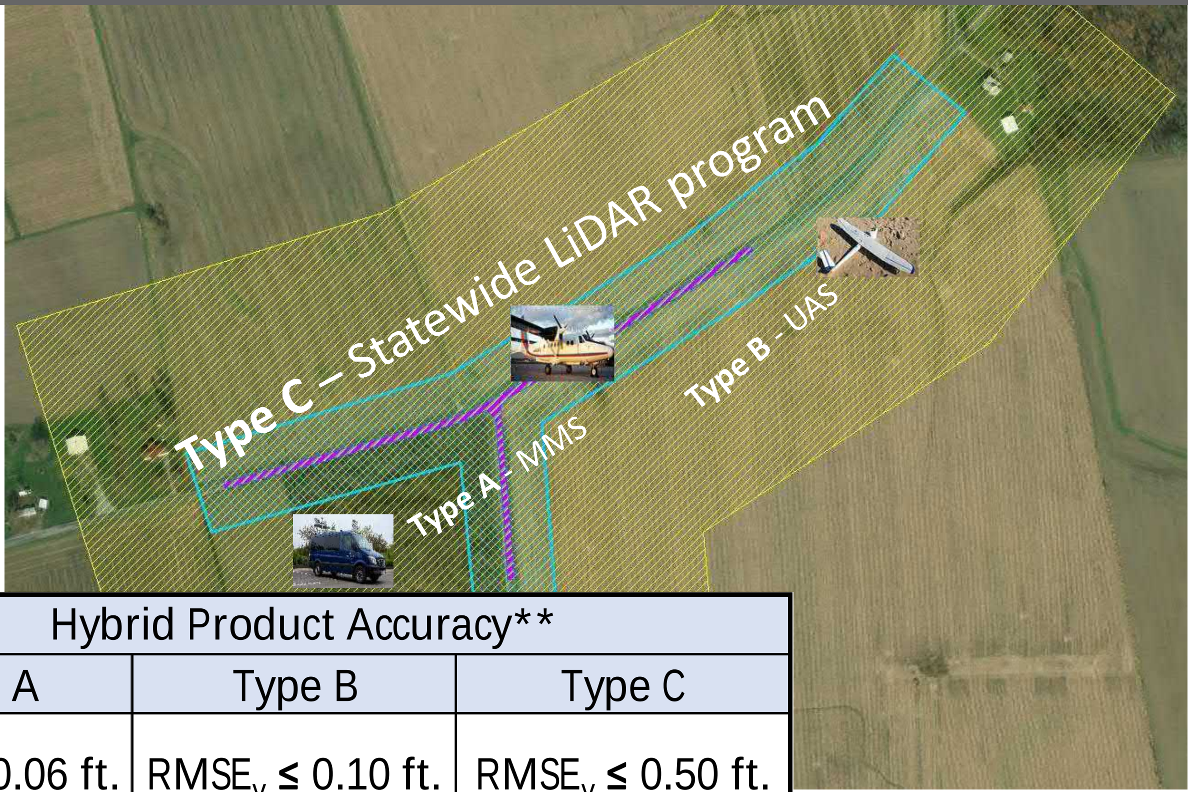
Resulting Products:
Seamless Dataset
One-foot contours

Hybrid Approach to Project Data

Outcome: Accuracy on Demand

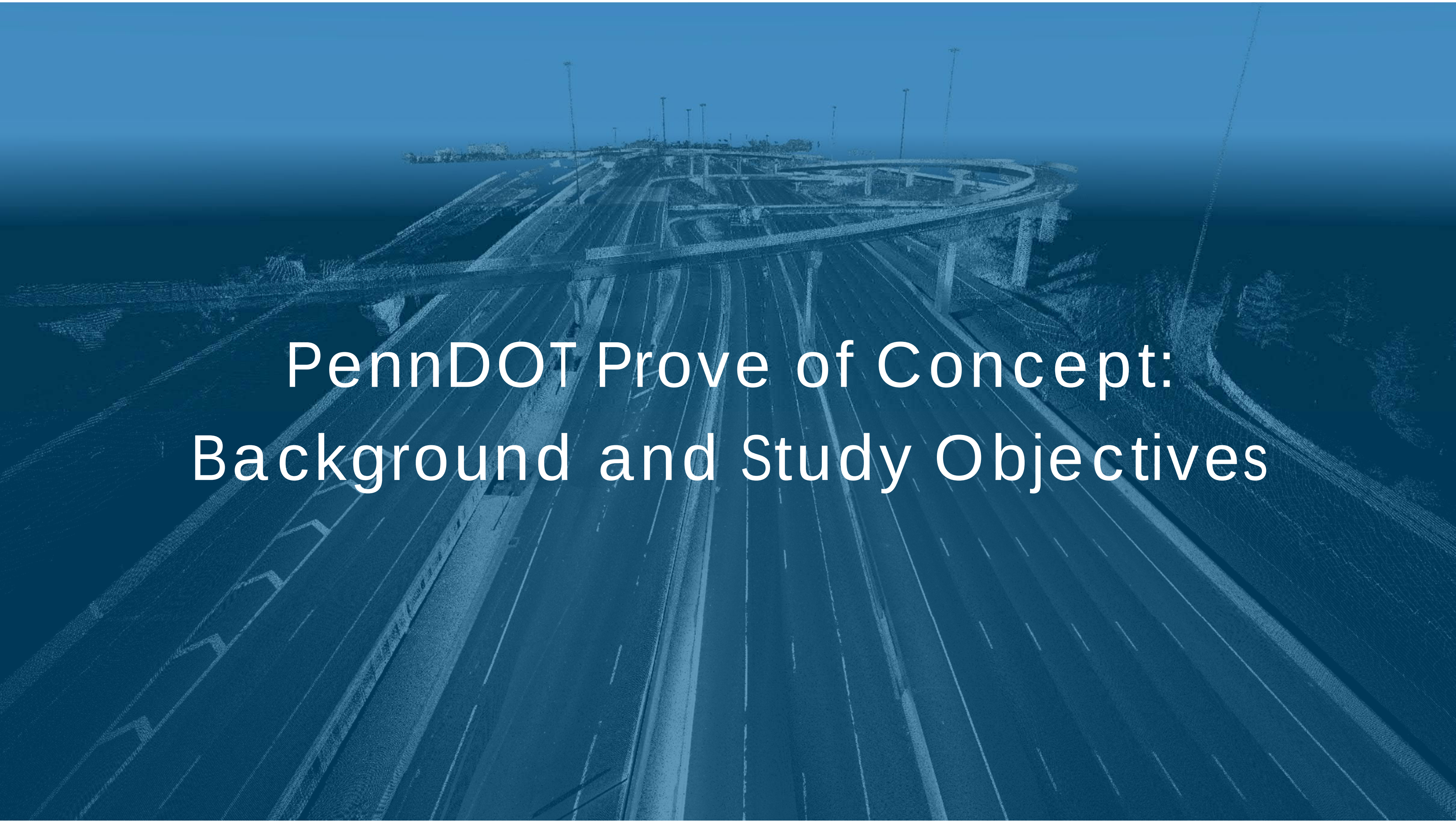
The Results

- Hybrid DSM that is more affordable and more suitable for site planning and project design
- Data Fusion provides accuracy where you need it most!



Product Specification	Hybrid Product Accuracy**		
	Type A	Type B	Type C
Terrain surface accuracy as verified using independent check points	$RMSE_v \leq 0.06$ ft.	$RMSE_v \leq 0.10$ ft.	$RMSE_v \leq 0.50$ ft.

** Type A = MMS lidar , Type B = UAS imagery-based points cloud, Type C = State wide lidar program


PennDOT Prove of Concept:
Background and Study Objectives

Project 2:

Mapping Products Generation from UAS: Proof of Concept for PennDOT

BACKGROUND

Woolpert acquired and delivered Mobile Mapping Lidar System (MMS) data and 3" natural colors imagery for PennDOT SR 081-360

OBJECTIVES

Woolpert pursued a proof-of-concept study to investigate the feasibility of using Unmanned Aircraft System (UAS) for the following PennDOT activities:

- Whether stereo compiled DTM from UAS can augment or replace the need for MMS to model edge-to-edge pavement modeling
- To evaluate the quality and suitability of the high resolution ortho-rectified imagery and points cloud generated from UAS within and outside ROW for other roads planning and design activities by PennDOT

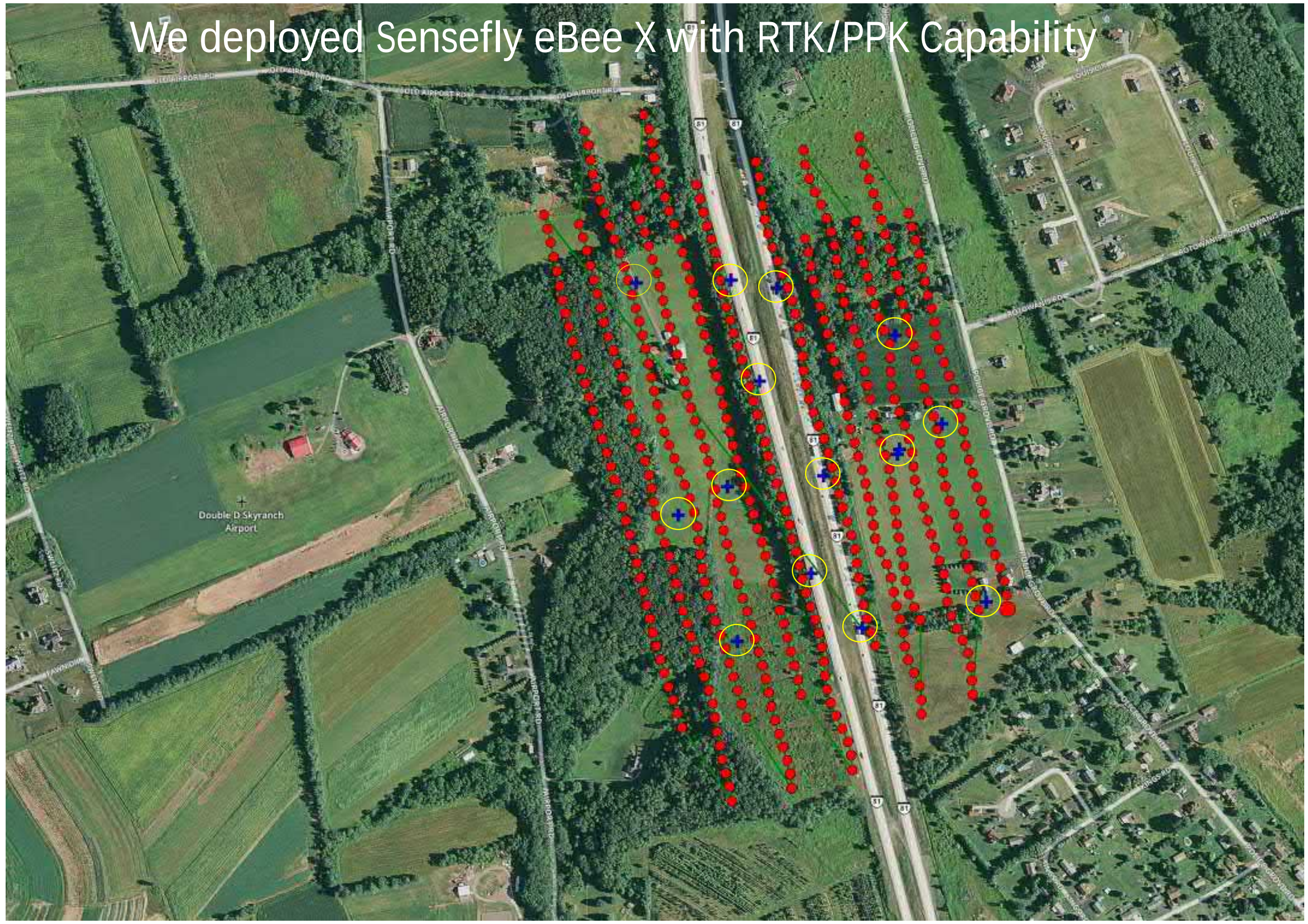
The Project Procedure

Project Design and Mission Planning

eBee X
Fixed-Wing Drone

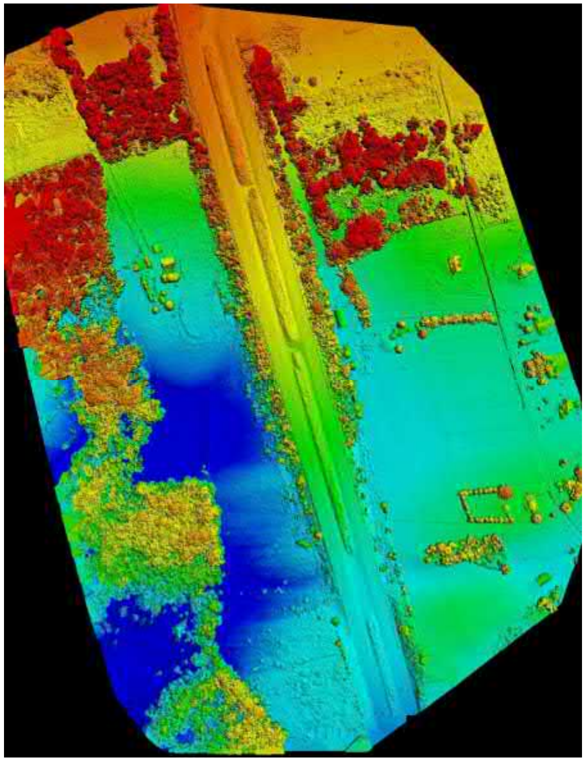
senseFly S.O.D.A. 3D
Mapping Camera

Collected imagery with
2.53-cm GSD (1")



Products Generated

Stereo Compiled Break lines



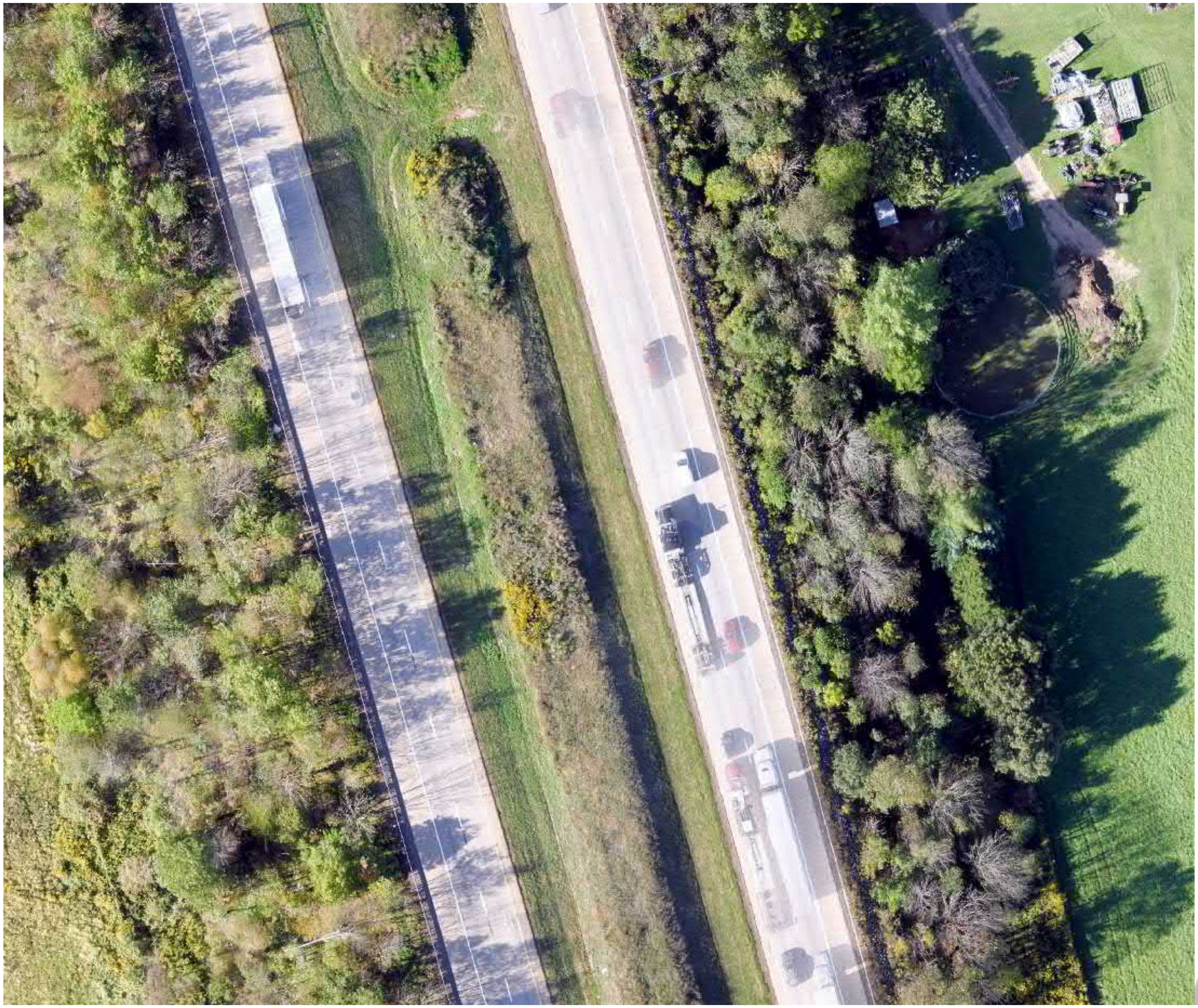
Digital Surface Model

Ortho-rectified Mosaic GSD = 2.5 cm (1”)

Products Quality

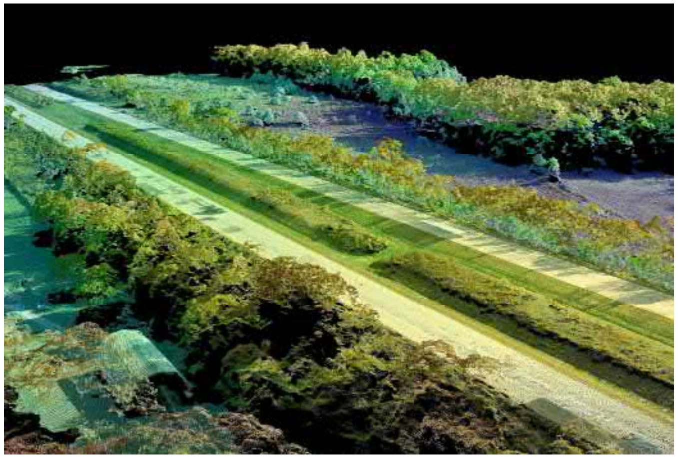
UAS Imagery Quality

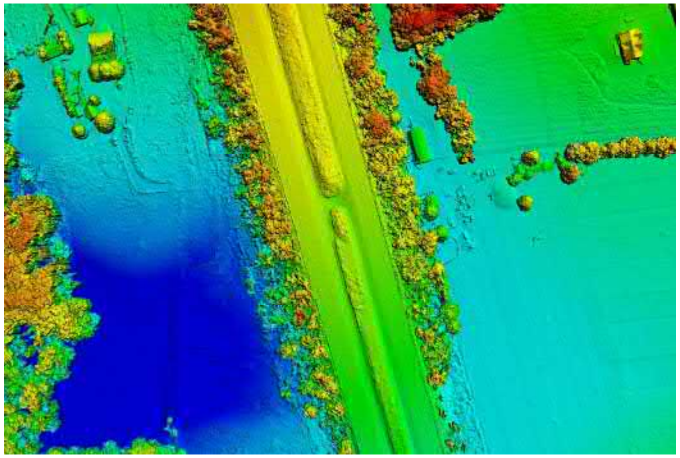
GSD = 1”
(2.54-cm)



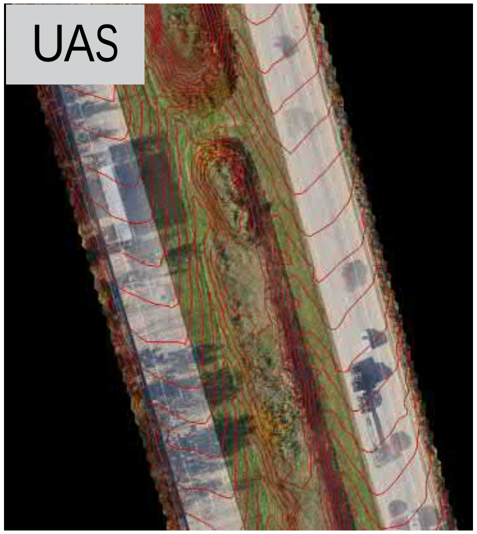
Imagery Quality: UAS versus Manned

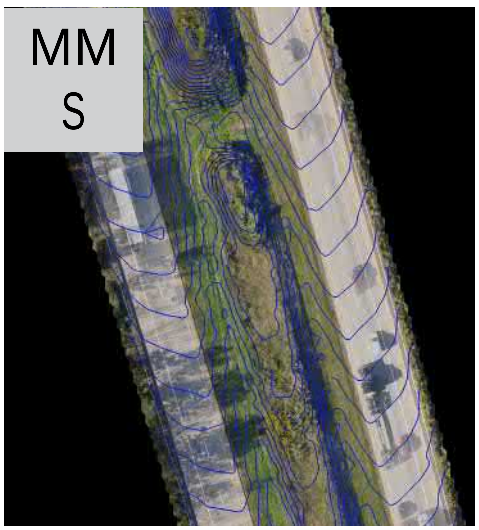
Points Cloud Quality

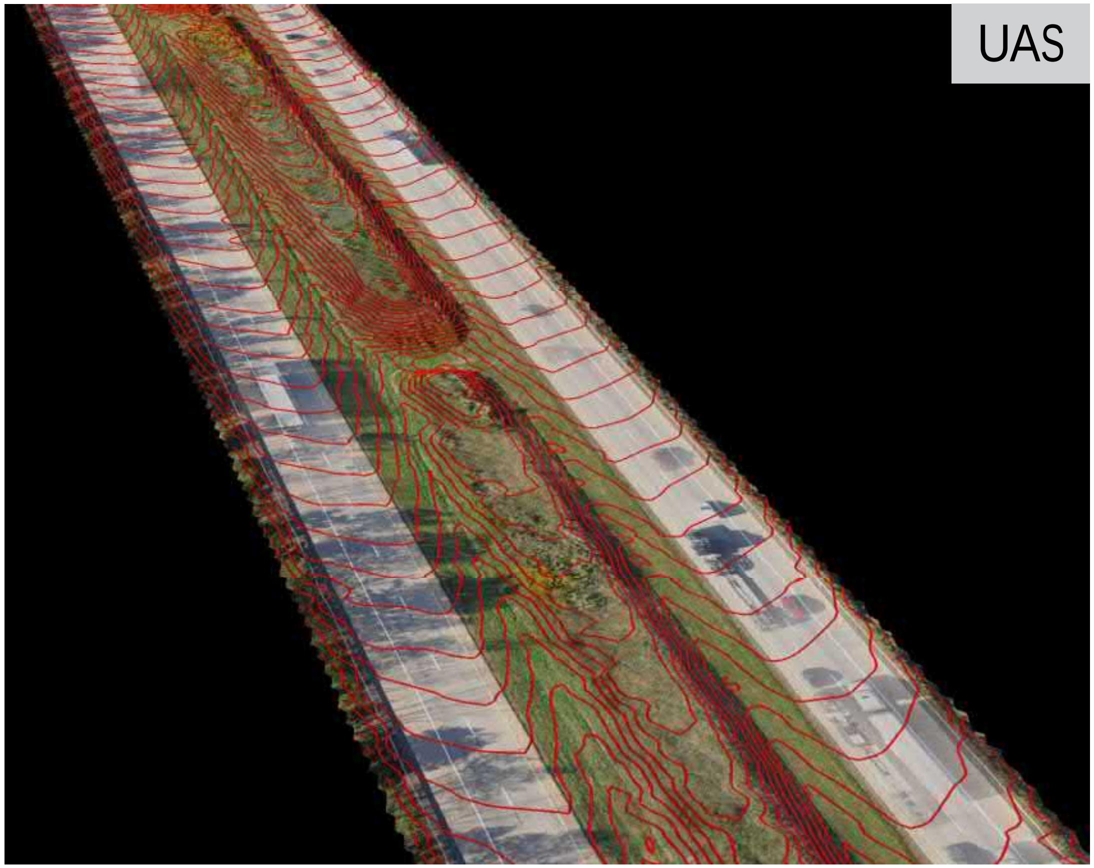


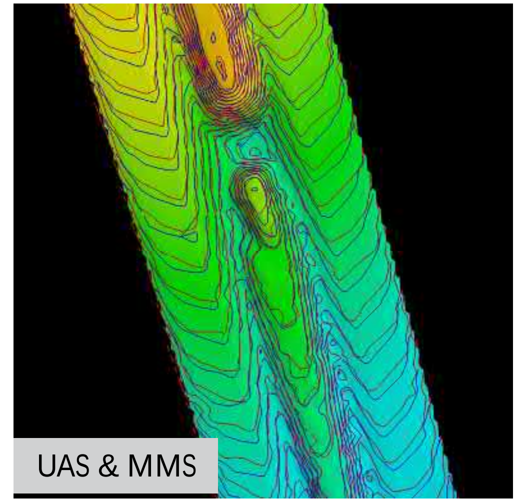


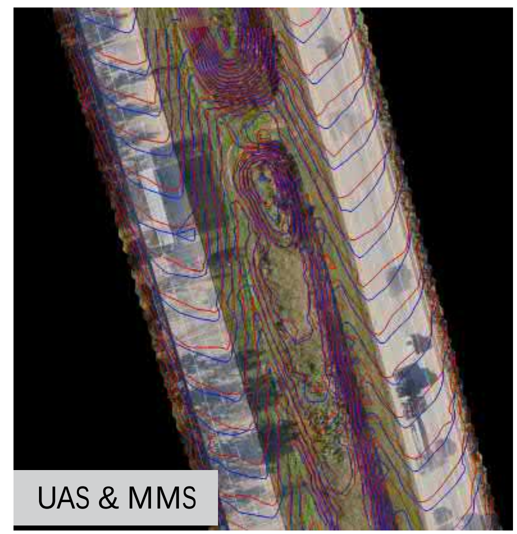
UAS Contours Quality









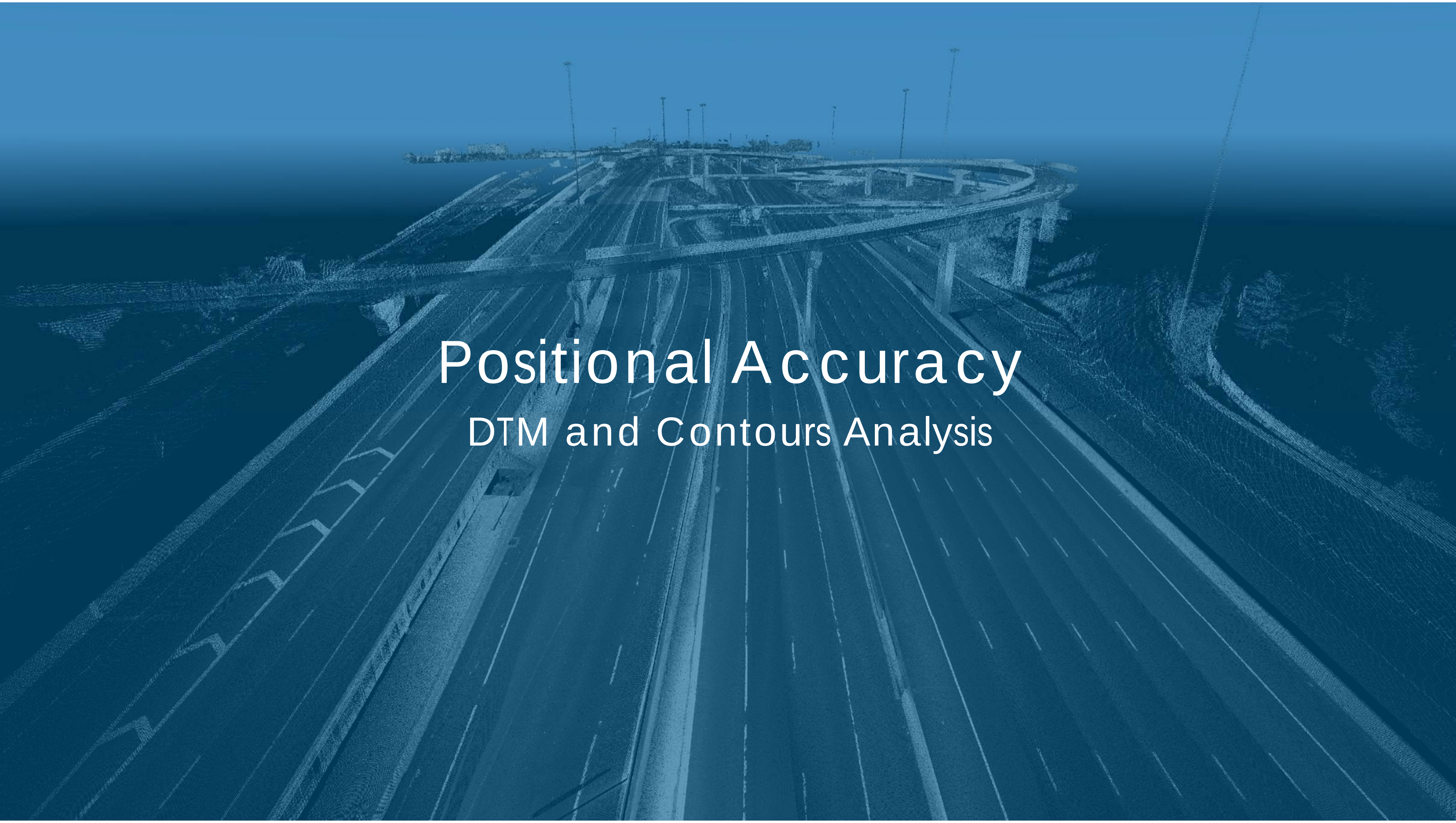


Red: UAS   Blue: MMS

MMS: Mobile Mapping System

Positional Accuracy

DTM and Contours Analysis

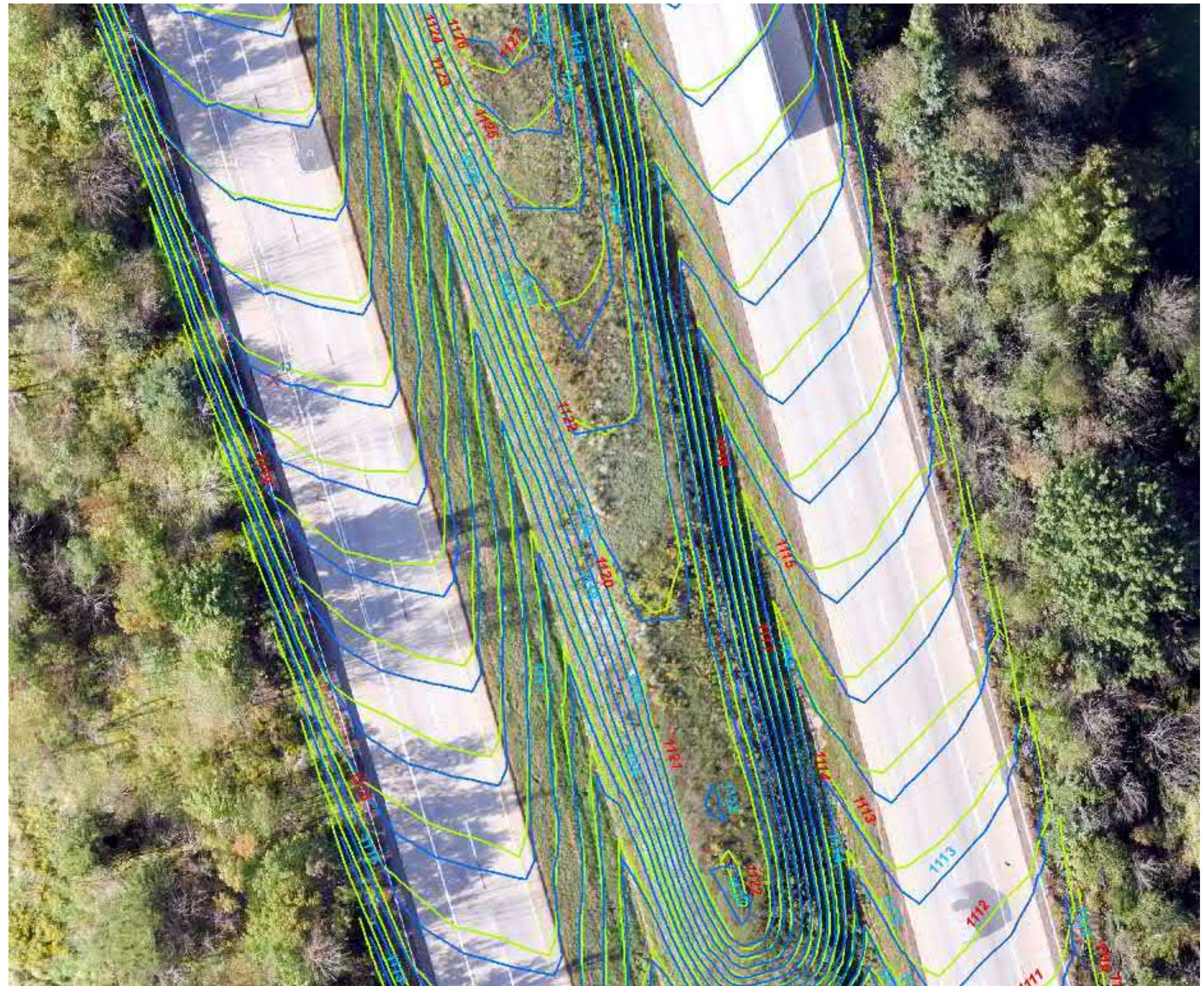


Contours Quality

Vertical Accuracy

Contours from UAS

Contours from UAS & MMS



Green: UAS Blue: MMS

Positional Accuracy of DTM

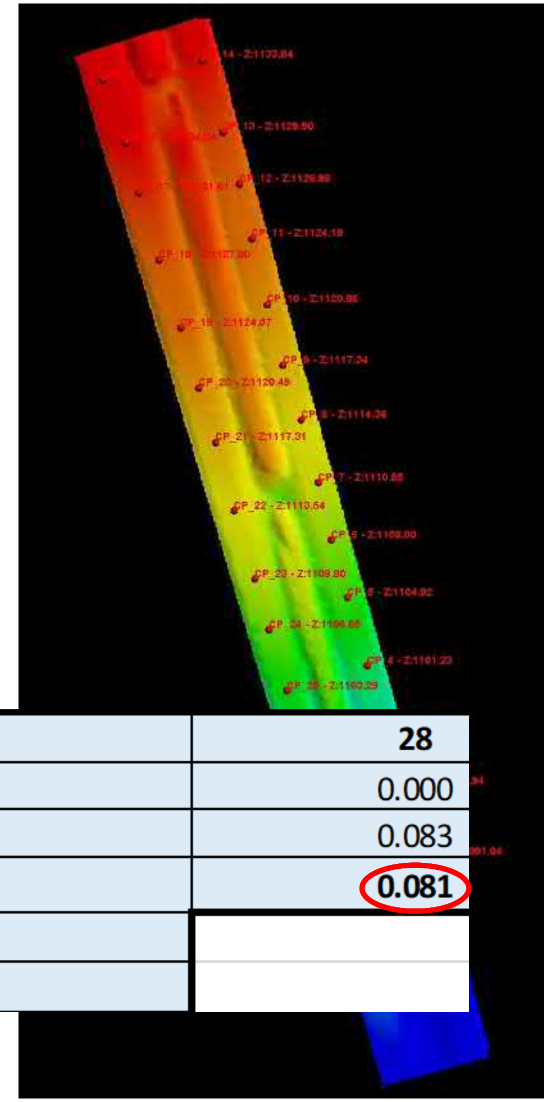
As verified by check points from Mobile Mapping System

Derived 28 2^{nd} Gen Check Points from MMS DTM

Comparing UAS DTM to Mobile Lidar using 28 Locations

PennDOT UAS Proof of Concept - Accuracy Analysis (Comparing UAS DTM to MMS DTM)						
Point ID	MMS Elevation			UAS Elevation	Residual Values (ft.)	Delta Z after Z-bias Removed (ft.)
	Easting (ft.)	Northing (ft.)	Elevation (ft.)	Elevation (ft.)	Error in Elevation (ft.)	
CP_1	2447813.6658	320999.2773	1091.2600	1091.0900	0.1700	-0.0539
CP_2	2447783.7307	321113.7985	1095.1700	1094.9800	0.1900	-0.0339
CP_3	2447759.1650	321215.2972	1098.4000	1098.1600	0.2400	0.0161
CP_4	2447733.0793	321308.6243	1101.5000	1101.2200	0.2800	0.0561
CP_5	2447700.7566	321419.0448	1105.1900	1104.8700	0.3200	0.0961
CP_6	2447674.8168	321511.8570	1108.2900	1107.9800	0.3100	0.0861
CP_7	2447653.6632	321604.4581	1111.2300	1110.8400	0.3900	0.1661
CP_8	2447626.2922	321705.3985	1114.6300	1114.3200	0.3100	0.0861
CP_9	2447596.3534	321793.1424	1117.7100	1117.3800	0.3300	0.1061
CP_10	2447571.4603	321890.3933	1120.9300	1120.8700	0.0600	-0.1639
CP_11	2447546.6611	321995.9759	1124.4200	1124.2700	0.1500	-0.0739
CP_12	2447526.5566	322083.3588	1127.2400	1126.9900	0.2500	0.0261
CP_13	2447500.2614	322166.6011	1130.1800	1129.9000	0.2800	0.0561
CP_14	2447466.4229	322281.2289	1134.0600	1133.8900	0.1700	-0.0539
CP_15	2447308.6649	322248.5215	1138.2900	1138.0900	0.2000	-0.0239
CP_16	2447344.7171	322148.4501	1134.5300	1134.3400	0.1900	-0.0339
CP_17	2447365.3790	322069.0943	1131.7300	1131.6100	0.1200	-0.1039
CP_18	2447397.6980	321961.4341	1127.9300	1127.8300	0.1000	-0.1239
CP_19	2447432.4695	321852.6548	1124.1800	1124.1000	0.0800	-0.1439
CP_20						
CP_21						
CP_22						
CP_23						
CP_24						
CP_25						
CP_26						
CP_27						
CP_28						
	Root Mean Squares Error ($RMSE_{x\ or\ y\ or\ z}$)				0.238	0.081
	NSSDA Vert Accuracy at 95% accuracy Level				0.467	
	NSSDA Vert Accuracy at 95% accuracy Level after z-bias removal				0.159	

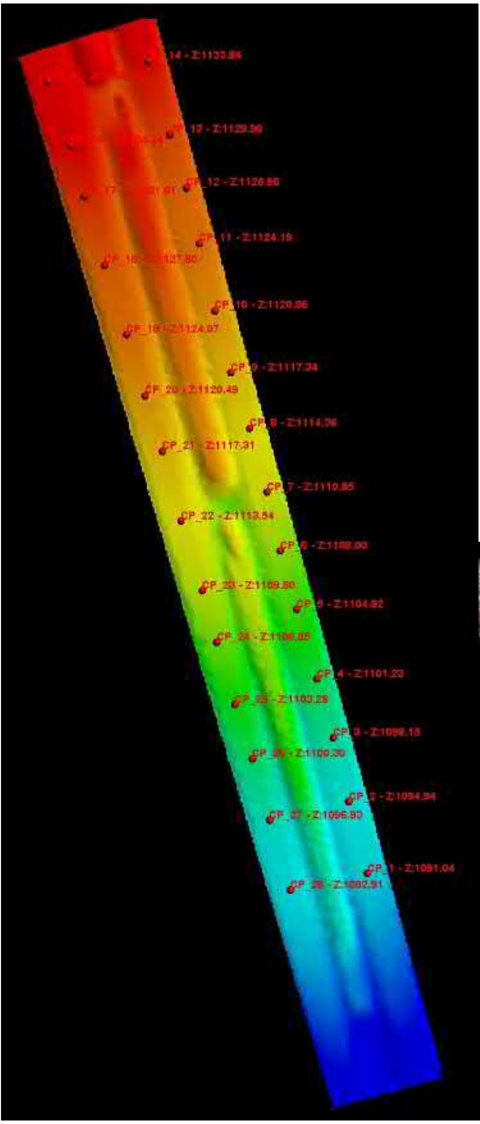
Number of Check Points	**28**	**28**
Mean Error	0.224	0.000
Standard Deviation (StDEV)	0.083	0.083
Root Mean Squares Error ($RMSE_{x\ or\ y\ or\ z}$)	**0.238**	**0.081**
NSSDA Vert Accuracy at 95% accuracy Level	**0.467**	
NSSDA Vert Accuracy at 95% accuracy Level after z-bias removal	**0.159**	



Positional Accuracy – The True Test

DTM and Independent Check Points from PennDOT

PennDOT independently, surveyed 28 check points to verify the DTM accuracy



UAS DTM Accuracy verified by PennDOT Field Survey

PennDOT UAS Proof of Concept - Accuracy Analysis (Comparing UAS DTM to PennDOT new check points)

Note: Elevation of check points were re-projected to Geoid 12B to match the vertical datum of the data

Point ID	Surveyed Elevation			UAS Elevation	Residual Values (ft.)	Delta Z after Bias Removal
	Easting (ft.)	Northing (ft.)	Elevation (ft.)	Elevation (ft.)	Error in Elevation (ft.)	
CP_1	2447833.0894	321000.2444	1090.7890	1090.6120	0.1770	[illegible]
CP_2	2447802.1717	321113.8212	1094.5240	1094.3850	0.1390	[illegible]
CP_3	2447772.2693	321223.4371	1098.1050	1097.9650	0.1400	[illegible]
CP_4	2447748.5271	321310.1031	1100.9470	1100.8140	0.1330	[illegible]
CP_5	2447717.8919	321422.8742	1104.6990	1104.4980	0.2010	[illegible]
CP_6	2447692.8522	321515.1178	1107.7650	1107.5460	0.2190	0.0204
CP_7	2447667.4935	321607.4306	1110.8140	1110.6590	0.1550	-0.0436
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
						-0.2386
						0.0814
						0.1714
						0.0804
						-0.0296
CP_24	2447552.5875	321369.0845	1106.8410	1106.5450	0.2960	0.0974
CP_25	2447581.7572	321268.5857	1103.2270	1102.8890	0.3380	0.1394
CP_26	2447606.8815	321181.3414	1100.1830	1099.9710	0.2120	0.0134
CP_27	2447634.7895	321084.3153	1096.7430	1096.5550	0.1880	-0.0106
CP_28	2447667.2819	320972.5669	1092.7720	1092.3410	0.4310	0.2324
	Number of Check Points				28	28
	Mean Error				0.199	0.000
	Standard Deviation (StDEV)				0.096	0.096
	Root Mean Squares Error ($RMSE_{x\ or\ y\ or\ z}$)				0.220	0.095
	NSSDA Vert Accuracy at 95% accuracy Level				0.431	
	NSSDA Vert Accuracy at 95% accuracy Level after z-bias removal				0.185	

Number of Check Points	28	28
Mean Error	0.199	0.000
Standard Deviation (StDEV)	0.096	0.096
Root Mean Squares Error ($RMSE_{x\ or\ y\ or\ z}$)	0.220	0.095
NSSDA Vert Accuracy at 95% accuracy Level	0.431	
NSSDA Vert Accuracy at 95% accuracy Level after z-bias removal	0.185	

Bias of 0.199 ft.

RMSEz = 0.095 ft. after bias removal

Concluding Remarks

- Imagery with resolution of 1” collected by UAS matched or exceeded the positional accuracy of imagery collected by manned aircraft with resolution of 3”
- The quality and details of the imagery collected by UAS exceeded the quality and details of the imagery collected by manned aircraft
- Stereo-compiled DTM from UAS imagery can augment or replace the DTM collected from MMS
- The DSM from UAS points cloud outside the ROW can be used for road planning and design purposes. It can replace some field surveying activities
- Products from UAS can be integrated with data from MMS and manned aircraft to generate a hybrid product that is more economically feasible.

Thank you!

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