Introduction to Remote Sensing and Geospatial Data Analytics

TRANSPORTATION
STORM DRAINAGE
WATER RESOURCES
WASTEWATER
SPECIALTY PROJECTS

50 Years 1969 - 2019 birkhoff, hendricks & carter, L.L.P.

50+ YEARS OF SPECIALIZING IN CIVIL ENGINEERING FOR MUNICIPALITIES AND GOVERNMENTAL AGENCIES

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Outline

- Introduction to Remote Sensing
- Example Remote Sensing Methods
- sUAS and Geospatial Databases
- Integration
- Case Studies and Discussions
- Questions

Introduction to Remote Sensing

- Collection of data from a distance
  - No or limited physical contact with the subject
- Use electromagnetic spectrum response characterization
- Passive vs Active Remote Sensing
  - Passive: record EM data radiated
  - Active: measure response to a generated EM wave
- Spatial and physical characteristic data
- Data into information
  - Organization of data
  - Spatial context

Introduction to Remote Sensing

Data

- “Raw”
- 1s and 0s

Information

- Organized data
- Determine conditions

Understanding

- Organized information
- Infer and predict

Strategic vs. Tactical Data

- “Big data”
- Large focus
- Multiple or un-defined goals

- Specific focus
- Multiple but defined goals

Introduction to Remote Sensing

- Benefits
  - Safety
    - Collection from a stand-off
    - Steep gradient, traffic, hazardous materials or environment
  - Access
    - Over, under, through, within
  - Data density
    - “Quantify not qualify”
    - Apply numbers to observed phenomena
  - Digital format
  - Cost
- Drawbacks
  - Requires specialized operators and equipment
    - Field and processing
    - Processing data requires knowledge and experience
    - Specialized software
    - Large file size requires computing power
  - Cost
    - Field and processing
    - Reduced time onsite and processing limits or reverse impact

Introduction to Remote Sensing

- Advances in technology have made remote sensing more accessible
  - Optics and sensors
    - Increase sensitivity and resolution
  - Battery
    - Reduced weight and increased output
  - Computing power
    - Smaller devices, reduced weight
    - Ability to process large datasets faster
    - Accessibility
  - Communications
    - Wireless local communications
      - Increases range of systems
    - Advanced data networks
      - 5G
      - Starlink

Example Remote Sensing Methods

- LiDAR
- Imagery
- Multi-spec Imagery
- Chemical Analysis
- Geophysics

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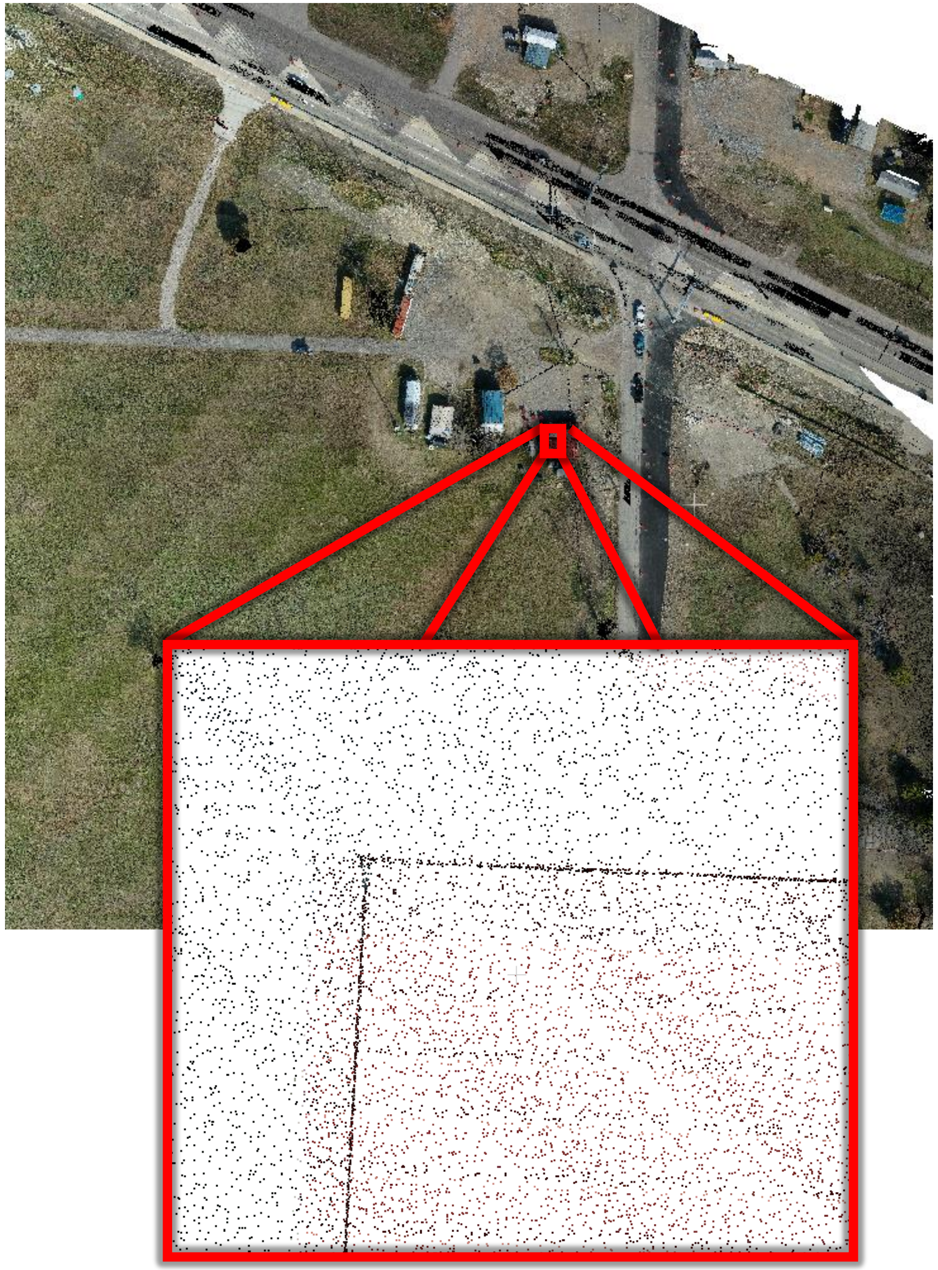
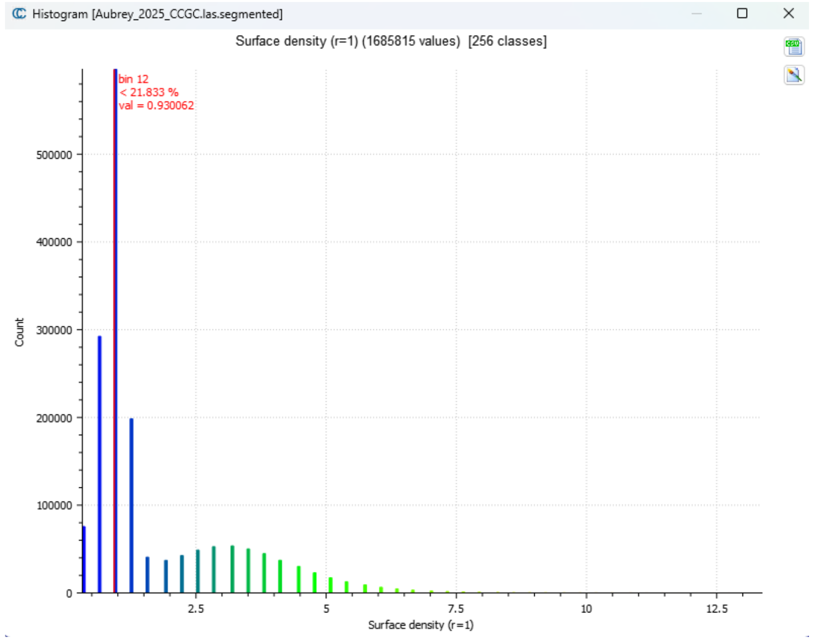
LiDAR

- Light Detection and Ranging (think RADAR)
  - Beam of photons is emitted and its two-way-travel time recorded
  - Known speed provides distance
  - Repeated millions of times per second
- Creates a “cloud” of points in 3D space
  - Create high-resolution 3D models of objects or areas
- LiDAR classification is a process where point data is assigned to a specific class, like vegetation, ground, buildings, etc.
- Terrestrial, aerial, mobile, SLAM
- Uses: Mapping of area, spaces and objects, spatial modeling, forensic engineering



LiDAR



Example of Aerial LiDAR (2025):

average of <1 point per square foot

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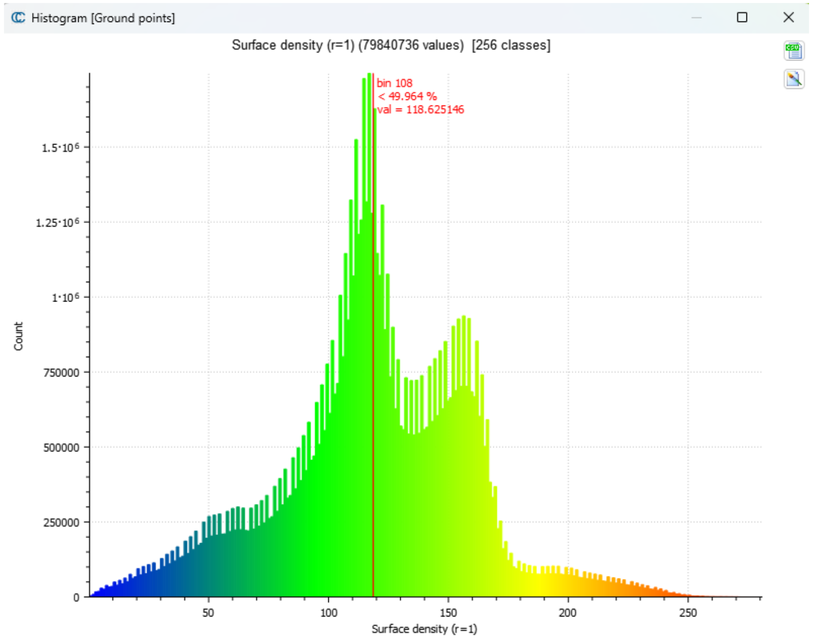
LiDAR

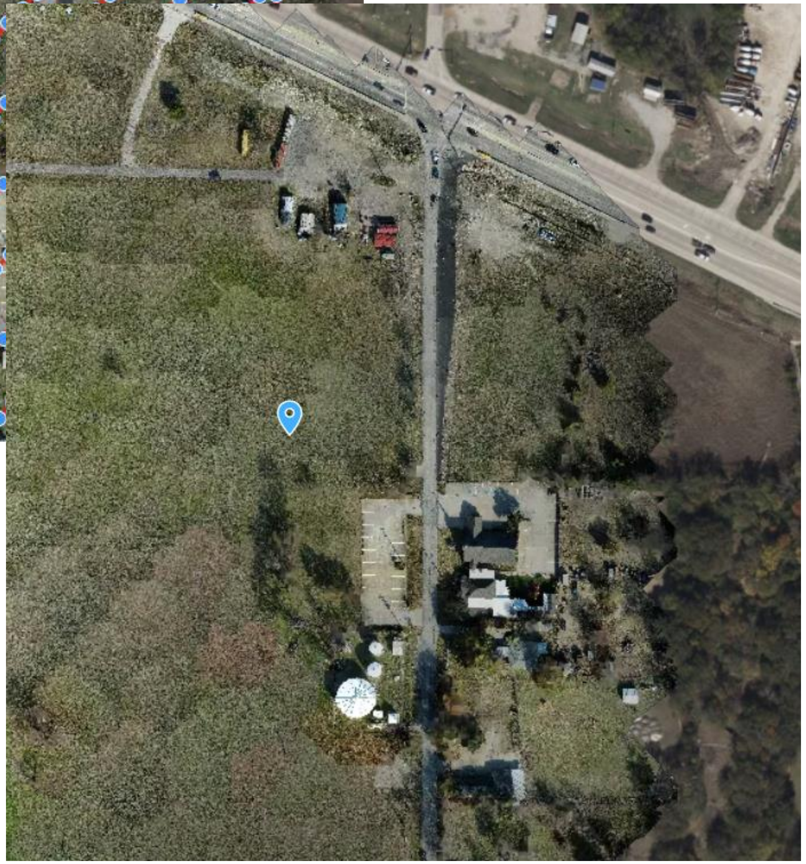


Example of sUAS LiDAR (2026):

average of 118 points per square foot

Imagery

- High-resolution photography
  - Passive remote sensing
  - R,G,B
  - Geo-located images
- Orthoimagery
  - Series of overlapping images
  - Merged to create a single image
  - Can be used to create 3D model
    - Gaussian splat imaging
- Uses: Mapping of areas, inspection, forensic engineering, asset management



Imagery

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Imagery

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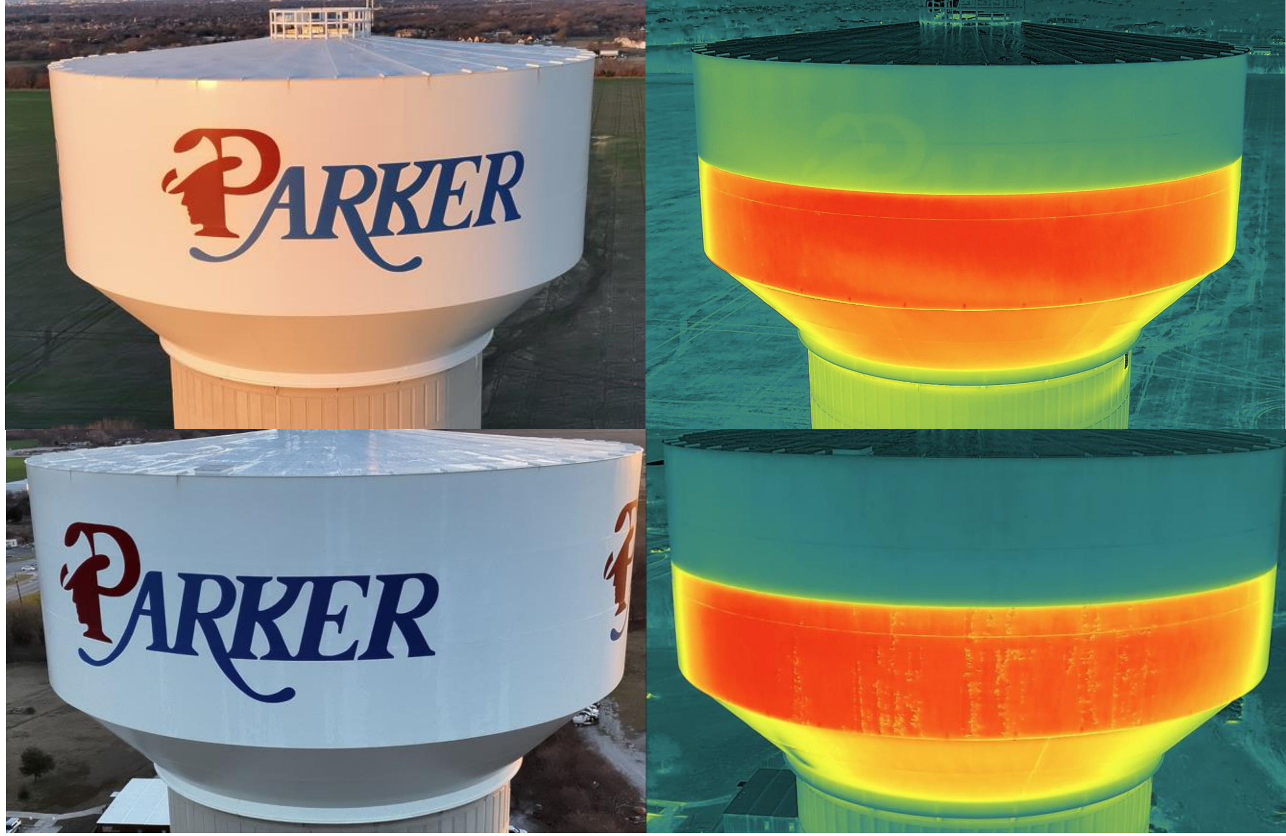
Imagery

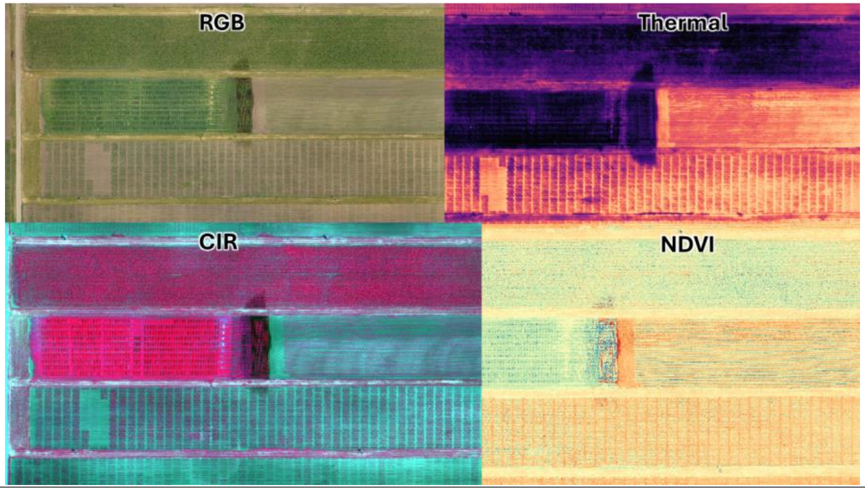
Imagery

Imagery

Multi-spec Imagery

- Passive collection of visual and beyond visual wavelength reflections
- IR
  - “Thermal” imaging
  - Showing variations in temperature
  - Relative vs absolute
- Multi-spec.
  - Collect individual wavelength
  - Beyond visual range
  - Can be combined and manipulated
- Uses: moisture identification and mapping, plume detection, plant health, spill identification





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Chemical Analysis

- Similar to standard field chemical detectors
- Tunable Diode Laser Absorption Spectroscopy (TDLAS)
  - Active system
  - Measure low concentrations
  - Integrated temperature measurements
  - Methane and Carbon Dioxide
- Optical Gas Imaging
  - Long Wave IR (LWIR)
    - Gas absorption of IR energy
  - Methane and other organic gases
  - EPA compliant
- Uses: leak detection, methane monitoring

Geophysics

- Records changes in the local electromagnetic response
  - Passive or induced
  - Magnetometer, GPR, bathymetry, resistivity, etc.
- Variation related to physical changes
  - Composition
  - Thickness
  - Orientations
- Infer surface and subsurface conditions
- Uses: exploration, object location, subsurface mapping

sUAS and Geospatial Databases

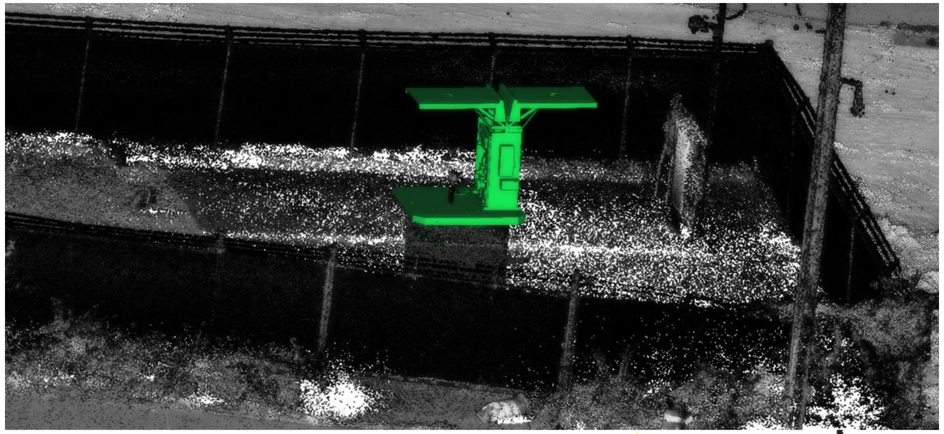
- Un-occupied systems
  - “Drones”
  - Air, land, water
  - Large and small
  - Power
    - Advanced batteries and alternative fuels
    - Larger payloads
    - More complex payloads
  - Duration
    - Increase collection
    - Increase in range and use
  - Systems are subject to governmental regulation
    - Part 108?
    - Federal
      - American Security Drone Act
      - “Blue Drones”
    - Region / local
      - Regulation of use OR operational restrictions
      - Private citizens

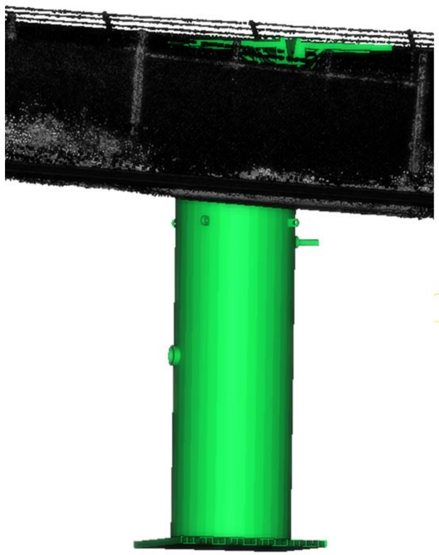
sUAS and Geospatial Databases

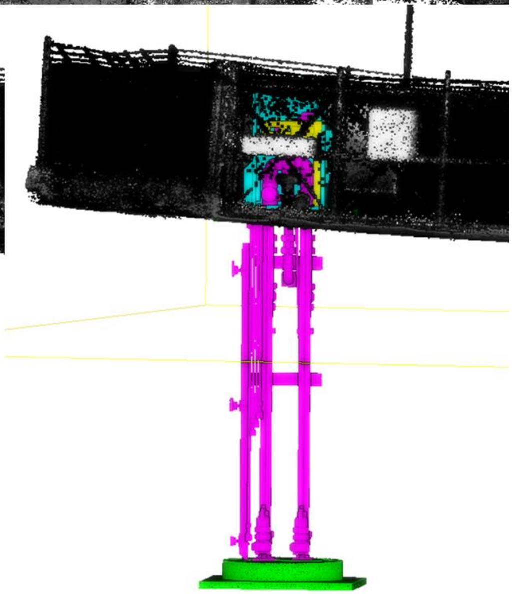
- Geodatabases and Remote Sensing
  - Remote data is spatial data
    - Digital format
    - Acceptable integration to GIS or BIM
  - Integrates into geodatabases
    - Allows multiple methods to be use
    - “layering”
      - Multi-spec + LiDAR
    - Independent confirmation
    - Provides associations with other data
  - Organization of temporal data
    - “4D” analysis
  - Useful for sharing and communicating data to stake-holders

sUAS and Geospatial Databases

- Geodatabases and Design Software
    - Design plans can be integrated into 3D data from remote sensing
        - Dense data to provide detailed information
    - CAD
        - Useful for larger areas
            - Alignments
            - Corridors
        - Provides base
            - Digitize features to create drawing
            - Surface creation
        - In product tools and specialized software for automation
    - BIM
        - Exterior and interior imaging
            - LiDAR or 3D imaging
        - Import to provide base
            - Automated "scan to model"
        - As-built or construction monitoring
        - Spectrum imaging to locate covered objects







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Integration

- New methods, same projects
  - Use data from remote sensing to conduct existing analysis
  - Generally faster collection
  - Higher resolution, more accurate data
  - Data integrates easier into spatial formats existing (GIS, BIM, CAD)
- Allow additional review of site
  - Expert does not need to be in field
  - Single dataset can be transferred to multiple people for different analysis types (no need to have two different specialist on the same site)
- Documentation
  - Record current conditions of site
  - Can be used as a “look back”
  - Missing data or holes can be easily identified and filled in
  - Information can be used in design phase
- Visualization of site
  - Striking imagery and models for Client
  - Annotation of model, “3D report”
  - Data can be transferred to Client for additional use or storage

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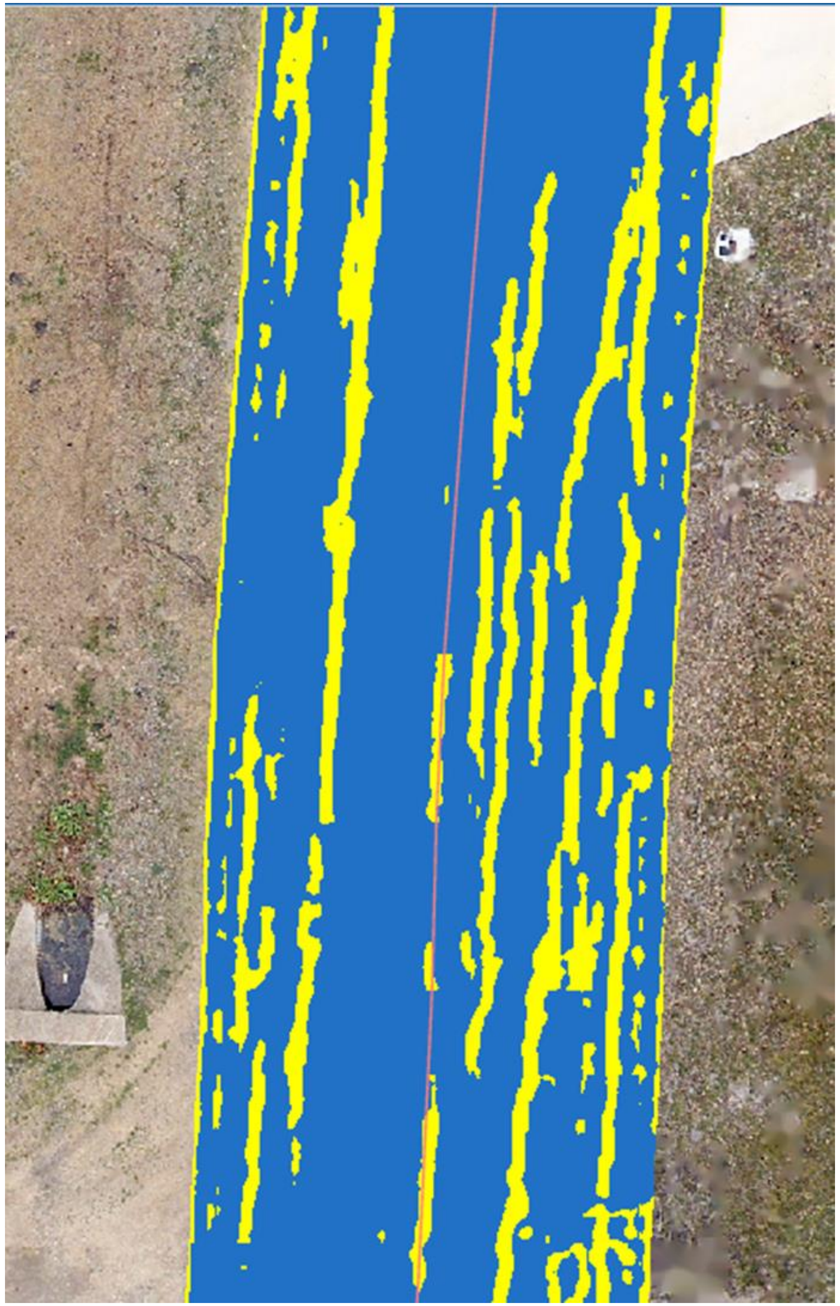
Integration

- Machine Learning and Artificial Intelligence
  - Advancement in computing power
    - Cloud computing
    - Open source
  - Uses algorithms to “think” like a human
    - Can increase efficiency by decreasing analysis time
  - Real world into digital format
    - How computers “see” the world
  - Requires training
    - Large training datasets
    - Time ($) investment
    - Quality of training directly impacts the results of the program
      - “Garbage in garbage out”
  - Regulation
    - Federal regulation is ongoing and likely fluid
    - Public perception



Integration

- Safety
  - Keeps works out of potentially hazardous environments
- Repeatability
  - More efficient for routine inspection or yearly monitoring
- Improved Access
  - Highly effective for getting close to inaccessible or remote locations to capture reconnaissance data
- Digital Format
  - Share a single data with multiple experts (bring field to the expert)
- Data Density
  - Can lead to more in-depth analytics

Case Studies and Discussions

Case Studies and Discussion

- Records and Geospatial Confirmation
  - Basic site imagery
    - Updated view of the site
    - Can be shared with team
  - Open sources not always accurate
- As-built Record
  - LiDAR and imagery of active construction site
    - Construction record not priority
  - Captured installation of assets
    - Collected data that would be needed for future work on the site
    - Can compare to data provided
- Site Drawing
  - Tree shown on older site drawing not seen on LiDAR derived update
  - Drafting team questioned
    - Using Google Earth and Drive
  - New LiDAR and imagery show removed
- Combination of Imagery and Geodatabase
  - Client provided database of assets with locations
  - Imagery collected
  - Update GIS and create more accurate locations of assets

Case Studies and Discussion

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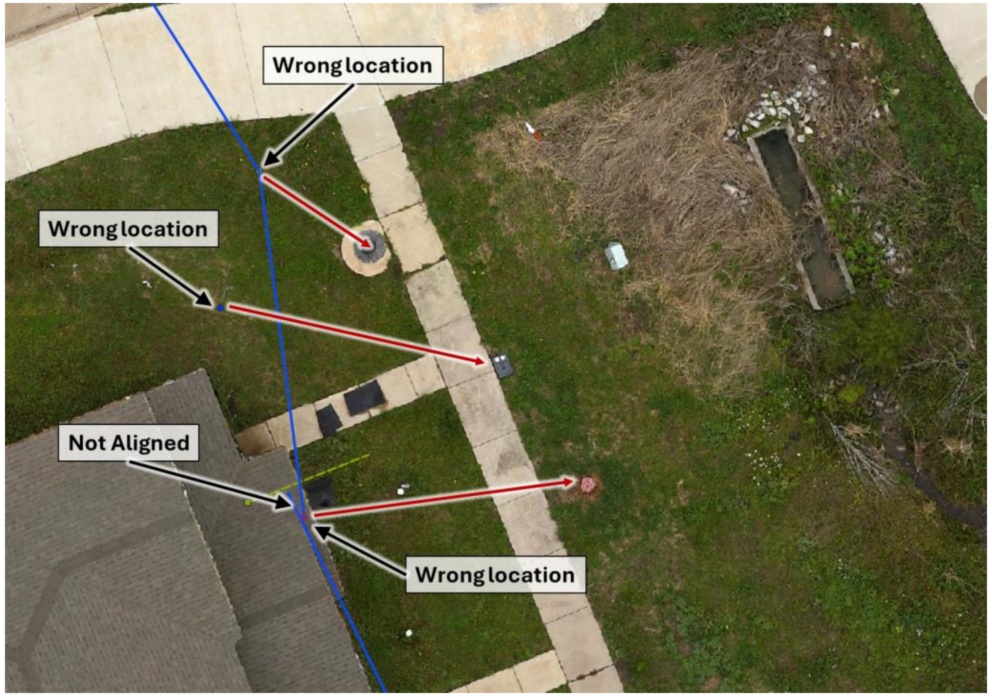
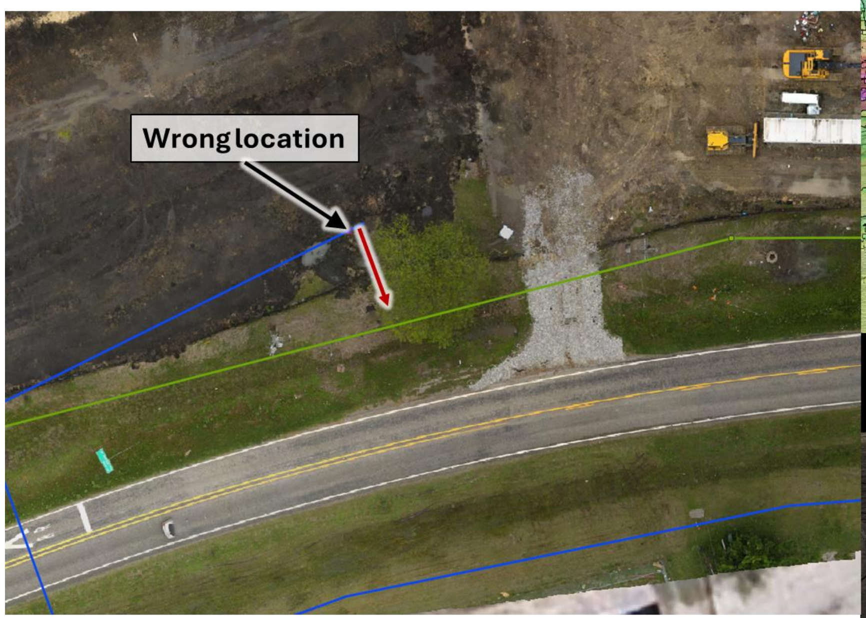
Case Studies and Discussion





Case Studies and Discussion

- Custom Transportation Asset Management Program
  - Developed a road condition rating system
    - Unlike PCI, focused on Client's needs
    - "Quantifying qualitative conditions"
  - Using sUAS data
    - sUAS is limited impact to community = more data collected
    - Improved perspective and spatial control
      - Ground level objects adjacent to road are collected
  - Integration of Machine Learning
- Process
  - Parameters
    - What elements are important to client on road condition
      - Centerline, slope, grade, potholes, ditch, markings, ruts, etc.
    - What is the preferred analysis unit (i.e. how many feet per road section)
    - Unit name (County designation or unique name)
    - Qualitative ranking
      - Good, fair, poor; or similar
      - Numeric
      - Summation, weighted, absolute
- Data collection and processing
  - sUAS LiDAR and imagery
  - Identify and classify features
    - Hybrid of spatial analytics, machine learning and human tasking
    - All features are individually tagged and geolocated
- GIS data model
  - Create a custom analysis model
    - Automates the rating process
    - Provides consistency across sites
  - Organize by data by date collected
    - Allows for "4D" analysis and understanding of evolution of asset
  - Post to online portal
    - Customizable dashboard for viewing results
- Review and modification
  - Modify for future needs
    - Client can direct changes in feature quantification methods as needed
    - "Living" program
  - Reclassify for new features
    - New features can be added
    - Integrate other assets features
      - Locations of fire hydrants, streetlamps, etc.
- Budget Calculator
  - Uses a customizable algorithm to rank road segments and prioritize repair
  - Coming soon
    - Late Q2 early Q3

Case Studies and Discussion

Asset Features and Rating Classes

Asset Features									
Feature	**Definition**	**Example**	**Rating Class**			**Application**			
			1	*2*	*3*		*good*	*fair*	*poor*
Pothole	non-linear, isolated, vertical variation, larger than 0.0900 sqm (1sqft)		depth of 0.0127m (0.5in) to 0.0254m (1in)	depth of +0.0254m (+1in) to 0.0508m (2in)	depth of +0.0580m (+2in)	function of % coverage of area and class	<5% area	5-10% area OR +1 class 2	>10% area OR +1 class 3
Linear Cracking	linear, isolated, surface variation over 0.6096m (2ft) long and 0.0254m (1in) width		0.6100-1.829m (+2-6ft) in length	1.8290-3.0480m (+6-10ft) in length	3.0480+m (+10ft) in length	function of total length and class	<3.5000 linear meters with no class 2	3.5000-6.5000 linear meters, <2 class 2	>6.5000 linear meters OR 3 class 2 or 1+ class 3
Pattern Cracking	linear surface variations appearing in association or pattern		<0.3710sqm (4sqft) in area	0.3710-1.000sqm (+4-10sqft) in area	>1.0000sqm (+10sqft) in area	function of % coverage of area and class	<2 class 1	<1.5000sqm (16sqft) OR 1 class 2	>1.5000sqm (16sqft) OR 2+ class2 OR 1+ class 3
Drainage	Analysis of road drainage basins from LiDAR data		not applicable			focus on flow along the road centre line or crossing the centre line	all flow is perpendicular to the road centre line	<25.0000m (82ft) of parallel to centre line flow in total	>25.0000m (82ft) of total parallel flow OR 1+ flow crossing centre line

Transportation Asset Condition Rating		
Good	***Fair***	***Poor***
All features are rated good	1-2 fair ratings on any feature	>2 fair ratings OR 1+ poor rating on any feature

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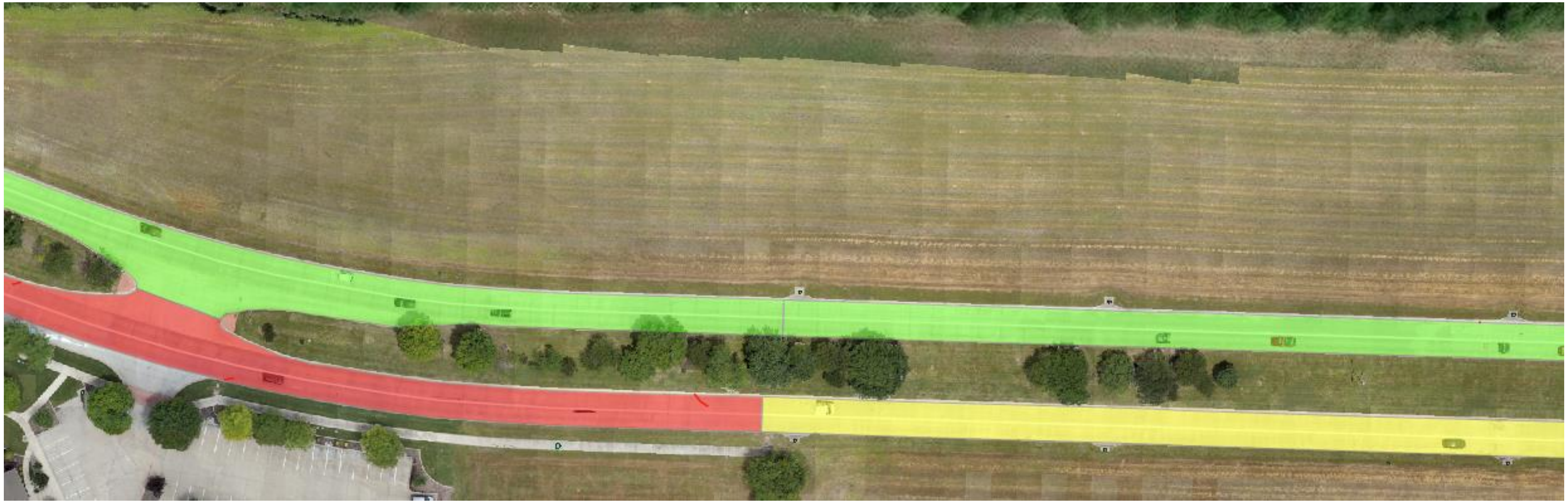

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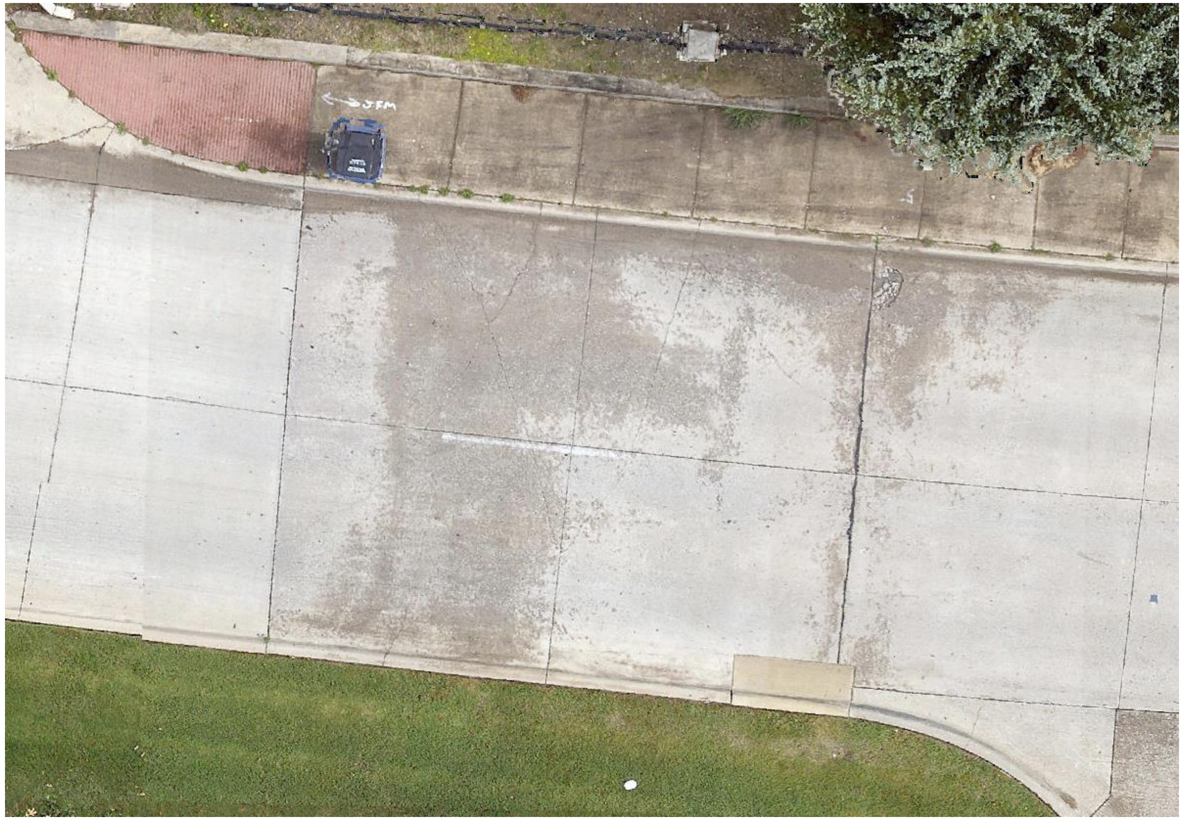

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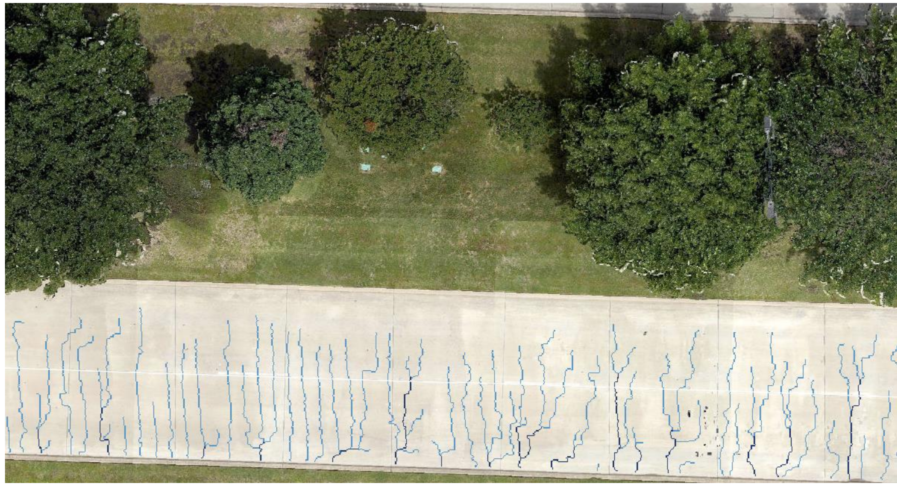

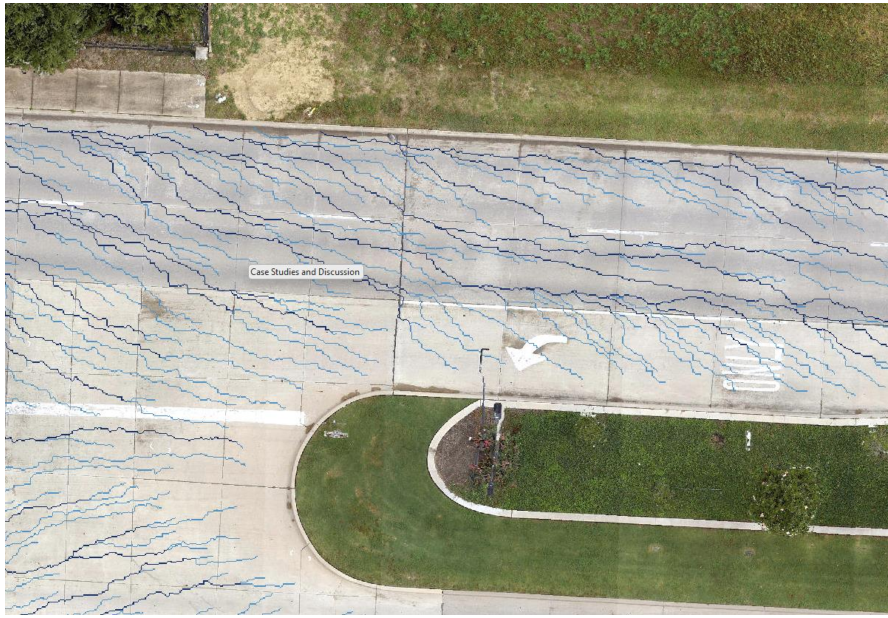

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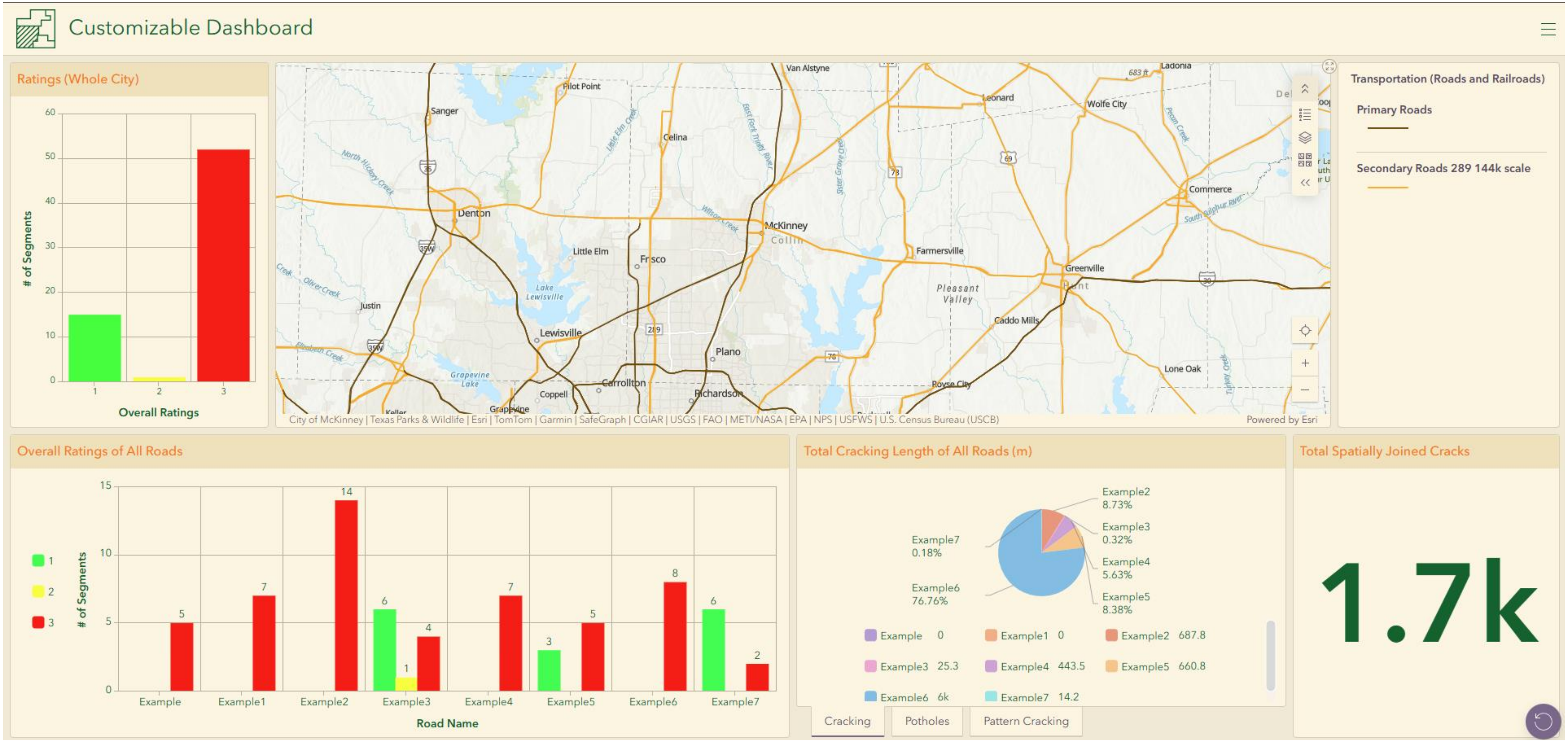

Case Studies and Discussion

- Model Integration
  - Points are points
  - Site planning
- Future EST Site
  - Site LiDAR and imagery collected
  - 3D design integrated into the site
  - Visualization of site prior to completion
- Construction Confirmation
  - Confirm grading plans (surfaces)
  - Verify object locations
- Multiple Collections
  - Monitor construction
  - Identify issues in early stages

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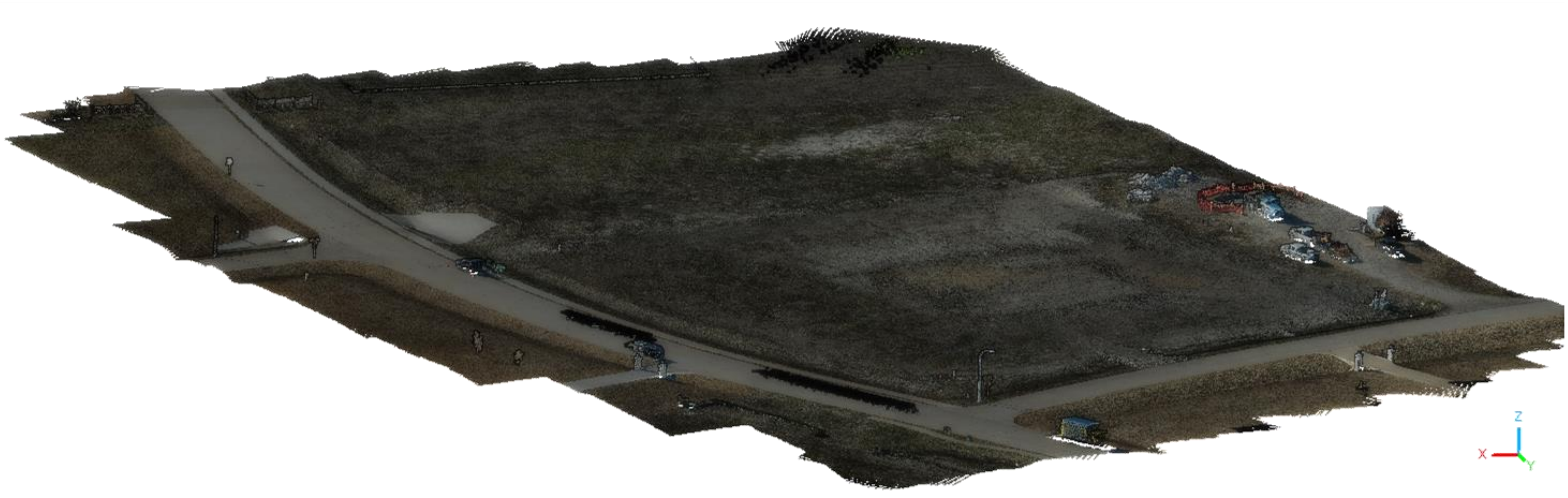
Case Studies and Discussion



Case Studies and Discussion

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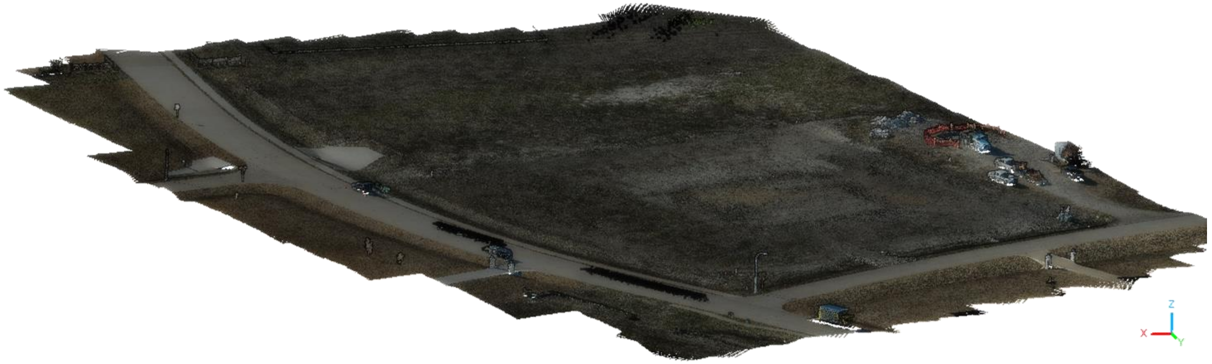
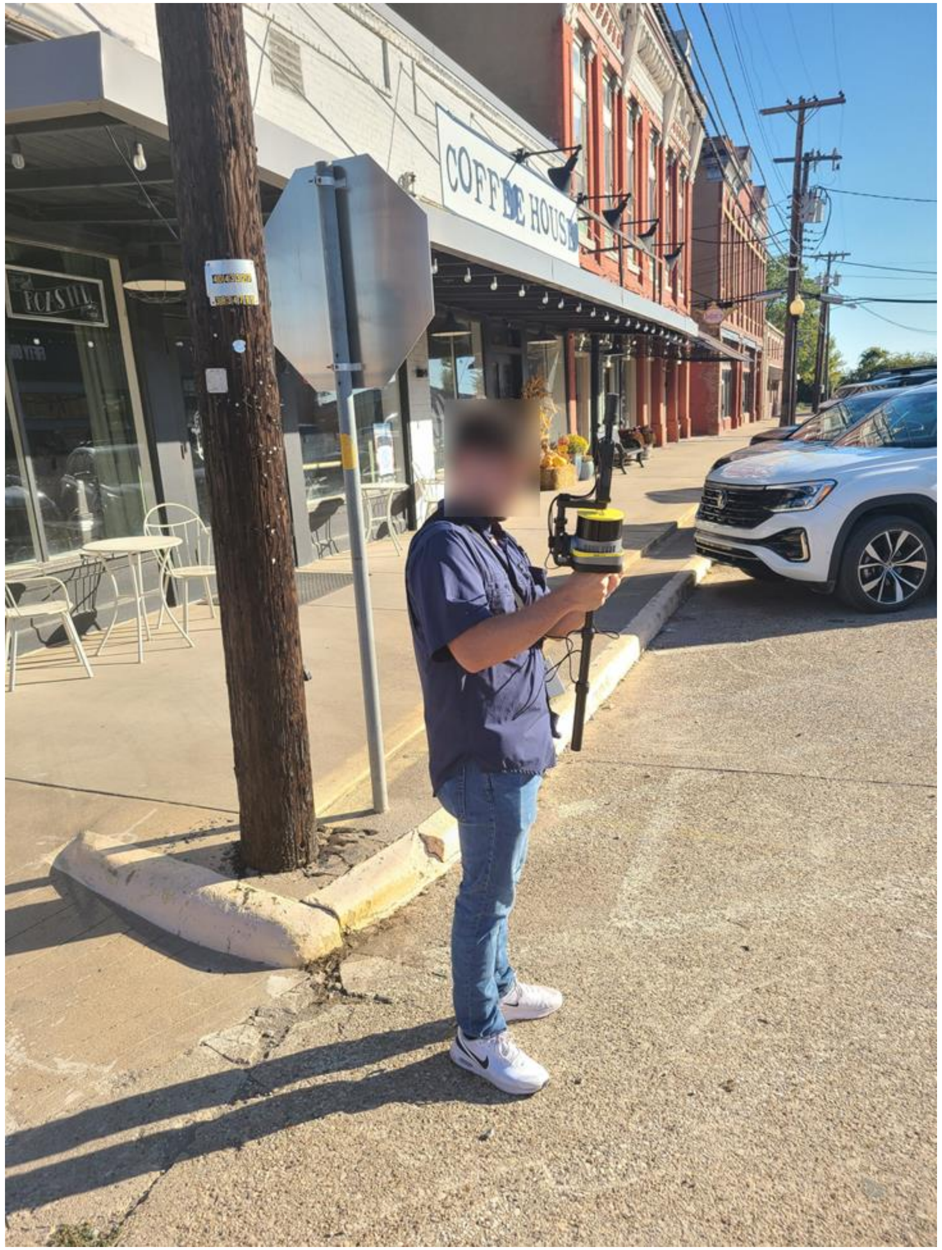


Case Studies and Discussion

- Hybrid LiDAR
  - Combination of sUAS and SLAM LiDAR
    - Same unit different modes
  - Complete record of site
    - Interior and exterior
- Elevated Storage Tank
  - Existing site
  - Mapping for site record and renovation
- Methodology
  - Exterior of site from sUAS
    - Tank exterior including top
  - Interior from SLAM
    - Start exterior to acquire GPS, move interior
  - Post processing to combine data
    - Use control points to link all scans
    - Provide wall thickness
    - Export to BIM



Case Studies and Discussion

Case Studies and Discussion

- Custom Wastewater Asset Management Program
  - Multimethod
    - Client provided GIS data
    - Aerial imagery and LiDAR
    - Remote sensing leak detection
    - Machine learning object recognition
  - Using sUAS data
    - Better view of ground level objects and features
    - Platform can host numerous sensing payloads
  - Increase robustness of GIS model
- Process
  - Initial data evaluation
    - Import Client GIS data
      - If it exist
    - Review maps and drawings
      - Digital plans or drawings (CAD)
      - Record drawing (paper)
      - Georeferenced data
- Data collection
  - sUAS LiDAR and imagery
  - Methane detection
    - sUAS based TDLAS
    - Map possible methane leaks from system
  - Thermal imaging
    - Leak detection
    - Both gas and near surface moisture
    - Best done in cooler seasons
- GIS data model
  - Machine learning object recognition
    - Identify features of interest
    - What is missing in initial data or wrong place
  - Remote sensing data
    - Correlate variations in data to locations of assets
- Review and modification
  - Modify GIS database to match real world locations
  - Identify potential leaks for physical investigation
  - Subsequent data collections can be incorporated creating an Asset Lifecyle timeline.

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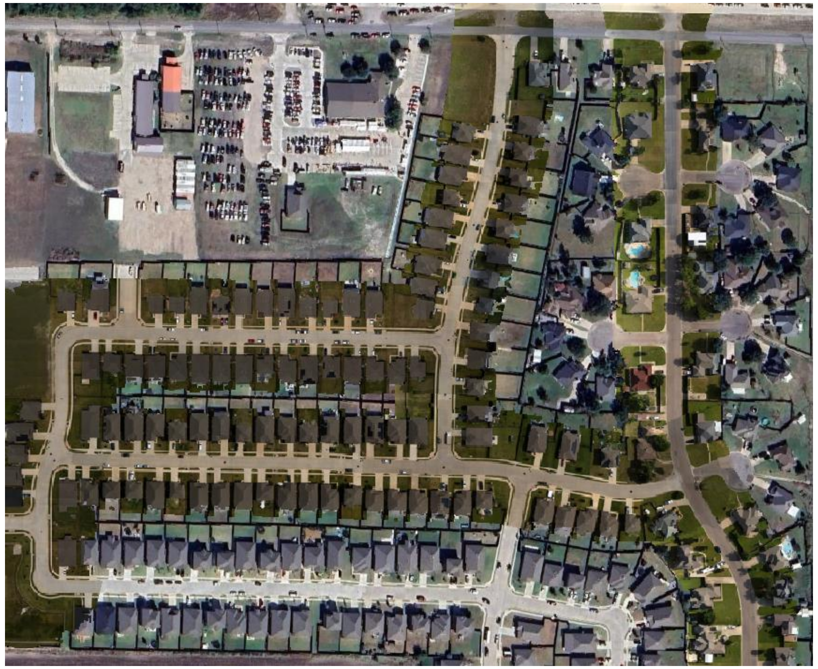
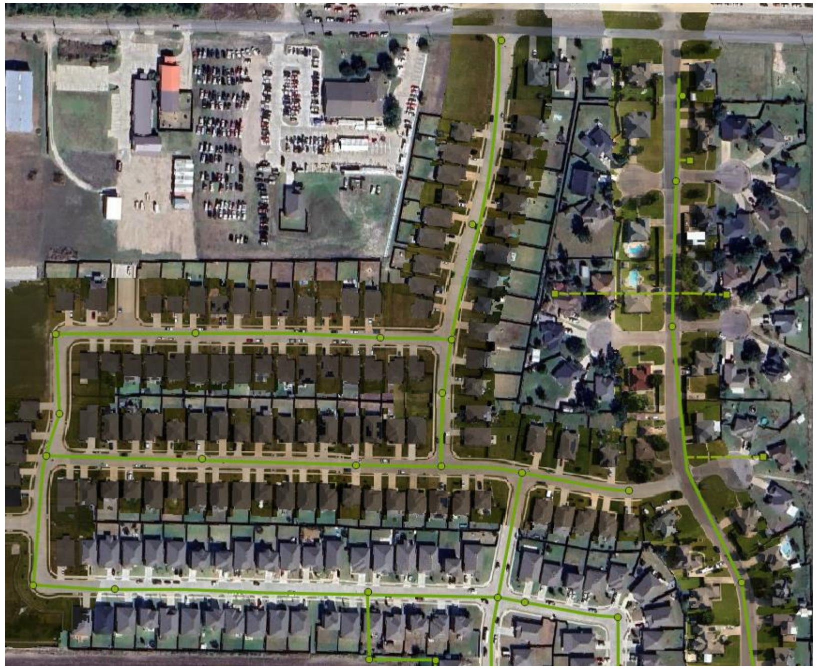
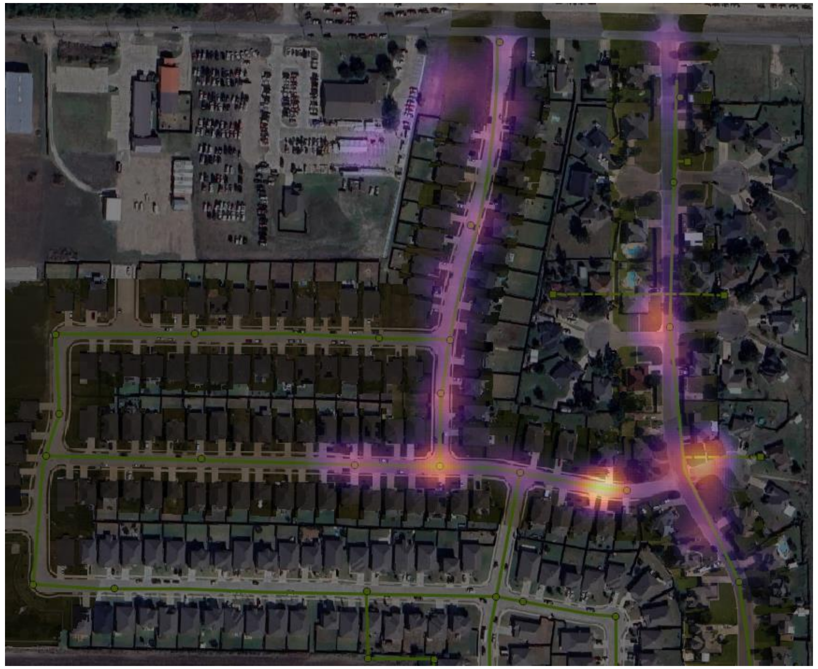
Case Studies and Discussion







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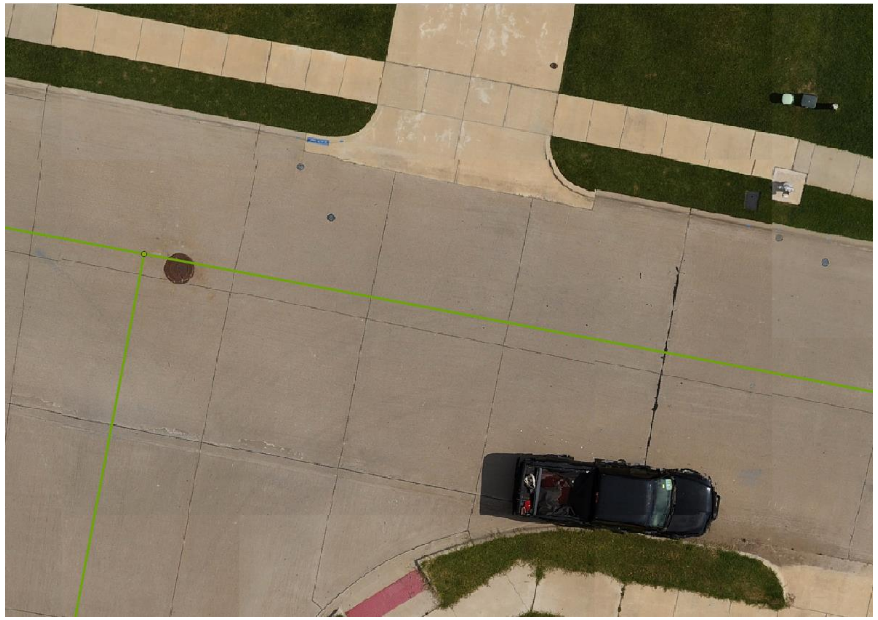

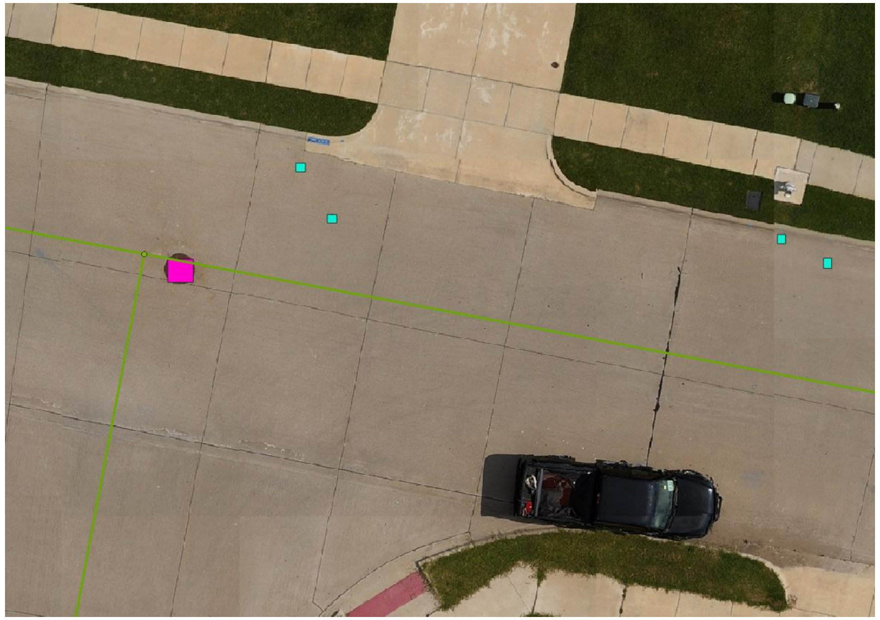

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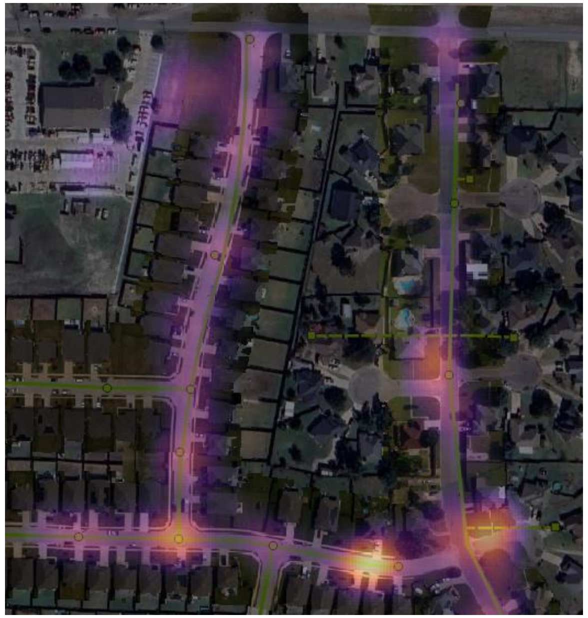

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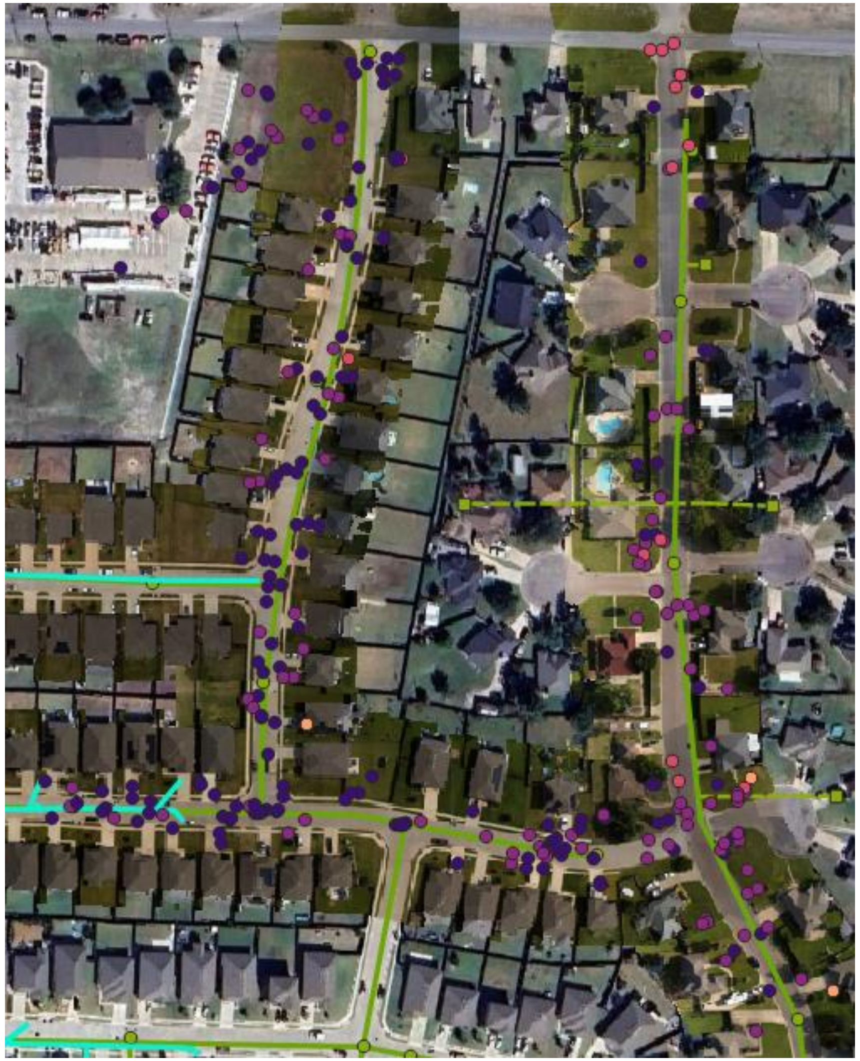

CH_4 ppm

- 0 - 68
- 68 - 136
- 136 - 205
- 205 - 273
- 273 - 341
- 341 - 409

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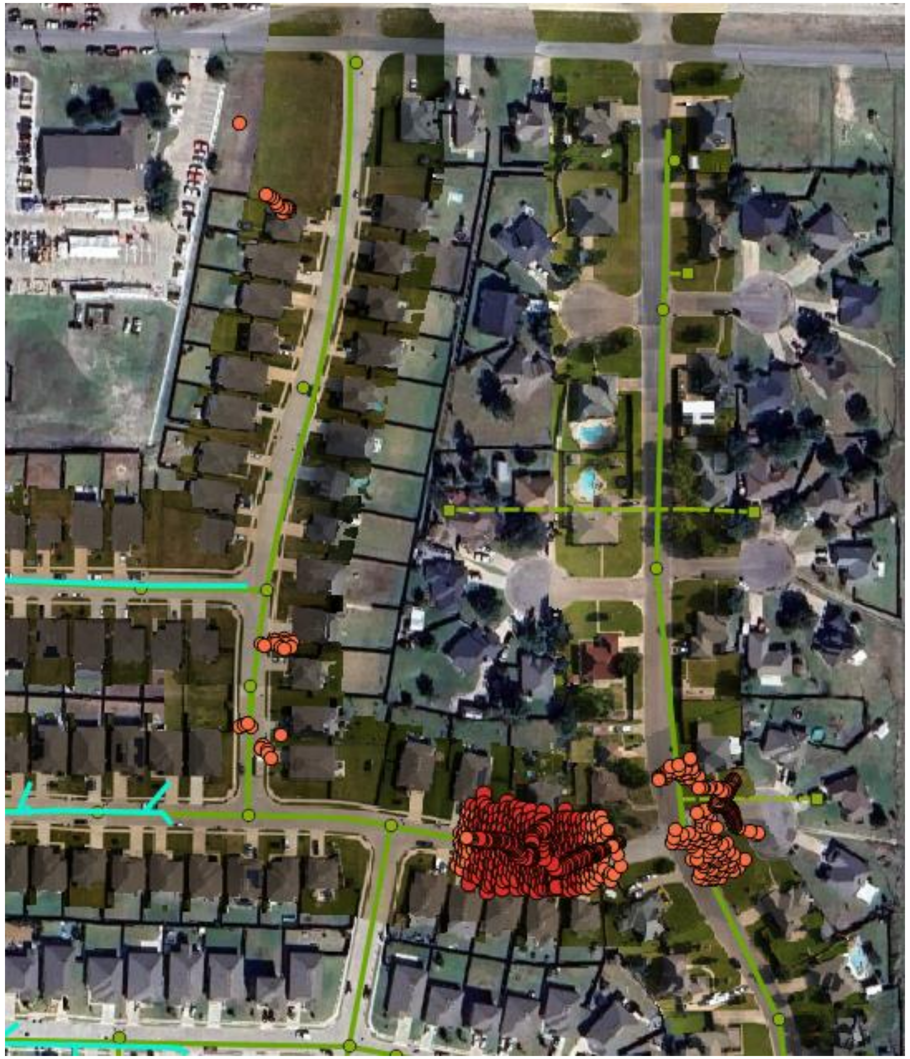
Case Studies and Discussion

Local Indicators of Spatial Association (LISA) Hotspot Analysis

Getis-Ord Gi*:
Cluster Identification



Local Moran's I:
Outlier Identification

Case Studies and Discussion

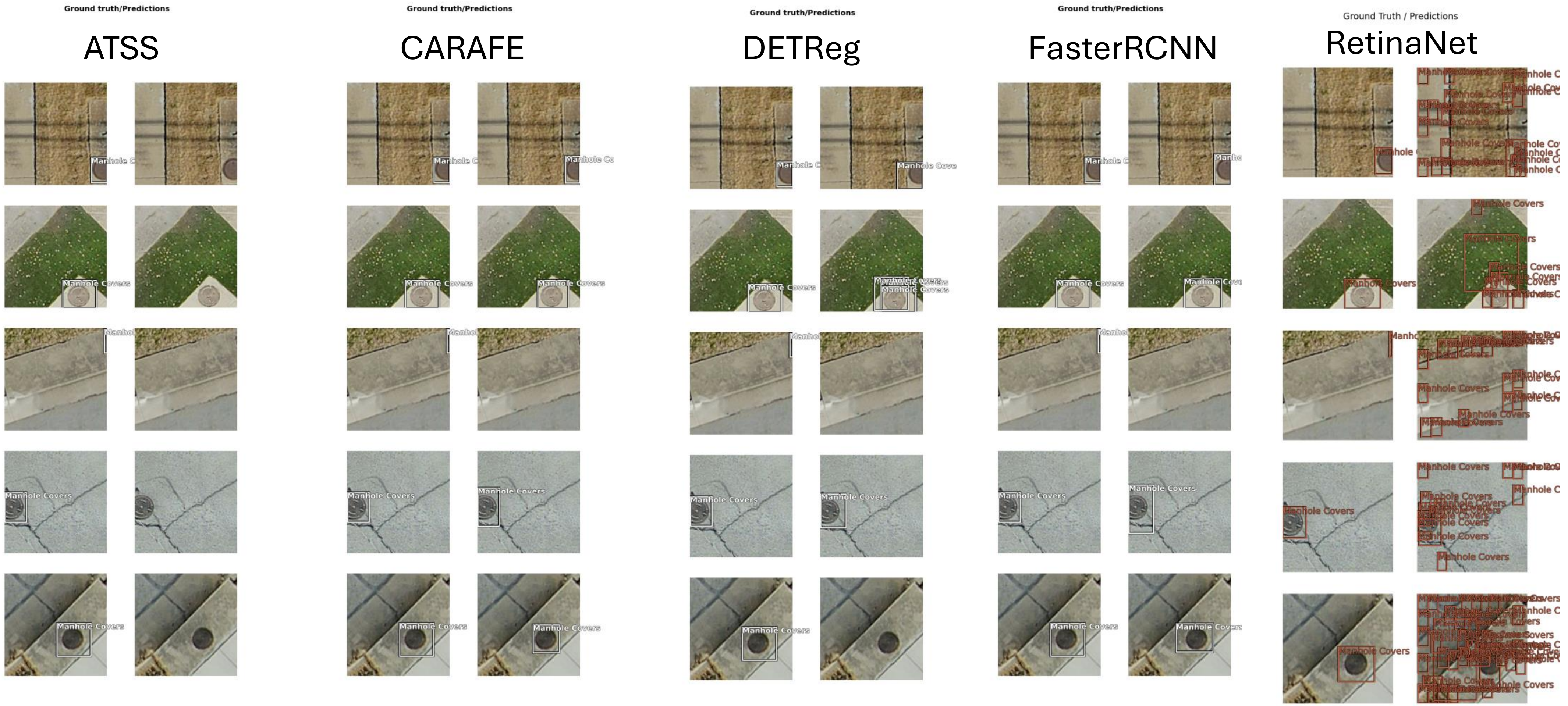
- Machine Learning Object Detection
  - Developed application
  - Using sUAS data collected from other projects
  - RGB imagery data
    - Other data types in “training”
- Process
  - Object selection
    - Target object selected based on needs
    - Best candidates are distinct and consistent
    - Must be visible at data resolution
  - Training data
    - Identify and isolate the object
      - Manual process
      - Number needed variable, typically 100+
    - Create training chips
    - Select ML method
    - Run method and review model scores
  - Reinforcement
    - Run model on other data
    - Highlight misses and remove false positives
    - Re-run model
  - Advancements
    - As more data is collected and classified, the model is improved
- Current custom objects
  - “Pre-trained” models
    - Many available
    - Shown to be ineffective in practice
  - Manholes
  - Water valves
  - Water meters
    - In reinforcement phase
  - Roof Top HVAC
    - In reinforcement phase
    - See below
- “Human in the loop”
  - All AI data is reviewed by a human
  - Tool to improve productivity, not replace evaluation
- Future custom objects
  - Fire hydrants
  - Utility markings and flags
  - Hybrid analysis
    - Use false color
    - Integrate GIS data for analysis
  - Suggestions?

Case Studies and Discussion

Object Identification

Training "Chips"

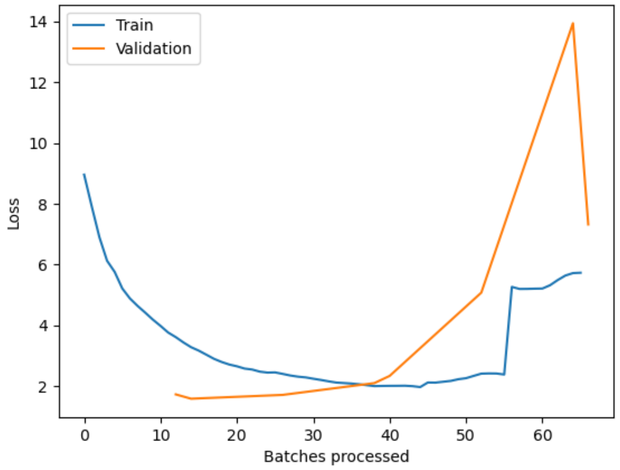
Case Studies and Discussion



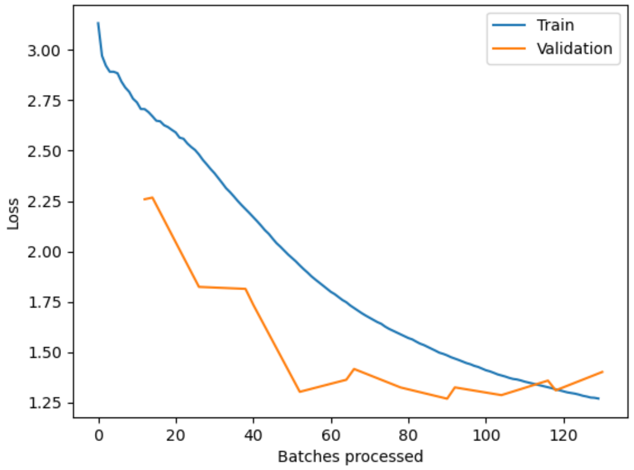
We run automatic functions for extended periods of time to compare different model architectures against one another to find the best fit.

Case Studies and Discussion

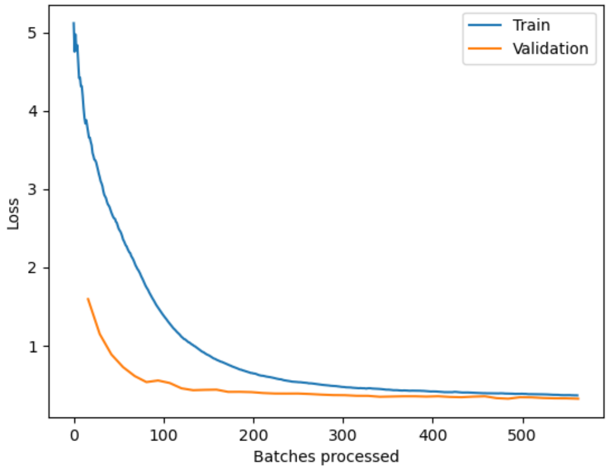
ResNet18



ResNet34



ResNet50



First graph shows initial learning, the second graph shows the model starting to learn but converges and overlaps, the third graph both the training and validation curves decrease smoothly and asymptotically, it demonstrates stable optimization, proper generalization, and excellent convergence.

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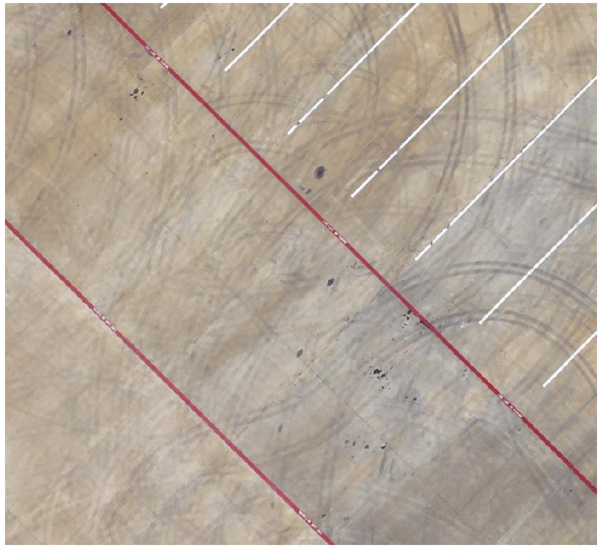
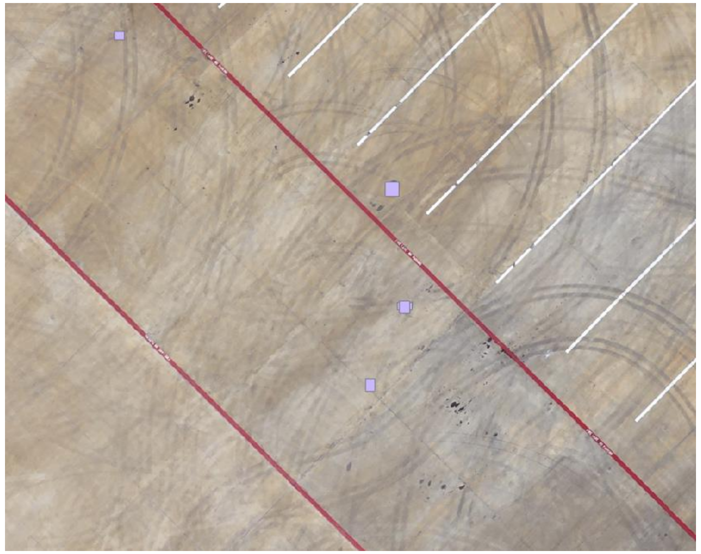
Case Studies and Discussion





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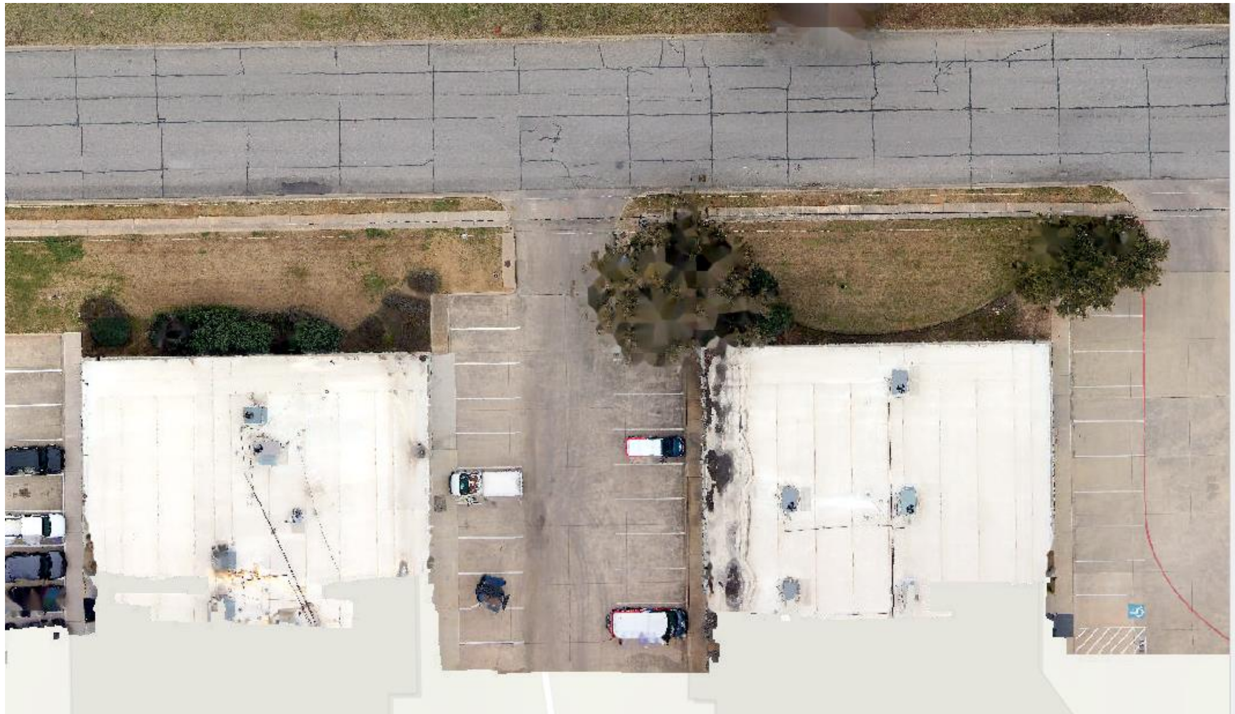
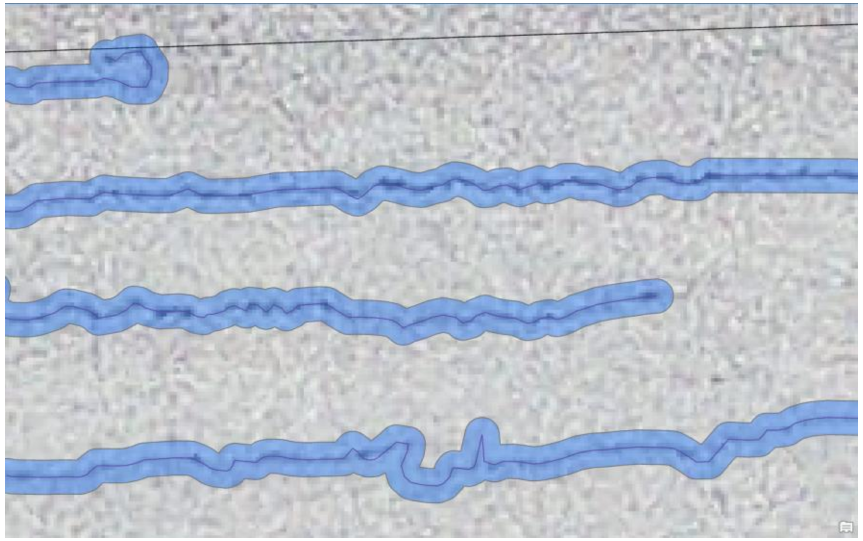
Case Studies and Discussion



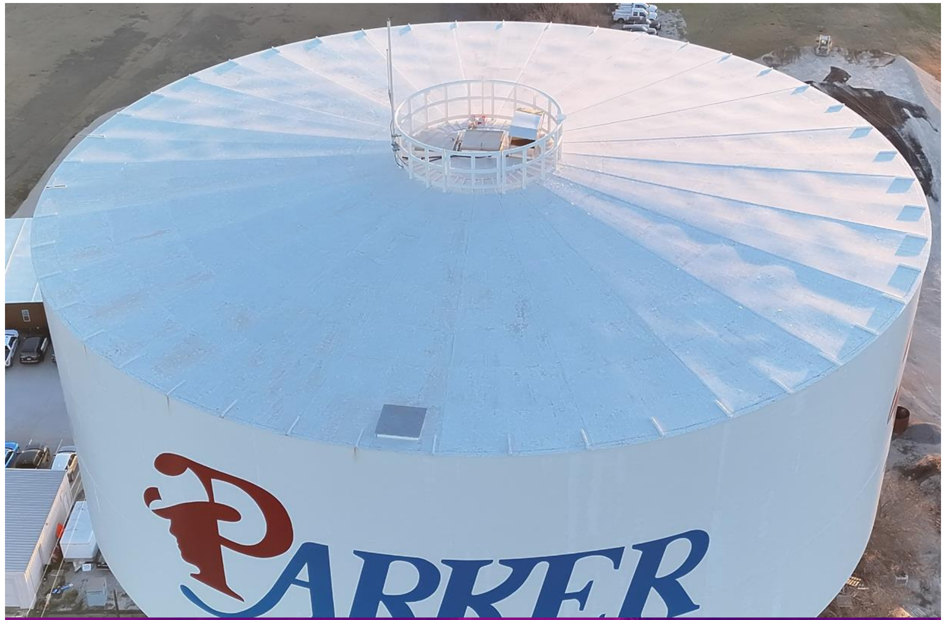
Machine Learning

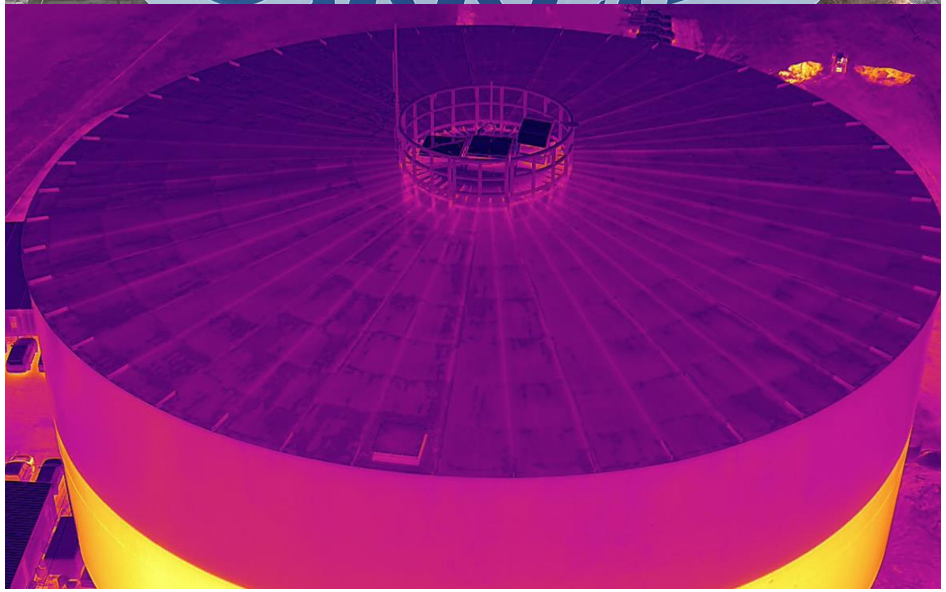


Case Studies and Discussion

Case Studies and Discussion

- Elevated Storage Tank Inspection
  - IR imaging
  - LiDAR model
  - sUAS based
    - Access and inspect from the ground
    - Elevated portion accessible (roof)
  - Multi-spectrum imaging coming in 2026!
- Infrared Imaging
  - "Thermal", temperature variations
  - Water level visible
  - Variations
    - Leaks
    - Coating issues
- LiDAR Model
  - General baseline
  - Determine physical variations





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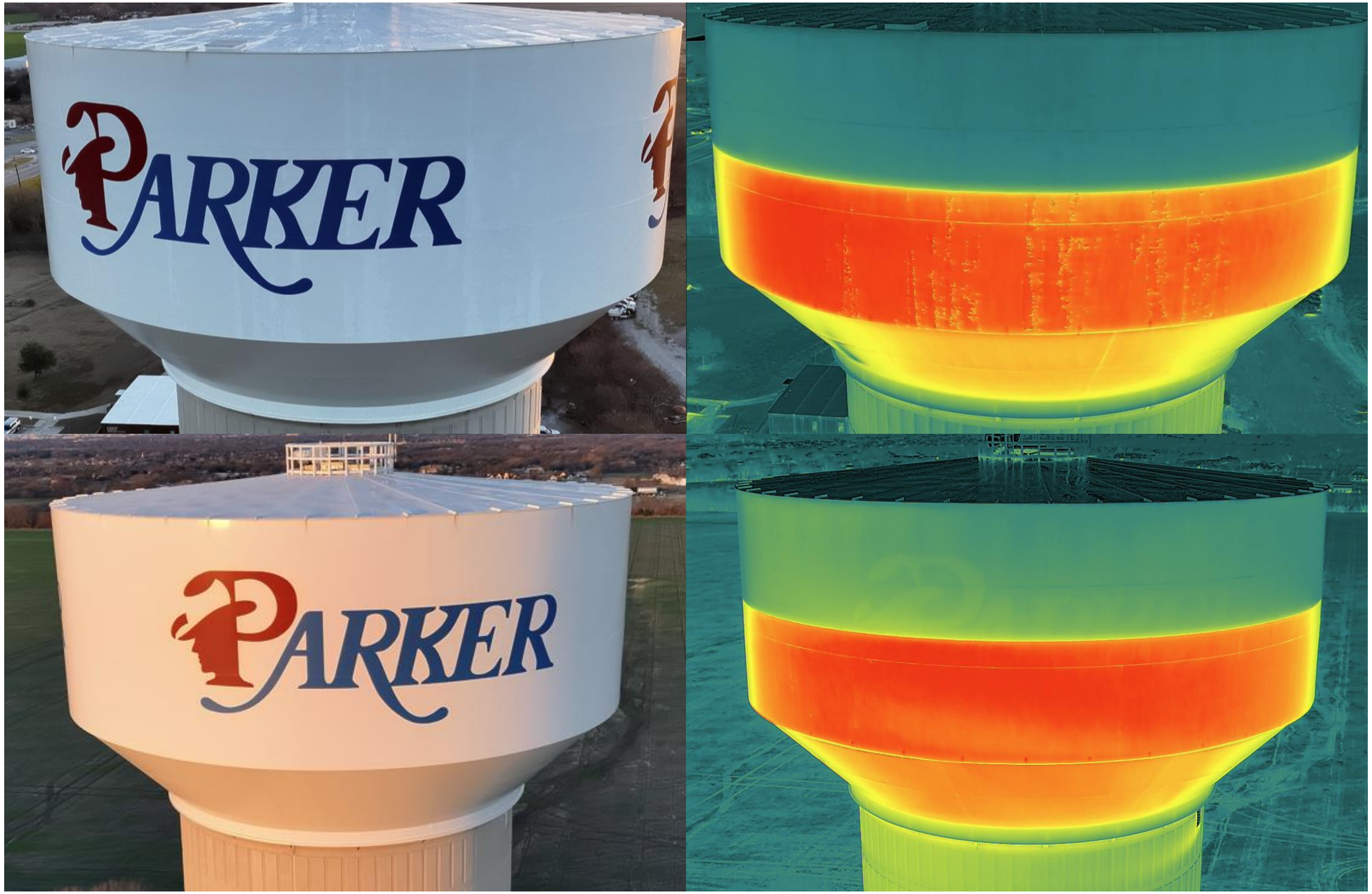
Case Studies and Discussion



Case Studies and Discussion

- Brick Wall Investigation
  - Identify deformation in a brick wall
    - Locations where leaning or "out of plumb"
  - Used data from an existing collection
    - Not initially part of study
    - Single dataset for multiple purposes
  - Can be done on any surface
- Process
  - Data collection
  - LiDAR data model
    - Isolate object of interest
    - Assign reference model
      - 3D design model
      - Simple plane or surface
    - Cloud to Mesh
  - Review and modification
    - Can be done multiple times to track rates of deformation or quality of repair

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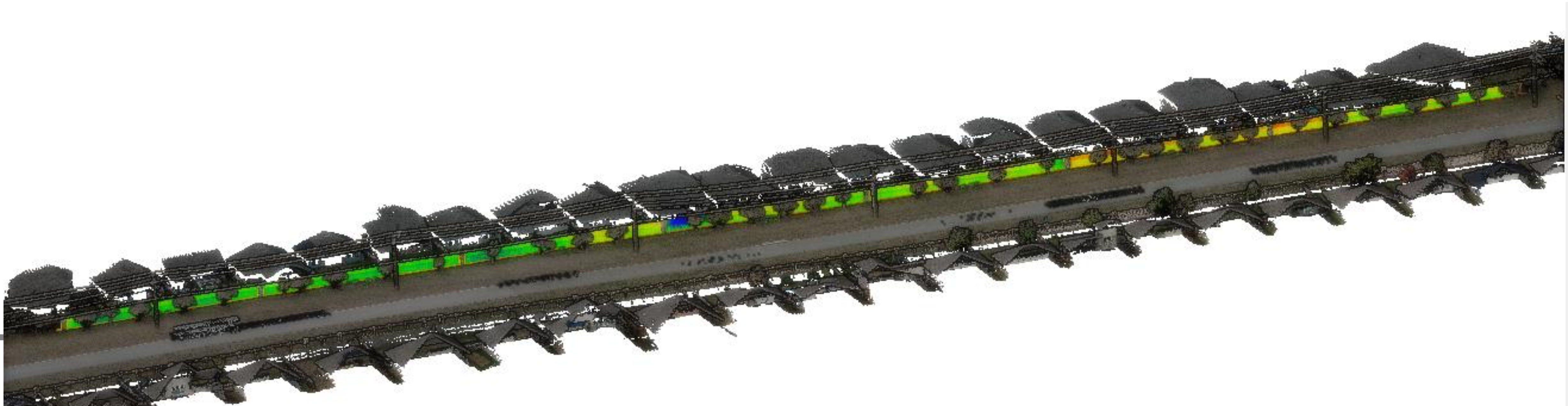
Case Studies and Discussion



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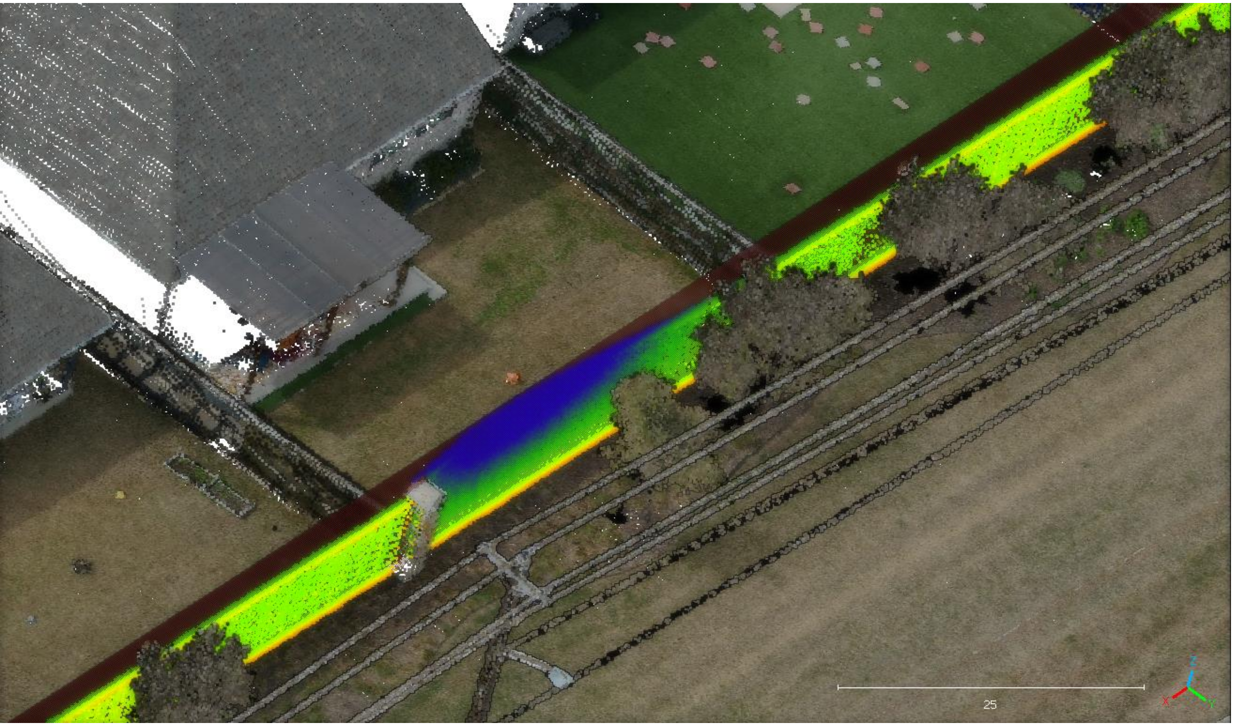
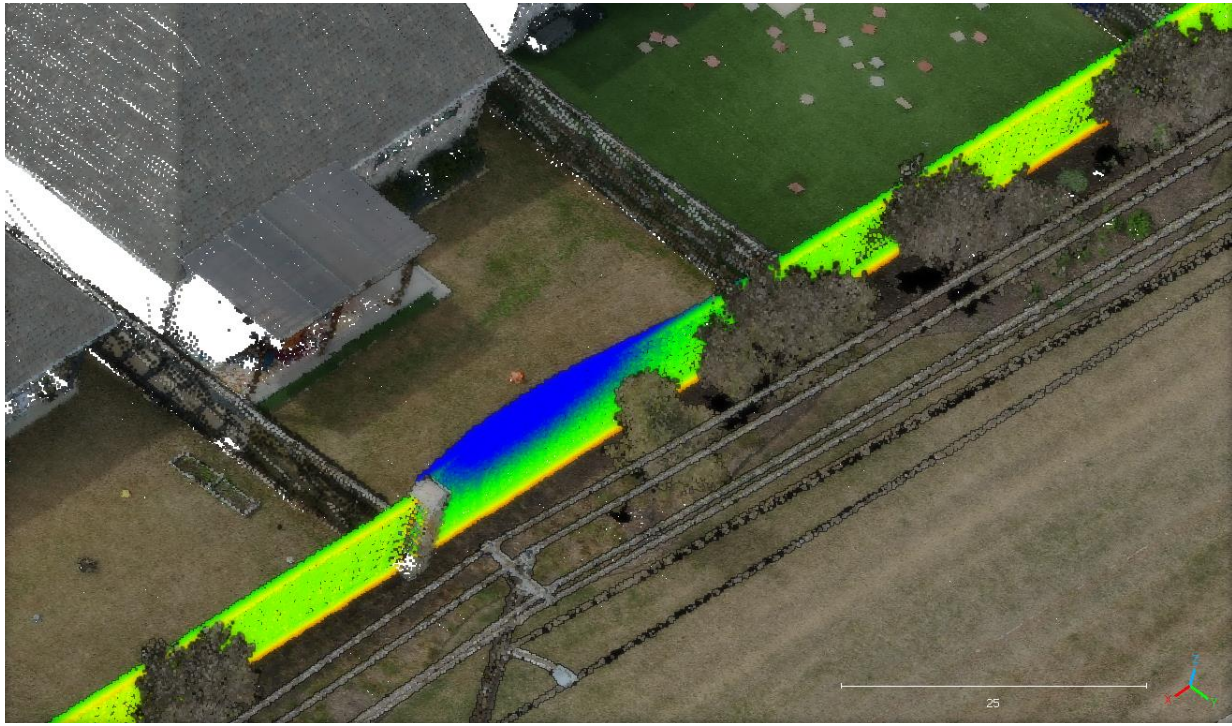
Case Studies and Discussion





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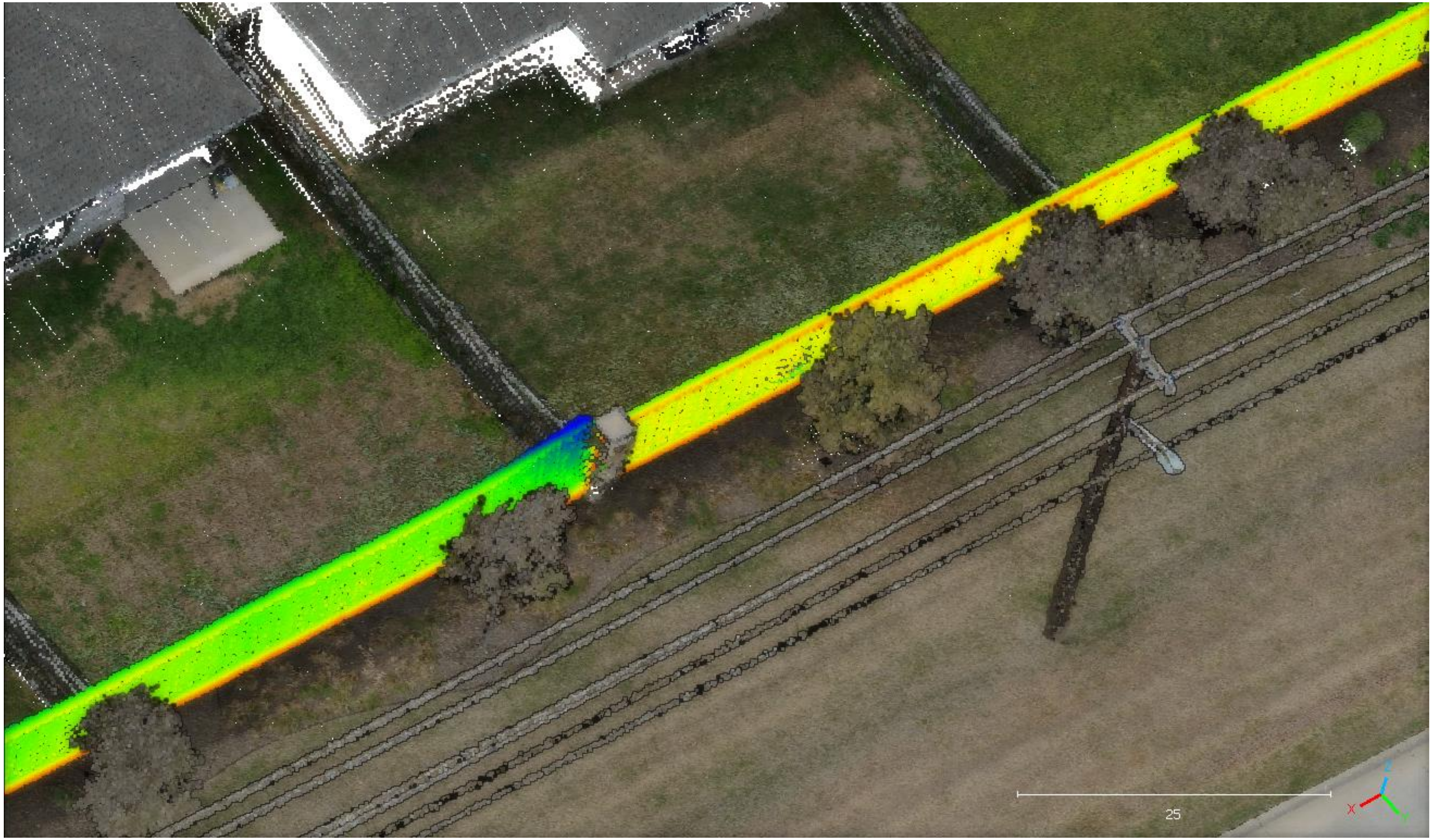
Case Studies and Discussion



Case Studies and Discussion

- Drainage Study
  - Using sUAS LiDAR
  - Data originally for construction
- Complaint of flooding during high rain
- Data used to locate culverts to divert water

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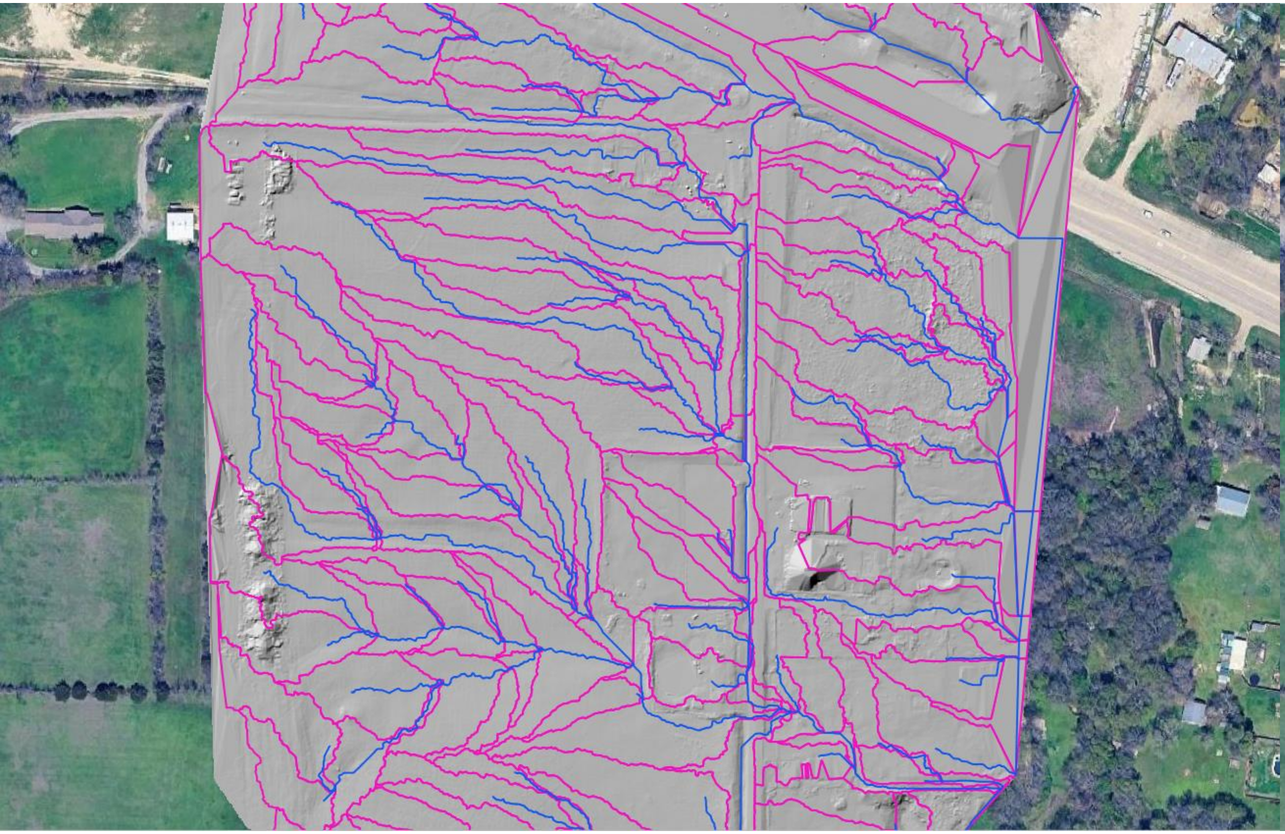
Case Studies and Discussion



Questions

At BHC we take technology from interesting to innovative through informed application.

Questions

ON THE FIRM OF THE FUTURE

"Engineering firms in the future won't be engineering firms—they will be technology firms that offer engineering consultancy services."

Michael Giacco, VP at AI Engineers, Inc.

ACEC Research Institute. (2026). *Redefining the firm: Talent, technology and transformation*. American Council of Engineering Companies. https://www.acec.org/resource/redefining-the-firm-talent-tech-transformation/