TxDOT UAS Aerial Mapping Specifications and Workflow for Design-Grade Mapping Applications

Gorrondona & Associates, Inc. – Scott Dunham, CP, CMS Lidar
TxDOT Design Division Remote Sensing Services Section

June 2025

Contents

This manual is intended to guide users on Unmanned Aircraft System (UAS) sensor technology requirements and workflows to provide American Society of Photogrammetry and Remote Sensing (ASPRS) Class 1 UAS aerial mapping. All UAS operations provided for TxDOT shall be in accordance with the TxDOT UAS Flight Operations and User's Manual. Please refer to the Unmanned Aircraft System (UAS) Flight Operations and User's Manual, April 1, 2023, which describes safe operation of UAS in compliance with all local, state, and federal regulations on all TxDOT projects. Adherence to the policies, rules, and regulations contained within this manual are mandatory on all TxDOT UAS projects. All UAS projects performed for TxDOT must follow the Traffic Control Plan (TCP) for Survey Operations, found in the Surveyors' Toolkit.

TxDOT describes UAS as a tool used to collect qualitative (i.e., visual) and quantitative (i.e., metric) data. The role of UAS is similar to other tools used to collect these same types of data: the Global Positioning System (GPS), Light Detection and Ranging (Lidar), RADAR, Sonar, optical surveying equipment, and close-range/vertical photogrammetry.

The Texas Department of Information Resources (DIR), has developed a plan providing state agencies guidance on managing personal devices used to conduct state business, titled Covered Applications and Prohibitive Technologies. TxDOT consultants must follow this DIR policy to ensure that the UAS manufacturer, developer, software, etc. is not listed as a prohibited technology. The DIR policy is a "living document" and DIR may add and remove technologies at any time.

UAS Components

Below are common UAS system components:

- **Flight controller**: The combination of embedded software on computing hardware, that issues commands to actuators based on the difference between the desired and actual position of a UAS.
- **Radio:** A device that enables communication by packaging, transmitting, and/or receiving modulated signals into or from electromagnetic waves in the radio frequency (RF) spectrum.
- **Data transmission device:** Electronic hardware that actively transfers electronic information from one digital system to another.
- **Camera:** A device that converts focused light onto a photosensitive sensor for the purpose of recording or transmitting visual images in the form of photographs, film, or video signals.
- **Lidar:** (NOAA Definition) is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.
- **Gimbal:** A mechanism, typically consisting of electromechanical actuators and a mechanical frame, which rotates about one or more axes to stabilize and properly orient cameras or other sensors.
- **Ground control system:** An electronic mechanism that enables a human operator to transmit data in order to influence the actions of an aerial vehicle remotely.

- **Data storage:** The collective methods and technologies that capture and retain digital information on electromagnetic, optical, or silicon-based storage media.

UAS Data Accuracy Standard

As stated in the TxDOT Photogrammetry Guide, prior to delivery, the geospatial data provider is responsible for testing and verifying that the data meets horizontal and vertical requirements including an evaluation of statistical parameters such as the kurtosis, skew, and mean error, as well as the removal of systematic errors or biases. TxDOT mapping must meet the American Society of Photogrammetry and Remote Sensing (ASPRS) Class I Map Accuracy Specifications. ASPRS Class I, the highest vertical accuracy class, is most appropriate for local accuracy determinations and tested relative to a local coordinate system, rather than network accuracy relative to a national geodetic network, as stated in the ASPRS Accuracy Standards for Digital Geospatial Data document.

Aerial Photography Accuracy Requirements

Aerial Photography accuracies are as follows:

- Hard Surfaces:
  - Vertical $RMSE_V$ accuracy of +/- 0.167-ft.
- Soft Surfaces:
  - Vertical $RMSE_V$ accuracy of +/- 0.33-ft.
- Refer to the established TxDOT Photogrammetry Guide provided in the TxDOT Surveyors' Toolkit.

Airborne Lidar Accuracy Requirements

Aerial Photography accuracies are as follows:

- Hard Surfaces:
  - Vertical $RMSE_V$ accuracy of +/- 0.15-ft.
- Soft Surfaces:
  - Vertical $RMSE_V$ accuracy of +/- 0.33-ft.
- Refer to the draft TxDOT Airborne Lidar Specifications and Workflow for TxDOT Design-Grade Mapping.

According to the ASPRS, horizontal accuracy is to be assessed using root-mean-square-error (RMSE) statistics in the horizontal plane, i.e., RMSEx, RMSEy and RMSEr. Vertical accuracy, however, is to be assessed in the z dimension only.

UAS Project Requirements

- An RPLS, ASPRS Certified Photogrammetrist, ASPRS Certified Mapping Scientist – UAS, or ASPRS Certified Mapping Scientist—Lidar must be precertified for TxDOT work categories 15.3.1 Aerial Photogrammetry and 15.3.6 Airborne Lidar, are required for overseeing TxDOT UAS aerial mapping projects.
- All required TxDOT UAS Flight Operations forms are provided at the TxDOT Unmanned Aircraft System (UAS) Services website.
- A flight plan providing information about the proposed flight.
  - Submit flight plans at the UAS Flight Plan TxDOT webpage.
- A Project Risk Assessment (PRA) completed prior to the flight.
- Appropriate liability insurance.
- Depending on the project, pre-approval from the TxDOT UAS Coordinator may be required prior to any flight operations.
- Any correspondence other than flight plans and pre-approval forms should be directed to the UAS Coordinator at https://www.txdot.gov/business/aviation/uas-services.html.
- For projects with risk factors, the UAS Coordinator will review the Flight Approval Request Form along with the flight planning data. The UAS Coordinator may consult with subject matter experts to determine if a flight operation should be approved. If the flight operation is approved, the UAS Coordinator will inform the flight planner by email with an attached copy of the signed approved request form.
- If the flight operation is not approved, the TxDOT UAS Coordinator will inform the flight planner of the specific deficiency. Depending on the deficiency, the flight planner may have an opportunity to revise the flight plan and submit a revised request for reconsideration. However, UAS users should be aware that certain flight operations may never be approved based on risk.
- Failure to perform the risk assessment, prepare the flight plan, or comply with the decision of the UAS Coordinator may result in discipline up to and including termination of employment.
- Airborne Lidar should also be performed along with aerial photogrammetry. TxDOT current point density requirements do not allow for effective 2D planimetric compilation from the Lidar point cloud. Aerial photography with a minimum 5cm ground sampling distance (GSD), as stated in the TxDOT Photogrammetry Guide, must be used for 2D planimetric feature identification and compilation.
- Prior to data acquisition, the control layout must be provided to the TxDOT PM and included with the final deliverables for each project.
- Ground control points must meet TxDOT Level 3 specifications, as specified in the "TxDOT Survey Levels of Accuracy for GPS".
- Lidar ground control points must be set prior to Lidar /aerial photography acquisition, panels must be seen in photography for aerial triangulation and visible in Lidar derived

intensified images from the Airborne Lidar point cloud to facilitate Lidar and image processing.

- A Lidar ground-truthing report must be provided as part of the final deliverables.
- Gound truthing report for the check point verification must follow the ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024).
-

UAS Sensor Requirements

- Camera Sensor:
    - Camera resolution must support at least 1.5cm ground sampling distance (GSD) with a flight height range between 175-ft. and 400-ft. above ground level (AGL) flight height with an appropriate focal length.
        - The UAS camera will be dedicated to aerial photogrammetric workflow, not to just serve as a RGB Mapping Camera for colorizing the Lidar point clouds.
    - Sensor Size: Commercial full frame 35mm or medium format with variable shutter speed and F-stop.
    - Lens must be sufficient in producing the required resolution for images.
    - UAS aircraft speed: User defined.
    - Flight Height: User defined to achieve the greatest resolution and require the least amount of photo frames and associated aerial ground control panels.
- Airborne Lidar Sensor:
    - Laser Class: Class 1, eye safe.
    - Onboard IMU and GNSS.
    - RGB Mapping Camera (optional for colorizing the Lidar pointcloud).

Aerial Photography Data Requirements

- Refer to the established TxDOT Photogrammetry Guide provided in the TxDOT Surveyors' Toolkit.

Orthophotography Data Requirements

- 3-in. pixel resolution orthoimagery in TIFF and a compressed format.

Airborne Lidar Data Requirements

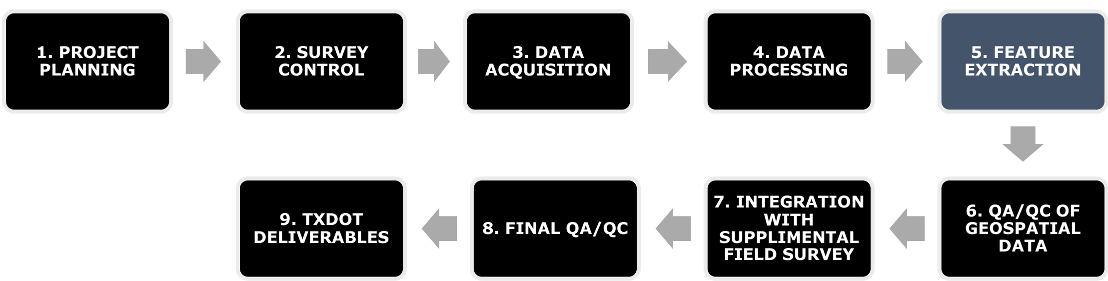
- To be determined in scoping with TxDOT PM.
- Classified point cloud data should be provided in LAS or LAZ format, accompanied by metadata.
- All Lidar data must be classified to bare-earth surface and adhere to ASPRS 1.2 (or above) specifications.

- The point cloud must be appropriately tiled to facilitate end-user computing efficiency.
- Point cloud with a point density of at least 100 points per meter^2 with a single pass within a flight height range of 175-ft. – 400-ft. AGL, unique to each project and determined by the UAS consultant.

UAS Aerial Mapping necessitates meticulous planning to establish a comprehensive flight plan capable of covering the entire project area. The flight plan must be formulated in a KMZ format and should be included with the control layout. Additionally, mapping limits for 2D/3D aerial mapping extraction will also be included and must be approved by the TxDOT PM. Any changes to the mapping limits could change the overall flight plan.

All UAS flights for TxDOT approved work authorizations must be approved by the TxDOT UAS Coordinator. The project planning phase is not complete until TxDOT and if any need for a FAA waiver is approved.

UAS Aerial Mapping Workflow



1. PROJECT PLANNING

The UAS consultant must provide the professional expertise, trained personnel, and equipment necessary to achieve the results that meet or exceed TxDOT aerial mapping standards.

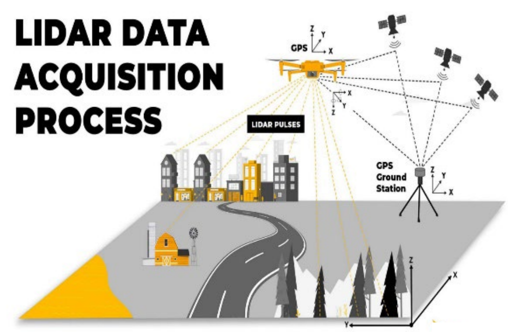
Mission Planning

- **Coverage and Planning Parameters** – These are parameters that shall be taken into consideration for planning the flight lines for the project area, ensuring the complete coverage of the project area. The mission planning parameters of point cloud post spacing, swath width, swath overlap, navigation, GPS, visibility, and tide-coordination (if project AOI is near the shore area) shall be considered in planning. TxDOT may supply recommendations and/or requirements for planning parameters. Instructions may define the point density of the point clouds and other requirements.
- **Collection Area** – The defined project area (DPA) shall be buffered by a minimum of 100 meters (m) (328-ft.) to create a buffered project area (BPA)
- **Mapping Area Buffer** – Buffered 50’ beyond established mapping limits.

- **UAS Airborne Lidar Overlap** – Adjacent swaths shall have a minimum overlap of no less than 35% of the mean swath width, while maintaining 100% coverage.
- **UAS Aerial Photography Exposure Overlap** – Exposure overlap along the line of flight shall be sufficient for aerial photography suitable for photogrammetric compilation.
- **Crab** – as measured from the line of flight and as indicated by the principal points of consecutive photographs, sufficient for aerial photography suitable for photogrammetric compilation.
- **Tilt** – defined as the departure of the optical axis of the camera from a plumb line, sufficient for aerial photography suitable for photogrammetric compilation.
- **UAS Airborne Lidar Data Voids** - in Lidar gaps in the point data coverage caused by surface absorbance, scattering, refraction in the near infrared, sensor issues, processing anomalies, improper data collection, or obstructions of the Lidar pulse. A data void is any area greater than or equal to $(4 \times \text{ANPS})^2$, which is measured using first returns only.
  Data voids within a single swath are not acceptable, except in the following circumstances:
  - where caused by waterbodies.
  - where caused by areas of low near infrared reflectivity, such as asphalt or composition roofing.
  - where caused by Lidar shadowing from buildings or other features.
  - where appropriately filled in by another swath.
- **Flight Direction** – Flight lines shall be flown in the most convenient direction, but adjacent, parallel lines should be flown in opposite directions to help identify systematic errors. Flight direction could be impacted by Federal Aviation Administration (FAA) airspace restrictions.
- **Lidar Survey Plan Report**
  - **Proposed flight lines** – Prior to data acquisition, it is important to submit digital map(s) clearly showing all proposed flight lines, and include coverage, scale, proposed ground control, and project area boundaries. Also included shall be information about scan angle, pulse repetition frequency (PRF), flight height, and aircraft speed over ground.
  - **Actual lines flown** – Similar map(s) showing the actual flight lines shall be included in the Final Report.
- **Cross lines** (for airborne Lidar)– At least one cross line (i.e., perpendicular to the primary flight lines) is required per survey. For longer survey areas, one cross line is required (approximately) every 25 km.
- **Flight Height** – Sensor shall not be flown at an altitude that exceeds that given in the manufacturer's specifications or that results in a significant number of "drop-outs" (i.e., pulses for which no return is received.)
- **Flight Clearances** – The survey plan shall comply with all required FAA regulations, including obtaining all required clearances.
- **Weather Conditions** – UAS data acquisition missions shall be flown in generally favorable weather. Inclement weather conditions such as rain, snow, fog, mist, high winds, and low cloud cover shall be avoided.

- UAS Aerial Photography – TxDOT requires cloud-free photography (UAS missions typically are flown below the cloud ceiling) to avoid shadows in the photography.
- UAS Airborne Lidar – shall not be conducted when the ground is covered by water (flood), snow, or ice, and shall not be conducted when the land-water interface is obscured by snow, ice, etc. Storm systems and events (e.g., hurricanes, northeasters, or storm fronts) that may cause an increase in water levels, tidal heights, and wave activity shall be avoided.

- **Time of Day** – Airborne Lidar acquisition operations may occur during either day or night, unless specifically called out in the Project Instructions. Unlike aerial photography, sun angle is not a factor unless supplemental imagery (e.g., digital imagery) is required to be acquired concurrently with the capture of Lidar data to help assist in identifying features in post-processing production.
- **Safety Planning** – Because Lidar systems typically employ Class 4 lasers, safety is a paramount concern. ANSI standards for safety shall be followed. A safety plan is prepared by adherence and enforcing to all TxDOT safety regulations and shall implement necessary internal controls to ensure the safety of all people in the aircraft and in the survey area below.
- **GPS Data Acquisition** – The consultant shall propose a GPS data acquisition frequency that shall never be greater than 1Hz, utilizing dual frequency receivers in the platform and in the base stations. This shall be materialized by two points of known coordinates (expressed in the same cartographic system of the project) and the distance between them shall not be more than 45 Km. GPS Manufacturer, receivers name, serial number and accuracy characteristics shall be included also (both for the instrumentation in the acquisition platform and on the base stations).



2. SURVEY CONTROL

Control Network Layout

Once the UAS project is approved by the TxDOT UAS Coordinator, an appropriate number of aerial photography and Airborne Lidar ground control points will be strategically positioned in flat (no slopes) and open areas. Aerial mapping ground control points will adhere to TxDOT Level 3 accuracy specifications. UAS consultants will have the latitude for aerial panel placement and frequency. Each TxDOT project is unique and will require a custom ground control network layout that will ensure TxDOT required accuracy is met or exceeded. UAS projects will have varied flight heights based on:

1. **Resolution Requirements:** Higher flight heights can provide broader coverage but result in lower resolution imagery, while lower flight heights yield higher resolution but cover smaller areas. The chosen height depends on the desired level of detail in the mapping.
2. **Ground Sampling Distance (GSD):** GSD refers to the distance between pixel centers on the ground with aerial photography. Lower aerial photography flight heights reduce GSD, providing higher spatial resolution. For detailed transportation infrastructure mapping, a maximum 1.5cm GSD will be required on all TxDOT UAS aerial mapping projects.
3. **Lidar Point Density:** Airborne Lidar point density is impacted by flight height, UAS air speed, scan angle and overlap, pulse rate and scan frequency, beam divergence, sensor characteristics, terrain characteristics, vegetation density and type.
4. **Terrain Complexity:** Varied terrain, such as hills or urban areas with tall buildings, may require different flight heights to maintain adequate ground coverage and image/Lidar quality. Adjusting flight height helps ensure consistent image/Lidar capture across diverse terrain.
5. **Regulatory Restrictions**: FAA regulations may impose maximum flight altitudes for UAS operations in restricted airspace. UAS pilots must adhere to these regulations, which may limit the available flight heights for aerial mapping.
6. **Sensor Specifications:** The type of sensor used on the UAS can influence the optimal flight height. Different sensors have varying capabilities and optimal operating altitudes. For example, Lidar sensors typically operate at higher altitudes compared to optical cameras. This must be considered when planning a UAS aerial data mission with simultaneous aerial photography and airborne Lidar data acquisition.
7. **Weather Conditions:** Wind speed and atmospheric conditions can affect UAS stability and image quality. In windy conditions, flying at lower altitudes may be safer and provide better image quality due to reduced motion blur.
8. **UAS Endurance:** Flight height affects the energy consumption of gasoline and battery UAS systems. Higher altitudes may increase energy consumption due to increased air resistance. UAS pilots must balance flight height with fuel/battery life to ensure mission completion without risking mid-flight fuel/battery depletion.
9. **Cost Considerations:** UAS aerial photography will require more control with the smaller image footprint (compared to a TxDOT approved large format digital camera), which may require a manned fixed-wing flight for aerial photography acquisition.

UAS Ground Control Points

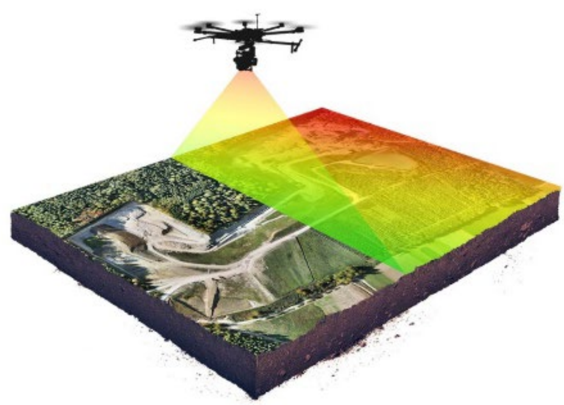
UAS ground control points are established prior to data acquisition to ensure visibility within the Lidar point cloud. UAS consultants may use any target shape or dimensions to successfully process aerial photography or airborne Lidar.

- Airborne Lidar will utilize the same control network required for aerial photogrammetry.
- Control spacing will be determined by the UAS consultant's ASPRS Certified Photogrammtrist. Each UAS project is unique and will have different spacing intervals of aerial control. Final data must meet TxDOT specifications.
- Aerial panel points must be set prior to UAS data acquisition.
- Final survey control must be received prior to trajectory alignment and processing of the aerial photography and Airborne Lidar point cloud.

Figure 1: Airborne Ground Control Lidar Panel Dimensions

3. DATA ACQUISITION

Refer to the TxDOT Photogrammetry Guide and the "Airborne Lidar Specifications and Workflow for TxDOT Design-Grade Mapping" for aerial photography and Airborne Lidar data processing guidelines.



Point Density

With the current TxDOT specification (in most scoping) for an Airborne Lidar pointcloud to contain a minimum of 20-25 points per meter^2, UAS Airborne Lidar is sufficient for DTM development, however, aerial photogrammetry will be required for compiling 2D planimetrics. Airborne Lidar will utilize the aerial photography control network. For UAS Airborne Lidar, TxDOT requires a greater point density due to lower flight heights and slower acquisition speeds. A minimum of 100 points per meter^2 for a single flight pass is required for UAS Airborne Lidar point density.

Flight Height

Typical flight height for UAS aerial photography/Airborne Lidar missions range from 150-ft AGL and 400-ft AGL. Flight height planning and considerations include airspace restrictions, cloud cover, and variation in terrain elevation. Flight height will be determined by the UAS consultant and will be dictated by any restricted airspace limitations. Flight height will impact FOV, flightline overlap, and the point density. The goal of flight height is to fly as high as possible, yet still meet TxDOT specifications. Data acquisition at higher altitudes results in less flightlines and turns, which result in higher acquisition costs for the State.

Field-of-View

The field-of-view (FOV) is defined as the angle which is covered by an Airborne Lidar sensor. For Lidar applications this is equal to the angle in which Lidar signals are emitted. Reducing the FOV angle will result in a denser point pattern while increasing the FOV is going to spread the Lidar returns farther apart.

Flightline Overlap

UAS Aerial Photography

UAS Aerial Photography must have sufficient percentage overlap for photogrammetric compilation.

UAS Airborne Lidar

For typical transportation corridors, sufficient overlap must be performed to ensure point density requirements are met.

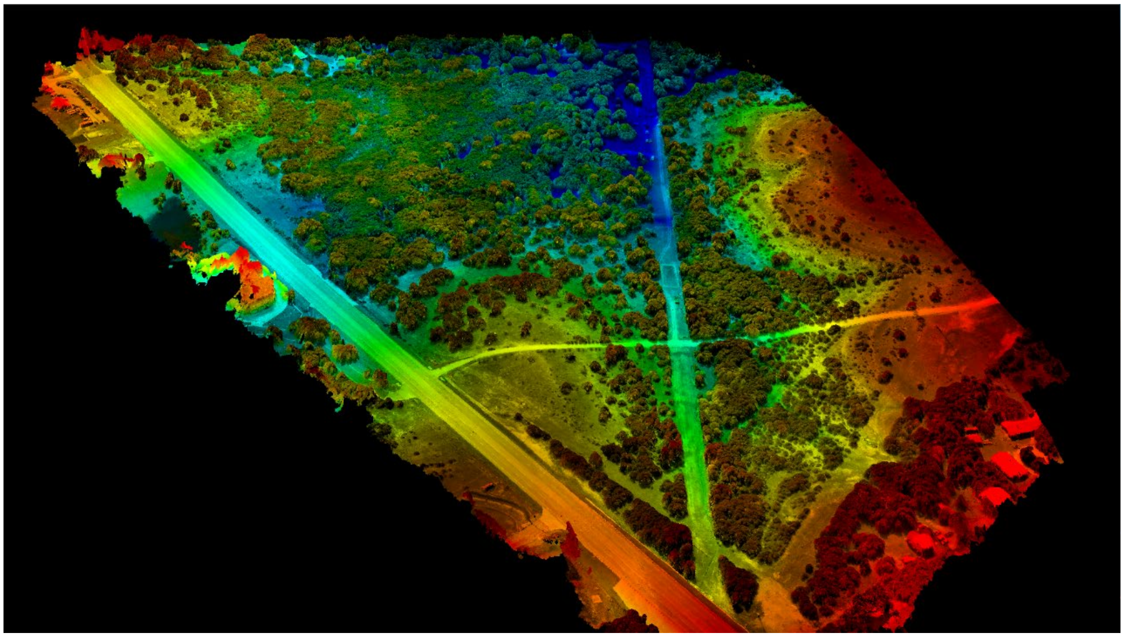


Figure 7 : UAS Airborne Lidar point cloud

4. UAS DATA PROCESSING

UAS Aerial Photography

- Quality review for each image.
- Analytical Triangulation – refer to the TxDOT Photogrammetry Guide, page 13.

Airborne Lidar Processing

- Refer to the Airborne Lidar Specifications and Workflow for TxDOT Design-Grade Mapping.

5. UAS DATA FEATURE EXTRACTION

2D planimetric/3D DTM feature extraction is performed using either or a combination of TopoDOT and Terrasolid software. Feature extraction is carried out by utilizing both the Lidar and calibrated, georeferenced images. All UAS aerial mapping feature extraction will adhere to the TxDOT Photogrammetry Feature Collection Standards provided in the TxDOT Surveyors' Toolkit.

2D planimetric feature extraction should be collected from the aerial photgraphy following aerial triangulation is performed. 2D planimetrics can also be extracted from intensity images after the Lidar flight has been processed.

The first step in the feature extraction phase is to identify obscured areas so that survey field crews can collect supplemental data concurrently with the Airborne Lidar mapping.

- Aerial Mapping Technicians will collect all 2D planimetrics (photogrammetry techniques) and 3D DTM features (Airborne Lidar pointcloud) typically shown at a 1" = 50' map scale, as standard in MicroStation Open Roads Designer (ORD) and will comply with TxDOT CADD Standards.

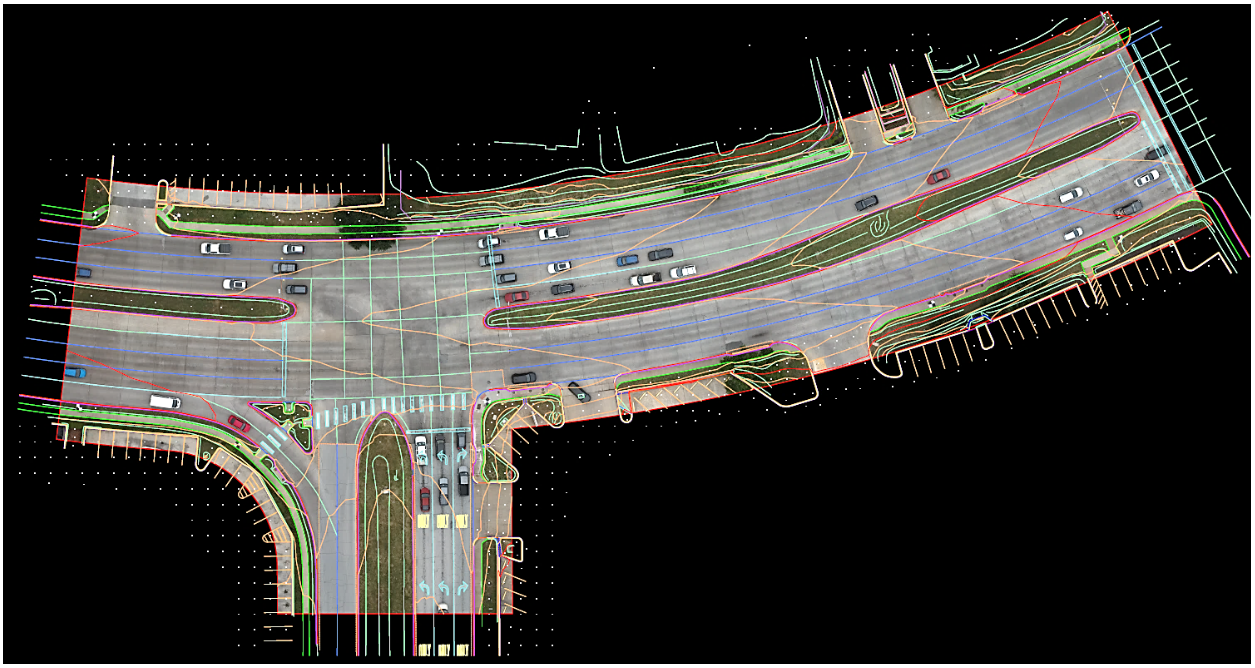


Figure 8 : UAS Feature Extraction

6. INITIAL QA/QC OF UAS AERIAL MAPPING:

Refer to the TxDOT Photogrammetry Guide and the "Airborne Lidar Specifications and Workflow for TxDOT Design-Grade Mapping" for aerial photography and Airborne Lidar data processing guidelines.

7. INTEGRATION OF UAS MAPPING WITH SUPPLEMENTAL SURVEY:

Integration of Airborne Lidar Mapping with Conventional Survey will be performed and reviewed by an RPLS. Any QC markups will be sent back to the Airborne Lidar Manager and the extraction team to perform any revisions and fixes. Any changes in the final data will require a TIN file to be re-generated and reviewed. All labeling, QC markups, and integration of aerial mapping with survey must be performed by an RPLS.

8. FINAL UAS AERIAL MAPPING QA/QC:

Refer to the TxDOT Photogrammetry Guide and the "Airborne Lidar Specifications and Workflow for TxDOT Design-Grade Mapping" for aerial photography and Airborne Lidar data processing guidelines.

9. TXDOT UAS AERIAL MAPPING DELIVERABLES:

- KMZ of mission plan, control layout, and aerial mapping limits.
- ASCII point file containing UAS aerial mapping ground control point locations with metadata.
- Completed Aerial Ground Control Submission (Form ROW-S-GrndCntrl).
- 2D Planimetrics, 3D DTM, and TIN in MicroStation Open Roads Designer (ORD).

UAS Aerial Photogrammetry Specific Deliverables

- 3-in. pixel resolution orthoimagery in TIFF and a compressed format.
- UAS Aerial Photography acquisition certification containing date, time, and weather conditions observed during data collection (flight report).
- Aerial Triangulation Report.
- RMSE report with statement of accuracy from photogrammetry ground-truthing checkshots.

UAS Airborne Lidar Specific Deliverables

- UAS Airborne Lidar acquisition certification containing date, time, and weather conditions observed during data collection (flight report).
- Processed and classified pointcloud in LAS or LAZ format with metadata.
- RMSE report with statement of accuracy from Lidar ground-truthing checkshots.

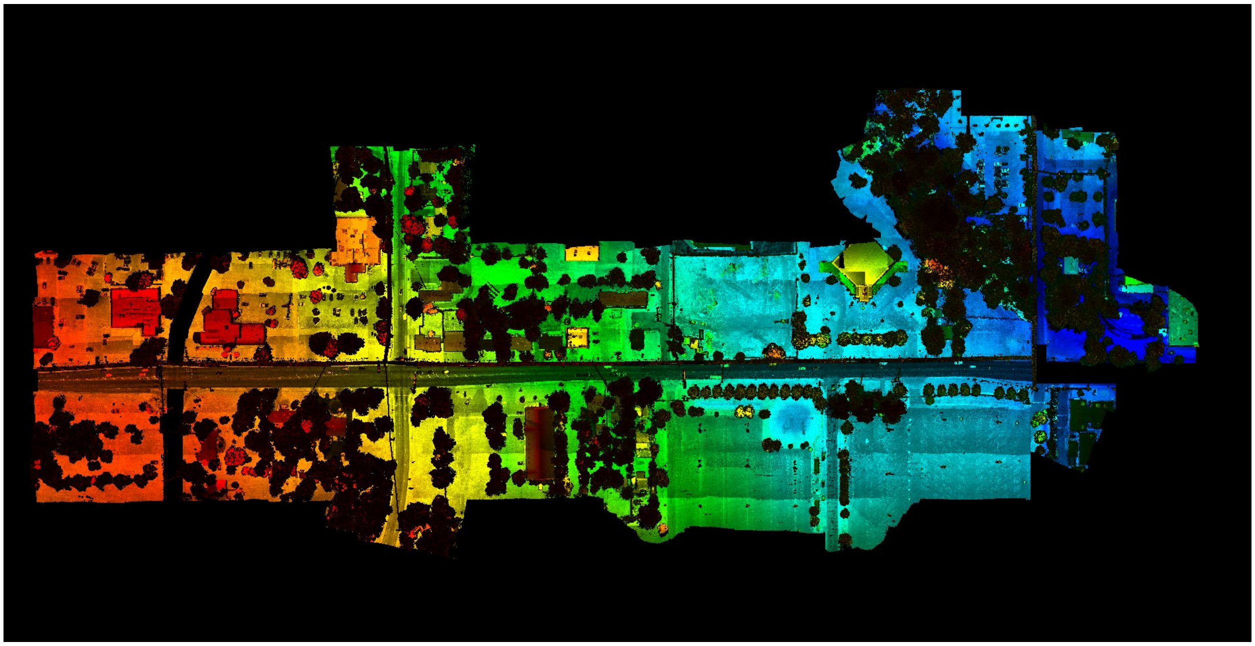


Figure 9: UAS Airborne Lidar, colorized by elevation