Oregon City Scope of Work for LIDAR flight performed by Merrick and Company

The specific deliverables/services to be delivered to the City of Oregon City are:

- 2 foot, 10 foot and 20 foot contours in ESRI coverage format
- Annotation along the 10 foot contour lines and contour lines attributed under text features
- All point data containing XYZ data for both bare earth and vegetation layer (canopy/miscellaneous),
- A DEM in ESRI binary format
- Data shall be delivered in the following projection: State Plane Oregon North, International feet, in NAD 83 horizontal, NAVD 88 vertical datums.

We have closely evaluated the project area for which LIDAR mapping services have been requested and the minimum deliverables. A successful LIDAR mission mandates accurate planning and data processing for the project to be a success. Merrick feels that our LIDAR, data processing capabilities, MARS™ LIDAR tool suite, and 40 year history of providing professional mapping services makes us uniquely qualified to provide Oregon City with the best possible data within the industry.

LIDAR is revolutionizing the acquisition of digital elevation data for large scale mapping applications. Merrick has embraced this technology from the onset through associations with several LIDAR acquisition vendors. Since 1997, we have successfully used LIDAR data as input to the contouring and digital ortho processes. We now operate our own proprietary digital imaging/LIDAR system and processes.

A typical LIDAR system rapidly transmits pulses of light that reflect off the terrain and other height objects. The return pulse is converted from photons to electrical impulses and collected by a high-speed data recorder. Since the formula for the speed of light is well known, time intervals from transmission to collection are easily derived. Time intervals are then converted to distance based on positional information obtained from ground/aircraft GPS receivers and the on-board Inertial Measurement Unit (IMU) that constantly records the attitude (pitch, roll, heading) of the aircraft.

LIDAR systems collect positional (x,y) and elevation (z) data at pre-defined intervals. The resulting LIDAR data is a very dense network of elevation postings. The accuracy of LIDAR data is a function of flying height, laser beam diameter (system dependent), the quality of the GPS/IMU data, and post-processing procedures. Accuracies of ±15cm (horizontally) and ±15cm (vertically) can be achieved. Accuracies better than 7cm (vertically) were achieved as a result of initial testing of Merrick's system.

Scope for the Oregon City project;

1. Merrick proposes to accomplish the LIDAR mission with one of the most advanced LIDAR sensor on the market today to provide a grid of highly accurate elevation postings as the source for the DTM and contours. The Ground Sample Distance (GSD) will be ~9.5' in the project area.
2. Merrick proposes flying the LIDAR mission in late April/early May. The most optimal GPS PDOP will determine the time of day that the LIDAR mission will be flown. LIDAR is not dependent on sun angle and can be flown at night. We are anticipating a total of 10 hours of acquisition time to accomplish the LIDAR mission.

3. Prior to flight and data acquisition, all airborne GPS reference base stations will be identified for use in controlling the project. Typically a single base station is required to cover a 25-mile flight radius. For the Oregon City project, two (2) GPS base stations will be utilized for redundancy on any given flight day. The base station points selected will be High Accuracy Reference Network (HARN) or other bluebooked National Geodetic Survey (NGS) control points. Base stations will be established on these points prior to any and all airborne data collection. GPS position data will be recorded at 1-second intervals, or epochs, throughout the entire mission.

System Description

Merrick & Company operates an airborne laser topographic mapping system based on the Leica / Helava Systems ALS40/50 platform. The system integrates a laser Altimeter, an Applanix POS/AVIMU Inertial Measurement Unit (IMU), GPS flight management and other sub-systems. This integrated system is capable of 30KHz operation at a 75-degree Field of View (FOV). The system configuration includes extended altitude range up to 4,000m@75 degrees, target signal intensity capture, and three (3) return capture. The sensor is capable of generating five (5) returns, however, the first three (3) returns generate the maximum collection and Merrick's sensor has been configured to maximize these first three (3) returns. This advanced sensor has the capability to collect terrain data at a swath width of over two (2) miles. The accuracy of laser generated terrain data exceeds 15cm RMSE, altitude dependent.

In-Flight data are logged to hard drives, which provides for immediate viewing of post mission data. Data quality, coverage, and other mission critical information are reviewed immediately to determine if re-flights are necessary.

Calibration

Similar to an aerial camera, it is generally not necessary to adjust parameters of a system that has been properly calibrated. Most project errors occur due to poor pre-flight initial calibration of the sensor and/or post-processing errors. Typical error sources are a result of poor mission planning or an untested set of variables. Calibration issues may include:

- Scanner Velocity – This can impact a condition known as encoder windup, which requires specific algorithmic correction for non-linear mechanical correction.
- GPS Lever Arms – If a new aircraft installation has been performed, the relationship of the GPS antenna as it relates to IMU and laser must be properly measured
- Boresite Calibration – The relationship of the IMU to the laser head must be precisely measured at maximum operational altitudes. The resulting angular offsets for pitch, roll, and yaw must then be applied to the post-processor for proper projection of the data when translating data from earth center to earth fixed coordinate systems.
- Pulse Rate – Lasers pulse width and shape is a variable based upon the pulse rate of the laser. While small in comparison to other error sources, a small vertical bias (1-5cm) is typical and should be accounted for in the total calibration.
- Extended GPS Baselines - Kinematic GPS errors can be on the order of 2ppm, which can translate to 20cm/100km. This must be accounted for by limiting baseline length for projects demanding large-scale mapping.

Full calibration / verification of our LIDAR sensor is verified on a regular basis (monthly) at Jefferson County Airport in Broomfield, Colorado, Merrick's LIDAR Operations facility. The site has over 500 GPS centimeter class accuracy control points, which include runways, taxiways, buildings, rooftops, and other features. Points are both surface and photo identifiable targets. In addition to GPS control, a rigorous photogrammetric solution was obtained utilizing photography flown at a scale 1"=600', which is utilized for stereo surface validation and 6-inch orthophoto reference imagery.

Calibration Methodology

Flights are performed over the calibration site across the full dynamic range for altitude; scan rate, and pulse rates from 4-cardinal directions and encompassing the full swath width of the on-ground scan over the GPS control surface data. Post-processed data is incorporated into CADD files where cross sectional profiles are measured and analyzed for flight line coherence and flight line ground truth coherence. Additionally, a histogram analysis is performed, which correlates the entire control network to the sample LIDAR data for adherence to the RMSE specification at selected altitudes. Note that our calibration procedures require that any project variables, which deviate from the normal calibration results, be investigated and resolved prior to post processing of data.

Project Calibration

Calibration validation is also performed at the project location to assure anomalies have not occurred en route to the site or during data collection. Typically, a limited survey is performed at the local airport to ensure mission performance. This often includes other control within the project boundary, as determined by project specifications. On projects of this size, flights are taken at the beginning and end of each mission over the calibration area(s). This assures that no drift or systematic errors have occurred during the LIDAR mission. Proper calibration also allows for errors to be evaluated and adjusted (if necessary) during post-processing and projection of DEM surface data to the project control. Merrick cautions against any other methodology as this is the only cohesive process that can ensure a mission has no anomalies from mechanical, electronic, GPS, or other atmospheric error sources.

Post-Processing of Multiple Return Data

In order to truly validate multiple return data, a known set of target coordinates must be measured against ground survey data. While a single pulse has the ability to be read 2-5 ranges, as is the case on most commercial LIDAR systems, the validity of this type of data has been minimally investigated. Many systems purport that they provide multiple returns but provide no accuracy claims. In truth, each return requires a separate vertical calibration correction, since it is a separate timing circuit. This can only be guaranteed if the signal strength is adequate from all returns. Typical project morphology provides minimal multiple return data beyond the 2nd return. Histogram analysis of data sets typically provides a maximum of 100% for 1st returns, 25% for 2nd returns, 5% for 3rd returns, and little or no 4th and 5th return data. This is a function of the ability of the electronic timing, and laser pulse width, which relates directly to a term known as range separation.

Range Separation is defined as the minimum vertical target separation required registering a valid return. Merrick's laser has < 3-meter range separation and is the highest accuracy currently available. Older systems vary from 6-12 meters. For the user, this means that buildings that are less than 6-meters high would probably not be resolved with older systems.

Validation of multiple return data is a difficult task, at best, beyond 2nd return data under normal flight conditions, and is best measured in a terrestrial environment under controlled conditions. However, most current users have little commercial use beyond building height measurement and true ground observations, which require 1st and 2nd return data. In the dynamic flight environment, a building is generally surveyed and is used as the control to verify the range(s). A laser shot must hit the edge of the building and have enough energy to produce a 2nd return on the ground. Then the returns are verified against the GPS control.

LIDAR Classification / Filtering

Merrick uses several significant process steps to filter (classify) data for project specified map accuracies ranging from 1' to 5' contour intervals. Each step takes the data to sufficient levels for the level of accuracy and processing required. These steps may be modified based on project requirements including but not limited to, map accuracy, terrain, and canopy morphology (i.e. urban, heavy or multiple canopy vegetation, water, and swamps).

Data is most often classified by ground and canopy, but specific project applications can include classifications of multiple data types including but not limited to buildings, power lines, etc. Typical deliverables for contour datasets are generally limited to include canopy and ground surface only.

Step 1: Logical Parsing of Data by File Size and Morphology

Before editing the LIDAR elevations, Merrick's filtering team parses enormous raw LIDAR data files into manageable, client specified tiles using Merrick's proprietary software. The software is called Merrick Airborne Remote Sensing (MARS™). MARS™ comprises a modular suite of tools that are used in the field, production workflow, and client deliverables. Data parsing is determined by geographic location, morphology, and logical file size for workflow process performance optimization.

Step 2: Automated Filtering

Next, custom filter macros are developed based on job specifications, terrain, and vegetation characteristics. These algorithms are applied to client data to derive a database separated into different classification groups; error points, ground points, and canopy-building points. The macros are tested in several portions of the project area to verify accuracy. Often, there are several filter macros for each project that optimize the program based on the unique characteristics of terrain, man made features, and vegetation type.

Step 3: LIDAR Environment Editing

LIDAR data is next taken into a graphic environment to edit noise or features that may remain in the LIDAR point cloud after auto filter. Data is cross-sectioned from the surface to reclassify non-ground data artifacts. The cross section on the left is edited and the TIN to the right is updated automatically to reflect change real-time during the editing process.

Step 4: Model Keypoint Generation

Next, a unique manipulation process normalizes the surface into one of the tightest digital surface models (DSM) available in the industry. Final data extraction for the client's keypoint (statistically significant points) and canopy-building file data are then generated.

Breakline Procedure

1. Utilizing a combination of automated filtering techniques, MARS™, and softcopy photogrammetry, Merrick derives "bare earth". Merrick will utilize the orthophotography provided by Oregon City for breakline extraction. The filtered LIDAR data is draped on these images. LIDAR data points, either individually or in groups, are edited to ensure that they are "on the ground." Supplemental breaklines are compiled in critical locations to ensure the final DTM and contours meet project accuracy specifications. As a final validation, contours are generated and again draped in 3-D. Merrick has integrated a combination of techniques, including 2D and 3D, to achieve the required accuracy specifications.
   - Because LIDAR point placement is accomplished randomly, the data does not often model steep slopes, retaining walls, culverts, roadside ditches and hydro features
   - Merrick's 2 and 3-D edit procedures takes the filtered LIDAR point cloud and, converts the resultant surface into raw contours. Contours are reviewed with digital imagery, Merrick's analysts can readily determine if there are any errors in the LIDAR point data, and determine where breaklines need to be added. Merrick's 2-D approach utilizes LIDAR points in attributing the Z values of the breakline.
   - The actual number and density of breaklines added to a LIDAR DSM are significantly less, when compared to a traditional photogrammetric DTM. This is due to the number of LIDAR points being hundreds of times denser. Additionally, the positional accuracy of the DSM data is far better than traditional photogrammetry.
   - Specific examples where Merrick's analysts would add breaklines and/or modify the LIDAR are listed below:
     - Points are also deleted from under bridges and a bridge polygon inserted to show where this was done
     - Water areas are surrounded by a water breakline and a water spot elevation placed in the water body
     - Roads are compiled with road breaklines and, if a crown is visible, a centerline breakline is compiled

3. Next, breaklines are used to delete point data from within water and roads then used as standard 3-D breaklines so that the final product will depict flat water surfaces and crowned roads. The LIDAR edit data proceeds to 3-D quality control, compilation edit, and LIDAR final surface adjustment.

Contour Generation

Following the collection, filtering, and verification of the LIDAR DSM, Merrick uses Siteworks to process the DSM and interpolate the final contours. SiteWorks is an engineering software package that works within Bentley's MicroStation environment.

The following outline provides a description of the significant procedures/milestones that will occur to create contours for the project.

1. The points in the DSM are related and connected to each other by creating a Triangulated Irregular Network (TIN). Drawing 3-D triangles whose corners are the DSM points creates the TIN.
2. When the points in the DSM are collected "on the ground" and in a sufficient density, the legs of the triangles that connect the points accurately represent the surface of the terrain. These triangles that are created to make the TIN are "drawn" within the contour interpolation (CIP) software according to certain rules.
3. The next step is to process the TIN to create the contour levels using contour interpolation software (CIP). After processing, attributes for elevation and line type are automatically populated for each line.
4. Contour data will be interpolated across sheet (tile) edges to form a continuous line. This will create an exact edge match of contours along the tile boundaries. Merrick will use the tile layout to "clip" continuous data into individual tiles. For this project Merrick will use a PLSS section grid.
5. Creating an aesthetic cartographic contour map is the next step in the process. At the editing workstation, contours are smoothed, enhanced, and verified to be within the tolerances of the accuracy specifications. Merrick will work with Oregon City to determine the cartographic quality of the contour database.
6. A final inspection of the vertical accuracy is then performed by comparing LIDAR elevations to the interpolated contours.

Contour Databases

Merrick utilizes ArcInfo GIS software tools to create topologically correct coverages, validate edgematching, and populate the database with appropriate attribute values. All final data will comply with the database design standards.

1. Merrick will convert the newly compiled planimetric / topographic databases (.DGN) into ARC coverages using ARCIGDS software tools. This data translation tool has been used successfully by Merrick over the past ten (10) years. The software uses a series of translation tables to "map" features into the appropriate coverages and Info tables. Regardless of the final destination system, Merrick uses ArcInfo to create GIS topology and connectivity.
2. If delivering contours in a tiled format, Merrick will "clip" the continuous data into individual tiles along section lines as defined by GIS shape files supplied by the City.
3. Merrick's existing AML's and ARC tools will be customized to meet the specific QC/QA requirements of the Oregon City project.
4. Following the on-line completeness verification, Merrick will then make corrections, if needed.

Merrick understands the necessity for providing our clients with topologically correct databases. Thus, all final processed graphic data will conform to standard GIS topology "rules":

- **Edge Matching**: All digitized features will be both visual and coordinate edge matched with features from existing data, adjacent tiles, sheet edges, and at model breaks or other artificial boundaries within a tile. No edge match tolerance will be allowed. Attributes for adjoining features will also be identical.

- **Common Boundaries**: All graphic features that share a common boundary, regardless of digital map layer, will have the exact same digital representation of that feature in all common layers.
- **Point Duplication**: No duplication of points will occur within a data string.
- **Connectivity**: Where graphic elements visually meet, they will also digitally meet. All confluences of line and polygon data will be exact mathematically; that is, no "overshoots," "undershoots," "offsets" or invalid "pseudo nodes will exist. Lines that connect polygons will intersect polygons precisely; that is, every end point will be an intersection point of the respective polygon.
- **Line Quality**: A high quality cartographic appearance will be achieved. Transitions from straight line to curvilinear line segments will be smooth and without angular inflections at the point of intersection. The digital representation will not contain extraneous data at a non-visible level. There will be no jags or hooks or zero length segments. Curvilinear graphic features will be smooth with a minimum number of points. When appropriate, line-smoothing programs will be used to minimize the angular inflection in curvilinear lines. Any lines that are straight, or should be straight, will be digitized using only two points that represent the beginning and ending points of the line.
- **Segmentation**: The digital representation of digital elements will reflect the visual network structure of the data type. An element will not be broken or segmented unless that segmentation reflects a visual or attribute code characteristic or unless the break is forced by database limitations.
- **Area and Polygon Closure and Centroids**: For area features being digitized, the last coordinate pair will be exactly (mathematically) equal to the first coordinate pair. Centroids will be placed in all polygon area features.
- **Point Criteria**: All point features will be digitized as single x, y coordinate pairs at the visual center of that graphic feature.

5. Merrick will create the alternate contour coverages of 10' and 20' intervals from the 2' contour coverage.

Deliverables
Merrick will deliver the following specific deliverables to Oregon City:

- **LIDAR Products**
  ASCII XYZ mass points filtered bare earth
  ASCII XYZ mass points filtered canopy
  MARS™ 30 day license

- **Contour Products**
  Final Breaklines in ASCII XYZ and Shape
  Entire DTM (breaklines and masspoints) in ASCII XYZ & ESRI binary grid.
  Final 2', 10' & 20' contour files (ESRI coverages).
  Annotation at 2, 10, and 20 foot contour interval and at a reasonable size and spacing for display purposes.

- **Reports**
  LIDAR RMSE report.