Topographic Surveys Guide

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0.2	Addition of Appendix on Total Stations as an example	2022/04/20	B. Maloney
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1.1	Unmanned Aerial Vehicles (Photogrammetric)	2022/10/13	S. Kasprzak
1.2	Added GNSS and minor edits	2022/10/20	R. Berg

Contents

Background & rational

Over the last several years the Association of Ontario Land Surveyors (AOLS) has had several claims related to topographic surveys performed by members. This guide was prepared to help members consider their practices related to performing topographic surveys. IT IS NOT COMPREHENSIVE AND SHOULD NOT BE USED ON ITS OWN IN DETERMINING PRACTICES. IT IS THE RESPONSIBILITY OF THE SURVEYOR TO DETERMINE APPROPRIATE EQUIPMENT AND PROCESSES TO MEET THE STATED OBJECTIVES OF THE SURVEY.

Health and Safety Considerations

Topographic surveying comes with a variety of risks ranging from: working in and around water, falling, traffic to confined spaces. This document does not address health and safety considerations. Surveyors should have policies related to their safety practices and these should be considered for each site.

Determining specifications and client requirements

Features to be captured (above and below ground)

It is critical that the surveyor understand the purpose of the topographic survey, and it's intended use. The client may specify features to be captured and the detail associated with those. As an example, for some clients capturing the corners of a bridge may be sufficient while for others they may want specific details such as positions of expansion joints, barriers, hand railings, etc. While this may be covered in the specifications provided by the client, it may not be. If specifications are not provided the level of detail required should be confirmed with the client in writing.

Features required may vary by area on the topographic survey. In many cases features, including elevations may be required beyond the subject site. It could be that features beyond the subject property may require less definition or accuracy.

The number of points required on features may be defined in the specifications but if not, this should be driven by accuracy and resolution considerations covered below.

Coding and representation of features is covered in Outputs/Deliverable/Formats below.

Boundaries

If boundaries of the property are included as part of the deliverables, the surveyor is bound by the requirements for Field Survey Standards (Sections 8 to 15) in Ontario Regulation 216/10.

Resolution and Accuracy

It is critical that the surveyor understand the resolution and accuracy requirements of the topographic survey. This should be specified in your contract.

Accuracies should always be defined with a confidence interval. As an example, points with an accuracy of a centimetre at a 66% confidence interval are likely only accurate to over 2 centimetres when specified at a 95% confidence interval. Most surveyors use a 95% confidence interval; however, this needs to be determined with the client and considered when choosing appropriate surveying techniques.

Resolution and accuracy will likely differ by feature. As an example, soft features like the drip edge of a tree line cannot meet the same accuracy specifications as a hard feature such as an edge of pavement. Similarly, the accuracy of elevations in a plowed field cannot be measured to the same accuracy as observations on a concrete walkway. This should be covered with the client.

Accuracy and resolution for a topographic survey need to consider the final product and not just point accuracy. While you may very accurately measure several points on a site, if the location and spacing of the points is not sufficient, the accuracy of the topographic survey may be inappropriate for the intended use. Conversely, you may take many points (e.g. from LIDAR) but if the accuracy of the observed points is not sufficient, the accuracy of the topographic survey may be inappropriate.

Typically, the number of points required will vary on a site depending upon variations in topography. A flat surface typically takes less shots to define than a hilly site. The client may limit the distance between points. From an elevation perspective, sufficient points should be observed such that any anomaly between observed points will differ by less than half of the required accuracy. As an example, if the required accuracy of pavement shots is 1 centimetre, and wheel rutting exists, it may not be sufficient to just observe the edges of pavement and the centreline. You may require many more observations to adequately model the topography.

When observing planimetric features, you also must consider the accuracy required in choosing the number of points from a horizontal perspective. This may also be specified by the client or may require further understanding of the requirements. As an example, if you are capturing curb and gutter at an intersection, is it allowable to capture only three points that could define a circular curve, or do you have to take many points that will be used with no further mathematical modeling?

Ensure that your field crews/operator understand the project requirements and how to determine adequate point spacing for the features being collected.

Resolution of observations will normally be driven by accuracy. There is no point recording and providing measurements to the millimetre if they are only accurate to the centimetre. In fact, this may result in a misinterpretation of the accuracy.

Outputs/Deliverables/Formats

Outputs in terms of file types and media will normally be defined by the client. That does not mean that you must work in those systems, and you may very well perform an Extract/Transfer/Load operation prior to providing the product. If you are not working in the native system being provided, sufficient checks should be made to understand that your transformation processes are appropriate.

The client may specify coding and/or layering and/or symbology for each feature provided. As above, you may choose to use your own standard processes to capture and process the data and then transform the output at the end. If this is the case, care needs to be taken to ensure that you have defined the features such that there is a one-to-one or many-to-one (not one-to-many) mapping of feature types. Additionally, as with changes in output format, checks need to be made to ensure that appropriate feature codes, layering or symbology have been generated. If coding, layering, or symbology are not defined by the client, your deliverables should include legends and coding and layering conventions.

Geodetic Reference Frames

Care should always be taken in completely describing the referencing system used. This includes adjustments (if necessary), the referencing system and epochs (if appropriate). Where coordinates are assumed, avoid using coordinates that are close to any existing standardized referencing system.

A topographic survey should never rely upon a single point (for elevation) or a pair of points (for horizontal positioning). There always must be redundancy to detect any potential movement of reference points or errors in coordinate values.

Determining Appropriate Technology

Limiting factor of the site

The site and the client requirements such as accuracy will determine the technology that can be used to complete the survey. The following are simply considerations when selecting technology.

Vegetation

Vegetation is an issue for consideration for any remote sensing technology ranging from prism less total stations to photogrammetric data capture. Depending on the accuracy requirements, ground cover such as grass or weeds can be an issue for any remote sensing technology. Often in the spring, low ground cover is compressed and may allow alternative technologies. Trees, whether coniferous or deciduous, can be an issue when using airborne sensors. The density of cover and the resolution of the required product will dictate the technology that can be used.

Physical obstructions

Physical obstructions such as buildings can influence the choice of technology. High rise and reflective buildings will increase the opportunity for multi-path errors if using GNSS technology and may mean it should not be used. If the spacing between buildings is limited it can also impact the use of photogrammetric techniques since it may require significantly more overlap of images and may not allow appropriate geometry to accurately determine elevations.

Water

If topographic information is required below water surfaces it can impact the technology required since some remote sensing technologies do not appropriately penetrate water (some frequencies of LIDAR will penetrate to some depth).

The timing of the survey can also have an impact in collecting the water's edge. If this is critical the client should be consulted in this regard.

Access Restrictions

There are times where it may not be possible to access the site. This could be because of the landowner not allowing access (Note: S.6 of the Surveys Act or the S.12 of the Drainage Act cannot be relied on for entry to land for topographic surveys – The Drainage Act only covers "Drainage Works") or other reasons such as topographic challenges. In these cases, some form of remote sensing technology should be considered ranging from terrestrial scanners to photogrammetric or LIDAR solutions. It is imperative that when performing a topographic survey that the owner of the property be contacted prior to entering, since as noted above, section 6 of the Surveys Act cannot be counted on as authority to enter the property.

Accuracy limitations of technology

Choosing the correct technology and processes for the intended accuracy and precision is a critical step. Technologies generally have specifications associated with them provided by manufacturers. These may or may not be accurate and should be confirmed by the surveyor through independent testing. The approach to this will vary depending upon the criticality of the information being collected. If the accuracy requirements and the consequences of error are high, independent redundant observations should be made to the points. In many cases, it is not cost effective or appropriate to have redundant observations on all points and sampling techniques will be employed to determine quality. It is still imperative that in these cases surveyors have done sufficient testing of their equipment and processes to understand the accuracy that they can expect.

Ultimate accuracy of captured points is dependent upon the accuracy of several factors, some of which are listed below.

Platform positioning accuracy

The position of the measuring instrument always has an impact on measurements. Errors can be as simple as set-up errors (e.g. instrument not plumb over reference point) to more complicated errors associated with moving platforms (e.g. a camera in an aircraft or drone). Since the platform position is critical, this should normally be determined using redundant observations if possible. This can range from aerial triangulation adjustments for cameras to resections or checks to redundant points for total stations.

Orientation accuracy

As with platform positioning, orientation of the sensors impacts the accuracy. The accuracy of orientation can impact how far features can be measured from the sensor. This should be considered in planning your topographic survey. This may range from flying height for a drone to how far observations can be taken from a total station.

Resolution and accuracy of observations

All survey equipment has accuracy and resolution limitations. These need to be considered in selecting equipment and processes.

Velocity/Timing Issues

Moving platforms such as airborne sensors require additional considerations since they have the additional dimension of time. This provides additional considerations for the surveyor, which may include wind as part of mission planning.

Location of Sub-surface Features

Sub-surface features are worthy of specific consideration. Although equipment such as ground-penetrating radar can assist in locating sub-surface features, accuracy can vary. Depending on accuracy requirements it may be necessary to uncover the features for collection. Locates and appropriate uncovering techniques need to be considered as part of the survey if features need to be uncovered. Accuracy and sources of any information used for sub-surface features should be clearly reported to the client.

Field Capture

Timing Restrictions

Winter Surveying

Frost can significantly impact the elevations of original ground especially in soils containing clay. Depending on accuracy requirements, this can be an issue and may need to be discussed with the client and reflected in the survey report.

Snow obviously impacts productivity and ability to survey and needs to be considered in mission planning.

Fall/Spring Surveying

If remote sensing techniques are being used there may be benefits to performing spring or fall operations to minimize the impact of vegetation (i.e. leaf off conditions, low growth).

Capture Processes

Calibration of equipment is critical to ensure accuracy and should be checked periodically. The use of test ranges (e.g. calibrated baselines) and observations of known points may be appropriate.

Systems set-up can be a source of errors. Crews are reminded to check instrument settings before surveying to ensure that they are appropriate.

Processes should be set up to minimize changes in practice. As an example, some organizations will use standard prism pole heights (e.g. 1.5 metres or fully extended) or fixed height poles.

Although clients may request different feature coding it is preferred to use transformation processes in the office and use consistent coding in the field to avoid blunders and increase field crew productivity.

Depending on the systems being used, feature strings can often be captured. These are important for defining break lines in topography or planimetric features. If feature strings cannot be captured in the software used and the generated point cloud is not sufficiently dense to avoid the need for feature strings, then sketches of field notes should be captured with point numbers to show break lines (this is particularly critical in the formation of TINs).

Points should be close enough together to ensure that the specifications for the project are met and need to be chosen to properly represent the topography (i.e. don't miss humps or hollows between points that would be beyond a straight line interpolation that would exceed the accuracy specifications). See Resolution and Accuracy above.

Inaccessible Features

There may be features that are not directly accessible such as underground utilities or pipe inverts in deep catch basins. As such it is possible that you will use other technology to locate these. Special care is required in doing so to ensure that additional error sources are considered and noted in client reporting.

It is equally important to note where features could not be captured. If external information (e.g. design drawings) are relied upon for location, these need to be clearly indicated along with any caveats on accuracy and reliance upon this information.

Calculations and Adjustments

It is impossible to go into detail regarding calculations and adjustments since many technologies and different software can be used to achieve the desired results. The following statements are generalities that should be considered.

There should always be redundancy in determining the overall geodetic references for the survey. Typically, clients will not want to address perceived errors in the data (even though they will always exist) and as such a best practice would be to adjust the control using a least squares adjustment.

Most software used to generate topographic surveys is powerful and has a variety of functionalities including the ability to distort and transform coordinates. As such it is always important to check final products to ensure there have been no unwanted datum shifts, rotations or translations applied to the coordinates.

The specifications for the project should have addressed the coordinate system being delivered. If coordinates are to be delivered in "ground" values, please ensure that the correct scale factor has been used throughout since this has been a source of error for many surveys and deliverables.

Quality Control/Assurance

There are many techniques for performing quality control and quality assurance. The methods noted below are only suggestions and other techniques can and may be used. It is important to perform some form of independent process to assure yourself that quality standards have been achieved. A best practice would see the checks performed and another independent person verify that the checks have been completed.

It should be recognized that testing tolerances will differ between hard and soft surfaces and between varying features.

Blind Points

If control has been placed or is being observed to it can be useful to capture additional points with three-dimensional values that are not used in the survey (e.g. they are not used in photogrammetric aerial-triangulation) but can be used as check points once the survey has been processed and completed. Results should compare within tolerances of the survey accuracy specified. Remember your confidence interval; just because one point doesn't meet specifications doesn't mean your overall survey is not acceptable.

Sampling

Sampling can be accomplished by independently capturing audit lines (cross sections) throughout the project area. The independent lines should be checked against lines generated using the processed survey product. The independent lines and generated lines should be within tolerances of the project specifications.

Reasonableness Tests

There are several visual tests that can help find errors or blunders.

By viewing a contoured final product, any unusually high or low point will pop out and can be considered. Similarly, any overly steep areas or weird looking modelling can be considered. Contour lines compared to hydrographic features can also point to errors (water should either be flat or run downhill. Undulations in contours at the shore point to problems).

Checking planimetric detail against other sources such as orthophotography can identify issues with referencing (e.g. shifts or rotations). These can occur in processing or may be the result of different referencing. In any event they should be explainable and should not be ignored.

Deliverables

Formats

It is important that the formats for deliverables be defined in the contract or agreed to.

Formats can include:

- proprietary or open software formats
- The type of product to be delivered (e.g. TIN, Contours, Points, grids)
- Layering expectations

Digital Products

(see https://members.aols.org/site_files/content/pages/best-practices/cad-file-release-considerations.pdf) Note: you will have to log in to the AOLS members' website to access this.

Plans

Titles of plans have been an issue. Where the boundary has been surveyed as part of a topographic survey it is appropriate to use the term "Plan of Survey".

Where the boundary has not been surveyed, the term “Plan of Survey” shall be avoided in favour of “Topographic Plan” or “Plan of Topography”.

Client Reporting

Contents

The contents of reports to the client are defined in Sec. 4 Ontario Reg. 216/10 and include the following:

a) the objectives, scope, area and date of the project;
b) the data sources and dates of acquisition for the project;
c) the names and versions of pertinent software for the project;
d) deviations from the initial project scope;
e) a declaration of compliance with all applicable Acts, regulations under them and practice standards;
f) statements of ownership and authorship of all deliverables for the project, including computer software developed within the scope of the project;
g) an explanation of the limitations of data received, manipulated and delivered under the project;
h) a description of field procedures for the project;
i) a statement describing the project map projection, zone, datum, and if applicable, adjustment epoch; and
j) documentation of all project milestones and quality assurance activities. O. Reg. 216/10, s. 4 (2).

In addition to the mandatory items listed above the following should be considered as well:

- A statement regarding the combined scale factor required to change dimensions to ground values (if coordinates are grid)
- A copy of the specifications used for the project including accuracy statements (for both hard and soft features)
- Any external data that has been relied upon including cautions in its usage (such as the need to uncover and verify the location of items); this may have been covered in item g) above.
- A list of symbology and layering conventions used.

Appendices

Total Stations (Prismless or with prism)

Overview of its usage for topographic surveying

Total stations have been used extensively for gathering topographic information for decades, although they are being replaced or augmented by other technologies for all or portions of topographic data collection. For the most part they represent some of the highest accuracy data collection depending on the method used. Where a prism and pole are used, accuracies can be quite good, however there are limitations in using them without reflectors.

Specific Considerations/Limitations with respect to feature capture

As previously noted, they represent some of the highest accuracy data collection possible. Since features can be captured directly when using a prism and pole, sub-centimetre accuracy is possible with correct equipment and processes. Of course, on soft surfaces or unclear features such as a drip edge of a tree line, accuracy will be reduced. Normally this will be a condition in the project specifications.

If a reflector-less approach is used, then consideration must to be allowed for vegetation and water, which will interfere with returns, potentially making this not a feasible option for portions of the survey. Consideration also must be given to the distance to the target and its angle to the line of sight (a very shallow angle can impact the accuracy of the horizontal location). The distance that an instrument can measure to a target may also be reduced due to the range of the instrument.

Accuracy Considerations

Like any survey instrument, total stations are impacted by uncertainty in their location and their orientation. An instrument set over a point will be subject to set-up error (the ability to plumb over a point). The orientation of the total station will be dependent on the accuracy and length of the backsight used. Short backsights should be avoided.

Instruments themselves vary in accuracy and will normally have an expected angular accuracy and distance accuracy (normally fixed error and parts per million). As a result, the further away a target is from the instrument the greater the positional error will be. Normally practices for topographic surveying will establish maximum distances to observed points depending on the accuracy trying to be achieved.

Calibration and Testing Practices

Total stations are subject to many internal errors that are generally corrected with proper calibration and procedures. Individual manuals should be consulted and followed. Examples of errors are:

- Laser plumb errors
- Circle eccentricity
- Trunnion axis tilt
- Prism errors
- Incorrect instrument settings (e.g. scale factor, atmospheric settings)

Instrument settings should be checked on at least a daily basis.

Since most topographic observations are recorded on a single face, it is essential that calibrations are checked on a regular basis. A good practice is to record observations in both faces to control shots, which will help identify calibration issues in checking.

Blunders can occur when improper backsights are used. It is recommended that a set-up should always include observations to two known points at the outset. This will allow confirmation of the location of the points and identify any identification errors in the points. Once observations of topographic points are complete from that setup, a shot back to the backsight should be observed prior to moving the instrument to ensure that no movement of the instrument has taken place. If working in less stable conditions (e.g. sunny frosty conditions, soft soils) frequent checks back to the backsight make sense to avoid wasted work.

Where prism poles are used, the height associated with the prism pole can be a major source of elevation error. It is recommended that where possible use a consistent prism pole height (e.g. 1.5m) which reduces the opportunity for error. Where heights must be changed, they need to be specifically recorded in field notes. Try to use as few variations as possible. Level bubbles on prism poles should be checked on a regular basis.

Global Navigation Satellite Systems (Ron Berg)

Much of the following has been summarized from "Guidelines for RTK/RTN GNSS Surveying in Canada. NRCan". Version 1.2, July 2015. The reader should refer to this document for complete details.

https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/Canada%20RTK_UserGuide_v1_2-EN.pdf

Overview of its usage for topographic surveying

Real-Time Kinematic (RTK) surveying using Global Navigation Satellite Systems (GNSS) is a common method used for both cadastral and engineering surveys. Additionally, Real-Time Networks (RTN) cover much of southern Ontario and select locations in the north. The distribution and status of RTN stations can be viewed at

https://webapp.csrs-scrs.nrcan-rncan.gc.ca/geod/data-donnees/rtk.php?locale=en

RTN surveys are popular where available, but RTK surveys are still the only option available in many parts of Ontario.

Both RTK and RTN GNSS surveys can achieve centimetre-level relative positioning however there are several factors to consider when striving for the highest accuracy, including: equipment calibration, atmospheric errors, multipath, satellite geometry, reference system integration, communications, initialization, time-windowing, redundancy, and validation.

Specific Considerations/Limitations with respect to feature capture

Communication between the base and the rover is key to successful RTK/RTN surveying. UHF, VHF or broad-spectrum radios are used for RTK whereas RTN communication is typically through cellular networks.

RTK/RTN surveying requires common satellites to be observed at both the base and rover antennas.

Project areas consisting largely of forests or tall concrete buildings (urban canyons) may make it difficult to achieve any results, let alone results meeting the required accuracy, due to satellite and/or communication blockage.

Orthometric and Ellipsoidal Heights - To get real-time orthometric heights, a geoid model or height transformation must be loaded into the rover. In local areas where the geoid model or height transformation may not meet the accuracy requirements of the project, there may be a need to calibrate the heights to local vertical benchmarks.

There may be instances where only part of a project is suitable for RTK/RTN. An example might be a project where the horizontal accuracy is suitable for RTK/RTN but the vertical accuracy requirements can only be achieved using spirit levelling.

Accuracy Considerations

The precision of RTK decreases as the baseline length increases, making it necessary to set up multiple base stations or to use a leapfrog method with relatively short baselines. Real-Time Network (RTN) surveying has been developed to extend this base-to-rover range limitation.

RTN should only be performed when the project area is contained inside the polygon formed by three or more nearby RTN base stations. Accuracy rapidly declines the further a survey project lies outside the umbrella of a RTN.

Only RTN base stations certified as compliant by Natural Resources Canada (NRCan) should be used. Consult the NRCan RTK networks website mentioned above.

Ensure only fixed ambiguity solutions are always used.

For best results work in areas with a clear view to the sky to avoid satellite signal blockage and multipath.

Recommended receiver settings: Elevation mask angle (10-15), minimum number of satellites (GPS-6, GNSS-8) and positional dilution of precision (PDOP) (2-3).

Many receivers also allow the user to set the horizontal and vertical QC values. These values are calculated internally by the receiver and give an indication of the precision of a single measurement. Typically horizontal and vertical QC values should be set to 1 cm for control points and 2-3 cm for topographic points, or as the project dictates.

Calibration and Testing Practices

Equipment

Check and calibrate all level bubbles on tribrachs and prism poles.

Modern GNSS equipment now have “tilt” compensation that allow accurate measurements without precise levelling of the prism pole. Critical tilted-axis measurements should be repeated with the prism pole in a different orientation.

Record antenna heights at the base and rover in both metric and imperial or use a fixed height pole to ensure an accurate height of instrument (HI).
Use a tripod or bi-pole when more accurate positions are required.

Base stations should be installed in a stable environment with calibrated centering, levelling, and HI measuring equipment.

Receivers should be configured to save raw observations which can be processed using CSRS-PPP or with the vendor software to verify the coordinates and stability of the setup.

GNSS equipment should be periodically validated on an established GNSS calibration site. Alternatively, measurements between reliable control points should be made frequently to ensure the complete field observation and processing procedure is producing accurate results.

Reference frame

For RTN surveying, the user needs to know which reference frame is broadcast by their network provider. In most cases it will be necessary to verify the accuracy of their RTN derived rover positions by measuring to known points in the user's required reference frame.

The user should confirm the reference frame, coordinate stability, and any station outages from the RTN provider and from Canadian Geodetic Survey at

https://webapp.csrs-scrs.nrcan-rncan.gc.ca/geod/data-donnees/rtk.php?locale=en

For RTK surveying, when possible, set up the base station on an existing control point of sufficient accuracy, then measure to other existing control in the area to verify the coordinates of the base station.

Checks to Known Control - The accuracy of the survey can be determined by performing checks to well known or accurately determined points. These ties to known points will also help to eliminate any human blunders. Survey known points after initialization and compare the coordinates. The coordinate differences should be within the accuracy requirements of your survey.

As mentioned, another good practice is to record raw observations in the base station and post process these data to verify the setup.

When working with RTK/RTN it is necessary to ensure the computed coordinates are compatible with the desired reference frame. If the coordinates are not compatible, then an empirical fitting of field RTK measurements to published control monument coordinates is required. This fitting is known as a local transformation or **calibration.** This calibration will require a minimum of four horizontal and four vertical control points well distributed around the local project area. Ideally these control points should form a rectangle outside of the project area to the best extent possible.

Checks

As with any measurement technique, repeated measurements are required for an accurate and reliable solution. The receiver quality indicators are useful in alerting the user of potential problems, but the user must also take steps to minimize the random and systematic errors associated with RTK/RTN surveys.

Most receivers will allow the user to compute a mean position over a specified time period (time window averaging). Recommended observation times are at least one minute for control points and five seconds for topographic points.

Periodically re-initialize on a known or previously surveyed point to check the repeatability of measurements and ensure the initialization is correct. A complete re-initialization should be performed several times per day.

Re-occupation of critical points should be preformed after a suitable time has passed, with a new initialization and ideally from a different base station.

For the ultimate check, establish multiple base stations and measure each rover point (or a subset) from more than one base station. This provides verification on all factors in the point determination: base station setup, base station (reference) coordinates, rover setup, antenna heights, and GNSS measurements.

For a quick check, compare RTK/RTN derived distances to total station derived distances between stable points.

Quality Control

To verify topographic field data collection meets accuracy standards, Quality Control Audit observations should be collected on all typical features surveyed at a suitable interval. If a digital terrain model (DTM) is being derived from the topographic survey, audit strings should be collected, and points compared to the final DTM surface.
Audit observations must be collected from an independent station set up from which the original data was collected. If RTK or RTN equipment was used for topographic collection, an alternate collection method should be used for independent Quality Control Audit observations.

Terrestrial Scanners (Mobile vs. static) (Paul Francis)

Overview of its usage for topographic surveying

Specific Considerations/Limitations with respect to feature capture

Accuracy Considerations

Calibration and Testing Practices

Unmanned Aerial Vehicles (LIDAR)

Overview of its usage for topographic surveying

Specific Considerations/Limitations with respect to feature capture

Accuracy Considerations

Calibration and Testing Practices

Unmanned Aerial Vehicles (Photogrammetric)

Overview

This report is intended to provide a living document, to overview the considerations and best practices for incorporating the use of aerial imagery and point cloud technologies into existing topographic survey workflows.

A Drone Survey may refer to the use of a remotely piloted aircraft system (RPAS) to capture aerial data with various sensors, such as RGB or multispectral (infrared, thermal, etc.) cameras or LiDAR payloads.

(For now) this guide will be restricted to the use of RGB cameras and the use of photogrammetry software to convert the image pixels to coordinates.

Goals

1. Broad overview of recommendations and best practices involving the use of drones & point clouds to prepare / integrate with topographic surveys
2. Promote quality control / quality assurance through discussion of risks and considerations
3. Focus on photogrammetry. LiDAR systems left as topic for future report.
4. Avoid repeating information presented in UAV for Managers (2019, Thomas Hoppe)
5. Compile list of industry terminology
6. Share links to further resources

To Own a Drone: Considerations

The question of whether or not to integrate a drone based imagery system into an existing workflow or into an existing survey firm, involves cost/benefit considerations such as:

1. Areas of existing practice that could benefit from improvement (ie data capture)

   Can this technology improve the existing workflows, or survey products, prepared by the survey firm?

   "Investigate if this technology will fulfill specific needs in a manner that your existing practice already addresses, but in a more efficient and potentially profitable manner" - Thomas Hoppe, 2019

2. New business applications, such as:
   a. Topographic Surveys (incorporating Orthomosaic or 3D Model)
   b. Volumetric surveys
   c. As-built surveys
   d. Infrastructure Inspections / Monitoring
   e. Building Information Modeling (BIM)
   f. 3D Modelling

3. Risks to implementing new technology / changing workflow
   a. Costs for training staff
   b. Capital expense for Drone Hardware, Software, Computer, Licenses
   c. Disruption to business practice
   d. Errors resulting from inadequate QA/QC
   e. Transport Canada Pilot License Requirements

Drone Mission: Pre-Flight

'Mission Planning' as a regular practice in drone data capture, is fundamental for the safety of the public, accuracy of the data, and profitable implementation of this technology in business over the long term.

Considerations for Mission to be determined and prepared, ahead of flight day:

1. Area of Interest (AOI)
    a. Flight altitude to cover entire site, determined by balancing available battery life vs. required GSD (ground sample distance) or "level of detail required"
2. Obstacles
    a. Physical (trees, buildings, power lines, radio towers)
    b. Geo-fences (No fly zones, Hospitals, Airports, Military airspace, etc.)
    c. Nearby aircrafts
    d. Site considerations (Visual Line of Site requirements, Transport Canada)
3. Safety Considerations
    a. Risks to flying over people, roads, property (license and insurance limitations)
    b. Mitigation measures (limiting site access, obtaining permissions, parachute hardware)
4. Weather; forecasted conditions
    a. Overcast is best
5. Type of Flight
    a. Waypoint
    b. Grid (single, double)
    c. Oblique
    d. Path / Corridor
    e. 3D object scan / dome
    f. Manual
6. Flight path(s) criteria
    a. Altitude & resulting Ground Sample Distance (GSD)
    b. Image overlap (recommended minimum 70% Side Overlap and minimum 80% Frontal Overlap)
    c. Flight time, battery power required

d. Ground control point distribution / layout

    i. Required to obtain acceptable accuracy for Non-RTK Drones

    ii. Highly recommended QA/QC for RTK-Drones

e. Take off and landing points

f. Speed (dependent on Shutter Speed, ISO, Altitude, light conditions, drone limitations, etc.)

g. Variation in terrain elevation

7. Site Challenges: obstructions to the camera to photograph the ground surface

    a. Tree cover

    b. Harsh light conditions (overexposing bright areas, underexposing shadows)

    c. Surface water (reflections)

    d. Agriculture (crops in fields, long grass, etc.)

    e. Tall buildings

    f. Vehicles, etc.

8. Emergency protocols

    a. Emergency landing locations

    b. Loss of comm-link

    c. Parachute deployment

    d. Feasibility of maintaining Visual Line of Sight (VLOS)

Drone Mission: Flight Day

Prior to flying, a comprehensive site inspection should be performed to identify any hazards not predicted in the Pre-Flight Mission Planning. All sources of risk must be minimized and managed. Until a qualified and licensed pilot has assessed all of the risks and has established a flight plan that is understood by all field personnel, the decision to fly will then be made on site.

All aspects of the Flight Plan should be known ahead of time, including but not limited to:

1. What type of Mapping Mission is used to map AOI?
2. How many flights are necessary to map AOI?
3. Can mapping missions be paused and resumed during battery swaps?
4. Emergency landing locations if loss of power or connectivity
5. Can the drone map AOI at the same altitude, or is the drone capable of ‘Terrain Following’?

Most commercial and even recreational drones have onboard calibrations and corresponding methods of error reporting. These are necessary procedures not only to ensure data correctness, and avoid duplication of fieldwork, but also to meet Transport Canada license requirements, and ultimately ensure the safety of the public when flying in populated areas. These may include but are not limited to:

1. Compass calibration
2. Gimbal calibration
3. IMU Calibration
4. Camera/lens Calibration
5. Software and firmware updates
6. Fly-Safe Zone updates
7. Physical inspections of equipment before and after each flight

Much the same way as Surveyors are required to record, maintain and provide field notes that describe the location, coordinate system, control, date, time, etc. of all fieldwork completed, a Drone Pilot is required to enter into their own record a report of various details of each drone flight, to meet Transport Canada License requirements. These are described in more detail on Transport Canada's website.

A final flight checklist must be followed before the Go/No Go decision is made.

Planning all details of a drone's flight for data acquisition, ahead of Flight Day, is prerequisite to successfully implementing this technology.

Use of Drones for Topographic Surveying

The integration of drone-based photogrammetry into a Topographic Survey workflow, most often, is done so with the intention of thereby substituting the labour of collecting 'ground spot elevations' collected with GNSS or Total Station. Not always but most often, a Surveyor's intended 3D Model is of the ground itself; This is known as a Digital Terrain Model (DTM), or a representation of the Earth's ground surface. A DTM differs from the raw data that a Drone originally collects, which includes all 'non-ground' information as well, such as cars, buildings, vegetation, etc., and known as a Digital Surface Model (DSM).

A DTM can be represented by a variety of data formats, but a typical workflow follows this pattern, from beginning to final product:

1. JPEG images captured with drone (plus EXIF data; ie. Drone position, IMU orientation, Camera settings, etc.)
2. Modeling Software generates 3D Point Cloud
3. Modeling Software classifies (reduces) 3D Point Cloud to ground surface points only
4. Modeling Software generates DTM based on classified ground surface points
5. Modeling Software, or CAD Software used to produce spot elevations, cross sections, contours, etc., based on DTM

6. Spatial Data incorporated together with GNSS or Total Station measurements (of features undetectable by remote sensing, such as ditches, regions under tree canopy, near buildings, etc.) to complete topographic survey.

A consideration to the many limitations of remote sensing, to reliably measure spatial information within a project's Area of Interest, is fundamental to successfully integrating this technology into a regular workflow.

A pre-flight site inspection should identify any hazards, or problematic areas, not detailed in the pre-flight mission planning.

Areas of dense vegetation, tall grasses, crops, must be noted in the field notes. In much the same way that accuracy and precision of GNSS observations is affected by error sources as such multipath (reflections from buildings, water bodies, etc.) and tree canopy (limiting satellite constellations); limitations of photogrammetry must be taken into the same consideration; to inform the Surveyor as to the time and place for its appropriate use for reliable spatial data acquisition.

In Southern Ontario, the Spring (after snowmelt and before new foliage) is the commonly accepted ideal conditions for Drone Surveys. Vegetation is flattened from the winter, allowing RGB cameras (and LiDAR sensors) to capture unobstructed ground elevations.

Areas populated with undesirable information such as parked cars, buildings, trailers, etc. must be considered and noted, and, if intended in the resultant topographic survey, this 'noise' should be eliminated from the Digital Terrain Model (DTM) to reduce complexity and uncertainty in deliverables, or alternatively reported to client. A 'Reasonable Test' when reviewing contours should be used to identify erroneous features that are not part of the DTM. While most Modeling Software can interpret the DTM surface under noise such as tree canopy or vehicles, it is necessary to evaluate the results for blunders, etc.

Use of photogrammetry to collect spatial information must be considered complementary to other existing tools, to achieve a targeted result. Photogrammetry cannot substitute the need for redundant checks of the modeled Digital Terrain Model (DTM). Audit lines or random checkpoints must be measured in conjunction (but independent from the data used to triangulate the photogrammetric survey) to evaluate the performance of the resulting modeled surface.

Point Clouds / Deliverables

Commercial software packages that convert jpeg images and exif data do so in a 'Black Box' fashion; complex algorithmic processes adjust and coordinate the inputted image pixels with unfortunately minimal reports on error, regions of higher or lower accuracy confidence, etc. It is up to the Surveyor to evaluate and ensure the data that is produced through photogrammetry meets all relative and absolute accuracies required, across the entire AOI.

Because of the volume of data that results from photogrammetric modelling (100,000 to 500M points), it is also necessary to have a clear understanding of the intended end product, not only to limit risk/liability to the Surveyor, but also to maintain efficient use of data. Large datasets are produced through remote sensing; the intended lifespan/path of the data should be considered when making decisions of file sizes/information complexity. Who is the end user/ what are their computational limitations?

The following questions regarding deliverables should be considered at the project outset, to ensure client's expectations are met regardless of the technologies used to produce the Topographic Survey:

1. The intended area of interest (AOI)
2. The type of product the client requires
3. The file format expected by the client
    a. Printed plan
    b. PDF
    c. CAD File
    d. Shape File
    e. DXF
    f. Point Cloud File
    g. BIM
4. The required resolution (GSD) of the ground surface
    a. Spot Elevations approximating a 10-m x 10-m grid?
    b. Deviation from mean by specific value (ex. Airport runway as-built)
    c. Contours at specific intervals capturing minimum undulation
    d. Specific features captured (ex. Rock outcrops, swale, etc.)
5. Level of complexity / detail that client requires, which will inform the Surveyor to how much simplification should be made to the point cloud
   Data is typically 'thinned' to generate simplified ground surface data that is more manageable (by Surveyor and Client) than full point cloud.
6. Results that will meet (and not exceed) the client's expected scope of work, computational limitations, and accuracy requirements.

Terminology

https://dronedeploy-www.cdn.prismic.io/dronedeploy-www/b5113c60-3e8b-4cbe-9669-6a8e9f632c92_2020+Q3+Drone+Glossary+ebook.pdf

https://www.hovrtek.com/drone-operations/drone-terminology/

https://www.dslrpros.com/dslrpros-blog/drone-vocabulary-glossary-terminology/

https://www.dronetechaerospace.co.uk/drone-industry-glossary-of-terms

https://www.microdrones.com/en/other/glossary/

https://www.sensefly.com/blog/drone-dictionary-essential-terms-every-pilot-should-know/

Links

To be added based on interest

Sub-surface (echo sounders)

Overview of its usage for topographic surveying

Specific Considerations/Limitations with respect to feature capture

Accuracy Considerations

Calibration and Testing Practices