City of Toronto
Geospatial Competency Centre

Specifications for
Aerial Photography and Photogrammetric Services
2013

This document may be used by agencies outside of the City of Toronto. It uses and where appropriate modifies geospatial standards and specification adopted by Canadian and US agencies listed at the end of section one. This document is modified to fit the City of Toronto Call Document Process.
AERIAL MAPPING SPECIFICATIONS

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1 PURPOSE

This document provides the language and specifications for aerial mapping and photogrammetric services to acquire, edit, or maintain the following spatial products:

1) Controlled Aerial Photography
2) Aerial Triangulation Results and Report
3) DSM/DEM/DTM as required
4) Stereo model images, orientation files (DVP format)
5) ASCII orientation files, match to item 4 for one other softcopy photogrammetric system
6) Ortho-image
7) Update Ground Control Point Database as required
1.1 Brand Name

Any reference to a trade name, brand name, or website of a particular manufacturer made within this document shall be understood to have been made solely for the purpose of establishing and describing general performance and quality levels of the deliverables to be supplied, unless otherwise specified. No reference to the trade name, brand name, or website shall be construed to restrict proponents/Contractors to that manufacturer, but proposals shall be deemed to be invited for an equivalent of any manufacturer.

1.2 Supporting Documents

All links checked as of March 01, 2012

1) Federal Digital Image General Contract Guidelines Version 1.0


6) Part 2, Digital Ortho-image, FGDC-STD-014.2-2008

7) ISO19127 Geographic information – Geodetic codes and parameters


9) Nova Scotia Topographic Database Specifications

1.3 Writers, Contributors, Peer Reviewers of this document include

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2) Mike Robertson, Manager, OMNR, Ontario Canada

3) Dr. Yuri Raizman | VP EMEA & Chief Scientist
2  CONTROLLED AERIAL PHOTOGRAPHY PROJECTS

2.1  Aerial Photography and Photogrammetric Services Deliverables
The following are the deliverables for Controlled Aerial Photography and photogrammetric service Projects:
1) Proposed flight plan over the coverage area in shape file format
2) Digital Image Collection Survey Plan
3) Quality management plan
4) Attend project management meetings as required
5) Email/telephone notices
6) Flight Execution and image analysis report
7) AT adjustment report
8) Status of stereo model coverage
9) Performance, status and progress reports.
10) Quality Control certificates
11) Stereo Model and Neat area Report
12) Final set of images and .dat and .par orientation files in DVPv7 format for 3D stereo feature collection
13) Set of orientation files for one other softcopy photogrammetric system to allow use of these images produced for this project in another softcopy photogrammetric system.
14) image warranty certificate
15) DEM update and report
16) Ortho-image Report
17) Delivery of ortho-series

All files delivered back to the City on an labelled internal SATA hard drives, with spindle speed no less than 7200rpm. The hard drives will become property of the City of Toronto.

2.2  Statement of Work - Annual Land Base Maintenance Requirements

1) In Toronto, controlled digital mapping camera Red, Blue, Green, Near infrared (RBGir) aerial images are normally acquired between March 1st and April 30th each year.
2) If the camera sensor includes a higher resolution PAN band, the pan band must be included in the delivery as a one set of stereo images with their own orientation files.
3) The maximum Ground Sample Distance is not to exceed 6cm in any Controlled Aerial Photography
4) Discrepancies on Ground Control Points (GCP) between geodetic and photogrammetric coordinates measured on a stereo model to have RMSE less than 8 cm\(^2\).
5) Elevation derived from stereo-models shall have a RMSE not exceeding 20cm in Z
6) The final stereo neat model should not be less than 0.08 sq km.
7) Complete stereo coverage up to and including the 2km buffer
8) The maximum image sensor bit-depth must be used in all captured images.
9) Exposure should be set to maximize the bit-depth within the range of the sensor and should not be overexposed/saturated.
10) All images shall be radiometrically balanced to ensure consistency throughout the entire project area
11) Derived ortho-images shall have a GSD not exceeding 8.5cm and RMSE not exceeding 10cm in XY

\(^1\) Dr. Yuri Raizman  |  VP EMEA & Chief Scientist, personal correspondence March 1, 2012
12) Final Minimum bit depth for stereo model images and ortho-image may be reduced to 8 bits unless modified by a change request order reflecting the City’s ability to process larger image files with High Dynamic Ranges.

13) Associated adjustment reports, stereo model images and orientation files to be delivered no later than 100 days after the last day the image was finally captured.

14) A sample stereo model deliverable should be provided to the City to ensure that it complies with our specification within one month of the date of acquisition.

15) If pan-sharpening is used, it must be noted where it used and what band was used for pan-sharpening purposes.

16) The Image shall be clear and sharp and evenly exposed across the format. The image shall be free from clouds and cloud shadows, smoke, haze, light streaks, snow, ice, flooding, excessive soil moisture, static marks, shadows, hot spots, and any other ground surface blemishes that interfere with the intended purpose of the Image.

17) All the spectral bands must be accurately aligned. All red, green and blue and near infrared colour bands must be collected at the required GSD to provide true multi-spectral image at that GSD.

18) The creation of interpreted, interpolated, or pan-sharpened colour band data for stereo modelling purposes is prohibited.

19) The Contractor shall deliver digital Image as overlapping frames with a single perspective centre.

20) Regardless of the sensor employed and the techniques used to orient the Image, the successful vendor MUST provide the interior and exterior orientation files to enable viewing of the final RGBir stereo models and feature data collection in our existing DVP softcopy photogrammetric environment.

21) The successful vendor MUST also provide the interior and exterior orientation files to enable viewing of the final RGBir stereo models and feature data collection in one other softcopy photogrammetric environment. It is expected that by summer 2013, the City of Toronto will have a new softcopy photogrammetric environment.

22)

23) All images used for stereo modelling shall be delivered with grid north at the top of the digital image with embedded meta-data recording the XYZ of the principle point and direction of the flight line along with the other required meta-data elements. (See section on Image Meta Data Requirements)

24) All digital frames/Image acquired shall be supplied to the City in numerical frame order on a hard drive. Unless otherwise specified, hard drives are provided by the Contractor as part of the deliverables and will not be returned. Each hard drive should be well labelled and include a readme file that identifies the complete set of deliverables on each drive. Associated product metadata and shapefiles (flight lines, tile indexes etc.) should also be included with each set of deliveries.

25) There is no requirement for contact prints.

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2 For 2012, all aerial imagery must be captured at the maximum bit depth of the sensor. As the City acquires faster CPU’s and GPU’s and system architectures develop to handle larger files with greater bit depth, the City will start taking advantage of High Dynamic Ranges to peek into the lightest and darkest area of an image. Wider dynamic range, (bit depths greater than 8), allows images to more accurately represent the range of intensity levels found in real scenes ranging from direct sunlit areas to faint shadow areas. The wider dynamic range increases the ability of stereo models operators to make wider and finer hue, saturation, and contrast image adjustments. However, for 2012, the Bit Depth = 8 in the final stereo model images and ortho-imagery.

3 There will always be shadows. Objective is to minimize the amount of shadows by limiting flying hours, and minimizing the time between successive passes of the same point where the shadow will change or two different shadow lines may occur – such as at a light standard.

4 Note – this is a software problem with DVP. The version of DVP does not know how to read the A3 images. This specification may be dropped one we replace or upgrade our DVP system purchased in 2001.
26) The 4 band, 16-bit data digital cameras seem to provide the best data yet for integrated photogrammetric and remote sensing mapping. Digital camera's strong geometry enables 4-band analysis at the “per-pixel” resolution. With larger overlapping frames, image features from adjacent overlapping frames can be confidently and accurately interrogated at the per-pixel resolution, to enable the advantages of increased classification accuracy.
3 GEOGRAPHIC EXTENT OF ANNUAL AERIAL MAPPING PROGRAM

(1) The contract areas for 2012, 2013, and 2014 are illustrated in Figure 1. It illustrates the 2km and 3km buffer around the City. The flight planning mission must be designed so that there are no gaps between images straddling the two kilometre buffer. At least two principle centres must fall within the 2km-3km zone. **Total Area within 2km Zone = 907 sq km**
3.1 Coordinate Reference System
The Coordinate Reference System for the City of Toronto's Enterprise Geospatial Environment and the final delivered stereo model images and associated .dat and .par files is:

1) Horizontal Datum: NAD 1927, 1974 adjustment
2) Projection: 3° Modified Transverse Mercator (MTM), Zone 10
4) Units: metric

1) For the ortho image series which are moved from 1968/74 adjustment of NAD'27 to NAD'83 CSRS, do not use the Provinces NTv.2 Grid shift file. In 2005 the City in conjunction with NRCan and the Province developed a City of Toronto specific grid shift file called TO27CSv1.gsb. This grid shift file provides transformations with far lower residuals than NTv.2. (Note - NTv.2 was developed to transform NAD'27 positions to NAD83 CSRS).

2) For the purposes of this contract all ground elevation points are to be reported as orthometric heights.

3.2 Ground control points
A ground control point file will be supplied by GCC. Contractors may supply their own ground control points used on previous missions over the Toronto region provided they support the computations required to achieve a RMSE of less than 8cm in the final stereo images. All Ground Control Points used must be reported as part of the Aerial Triangulation Adjustment Report.

All Ground Control Points coordinated will be reported using NAD 1927, 1974 adjustment, 3° MTM

3.3 Ground Control Point coding scheme
1) A minimum of 20 survey grade check points will be utilized to verify bundle adjustment results.
2) Check points will be measured and their weights set to zero (0) for all iterative and preliminary adjustments.
3) Check point residuals should be within the accuracy specifications defined in this document, without any weight applied.

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5 The City of Toronto was adjusted in 1968. The province performed its first adjustment in 1974. That adjustment held the Toronto control from the 1968 adjustment as fixed, thereby including the 1968 coordinates in the 1974 adjustment, so the City control values from the 1968 adjustment are part of the province's 1974 adjustment

6 The city is CGVD 28 excluding or preceding the 1978 Southern Ontario Re-adjustment. The City did not adopt or incorporate the 1978 readjustment values and sustains the PRE 1978 values.

4) For proposed reduction and final adjustments (Systematic Reduction and Final Adjustment), check points will be re-classified as horizontal, vertical or full/combined control and used as such to add strength to the bundle adjustment solution.

3.4 Ground Control Numbering System

1) Visible Ground Control Points used will be located coded, and symbolized. Suitable point symbolization will be applied. Sketches, drawings or, preferably, digital images of the location of each ground control points should also be included as a deliverable. These are necessary to ensure that the GPC’s are easily discovered during the Quality Assurance process.

2) Flight Line numbers, image annotation codes are pre-determined before Aero triangulation, and should be adhered to unless otherwise instructed.

3) Annotation Code: is the annotated photo number applied after the photography is flown.
   a) <YYYY-Mission-Line-exposurenumber

3.5 Flight planning data provided to contractor during the Call Process

1) The City of Toronto will provide sample products to illustrate the quality and accuracy of the products to be delivered.

2) The City of Toronto will provide a digital elevation model, the Toronto Street Network, digital extent of coverage, and digital index of visible ground control points8 to assist with flight planning.

3) Series meta-data structure, and file meta-data structure.

3.6 Production of DVP v7 format files

1) The stereo pair of images and associated orientation files in DVP v7 format shall:
   a) include all bands aligned and non-pan-sharpened
   b) Display the approximate GSD resolution being offered as indicated in this statement of work
   c) have a minimum bit depth of 8 bits per colour/infrared channel
   d) The contractor shall provide a high level description of the sensors and process proposed for this project

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8 Note: A quality control set of visible ground control points will held back by the City and will be used to test the horizontal and vertical RMSE for a selected sample of images used for stereo-modelling purposes.
4 IMAGE ACQUISITION REQUIREMENTS

4.1 Flight Planning

1) Acquisition period is between March 1st and April 30th each year unless otherwise noted in statement of work or until leaf-out conditions occur.

2) This section assumes an airborne platform will be used to capture required Image. Alternate forms of Image will be considered if it can be demonstrated it meets our requirements.

3) As stated in the statement of work requirements, all aerial image acquisition flights must be completed before leaf-out conditions.

4) It is the responsibility of the contractor to obtain all approvals to fly over the City for this Project.

5) The Contractor shall select a suitable focal length and flying height to achieve the required ground sampling distance and minimize the tall structure lean effect not more than 15%\(^9\) in both directions – along and across the flight line in built up areas.

6) The flight plan must be designed to enable generation of final stereo-model images\(^{10}\) having a maximum pixel ground sample distance, GSD, of less than 0.06 m for the purposes of softcopy Photogrammetric Mapping, photo-interpretation, change detection, digital elevation modeling, and the generation of high resolution ortho-images. The geometric accuracy of the images must be better than 2µm.

7) For the purposes of planning, the GSD is at the edge of the camera's field of view. Section 12.4 GSD, provides a sketch illustrating that the our requirement, 6cm > max GSD at the edge of FOV > Nadir GSD.

8) It is the responsibility of the contractor to flight plan each mission and select the appropriate aerial platform, GPS/IMU and camera sensor to meet our project specifications.

9) North/South flight lines do not move easily into a stereo-environment. Our default flight orientation assumes that the flight lines are flown east/west. It is our goal to be able to see as many objects on the ground as possible, and minimize the number and size of the stereo-models needed to cover the land out to the 2km buffer. It is up to the aerial mapping company to develop the most efficient and effective flight pattern to minimize temporal changes between lines\(^{11}\).

10) Each flight line will cover the City and the 2km buffer around its boundaries. Each flight line will extend outside the 2km buffer area by a minimum of two principal points at the beginning and end of each run.

\(^9\) Dr. Yuri Raizman | VP EMEA & Chief Scientist, personal correspondence, March 1, 2012

\(^{10}\) this implies that the raw aerial images captured need to have geometric accuracy of the images is better than 2µm

\(^{11}\) For consideration if flight lines can be flown parallel or perpendicular to the final MTM grid lines, this may result in a more efficient file size, less resampling of the of Imagery, and better edge matches prior to creation of the orthoimage tiles.
11) The first and last runs will have a minimum of 20% of each photograph extending laterally outside of the boundaries of the specified area.

12) The proposed flight plan must be delivered in ESRI .shp format, showing actual start and end of each numbered line.

13) The Contractor is responsible for selecting all imaging lapping parameters, (for example forward lap, sidelap, end lap) and to state what overlaps are used to minimize tall structure building lean to less than 15% and to ensure enough overlap to assist the automatic creation of DSM.

14) The design of the flight and image capture equipment used should enable and maximize the use of Multi-ray processing for auto generation of DSM.

15) Where tilt and/or crab are greater than 5° the photography may be rejected. In addition relative tilt between successive photographs shall not exceed 5°, and the average tilt for any flight line shall not exceed 2°.

16) Compensation is to be made for crabbing and drift by rotating the camera about the vertical axis such that the lateral edges of each frame are parallel to and not displaced laterally from the intended flight path by more than 5% of the specified side overlap. Vertical Image should not show the effects of forward motion of the aircraft. Image movement should not exceed 20 microns in any axis. Average Aircraft tips and tilts and crabbing effect for any flight line shall not exceed 2°.

17) Shoreline coverage - Flight lines running parallel to a shoreline may be repositioned to reduce the proportion of water covered provided the coverage extends beyond the limit of any land feature by at least 30 per-cent of the strip width. The City desires to have no black or no data pixels present within the two kilometre buffer around the City. The lake area beyond the 30 per-cent strip width may be flown at a “higher altitude” with less overlap to ensure that no “black or null Pixels” exist within lake side 2km buffer in the final ortho-images. Contractor is to ensure that these coarser lake only images are colour balanced to the higher resolution imager where they overlap the 30 per-cent strip. GSD, horizontal accuracy, and vertical accuracy will be relaxed between the 30 per-cent strip and the 2km buffer over water. Optionally, existing lesser resolution Raster Image may be used in this area only provided it was captured at or near the time as the flight for this standard and specification. The objective is to be able to see sediment patterns out to the 2km buffer.

18) The sun angle for this project must not be less than 30° and preferably closer to 35°.

19) Digital Image Collection Survey Plan – Prior to data acquisition, the contractor shall create a Digital Image Collection Survey Plan which will be provided to the City’s Project Manager, that contains and specifies:
   a) General overview of Digital Image Collection Survey Plan

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12 According to Dr. Yuri Raizman, For RC30/150 - forward overlap 80% yields maximal building leaning along flight 16%, side overlap 30% yields maximal building leaning 56% across flight. For other cameras such as the UC-Xp to get maximal building leaning of 15% you need to fly with side overlap of 71%, and for forward overlap of 60% the building leaning will be 13%. It seems that that since we want to have a geometrically homogeneous ortho-photo, the only way to do it – to define the building leaning as a main parameter and not a side/forward overlap!!!

13 Digital cameras have 12-16 bit dynamic range which in theory, should provides longer flying times. Useful data can be extracted from the images in poorer flying conditions.
b) Proposed map of the flight plan over the coverage area

c) Image acquisition and processing workflow

d) the **Quality management plan** and measures used to ensure all products delivered meet our specifications.

e) the data collection parameters to be used matching our specifications

f) Minimum/Maximum solar angle

g) Time between parallel flight lines to minimize shadow shifting

h) Physical configuration of sensors, GPS/IMU

i) Camera type and Camera sensor resolution, pixel reference\(^\text{14}\)

j) Calibrated focal length

k) Flying height and how departures from flight heights will be controlled to met our GSD of less than 6cm

l) Proposed Average Speed over ground and max speed to minimize image smearing. Maximum speed not to exceed the sensor manufacturer's guidelines

m) Image smear shall be kept below 1%\(^\text{15}\).

n) Proposed distance between (image frame) photo centres

o) Proposed image footprint

p) Minimum image over-lap parameters at the mean elevation of the ground to meet our stereo modelling requirements

q) Proposed neat model coverage

r) Maximum Crab, and how crab is controlled to maintain required side lap between flight lines

s) Maximum Tilt in degrees for the entire project

t) where the departure from the vertical stops aerial image capture and how tilt is controlled between successive images

u) Maximum roll

20) The Contractor shall notify the City when the aircraft will be flying over the City, on a daily basis until the acquisition has been completed.

\(^{14}\) Pixel reference. The reference of the camera sensor coordinate need to be stated as they may be at the centre of the pixel or to one corner of the pixel. A correct definition is required to correctly define the principle point offsets. A shift of half a pixel may have considerable impact on the AT results.

\(^{15}\) Bidder to state what percentage will be met. I don't want to limit the type of camera used, but I do want sharp clear photography with little or no smearing.
4.2 Flight Execution and Flight/Image Analysis

1) It is the responsibility of the contractor to obtain all approvals to fly over the City for this Project. The Contractor will notify the City when the aircraft will be flying over the City, on a daily basis until the acquisition has been completed.

2) Aircraft Operation. The contractor is to ensure that aerial platform used meets all Transportation Canada’s standards and specifications for aerial mapping missions.

3) The contractor shall ensure that the crew and aircraft used have permission to fly and land in Ontario.

4) The contractor shall adhere to their Quality management plan and report on the methods, procedures, and measures to ensure that our project requirements are met.

5) Daily progress reports are required to be transmitted to the City Project Manager one day after each day of progress during the flight execution stage and flight/image evaluation stages of this contract.

6) The Contractor shall inspect and monitor the image coverage, image quality and spatial resolution to ensure that the images are clear and without visible sensor artefacts after each daily mission is completed.

7) The Contractor must avoid excessive shadow movement in the Image between flight lines. Different shadow angles can have an adverse effect on stereo viewing and automated join routines between flight lines where automatic point selection is used in the aerial triangulation phase. If the project area cannot be completed in one sortie, or on the same day, every effort must be made to complete the outstanding flight lines at the next weather window of opportunity with overlapping runs captured as near as possible to the same time as the previous runs.

8) Image smear. When image smears or artefacts occur, efforts shall be made to correct them or to identify them as anomalies. Where feasible, areas of image smear may spatially be defined as polygons, linked to documentation in lineage metadata.

9) Re-flights shall immediately be undertaken where image coverage, image quality and spatial resolution fails to meet the minimum requirements of the contract specifications.

10) All deficiencies in the quality of the Image must be reported to the City Project Manager and how they were corrected.

11) Any delays need to be reported.

12) If in the opinion of the City's Project Manager, the Contractor has adhered to the specifications and has exercised reasonable care to meet our requirements, allowances may be made for unavoidable shadows, snow, ice, reflectance, and leaf-on conditions.
5 QUALITY REPORT AFTER MISSION

5.1 Airborne positioning and orientation report

1) Actual completed flight log listing for example:
   a) sortie/mission number;
   b) pilot and crew identification sheet
   c) Datum and projection used for Sensor, GPS, IMU
   d) Data set ID
   e) flight lines flown on this flight area covered by the data set
   f) Sensor Model Definitions settings, with data collection parameters set matching our specifications
   g) calibration reports
   h) Image Bit-depth
   i) Filters used if any
   j) general altitude
   k) sun angle at start and stop of each flying mission
   l) Deviations from planned forward-lap, side-lap, end-lap, overlap
   m) all images to be internally labelled with filename
   n) ascii table Date/time of image capture, frame_image#, altitude, Grid XYZ for each photo centre.
   o) Confirmation that Quality management plan was implemented and measures used to ensure all products delivered meet our specifications.
   p) See Section 9, Packing and Marking, for file naming conventions

2) Report on actual flight conditions at time flight listing for example:
   a) cloud cover;
   b) ground conditions
   c) atmospheric conditions
   d) filters used
   e) how crab, tilt and roll is controlled while collecting digital image in order to maintain agreed to image overlap

3) State positioning methodology, GPS processing solution, ground stations used
   a) State where GPS lock was lost and method used to recover lock
   b) Provide max, average, and minimum PDOP/VDOP observed during flight.

4) Contractor to provide a digital file of flight lines, re-flight lines, and point index of all aerial image principle points by filename.

5) A plot shall be provided illustrating:
   a) the annotated flight lines
   b) the number of the starting image along the flight line, every tenth image number, and the ending image number

6) Plot Statement - "The Digital Image Collection Survey" was executed and all image provided for stereo modelling purposes has an oblique ground sample distance at the widest field of view not exceeding 6cm"
6 AERIAL TRIANGULATION

6.1 Aerial Triangulation plan

1) The Contractor will design the Aerial Triangulation plan to maximize the geometric accuracy of all the required products and ensure that the final images and their associated orientation files in DVPv7 format will meet or exceed our project specifications and achieve our point positional accuracy of less than +/- 0.08m in X and Y and +/- 0.20m in Z.

2) The Root Mean Square Error (RMSE) of the observations on well defined points within an image should be no larger than 0.5 pixels\(^{16}\). Any RMSE greater than 0.5 pixels, or in other words greater than half the scanning resolution of the image, infer systematic and/or observation errors and will be rejected.

3) Excessive errors due to poorly measured points or incorrect calibration parameters may be justification for rejection of aero triangulation submissions.

6.2 Ground Control Point Measurements

1) The City's database of visible horizontal and vertical Ground Control Points\(^{17}\) will be provided to the Contractor for the purposes of this contract.

2) If the contractor identifies a requirement for additional ground control and/or placement of targets, they are to notify the City and make a change request. Once the change request is approved, the contractor may undertake the necessary work. A copy of all new Ground Control Points XYZ values, diagrams, location sketch, site photographs, are to be supplied to the City.

3) Any Ground Control Points from other sources must be delivered to the City along with a report of the source material's lineage, including:
   a) date of acquisition;
   b) Datum, projection;
   c) producer(s) of the data set;
   d) source products used;
   e) methods used to derive the control points;
   f) accuracy specification requirements under which source data was produced;
   g) photo scale;
   h) GSD; and
   i) estimated horizontal spatial accuracy if not known.
   j) Copyright if any

6.3 Interior orientation parameters (IOP)

1) It is assumed that the IOP determination of the interior perspective of the image is as it was at the instant of exposure. Interior orientation refers to the geometric relationship between the image plane and the perspective center of the lens.

2) For Digital mapping cameras such as Vexel UltraCam – the interior orientation is the same for each frame.

\(^{16}\) http://www.nsgc.gov.ns.ca/mappingspecs/Specifications/Aero/SoftcopyAerotriangulation/default.htm

\(^{17}\) Given that the final RMSE of the images need to be less than 8cm and that the final GSD in all images needs to be less than 6cm; it seems that any Ground Control Points have a RMSE of less than 1/2 pixel which is approximately 3cm.
6.4 Tie Points
1) The root-mean-square error (RMSE) for tie points should be less than 3-4µ in x and y. Contractor shall state the RMSE for tie points achieved. Triangulation results for automatic tie point matching should indicate an accuracy of 0.1 – 0.2 pixel.

6.5 Aerial Triangulation Block Preparation
1) It is important to process the data from the initial flight as soon as possible. This includes matching the image frames to ABGPS and IMU data. Problems related to snow, ice, or water on the ground, sun angle to low or too high, clouds or their shadows in the Image, missing frames, and stereo gaps may require re-flying. If re-flights are required, report on which image sets will be used for the AT process.
2) Additional Ground Control Points may be needed at key locations to support setting up of the final stereo-models, ensuring that lake surface is level, and that watercourses maintain a correct directional flow.

6.6 3D Bundle Adjustment
1) The Contractor must process aerial images along with airborne GPS/IMU positional data and Ground Control Points as required and complete the aerial triangulation with the largest blocks possible.
2) The City reserves the right to hire a qualified independent contractor, if required, to examine the adjustment solution. The Contractor must provide full cooperation and resources to resolve issues that may arise regarding the adjustment solution.
3) The aerial mapping contractor will test the derived accuracy of points from the stereo model by comparing the stereo model coordinates of well-defined points in the dataset with coordinates of the same points from an independent source of higher accuracy.
4) Vertical accuracy shall be tested by comparing the elevations in the dataset with elevations of the same points as determined from an independent source of higher accuracy.
5) Errors in recording or processing data, such as reversing signs or inconsistencies between the dataset and independent source of higher accuracy in coordinate reference system definition, must be corrected before computing the accuracy value.
6) A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset.

6.7 Accuracy Reporting
1) Positional accuracy values shall be reported in ground distances.
2) Metric units shall be used.
3) The number of significant places for the accuracy value shall be equal to the number of significant places for the dataset point coordinates.
4) Accuracy reporting in ground sample distances (GSD), allows users to directly compare datasets of differing scales or resolutions. A simple statement of conformance (or omission, when a map or dataset is nonconforming) is not adequate in itself. Measures based on map characteristics, such as
publication scale or contour interval, are not longer adequate when data can be readily manipulated and output to any scale or to different data formats.

6.8 Precision of measurements in an AT Block

1) Manual point measurement accuracy is approximately 1/3 pixel. Automatic measurement accuracy is up to 1/10 pixel on open flat terrain while under less favourable conditions the measuring accuracy is in order of 1/5 to 1/3 of a pixel.
2) One free net adjustment – bundle block adjustment that does not use any ground control points or AGPS/IMU or any EO parameters – shall be performed and statistical results delivered as defined in the appropriate section of the AT report. The results will include:
3) Sigma naught – the computed a posteriori standard deviation of the AT block adjustment in relative mode:
4) shall be < ±10 microns
5) 2. Max rx and ry – maximum residuals in x and y coordinates in image space: shall be < ±25 microns

<table>
<thead>
<tr>
<th>The RMSE values and Max residuals in X and Y direction from the free net adjustment shall be delivered in tabular format in the AT report:</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS value</td>
</tr>
<tr>
<td>Max residual</td>
</tr>
</tbody>
</table>

6.9 QC/QA of Relative Orientation

1) Project contractors shall perform data cleaning of all photogrammetric observations and produce a set of measurements that shall satisfy all specified tolerances of the aerial triangulation solution that are related to the relative solution.
2) The maximum image point residual for any point shall not exceed 25 microns. With manual data cleaning all observations shall be rejected and re-measured if their residuals > 25 microns.
3) All single observations (points measured only in one photograph) shall be removed and not present in the final set of the photogrammetric measurements.

6.10 Aerial Triangulation Deliverables

1) The Contractor must provide an aerial triangulation report containing, as a minimum, the following items:
a) Starting Datum and projection, ending Datum and projection, and method used to transform to City coordinate system
b) Description of the system, software, and procedures used to complete the Aerial Triangulation
c) Analysis of size of block and number of frames used for adjustment
d) Analysis of automated tie point collection
e) Analysis of the interior orientation, airborne GPS processing, results of exposure station computations, bundle adjustment, and transformation to project coordinate projection
f) The final residuals of image coordinates and expected Pixel accuracy
g) Explanation of any problems encountered and how they were resolved
h) Description of work conducted with the City’s Adjustment Contractor to revisit the procedures to achieve the most accurate adjustment, if such work is necessary
i) Weekly QA/QC analysis including status of aerial triangulation progress.

6.11 Generation of Stereo Models

(1) The results of the aerial triangulation will be converted into APS-DVP v7 .par and .dat files that will enable collection of topographic features using the four band RGBir stereo-models within our DVP softcopy photogrammetric system.

(2) In the near future, our DVP system will be retired. The Contractor is generating the exterior orientation files in another system, (for example, BAE SOCET SET, Inpho, I.S.M, Intergraph, KLT-Atlas, Leica LPS or other), and then converting into DVP format, we require the source files, (for example the .sup, Match-AT, DiAP .mod, ISAT, .res, ORIMA text files). Contractor must provide comment in their submission regarding the problems moving the 2011 images into another softcopy photogrammetric system in 2012.
6.12 Warranty - Stereo Model Certificate

1) The following is the Sample Stereo Model Certificate for ESM 2012
2) This certificate is to be attached to the final stereo-model image deliverables
3) All variables noted by <variablename> are to be filled in.

ESM2012 – Stereo Model

1) The <Year> four band RGBir stereo model images and associated .dat and .par files in DVPv7 format are derived from Controlled Aerial Photography flown between <date range of flights> by <name of company> using a <camerasensor> coupled with <GPS/IMU name of system>

2) ESM2012 consists of <number of stereo neat models> covering an area of 907 square kilometres up to and included the 2km buffer illustrated on the attached sketch, "Geographic Extent of Aerial Imagery Work Area”.

3) Spatial Resolution
   a) The stereo model image pixels have a Ground Sample Distance of less than 0.06 metres

4) The coordinate system for ESM 2012 stereo model images is:
   a) NAD27 1974, 3° MTM
   b) Canadian Geodetic Vertical Datum 1928, pre 1978 Southern Ontario Re-adjustment

5) Spatial Accuracy
   a) The MTM easting and northing coordinate at the centre point of any stereo model image pixel has a point positional horizontal accuracy RMSE less than 0.08 metres at the 95% confidence level
   b) The elevation of an image point are orthogonal heights and has a vertical accuracy RMSE less than 0.20 metres at the 95% confidence level.
   c) The panchromatic band is < > and has a GSD of less than 0.06 meters. All other bands are aligned with this band.

6) Spectral Resolution
   a) The Electromagnetic Spectrum wavelengths for the Blue band ranges from <0.4 – 0.5 micrometers>
   b) The Electromagnetic Spectrum wavelengths for the Green band ranges from <0.5 – 0.6 micrometers>
   c) The Electromagnetic Spectrum wavelengths for the Red band ranges from  <0.6 – 0.7 micrometers>
   d) The Electromagnetic Spectrum wavelengths for the NIR band ranges from  <0.7 – 2.0 micrometers>

7) Radiometric Resolution
   a) The dynamic range, or number of possible data file values in each band is <n-bit>

8) Ownership and copyright of all deliverables, all rights reserved, belongs to the City of Toronto

Professional photogrammetrist\(^{19}\) signature, date

I have the authority to bind the Company

\(^{18}\) The contractor should capture their aerial imagery at the max bit depth greater than 8. We would like to use the higher bit depth (12-18) to maximize spectral resolution.

\(^{19}\) Includes OLS(photogrammetry), or a competent individual capable and authorized by the company to certify the quality of the products produced for this contract.
7  UPDATE OF DSM/DEM/DTM

7.1  DEM/DTM Update Requirements - if required by contract

1) The City will provide the Digital Terrain Model (DTM) originally constructed for the 1999 and updated in 2011 which includes mass Points and break lines. It is currently maintained in 3D oracle spatial as SDO 3001, 3002, and 3003 type records.

7.2  DEM/DTM Deliverables

1) The Contractor should deliver a report on the following:
   a) finding regarding the review of City DEM/DTM;
   b) processes that will be used to update DEM/DTM;
   c) automated DSM/DEM/DTM extraction process used to supplement the existing DEM;
   d) review of the terrain dataset automatically derived from the Image;
   e) 3D Mass Points added or deleted to the City's DSM/DEM/DTM model;
   f) terrain editing/modification to the DSM/DEM/DTM as needed to represent the surface of the earth;
   g) new break lines added or deleted;
   h) quality control procedures to verify that the DTM accurately captures the ground surface characteristics; and
   i) commentary on the resultant DEM/DTM.
   j) DEM certificate, that it is of sufficient quality to support the production of GSD=8cm ortho-images

2) If the Contractor chooses to use airborne LiDAR measurements to supplement and improve the DEM/DTM and improve its ability to auto generate contours, the Contractor must deliver a LiDAR report that includes the following information:
   a) .las files from the project, (Classified and unclassified)
   b) flight report;
   c) ground control report;
   d) report on the geoid model used;
   e) system calibration report;
   f) data processing method used;
   g) final LiDAR scan rate and pulse rate;
   h) scan angle;
   i) capability for multiple returns from single pulses;
   j) how artefacts were treated;
   k) accuracy of LiDAR data collected;
   l) method used to update DEM/DTM;
   m) accuracy of the Topographic surface deliverables;
   n) digital spatial index of new Mass Points and break lines; and
   o) Suggestions to improve future data collection processes and activities.
8 GENERATION OF ORTHORECTIFIED IMAGE

(1) The ortho-image will be used to:
(a) capture features such as streams, transportation features, park features, trails, infrastructure and updates by clients within the City;
(b) support air photo interpretation of material type of features such as paved road, gravel road, brick boulevards and others;
(c) display seamless background information for thematic mapping purposes and GIS analysis; and
(d) event planning, and many other uses.

8.1 Orthorectified Image Requirements

1) In general20 each of our ortho-image series cover the City plus the 2km band around the City boundary. Area of coverage is approximately 907 square kilometres for the purposes of this specification.

2) Ortho-image derived from source image will always have a pixel size larger than the source image. The original GSD=0.06 metres in the 3D stereo model images will increase in pixel size as the image is rotated, transformed, and stretched into new 2D ortho-image projections. The smallest spatial resolution for ortho-image shall not be less than the diagonal of the source pixel GSD. For example the source GSD=0.06m has a diagonal of approximately 8.48cm and therefore the corresponding ortho-image will have a GSD of not less than 0.085m

a) The MTM easting and northing coordinate at the centre point of any ortho image pixel shall have a point positional horizontal accuracy RMSE less than 0.10 metres at the 95% confidence level

3) The bit depth for the generated ortho-image must not be less than 8 bits.

4) The ortho-image Radiometric Resolution should be the same Radiometric Resolution as the stereo model image.

5) It is unacceptable to use a source panchromatic GSD that is coarser that the final ortho-image Pixel size.

6) All spectral bands shall be aligned and pan-sharpened if required. All spectral bands shall be orthorectified together in a coordinated process.

7) Ground control from surveyed ground targets and control points established in aerotriangulation (AT) shall be sufficient to meet or exceed the accuracy requirements of the intended resolution of the digital ortho-image.

8.2 Staging of Series

(1) The City prefers that updates to the DTM and ortho-image series be staged to ensure prompt delivery.

20
8.3 Ortho-image tiling index, naming

(1) The ortho-images shall be organized into a tile grid structure based on its coordinate value. A sample ortho-image tile index, for each series, will be provided to the Contractor in .dgn format on disk.

(2) The tile dimension is to be an integral multiple of the ortho Pixel size. There may not be any partial Pixel overlap or gap along the edge of the tile.

(3) All ortho-image tiles must depict complete aerial Image. Black or null pixels must only be acceptable in cases where there is no image available. No clipping of an image should be done using the project boundary files.

8.4 Colour balance

(1) The final ortho-images shall undergo any necessary colour processing steps to ensure that the Image is consistently radiometrically balanced throughout the project area.

(2) There shall be no noticeable colour shifts or contrast patterns visible when the full data set is viewed simultaneously.

(3) Some form of dodging of the Image may be required in order to achieve this goal. If the Image undergoes any dodging it shall not leave any artefacts such as lighter or darker toned halos around objects.

8.5 Mosaics

(1) The deliverables in their final form shall be seamless. This requires that at normal viewing scales the mosaic seam lines will not be readily visible to the observer.

(2) In urban areas, building lean in the final product should be avoided as much as possible in order to enable the future mapping of the building footprint and/or the roof/eaves overhang, street furniture, designated areas along the street, and other objects.

(3) Geometric mismatches across seam lines are causes for rejection for not being sufficiently seamless. Image must match geometrically to within four ortho Pixels at the seam.

(4) The mosaic seam line positions shall be documented in the form of a line or polygon shapefile. A polygon of the seams for each frame used would be preferred.

(5) The seams must agree with the actual seam lines in the ortho-images.

(6) The seam shapefile will have attributes that define the frame(s) that each of the seams refers to.

(7) The seam line between mosaic images must be chosen to minimise the obtrusiveness of the join.

(8) Where the forward overlap has been increased in the City core, the Contractor must use all available images to further reduce the presence of building lean and improve the overall quality of the ortho-image product.
The ortho-image rectification process must include break lines where severe elevation changes may impact the visual quality of the image. There must be no visual “sagging” of an image along bridges, pathways or where other vertically disconnected feature exists. In those cases the break lines used for Orthorectification must have a Z value accuracy consistent with the specifications described above for elevation products.

The Contractor must provide a report on the images used during the mosaic process to ensure that the optimum number of images is used to generate the final ortho-image product. The report should also identify, where applicable, where a sub-contractors was used in the production/manipulation of the image.

**8.6 Image Quality**

(1) The ortho-images shall be generally free of artefacts, however the following tolerances will be applied on an average per square kilometre basis:

(a) less than 5 Pixels square (25 Pixels) that are saturated or near saturated, that is, devoid of image detail.

(2) The mosaic seam lines will meet the following criteria:

(a) seams will match geometrically within an average of less than 2 Pixels within each tile;
(b) in no case will a seam line have a geometric seam line mismatch greater than 4 Pixels.

(3) Image radiometry will be smooth and continuous throughout the Project area. This means that:

(a) in no case shall a seamline be visible due to radiometric differences across the seamline for more than a 20 Pixel length along the seamline;
(b) on average per tile, there shall be no more than 1 seamline visible due to radiometric differences across the seamline for more than a 10 Pixel length along the seamline;
(c) when the individual ortho-image tiles are viewed at a scale that a group of three by three tiles fill the screen, no radiometric differences shall appear to the human viewer;
(d) when a large number of tiles are viewed at one time at a smaller scale there shall be no appearance of a “patchwork quilt” pattern;
(e) when a larger number of tiles (a rectangle of greater than ~ 10 by 10 tiles) are viewed at one time at a small scale there shall be no appearance of a ramping of brightness, contrast, or colour balance from one part of the project area to another.

(4) Occasionally there may be spikes in the elevation data and image smear anomaly may occur. Where found, these image smears should be corrected. Determining an acceptable amount of smearing in an image is subjective. However, image smears may be determined to be unacceptable when artefacts appear in areas where critical features are evident or if those artefacts are visible to such an extent they render the image unusable.

(5) The use of manual image manipulation (“painting”/Photoshop alterations etc.) is discouraged and should be avoided as much as possible. Shapefiles showing where such alterations occurred in an image, along with the source of the alterations must be provided in a similar fashion as the seamlines.

**8.7 Ortho-image Meta Data**

(1) The ortho image series meta data, (one per ortho set) is based US National Spatial Data Infrastructure and FGDC-STD-008-1999 Content Standards for Digital Orthoimagery.

(2) Each ortho image within an ortho image series will have meta data within its GeoTiff GeoKey tags based on FGDC-STD-014.2-2008 content standards for ortho-image.
The ellipsoid, datum, and projection codes must be derived from the EPSG list compiled by the Petrotechnical Open Software Corporation (POSC).

A sample ortho image GeoTiff GeoKey set will be provided to the successful contractor based on FGDC-STD-014.2-2008 content standards for ortho-image.

8.8 Warranty – Ortho Image Series Certificate

1) The following is the Sample Ortho Image Series Certificate for ESM 2012
2) This certificate is to be attached to the final ortho image deliverables
3) All variables noted by <variablename> are to be filled in.

**ESM2012 – Ortho Image Series [one:two:three]**

1) This ortho image series was derived from <Year> four band RGBIR stereo model images and associated .dat and .par files in DVPv7 format derived from Controlled Aerial Photography flown between <date range of flights> by <name of company> using a <camerasensor> coupled with <GPS/IMU name of system>

2) ESM2012 Ortho Image Series [one:two:three] consists of <number of ortho tiles> covering an area of 907 square kilometres up to and included the 2km buffer illustrated on the attached sketch, "Geographic Extent of Aerial Imagery Work Area".

3) Spatial Resolution:
   a) The ortho image pixels have a Ground Sample Distance of less than 0.085 metres

4) The coordinate system for ESM 2012 stereo model images is:
   a) <Datum, Projection, Zone>
   b) Canadian Geodetic Vertical Datum 1928, pre 1978 Southern Ontario Re-adjustment

5) Spatial Accuracy
   a) The easting and northing coordinate at the centre point of any ortho image pixel tested point positional horizontal accuracy RMSE is less than 0.10 metres at the 95% confidence level
   b) The ortho-rectification process was based on a Digital Elevation model orthogonal heights and having vertical accuracy RMSE less than 0.20 metres at the 95% confidence level.

6) Spectral Resolution
   a) The Electromagnetic Spectrum wavelengths for the Blue band ranges from <micrometers>
   b) The Electromagnetic Spectrum wavelengths for the Green band ranges from <micrometers>
   c) The Electromagnetic Spectrum wavelengths for the Red band ranges from <micrometers>
   d) The Electromagnetic Spectrum wavelengths for the NIR band ranges from <micrometers>

7) Radiometric Resolution
   a) The dynamic21 range, or number of possible data file values in each band is <n-bit>

8) Ownership and copyright of all deliverables, all rights reserved, belongs to the City of Toronto

   Professional photogrammetrist22 signature, date
   I have the authority to bind the Company

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21 The contractor should capture their aerial imagery at the max bit depth greater than 8. We would like to use the higher bit depth (12-18) to maximize spectral resolution.

22 Includes OLS(photogrammetry), or a competent individual capable and authorized by the company to certify the quality of the products produced for this contract.
9  PACKAGING AND MARKING

This section of the contract provides packaging, packing, preservation, and marking requirements.

9.1 Media Specifications – Hard drives

1) Portable hard drives shall be used for deliverables unless otherwise stated in this contract. Other media such as Secure FTP, DVDROM, CDROM, or DLT may be negotiated depending on feasibility of data transfer and the amount of data under consideration.
2) The Contractor shall maintain a copy of the data until the City acknowledges receipt and acceptance.
3) Portable Hard Drives: All internal hard drives shall be “Combo” style drives, at a minimum capable of SATA, USB2.0 and IEEE1394 (Firewire) connections. The drives shall become property of the City and shall not be returned to the Contractor.
4) Each drive must be well labelled and contain a readme file identifying the contents of the drive.
5) The drive shall be shielded during transit by enclosure in an antistatic bag or container and packaged to ensure protection from impact.

9.2 Media Specification – DVD

1) Digital Versatile Disks (DVDs) shall be delivered on archival media, at least 4.7 Gigabytes (GB) (120minute) per disk DVD+/R, hybrid ISO 9660 Mode 1 format using level 2 interchange with Rockridge and Joliet extensions23.
2) All disk must be new and not previously used. No other archive members will be allowed on any media.
3) The Contractor must insure that each and every copy session has been properly closed. No multi-session enabled DVDs shall be acceptable.
4) The DVD media shall have a label attached identifying the digital contents of the DVD
5) DVD media shall be packaged in standard single DVD jewel cases (55/8" x 415/16" x 3/8") with a clear front cover.
6) The DVD label should be readable without opening the case or removing the DVD from the case. “Slim” or other non-standard sized jewel cases shall not be accepted.
7) No more than one project item area may be placed on a specific media item
8) Delivered files shall not contain symbolic links, use compression of any type, be created using GNU extensions, or as the super user (e.g., root)

9.3 Shipments

1) Data Shipment Notice. The Contractor shall notify the City's Project Manager each data shipment's contents and date of shipment and expected time of arrival. Where applicable, if a courier is used for shipping, the tracking number must be provided with the notification of delivery.
2) A packing slip is required with each delivery. Packing slip shall include the date shipped and every item in the shipment.
3) The contract number shall be on the packing slip.

23 This DVD format allows long file names up to 64 characters in length, and is readable by both Windows and UNIX systems
10 INSTRUCTION AND ACCEPTANCE

This section of the contract includes inspection, acceptance, quality assurance, and reliability requirements.

10.1 Inspection
The City's Project Manager or designate will inspect and accept/or reject products provided under this contract.

10.2 Inspection Procedure

1) Inspection of the deliverables will be randomly sampled to determine conformance to all contract requirements and specifications.

2) If inspection of materials reveals deficiencies that may cause increased time and effort in using the digital image and aerial photography as intended, the City may require the Contractor to perform the services again in conformity with contract requirements, at no increase in contract amount.

3) When the defects in products cannot be corrected, the City may
   a) Require the Contractor to take necessary action to ensure that future performance conforms to contract requirements and
   b) Reduce the contract price to reflect the reduced value of services performed.

4) Quality Performance Requirements: This table provides examples of the deliverable properties that may be evaluated, the basis of the evaluation, the threshold value for acceptable quality, and the means by which the property is evaluated.

10.3 Inspection Schedule

1) The City will start the inspection process the image and related data materials within 30 calendar days after they are received at the point designated.

2) Should the inspection procedure be delayed longer than X days, the Contractor will be notified of the reason(s) for delay and given the estimated completion date.

3) Contract materials will be inspected in the order of their receipt, unless otherwise prioritized by the City.

4) The Contractor will be notified in writing via email whether the materials are satisfactory and what materials, if any, shall be remade because of non-conformance with contract requirements.

10.4 Deliverables

1) Digital Image Collection and Survey Plan
2) Aerotriangulation data used in the orthorectification process shall be submitted as a deliverable.
3) Elevation data used in the orthorectification process shall be submitted as a deliverable in a non-proprietary format.
4) Airborne Positioning And Orientation
5) Raw GPS and IMU data files
6) Processed trajectory files
7) If IMU geo-referencing is employed, submit the exterior orientation file with the EO parameters
8) Supplemental Ground Control data
9) Project Data Files
10) Production Process File as specified in Section C
11) Project Data Files as specified in Section C
12) Image Frame-Center Data File as specified in Section C
13) Text-based index.
a) Provide ASCII list of tiles and the DVD on which they are submitted. Place the text-based file on the first DVD in the series, after the metadata.

14) Graphic index.
   a) Provide a shape file identifying the tiles in the project, attributed by tile identifier.

15) Attributes in the shape file should, at a minimum, include:
   a) Column 1 – Tile name
   b) Column 2 – Year of acquisition
   c) Column 3 - Contractor name

16) GPS ground control point list
17) Airborne GPS adjustment statistical report.
18) Accuracy and Quality Control Reports
19) Flight Reports
   a) Submit the completed, copy of Flight Logs with the data
20) Image Supplemental Report:
   a) A report of all image flown shall be produced for and included with each flight line.
   b) The report shall show the flight line numbers and flight track.
   c) The report shall also include (at a minimum) the photo centre coordinates of each image, along with the date, time, altitude, line number, frame number, camera ID, speed,

21) Aerotriangulation data:
   a) A statistical report summarizing the results of the aerotriangulation adjustment shall also be included with the aerotriangulation data.
22) Calibration Reports
   a) The calibration reports shall contain, at a minimum, the following information:
      i) The date the calibration was performed
      ii) The name of the person, company, or organization responsible for performing the calibration
      iii) The methods used to perform the calibration
      iv) The final calibration parameters or corrections, including any boresight calibration values, determined through the calibration procedures
      v) Sensor Maintenance Provide maintenance history of the sensor to be used for acquiring images to the CO before completing project

23) Unusual Circumstances
   a) The Contractor shall also notify the City Project Manager of any unusual circumstances that occur during the performance of this project which might affect the deliverables or their quality and especially of any deviation from this project.
   b) This may be included in the status reports emailed weekly as required below, unless urgent
24) Status Reports
   a) The Contractor shall submit project status reports via email to the City Project manager every week, until the work is complete.
   b) These reports shall include a summary of completed data acquisition, with dates completed; data shipped, and dates; and any unusual circumstances, equipment malfunctions, and/or any disturbance of the sensor.
   c) A weekly status report is required even if no progress has been made, starting from when the task order is received and ending when the City accepts all deliverables for that task order

25) Final Report
a) The Contractor shall supply to the City a Final Report incorporating all of the information in this Deliverables section including, at least, the sections suggested below:
b) Work performed under this contract, discuss each deliverable including: the maximum range from the base station, standard deviation and residuals in GPS trajectories, and an explanation of product labelling
c) Equipment used to perform this work, including hardware models and serial numbers, calibration reports, and software names and versions (include aircraft and digital imaging system info)
d) Flight line map(s), and project coverage area
e) Discussion of data quality including quality assurance (QA)/quality control (QC) procedures
f) If applicable, identification of sub Contractors that were used in the project and their roles (i.e. where they were involved in the acquisition, processing, QC etc.)
g) Ground Control Report, including a station list in table format
h) Airborne navigation and kinematic GPS Report
i) Weather, solar altitude, and time of year
j) Any unusual circumstances or problems, including equipment malfunctions
k) Deviations from the SOW
l) Any recommendations for changes in the Digital Imaging SOW for future work

10.5 Product Formats
1) Stereo image format
   a) Format GeoTiff
   b) Media Disk
   c) Naming Convention
   d) Date of First Submittal No later than thirty (30) calendar days after acquisition period.
   e) Early and/or incremental delivery is highly encouraged.
   f) Submittal Frequency Once
   g) City Approval Required
   h) Required Metadata

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Contractor need to consult with City project manager if different format is required, ie MrSID (MG2/MG3); JPEG (JPG/JP2/JPF); ECW
11 QUALITY ASSESSMENT AND ACCEPTANCE OF DELIVERABLES

11.1 Quality Assessment and Acceptance of Deliverables

(1) The City will provide sample areas, seed files, existing macros, cells, and systems based on City standard and specification. The Contractor, prior to commencing the work will be required to attend an orientation session with City staff to ensure that our standard and specification are understood and that the final deliverable met our Requirements.

(2) The Contractor will provide a quality guarantee for a period of two (2) years. Should the City identify a stereo image or block or ortho-image that has geometric deficiencies or radiometric deficiencies, the Contractor will provide a remedy at no additional cost to the City. The timeliness and method of remediation will be approved by the Project Manager.

(3) The City will assess the quality of the Deliverables to ensure that:
   1) Flight line index and neat model index are in digital form and available for use within the City;
   2) The aerial images are available with appropriate internal and external orientation parameters for public use;
   3) The aerial triangulation provides acceptable spatial accuracy (horizontal and vertical);
   4) Stereo-pairs are loaded and useable within existing DVP softcopy environment
   5) DSM/DEM/DTM is updated as required to support ortho map series;
   6) Mosaicing and colour balancing is completed according to the specifications for the project
   7) Geometric errors associated with terrain relief or faulty elevation data are not present;
   8) Image smears or busts not present or at least noted;
   9) Three (3) sets of ortho map images delivered in agreed to format and cut to City tiling system;
  10) Seamless edge matching between ortho-image tiles is complete;
  11) All City material delivered to contractor is returned;

(4) Compliance to the data collection hierarchy and rules of capture are required for acceptable Deliverables. Conditions that may result in rejection of Deliverables include:

   (a) Spatial error of two Pixels (horizontal or vertical);
   (b) Duplicate elements;
   (c) Co-incident elements (vectors that represent the same feature within 30cm of each other);
   (d) Curbs with insufficient smoothness.
12 DEFINITIONS AND TERMINOLOGY

12.1 References to Labelled Provisions

Each reference in this Standard and Specification to a numbered or lettered “section”, ”subsection“, “paragraph, “subparagraph”, “clause” or “sub clause” shall, unless otherwise expressly indicated, be taken as a reference to the correspondingly labelled provision of this Standard and Specification (SS).

12.2 Definitions

Throughout this document, unless inconsistent with the subject matter or context,

"3D Bundle Adjustment” is a programmed approach used within an aerial triangulation program to process the photographic measurements in the final ground XYZ coordinates of all the measured points.

"accuracy" is the closeness of agreement between a test result and the accepted reference value [ISO3534]- also see RMSE, reporting Horizontal and vertical accuracy

“Aerial Mapping” is the operation of an aircraft for the purpose of mapping by use of a camera/sensor, or other measuring and recording devices.

"Aerial Triangulation" - The main objective of aerial triangulation is to produce from horizontal ground control points, sufficient points in the photogrammetric models to ensure that each model can be oriented accurately as required for either ortho-image production or stereo compilation for line mapping in digital or analogue form.

"Airborne GPS" (aka ABGPS, AGPC, AGPSD), refers to observations from a GPS receiver used during the photo flight mission for navigation purposes and indirectly used to obtain co-ordinates of the perspective centre. An on board GPS receiver records an event marker from the camera, logging the precise time of each exposure station or photo center. This time record is then correlated to the location of GPS ground stations (at known, surveyed locations), which were recording during the flight. This observations are used in a simultaneous block adjustment in order to reduce the number of required ground control points.

“Cell” refers to the smallest unit of information in Raster data. Pixel is an abbreviation for picture element and is often used when describing Image, whereas Cell is often used when describing Raster data. Cells and Pixels have a dimension and value.

“Coordinate” means one of a sequence of \( n \) numbers designating the position of a point in \( n \)-dimensional space. NOTE: In a Coordinate Reference System, the coordinate numbers are qualified by units.

“Datum” a point, line, surface or set of quantities used as a reference upon which measurements are based

“Deliverables” means the deliverables as defined in the article 3.0 of this document.

"DEM/DTM" means Digital Elevation Model/Digital Terrain Model. DEM is an array of spot elevations which portrays a Topographic surface. If the DEM is sufficiently dense, it accuracy describes the Topographic surface. A DTM, not only includes DEM points, but also any 3D terrain features which may provide a better definition of the Topographic surface. Break lines are used to define abrupt changes in the earth surface and may be a 3D feature such as a curb line. Triangulated Irregular Network (TIN) connects DEM points and / or DTM points/break lines to their nearest neighbour to comprise a wire frame
or near equilateral triangles which approximate the Topographic surface. A Contour Interpolation Program (CIP) may be applied to the interpolated TIN model for a chosen contour interval along the triangle sides.

Elevation data models - Elevation data may be modeled in various forms, such as in an evenly spaced grid or as irregularly spaced points (triangulated irregular network, hypsography, or mass points) (FGDC-STD-014.0-2008)

Elevation data terrestrial - Terrestrial (land) elevation data contain georeferenced digital representations of terrestrial surfaces, natural or manmade, which describe vertical positions above or below a datum. The terrestrial data, in its various forms, support the elevation theme of the framework data. (FGDC-STD-014.0-2008)

Ellipsoid - a smooth mathematical surface which resembles a squashed sphere and is used to represent the earth's surface

"ESM" means Enterprise Stereoscopic Model. It is composed of original aerial Image, LiDAR data, aerial triangulation, stereo-model, DEM/DTM/TIN, 3D Topographic database and integrated orthorectified image series.

"Ground Control Points" are visible points on the terrain with known co-ordinates in the City of Toronto coordinate reference system, which can be identified and measured in an aerial image. Both, the terrain co-ordinates and the photogrammetric measured co-ordinates are used in block adjustment as observations.

geodetic coordinate system - an earth-centred coordinate system where latitude is the positive angle from the centre of the earth northwards from the equator and longitude is the positive angle from the centre of the earth eastwards from the Greenwich Meridian

geoid - the equipotential surface (i.e. the surface on which the gravity potential is constant) which best approximates mean sea level

gеoid model - describes the pattern of geoid undulations over the earth's surface as a function of latitude and longitude

gеoid height - the height difference between the geoid and ellipsoid at any given point on the earth's surface (also referred to as geoid undulation)

"GSD" means Ground Sample Distance. The spacing between the centre points of two adjacent sensor pixels on the ground. GSD will increase as the height above the ground increases, and will decrease as the height above ground decrease

"Image" or "Image(s)" means visible representation of objects and/or phenomena as sensed or detected by cameras, infrared and multispectral scanners. It's a two dimensional, pictorial representation. They are not dependent on a wavelength, or remote-sensing device, such as a satellite, aerial camera, or terrain sensor. An image is displayed on the screen, or printed. Images can be viewed.

“IMU” means Inertial Measurement Unit. An instrument that records the pitch, roll, and heading of a remote sensing platform

"IFOV" means Instantaneous Field of View.
"LiDAR” means Light Detection And Ranging. It is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target.

“Mass Points” means terrain elevations for ground positions regularly spaced horizontal intervals.

"may” and "should" used in this STANDARD AND SPECIFICATION denote permissive (not mandatory).

“MFIPPA” means the Municipal Freedom of Information and Protection of Privacy Act.

"NIR” means Near InfraRed.

**Orthometric height (H):** It is the elevation of a point above the geoid. It is measured along the plumb line, which is perpendicular to the equipotential surfaces. (Unit: m)

"Orthorectification" means the process of removing geometric errors inherent within Image caused by relief displacement, lens distortion, and orientation of image.


"Pan-Sharpening" means fusing of high resolution panchromatic Image with lower resolution multispectral Image to create a high resolution multispectral image.

"Pixel" means the smallest addressable digital element in the file. Each Pixel can be assigned ground coordinates. Pixel is often used synonymously with Cell.

"Photogrammetric Mapping" means the process of obtaining reliable geographic and dimensional information about physical objects and their environments through the recording, measuring, and interpreting of aerial photographic images.

“Radiometric Resolution” describes the ability of a sensor to distinguish objects viewed in the same part of the electromagnetic spectrum. It determines how finely a system can represent or distinguish differences of intensity, (radiant flux), and is usually expressed as a number of levels or a number of bits, for example 8 bits or 256 levels. The higher the Radiometric Resolution, the better subtle differences of intensity or reflectivity, (contrast, hue) can be represented.

"Resolution" is the ability to separate closely spaced objects on an image or photograph. Resolution is commonly expressed as the most closely spaced line-pairs per unit distance that can be distinguished.

"Resolution target" Series of regularly spaced alternating light and dark bars used to evaluate the resolution of images or photographs.

"Resolving power" A measure of the ability of individual components. and of remote sensing systems, to separate closely spaced targets.

"Raster(s)" means the data model that describes how Images are stored. A Raster defines the Pixels (cells) in rows and columns, the number of bands, and the bit depth that compose the image. When you view a Raster, you are viewing an Image of that Raster data.
RMSE – means root mean square error. The City uses root-mean square error (RMSE) to estimate positional accuracy. Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.

"Sensor Model Definitions" means the properties and characteristics associated with the sensor to capture an image.

"Spatial Resolution”, also known as cell size, is the dimension of the area covered on the ground and represented by a single sensor Pixel. It is expressed as Pixel resolution or ground sample distance (GSD). It defines the area of the ground represented in each Pixel in X and Y components.

"Stereo-Pair", “Stereo Model” means an image that contains two views of a scene side by side. One of the views is intended for the left eye and the other for the right eye. These images will be viewed within the City of Toronto's DVP/Microstation softcopy photogrammetric system viewed with special equipment to direct each eye on to its intended target. Specifically, two aerial images having sufficient perspective overlap to record parallax of detail to make possible stereoscopic examination of an object or an area common to both images.

“Topographic” is an adjective used to indicate that the cartographic representations show the shape of both natural and man-made features and their relative elevations.

“Vertical Datum” means a coordinate surface to which orthometric heights, taken as vertical coordinates of points, are referred.
12.3 Reference Diagrams and Figures

12.4 GSD

As height above ground increases, the resultant GSD increases.
As height above ground decreases, the resultant GSD decreases.
So in the specifications we say MAX GSD not to exceed 6cm.
Since sensor pixel size is fixed, one can expect the GSD to vary from 4cm to 6cm as the terrain changes or as the altitude of the camera goes up and down.
Aerial triangulation does not change the size of the image pixel and its GSD.

We require adequate horizontal and vertical to ensure the the coordinate value of a point measured within any given stereo model will not be further away from its actual ground coordinates by more than 0.08 metres. RMSE = 8cm

One aerial image pixel is the same size as the stereo model image pixel and should have a GSD not exceeding 6cm.

GSD = 0.06m. Stereo Image pixel And controlled aerial image pixel

RMSE = 0.08m

After transformation, the smallest ortho pixel is about 1.41x larger than its source pixel. In our case, the resultant ortho GSD is approximately 8.5 cm and now has a RMSE of about 10cm.

GSD = 0.085m. Ortho Image pixel after transformation

RMSE = 0.10 m