# THE USE OF AIRBORNE DIGITAL FRAME CAMERA IMAGERY FOR DEM GENERATION

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*Stereo airborne digital frame camera imagery was acquired over an area of the Gatineau Park, Quebec using a 1320 x 1035 digital frame camera with ground pixel size of 1.52m and spatial coverage of 1.9 x 1.5km² per image. Digital elevation models were automatically generated from both the airborne digital frame camera imagery and scanned 1:6 500 existing aerial photographs using the HI-VIEW software package. Both DEMs were compared using ground points derived analytically from the photogrammetric model. Both elevation models were reasonably accurate overall, providing mean differences in elevation with the reference data of less than 1m. The standard deviation of the elevation differences was 6.1m (4 pixels) for the digital frame camera derived DEM and 1.4m (2.14 pixels) for the photography derived DEM.*

*Des images numériques de caméra stéréo aéroportée images ont été prises sur une partie du parc de la Gatineau (Québec) en utilisant une caméra numérique à de 1320 x 1035 avec une dimension de pixel au sol de 1,52 m et une couverture spatiale de 1,9 x 1,5 km² par image. Les modèles numériques d'élévation (DEM) furent générés automatiquement à partir à la fois de l'imagerie numérique d'une caméra aéroportée et de photographies aériennes existantes balayées à l'échelle de 1/6500 en utilisant le logiciel HI-VIEW. Les deux modèles (DEM) furent comparés à l'aide de points au sol dérivés analytiquement du modèle photogrammétrique. Les deux modèles d'élévation étaient raisonnablement précis dans l'ensemble, offrant des différences moyennes d'élévation de moins de 1 m avec les données de référence. La déviation standard des différences d'élévation était de 6,1 m (4 pixels) pour le modèle dérivé des images numériques prises à partir de la caméra aéroportée et de 1,4 m (2,14 pixels) pour le modèle dérivé de la photographie.*

## *Introduction*

Airborne remote sensing for multispectral and photogrammetric mapping has developed in the past decade to high levels of sophistication capable of providing very precise thematic and positional information. Two approaches which have received the most attention have been the development of high resolution solid-state linear array image sensors such as the MEIS II for both multispectral and topographic mapping [*Gibson et al.* 1994], and the development of digital photogrammetric techniques for scanned aerial photographs [*Helava* 1991; *Heipke* 1995]. An alternative approach to expensive sensors and scanners is to use digital frame cameras (DFCs). Such cameras were introduced into the industrial/commercial imaging domains about five years ago and have since seen slow but accelerating attention by remote sensing researchers. They can currently provide image formats up to, and over 5k x 5k, at proportionally varying cost. Higher resolution cameras will begin to replace standard 23cm format photography when the capability to process and store such large digital images becomes cost-effective (i.e. with further technology advancements and cost reductions). This paper is not concerned with evaluation of DFCs as replacements of photographic cameras in applications requiring small ground pixel sizes (e.g. 5 - 25cm). Instead it emphasizes the evaluation of "lower" resolution DFCs which have the potential for application in situations where photography and higher resolution cameras provide too much detail. Such applications typically have required pixel sizes between 0.5 and 3m. These DFCs are currently very low in cost and have the potential to be used as dual purpose imagers, providing both multispectral data and stereo data for thematic and positional mapping, respectively. The research described here deals with evaluation of a digital frame camera in the generation of DEMs. It is part of an integrated research program at Carleton University to develop a low cost multispectral/mapping sensor for environmental

GEOMATICA Vol. 49, No. 4, 1995, pp. 489 to 497

and resource analysis [*King* 1995; *Lévesque and King* 1995; *King* 1992].

## Digital Frame Cameras

The following description of DFCs provides a summary of the characteristics pertinent to this research. More detailed descriptions are given in *King* [1995] and elsewhere. Solid-state digital frame cameras consist of a two-dimensional array of photosites embedded in a substrate material such as silicon. Incident photons excite electrons in each photosite which can be converted to an analog signal in direct linear proportion to the incident radiation. The analog signal is then digitized within the camera in a format which usually matches the photosite format, that is, the same number of digital pixels are produced as there are photosites in the array. Digitization is most commonly 8-bit but most solid-state arrays can also be digitized at 10, 12, or higher bit rates. The radiometric sensitivity of silicon is higher than standard film and the spectral sensitivity generally spans the visible and near-IR ranges between about 400nm and 1000nm, peaking between 700nm and 800nm. With almost 1/2 the sensitivity in the near-IR, the dynamic range of DFCs can be improved even more by acquiring panchromatic visible/near-IR imagery (there are some possible detrimental effects on spatial resolution, however, when imaging in the near-IR). An example showing the resolution capabilities, high contrast, and dynamic range of a 1280 x 1024 color DFC in relation to 70mm photography and VHS video was published by the principal author in *Mausel et al.* [1992].

*Research in evaluation of DFCs in mapping and digital elevation modelling has been steadily increasing....*

DFC exposure control is most commonly computer-based. Exposure time, the interval between exposures, the number of exposures, and the camera gain are examples of imaging variables which are controlled via the keyboard. In addition, integration with a GPS system for encoding of camera position, and/or triggering of the camera at specific locations is simple to accomplish. Some cameras designed for imaging domains such as photojournalism are set and triggered manually, but these too can be adapted to aircraft operation in the same manner as a 35mm photographic camera would be.

## Digital Frame Cameras in Mapping

Research in evaluation of DFCs in mapping and digital elevation modelling has been steadily increasing, and a few examples will be given here. Research in mapping using solid-state arrays began in close-range photogrammetry using video cameras. The research typically emphasized geometric calibration and results of focal length, principal point position, spatial distortions, pointing accuracy, etc. were often reported for various camera types and resolutions. *El Hakim et al.* [1989] provide details for video CCD imagers to that point. Examples of calibration of 1280 x 1024 DFCs are given in *Beyer* [1992] and *Novak* [1992]. Earlier research conducted by *King et al.* [1994] did not include camera calibration but instead incorporated a sensitivity analysis of focal length and principal point position within a bundle adjustment to determine values which optimized the solution (assuming these would be close to the actual values). DFC imaging for elevation modelling is being increasingly pursued at various levels of sophistication depending on the sensor used. Examples of the range of DEM research using digital video and non-video cameras include: *Ehlers et al.* [1989] using video cameras (in the range of 792 x 480), *Novak* [1992] using a 1280 x 1024 camera, and *Jurvillier and Thom* [1993] using a 4000 x 4000 camera.

The principal limiting factor in application of DFCs in mapping at this time is the small view angle associated with the small image array size. Typical arrays are in the order of 8-21mm on one side, producing total view angles of between about 10° and 50° for the variety of focal length lenses available for them. Thus, to obtain similar coverage as photography (using typical lenses), much higher altitudes are required with an associated increase in ground pixel size and atmospheric effects. The potential of DFCs for regional mapping, which has been a primary application of photography (e.g., the Ontario Forest Resources Inventory Program), is currently limited. The number of images required at the necessary spatial resolution for such applications is too high to be cost-effective. Currently, the greatest potential of DFCs for mapping lies in local site-specific mapping, or in linear/transect mapping [*King* 1995].

The research presented here began in 1990 with evaluation of elevation determination using a Kodak Megaplus 1.4 camera and 0.7m pixel imagery of an urban area. A standard bundle adjustment was applied with residual RMS values for blind test points being a little greater than the pixel size [*King et al.* 1994]. This was followed up by an evaluation of several standard interpolation routines which were applied to the bundle adjusted points to produce an elevation model. The kriging method was found to provide the best accuracy of interpolation for test points with an RMS value of 1.1 pixels. This led to the conclusion that a digital frame camera could be used without predetermined rigorous geometric calibration in DEM production with accuracy in the order of the ground pixel size simply by using commonly available, bundle adjustment and interpolation software [*King and Chichagov* 1993].

# Gatineau Park Case Study

## Objectives

Subsequent to the previous research, it was decided to evaluate the digital frame camera in DEM generation in natural terrain where survey control is not abundant or evenly distributed across airborne images. The evaluation was to be conducted relative to aerial photography using standard mapping software. The specific objectives were:

1. Acquire airborne stereo black and white digital frame camera imagery of the Gatineau Park, Québec with coverage approximating that of 1:10 000 standard format aerial photography.

2. For a selected study area, develop a DEM from a pair of overlapping DFC images using commercial mapping software.

3. Digitize a pair of stereo 1:6 500 aerial photographs covering the study site and develop a DEM using the same techniques and software,

4. Determine the elevations of a suitable number of check reference points.

5. Evaluate the precision and accuracy of the DEMs derived from DFC and air photos by comparison of calculated model elevations with check reference elevations.

## Study Site

The Gatineau Park in Québec, just north-west of Ottawa, Ontario was selected as the study area to provide a much more difficult situation for elevation modelling than was present in the previous urban studies. It has rugged terrain typical of the Canadian Shield, and it is mostly forested with only a few roads crossing its interior. The intent was to compare elevation modelling accuracy and precision to the urban studies to provide a range of potential DEM quality for these "best" and "worst" cases. The study site was selected because of its potential to provide an adequate number of test points, its accessibility, its representation of typical terrain conditions, and its overlap in coverage with existing aerial photography.

## Airborne Data Acquisition

Airborne stereo imagery was acquired on May 23, 1993 (leaf-off) using the Kodak Megaplus 1.4 digital frame camera. This camera produces a 1320 x 1035, 8-bit image using a 9 x 7mm$^2$ sensor array. With a 15mm focal length lens, the angle of view was 33.3° (horizontally) x 26.4° (vertically). The complete DFC system comprised the camera body and lens, the camera controller which controls the camera shutter and image gain, a 13inch (33cm) Super VGA command monitor, a 17inch (43cm), 1280 x 1024 image display monitor and a 50MHz 486 personal computer housing the frame grabber and image acquisition software. An Imagraph Inc. HI*DEF 1280 frame grabber board was coupled to a frame buffer for real time display of images in the aircraft. The image acquisition software was based on IPPLUS from Media Cybernetics Inc. Custom software written to interface with IPPLUS allowed user input of the number of images per flight line and the time interval between images (calculated for 60% overlap). In-flight, the aperture and gain were adjusted to provide optimum visual exposure levels. A differential kinematic GPS was linked to the camera to provide aircraft position at each exposure for use in deriving the positions of the camera stations. However, these data were not used in this study. Images were acquired from an altitude of 3 350m above ground, giving ground coverage of 1.945 x 1.556km$^2$. Because of variations in aircraft velocity and moderate headwinds, the actual forward overlap was about 52% along the 7mm side, resulting in a base-to-height ratio (B/H) of 0.24. This very low value of B/H is a consequence of the small view angle and reduces the stereoscopic effect, potentially adversely affecting the reliability of the geometric model and DEM to be derived. The nominal ground pixel size for each 1320 x 1035 image was 1.52m. The original intention was to match the DFC horizontal image field of view with that of 1:10 000 23cm format photography (2.3km) to provide direct comparison with the accuracy specifications of the elevation models of Ontario Ministry of Natural Resources Basic Mapping Series. However, constraints of a high cloud cover and maximum aircraft operation altitude without use of oxygen did not allow the 2.3km coverage to be attained.

*The Gatineau Park in Québec, just north-west of Ottawa, Ontario was selected as the study area ....*

The aerial photography had been previously acquired at 1:6 500 scale with stereo-coverage of about 1.5km x 0.9km and B/H of 0.6. The photography was first scanned at 25μm pixel resolution (1000dpi) resulting in a 0.16m ground pixel. This high resolution imagery was used in the determination of the exterior orientation parameters of the stereo-pair. However, because of the large image size (85Mb), and to increase the success of the automatic image matching process for the DEM, the photographic images were resampled by a factor of 4 to produce a 64cm pixel size, which is equivalent to a scanning resolution of 250dpi.

Figure 1 shows the DFC imagery while Figure 2 shows part of the digitized 1:6 500 aerial photography.

## *Photogrammetric Orientations and Point Determination*

Both the DFC and scanned photographic images were processed using HI-VIEW software (originally developed by Horler Information Inc., now distributed by PCI Inc.; e.g. see *Ostrowski et al.* [1993]). HI-VIEW determines the exterior orientation parameters (geometric modelling) using the well known collinearity equations (without self-calibration) in a least squares adjustment if more than three control points are available in the image overlapping area. It is recommended to use additional points to provide redundancy, improve the solution, and provide a quality check. A total of 14 points could be found within the overlap region of the DFC and photographic image pairs that were suitable for use as control or check points. Each was surveyed in the field using static survey differential GPS techniques with an accuracy better than 0.50m. The ground points were not well distributed due to the difficulty in matching points on the ground with image points except in the developed sections of the park, thus resulting in a weak geometric configuration for the

**Figure 1: Digital Frame Camera Imagery.**

space resection. For the DFC geometric modelling, five points were used as full control, one was used as planimetric control ($x,y$ positions only), one was used as elevation control ($z$ position only), and two were used as check points. For the aerial photographic geometric modelling, eight points were used as full control and one as a check point. The number and type of points vary for the two image types because they did not cover exactly the same area; five of the 14 points occurred in both the DFC imagery and the photography. Tables 1a and 1b give the results of the exterior orientation for the DFC imagery and photography, respectively.

Geometric modelling of the DFC imagery gave low RMS residual errors for the control points in planimetry, but high RMS error in elevation. These convert to 1.48 ($x$), 0.55 ($y$), and 2.76 ($z$) times the ground pixel size, respectively. Conversely, the geometric modelling results for the photography were 0.63 ($x$), 0.88 ($y$), and 1.38 ($z$) times the ground pixel size, respectively. The RMS values of the two check points in the DFC geometric model were 2.88 ($x$), 0.57 ($y$), and 8.96 ($z$) times the ground pixel size. For the photography the sole check point gave 4.81 ($x$), 12.38 ($y$), and 0.25 ($z$) times the ground pixel size. It is evident that the DFC imagery, while providing suitable planimetric results, performs much poorer in the determination of the elevation.

Given the difficulty of obtaining precise GPS field elevations for an adequate number of test points, the photo-coordinates of 22 points were measured from the photographs on the Wild A-10 stereo-plotter (existing stereo-comparator set-up at CCTI). Their ground coordinates were determined analytically using the existing control points and the SPACE-M [*Blais* 1977] aerotriangulation program.

## *Automatic DEM Generation*

HI-VIEW incorporates an automatic process to determine the conjugate pixels in a stereo image pair by using iterative area-based image matching over increasing image resolutions [*PCI, HI-VIEW* 1995].

The reduced resolution images are generated by pixel averaging with reduction factors of 2 or 4 between iterations. The elevation for each matching pixel is computed afterwards using the parallax equation. The matching process is performed by calculating the correlation values between two window templates centered on the pixel/epipolar line under consideration in the reference and search images. After the maximum correlation is determined its pixel position determines the conjugate point. The correlation is performed in two steps. In the first step the search for the matching pixels is performed along the epipolar lines. In the second step a two-dimensional search is performed in the neighborhood of the matching pixel determined in step one. The generated DEM is in the model space and is absolutely oriented to the ground reference system using the existing control points. The elevation of points between the conjugate pairs for which matches could not be found are interpolated to fill in the rest of the raster DEM.

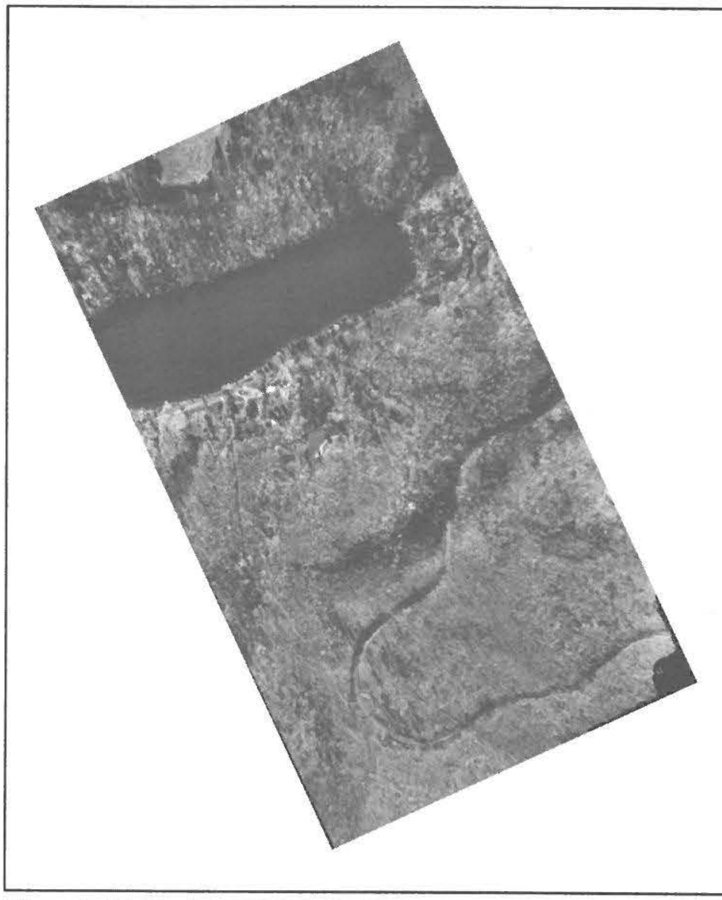

**Figure 2: Digitized 1:6 5000 Aerial Photography.**

The DEM can be edited for gross error removal and verified against available ground control points. Gross errors in the DEM can result from matching wrong pixels in the two images or from failing to find conjugate matches. Variations in the radiometric appearance, texture and the different perspective geometry of the images contribute to the failure of the image matching process.

To evaluate the DEMs produced from the DFC imagery and photography, the set of the 22 triangulated points was used. Of these, 13 were

**Table 1a: Exterior Orientation Solution for Digital Frame Camera Control and Check Points.**

**Control Points:**

| Point ID | X | Y | Z | DX (m) | DY (m) | DZ (m) |
|---|---|---|---|---|---|---|
| 30045 | 432655.84 | 5037969.66 | 274.15 | -1.61 | 0.05 | -6.25 |
| 10065 | 433312.42 | 5037986.24 | 232.36 | | | -1.86 |
| 10075 | 432965.01 | 5037254.91 | 198.42 | -1.89 | 0.37 | 2.65 |
| 10095 | 433129.95 | 5037300.70 | 207.33 | 2.73 | 1.39 | 5.60 |
| 10115 | 433490.67 | 5037480.77 | 214.54 | 1.51 | 1.07 | |
| 10145 | 433764.59 | 5037606.01 | 206.39 | -3.41 | -0.49 | 4.77 |
| 10155 | 433907.93 | 5037665.91 | 199.17 | 1.79 | -0.89 | -2.15 |
| RMS errors in 7 control points: | | | | 2.26 | 0.84 | 4.25 |
| $\hat{\sigma}o$ (image) = 1.352 pixels; $\hat{\sigma}o$ (ground) = 2.053 m | | | | | | |

**Check Points:**

| Point ID | X | Y | Z | DX (m) | DY (m) | DZ (m) |
|---|---|---|---|---|---|---|
| 10105 | 433181.01 | 5037323.53 | 220.52 | -0.61 | 0.60 | 13.60 |
| 10135 | 433638.40 | 5037566.45 | 214.02 | -6.14 | -1.07 | 13.64 |
| RMS errors in 2 check points: | | | | 4.37 | 0.87 | 13.62 |

**Table 1b: Exterior Orientation Solution for Aerial Photography Control and Check Points.**

**Control Points:**

| Point ID | X | Y | Z | DX (m) | DY (m) | DZ (m) |
|---|---|---|---|---|---|---|
| 10029 | 432851.15 | 5038028.27 | 285.46 | 0.04 | -0.23 | 0.24 |
| 10055 | 433182.07 | 5038196.85 | 261.44 | 0.02 | 0.15 | -0.11 |
| 10065 | 433306.93 | 5037977.98 | 233.96 | -0.03 | 0.00 | -0.11 |
| 14019 | 433567.21 | 5037826.18 | 234.46 | -0.06 | -0.14 | 0.13 |
| 10095 | 433127.15 | 5037299.52 | 201.72 | -0.07 | 0.21 | -0.01 |
| 10105 | 433177.23 | 5037322.09 | 207.08 | 0.10 | -0.01 | -0.26 |
| 18029 | 433260.67 | 5037084.74 | 195.23 | -0.10 | 0.07 | 0.39 |
| 10115 | 433489.06 | 5037479.92 | 200.86 | 0.21 | 0.01 | -0.29 |
| RMS errors in 8 control points: | | | | 0.10 | 0.14 | 0.22 |
| $\hat{\sigma}o$ (image) = 1.095 pixels; $\hat{\sigma}o$ (ground) = 0.176 m | | | | | | |

**Check Points:**

| Point ID | X | Y | Z | DX (m) | DY (m) | DZ (m) |
|---|---|---|---|---|---|---|
| 12019 | 433375.07 | 5038158.76 | 247.86 | 0.77 | -1.98 | -0.04 |

common to both DEM coverages, two were present only in the final photographic model (for a total of 15) and eight were present only in the final DFC model (for a total of 21). The results for the 21 check points in the digital frame camera DEM are given in Table 2a. Table 2b gives the corresponding results for the 15 check points in the photography model.

In comparing the two image types for elevation modelling accuracy, the DFC model has produced mean differences closer to zero than the photographic model. This may indicate a small systematic error in the photography such as greater influence of vegetation. However, the precision associated with the DFC model is lower. The standard deviation of the elevation differences is 4.0 times the ground pixel dimension compared to 2.14 times for the photography.

## *Summary Discussion*

The potential of using an off-the-shelf digital frame camera for automatic DEM generation with the HI-VIEW commercial software for environmental and resource applications was investigated through this research project. The area selected and the conditions were not optimal, thus resembling real case operations. The DEM precision obtained from the DFC was 4 pixels compared to the expected 1.5-2 pixels. This may be explained by: a) the small B/H ratio, which can be slightly improved by putting the longer side of the DFC along the flight line; b) difficulty in matching field survey points to image points in this lower resolution image; c) the lack of an image motion compensation mechanism (the image motion was about 0.4 pixels); d) the small image scale; e) the lack of camera calibration, which can be handled with the use of additional parameters in the geometric modelling stage; and f) the lower accuracy of DEM values for the check points which were interpolated from nearby matched image points. On the other hand, the use of DFCs in the resolution range tested here allows the direct collection of digital images without expensive sensors or scanners. Its potential lies in low cost acquisition of medium accuracy DEMs for custom applications. Other DFCs with much higher resolution would be expected to produce much better results, but at proportionally higher cost and with some of the same limitations as those listed above.

The next phase of the sensor development will be completion of kinematic GPS integration, camera calibration, and refinements to the multispectral components of the sensor to produce a low cost operational thematic/positional mapping sensor. As a follow-up to the tests described in this paper, efforts will be made to improve DEM and ortho-image accuracy and the methods will be expanded to include blocks of images.

## *Acknowledgements*

The authors greatly appreciate the contributions of the Canada Centre for Mapping in providing data and data analysis capabilities, the Natural Sciences and Engineering Research Council of Canada, Horler Information Inc. of Gatineau Québec in providing the HI-VIEW software and much advice, GEOsurv Inc. of Ottawa for integration of the GPS with the digital frame camera and arranging the aircraft data acquisition, Hauts Monts Inc. of Québec in providing aircraft and crew, and Peter Curran of Cadix Inc. of Toronto for timed interval data acquisition software.

**Table 2a.: Elevations (and *x,y* position) of the 21 test points determined by HI-VIEW elevation modelling of the digital frame camera imagery compared to those derived analytically from the aerial photographs (the reference data).**

| ECP ID | *X* | *Y* | *Zg* | Row | Column | *Zc* | *DZ* |
|---|---|---|---|---|---|---|---|
| 10015 | 432390 | 5037524 | 279.13 | 333.87 | 209.02 | 282.12 | 2.99 |
| 10035 | 432442 | 5037934 | 269.36 | 62.67 | 247.79 | 273.65 | 4.29 |
| 10045 | 432653 | 5038030 | 283.44 | 1.98 | 386.50 | 278.48 | -4.96 |
| 20045 | 432656 | 5037970 | 281.44 | 41.72 | 388.40 | 282.12 | 0.68 |
| 10065 | 433307 | 5037978 | 234.07 | 42.22 | 820.05 | 247.28 | 13.21 |
| 10075 | 432967 | 5037255 | 196.05 | 504.66 | 590.42 | 185.82 | -10.23 |
| 10095 | 433127 | 5037299 | 201.73 | 478.76 | 694.35 | 207.98 | 6.25 |
| 10115 | 433489 | 5037480 | 201.15 | 366.54 | 931.05 | 198.26 | -2.89 |
| 10135 | 433645 | 5037568 | 200.38 | 311.60 | 1033.44 | 205.74 | 5.36 |
| 10145 | 433768 | 5037607 | 201.62 | 287.87 | 1114.61 | 197.80 | -3.82 |
| 10155 | 433906 | 5037667 | 210.33 | 251.01 | 1207.08 | 201.53 | -8.80 |
| 10029 | 432851 | 5038029 | 285.22 | 4.78 | 518.52 | 276.28 | -8.94 |
| 12029 | 432963 | 5037778 | 240.25 | 169.85 | 591.89 | 240.85 | 0.60 |
| 14029 | 433144 | 5037500 | 239.91 | 354.12 | 707.71 | 237.89 | -2.02 |
| 14019 | 433567 | 5037826 | 234.33 | 144.62 | 989.68 | 235.65 | 1.32 |
| 11004 | 433723 | 5037578 | 198.42 | 305.38 | 1084.30 | 196.91 | -1.51 |
| 21004 | 433807 | 5037376 | 198.38 | 437.07 | 1136.16 | 208.27 | 9.89 |
| 31004 | 433561 | 5037306 | 198.38 | 478.92 | 975.19 | 196.95 | -1.43 |
| 41004 | 433304 | 5037238 | 198.37 | 519.63 | 808.01 | 199.27 | 0.90 |
| 51004 | 433274 | 5037338 | 198.43 | 455.23 | 789.72 | 201.60 | 3.17 |
| 61004 | 433526 | 5037477 | 198.66 | 368.60 | 954.97 | 192.07 | -6.59 |
| The mean value of the differences: | | | | | | | -0.12m |
| The standard deviation of the differences: | | | | | | | ± 6.09m |

**Table 2b: Elevations (and *x,y* position) of the 15 test points determined by HI-VIEW elevation modelling of the photography compared to those derived analytically using the aerial photographs (the reference data).**

| ECP ID | *X* | *Y* | *Zg* | Row | Column | *Zc* | *DZ* |
|---|---|---|---|---|---|---|---|
| 10055 | 433182 | 5038197 | 261.55 | 2000.61 | 529.91 | 262.05 | 0.50 |
| 10065 | 433307 | 5037978 | 234.07 | 1570.61 | 485.27 | 234.15 | 0.08 |
| 10095 | 433127 | 5037299 | 201.73 | 732.32 | 1157.72 | 206.77 | 5.04 |
| 10115 | 433489 | 5037480 | 201.15 | 746.44 | 542.96 | 203.32 | 2.17 |
| 10135 | 433645 | 5037568 | 200.38 | 766.21 | 271.88 | 200.23 | -0.15 |
| 10145 | 433768 | 5037607 | 201.62 | 739.44 | 76.75 | 201.30 | -0.32 |
| 10029 | 432851 | 5038029 | 285.22 | 2005.00 | 1166.37 | 285.21 | -0.01 |
| 12019 | 433374 | 5038161 | 247.90 | 1800.15 | 266.76 | 247.65 | -0.25 |
| 14019 | 433567 | 5037826 | 234.33 | 1175.45 | 213.31 | 234.13 | -0.20 |
| 11004 | 433723 | 5037578 | 198.42 | 731.08 | 157.36 | 199.41 | 0.99 |
| 21004 | 433807 | 5037376 | 198.38 | 401.87 | 172.75 | 199.37 | 0.99 |
| 31004 | 433561 | 5037306 | 198.38 | 465.06 | 554.17 | 199.95 | 1.57 |
| 41004 | 433304 | 5037238 | 198.37 | 536.84 | 949.47 | 199.55 | 1.18 |
| 51004 | 433274 | 5037338 | 198.43 | 691.77 | 927.90 | 198.87 | 0.44 |
| 61004 | 433526 | 5037477 | 198.66 | 719.32 | 492.74 | 199.35 | 0.69 |
| The mean value of the elevation differences: | | | | | | | 0.84m |
| The standard deviation of the differences: | | | | | | | ± 1.37m |

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