Land Information New Zealand
Toitū te whenua

Guidelines on geo-referencing and orthorectification of historic aerial imagery

November 2014

New Zealand Government

Contents

Introduction to these guidelines

These guidelines were developed as part of a pilot project undertaken by LINZ to scan negatives from the Crown Aerial Photo Archive. The negatives contained in the Archive represent some 70 years of aerial surveys flown over New Zealand.

The guidelines aim to:

- provide information and guidance on geo-referencing and orthorectification to assist in determining the most appropriate level to apply to historic imagery projects
- provide context and understanding of the "level of product" delivered by the LINZ digitisation effort
- set out what these newly scanned images represent, how they came to be, and the photogrammetry process that was used to create topographic mapping
- provide an unambiguous understanding of terms such as geo-referencing and orthorectification, which are often used interchangeably in the imagery industry in New Zealand, and
- describe the various processes, options, and relative costs involved in creating post-scanning products.

The vast majority of the products created from these historic aerial surveys were topographic maps, which were produced in an era before digital data and GPS. To create products from these historic aerial negatives now—even when scanned—requires a different approach than the processes used to create products today.

In addition, the decisions involved in creating products from scanned historic aerial negatives are not straightforward. Options can range from undertaking a cheap five-minute process to months of work requiring specialist software and experienced technicians.

This document should help historic imagery users in making these decisions, providing the information they need to consider the historic imagery products that best fits their needs.

A history of the Crown Aerial Film Archive

The origins of the Archive's identity as a national reference source go back to the years before World War II.

A letter from the Prime Minister, George Forbes, on November 11, 1935, saw the start of co-ordinated topographical mapping of New Zealand and recognition of aerial survey[1] as being the most economic means of map production. Not long after, the necessity of keeping a complete register of all aerial photography was recognised, and within a few years, the Department of Lands & Survey (L&S) was able to supply maps showing the areas that had been photographed.

As early as 1937, the wide-ranging value of aerial photographs had begun to be recognised, not only for compiling basic topographical information, but also in soil, irrigation, geological and other surveys; for Defence's training and general requirements; applications in road extensions and deviations, drainage, and power transmission; the location of extraction routes, forest roads, rides, firebreaks, and lookouts by the State Forest Service; local bodies' needs for regional and town planning; and as a record of permanent up-to-date local data.

Public interest was also considerable, and soon photos were available for purchase.

Consideration was also given to the use of a private contractor to undertake at least part of the aerial survey work, and possibly all of it. The committee favoured a quotation submitted by Piet van Asch of New Zealand Aerial Mapping LTD (NZAM) in 1937, which established the firm as a contractor to the Crown.

Formal storage of the films was also being considered prior to World War II. After his 1937 visit to the British Air Ministry—and a 1940 visit to New Zealand to examine their provisions for film storage—George Railton, the first chief photogrammetrist of L&S, drew up specifications for a purpose-built vault. The vault was in operation by December 1941.

The cataloguing system for assigning survey numbers and unique numbers to each photo within them was also a George Railton initiative. For example, the 1937-39 coverage of Earnslaw-Glenorchy is Survey number 40.

It is a testament to the preparation that went into these early decisions that the storage and cataloguing of the films has continued pretty much unchanged since the early years.

A situation that needed addressing in the 1980s was the deterioration of the nitrate-based films. NZAM Ltd investigated the possible solutions and located equipment in Australia which could be used to copy all susceptible films. The work was undertaken between 1983 and 1985 at a total cost approaching $300,000, mostly funded by L&S, with contributions from New Zealand Forest Service and Department of Scientific and Industrial Research.

National Archives was also approached as another possible contributor. While unable to assist financially, the Director, R F Grover said, "I must congratulate your department on the initiative it is taking to ensure the continued preservation of what can be regarded as the single most important visual record of twentieth century New Zealand" (R F Grover, Director, National Archives to Surveyor General, 10.3.83, 17/474/3/2.)

Today the films are stored in a protected vault.

[1] Aerial survey is the term given to the collection of aerial photographs that cover a specified area of interest. Each survey comprises a series of runs, each with a number of photographs. Each photo is assigned a unique number made up from the survey, run and photo number.

What photography is in the Archive, and how did it get there?

Aerial photography funded by L&S has provided most of the coverage of New Zealand in the Archive.

The department took over financial responsibility for all government aerial surveys from the Army in 1946-7, with a budget of £20,000. Although after 1956, other departments paid for their own surveys, the most extensive surveys were still paid for by L&S. The department's expenditure continued to rise, exceeding half a million dollars per annum by 1981.

By 1956, the policy of coordinating all government departments' requirements into a single programme of photography at standard scales was ceasing to meet the rapidly growing need for specialist surveys for roading, irrigation, town planning, river control, forestry, mining, power schemes, and land development projects.

The Crown archive contains 500,000 photos on film from 5,000 aerial surveys captured for various purposes from 1936-2005.

In September that year, a meeting was organised comprising the Airforce, Army, Lands & Survey, Mines, Navy, and Scientific & Industrial Research, as well as NZ Forest Service, Ministry of Works, and the Soil Conservation and Rivers Control Council. Piet van Asch of NZAM Ltd. also attended. Each department had been requested to table their requirements prior to the meeting, proving that the amount of aerial survey work needed was substantial. It was agreed that L&S should bear the cost of photography and mapping for the standard 1:25,000 and 1:63,360 topographical map series, and that the cost of photography for any other purpose should be borne by the department concerned.

Over the convening years this committee continued, expanding its membership to include other departments such as the Housing Corporation and the New Zealand Post Office. L&S retained its role as central ordering agency for Crown aerial surveys, and in so doing also became the central source of information on all existing Crown photography.

The task of co-ordination became more complex from 1970 onwards. Other flying companies were becoming more active in seeking an increasing variety of government work, and the parties were keen to establish direct relationships.

Mairi Clark, Chief Photogrammetrist with L&S, commented[2] "With the replacement of government departmental structures by State-owned enterprises, this trend is likely to increase. It will be a pity however if, in the pursuit of autonomy, an awareness is lost of the reason why the original call for interdepartmental co-ordination was made: the avoidance of wasteful proliferation of effort and expense, at a time when the country's financial climate called for particular emphasis to be placed on economy of operation."

None-the-less, L&S were still investing heavily in photography, carrying out surveys both for the creation of the topographic mapping series, and for what was known as resource flying. Resource flying was general purpose photography flown initially at imperial scales and latterly at 1:25,000. Re-coverage of the country was planned for a 10-year cycle.

In 1987, the Department of Lands and Survey was wound up and the Department of Survey & Land Information (DOSLI) was formed. DOSLI was given cost-recoverable targets and reduced government funding. As a result, interdepartmental coordination lessened and resource flying was no longer undertaken.

The next restructure of 1996 dissolved DOSLI and formed the State-owned Enterprise Terralink Ltd, and the government department of Land Information New Zealand (LINZ). This restructure was made in the belief that commercial acquisitions would be more efficiently handled by the private sector. Terralink along with other companies would compete for the work, providing quality products at competitive costs. From that point, LINZ's acquisition of aerial photography concentrated only on that required for the update of the 1:50,000 topographic mapping database.[3]

In the 2000s, an increasing government focus on the potential of geospatial information to benefit New Zealand's economy and society prompted a renewed recognition (almost as predicted by Mairi Clark in the late 1980s) of the need to better coordinate government spending on imagery and to make it open for use. Open licensing improves transparency, enables better decisions to be made in all sectors of society, and stimulates innovation and growth.

The 2010 and 2011 Canterbury earthquakes very much highlighted the need to open up access as the aftermath of the earthquakes saw a high demand for imagery to assist with emergency services and recovery and rebuilding. At that time, only 6 percent of government imagery was publicly available due to licensing arrangements, and most datasets were effectively locked up in internal systems.

Soon after, LINZ developed the National Imagery Coordination Programme[4] to develop and implement a coordinated approach for acquiring and disseminating imagery. The aim was to improve its ease of access and use, achieve better value for public sector investments and drive economic growth.

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[2] "The Role of the Department of Lands & Survey in Aerial Survey and Photogrammetry"; Mairi Clark, 1987, updated in 2008.

[3] The first orthophotos while digital, were created in the pre-geo-referencing area. However all have been subsequently geo-referenced and are available from the LINZ Data Service

[4] http://www.linz.govt.nz/topography/national-imagery-coordination

What products can be made using historic aerial photography?

This section outlines what can be created from historic aerials, ranging from topographic mapping derived from photogrammetry to geo-referenced images and orthophotos.

TOPOGRAPHIC MAPS PRODUCED USING PHOTOGRAMMETRY

In the vast majority of cases, the aerial photographs held in the Archive were flown specifically for the creation of topographic maps: each photograph overlapped its neighbour by 60 percent, and each survey run overlapped the adjacent by 20 percent. The technique used to undertake the mapping is known as photogrammetry.

Photogrammetry is the science of making measurements from photographs. The output of photogrammetry can be a map, drawing, measurement, or a 3-D model of some real-world object or scene.

The core concepts and mathematical functions of photogrammetry remain the same as the traditional photogrammetric techniques developed over the past 100 years. The principle is straight-forward. Given two photographs of the same area—taken from slightly different viewpoints—one is able to see a three-dimensional "stereoscopic model". The essential condition to be satisfied is that each eye sees only one of the two views.

In New Zealand, World War II temporarily halted the acquisition of the first photogrammetric plotters (one, a Multiplex had been ordered by L&S in 1939), but by 1951 four second-hand ones were in use in L&S. By the mid-1980s, over 20 photogrammetric stereoplotters were in use, both analogue and digital.

Analogue photogrammetry was undertaken in the early years, which employed optical-mechanical components and stereo (overlapping) photographic film diapositives[5]. Physically altering the positions and rotations of the stage plates holding the films relative to each other, enables the creation of a stereoscopic model that had an exact relationship to the land it portrayed.

To do this, a certain amount of information had to be available in the form of "control" points. Control was supplied by land surveyors who visited the area concerned and established co-ordinated positions and heights and identified them on the photographs. "Trig" stations, white crosses marked on the ground and other clearly defined features were also used for this purpose. A network of additional "supplementary" control points were also fixed by a photogrammetric process known as aerial triangulation.

Mapping with the Wild A8 analogue photogrammetric scanner in the 1980s.

[5] A diapositive is a positive photographic image on a transparent base

Analytical photogrammetry was the second developmental stage. Similar hardware and film components were employed, but a stereoscopic model was achieved using a computer to calculate solutions and record the compiled data.

In the current system, film has been replaced by digital imagery. The costly optical-mechanical components have been completely replaced by computers and monitors. The solution is obtained mathematically using basic photogrammetric principles and image-processing techniques. Using today's technology in airborne GPS control and inertial measurement data, the need for many ground control points and aerial triangulation can be reduced or eliminated. Mapping can often be delivered to clients in days instead of months.

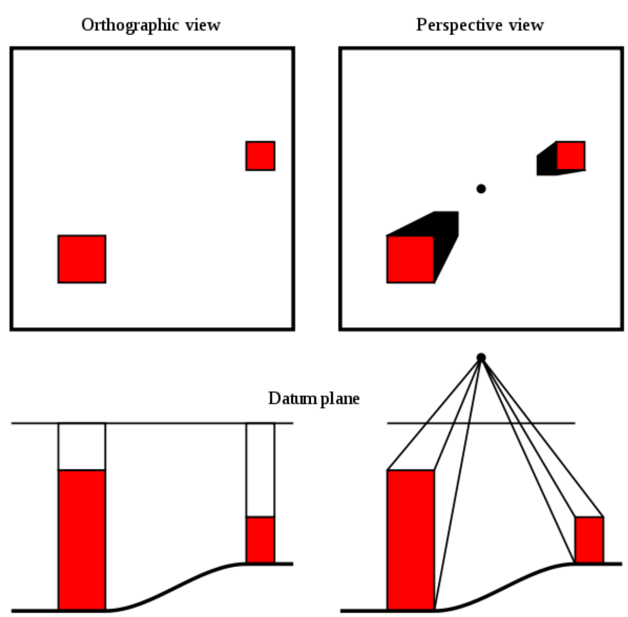
Common to analogue, analytical and digital-era photogrammetry is that—through viewing the stereoscopic model—the photogrammetrist can trace the lines of fences, streams, roads and railways and create polygons for such features as buildings and areas of vegetation. Contour lines can be delineated at set elevations and spot heights measured.

Soft photogrammetry further offers the ability for automatic extraction of elevation data, orthophoto generation and terrain analysis.

IMAGE PRODUCTS

For many purposes, a photographic representation of the terrain is preferable to a map Because a photograph provides a perspective view of the area it represents, there will always be some displacement of details from their true plan positions and some variation of scale, unless the area concerned is completely flat and the area being measured is at the centre of the image.

The amount of error depends on a number of factors, including the focal length of the camera, the variation in terrain height[6], and the amount of tilt of the camera relative to the ground when the photograph was taken.



For some uses—involving interpretation rather than measurement—the presence of this type of error is not significant, but when calculations of areas or distances are to be involved, or when one wishes to combine true-to-scale detail and/or contours with photos, discrepancies will inevitably occur.

There are many photogrammetric techniques that can be used to turn a photographic or satellite image into an image with the same lack of distortion as a map. The accuracy of the result will depend on the technique used and the quality of the components. An issue with image products is that the accuracy of the product is not immediately apparent.

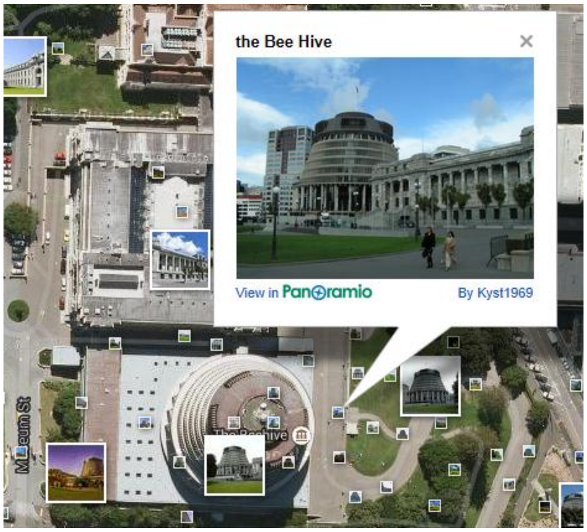
[6] See Appendix A for a mathematical explanation.

-GEO-TAGGING

Geo-tagging a photograph or image is the process of adding geographical identification metadata in the form of coordinates, and possibly also altitude and bearing.

It enables users to identify the location of the content of a given picture. It is probably most familiar in its application in Google Earth and Google Maps where photographs are given the coordinates either of the position where the photograph was taken, or the position of the subject.

Most smart phones already use a GPS chip along with built-in cameras to allow users to automatically geo-tag photos.



-GEO-TAGGING PLUS

Almost any digital photograph can be post-processed with software to write the location information to the image's header. When undertaken with aerial imagery, a mosaic of photographs can be formed where each is located at approximately in their true position.

For an aerial photograph to occupy approximately the same area represented by its contents, a scale and rotation will also need to be applied.[7] In the context of this document this is called "geo-tagging plus".

The geo-tagging process alone does not alter the internal geometry of the photograph in any way. So if measurement is required, rectification or ortho-rectification will be required.

Because a photograph provides a perspective view of the area it represents, there will always be some displacement of details from their true plan position and some variation of scale.

[7] The nominal scale is part of the metadata for the NZ Pilot Project for the Scanning of the Historic Aerial Film Archive; or the polygon of the photo footprints can be used https://data.linz.govt.nz/#layer/1002-nz-aerial-photo-footprints-mainland-nz-1936-2005-polygons/

-RECTIFICATION / GEO-REFERENCING

Rectification is accomplished by matching corresponding image and existing map or surveyed control points. These points are then used to generate a transformation to align the image to the target map or control. This process is known as rubber sheeting, also more commonly today as geo-referencing.

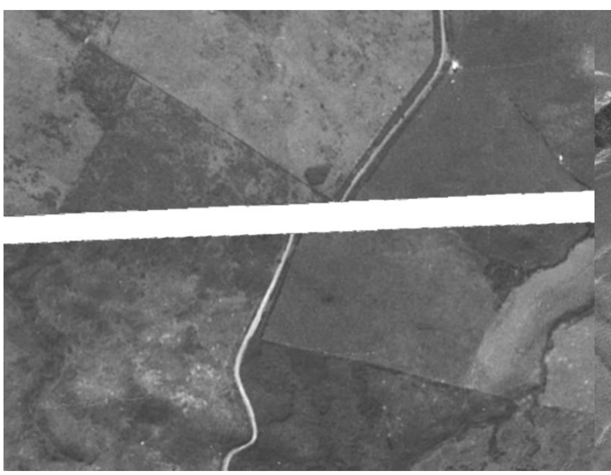
These sorts of products can also be mosaicked to form a layer or theme in a GIS. Depending on the parameters chosen during the process, such products can take less time than full orthorectification and should be "good enough" to use for tasks that do not require exact positioning, e.g. vegetation analysis.

When the technique is used on very flat areas it can provide an acceptable product. However, rectification does not correct for terrain displacement, or position of the aeroplane capturing the aerial imagery, or lens or image distortions.

Because it is an approximate process, there may be gaps or overlaps between adjacent images, particularly in steep terrain. Areas of the image may mismatch where the individual images have been mosaicked. Overall, the end product may not match data or layers/themes that have been corrected.

Rectified images typically contain information embedded in the file (or to be compatible with ArcGIS, supplied as a separate .tfw file) that enables the image to be located when imported into a GIS, Google Earth etc.

However, this is not necessarily always the case, and especially may not be the case for older products where the original format of the product was hard copy. The process whereby location information is added to the header is sometimes confusingly also referred to as "geo-referencing".



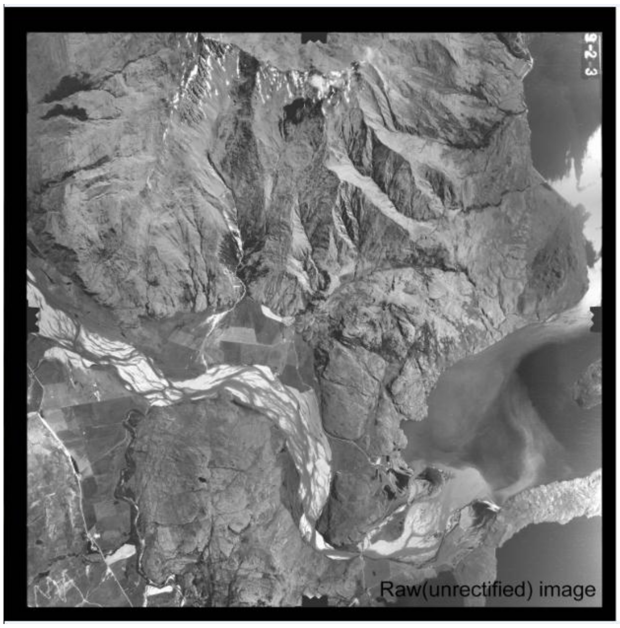
Example of a gap between adjacent images.

A misaligned road is an effect of mosaicking to form a single product, or layer/theme in a GIS from rectified–only images. This result is typical of areas of steeper terrain where the effects of terrain displacement are more pronounced.

-ORTHOPHOTOS – ACCURATE AND NOT-SO ACCURATE ONES

An orthophotograph (or orthophoto) is a photographic image prepared from aerial perspective image in which the displacements due to tilt **and** relief have been removed. The resulting image has the lack of distortion and true-to-scale qualities of a map.

Production of orthophotos involves progressively correcting small areas of the photograph for the effects of both relief and camera tilt, a process known as differential rectification.



An original aerial photograph

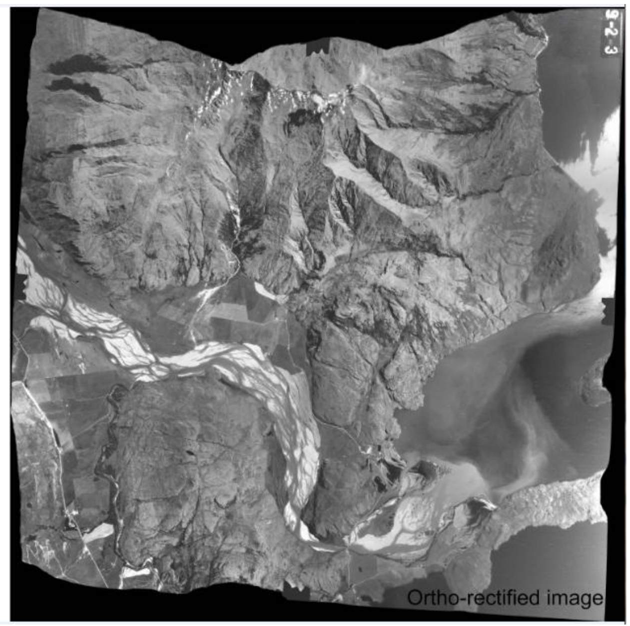


Image after orthorectification. Note the differences along the edges of the image, which illustrate the distortions in the original photograph.

Specialist equipment is required. Since the patenting of the first instrument of this type in 1927,[8] a variety of designs have been innovated, refined and superseded.

The accuracy of an orthophoto depends upon the quality and accuracy of each element in the process of its creation. A very accurate orthophoto can be achieved using a highly accurate and detailed elevation model, low-altitude flying, a high-resolution aerial camera, camera calibration report, and accurate geographic ground control. If any element is of a lower accuracy or quality, the accuracy of the final orthophoto will be affected. It is possible for the absolute accuracies of two orthophotos of the same area to be quite different, even when they look visually similar.

Appendix B on page 19 outlines in very general terms the different types of terrain models available today. It is necessary to understand the strengths and weaknesses of the various types as these will influence the accuracy and visual appearance of an orthophoto on which they are based.

Terrain-measuring technologies typically capture surface elevations,[9] although both LiDAR and multi-band radar have the potential to penetrate vegetation to provide bare-earth elevations. As a general rule, using a surface model to create orthophotos over rural areas is acceptable. However, use of a bare earth terrain model is preferred over urban areas, especially where multi-storey buildings are present. Creation of an orthophoto correct at

[8] C D Burnside, *Mapping from Aerial Photographs*, 2nd edition. William Collins Sons & Co Ltd, London. 1985.
[9] See the Terrain Model Appendix on pages 19-22.

both surfaces is possible (known as a true orthophoto)[10]. In this case, roof/canopy level **and** ground level datasets or terrain models are required, which increases the cost.

As mentioned previously with rectified products, today digital orthophotos will typically contain information embedded in the file (or to be compatible with ArcGIS, supplied as a separate .tfw file) that enables the image to be located correctly when imported into a GIS, Google Earth etc. However, this is not always the case, and especially not for older products where the original format of the product was hard copy.

Overall appearance of orthophotos

An aspect of all forms of orthophoto production that can influence the processing is the time spent creating what appears to be a single seamless image from all the individual images.

The main techniques used to influence the overall appearance are those associated with balancing the colour tones, and those with the way the individual images are mosaicked.

Colour balancing is the general term used for editing an image to even out the tones; for example, areas of bright sunshine/cloud, morning/afternoon, spring/autumn.

It can be a lot of work to achieve a good tonal balance for a project that covers a large area and that is likely to contain tonal differences due to weather and the time of day and year. It may well be that the end result is a poor average of all the conditions.

Although it may not achieve a consistent appearance over the entire project, colour balancing of smaller tiles or blocks may result in a clearer image within each tile, and be easier to undertake.

An example of where colour balancing between images has not been undertaken.

An example of colour balancing over an entire aerial survey. https://data.linz.govt.nz/#layer/1915-northland-1m-rural-aerial-photos-2006/

[10] See pages 14-15.

An example of where colour balancing has been applied on a per tile basis. https://data.linz.govt.nz/#layer/1907-northland-125m-rural-aerial-photos-2000/

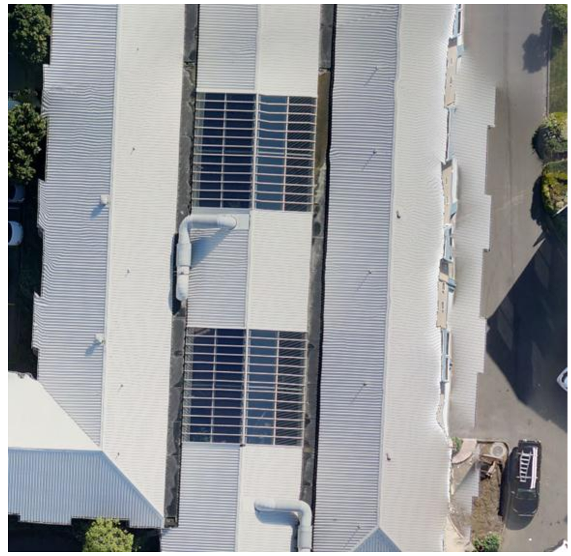
Mosaicking is the technique used to join separate images into a single product. Many different methods can be used, from simply creating a template and cookie-cutting regular portions from each image and joining them up, to selecting seam lines along areas of natural change such as like a road, ridge or stream. Feathering is a common process that can further reduce the image joins.

Software that automatically generates the mosaic will be very quick, but the end result may not be visually pleasing.

An example of mosaicking by template.

In a professionally generated orthophoto the seam lines should be almost invisible.

Accuracy



The wobbly roof lines and duplicated/displaced roof line, particularly on the right-hand building, are likely the result of using an auto-correlated digital surface model[11] and mosaicking without any manual checking and adjustment.

A second order orthophoto is a term commonly used when a less accurate product is required. All the same elements (displacement and scale differences caused by uneven terrain, and distortions caused by the plane's position) are taken into account, but less accurate control and a less accurate terrain model[12] are used.

If satellite imagery is being used to create the orthophoto, some software will have provision to input the RPCs (rational polynomial coefficients, or the tip, tilt and swing or pitch, roll, and yaw, variables).

Experience and knowledge of the technology is needed to ensure a desirable result is achieved. The software used here includes ERMapper and ARC GIS Create Ortho-corrected Raster Dataset Tool,

Colour balancing and mosaicking are addressed, usually with automatic routines. Frequently, little or no manual checking and manipulation is carried out, which can influence the appearance and accuracy of the final product.

Building lean removal

A true orthophoto is the term used to describe a specific product where the radial displacement (often referred to as "building lean" or "roof displacement") is removed.

Distortion increases with the distance from the centre of the photograph so features such as buildings lean noticeably. The amount a feature leans depends on the percentage of overlap in the photography and the height of that feature. The higher percentage of overlap in the photograph used, the less features will lean because the amount of photography used from the outer edge is reduced.

Radial displacement removed.

Radial displacement not removed. The top of the building obscures half of the road of the right.

[11] See Appendix B for definition of a DSM.
[12] See Appendix B for the types of terrain models.

Specialist photogrammetric software—such as SOCET SET & GXP and Inpho—is required to produce quality orthophotos and true orthophotos. These tools enable features such as buildings to be photogrammetrically modelled at roof level, and bridges at deck level. The highest point of turrets, bridge pylons and all features with significant changes in level, are captured.

The roof level **and** ground level datasets or terrain models are used to place the building top imagery over the building footprint.

Pieces of imagery from an increased overlap (typically a minimum of an 80 percent overlap is required for creating true orthophotos) are inserted into the original image where previously the building lean obscured the image of the ground. Insufficient extra images will result in blank areas where the camera was unable to obtain a view of the ground.

Given the usual requirement for an 80 percent overlap, it's unlikely that many true orthophotos will be able to be created from historic imagery.

Creating products from photos scanned from the Archive

In a pilot project, LINZ and Waikato Regional Council scanned 27,500 negatives from the Crown archive as very high resolution (14 and 20 micron) images, using a photogrammetric scanner. Photocentre coordinates, enabling the images to be geo-tagged, are supplied as part of the image metadata.[13] This will enable users to view the photos and know roughly where in the world that view is, but will not allow for accurate measurement.

Orthophotos are generally the product of choice today. Although there are only a few elements required to create orthophotos, as outlined on pages 11-15, varying decisions relating to the quality, accuracy and type will influence the cost, accuracy and visual appearance of the end product. To facilitate the creation of such products, the photo metadata also contains the nominal altitude and camera identification information that can be linked to camera calibration parameters.

In addition, if an accurate orthophoto is required from historic imagery it will be necessary to generate a terrain model of the ground as it was at the time the photography was taken.

Some level of "control" will also be needed. Today, with the combined use of survey grade airborne GPS and an inertial measurement unit, radically fewer ground control points are needed.

This original control no longer exists, and the information today provided from airborne GPS and inertial measurement units is not available. Consequently, it is necessary to either:

- find a point on the imagery that still exists today and which can be assigned coordinates based on, say, existing orthophotography or a map, or
- obtain new survey control.

Whether this is easy or not entirely depends on the type of country (urban areas are typically easier because of the likelihood of finding a common road intersection or building) and the age of the photography.

The older the image, the less likelihood there is of finding a common feature. For very old imagery it is possible that—if no common features can be found—an interim survey at a date between the present and the older imagery may be used to find one set of points common between it and the older survey, and another set between it and the present.

If a high degree of accuracy is not an immediate requirement, then rectification of a mosaic of the photos in a survey could be a cost-effective initial product. Before embarking on a mosaicking project, a decision must be made on the level of product required since such products do not lend themselves to future upgrades to higher-level products.

[13] Along with the scanned image, two types of metadata will be generated: metadata to do with the scanning process, and metadata about the aerial survey to which the image belongs.

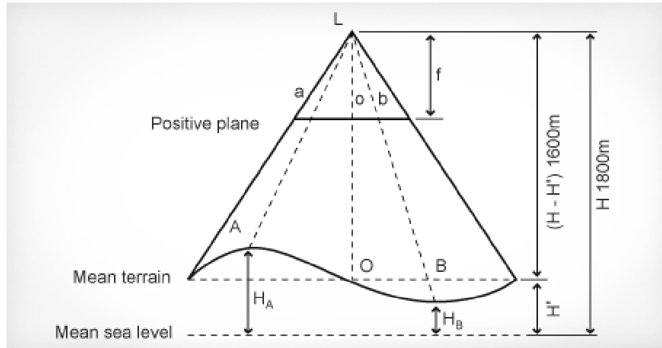
The table below provides a summary of the product levels from a geo-tagged photo through to orthorectified imagery. True costs can not be provided due to the large variability in requirements, job sizes, marketplace, and division of labour between customer and supplier, but indicative costs have been generalised from real projects. Several New Zealand and overseas geospatial service providers are positioned to provide these products from the scans that are produced from the LINZ scanning initiative which seeks to deliver "Geo-tagging plus" where the source data is readily available.

Level of product	**Useful for**	**Relative cost**	**Expertise to produce**
Geo-tagging – Associating a photo and its geographical point location (lat/long). The photo geometry is not changed.	Indexing, finding approximate location on a map. Visual qualitative queries.	$	Consumer
Geo-tagging plus - Scaling and orienting a photo to its approximate geographical location. The photo internal geometry remains unchanged.	Rough map overlays of individual photos. Visual qualitative queries.	$$ 2013 indicative cost: <$5/photo	Advanced consumer
Rectification - Aligning with horizontal control points, and often mosaicking multiple photos, to allow for rough overlays in a GIS viewer.	GIS layers where the best quality and accuracy are not critical.	$$$ 2013 indicative cost: $10/photo, $15/photo for mosaic	GIS professional
Second order orthophoto – Differential rectification: progressively correcting small areas of the photograph for the effects of both relief and camera tilt. Typically undertaken with less accurate control and terrain model; and automatic routines for mosaicking.	GIS layers for analysis, alignment with other datasets, and imagery.	$$$$ 2013 indicative bulk cost: $5-10 per photo $10-15 per photo for a mosaicked product	GIS/geospatial service provider
True orthophoto – Differential rectification: progressively correcting small areas of the photograph for the effects of both relief, camera tilt, and effect of building lean. Accurate control, bare earth and surface terrain models, high percentage photo overlap all required; colour balancing and mosaicking a combination of automatic routines and manual input.	GIS layers for precise analysis, high quality alignment with other datasets, undistorted map-grade imagery.	$$$$$ 2013 indicative cost: $100 per photo for a large survey mosaicked product	GIS/geospatial service provider/ photogrammetry

Appendix A: Variable terrain

SCALE OVER VARIABLE TERRAIN

The figure to the right shows variable terrain where the ground point A has an elevation of HA and the ground point B has an elevation of HB. On the positive plane, these points will appear at a and b respectively. Since A lies in a horizontal plane closer to the camera lens than B, it is reasonable to assume that the photographic image of a will be at a larger scale than b.



CALCULATING SCALE OVER VARIABLE TERRAIN

The variation in scale on a photograph may be more easily appreciated if we assume a set of values as an example.

Given:

H	=	1800m
H_A	=	300m
H_B	=	100m
f	=	152.4mm

Then:

$$S_A = \frac{f}{(H - H_A)} = \frac{152.4\text{mm}}{(1800 - 300).10^3} = \frac{152.4}{1\,500\,000} = \frac{1}{9843}$$

Scale at A is 1:9840

$$SB = \frac{f}{(H - H_B)} = \frac{152.4\text{mm}}{(1800 - 300).10^3} = \frac{152.4}{1\,700\,000} = \frac{1}{11155}$$

Scale at B is 1:11160

Thus in this example, a scale variation from 1:9840 to 1:11160 occurs. Note that the maximum scale occurs at the maximum ground elevation above mean sea level.

SOURCE: *https://nationalvetcontent.edu.au/alfresco/d/d/workspace/SpacesStore/315d1432-4519-45f6-b5c9-9d46aa4980a9/12_02/toolbox12_02/resources/html/res_calcscaleaerial.htm*

Appendix B – Terrain model definitions

Terrain model generation is already an everyday process within the spatial information industry. There are a number of sensor types currently being employed to produce surface and ground models, with varying levels of horizontal resolution and vertical accuracy, and with differing levels of process automation and cost

There are many different definitions for the different types of terrain models. However, all are seeking to describe two main elements:

- <u>what is being modelled:</u>

  EITHER the bare earth, i.e. the surface of the earth devoid of any vegetation or man-made structures

  OR the bare earth and—where there are features above ground such as buildings and vegetation—the heights of the tops of those features.

  This model is also sometimes referred to as the "first return surface" or a "first point of return" model, which refers to those points that are the first reflection from a laser pulse from LiDAR equipment. Therefore, the first reflection the first surface that the pulse reaches, such as the top of a building or vegetation canopy.

- <u>the file structure of that model:</u>

  EITHER a regularly spaced grid, of which there are two types:

  The first type can be defined by X (easting) and Y (northing) values, e.g. an ASCII file

  X, Y, Z (height)
  100, 1000, 45.3
  120, 1000, 54.2
  140, 1000, 64.4
  100, 1020, 45.4
  120, 1020, 62.3
  140, 1020, 33.4
  100, 1040, 23.6
  120, 1040, 19.4
  140, 1040, 58.5

  The second type is a raster file where each pixel is assigned a height.[14] Each height is often then assigned a colour. When the colours are greyscale, the raster grid can begin to resemble a photograph or map.

  OR a irregularly spaced collection of points, of which there are two types:

  One type consists of **strategically** placed height points and usually breaklines are included. Breaklines are linear features that represent a distinct interruption in the slope of a surface, such as a ridge, road, or stream. Conventional photogrammetry or ground survey is the most common forms of collections of this type.

  The other is an entirely random collection of points. Collections of this type are typically the result of a remote sensing survey like LiDAR.

[14] Terrain models where the height of an area feature is assigned a single height value is often referred to as a 2.5D model. In this context a 2.5D model describes a terrain model whereby the 3rd dimension (the Z value or height) is assigned to a polygon, e.g. a pixel, regardless of the fact that the polygon surface is likely not flat, but represents sloping terrain. Importantly, it may not be the average, or even the height at the centre of the polygon; it may simply be a random value of somewhere within the area.

The following definitions of terrain models are based on the Intergovernmental Committee on Surveying and Mapping definitions:

DEM: Digital Elevation Model.

The surface model is the bare earth devoid of any vegetation or man-made structures.

The file structure is a regularly spaced grid (ASCII or raster).

DTM: Digital Terrain Model.

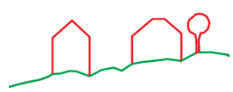
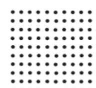
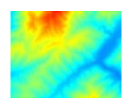
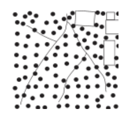
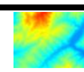
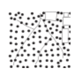
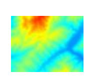
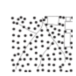
The surface model is the bare earth devoid of any vegetation or man-made structures.

The file structure is an irregular **but strategically** spaced collection of points.

DSM: Digital Surface Model

The surface modelled is the ground and where there are features above ground such as buildings and vegetation, the heights of the tops of those features.

The file structure can be **either** a regularly spaced grid (ASCII or raster), **or** an irregularly and randomly spaced collection of points.

summary	model	file structure
	 *first return surface* *or* *bare ground*	  or  *ASCII or raster regular-spaced grid* / *irregularly spaced height points with breaklines*
DEM		 or 
DTM		
DSM		 or  or 

TERRAIN MODEL ACQUISITION TECHNOLOGIES

Ground survey, photogrammetry, airborne light detection and ranging (LiDAR),[15] interferometric synthetic aperture radar (IFSAR), and bathymetric sonar, are all current popular techniques for generating terrain data.

In the case of photogrammetry and IFSAR, the sensor platforms can be either airborne or space-borne. Airborne laser scanning can also be used for shallow water bathymetry as well as for topographic surface-modelling.

Photogrammetry and image correlation

Historically, it was a manual process to photogrammetrically observe elevation data. Height points, contours and breaklines can still be observed and captured by manual observation using photogrammetric equipment. In today's terminology these observations constitute a DTM.

With the advent of digital softcopy photogrammetric processes, automated DSM generation using image-matching technology became feasible.

Image correlation is a means of processing aerial and satellite images to produce high-quality 2.5D[16] surface models. It is a computerised technique to match the similarities of pixels in one digital image with comparable pixels in its digital stereo image to automate or semi-automate photogrammetric compilation.

However, stereo image correlation is not as straight-forward as it sounds. In an effort to simplify the process, SGM (Semi Global Matching) was developed. It is a high-performance stereo correlation algorithm designed to produce a high-resolution DSM in the ground sampling resolution of the input images.

Using stereo image correlation techniques, the generation of a DSM from digital aerial or satellite imagery can sometimes be almost fully automated and can be a cost-effective alternative to conventional compilation for some modelling applications.

However ,the cost of the DSM-to-DEM conversion can be significant, and can exceed the total cost of producing the DSM. And, depending on the quality requirements of the terrain model, manual intervention may be required.

ALS or LiDAR

LiDAR—sometimes referred to as airborne laser scanning—is a technique that can provide a dense collection of height points from equipment carried in an aeroplane. It relies heavily on GPS and IMU[17] technology.

LiDAR technology was developed over 40 years ago and was initially used for mapping particles in the atmosphere. It can be used both from the air and on the ground.

LiDAR systems emit intense, focused beams of light to measure the time it takes for the reflections to be detected by the sensor. This information is used to compute ranges, or distances, to objects.

The three-dimensional coordinates (e.g., x,y,z or latitude, longitude and elevation) of the target objects are computed from a) the time difference between the laser pulse being emitted and returned, b) the angle at which the pulse was "fired", and c) the absolute location of the sensor on or above the surface of the Earth.

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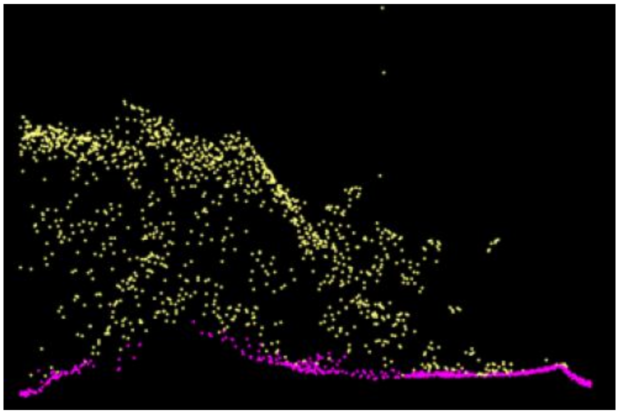
[15] Also known as airborne laser scanning.

[16] In this context, a 2.5D model describes a terrain model whereby the 3rd dimension (the Z value or height) is assigned to a polygon (e.g. a pixel), regardless of the fact that the polygon surface is likely not flat, but represents sloping terrain. Importantly, it may not be the average, or even the height at the centre of the polygon; it may simply be a random value of somewhere within the area.

[17] Inertial Measurement Unit; a precision gyroscope.

To achieve a high level of accuracy, this process is a bit more complicated since it is important to know—almost exactly—where the plane is as it flies at 100 to 200 miles per hour, bumping up and down, while keeping track of hundreds of thousands of LiDAR pulses per second. Fortunately, several technologies—especially the Global Positioning System (GPS) and precision gyroscopes (IMU)—came together to make it possible.

LiDAR cannot penetrate vegetation. However, often the point coverage is dense enough to allow ground measurement through gaps in the canopy.



Raw LIDAR data (also referred to as a point cloud) showing the tops of trees (yellow) and the bare ground surface (purple).

As with the other DSM-to-DEM conversions, depending on the quality requirements considerable manual post-processing of the filtered and thinned-out LiDAR DEM is required to "clean" the bare-earth representation.

IFSAR

Interferometric Synthetic Aperture Radar (IFSAR) is a technique using two or more radar images to determine relative ground heights. These systems can produce DSMs to around 1m vertical accuracy and with a post spacing of 5m. Also the use of stereo radar imagery as a complement to the process allows a semi-automated DSM-to-DEM conversion.

Airborne IFSAR can record data at a very rapid rate, with swath widths exceeding 10km, and importantly, data collection is not impeded by clouds. A potential downside is that IFSAR is side-looking, which can leave shadowing and data voids in the oblique ranging data, thus complicating somewhat DEM acquisition over urban areas. It is likely only to be cost-effective at the present time for large area DEMs with vertical accuracy of around 1m and horizontal resolutions between 5m and 30m.

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Further reading:

"Specifications and guidance notes for the purchase of orthophotography by the New Zealand public sector, in support of the National Imagery Coordination effort"

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