

ABSOLUTE AND EXTERIOR ORIENTATION USING LINEAR FEATURES

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ABSTRACT

For many years we have had digital photogrammetric systems available that can perform automatic interior and relative orientation of aerial photographs. Developments in absolute and exterior orientation are not so robust because the problem is significantly more difficult. The reason for the increase in difficulty is that there is no easy way to create the master image or target patch which represents the traditional ground control point. If we have such an image then there are a number of techniques that are well established to undertake area or feature based matching to find the corresponding point on the photograph. There are also an increasing number of users of photogrammetric techniques and software who would like to be able to provide control for absolute or exterior orientation in a very easy and efficient way without having to rely on careful identification of ground control points. These two issues have been the motivation to investigate the general issue of improving the flexibility and ease of providing ground control for the processes of absolute and exterior orientation using analytical and digital techniques.

This paper will present a new approach to absolute and exterior orientation based on the measurement of linear features and their automatic matching. The results show that the technique can produce results suitable for many environmental mapping applications and in some instances is suitable for topographic mapping. It is also shown to have the capability of automatic relative orientation.

1 INTRODUCTION

1.1 Digital Photogrammetry

The advances in digital photogrammetry have brought many changes to traditional photogrammetric procedures and products. Although these advances are bringing exciting changes to the users of photogrammetry there is still a role for analytical photogrammetry to play, particularly in traditional vector mapping and in many special engineering applications. Perhaps the most important benefit brought by digital photogrammetry is the potential for automation. Having the photographs in digital image format provides them in a suitable form for computer manipulation and processing. Automation is important for a number of reasons although the main drive is the quest to bring about productivity gains by reducing the time taken to perform a task. From the point of view of job satisfaction there are mixed feelings, as automation can remove the monotony and tedium of a repetitive task. For example digital elevation observation can de-skill a task such as performing relative orientation or leave the photogrammetrist to clear up the problems of unsatisfactory matching in digital elevation modelling (DEM) generation during quality control. There are some tasks where automation can bring consistency of observation and quality. This might be noticeable when a human observer tires and for example may result in a reduction in their ability to perform relative orientation.

One of the side effects of introducing automation and de-skilling the tasks is that it enables a wider group of people to use the techniques, largely as tools. Many traditionally accepted photogrammetric techniques are being included in standard remote sensing image processing software. These can now be seen and used as tools by a non-specialist photogrammetric community. It is easy to see that this will increase in the future. This 'non-specialist' group might include geologists and environmental managers, it might also include archeologists, geographers, planners and users of remote sensing. To these users, the highest metric accuracy is often not of major concern as the nature of the detail /information being extracted is not accurately definable, it is typically 'soft' detail. What is important to these users is that the tools must be easy to use, with minimal 'specialized' skill required.

1.2 Absolute and Exterior Orientation

Two of the most difficult photogrammetric tasks to automate are absolute and exterior orientation. This is because traditionally ground control points are traditionally natural pieces of detail which are difficult to record in a convenient and suitable computer compatible form. Pre-marked targets on the ground can be recorded as a 'target' master pattern in a computer and used in automatic matching with the corresponding 'target' patch in the digital image. Researchers have investigated the use of specific features such as manhole covers or existing maps or CAD models as 'targets' (Schickler, 1992; Drewniok and Rohr, 1997a 1997b; Morgado and Dowman, 1997; Dowman, 1998) with some success. However these tend to be solutions when very specific ground data is available. What is required is a technique that is more general, and where the ground coordinate data is easy to obtain.

1.3 In-flight use of the Global Positioning System (GPS) and Inertial Measurement Unit (IMU)

The use of in-flight control in the form of GPS and IMU is a practical reality. Operational systems are available and research is being undertaken to realize the full potential that can be achieved. This will play a significant role in providing control for images in the future. The aim is to enable the parameters of exterior orientation of a photograph to be directly measured and introduced into a photogrammetric plotting instrument or workstation. This technology is still relatively new and not widely used at present. Therefore there is still a considerable amount of aerial photography taken without direct measurement of position and attitude. Besides this photography, there is obviously a vast archive of photography available around the world which similarly does not have any in-flight control associated with it. This archive photography is often the photography that the 'non-specialist' user of photogrammetry might be interested to use. So there is still a need for an easy form of indirect image orientation.

1.4 The aim of a new approach to absolute and exterior orientation

The aim of any new approach should consider the following points:-

- it needs to be easy to use;
- the ground control must be easy to obtain;
- it needs to have the potential for automation;
- it needs to be flexible and suitable for analytical and digital techniques so it has the widest possible application.

2 A NEW APPROACH TO ABSOLUTE AND EXTERIOR ORIENTATION

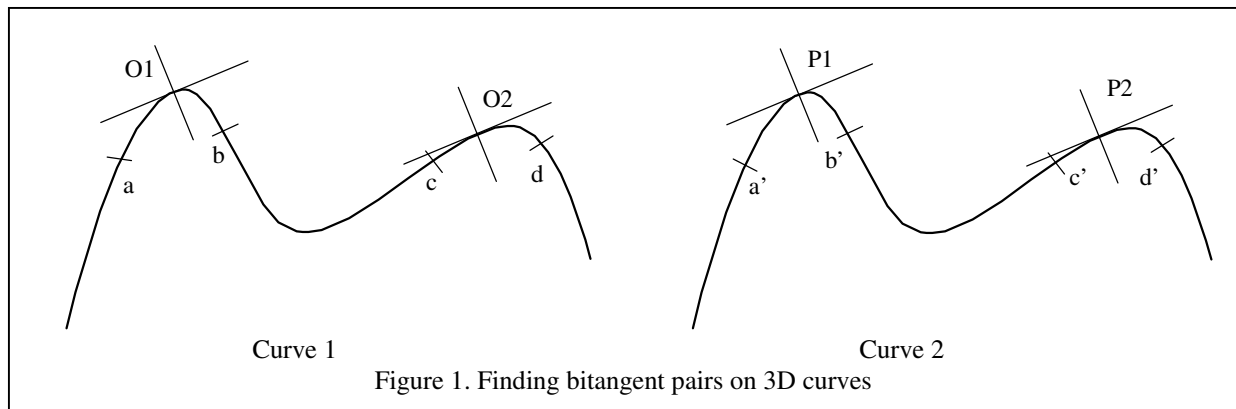
After consideration of the above points in section 1.4 and studying readily available features on aerial photography that might be suitable for ground control, a number of conclusions were drawn. It was realized that it would be difficult to find a small target in any image that was very 'cluttered' with detail. Premarking would perhaps be helpful with new photography but of no use with archive photographs. Detailed selection of traditional ground control points of natural features is not sufficiently easy as it requires too much skill and time. Finally it was decided to investigate the use of linear (or curvilinear) features as ground control as these were easily visible on the image and often accessible on the ground. This also had the advantage that a number of researchers were investigating, with some success the automatic extraction of linear features from aerial and satellite images for example, Gruen et al. (1995, 1997). The ways of obtaining 'real world' (ground) coordinates of the linear features are numerous. These could be available from an existing map or data base. With the increasing availability of GPS, the curves could be obtained by an individual walking along the linear feature, in the case of foot paths, or driving along the curves, in the case of a road network. Obviously the accuracy might be expected to reduce as the clarity of the definition of the curve due to the method of data capture (perhaps on a motor vehicle) becomes poorer. The interesting point about linear features is that they take many forms, including roads, paths, fence lines, waterways, etc. Also they are frequently visible on a wide variety of photographs. It is also possible to measure these features equally well using diapositives in an analytical plotter.

The concept is that linear features will be extracted from individual photographs or in a stereo model. These features could be obtained by manual or automatic means in an analytical plotter or by using digital techniques. The corresponding ground curve will be coordinated in three dimensions, by any suitable means (GPS, digital map plus DTM, etc.). The curves are then automatically matched to find the 'best' fit together. Finally the transformation, three dimensional for absolute orientation or perspective transformation for exterior orientation, will be performed from the corresponding point coordinates of the matched curves. This project has concentrated on the automatic matching of the two curves.

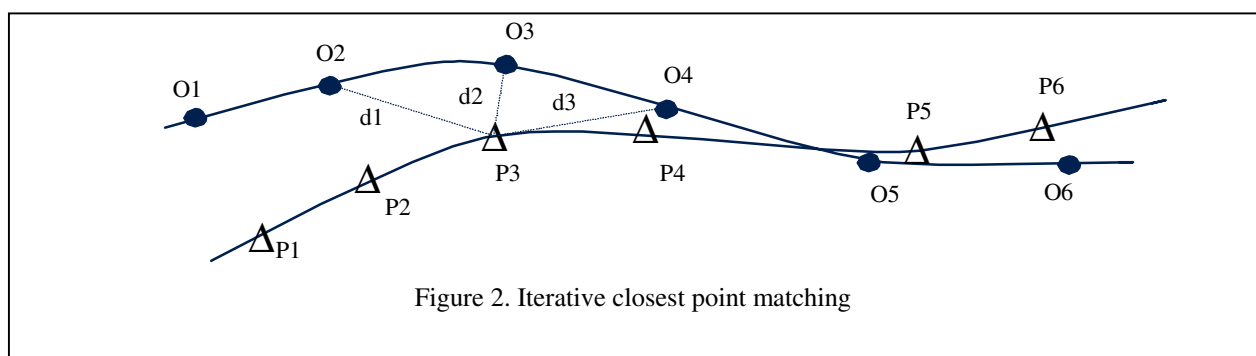
3 THE TECHNIQUE OF CURVE MATCHING

The automatic curve matching takes place in two stages; firstly a gross (or bulk/coarse) transformation, followed by an iterative fine adjustment process to obtain the 'best' match. The basic methods for each stage are presented. The first stage was not always needed if the curve coordinate systems were not too dissimilar. The method is best explained by considering 2 three dimensional (3D) curves. These 3D curves are defined by a series of points with X, Y and Z coordinates. There is no attempt to record corresponding points in each curve during the observation or collection of the curve data. The matching process attempts to match a point on curve 1 to a point on curve 2 that is closest to where the corresponding point on curve 2 should be. The potential quality of the curve fit will be based on either extremely high redundancy or the filtering out of match points that are not good corresponding points. This filtering should leave a relatively small number of points that are 'reasonably' (within a tolerance) well matched.

Although a bulk translation can be performed by using the centroid of the coordinates the rotation is not quite so easy to determine. A method of bitangent pairs was investigated, see figure 1.



On curve 1 a point O1 is selected and a normal and tangent are determined (method from Bu-Quing, 1989). A further point on the curve, point O2, is found with 'the same' (within tolerance) normal and tangent. If no 'O2' is found a new O1 is chosen and the process is repeated. An attempt is then made to find the corresponding points on curve 2 by exhaustive searching to find a similar bitangent pair of points. Once a possible pair of corresponding points are found (P1, P2) a local curve fit between points a to b and a' to b' and similarly c to d and c' to d' is performed. If the fit is within tolerance then a bulk transformation is performed using these points. If not the process is repeated with new O1 and O2. To 'fine tune' the transformation (to get a better match) the method known as the Iterative Closest Point (ICP) matching algorithm is used, see figure 2, developed by a number of researchers in the early 1990's (e.g. Besl & McKay, 1992; Chen & Medoni, 1992).



As an example consider point P3 and calculate the distance to points on the 'O' curve d1, d2, d3. The shortest is d2 therefore O3 is accepted as the matched point. This is performed for all points on 'P' curve. Then the statistical filtering is performed to check each point to see if the value of d is less than a tolerance value, D. After the first iteration the value of D is related to the mean and standard deviation of the values of d. Points outside the criteria are temporarily rejected. The matched points are used to compute a new transformation and the ICP process is repeated. Temporary rejection becomes permanent if a point is continuously 'temporarily rejected'. Termination of the whole process occurs when the rate of change in the choice of matched points between iterations, or the number of matched pairs drops below a threshold value. The result is a list of coordinates of matched points on each curve.

A further development of the technique was introduced to increase the number of points in a curve by generating intermediate points using spline curve fitting.

4 POTENTIAL INFLUENCES ON THE QUALITY OF THE RESULTS

Initially some theoretical, simulated data tests were performed to test the correct operation of the software and to undertake some basic tests of the algorithms. It was found that the initial difference in position, scale and orientation was within normally accepted tolerances for photogrammetric processes, for example $\pm 6^\circ$ of tilt were not a problem. Practical testing would reveal the effects of:

- the distance between points on the curves;
- the geometry of the curve (shape);
- the quality of the curve definition for example, was the road centre line followed, curb line or somewhere in between?

Overriding influences on these effects is the problem of 'dead' ground on the imagery and, as RTK GPS was used to produce 3D ground curves the problem of loss of lock on satellites, due to masking of the sky, creating gaps in the ground curves.

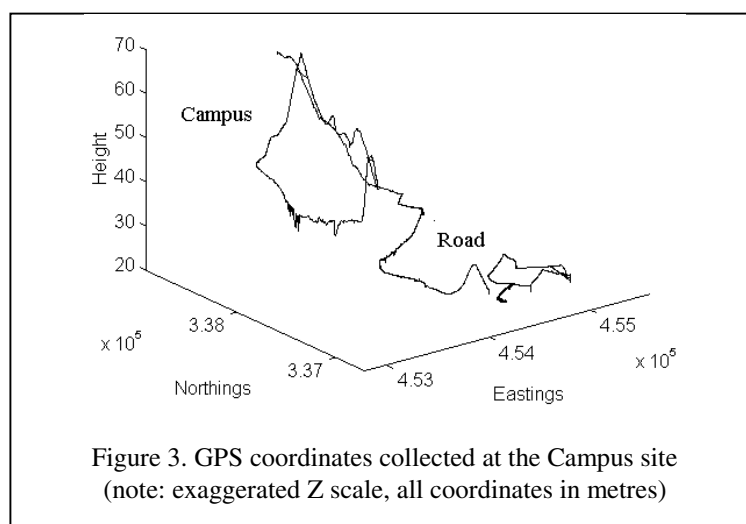
The practical trials were undertaken with three stereo pairs of photographs of different types of terrain, with different distribution of linear features and with different observing strategies. The process of absolute orientation and exterior orientation are investigated.

5 RESULTS

The results will be discussed in two sections, the first will deal with the process of absolute orientation where coordinates from a stereo model will be matched with coordinates derived from GPS measurements. The second section will deal with results from using curves measured on individual photographs (the case of exterior orientation).

5.1 Absolute Orientation

5.1.1 Nottingham University Campus photography results. The 'campus' photography is 1:10 000 scale photography covering an area of gradual but significant changes in height as can be seen from figure 3.



The GPS curve was recorded by walking round the road with a real-time kinematic (RTK) GPS system. RTK GPS can provide significantly higher accuracy than is required for the ground coordinates for this scale of photography, but this system does allow easy recording of the curve data by following the kerb line with the antenna. The model coordinates were observed using the Leica SD2000 analytical plotter.

Curve 1 (model data) = 1021 points (average 8.9m between scaled points)

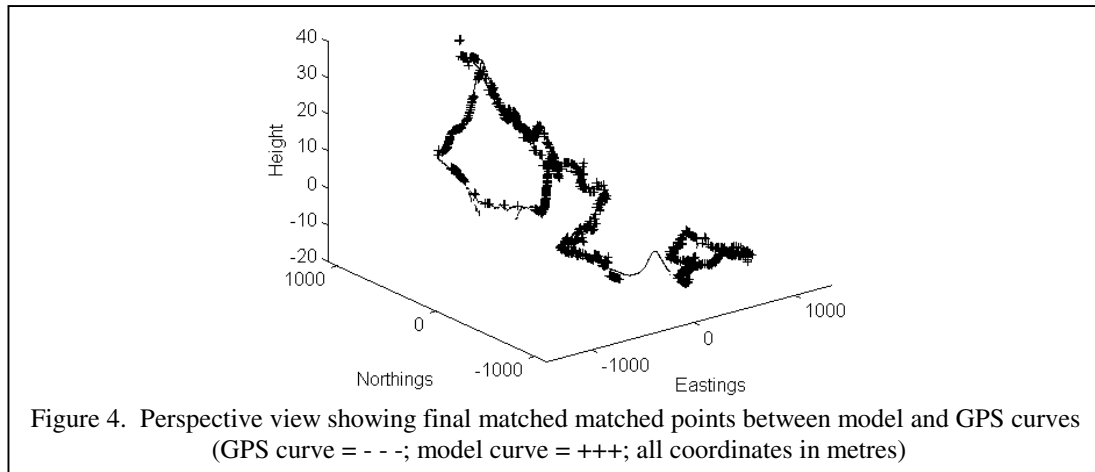
Curve 2 (ground data) = 3535 points (average 2.7m between points)

Number of matched points = 352 points

Figure 4 shows the distribution of points that have been matched.

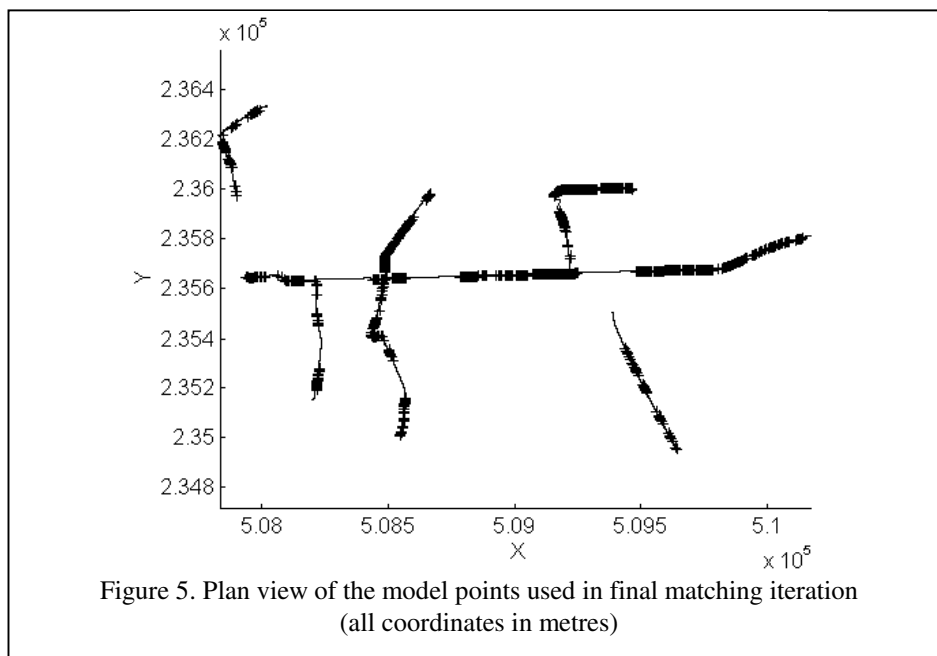
RMSE plan = 0.54m

RMSE height = 0.52m



Using traditional ground coordinated points this model has a particularly good absolute orientation with RMSE X = 0.15m, RMSE Y = 0.14m and RMSE Z = 0.13m. More typical for 1:10 000 scale photography you might expect coordinate values in the region of 0.25 – 0.35m which is still a little better than achieved (≈ 0.5 m). So, although the curve matching is not good enough for perhaps traditional topographic mapping it would be suitable for many other less demanding applications such as geological and environmental purposes.

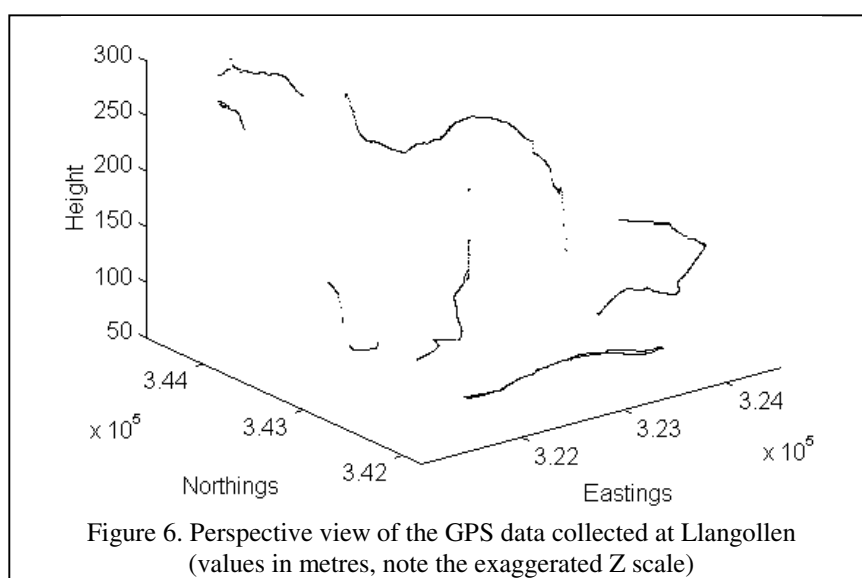
5.1.2 Silsoe, Buckinghamshire photography results. The photography is 1:10 000 scale of a relatively flat area with some gentle slopes at the edges of the model. The linear features (roads and paths) are fairly straight and approximately perpendicular or parallel to each other see figure 5. Curves were recorded on foot by kinematic GPS and on the SD2000 for model coordinates.



Curve 1 (model data) = 1768 points (average 3.1m between scaled points)
 Curve 2 (ground data collected on foot) = 8184 points (average 0.8m between points)
 Number of matched points = 444 points
 RMSE plan = 0.21m
 RMSE height = 0.19m

Setting this model up using traditional ground control for absolute orientation (9 points) gave RMSE values in plan = 0.62m and in height = 0.31m. So the curve matching technique has provided significantly better results. This is probably due to the very high density and therefore a large number of matched points. The matched points (linear features) also have a very good distribution.

5.1.3 Llangollen, North Wales photograph results. Again 1:10 000 scale photography was used, but this time a vehicle collected GPS data around a road network in Llangollen that consists of very rugged terrain (see figure 6). On occasions the vehicle reached speeds in excess of 40mph. To add practical reality, the photogrammetrist was not involved in the field data collection and attempted to observe the same route in the stereo model on the SD2000 from a brief written description.



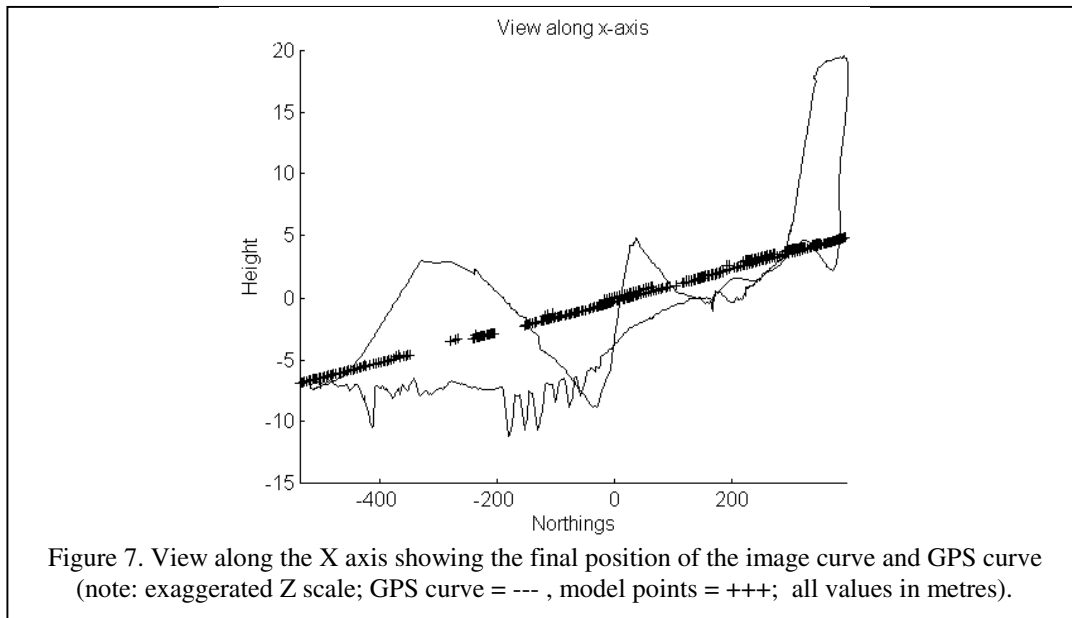
Curve 1 (model data) = 435 points (average 12.9m between scaled points)
 Curve 2 (ground data) = 3527 points (average 2.8m between points)
 Number of matched points = 355 points
 RMSE plan = 9.3m
 RMSE height = 4.5m

The small number of model points and the large changes in the relief has resulted in a match/transformation worse than expected. Using traditional ground control in this stereo model the absolute data collection and thus the orientation is not particularly good with RMSE values X=2.6m, Y=2.6m and Z=0.54m. A further effect which has contributed to the larger than expected RMSE values is the difficulty for the two curves to follow exactly the same track for example, the vehicle was obviously limited in its route line by the road conditions. Taking this into account the result is perhaps not so surprising.

5.2 Exterior Orientation

The curve matching technique is ideally suited to matching curves of like dimensions; 2D to 2D and 3D to 3D curves. In the process of exterior orientation we are relating 2D image to a 3D real world coordinate system. The relationship between the 2D image and 3D world is given directly and efficiently by the collinearity equations. An example of taking 2D image coordinates (Z value held constant at zero) and fitting to a 3D curve using the technique developed produces a typical result shown in figure 7. This example comes from part of the data set for the Nottingham University Campus photography. The following results were obtained:

Curve 1 (photo point data) = 375 points (average 8.3m between scaled points)
 Curve 2 (ground data) = 1180 points (average 2.7m between points)
 Number of matched points = 110 points
 RMSE plan = 1.1m
 RMSE height = 1.1m



Two options were considered, the first was to introduce a height into the 2D image coordinates by taking the height from the previous iterations matched ground point. Using the Campus photography the following results were obtained:

Curve 1 (LH photo point data) = 1768 points (average 3.1m between scaled points)
 Curve 2 (ground data) = 8184 points (average 0.8m between points)
 Number of matched points = 918 points
 RMSE plan = 0.5m
 RMSE height = 0.0m (expected because of the method)

Curve 1 (RH photo point data) = 1768 points (average 3.1m between scaled points)
 Curve 2 (ground data) = 8184 points (average 0.8m between points)
 Number of matched points = 1061 points
 RMSE plan = 0.5m
 RMSE height = 0.0m (expected because of the method)

The second option is to use the curve matching to find corresponding photograph points to perform a relative orientation between the pair of photograph. The model coordinate curve is then used in a 3D-3D transformation to perform absolute orientation. The following results are from a matching of left and right hand Nottingham photo curves (1021 points). The matched points are used to create a 3D model coordinate curve (relative orientation) which is then matched with the ground GPS curve (absolute orientation). The photograph curve coordinates were observed stereoscopically and therefore should produce a good match and result. The RMSE in plan = 0.8m (0.5m) and in height was 1.0m (0.5m), bracket values are those obtained from the absolute orientation results, see section 5.1.

6 CONCLUSIONS

The new technique to perform absolute and exterior orientation has produced some interesting results that have proved the viability of the method. It can be used in analytical and digital techniques and, if combined with an automatic linear feature extraction technique, has the potential for almost complete automation. The method has shown how ground, “real world” coordinates are captured in an easy manner using RTK GPS, although a wide variety of sources of ground coordinate data could be used (GIS, Digital Map, etc.). The curve data needs to be as dense as possible and have a wide

coverage over the area of the stereo model. As the final data is in point coordinate form it has the potential to be used with other control in analytical techniques to determine absolute or exterior orientation of the photography and in for example aerial triangulation. By performing 2D to 2D photograph curve matching an alternative automatic process of relative orientation has also been performed.

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