

CONNECTIVITY GRAPH TO COPE WITH TILTED VIEWS

Automated Processing of Oblique Imagery

Oblique multi-camera systems are rapidly maturing and expanding the market for airborne technology and services. Because datasets of oblique images are large, automated processing is a necessity. Here, the authors present a workflow for the automated orientation of large oblique blocks using a connectivity graph and discuss automated dense matching of oblique images.

Oblique airborne multi-camera systems are increasingly complementing traditional vertical views. Previously hidden façades and building footprints are unveiled in oblique views, which makes oblique imagery useful for 3D city modelling and cadastral purposes as well as emergency rapid response and scene interpretation. In the past,

the spotlight was on visualisation and inspection of oblique images by human operators. However, today's interest is focused on the metric capabilities.

TILTED VERSUS VERTICAL

Tilted views are richer in content compared to vertical views, but they bring more occlusions and

degradation in similarity between image features as well as significant scale and illumination differences. Oblique images are also more prone to hot spots and sun glints which arise when looking towards or away from the sun. Additionally, instabilities in the flight trajectory are more harmful. As a result, efficient execution of large-scale projects requires reliable solutions, automated extraction of tie points and dense matching for 3D reconstruction.

TIE POINTS

Interior and exterior parameters of



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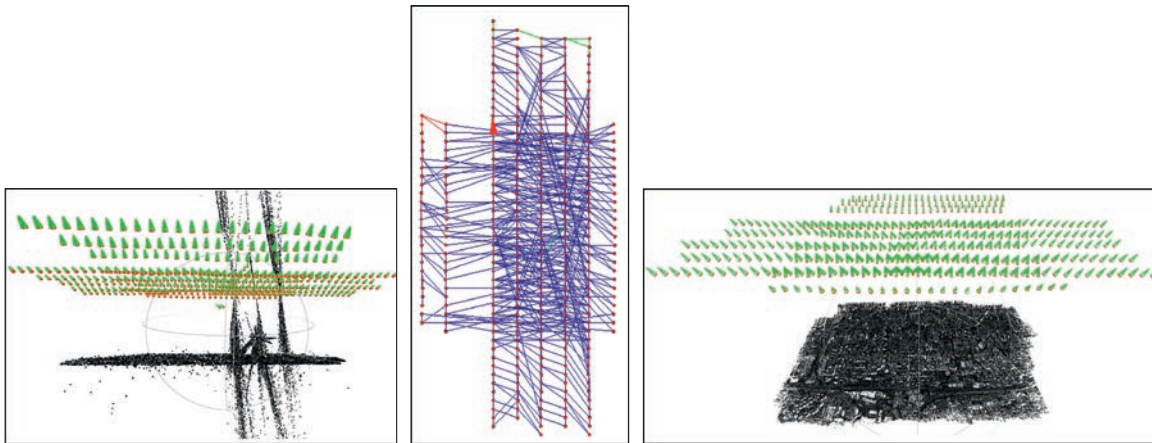


Figure 1, Maltese-cross obliques show orientation failures if no connectivity graph is used (left) but with such a graph (middle) the correct parameters are produced.

aerial images are commonly known beforehand. Interior parameters are retrieved through lab calibration and exterior parameters are measured directly with on-board sensors (GNSS/IMU). Nevertheless, these parameters are just approximates for metric and automatic applications; therefore, an adjustment in a least squares sense has to be conducted. Direct georeferencing of oblique images without using ground control points is still an issue to be resolved. Experiences gained in processing terrestrial images – which, just like oblique aerial images, are convergent and unordered – provided enough insight to adopt and adjust the terrestrial methodologies for use in processing airborne oblique imagery. The main obstacle is the time-efficient generation of

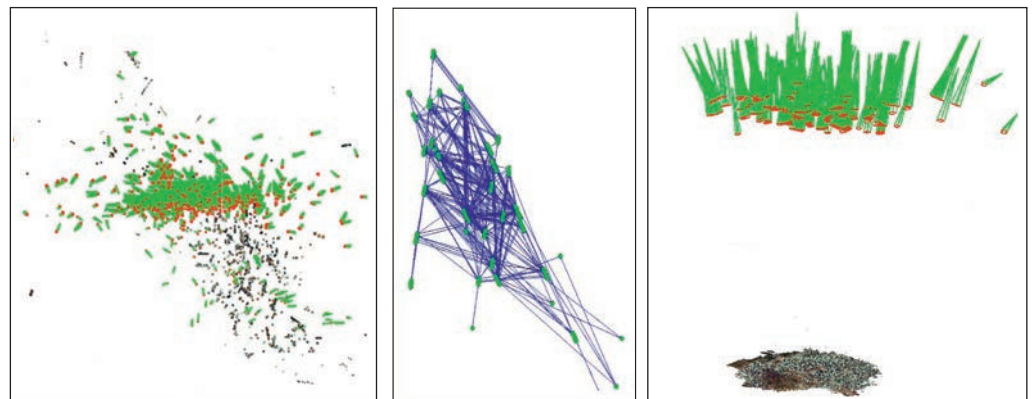


Figure 2, As Figure 1, but here for fan-type obliques.

putative correspondences between overlapping images. Pairs, triplets or larger sets of images with maximum similarity are first identified using GNSS/IMU information and a connectivity graph and subsequently matched. A connectivity graph expresses the spatial relationships

between the images, speeds up the determination of image correspondences and reduces the number of outliers. The connectivity between images is described in the form of a graph of which the nodes represent images and the edges represent their relationships, i.e. two images are linked with an edge if they are spatially compatible. An image pair has to fulfil three conditions in order to be connected: (1) their footprints coincide by a given percent, (2) cameras' look directions are similar or one of the cameras is nadir, and (3) the number of extracted homologous points exceeds a threshold.

Series on Oblique Photogrammetry

This article is the second in a series on oblique photogrammetry, a joint initiative of EuroSDR Comm. 1, Delft University of Technology and University of Twente (ITC). Edited by Mathias Lemmens, the series is intended to cover concepts, applications and camera systems currently available on the market. You are cordially invited to contribute. To do so, feel free to contact the editorial manager at wim.vanwegen@geomares.nl or the senior editor at m.j.p.m.lemmens@tudelft.nl.

BUNDLE BLOCK ADJUSTMENT

The connectivity graph limits the number of mismatches. But the complexity of a network's geometry of oblique image blocks and the non-linearity of collinearity equations require good initial approximations of unknowns. The Apero bundle adjustment software the authors usually employ allows a concatenation of direct methods (spatial resection, essential matrix) which avoids the need for precise initial approximations and allows unknown camera positions and 3D object coordinates to be derived (Figures 1 and 2). The bundle adjustment of multi-camera images must handle n different cameras with different interior (IO) and exterior orientation (EO) parameters. The camera parameters can be retrieved without constraints – each image is oriented using an independent EO for each acquisition – or with constraints, which describe the relative rotations and displacement between cameras and are added to the mathematical model, lowering the number of unknowns and stabilising the bundle solution. Additionally, the IO of each camera can be assumed known from a lab calibration or simultaneously be computed in the bundle solution through self-calibration. The large redundancy in oblique images (Figure 3) helps to select the best correspondences and achieves high accuracy in 3D reconstructions.

DENSE MATCHING

Compared to vertical images, oblique images give a deeper and more complete description of urban areas, allowing the extraction of denser point clouds and more information in the 'smart city' domain, with façades and buildings completely reconstructed (Figure 4). Mismatches or wrong reconstructions can still be present because of: (1) buildings, roads or other objects having been captured with different scales, (2) presence of occluded areas, (3) depth and image GSD changing more

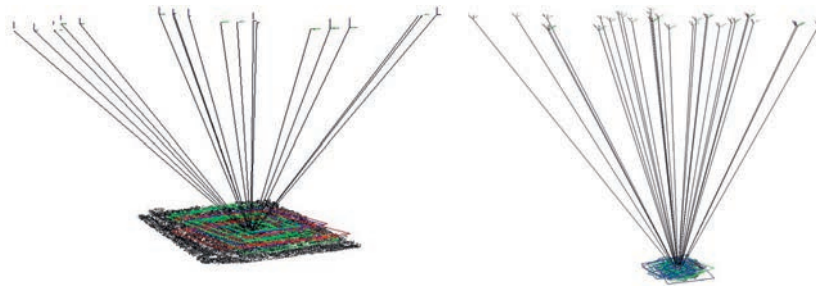


Figure 3, Redundancy in the observations of Maltese-cross configuration (left) and fan.



Figure 4, Colour-coded dense point cloud of an urban area.

suddenly than for vertical images, and (4) the smaller intersection angles and baseline between images making point cloud generation sensitive to noise. Higher overlaps may overcome some of these issues, although they increase the size of datasets and the number of point clouds.

CONCLUDING REMARKS

Traditional processing procedures are being challenged. Because oblique systems are still rather new, however, many questions remain open including: When should oblique imagery be used? What

are its strengths and weaknesses? What is the optimal acquisition pattern for metric mapping? How can illumination and scale changes be dealt with? Which processing software is reliable and efficient? Methodologies need to be fine-tuned in order to improve automated processing, feature extraction and scene interpretation, and for other mapping purposes.

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FURTHER READING

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