Dense Image Matching

reconstruction using dense image matching is a hot topic as it enables the automatic extraction of 3D urban models, notably from airborne oblique imagery. However, applying DIM algorithms to oblique imagery is challenging because of large scale variations, illumination changes and the many occlusions.

Here, the authors present a methodology for evaluating the performance of DIM algorithms and show the initial results from four DIM packages: Agisoft PhotoScan, Leica Xpro SGM, OpenCV StereoSGBM and SURE.

Dense image matching (DIM) aims at computing a depth value for each and every pixel of an image. This facilitates the generation of accurate and highly detailed digital surface models (DSMs). Until now, the studies performed on DIM have been mainly limited to nadir imagery, with only a few studies addressing oblique images. The methodology we have developed for the evaluation of DIM solutions applied to oblique imagery includes performance measures ranging from completeness and differences in image space to density and deviations from reference geometries in object space. Deviations to planes fitted through patches lead to an indicator for a single point cloud while deviations between the DIM output and reference points or profiles indicate performance of multiple point clouds, generally from different sources.

DIM Software

The four DIM solutions tested are mostly based on the semi-global matching (SGM) algorithm introduced by Hirschmüller (2008), and include:

- **PhotoScan** from Agisoft LLC implements a full photogrammetric processing chain based on computer vision algorithms
- **Xpro SGM** from Leica Geosystems, originally developed for DSM generation from ADS pushbroom data and later adopted to frame sensors, is not yet fully optimised for oblique images
- **StereoSGBM** from the open source library OpenCV consists of a simplified variant of the SGM algorithm and is limited to a radiometric resolution of 8 bit
- **SURE** from the University of Stuttgart and now distributed by its spin-off nFrames.

The workflow to arrive from stereo images to a DSM can be subdivided into five stages: (1) image rectification; (2) image matching and depth map extraction; (3) point cloud generation; (4) DSM computation; and (5) DSM texturing. The two DIM packages Agisoft PhotoScan and SURE perform all these tasks and are therefore the most complete with respect to workflow (Table 1).
Site and Data

The test area covers 5 hectares of Zürich West (Figure 1). The urban area has been recorded with a Leica RCD30 Oblique Penta which consists of five camera heads, one looking nadir and the others looking forward, backward, to the right and to the left with a tilt angle of 35 degrees. Each head has a sensor size of 60MP with a pixel size of 6 micron and a radiometric resolution of 14 bit. Images were captured with a nadir overlap of 70%/50% at a flying height of 520m. With a focal length of 53mm the ground sampling distance (GSD) of the nadir images is 6cm and the GSD of the oblique images ranges from 6cm to 13cm. Prior to matching, the images were precisely georeferenced. Reference data includes point clouds from terrestrial laser scanning (TLS) and a DSM derived from Leica ADS100 data.

Concluding Remarks

Completeness is the ratio between the number of pixels to which the software assigns a depth value and the total number of pixels. Areas covered by vegetation and shadows were particularly challenging. For the whole test area, SURE shows the highest completeness with 78%, and with 60% Leica Xpro SGM shows the lowest. Figure 2 illustrates the spatial distribution of the points for which a match was found for a 0.5ha cropping of the test area. Although the depth map of Xpro SGM shows fewer holes than that of PhotoScan or StereoSGBM, the percentage is lower as the point density in the matched areas for Xpro SGM is generally lower. Figure 3 depicts – in the form of maps, histograms and values – the depth differences for building façades generated from left-view DIM and TLS points. The systematic errors range from 21 to 30cm and the root mean square errors (RMSEs) reach up to 50cm. SURE shows the best results.

Profiles and Points

Reference profiles are a proven method for analysing matching resolution, potential systematic errors and accuracy. Figure 5 shows that profiles of roof shapes generated from point clouds. Therefore, three adjoining planes such as roof parts were fitted through the respective point cloud and intersected. Reference profiles are a proven method for analysing matching resolution, potential systematic errors and accuracy. Figure 5 shows that profiles of roof shapes generated from point clouds. Therefore, three adjoining planes such as roof parts were fitted through the respective point cloud and intersected. Absolute point accuracies are about 1 GSD horizontally and vertically for nadir and oblique imagery with camera heads facing across the flying direction, and 1 to 2 GSD for forward and backward oblique viewings. The methods for evaluating and comparing DIM performance have proven to be efficient and practical for different image matchers, for diverse oblique viewing geometries and for complex urban scenes, including building façades and other vertical structures. The systematic errors range from 21 to 30cm and the root mean square errors (RMSEs) reach up to 50cm. SURE shows the best results.

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Further Reading
