3D Reconstruction of Building Edges
Experiences with LH-Systems' ADS40 Three-Line Scanner Data

Since the arrival of airborne digital cameras, like the ADS40 three-line scanner of LH-Systems, high resolution digital image data is available without the necessity of an AD-conversion. Besides this, three major advantages of three-line scanner data compared to analogue frame images are high radiometric resolution, multi-spectral capacities and three stereo angles. Test data is used in a research topic about geometric properties and reconstruction possibilities from three-line scanner data. This paper presents our experiences with 3D reconstruction possibilities from ADS40 data.

By Sander Oude Elberink, Delft University of Technology.

In the past ten to fifteen years a lot of progress has been made in the automation of photogrammetric processes, along with the development of more and more sophisticated GIS applications. The growing interests for flexible and accurate 2D and 3D mapping purposes included the demand for digital image data with stereo capabilities. Since the arrival of airborne digital cameras, like the ADS40 three-line scanner, high resolution digital image data is available without the necessity of an AD-conversion.

Digital photogrammetry

Since the introduction of airborne digital sensors with multi-spectral capacities, like the DMC frame camera and three-line scanners like the ADS40, a great part of the gap between Remote Sensing and Photogrammetry has been filled. The combination of various digital data sources, more than the specialisation, will lead to improved or even new applications. Thanks to the progress in exchanging geographic data in GIS systems, all kinds of digital data can easily be analised and processed in one system. For example, updating 2D maps will more and more be done by superimposing data from several sources. Last year a research project at the TU Delft started in order to analyse the capacity of three-line scanners in the field of 2D and 3D mapping purposes.

Three-Line Scanner

Three panchromatic sensor lines of the three-line scanner produce forward, nadir and backward views along the strip. The three lines, each consisting of a CCD array of 12.000 pixels, lie in the focal plane, perpendicular to the flying direction, see figure 1. Three major advantages compared to analogue frame images are:

1. high radiometric resolution of 16 bits (8 bits dynamic),
2. triple viewing angle,
3. acquisition in multi-spectral domain (RGB and Near IR).

These properties may result in better interpretation and segmentation of the acquired scene compared to normal analogue images, especially in low-contrast areas like shaduwed places. Due to the high dynamics of an airborne environment the raw image data has to be rectified by projecting raw data on a projection plane. One major disadvantage is the weak geometry of three-line scanners. Even after rectification, errors due to line-perspective geometry and aircraft movements are not removed completely, and depend on the height of the scene above projection plane.

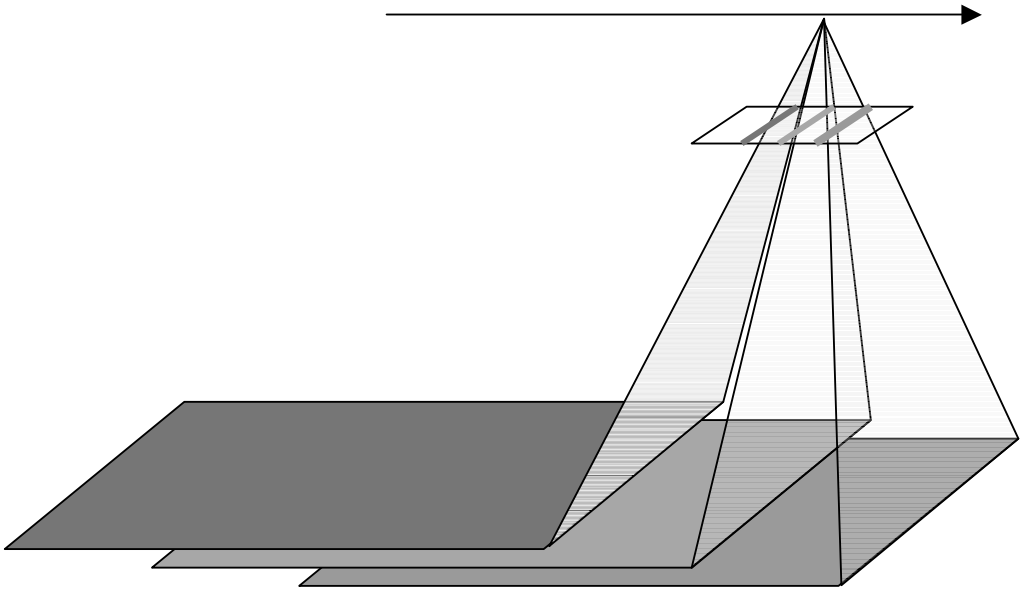

Figure 1: Three-line scanner configuration.

ADS40 Test CD-Rom

On the occasion of the introduction of the ADS40 at the ISPRS congress 2000 in Amsterdam, LH-Systems has released a CD-Rom (Information Kit) with test data of the sensor. The data has been acquired near Berlin in August 1999, and contains a rural scene with an airport and a few buildings. The CD-Rom includes calibration and orientation files, as well as (panchromatic) raw imagery and rectified images in all three viewing angles. This gives the user the possibility to rectify the raw data with his own software and compare his result to the result on the CD-Rom. In figure 2 image data before (left) and after rectification (right) with our own software is shown.

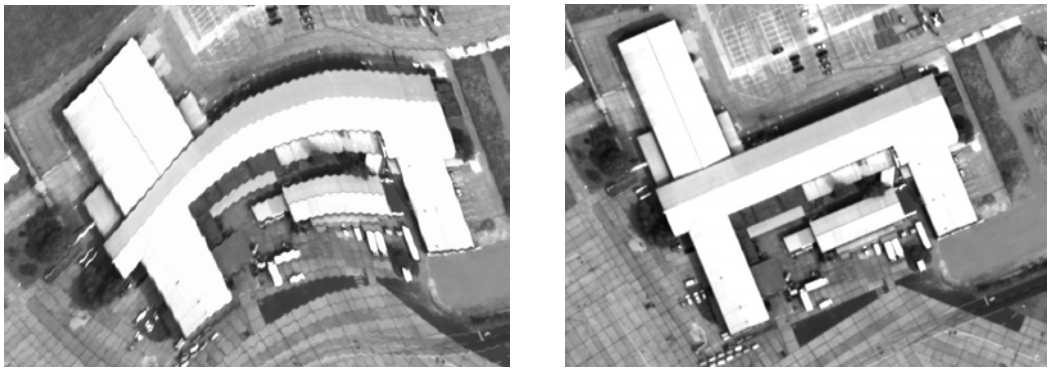

Figure 2: Raw image (left) and rectified image (right).

Table 1 Sensor properties of the ADS40

System properties	
Number of pixels per scan line	12.000
Flying height	3000 m
Ground sample distance	24 cm
Radiometric resolution	12 bits (8 bits dynamic)
Stereo angles (forward-nadir / nadir-backward)	16° / 26°
Field of view	42° x 64°

Misalignment Errors

An absolute condition to the use of line scanner data, is the necessity of exterior orientation parameters of the scan lines at every exposure. This means that position and rotation of the platform has to be known about 200 times per second. This can be established by using an integrated GPS/INS system together with the use of a few ground control points (to estimate errors like GPS cycle slips and the misalignment of the GPS/INS system). The exterior orientation of the test data on the CD-Rom has been determined by only using GPS/INS data, resulting in inaccurate orientation data. These so-called misalignment errors can increase up to two meters in horizontal direction at the projection plane. By using additional information like ground control points, these errors can be estimated; this should prevent inaccurate orientation parameters.

3D Reconstruction

Our main goal is the 3D reconstruction of edges of buildings. Buildings are the most important objects in 3D city models, which are used in a widely spread range of GIS applications like:

- urban planning,
- virtual reality,
- tele-presence and
- noise prediction models.

The majority of the objects are built-up in polygonal models which consist of a collection of straight lines. Although the automatic reconstruction of objects itself is not new, the source data is new. Three viewing angles and high radiometric resolution of three-line scanner data will theoretically result in more reliable extraction of 2D and 3D information. Because the focus is on object line reconstruction, our method follows a line-based approach, see figure 3. Straight lines are extracted in all three images,

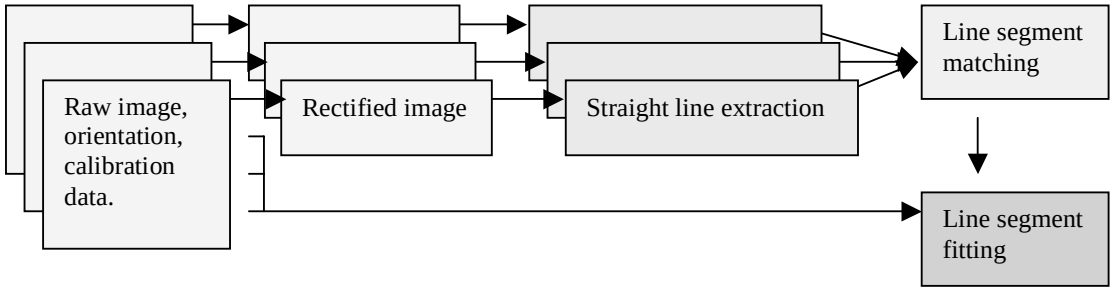

Figure 3: Flowchart from original data to 3D edges.

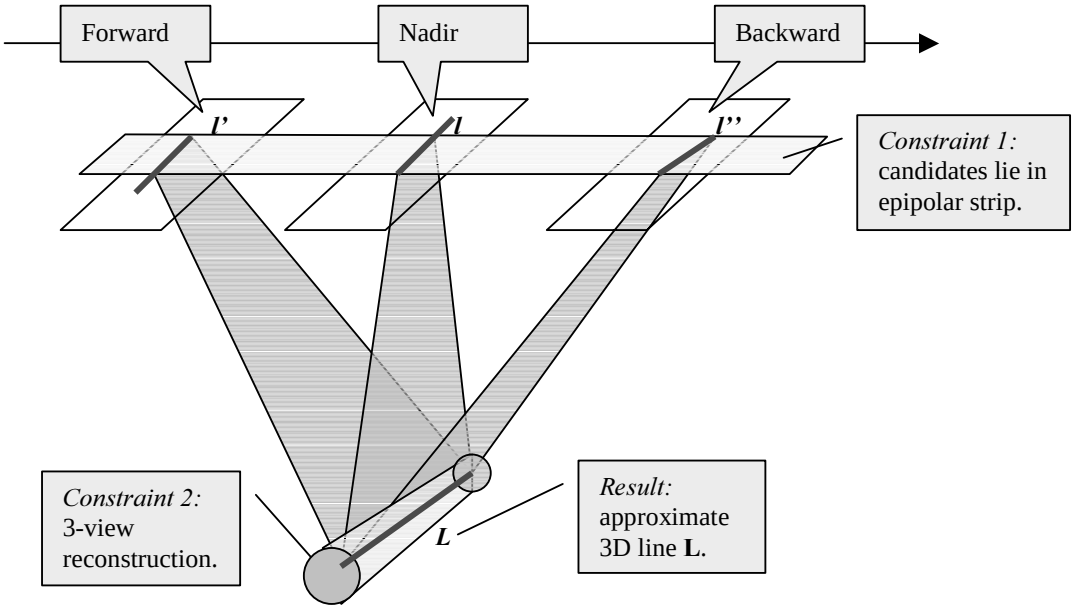

Figure 4: Line matching procedure.

followed by a matching step to get 3D information. Refinement of the reconstruction is done in the fitting algorithm by using the matching results and the original data, in order to remove the rectification errors.

Line Segment Matching

For 3D line reconstruction straight line segments at object edges need to be matched in at least two overlapping views. Straight lines that are characteristic for man-made objects will appear as straight lines in the rectified images. They are extracted by grouping adjacent pixels with similar gradient direction and fitting a straight line with sub-pixel precision through these pixels. Often this leads to fragmented line segments or multiple line segments representing one object line, for example when shadows cut edges. Due to fragmentation in the 2D line extraction, the reconstructed 3D object lines are fragmented as well. The fragmentation even increases in 3D due to the property that only the overlapping part of three extracted lines will be reconstructed. One 2D extracted line can thus be cut in more than one 3D line segments. In figure 4 an overview of the matching procedure is shown.

The surplus value of three viewing angles is expressed in the reduction of mismatches of about 75 % in our test region. Repetetive patterns will always cause a few mismatches in an automatic matching procedure. The accuracy of the reconstruction of the object lines after matching is about 50-60 centimeter in horizontal and 100 centimeter in vertical direction. Results are shown in figure 5 for the same building as in figure 2.

Fitting Algorithm

In order to remove the projection errors and its negative influences on the 2D and 3D reconstruction, we use the height information from the matching procedure to project raw data on a local plane through the 3D object line. Next, in an iterative fitting algorithm the 3D line is adapted in such a way that the line is determined by pixels with high gradients

in all three images. This has been done by minimalising the distance between the line and pixels with high gradients.
The accuracy of the line reconstruction after fitting is about 15 centimeter in horizontal and 25 centimeter in vertical direction. So, the fitting algorithm increases the accuracy of the reconstructed object lines with a factor between 3 and 4.

Figure 5: 3D view on matched line segments (left) and fitted line segments (right).

Concluding Remarks

The use of digital data instead of analogue images speed-up object reconstruction, because time consuming A/D-conversions become superfluous. Three-line scanners proof to produce suitable data for automatic 3D line reconstruction. This suitability is expressed in high geometric and radiometric resolution, together with the reliability of a triple viewing angle. When using rectified images, feature-based matching algorithms produce 3D lines, which still contain errors. We proposed to use the geometry of the recording situation in a least squares fitting step in order to remove these errors, finally resulting in accurate 3D line equations. Fitting results showed the convergence of fragmented reconstructed lines to one object line. Thus, accurate 2D and 3D information can be obtained from line scanner data when using good approximate height information.

Biography of the Author

Sander Oude Elberink received a master degree in Geodetic Engineering from the Delft University of Technology, The Netherlands in May 2000. After his study, he started as a junior-researcher on the topic of geometric properties and reconstruction possibilities of three-line scanner data. Since September 2001 he is working at the Survey Department of the Ministry of Transport, Public Works and Water Management.

Sander Oude Elberink MSc
Delft University of Technology, Faculty of Civil Engineering and Geosciences, Section of Photogrammetry and Remote Sensing, NL-2629 JA Delft, The Netherlands, E-mail: S.J.OudeElberink@geo.tudelft.nl