High Precision Photogrammetric Data Set for Building Reconstruction and Terrain Modelling

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1 Preliminary

1.1 Purpose

This document describes a test data set prepared for use in the project AMOBE[1] being conducted at ETH Zurich between the photogrammetric (IGP) and vision (IKT) groups and in cooperation with SRI. We are distributing this data with the purpose of providing a basis for comparison and evaluation of image understanding techniques, in particular those dealing with the reconstruction of man-made objects. Features of this data set include provision of the full photogrammetric information, four-way image overlap and ground truth. It is intended that the Avenches set compliment the ISPRS Working Group III/3 data[2].

1.2 Photography

The Avenches data set is based on aerial photography collected over Avenches (Switzerland) in 1991 for the ETH project *Processing of Geographic Data for CAAD-Supported Analysis and Design of Urban Areas*. This photography has an image scale of 1: 5000 and was flown with 60% forward and sidewards overlap. The image scale is typical of a campaign for high detail photogrammetric surveys. The photographs were handled on many occasions before they were scanned, i.e. for the manual measurements and aerotriangulation (but also by architects!), the effects of which are readily apparent: in all images, significant amounts of dust, sometimes hairs, and even scratches are to be found. This is unfortunate but nevertheless represents realistic conditions: techniques for man-made objects reconstruction must be robust enough to be able to cope with such disturbances.

2 Scanning

The 23cm x 23cm original colour diapositives of Avenches were scanned at 15 μm on the Zeiss-Integraph PS1 scanner at the University of Stuttgart. This scanner has a nominal geometric precision of 2 to 4 μm. Because

[1] **A**utomation of Digital Terrain Model Generation and **M**an-Made **O**bject **E**xtraction from Aerial Images.

[2] This data set was distributed early 1994 via the "vision list". Details can be obtained from Monika Sester at monika.sester@ifp.uni-stuttgart.de

a full photograph scanned at 15 μm produces images of around 15k x 15k pixels (for RGB about 640Mb!), only ROI (regions of interest) images are provided - one of an industrial area and the other new residential. Each of the images is of size 1800 x 1800 pixels and contains a sufficient number of buildings and variations in building form to provide a good starting point for developing and testing reconstruction techniques. For efficiency reasons, the ROIs were selected to cover approximately the same ground area. Thus, the respective parallaxes have been reduced to almost zero.

As the scan parameters were "optimized" for each full photograph - and not for the selected ROIs - variations in the overall intensity between the images is noticeable.

It should be noted that the scanning was performed under less than optimal conditions, i.e. temperatures up to 33 degrees resulting in some noise. In addition, scan swath borders can be noticed in some of the images. The scanner employs a 2048 pixels long line CCD scanning at a resolution of 7.5 microns. Neighbouring swaths have in certain cases radiometric differences due to wrong CCD calibration and/or illumination instabilities. The images were contrast enhanced and and visually checked to detect such problems. The detected problems are listed below (image number, x- and y- pixel coordinate where the problem is clearly visible, approximate max grey level difference (error) between neighbouring swaths):

- 5898: x = 873, y = 904, error = 11 grey levels
- 5873: x = 645, y = 804, error = 7 - 10 grey levels
- 5873: x = 1669, y = 1410, error = 10 grey levels
- 5874: x = 344, y = 1652, error = 10 grey levels
- 5874: x = 1369, y = 921, error = 10 grey levels
- 5883: x = 544, y = 1185, error = 10 - 14 grey levels
- 5883: x = 1568, y = 393, error = 4 grey levels

3 Data Sets

Each data set is comprised of four images scanned from the common overlap region of a 2 x 2 block. Table 1 indicates from which photographs the images were scanned, their respective flight strips, and to which data set they belong. The ROI files have been prefixed with the photographs numbers. Section 6 contains overviews of these images.

	Residential	**Industrial**
strip 1	5888, 5889	5873, 5874
strip 2	5897, 5898	5882, 5883

Table 1: ROIs and their image numbers

Characteristics of the data sets are listed below:

- Image format: Sun Raster.
- Image files: Red, Green and Blue files are provided for each image. Additionally, a grey level file of each image was prepared based on the V (intensity) channel of the HSV color model.

- Pixel size: 15 μm. This amounts to a ground area of approximately 75 x 75 millimeters. The images can, of course, be re-sampled if the resolution is considered too high.

Ground truth for the ROIs is provided in the data set. In both cases the coordinate system corresponds to the Swiss Landeskoordinatensystem:

- Buildings: separate DXF and IGES files for the residential and industrial ROIs contain building roof models. These models are represented in terms of line entities manually measured by an operator to an expected accuracy of $\pm 0.1m$. Figures 1 and 2 illustrate projections of the residential and industrial roofs into ROIs 5888 and 5897, respectively.
- Digital Terrain Model (DTM): a separate ASCII file for the residential and industrial ROIs contains DTM information for the two ROIs. The data given is the result of resampling the original measurements on a 10 meter grid. The original data was manually measured on an AC3 analytical plotter to an expected accuracy of $\pm 0.1m$. Contour information is contained in DXF- and IGES-format CAD models. Note first that the DTMs model (only) the terrain and do not include the buildings; second, they extend beyond the ground area covered in the ROIs.

Figure 1: Ground truth overlaid on image 5888.

Orthophotos for the images are also distributed with the data set. The orthophotos were produced using the grey level images and the DTM. The map coordinates of the orthophotos and the grid spacing are given in the file *stat* of the directory *orthos* under the *resid* and *indust* directories. The images are in Sun Raster format and their ground resolution is approximately equal to the resolution of the original images. For each of the residential and industrial areas there are 4 orthophotos. If the sensor orientation, scanner calibration, and DTM are accurate and the radiometric properties of the images similar, then the 4 orthophotos should be identical in their overlap regions. Since the buildings are not included in the DTM, subtraction of the orthophotos will highlight areas containing buildings.

A *digital surface model* (DSM) of the residential ROI is distributed as an example of the results obtainable with commercial software. As opposed to a DTM, the DSM includes modelling of the surface of all entities e.g.

Figure 2: Ground truth overlaid on image 5873.

buildings, and not just the terrain. It was computed using a pyramid-based correlation technique on the Helava DPW with an interval of 0.25m. Figure 3 illustrates this DSM represented as (a) a grey level image, and (b) "embossed" to better show the elevation variations. The bright blobs represent the higher points, e.g. houses and tree stands.

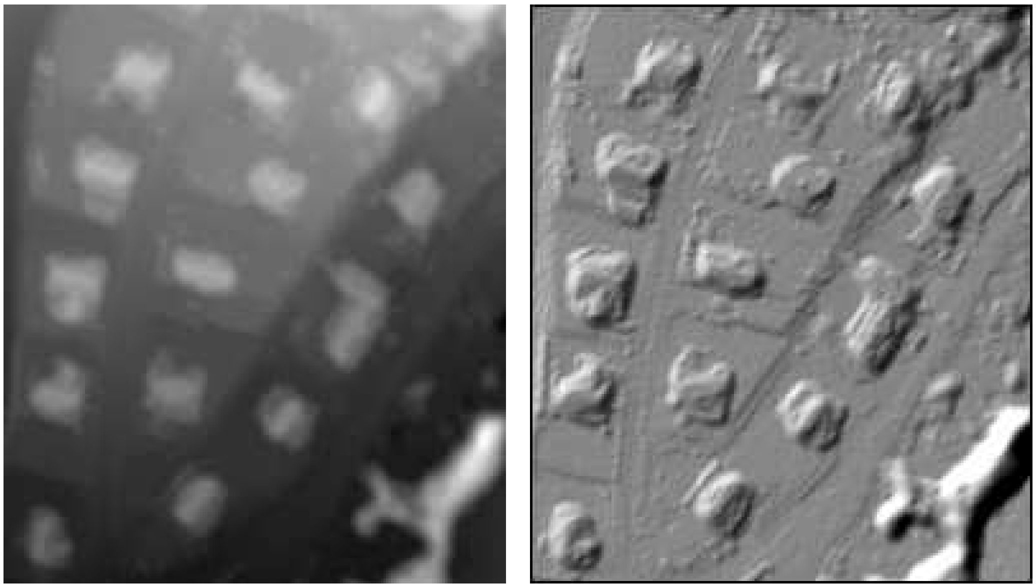
4 Transformations

4.1 Interior Orientation

From the camera calibration protocol the principal point of autocollimation (PPA) is given as $(+0.003, +0.005)$ and the camera's principal distance as 152.85 mm. Radial lens distortion is on the order 1-3 μm (i.e. up to 0.2 pixels). For object reconstruction purposes the given calibration values can be adopted. By ignoring radial distortion and other additional parameters (APs) the camera model required is simplified without significant loss of accuracy. The orientation parameters given below have been estimated in a bundle adjustment of the full Avenches block (some 45 photographs) without self-calibration. The σ_0 a posterior value for this adjustment was 5.67.

4.2 Pixel to Image Coordinate Transformation

Transformations are needed to relate measurements made in pixel coordinates to the image (photogrammetric) coordinate system. Note that this transformation includes a reduction to the PPA. Input to the transformation are the coordinates of a point in pixels in each image (x_{pix}, y_{pix}) and output is the coordinates of the point in millimeters in the image coordinate system (x_{img}, y_{img}). The transformations are formulated in terms of a 6-parameter affine transformation:



(a) (b)

Figure 3: DSM of the residential ROI: (a) intensity "image" of the model; (b) embossed version of this image.

$$x_{img} = a_1 + a_2 x_{pix} + a_3 y_{pix}$$
$$y_{img} = a_4 + a_5 x_{pix} + a_6 y_{pix}$$

The following transformations are given for a pixel coordinate system with origin $(0, 0)$ defined at the center of the upper left-hand pixel (see Figure 4. The inverse transform, i.e. image $\rightarrow$ pixel, for each ROI is also provided. Data files containing these transformations are included in the data set.

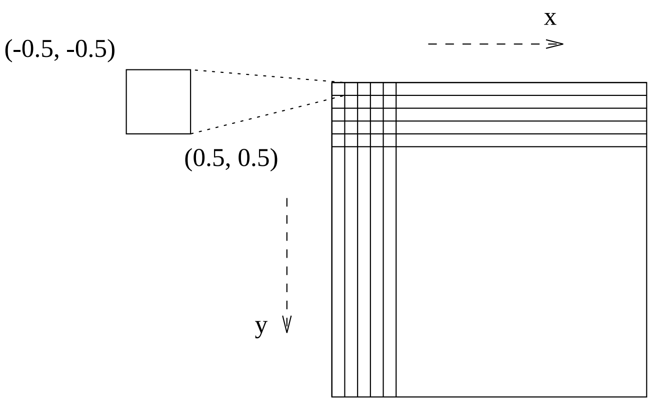


Figure 4: Definition of pixel coordinate system. The origin is located at the center of the upper left-hand pixel.

4.2.1 Image 5873

Pixel-to-Image:

$$x_{img} = -31.49550 + 0.01500x_{pix} + 0.00000y_{pix}$$
$$y_{img} = 75.98750 + 0.00000x_{pix} + -.01500y_{pix}$$

Image-to-Pixel:

$$x_{pix} = 2099.7000000000 + 66.6666666667x_{img} + 0.0000000000y_{img}$$
$$y_{pix} = 5065.8333333333 + 0.0000000000x_{img} + -66.6666666667y_{img}$$

4.2.2 Image 5874

Pixel-to-Image:

$$x_{img} = 47.00450 + 0.01500x_{pix} + 0.00000y_{pix}$$
$$y_{img} = 75.73750 + 0.00000x_{pix} + -.01500y_{pix}$$

Image-to-Pixel:

$$x_{pix} = -3133.6333333333 + 66.6666666667x_{img} + 0.0000000000y_{img}$$
$$y_{pix} = 5049.1666666667 + 0.0000000000x_{img} + -66.6666666667y_{img}$$

4.2.3 Image 5882

Pixel-to-Image:

$$x_{img} = -26.99550 + 0.01500x_{pix} + 0.00000y_{pix}$$
$$y_{img} = -22.76250 + 0.00000x_{pix} + -.01500y_{pix}$$

Image-to-Pixel:

$$x_{pix} = 1799.7000000000 + 66.6666666667x_{img} + 0.0000000000y_{img}$$
$$y_{pix} = -1517.5000000000 + 0.0000000000x_{img} + -66.6666666667y_{img}$$

4.2.4 Image 5883

Pixel-to-Image:

$$x_{img} = 44.00450 + 0.01500x_{pix} + 0.00000y_{pix}$$
$$y_{img} = -24.51250 + 0.00000x_{pix} + -.01500y_{pix}$$

Image-to-Pixel:

$$x_{pix} = -2933.6333333333 + 66.6666666667x_{img} + 0.0000000000y_{img}$$
$$y_{pix} = -1634.1666666667 + 0.0000000000x_{img} + -66.6666666667y_{img}$$

4.2.5 Image 5888

Pixel-to-Image:

$$x_{img} = -12.49550 + 0.01500x_{pix} + 0.00000y_{pix}$$
$$y_{img} = -72.26250 + 0.00000x_{pix} + -.01500y_{pix}$$

Image-to-Pixel:

$$x_{pix} = 833.0333333333 + 66.6666666667x_{img} + 0.0000000000y_{img}$$
$$y_{pix} = -4817.5000000000 + 0.0000000000x_{img} + -66.6666666667y_{img}$$

4.2.6 Image 5889

Pixel-to-Image:

$$x_{img} = 65.87950 + 0.01500 x_{pix} + 0.00000 y_{pix}$$
$$y_{img} = -75.51250 + 0.00000 x_{pix} + -.01500 y_{pix}$$

Image-to-Pixel:

$$x_{pix} = -4391.9666666667 + 66.6666666667 x_{img} + 0.0000000000 y_{img}$$
$$y_{pix} = -5034.1666666667 + 0.0000000000 x_{img} + -66.6666666667 y_{img}$$

4.2.7 Image 5897

Pixel-to-Image:

$$x_{img} = -8.12050 + 0.01500 x_{pix} + 0.00000 y_{pix}$$
$$y_{img} = 39.23750 + 0.00000 x_{pix} + -.01500 y_{pix}$$

Image-to-Pixel:

$$x_{pix} = 541.3666666667 + 66.6666666667 x_{img} + 0.0000000000 y_{img}$$
$$y_{pix} = 2615.8333333333 + 0.0000000000 x_{img} + -66.6666666667 y_{img}$$

4.2.8 Image 5898

Pixel-to-Image:

$$x_{img} = 68.00450 + 0.01500 x_{pix} + 0.00000 y_{pix}$$
$$y_{img} = 47.48750 + 0.00000 x_{pix} + -.01500 y_{pix}$$

Image-to-Pixel:

$$x_{pix} = -4533.6333333333 + 66.6666666667 x_{img} + 0.0000000000 y_{img}$$
$$y_{pix} = 3165.8333333333 + 0.0000000000 x_{img} + -66.6666666667 y_{img}$$

4.2.9 Affine Parameter Terms for Other Pixel Coordinate Systems

If the image measurement software being used is not based on having the origin at the center of the upper left-hand pixel, corrections to the a_1, a_4 terms of the above given transformations will be required. Table 2 summarises the correction terms for a pixel coordinate system with center of the upper left-hand pixel at $(0.5, 0.5)$ and for a pixel coordinate system with center of the upper left-hand pixel at $(1.0, 1.0)$. These correction terms refer to the transformation Pixel-to-Image; analogous correction should be also applied to the Image-to-Pixel transformation.

Term	**0.5 system**	**1.0 system**
a_1	$a_1 + 0.0075$	$a_1 + 0.015$
a_4	$a_4 - 0.0075$	$a_4 - 0.015$

Table 2: Affine parameter term corrections.

4.3 Exterior Orientation Data

In this section the exterior orientation parameters of each of the eight images is given in a form suitable for direct use in the collinearity equations. The collinearity equations are defined below:

$$x_{img} - c\frac{a_{11}(X-X_o)+a_{21}(Y-Y_o)+a_{31}(Z-Z_o)}{a_{13}(X-X_o)+a_{23}(Y-Y_o)+a_{33}(Z-Z_o)} = 0$$

$$y_{img} - c\frac{a_{12}(X-X_o)+a_{22}(Y-Y_o)+a_{32}(Z-Z_o)}{a_{13}(X-X_o)+a_{23}(Y-Y_o)+a_{33}(Z-Z_o)} = 0$$

Here x_{img}, y_{img} are the coordinates of a feature in the image coordinate system (in millimeters) with the correction to the principal point already being taken into account (see Section 4.2), c is the principal distance of the camera, here $c = -152.85$[3], (X, Y, Z) are the coordinates of the object feature in the Swiss Landeskoordinatensystem in meters, $(X_o = Easting, Y_o = Northing, Z_o)$ is the location of the perspective center in the Swiss Landeskoordinatensystem in meters, and the a_{ij} are the elements of the rotation matrix. For each photograph, the exterior orientation data is given in the following form:

$$\begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix}, \begin{bmatrix} long \\ lat \end{bmatrix}, \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

They are supplied in a file for each photograph. Additional files distibuted with the data set contain the upper-triangle sub-matrices of the variance-covariance matrix for each photograph. Note that the longitudes and latitudes of the perspective centers are given (in degrees, minutes and seconds) with respect to the Bessel 1841 ellipsoid (relevant parameters are $a = 6377.39715500$ and $1/299.1528128$ in kms).

Orientation parameters for 5873

$$\begin{bmatrix} 570031.274 \\ 193179.910 \\ 1197.653 \end{bmatrix}, \begin{bmatrix} 7 & 2 & 46.689957 \\ 46 & 53 & 25.345774 \end{bmatrix}, \begin{bmatrix} 0.761928 & -0.647454 & 0.016370 \\ 0.647454 & 0.762081 & 0.006027 \\ -0.016378 & 0.006007 & 0.999848 \end{bmatrix}$$

Orientation parameters for 5874

$$\begin{bmatrix} 570304.644 \\ 193431.454 \\ 1190.971 \end{bmatrix}, \begin{bmatrix} 7 & 2 & 59.545471 \\ 46 & 53 & 33.536590 \end{bmatrix}, \begin{bmatrix} 0.759380 & -0.650533 & -0.012183 \\ 0.650647 & 0.759262 & 0.013410 \\ 0.000527 & -0.018110 & 0.999836 \end{bmatrix}$$

Orientation parameters for 5882

$$\begin{bmatrix} 570367.787 \\ 192804.974 \\ 1190.536 \end{bmatrix}, \begin{bmatrix} 7 & 3 & 2.675398 \\ 46 & 53 & 13.257296 \end{bmatrix}, \begin{bmatrix} 0.743120 & -0.668847 & 0.020408 \\ 0.669158 & 0.742725 & -0.024229 \\ 0.001048 & 0.031662 & 0.999498 \end{bmatrix}$$

Orientation parameters for 5883

$$\begin{bmatrix} 570624.241 \\ 193049.028 \\ 1191.293 \end{bmatrix}, \begin{bmatrix} 7 & 3 & 14.733393 \\ 46 & 53 & 21.202351 \end{bmatrix}, \begin{bmatrix} 0.733490 & -0.679667 & 0.006702 \\ 0.679697 & 0.733480 & -0.004286 \\ -0.002003 & 0.007699 & 0.999968 \end{bmatrix}$$

[3] Those who have coded the collinearity equations with the normal case $x_{img} + c...$, take the positive camera constant.

Orientation parameters for 5888

$$\begin{bmatrix} 570129.749 \\ 191310.429 \\ 1188.465 \end{bmatrix}, \begin{bmatrix} 7 & 2 & 51.783552 \\ 46 & 52 & 24.815877 \end{bmatrix}, \begin{bmatrix} 0.747876 & -0.663436 & 0.023086 \\ 0.663800 & 0.747755 & -0.015252 \\ -0.007144 & 0.026731 & 0.999617 \end{bmatrix}$$

Orientation parameters for 5889

$$\begin{bmatrix} 570398.306 \\ 191562.404 \\ 1187.536 \end{bmatrix}, \begin{bmatrix} 7 & 3 & 4.407846 \\ 46 & 52 & 33.019742 \end{bmatrix}, \begin{bmatrix} 0.757069 & -0.653334 & 0.001236 \\ 0.653158 & 0.756907 & 0.021805 \\ -0.015182 & -0.015701 & 0.999761 \end{bmatrix}$$

Orientation parameters for 5897

$$\begin{bmatrix} 569790.379 \\ 191721.565 \\ 1189.313 \end{bmatrix}, \begin{bmatrix} 7 & 2 & 35.657851 \\ 46 & 52 & 38.075879 \end{bmatrix}, \begin{bmatrix} 0.733653 & -0.679466 & 0.008883 \\ 0.679494 & 0.733681 & 0.000135 \\ -0.006425 & 0.006135 & 0.999961 \end{bmatrix}$$

Orientation parameters for 5898

$$\begin{bmatrix} 570062.709 \\ 191977.573 \\ 1194.495 \end{bmatrix}, \begin{bmatrix} 7 & 2 & 48.459581 \\ 46 & 52 & 46.411461 \end{bmatrix}, \begin{bmatrix} 0.755960 & -0.653383 & 0.040189 \\ 0.654339 & 0.756005 & -0.017222 \\ -0.019130 & 0.039316 & 0.999044 \end{bmatrix}$$

5 Additional Image Data and Considerations

5.1 Photograph Acquisition Times

The following data is useful to *shape-from-shadow* computations. The photograph acquisition times on 28 March 1991 are listed in Table 3. The longitude and latitude of Avenches is approximately +46 degrees 53 minutes and +7 degrees 03 minutes, respectively.

Photograph	**Time**
5873	13:18:02 h
5874	13:18:08 h
5882	13:24:16 h
5883	13:24:23 h
5888	13:31:22 h
5889	13:31:29 h
5897	13:36:59 h
5898	13:37:07 h

Table 3: Photograph acquisition times.

5.2 Refraction Effects

With an image scale of 1: 5000 (flying height above ground about 750 m) maximum *refraction effects* under normal conditions would be on the order of 2-3 μm (i.e. up to 0.2 pixels) and for practical purposes can be neglected.

6 The ROIs

The figures 5 to 12 illustrate the ROIs (at reduced resolution). The layout of the images is such that the camera base is horizontal, i.e. each rows of images forms a stereopair with across the page being the flight direction.

7 Acknowledgements

Martina Meister prepared and provided the original Avenches data. The scanning of the photographs was carried out with the help and expertise of Werner Schneider and Monika Sester (University of Stuttgart).

Figure 5: Image 5889

Figure 6: Image 5888

Figure 7: Image 5897

Figure 8: Image 5898

Figure 9: Image 5883

Figure 10: Image 5882

Figure 11: Image 5874

Figure 12: Image 5873