THE CONSTRUCTION OF DEM'S USING AERIAL VIDEO IMAGE SEQUENCES

Luuk Spreeuwers and Zweitze Houkes
Laboratory for Measurement and Instrumentation
University of Twente
Netherlands
luuk@mi.el.utwente.nl, hks@mi.el.utwente.nl

KEY WORDS: Digital Elevation Map, Image Sequence, Remote Sensing

ABSTRACT

In this paper a method for construction of Digital Elevation Maps (DEM's) using aerial video image sequences is presented. Using video images sequences implies that many images of relatively low resolution are available. From these image sequences position measurements of point and line features are obtained and measurements of surface orientation. This results in several different types of measurements with different accuracies. A method is presented that can combine these different types of measurements and provides a measure of accuracy for each point in the DEM.

1 INTRODUCTION

In this paper a new method for fully automatic generation of Digital Elevation Maps (DEMs) from video image sequences is presented. The video sequences are obtained from an aeroplane that is flying along a straight line and a camera looking either straight down or with a fixed angle. The viewing direction is always perpendicular to the flight direction, see fig.1 The application of video image sequences means a dense time sequence of images is available with, relative to aerial photography, low resolution. The objective is to obtain an accuracy of better than 1 m for the height estimation and a ground resolution of better than 1 m also.

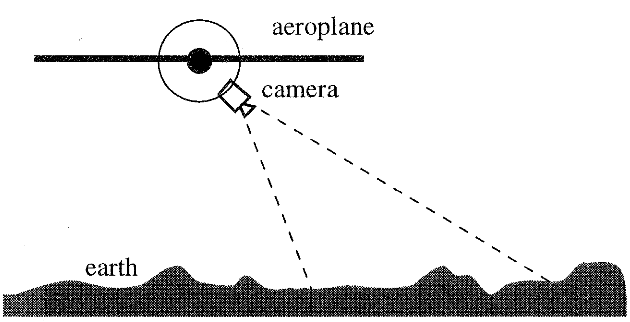

Figure 1: *Illustration of the recording of video image sequences. The aeroplane is flying perpendicular to the paper and the viewing direction of the camera is perpendicular to the flight direction. The camera does not have to look straight down, however.*

1.1 Type of scene

The scenes we are concentrating on are mainly agricultural scenes, which means mostly textured scenes with relatively few clearly detectable feature points and position measurements will tend to be less accurate. On the other hand the positions of clearly detectable features like corners of roads can be determined with high accuracy. Furthermore in agricultural scenes generally the surface is smooth without steep cliffs. Any steep height transition must be an object on top of the surface itself. Hence the problem can be formulated as the desire to build DEM's from relatively low resolution video image sequences for scenes that contain few clearly distinguishable feature points and a rather smooth surface.

1.2 Requirements

The proposed method must be able to handle different types of measurements with different accuracies. Furthermore an attractive feature would be if the DEM could be built sequentially, since the measurements during a flight are also obtained sequentially. Closely related to this is the requirement of being able to update or fill in an existing DEM, i.e. new measurements can be used to improve the accuracy of an existing DEM, while the existing DEM can be used as an initial estimate. An important requirement is further that for each position the accuracy of the estimation of the elevation must be known.

1.3 Methods

The approach that is proposed in this paper combines a number of techniques to realize this goal. Feature point tracking is used to obtain high accuracy height estimates for the few available clearly distinguishable feature points. Shape from shading techniques are used to obtain estimation of the local orientation of the landscape. Edge features are also tracked through the image sequence to obtain height measures for the borders of fields and other objects. Finally the more classical approach by using stereo images can be used to obtain depth measurements (see e.g. [Cochran, 1992]). However, these will only be accurate if the difference between the viewing angles of the stereo image pair is large. Since the difference of viewing angle is small for successive images, the images will have to be stored for a longer period. The other methods do not require this.
The proposed method for DEM construction consists of two processes:

- propagation of the measurements
- combination of measurements

The first process describes what can be deduced about the height at a position $p2$ given a measurement at position $p1$ with a certain accuracy and the current DEM.
The second process describes how a new measurement can be used to update the DEM and makes use of the first process.

In the following sections first briefly the different types of measurements are described: tracking feature points, shape from shading and tracking edges. The main subject of this paper is the combination of the different types of measurements and is presented in section 3.

2 TYPES OF MEASUREMENTS

2.1 Tracking feature points

Because a time sequence of many images is available, features can be followed through the sequence of images. This is far easier than the more common practice of trying to find corresponding features in images recorded by camera's with large differences in viewing angles. The features in successive images in the sequence will move and differ only slightly. If accurate feature models and a model for the acquisition process is available, Kalman filtering techniques can be used to obtain accurate position estimations of the feature points. The accuracy increases with the number of images that contains the feature. And since each feature is present in many images, the resulting accuracy will be much higher than would be obtainable by just using stereo image pairs with similar image resolution. An additional advantage is that it is rather simple to take into account a complex camera model including lens distortions. The image doesn't have to be warped first, but the estimated 3D feature points are projected back into the image plane using the complex camera projection model.

2.2 Shape from shading

However, as stated earlier, such feature points may be sparse. Hence an interpolation technique must be applied to obtain the DEM for every point in the scene. Simple interpolation techniques will give a very poor result, because of the few available feature points.
Shading in the images gives a rough indication for the local orientation of the surface. This can be used to improve the interpolation process considerably. The estimated orientations, however, are far less accurate than the measurements obtained by feature tracking. These orientation measurements are available also in areas without clear feature points, however.

2.3 Projection of edges

The edges of objects, e.g. fields, roads etc. also provide a means to obtain height measurements. However, the shape of the edges will change from image to image, and also their orientation and positions. A 3-d model of surface patches is used to project the edges back on the images and find an optimal fit on the edges detected in the images. Since edge features will differ just slightly in subsequent images, the matching process is relatively simple. Once the 3-d models of these segment boundaries are known, also the height and curvature of the surface locally on the boundaries are known. The accuracies of these measurements will generally be somewhere in between the accuracies of the other two measurements.

2.4 Other measurements and foreknowledge

It is also possible to include other measurements, e.g. using existing stereo techniques. Furthermore often a rough model of the landscape is available, which can be used as an initial estimate and often there is a good idea of the smoothness of the surface.

3 DEM construction

The construction of a DEM means to find a model such that it best fits the measurements and can be used to predict the elevation for arbitrary positions:

$$\hat{z}(\vec{p}) = M(\vec{\theta}, \vec{p}) \tag{1}$$

and:

$$\vec{\theta} = \overset{argmin}{\theta} \sum_i \Delta(z_m^i(\vec{p}), M(\vec{\theta}, \vec{p})) \tag{2}$$

Where $\hat{z}(\vec{p})$ is the estimate for the elevation at a position $\vec{p}$, and M is the digital elevation model function with parameters θ. (This only shows the fitting for feature point measurements, but similar expressions can be obtained for orientation measurements using $\frac{\partial M}{\partial x}$, $\frac{\partial M}{\partial y}$ etc.)

Since land surfaces generally are rather complex, many parameters are required for an accurate description. A problem with these many parameter models is that often there is not a unique fit for the measured data.

Therefore, a different approach is taken here. Each measurement is 'propagated' through the DEM, i.e. from it estimations of elevation and surface orientations for all other positions are derived using the existing DEM and foreknowledge about the local properties of the surface. Next the existing DEM is updated using these new estimations.

3.1 Propagation of measurements

For simplicity first a 2 dimensional DEM (only x and z directions) is considered. Suppose it is known that the maximum gradient of the surface is z'_{max} (e.g. 10%, i.e. 10cm per meter.) An elevation measurement at position x_0 now bounds the possible elevations on all other positions by:

$$z(x_0) - \mid x - x_0 \mid * z'_{max} < z(x) < z(x_0) + \mid x - x_0 \mid * z'_{max} \tag{3}$$

The combination of different measurements in this case is simply the intersection between the ranges. Each new measurement further bounds the elevations. This is shown graphically in fig.3.1.

A step further is not to assume a maximum surface gradient, but a certain distribution for the gradient. Suppose that the distribution of the surface gradient is normal with expectancy 0:

$$f(z') = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(z')^2}{2\sigma^2}} = G(0, \sigma_{z'}^2) \tag{4}$$

For a measurement at position x_0 with an accuracy that is also given by a normal distribution $G(z_0, \sigma_0^2)$, the propagation can then be described as follows:

$$E\{z(x)\} = z_0 + (x - x_0)E\{z'(x)\} = z_0 \tag{5}$$

and

$$\sigma^2\{z(x)\} = \sigma^2\{x_0\} + (x - x_0)^2 \sigma^2\{z'(x)\} = \sigma_0^2 + (x - x_0)^2 \sigma_{z'}^2 \tag{6}$$

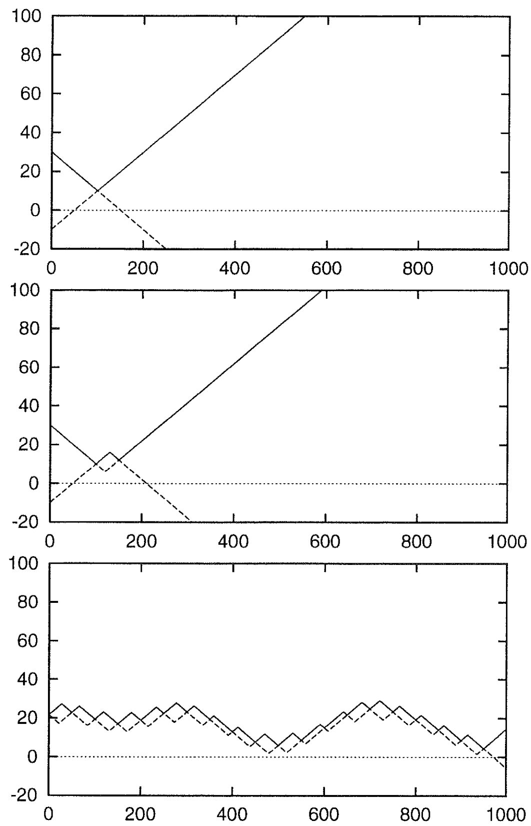

Figure 2: *Each additional measurement further bounds the elevation estimations*

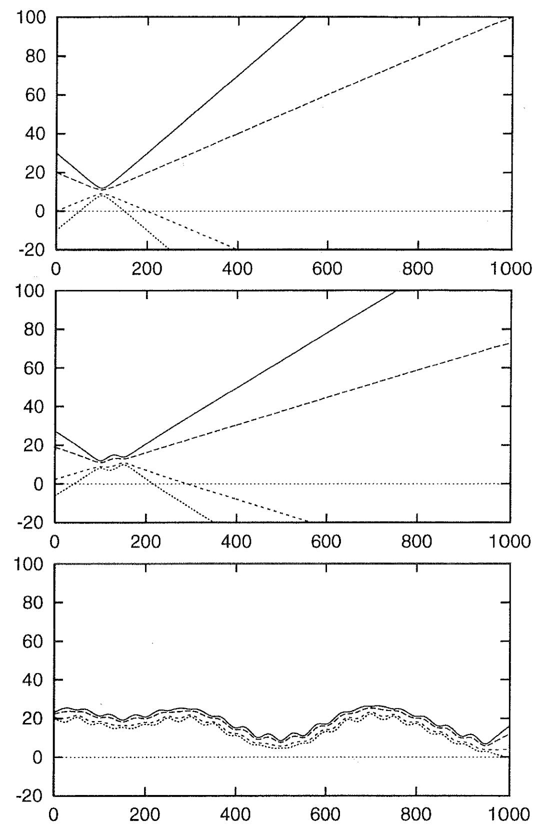

Figure 3: *Bounding of the elevations by using estimations with a Normal distribution. Shown are the σ and 2σ boundaries*

Refer to appendix 4 for the derivation of this equation.

Note that this is a very simple model for the propagation of the measurements. It should be extended by using the current DEM and the surface orientations.

Thus from each measurement other 'measurements' can be derived for arbitrary positions.

3.2 Combination of the measurements

If for two measurements at the same position the probability densities are given by z_1 and z_2 the variances are given by σ_1^2 and σ_2^2) and the measurements are independent, then the combination is given by (see e.g. [Papoulis, 1984]):

$$E\{z\} = \frac{\sigma_2^2 z_1 + \sigma_1^2 z_2}{\sigma_1^2 + \sigma_2^2} \qquad (7)$$

and

$$\sigma_z^2 = \frac{\sigma_1^2 \sigma_2^2}{\sigma_1^2 + \sigma_2^2} \qquad (8)$$

The propagation step delivers the derived measurements that can be used for the combination.

Figure 3.2 shows the results for the same examples as were shown for the simpler min-max approach earlier. The 2σ boundary corresponds to the z'_{max} of fig.3.1 and the variance of the measurements is 1m.

A disadvantage of the proposed method is that near a measured elevation of a feature point the gradient of the surface is estimated badly. This is because close to a measurement the propagated measurements are almost solely depending on the original measurement. This can be improved if surface orientation measurements are used as well.

3.3 Including surface orientation measurements

Including surface orientation measurements is straightforward. In eq.5 the expectation of $z'(x)$ is not 0 now, but the measured orientation. Like the point feature elevation measurements the surface orientation measurements can be propagated as well.

3.4 Extension to 3 dimensional DEM's

The extension to the third dimension is straight forward. For each position (x, y) in the DEM, now the following properties are kept:

- elevation estimation: z
- variance of elevation estimation: σ_z^2
- surface gradient: $(\frac{\partial z}{\partial x}, \frac{\partial z}{\partial y}) = (z'_x, z'_y)$
- variance of surface gradient: $\sigma^2_{z'_x}, \sigma^2_{z'_y}$

An example of a 3 dimensional DEM and its estimation is shown in fig.3.4. The reconstruction of the DEM was done using 1000 measurements of the elevation for arbitrary chosen positions and with different accuracies.

Unfortunately the feature point tracking and surface orientation measurement systems were not available yet, hence only results on simulated surfaces are shown. The complete system will be evaluated using a landscape model with a movable camera setup.

4 CONCLUSION

A method for construction DEM's is presented that allows the combination of different types of measurements with different accuracies. The proposed method also provides a measure of accuracy for every position and allows for sequential addition of measured points. Foreknowledge in the form of an existing DEM of (a part of) the examined area can easily be included. These properties are of specific importance in our approach to video image sequence analysis, wherein different types of measurements are obtained. The proposed method is based on propagation of measurements to any position and the combination of the thus obtained derived measurements.

REFERENCES

[Cochran, 1992] Cochran, S., Medioni, G. 1992. 3-D surface description from binocular stereo, IEEE Trans. PAMI, Vol. 14, no. 10, pp. 981-994

[Guillemin, 1993] Guillemin, Y., Nguyen, H.H., Cohen, P. 1993. Automated aerial cartography from extended sequences. Proceedings of the 8th Scandinavian Conference on Image Analysis SCIA '93, Vol.I, pp. 681-689

[Papoulis, 1984] Papoulis, A. 1984. Probability, Random Variables, and Stochastic Processes. McGraw-Hill, Inc. Singapore, ISBN 0-07-Y66456-X

APPENDIX

Propagation of measurements

Assume that for a elevation measurement at position p the probability distribution function is Normal (Gaussian) around the measured elevation z_p:

$$f_{z_p}(z(p)) = G(z_p, \sigma_p^2) \tag{9}$$

Furthermore the orientation of the surface is distributed Normally as:

$$f_{z'}(z') = G(0, \sigma_{z'}^2) \tag{10}$$

Then the conditional probability for the elevation at a position with distance Δ from p is given by:

$$f_{z_\Delta}(z(p+\Delta)|z(p) = z_p) = f_{z'}(\frac{z_\Delta - z_p}{\Delta}) = G(z_p, \Delta^2\sigma_{z'}^2) \tag{11}$$

The unconditional probability for the elevation at this position can be obtained by integrating over all possible elevations at z_p:

$$f_{z_\Delta}(z_\Delta) = \int_{\infty}^{\infty} f_{z_p}(z_p) f_{z_\Delta}(z_\Delta|z_p) dz_p \tag{12}$$

This integral can be solved straightforward and yields:

$$f_{z_\Delta}(z_\Delta) = G(z_p, \sigma_p^2 + \Delta^2\sigma_{z'}^2) \tag{13}$$

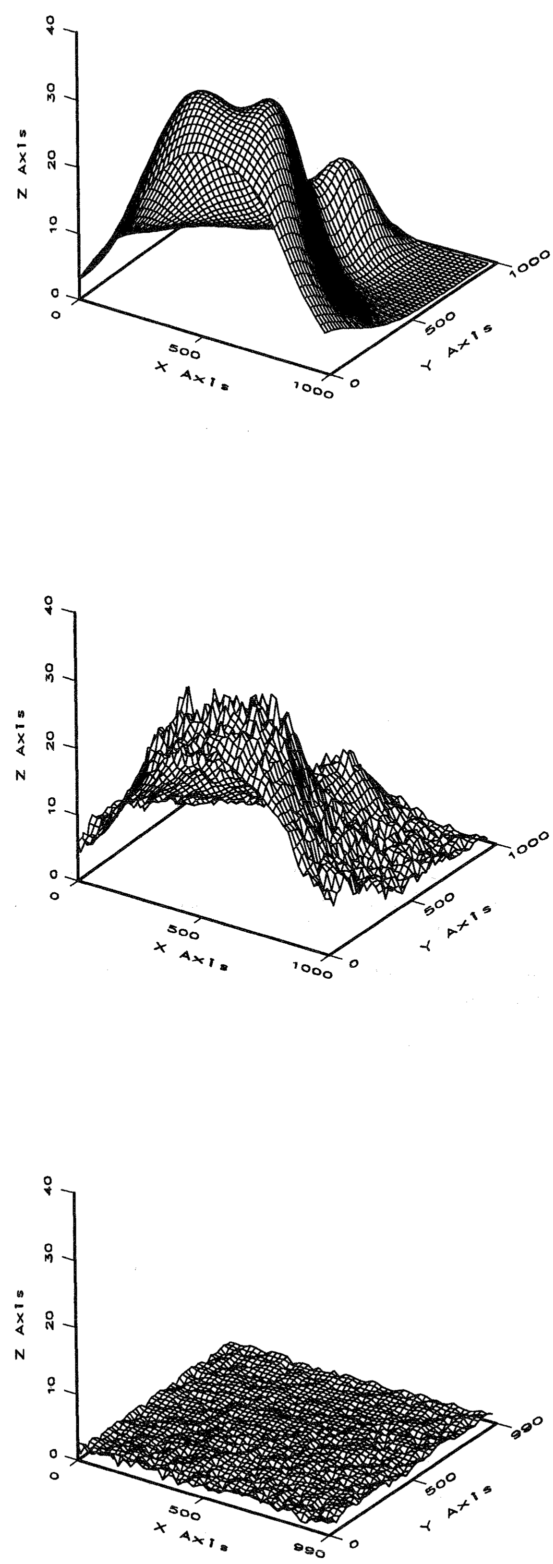

Figure 4: *An example of a 3d DEM estimation. From top to bottom: true landscape surface, estimated landscape surface and standard deviation of the error. The DEM was reconstructed using 1000 randomly chosen point feature measurements with different accuracies*