Simplified Rasterstereography Using a Metric Camera

W. Frobin and *E. Hierholzer*
Abteilung Biomechanik, Orthopädische Universitätsklinik, D-4400 Münster,
Federal Republic of Germany

ABSTRACT: *Using a metric camera with built-in fiducial marks enables a simplified automatic evaluation of rasterstereographs. The rasterstereographs are prepared in the usual way by projecting a line raster onto the object to be measured. In addition, two fiducial marks produced by light emitting diodes are projected into the film plane of the camera. The light emitting diodes are fixed with respect to the camera. In addition, the relative orientation of the camera and the raster projector is fixed. The automatic processing of rasterstereographs is considerably simplified, because now only one initial calibration of the recording system is needed. Registration of the control point system is no longer necessary. Thus, the image structure of the rasterstereograph is greatly simplified. The model reconstruction is performed using the fiducial marks and the predetermined elements of interior and exterior orientation.*

INTRODUCTION

RASTERSTEREOGRAPHY is a modification of stereophotogrammetry, where one of the two cameras is replaced by a projector with a raster diapositive (Frobin and Hierholzer, 1981). Using a line raster results in a particularly simple image structure which enables an automatic evaluation (Frobin and Hierholzer, 1983a, 1983b). However, in the application reported, the use of non-metric photographic equipment leads to the need for photogrammetric calibration of each individual rasterstereograph. As a normal procedure for calibration, a three-dimensional control point system must be photographed together with the object.

As outlined by Frobin and Hierholzer (1983a, 1983b), the control points and planes introduce a considerable complexity into the rasterstereographs as well as into the automatic evaluation procedure. Consequently, a large amount of computing time is spent for scanning, identification, and localization of the control points. This is particularly cumbersome, for example, in routine applications in medicine. Initial experiments show that the total image processing time is reduced by a factor of about seven by using a metric rasterstereograph without control points.

A metric recording system is generally characterized by a fixed-geometry configuration and by fiducial marks mounted in the film plane(s). The geometry parameters (interior orientation) are determined just once using a control point system. The fiducial marks define a coordinate system in the camera image plane which is fixed with respect to the imaging lens.

In the present paper a special metric system for use in line rasterstereography is described.

RASTERSTEREOGRAPHIC RECORDING SYSTEM

In the case of rasterstereography one camera of a stereo system is replaced by a projector with a raster diapositive. If the raster diapositive is fixed with respect to the projecting lens, the raster lines themselves may be considered as fiducial marks, provided that an origin line is marked in the diapositive (e.g., by a unique pattern of light and heavy lines (Frobin and Hierholzer, 1983a, 1983b)). In the case of line rasterstereography the origin of one projector image coordinate (along the raster lines) is not needed in the calibration procedure. Therefore, the raster lines themselves define the required fixed reference coordinate system in the projector image plane. Thus, no extra provisions need to be made for the projector to be used in a metric rasterstereographic system, except that a reliable fixed mounting for all optical elements is necessary.

As a camera, in principle any metric camera can be used. However, as pointed out earlier (Frobin, and Hierholzer, 1981), using a negative line raster (i.e., light lines on a dark background) is most favorable for automatic processing of rasterstereographs. In this case the usual fiducial marks can hardly be detected in the camera image. The same holds true for reseau marks. The best choice would be the use of self-luminous fiducial marks mounted in the film plane of the camera.

In order to avoid a serious modification of the camera, we decided to use fiducial marks consisting of light emitting diodes (LED) which are projected into the film plane through the camera lens. The basic principle was already outlined by Frobin and Hierholzer (1981, Figure 7). The details of the present construction (designed for a Hasselblad 500

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 51, No. 10, October 1985, pp. 1605-1608.

0099-1112/85/5110-1605$02.25/0

EL/M, equipped with a Zeiss Sonnar *f*:4/150 mm lens) are given in Figure 1.

Using a standard enlarging lens (Rodenstock 4.5/75 mm) and a partially reflecting mirror (85 by 85 by 4 mm, manufactured by Spindler & Hoyer, Göttingen) a virtual image of the LED is produced at the site of the object. By means of the camera lens, the object and the superimposed LED image are then imaged into the film plane.

Using green LED's (Type MV 52 or CQY 73), enough intensity is obtained in the film plane if a simple plane-parallel glass plate is used as a partially reflecting mirror (reflectance approximately 10 percent at 45°). In order to avoid ghost images, one side of the glass plate bears a high efficiency antireflective coating. Nevertheless, a weak but disturbing ghost image of the LED was observed. This could be extinguished almost completely by introducing a properly oriented polarizer into the light path. The insertion of a plane-parallel plate into the light path introduces a little image distortion. In the present application, however, the distortion is negligible as compared to other errors (e.g., film shrinkage). In order to obtain a clearly defined circular fiducial mark in the film plane, we are using pinholes (diameter 300 μm) as used in electron microscopy.

At least two fiducial marks must be produced in the film plane in order to establish a camera fixed image coordinate system. To ensure good accuracy, the fiducial marks should be as far apart as possible, lying for example at the right and the left margin of the image. However, due to limitations in the field width, it is impossible to produce these marks with one and the same enlarging lens. Therefore, two separate systems, each consisting of an LED, a pinhole, an enlarging lens, and a polarizer must be used. They are mounted to the left and the right of the vertical camera symmetry plane, as shown in Figure 2. In this figure the partially reflecting mirror is omitted for the sake of simplicity, and the LED systems are folded into the plane of the paper along the dashed line *AA*. In order to achieve the best image quality, the LED's are mounted on the optical axis of the enlarging lenses, which must therefore be tilted with respect to the optical axis of the camera lens.

All the optical elements, including the camera, are mounted in a rigid mechanical construction as shown in Figure 3. In addition, the focusing ring of the camera has been fixed with a ring-shaped cap in order to maintain the principal distance of the camera. The whole system, including the raster projector, is mounted in a solid frame in order to preserve the relative orientation of the camera and the projector (see Frobin and Hierholzer (1981) Figure 4).

A rasterstereograph of the human back, prepared with this camera, is shown in Figure 4. The fiducial marks are represented by the two circles of 0.6-mm diameter to the left and the right of the patient.

CAMERA CONTROL

Special care must be taken in order to ensure that the fiducial marks are recorded in each rasterstereograph. Otherwise, the image cannot be evaluated and is useless. Therefore, an electronic interlock system has been designed which inhibits releasing the camera shutter unless both LED's are lighting with sufficient intensity. In order to extend the lifetime of the LED's, they are normally driven with reduced current. Only just before the shutter release are they momentarily pulsed to high intensity. If the LED current fails to increase to the predetermined value, the camera relay is blocked and the shutter is not released. Thus, missing of fiducial marks in the rasterstereographs caused by malfunction or erroneous operation is safely prevented.

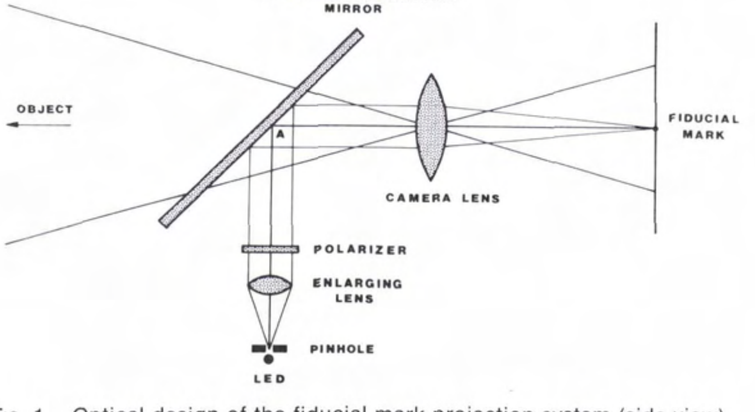

FIG. 1. Optical design of the fiducial mark projection system (side view).

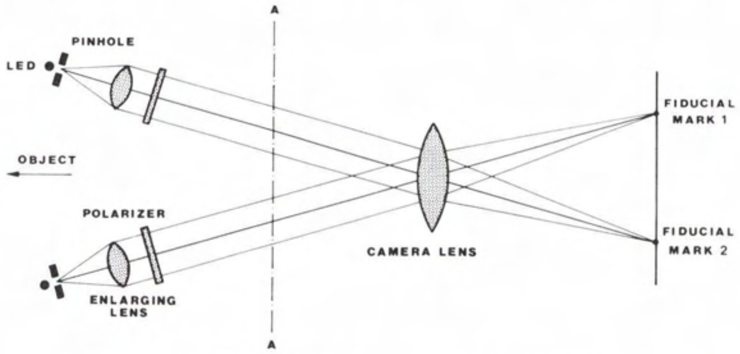

FIG. 2. Optical design of the fiducial mark projection system (top view).

IMAGE PROCESSING

Assuming that the rasterstereographic recording system has already been calibrated (see next section), the automatic image processing now consists of two essential steps:

(1) Detection of the fiducial marks and calculation of their centers, and
(2) Detection and measurement of the raster lines.

For both procedures, the methods described in previous papers (Frobin and Hierholzer, 1983a, 1983b) can be used essentially without modification.

The detection and measurement of the fiducial marks is exactly equivalent to that of the control points (see Frobin and Hierholzer (1983a, 1983b) p. 383). Thus, we need not go into details here. By means of digital image processing, the area of the fiducial mark is isolated. Either the (intensity weighted) centroid or the (geometrical) center of the circular area may be used as the desired reference point. From the two fiducial mark centers, a camera-fixed image coordinate system can be established, which serves as a reference frame for all subsequent calculations.

The measurement of the raster lines exactly resembles the method described earlier (Frobin and Hierholzer, 1983a, 1983b), except that the raster line coordinates are now converted into the LED reference system. In the subsequent image data analysis substantial simplifications are possible in consequence of the greatly simplified image structure.

CALIBRATION

The calibration of the rasterstereographic camera system must be performed according to the pre-

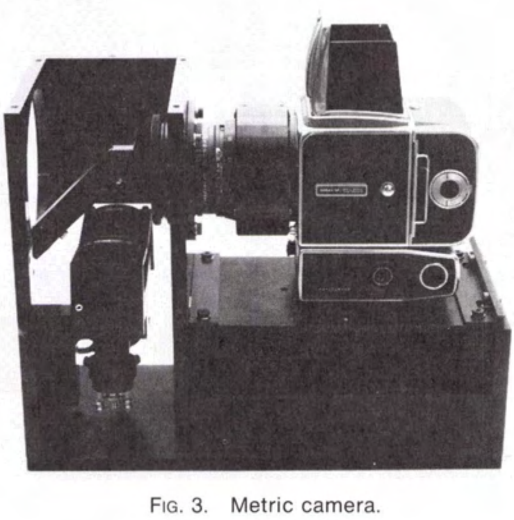

FIG. 3. Metric camera.

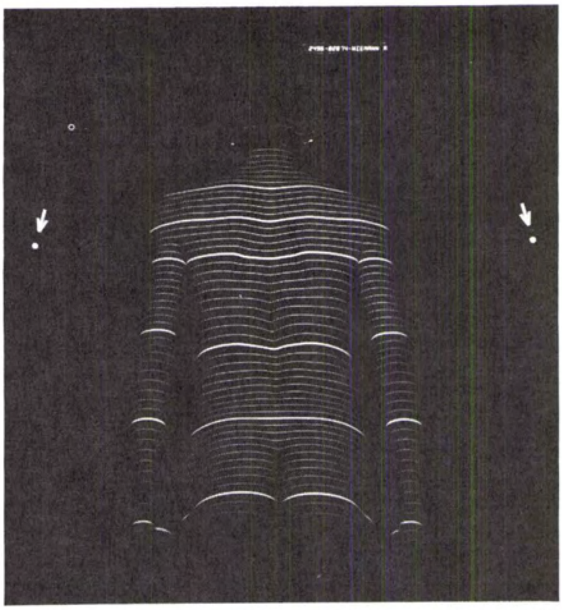

FIG. 4. Rasterstereograph prepared with the metric camera (fiducial marks indicated by arrows).

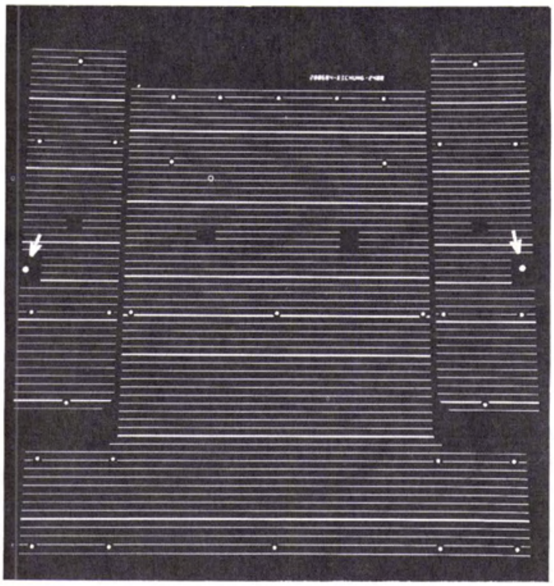

FIG. 5. Calibration rasterstereograph with control points and fiducial marks (indicated by arrows).

vailing procedure. In addition to control points and the raster lines on the control planes, the calibration rasterstereograph now contains the two fiducial marks (Figure 5).

Before the calibration procedure can be performed, the fiducial marks must be identified and measured. They may be distinguished from the control points either by their known location or by their different diameter. After establishing the camera-fixed image coordinate system, all control point and raster line coordinates are transformed into this reference system. The calibration can then be performed as described in a previous paper (Frobin and Hierholzer, 1982a, 1982b). The orientation elements are now defined with respect to the camera-fixed LED coordinate system.

ACCURACY

The prevailing method, using an "intrinsic" calibration of each individual rasterstereograph, is of course more accurate than the method described here. The accuracy of the new method is mainly influenced by the error of the measurement of the fiducial marks.

Assuming that the mechanical construction of the setup is sufficiently rigid and stable, errors of the fiducial mark location result predominantly from film shrinkage and fluctuations of the gray density of the film. The latter may be due to film granularity, fluctuations of film sensitivity, and non-uniform illumination by the LED's.

The statistical fluctuations of the distance of the two fiducial marks may be considered as a good measure of the accuracy of the method. Sample measurements yielded the following standard deviation of the marker distance of about 50 mm:

(a) 10 measurements of the same negative: $\sigma = 4\ \mu m$

(b) 12 different negatives of the same film: $\sigma = 7\ \mu m$

(c) 28 different negatives of different films: $\sigma = 23\ \mu m$

The error of measurement (a) mainly represents the digitizing error of our film scanning system. This error is small as compared to the error of measurement (c), which represents the resulting overall error of the fiducial mark measurement. Because standard acetate films (Ilford HP5) were used, the overall error is probably produced mainly by film shrinkage. The accuracy might thus be improved by using films with a dimensionally more stable base such as polyester (e.g., Kodak Estar films).

Due to the lack of more detailed information about film shrinking effects, a simple scaling transformation may be applied as a first-order correction. The scaling factor may be calculated from the measured effective distance between the fiducial marks.

The influence of this error on the final result of model reconstruction is difficult to estimate. To the first order, an overall motion (rigid body translation and/or rotation) of the model might result. Fortunately, in close-range photogrammetry one is rarely concerned with the absolute position and orientation of the model. Model deformations affecting the shape are of higher order and are thus less important as compared to rigid body motions. Furthermore, the spatial resolution of the measurement is not affected by the fiducial mark error.

REFERENCES

Frobin, W., and E. Hierholzer. 1981. Rasterstereography: A photogrammetric method for measurement of body surfaces, *Photogrammetric Engineering and Remote Sensing*, Vol. 47, pp. 1717-1724.

———, 1982. Calibration and model reconstruction in analytical close-range stereophotogrammetry. Part I: Mathematical fundamentals, *Photogrammetric Engineering and Remote Sensing*, Vol. 48, pp. 67-72.

———, 1982. Calibration and model reconstruction in analytical close-range stereophotogrammetry. Part II: Special evaluation procedures for rasterstereography and Moire topography, *Photogrammetric Engineering and Remote Sensing*, Vol. 48, pp. 215-220.

———, 1983. Automatic measurement of body surfaces using rasterstereography. Part I: Image scan and control point measurement, *Photogrammetric Engineering and Remote Sensing*, Vol. 49, pp. 377-384.

———, 1983. Automatic measurement of body surfaces using rasterstereography. Part II: Analysis of the rasterstereographic line pattern and three-dimensional surface reconstruction, *Photogrammetric Engineering and Remote Sensing*, Vol. 49, pp. 1443-1452.

(Received 21 July 1984; accepted 25 January 1985; revised 26 March 1985)