A KNOWLEDGE BASED SYSTEM FOR CLOSE RANGE DIGITAL PHOTOGRAMMETRY

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ABSTRACT:

The design of a software package for highly automated compilation of close range objects from digital images for medical examinations is presented. The images taken by two or more CCD cameras are analysed by using techniques of pattern recognition and image matching. An automatically extendable and improvable knowledge base and strict geometric constraints support interpretation and measurement. The goal is for the exact determination of the shape of the object as well as the derivation of parameters describing the accuracy achieved.

KEY WORDS: Surface Model, Image Matching, CCD Camera.

1. INTRODUCTION

Despite the low resolution video images compared to images taken on photographic film, CCD cameras are already an important tool for mensuration in various fields, particularly in robotic systems where near real time is necessary. The usage of CCD cameras in photogrammetric systems where high geometric accuracy is required is limited but they are successfully used for measuring 3D coordinates of well targeted points (Beyer, 1991).

The project presented here in this paper deals with the derivation of a digital surface model in particular for surgeons who need to screen patients for monitoring medical symptoms and their correction. Real time is not necessary but the results should be available within a few minutes. This medical application is the first goal of our development, but ultimately the development will be available for a range of applications.

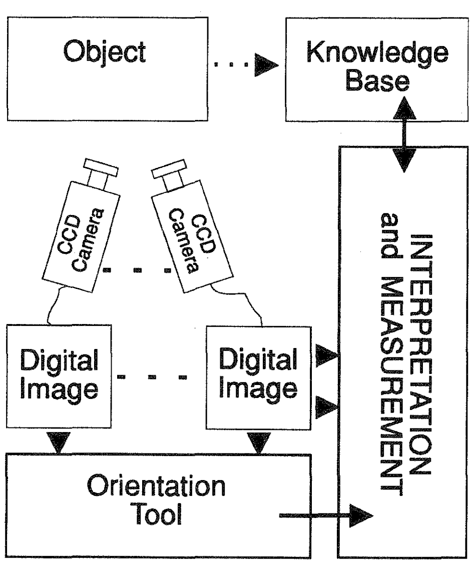

Figure 1: Overview

One of the main differences between inspection systems or systems for quality control during mechanical manufacturing is the additional calculation of parameters describing the accuracy and reliability achieved.

As this tool will not be used by photogrammetric experts an appropriate knowledge base should be included which offers support for unexperienced users, reliability checks, elimination of ambiguities as well as planning suggestions for the camera arrangements and settings (Figure 1).

2. CONSIDERATION ABOUT THE ACCURACY OF CCD CAMERAS

As mentioned above the low resolution is one of the main limitations of video cameras. Subpixel matching is the only way to obtain results of reasonable accuracy. An important matching algorithm is the area based least square matching. Depending on the texture and contrast of the surface an matching accuracy of 1/3 to 1/50 of a pixel can be achieved (Trinder et al., 1991). Tests using various patterns and contrasts showed that for non targeted object points an average accuracy of 1/10 of a pixel can be expected.

Independent of the methods of digital image processing, the CCD cameras themselves are of poor geometric quality compared with conventional photogrammetric metric cameras. There are many factors influencing the geometric quality caused by the optical, mechanical and electronical parts of the camera, the digitizing and the frame grabbing module which decrease the internal accuracy of the image. Additional parameters introduced into the photogrammetric bundle adjustment are able to cope with this distortions but experiences reveal that some of these influences are unstable and vary even during data acquisition. A calibration of the camera under laboratory conditions is not sufficient as it can only give an overview of the behaviour of the elements of the acquisition system and the various settings.

Our system uses a bundle adjustment with the following orientation parameters:

Interior orientation:
- Focal length (not adjusted)
- Separate image scales for x and y
- x,y coordinates of the principal point
- cubic and power 5 term of lens distortion
- linear skewing factor for scan line shift

Exterior orientation:
- X,Y,Z coordinates of projection centre
- three rotation angles

It is absolutely necessary to repeat the calibration in situ before data capture and if possible to include terms for selfcalibration in the mathematical model used for compiling the image data.

Preliminary tests showed that distortions caused by our digital system (Minitron CCD Cameras with SONY 16 mm wide angle lenses, ITEX Monochrome framegrabber) can be modelled with the bundle adjustment mentioned above. The power of 5 term of the lens distortion and the skewing factor were of least significance and only a high accuracy calibration might return reliable values for these parameters.

For handling all data of the bundle adjustment and for a quick editing possibility all observations and adjusted data are organized in tables. (Figure 2). There is a table for the object space which contains the object coordinates of all control points, a constraint table which contains mainly the observed distances in object space and an image space table which includes the coordinate lists of all measured image points and the provisional and adjusted values of the orientation parameters. The data of all tables can be edited.

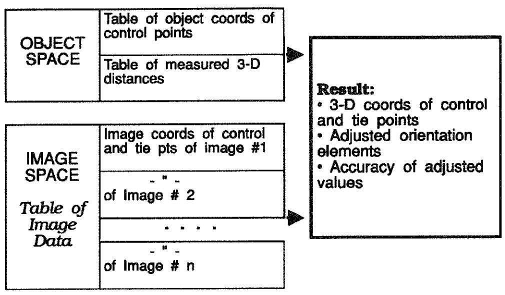

Figure 2: Overview of Bundle Adjustment

3. CALIBRATION AND ORIENTATION OF THE CAMERAS

In this development two or more cameras will be used simultaneously for image acquisition. For the calibration of the cameras and calculation of the camera arrangement a calibration cube is used. Its size is 50 x 50 cm and is built of black iron rods. Mounted on these rods are bright white balls with a diameter of 12 mm which are used as control points. The locations of these control points were measured by using three high precision theodolites. The network included 2 high precision scale bars. The accuracy after adjustment was 0.07 mm.

If the cube fits exactly in one image then the pixel size is approximately 1 mm in the object space (assuming a sensor matrix of about 512 x 512 pixels). Then 0.07 mm in the object is less than a tenth of a pixel in the image, which is consistent with the matching accuracy expected.

The cube can be relocated and the re-calibration done anywhere. For the calibration itself, it is necessary to find the locations of the control points in the images. A simple thresholding is sufficient if the background is very dark compared to the bright targets. The image points found after thresholding are checked for their circular shape. If they are not circles the points are rejected. This can be caused by occlusions of parts of the target or by the detection of elements which are not actual targets. The computation of the image coordinates of the targets is again done in the original greyscale image by calculating the centre of gravity (Trinder, 1989).

They only remaining problem is an automatic number assignment for the control points. There are two possibilities for finding the right number for a measured point. Firstly, if the orientation elements of the cameras (especially the exterior orientation) is accurate enough their imaged position can be precalculated and compared with an actually found position. The comparison of the point distribution is more important than the estimated position. Secondly, the previous method fails in cases where only rough approximations of the camera are known. Interaction of an operator becomes necessary in this case. He must assign point numbers to at least 4 well distributed control points. After this a first bundle adjustment (or spatial resection) can be calculated and the previously mentioned automatic assignment can be started. Finally a bundle adjustment calculates the interior and exterior orientation elements which are used later for compiling the images.

4. DERIVATION OF THE OBJECT SHAPE

One of the main problems of the derivation of object shapes in close range applications are the large parallaxes and the occlusions which make searching for corresponding points in the images very difficult. The least squares matching algorithm needs very good approximations within four to five pixels. There are several possibilities to obtain these first approximations very quickly without complicated and time consuming image interpretation tasks. In our project the following two approaches were selected:

- binary coded structured light
- epipolar constraints of more than two images

4.1 Binary Coded Structured Light

This principle has been used successfully in several projects (Stahs and Wahl, 1990, Kim and Alexander, 1991). The minimum equipment is one calibrated slide projector and one camera. We are using a slide projector and two cameras. In this case the slide projector does need not to be very accurate. Lens distortions of the projector lens for instance or distortions of the slide image (if these distortions are common to all slides) do not have any influence on the geometric quality of the result. A calibration of the projector is therefore not necessary. The pattern projected onto the object surface is used for image segmentation. For matching the correct geometric position and for calculation the 3D coordinates only the images of the CCD cameras are involved (Figure 3).

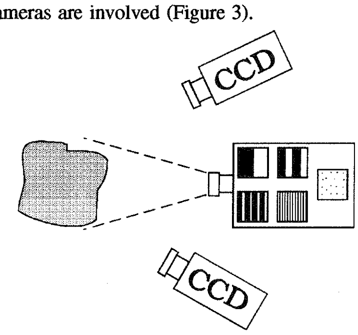

Figure 3: Slide Projector and CCD Cameras

A sequence of, at the most, 8 black and white stripe patterns with frequencies increasing by a power of two, and two pictures for normalization and maybe one further picture with a random pattern are projected onto the object surface. The direction of the stripes must be approximately orthogonal to the photogrammetric base. The images taken by the cameras are normalized and thresholded giving 8 binary images for each camera. These 8 images are combined into one greyvalue image by a simple addition which resembles a greywedge projected onto the surface of the object. The same area of the object is covered by a stripe of the same greyvalue in the left and right images. Black areas indicate the areas where matching is impossible, caused by shadows or very dark object regions. Corresponding positions within a stripe can be found by calculating the intersection of a stripe with an epipolar line.

Although this type of segmentation can be done very quickly there is one major drawback. Since 8 subsequent images must be taken the object must not move during data capture. The time necessary for capturing the image data depends mostly on the ability of the slide projector to change the slides very fast. The ideal slide is an LCD slide where the pattern is generated and changed computer controlled without any mechanical movement. It is hoped to incorporate such a system into the method in the future.

4.2 Epipolar Constraints of More Than Two Cameras

If the projection of stripe patterns is not possible for some reason a further possibility exists to find corresponding points in images. If more than two image are taken of the same object the epipolar constraint of all images together can be used for eliminating ambiguities (Maas, 1991). The precondition for this method is a good random (dot-)texture on the object surface which can be projected artificially if necessary.

5. FINAL FINE MATCHING

After the intersection of the stripes in the image with the epipolar lines the image coordinates of two corresponding image points are available. The accuracy of the object coordinates will depend on frequency of the stripe pattern and on the accuracy of the projection centres. If this accuracy is not sufficient and the object surface shows a suitable texture an additional fine matching can be commenced. The already calculated image coordinates are good starting values for a least square matching procedure.

If the epipolar constraints of more than two images is used to obtain corresponding image details a fine matching procedure must follow. It is sufficient to use only two of the images for matching as all additional images are used to eliminate ambiguities. Again the least squares matching algorithm can be used or in case of a pattern of bright dots, the calculation of the centre of gravity of the dot is also possible.

6. PROJECTION OF A RANDOM PATTERN

Least squares matching only gives good results if there is a texture of reasonable contrast on the object surface. If this is not the case an artificial pattern must be projected onto the object. This pattern should have a random structure to avoid ambiguities. High frequency random elements (such as single bright dots) are useful for the elimination of ambiguities and for good accuracy of least square matching. One the other hand a low frequency texture increases the radius of convergence of the matching procedure. Therefore, our artificial pattern consists of randomly distributed bright dots laid over a low frequency greyvalue pattern where the dots are located in the middle of the darkest areas of the grey pattern.

7. DIGITAL SURFACE MODEL AND KNOWLEDGE BASE

The digital surface model used during the derivation is a 2 1/2 dimensional geometry where the direction of the elevation is roughly the same as the direction of the cameras. A transformation to a really 3 dimensional model must be done in a separate step if required. The main problems for automatic matching are caused by occlusions, geometric discontinuities of the surface, border lines of the area of interest and radiometric discontinuities such as shadows or dark areas of the object and areas without texture. Some of these problems can be eliminated during the segmentation step (shadows, too dark areas). As mentioned earlier bright areas without texture can be avoided by projecting an artificial pattern on the object.

A knowledge base can help to solve the ambiguity problems by checking the reliability of computed results or by avoiding areas where matching is not required or impossible. If a basic knowledge base is not available or of poor quality there must be a possibility for an operator interaction. But even the best image interpretation software and the most sophisticated expert systems are not able to calculate error free results. Although reliability checks are essential and a good knowledge base can help to detect matching errors, operator supervision will still be necessary.

The quality of all checks depends mainly on the setting of appropriate thresholds. These various thresholds cannot be constant for the whole image area. An adaptive setting is the only way to obtain results as accurate as possible covering as much as possible of the area of interest with surface values. This means that the quality of the surface model varies from point to point depending on the local conditions of the images or the object. Therefore, the quality of the whole model cannot be described by one single parameter or value. Only a digital accuracy model can describe the reliability and accuracy of a surface model in a sufficient way. Eventually it is very easy to eliminate or include points below or above a certain level of accuracy depending on the requirements of the current application.

8. MEDICAL APPLICATIONS OF THE SURFACE MODEL

The photogrammetric part of the program only provides the basic information for further computations. More or less complicated software must follow to process the requirements of the doctors. A module for a 3-dimensional graphic display of the surface is very important and it might be included into the photogrammetric part. Firstly, a picture of the surface is still one of the best checks for gross errors. Secondly, many of the medical applications are monitoring tasks of the shapes of human bodies or parts of them. A surface display may be a vector based wire frame model or preferably a pixel based greytone model. Other modules are editing programs where the current surface can be changed according to planned corrective measures. The calculations of differences and their display is necessary for monitoring corrective measures or healing progress in time series.

9. FINAL REMARKS

Digital photogrammetry with images taken from CCD cameras can yield accurate results. If the process need not be in real time there are various possibility to improve the geometric accuracy by applying more sophisticated algorithms. Although conventional photogrammetric methods using photographic films are still more accurate there are many applications where classical photogrammetry is too slow if the result must be available minutes after data acquisition. Very often speed (even though not real time) is more important than the highest accuracy. In such cases CCD cameras are appropriate photogrammetric tools. With a knowledge base in the background photogrammetric systems become an important tool even for non-photogrammetrists like doctors.

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