

HIGH RESOLUTION DATA ACQUISITION TO OBSERVE MOVING OBJECTS

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ABSTRACT

Due to their on-line and real-time capabilities digital photogrammetric close range systems are well suited to the task of object tracking and motion analysis. In this paper, test measurements of a moving object using high resolution digital cameras (2K x 2K, 3K x 2K pixel) are described. On-line and off-line data processing is performed by the digital photogrammetric system V-STARS. The results of the photogrammetric technique and a 3-D laser tracker are compared.

KURZFASSUNG

Digitale Systeme der Nahbereichsphotogrammetrie sind wegen ihrer Möglichkeiten zur on-line und real-time Messung gut geeignet für die Objektverfolgung und Bewegungsanalyse. In diesem Bericht werden Testmessungen an einem bewegten Objekt mit Hilfe hochauflösender digitaler Kameras (2K x 2K bzw. 3K x 2K Bildelemente) beschrieben. Die on-line bzw. off-line Auswertung der Bilddaten wird im digitalen photogrammetrischen System V-STARS durchgeführt. Die Ergebnisse des photogrammetrischen Verfahrens werden mit denen eines Laser-Trackers verglichen.

1. INTRODUCTION

3-D object tracking and motion estimation have been effectively applied in areas such as biomechanics, sports sciences, material testing, medicine, hydro-mechanics, robotics, monitoring and quality control in industry. A variety of measurement equipment and methods have been used, including servo controlled theodolites, interferometry, photogrammetry etc..

Digital photogrammetric close range systems allow for on-line or even real-time data acquisition and processing. Therefore, a great number of motion measurement tasks can be solved, e.g. particle tracking for the evaluation of fluid motion, robot guidance and monitoring, determination of human movement, control of systems for autonomous driving, observation of moving objects in an assembly line (see e.g. the sections "Motion estimation and tracking" and "Image sequence analysis" in Baltsavias (1995); Gruen, 1992; Maas, 1994). Standard CCD cameras providing 25 or 30 frames per second and up to 750 x 580 pixels are mainly used to acquire the digital image data. Higher video rate but lower resolution is obtainable with high speed video cameras.

In this paper, motion recording performed with high resolution digital data acquisition devices is discussed. Cameras providing a 2K x 2K or 3K x 2K sensor are

applied to increase the achievable accuracy of object motion reconstruction. On-line 3-D point determination is carried out with Kodak Megaplus 4.2 cameras and the Leica V-STARS/M2 digital photogrammetric measurement system. Kodak DCS 460 cameras are used in an off-line approach. The object is signalized with active or passive markers (LED's or retroreflective targets, respectively) and recorded by the cameras with open shutter. During object motion, light points or light traces are generated in single images.

It is aimed to present different high resolution photogrammetric methods suitable to different motion analysis tasks and to give results of a performance test using the same moving object. In addition, the photogrammetric systems are compared with the outcome of a Leica SMART 310 3-D Laser Tracker.

2. TEST SETUP

A system for the measurement of kinematic processes should be able to record more or less continuously information from which 3-D coordinates can be derived. Depending on the task, it can be necessary to track only a single point but also multiple points. Besides, the measurement systems described in the following sections provide very different data acquisition rates. The laser tracker is able to record 1000 single points per second (point after point), whilst the digital photo-

grammetric system with Megaplus 4.2 cameras allows to determine each two seconds the coordinates of about 50 object points (all points at the same time).

To compare the different systems by means of the same moving object a rotation bar commonly applied to calibrate the SMART laser tracker was chosen (Fig. 1). The motor driven bar rotates approximately 10 times per minute at most. This maximum speed was used for all investigations. A target fixed to the bar moves on a circular track during rotation. The maximum radius to be performed is about 550 mm according to the length of the bar. The accuracy of the circle which corresponds to the track of the attached target amounts to less than $5 \mu\text{m}$, i.e. deviations from the nominal radius and the nominal plane in which the circle lies are expected to be less than $5 \mu\text{m}$.

The motion measurement systems use different targets fixed to the bar at slightly different positions. Thus, the radius generated by a moving target is not appropriate to compare the measurement results. A best fit circle was calculated by least squares adjustment from the 3-D coordinates of all points of the track. The root mean square (rms) of the deviations of these points in relation to the best fit circle and best fit plane serves to estimate the quality of the measurement system.

3. ON-LINE 3-D COORDINATE MEASUREMENT WITH V-STARS/M

The V-STARS digital close range measurement system for industrial photogrammetry is able to determine position and form of spatial objects from digital images (Brown and Dold, 1995). On-line 3-D coordinate measurement can be performed with digital Kodak Megaplus 4.2 cameras providing a resolution of about 2000×2000 pixels (Fig. 2). Due to the fast throughput of these cameras two images are imported into the computer memory within a second and 3-D coordinates of about 50 object points are computed in one additional second. Thus, object tracking can be carried out in a cycle of two seconds.

The camera setup to record the rotation bar is shown in Fig. 3. Five targets were fixed to the bar which was located in front of a wall with a cluster of 20 stable control points. Within two seconds, V-STARS/M acquired the images from the two Megaplus cameras, computed the coordinates of the five targets and utilized the control points on the wall to update the position and orientation of the cameras. Thus, the accuracy of the measurement process could not be influenced by vibrations of the camera locations. Because one full rotation of the bar takes six seconds the bar had to rotate several times to obtain a number of different positions on the circular track. A series of measurements were done with 8 records per track at minimum up to 145 per

track. The centers of gravity of the five targets per record were used to calculate the best fit circle.

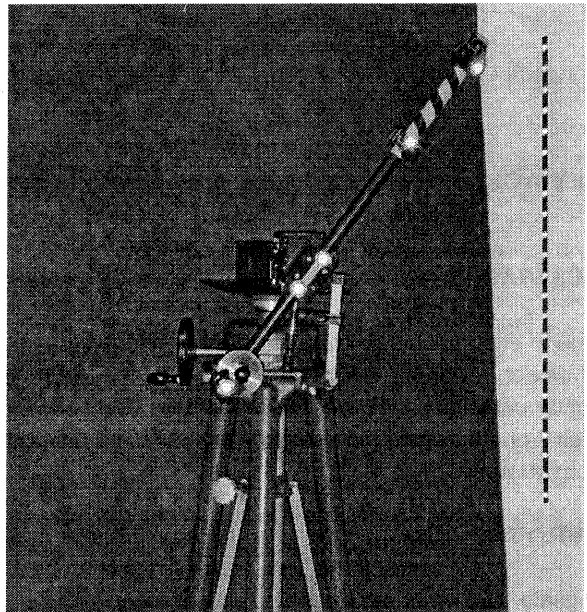


Figure 1 Rotation bar used as moving object

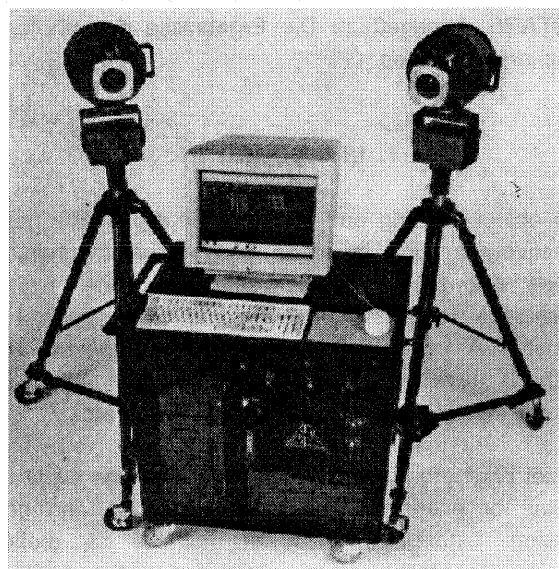


Figure 2 V-STARS/M system

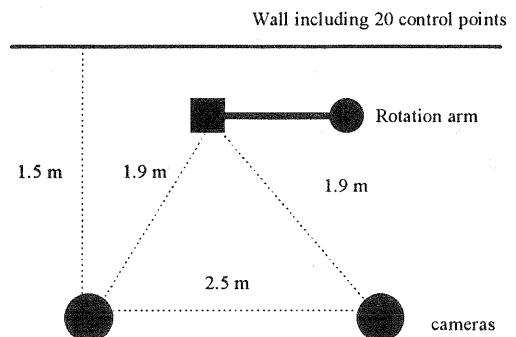


Figure 3 Camera setup

Number of points per track	Circularity (μm)	Out of plane (μm)
8	30	30
9	25	30
9	26	40
9	28	25
16	29	31
16	27	31
16	27	38
16	28	28
18	28	36
16	28	37
16	28	37
16	27	32
146	29	39

Table 4 Measurement results

Deviations from circularity and out-of-plane measures are given in Tab. 4. The repeatability of the results shows that the measurement is nearly independent of the number of points per track. The rms deviations from the circularity are between 25 and 30 μm and the deviations from the best fit plane are between 25 and 40 μm .

4. OFF-LINE MEASUREMENT WITH KODAK DCS 460 CAMERAS

If an object is signalized with a number of tiny lamps or LED's, continuous light traces can be observed during object motion and recorded in a single image taken by a camera with open shutter. Pulsed light sources create light points or streaks at regular intervals. This measurement technique has been applied successfully using photographic cameras (Dorrer and Peipe, 1987;

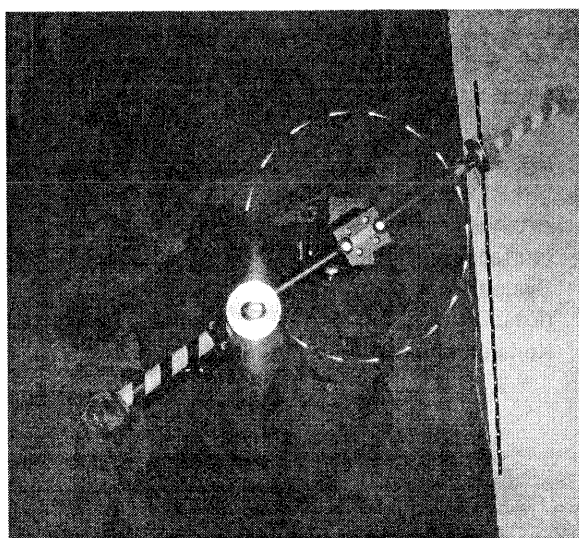


Figure 5 Digital motographic image

Güthner and Peipe, 1988). Now Kodak DCS 460 high resolution (3000 x 2000 pixel) digital cameras which can be operated like photographic small format cameras are used to acquire such motographic images.

If a moving object is signalized with retroreflective targets, a similar single image technique can be applied. A flashlight illuminates the targets several times and the imaged light points represent the object motion.

Both methods were tested using the rotating bar as moving object. One active or passive target was attached to the bar. The circular light traces were recorded by two DCS 460 cameras (Fig. 5). As result of the image measurement and object reconstruction, 3-D coordinates of the light points or streaks were determined with an accuracy of about 100 - 150 μm . Further investigations are necessary to improve the recording techniques and the accuracy of motion estimation.

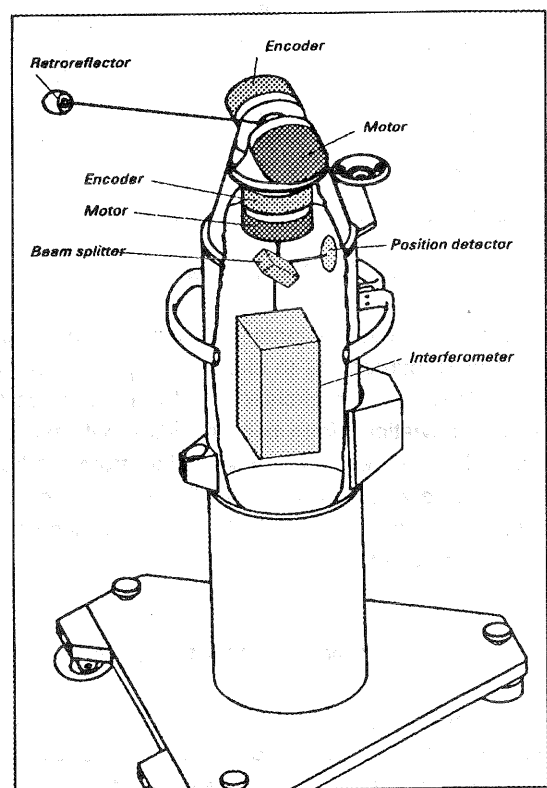


Figure 6 SMART Laser Tracker

5. ON-LINE 3-D COORDINATE MEASUREMENT WITH THE SMART LASER TRACKER

The SMART 310 Laser Tracker (Fig. 6) is a 3-D metrology system that uses a single beam laser interferometer to measure the distance and two angle encoders to measure the horizontal and vertical angles between the measuring head and a reflector

(Schertenleib, 1995). If the reflector moves through 3-D space, the instrument follows and determines simultaneously the changes in position of the reflector with a typical accuracy of 0.025 - 0.150 mm within a 2.5 - 15 m working area. The laser tracker allows for on-line measurement of one object point with a high data collection rate of about 1000 points per second.

The target of the laser tracker, the cateye, was attached to the rotation arm. For measuring the circularity of the track, the instrument was setup in 2 m distance relative to the arm. Because of the high data rate of the laser tracker it was possible to determine all points within one full rotation of the bar. To achieve highest accuracy the laser tracker was positioned in a stable location.

Number of points per track	Circularity (μm)	Out of plane (μm)
8	8	2
8	9	3
8	8	2
8	9	3
8	8	3
8	8	3
73	8	2
73	6	2
66	7	2

Tab. 7 Measurement results

A series of measurements with different numbers of points were carried out to show the repeatability of the results (Tab. 7). The circularity of the determined track has rms deviations from best fit radius between 6 and 9 μm . The rms deviations of all points from the best fit plane are between 2 and 3 μm . The higher accuracy in recording direction is due to the high precision built-in laser interferometer.

6. CONCLUDING REMARKS

The on-line and off-line measurement methods for high resolution motion estimation briefly surveyed in this paper show some evident differences in tracking speed, number of points to be measured at the same time, continuity of the acquisition process, accuracy, etc.. The laser tracker allows for high precision determination of only one target but with a high data rate. The

V-STARS/Megaplus system is able to locate highly precise up to 50 points at the same time. Stroboscopic and motographic methods - although not working operational at this moment - record the motion of several points simultaneously in single images. Thus, some high resolution measurement systems for object tracking and motion estimation are available to allow the user to select the system appropriate to his special task.

REFERENCES

- Baltsavias, E.P. (Ed.), 1995. Proceedings ISPRS Intercommission Workshop "From Pixels to Sequences", Int. Arch. Photogrammetry & Rem. Sensing, Vol. 30/5W1, Zurich, pp. 73-149 (Poster Session 1: Image sequence analysis and other algorithmic aspects) and pp. 201-225 (Motion estimation and tracking).
- Brown, J., Dold, J., 1995. V-STARS - A system for digital industrial photogrammetry. In: Optical 3-D Measurement Techniques III (Eds. A. Gruen and H. Kahmen), Wichmann, Karlsruhe, pp. 12 - 21.
- Dorrer, E., Peipe, J. (Eds.), 1987. Motografie. Schriftenreihe Vermessungswesen Universität der Bundeswehr München, Vol. 23, 280 p.
- Gruen, A., 1992. Tracking moving objects with digital photogrammetric systems. Photogrammetric Record, Vol. 14 (80), pp. 171-185.
- Güthner, K., Peipe, J., 1988. Motography and photogrammetry for the study of movements. Int. Arch. Photogrammetry & Rem. Sensing, Vol. 27/B10, Kyoto, Japan, pp. 246-254.
- Maas, H.-G., 1994. A highspeed camera system for the acquisition of flow tomography sequences for 3-D least squares matching. Int. Arch. Photogrammetry & Rem. Sensing, Vol. 30/5, Melbourne, Australia, pp. 241-249.
- Schertenleib, W., 1995. Measurement of structures (surfaces) utilizing the SMART 310 Laser-Tracking-System. In: Optical 3-D Measurement Techniques III (Eds. A. Gruen and H. Kahmen), Wichmann, Karlsruhe, pp. 59-68.