MOTOGRAPHY AND PHOTOGRAMMETRY FOR THE STUDY OF MOVEMENTS

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ABSTRACT

Motography based on the well-known cyclography technique is an efficient method for recording spatial movements. Photogrammetric measurement of motographic images yields the determination of three-dimensional coordinates of light-traces which represent the movements of marked object points. Velocity and acceleration can be calculated subsequently.

The recording and measuring procedure is illustrated by examples relating to the investigation of industrial robots, the determination of object oscillations and deformation measurement.

1. Introduction

Motography is being effectively applied to motion analysis in disciplines such as ergonomics, biomechanics, sports sciences, botany, soil mechanics, material testing, medicine and robotics (BAUM 1986, DORRER and PEIPE 1987). Movements of selected and marked points of an object are photographically recorded by means of light-traces. Photogrammetry enables the precise spatial restitution of the recorded movements by measurement in one or more photographs of the same scene. The achievable accuracy depends on the quality of the imaged light-traces, the recording device, the configuration of photographs, the measuring instrument and the restitution method (DORRER 1987, PEIPE 1987).

2. Motographic recording technique

A limited number of discrete points which may represent an object in motion is marked by tiny incandescent lamps or light-emitting diodes (LED). Similar to cyclography (ATHA 1984) their movements appear as continuous paths of light in a single photograph taken by a camera with open shutter in the dark or in subdued light. If a pulse generator controls the markers so that they flash on and off at regular intervals, the movement is registered as a broken line. Known time intervals allow for the calculation of velocity and acceleration of motion provided that the distances between successive points of the light-trace are determined in object space (e.g. ZELLER 1950, BREWER 1962, BLUMENTRITT and SCHÖLER 1984).

The combination of special filters and light-sources enables motography under lights, for instance by applying the so-called band absorption (BA) technique. The BA-process uses lamps emitting almost monochromatic orange-red light ($\lambda \approx 590$ nm) for the illumination of testing rooms. This ambient light is absorbed by

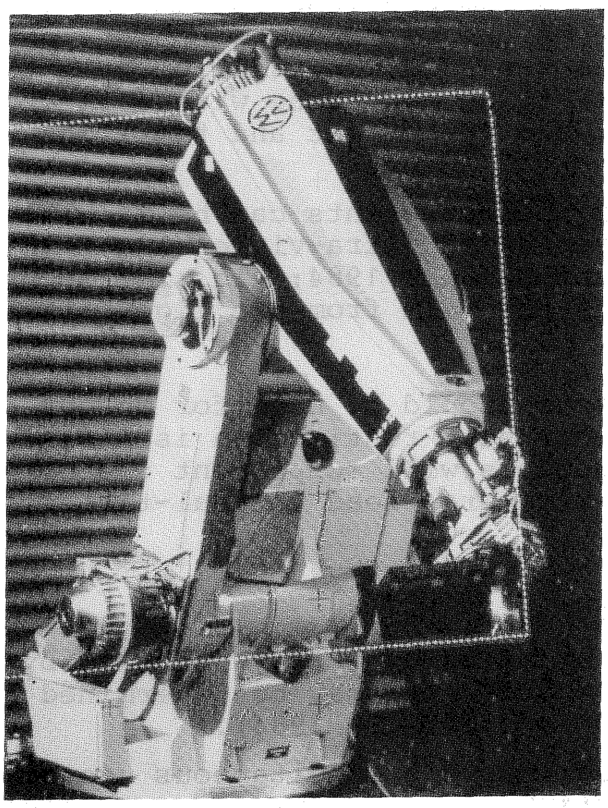


Fig. 1
Motography using BA-technique:

Testing an industrial robot. One pulsed-light lamp is attached to the robot. The light-trace shows how the robot really follows a reference path (photographed by E. Baum/M. Beer; BAUM 1987, PEIPE 1987).

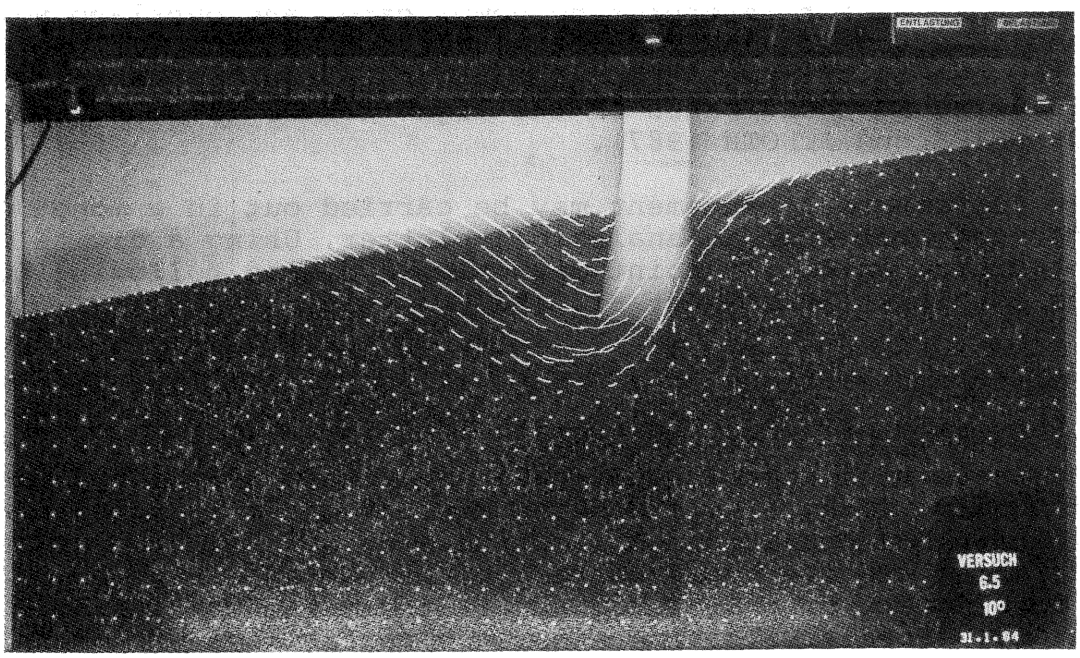


Fig. 2 Motography using UV-technique:

Recording of deformations in subsoil for stability analysis of foundations and earth-structures. In this model test a wall of cylindrical aluminium rodlets serves as a substitute for the real soil. Only the rodlets marked with luminous paint appear as light points if the model is illuminated by a UV-lamp. Their displacements caused by overloading the soil become visible as dotted light-traces (PEIPE and GÜTHNER 1984).

a didymium filter in front of the camera lens (HELLMEIER 1980, BAUM 1983; fig. 1). The light of the markers, of course, passes through the filter and exposes the film. In addition, the test object may be imaged by illuminating the scene with a flash in order to see the relation between the object and the light-traces (fig. 1).

Instead of pulsed-light lamps, object points can be marked with luminous paint which fluoresces under ultra-violet light (UV-technique; BAUM 1983, PEIPE and GÜTHNER 1984; fig. 2). In this case, a yellow filter protects the film from the light of the UV-lamp.

Metric or partial metric cameras should be used for motographic recording if a photogrammetric object restitution is intended. In the near future, digital methods will supplement the common analogue technique. CCD-matrix cameras lead to real-time measurement of movements.

3. Photogrammetric restitution

A two-dimensional motion may be motographically recorded by a single camera and the object coordinates may be determined by numerical rectification (PEIPE and GÜTHNER 1984).

A three-dimensional motion requires the simultaneous use of two or more cameras. Stereophotography is, in general, not necessary but helpful for interpreting complicated and overlapping traces of movement. Analytical restitution methods, in particular the bundle triangulation approach, are best suitable for calculating 3D-coordinates of the light-traces (e.g. HELLMEIER 1980, PEIPE and SCHOTH 1987).

Image coordinate measurement may be carried out in a mono- or stereo-comparator or an analytical plotter. Using a digital monocomparator automatic point detection and line following becomes possible (LUHMANN et al. 1987).

4. Recent applications

4.1 Surveying of industrial robots

Robots have been increasingly used in manufacturing over the past decade. Today they are being applied not only to simple pick-and-place operations or spot-welding but also to various tasks which require high accuracy of performance. Therefore, the development of procedures and instruments for testing the accuracy, repeatability and kinematic performance of robots is of vital importance.

The dynamic behavior of industrial robots can be clearly demonstrated by means of motography (MONCZKOWSKI and REGENSBURGER 1984, SCHMID et al. 1986, BAUM 1987). For instance, movements of markers mounted on a robot are recorded, spatial point coordinates of the imaged light-traces are determined by photogrammetric measurement and deviations in path and velocity are calculated. Fig. 1 and 3 show an industrial robot following a reference path. The photogrammetric restitution of the light-trace of fig. 1 yields accuracies of 0.3 mm in X, Y and Z after bundle adjustment with the program MOR (WESTER-EBBINGHAUS 1985). A partial metric camera Rolleiflex SLX Réseau was used as imaging system. The photographs were measured in a Zeiss Planicomp analytical plotter (PEIPE 1987).

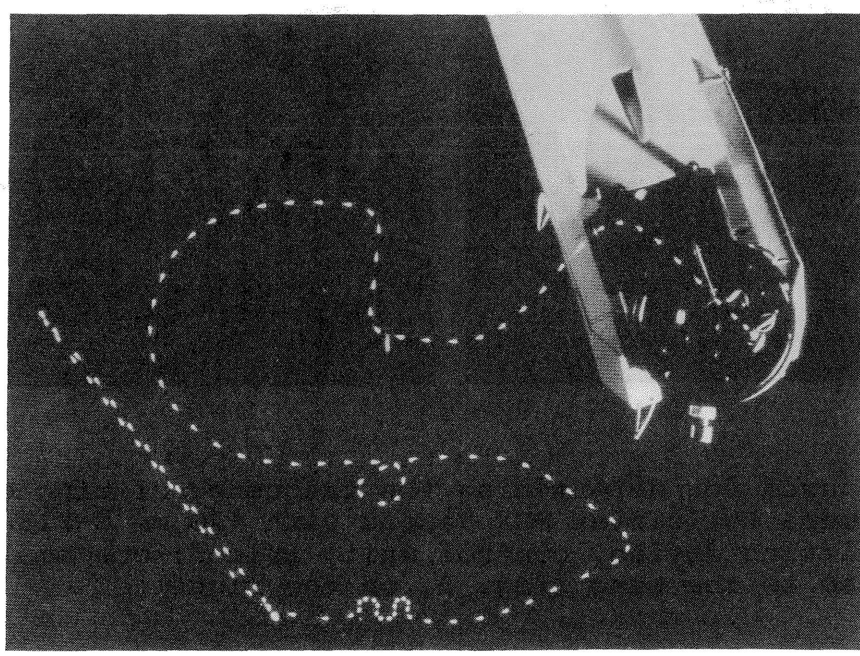


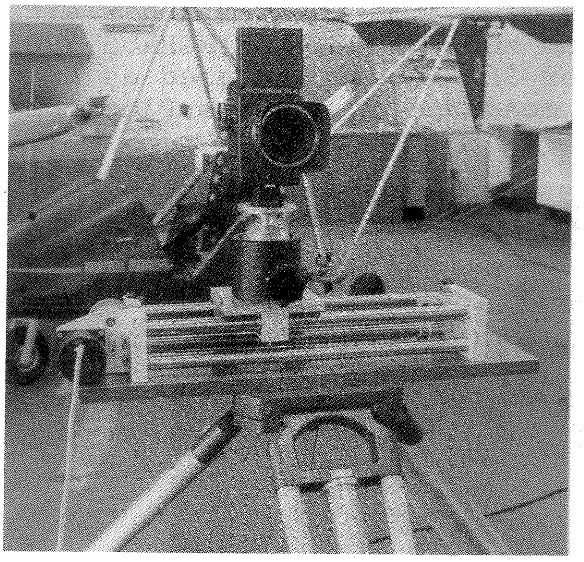
Fig. 3 Reference path recorded by BA-motography.

The robot follows a test figure composed of some corners and circles without a stopping or a commanded reduction in velocity (photographed by M. Beer/A. Nietzold; SCHMID et al. 1986).

4.2 Determination of object oscillations

Change of position and shape of an object can be recorded motographically, i.e. the movements of selected points are "frozen" in time on a single photograph. If repetitive cyclic movements are investigated the imaged light-traces are superimposed and quite blurred. In order to prevent this result the film may be continuously transported inside the camera during the exposure of oscillating objects (gliding-cyclography, ATHA 1984; BAUM 1980). But the interior orientation of the camera also changes continuously so that the procedure should only be used if a mere interpretation of motion is sufficient.

Instead of moving the film it is advisable to move the camera during exposure. In this case, an equipment suitable for the analysis of harmonically oscillating structures consists of a shifting device and, if necessary, a timer (GÜTHNER and PEIPE 1987).Fig. 4 and 5 show the Rolleiflex mounted on a linear shifting device (PHYSIK INSTRUMENTE 1985). Velocity, direction and distance between the beginning and the end of camera motion are preselected on a control unit. A stepping motor generates velocities up to 0.20 m/s.



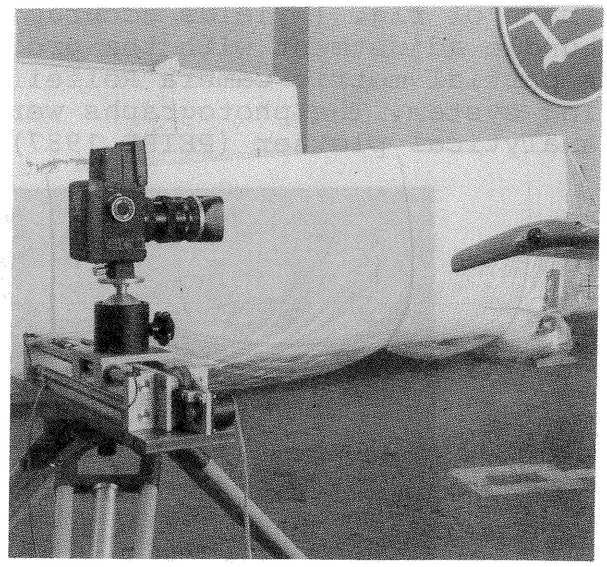
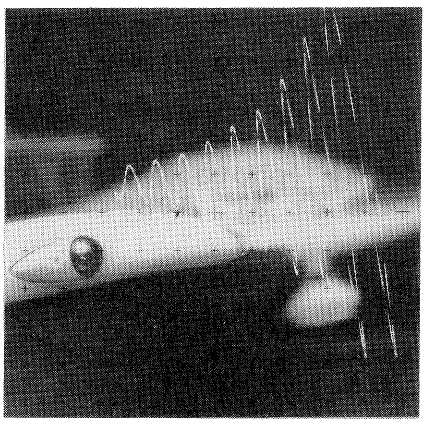


Fig. 4 Fig. 5

Equipment used for determining the frequency of wing oscillations: camera Rolleiflex SLX Réseau with 120 mm S-Planar lens, linear shifting device, control unit, tripod; one small lamp is attached to the wing (fig. 5, on the right).



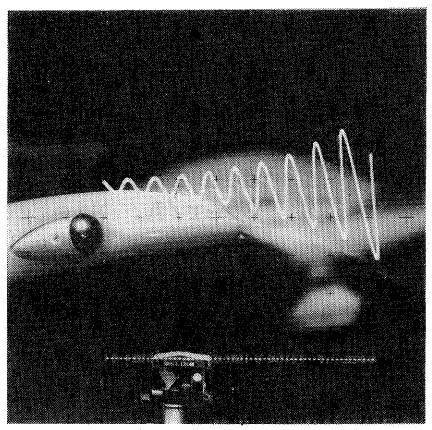


Fig. 6 Fig. 7

The light-trace produced by an incandescent lamp makes the movement of the wing visible (original photo scale 1:10, shifting velocity of the camera 0.03 m/s, exposure time 8 s).

The equipment was applied to the determination of the eigenfrequency and damping constant of a power glider wing (fig. 5). The amplitude of the wing motion amounted to 0.15 m, the frequency to around 1 Hz. The camera axis was perpendicular to the direction of motion.

The motographic recording of a pulsed-light lamp on the wing contains all information required including time (fig. 6). But the reversal points of the oscillation are insufficiently imaged. A better result is obtained if the lamp is glowing permanently and the time information is being separately recorded.

Fig. 7 shows the additional light-trace of a lamp which is not connected with the wing and flashes with known frequency.
The photographs document the present state of the wing. The calculated values of frequency and damping constant may be compared with the results of former tests in order to note material changes over the time.

In automotive industry, the equipment was used, for instance, to investigate the damping out of shock absorber oscillations. The test was performed in a similar way as for the wing motion. Fig. 8 shows a car and the motographic recording instrumentation. The car-body is forced to oscillate in vertical direction and released at the moment of maximum amplitude. The damping of the oscillation indicates the quality of the shock absorber (fig. 9 and 10).

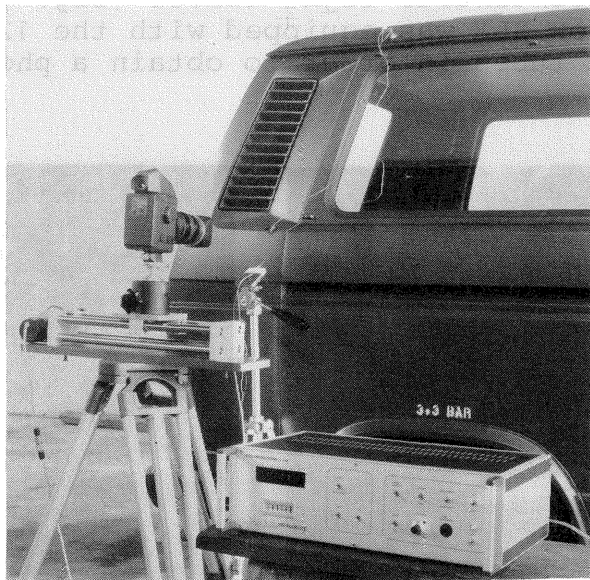


Fig. 8 Shock absorber examination

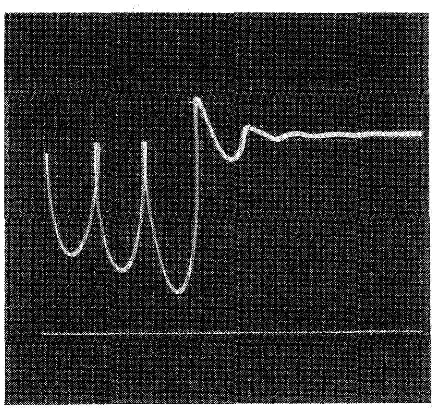


Fig. 9

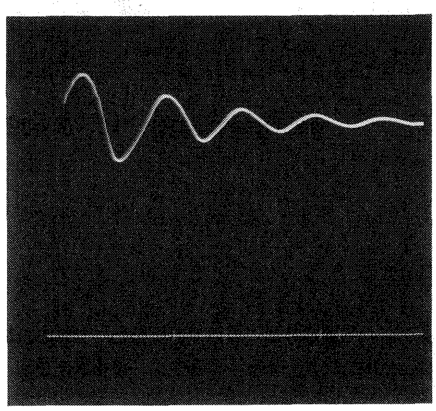


Fig. 10

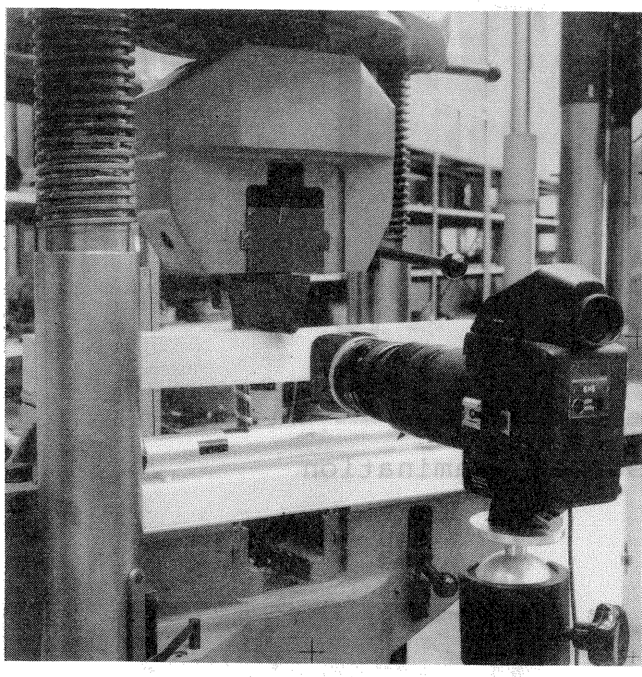
Motographic images of shock absorber oscillations (original photo scale 1:2.5). The good (fig. 9) or bad (fig. 10) damping condition can be identified.

4.3 Deformation measurement

At the XV. ISPRS Congress, these authors presented a paper on the determination of deformations and failure lines in soil by means of motography and photogrammetry (PEIPE and GÜTHNER 1984; fig. 2).

A further application deals with material testing. Motography may be used for deformation measurement of materials instead of mechanical or electrical pick-up systems such as strain gauges etc. The representation of small displacements during three-point-bending is described as an example.

A 600 mm timber beam supported on two points is loaded by a punch (fig. 11). A point pattern marked with luminous paint is illuminated by UV-light. When loading the timber beam the deformations appear as continuous light-traces (fig. 12). In this case, the Rolleiflex SLX was equipped with the 120 mm S-Planar lens and extension tubes in order to obtain a photo scale of about 1 : 1 .



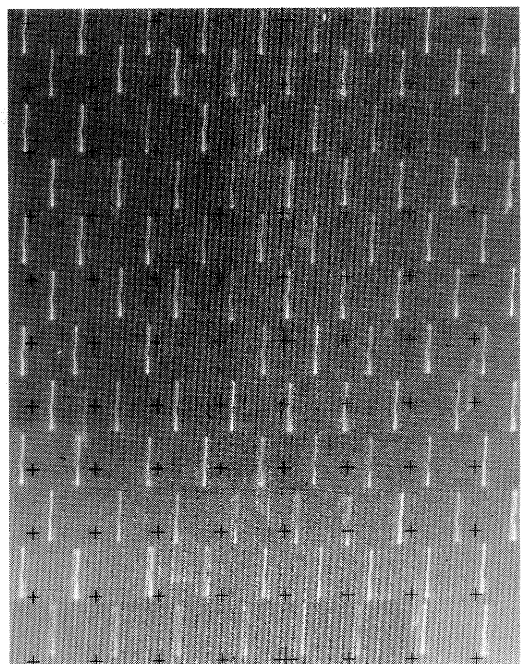


Fig. 11 Recording of timber beam deformations Fig. 12

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