A NEW APPROACH FOR SPATIAL MEASUREMENT OF DYNAMICAL PROCESSES

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ABSTRACT:

The ability of modelling dynamical processes represents a rather new field of research. Conditioned by the great improvements of powerful computers in the last years, it is possible to connect the advantages of high precision photogrammetric measurement of static objects with the visualisation of motion. In the project presented in this paper video-cameras are used in order to register a dynamical process. The recorded sequence of 2D images, which is supplied by each of the cameras, can be interpreted as one single 3D image cube. Using feature extraction operators and matching algorithms corresponding object points are tracked through the image cube, building a motion curve. Finally, the 4D co-ordinates X, Y, Z and T of the motion model are determined by spatial intersection of corresponding motion curves from different image cubes.

KURZFASSUNG:

Die Modellierung dynamischer Prozesse stellt ein relativ neues Forschungsgebiet dar. Bedingt durch die in den letzten Jahren enorme Leistungssteigerung im Bereich der Computertechnik ist es möglich, die Vorteile einer hochgenauen photogrammetrischen Vermessung statischer Objekte mit der Visualisierung von Bewegungsabläufen zu verknüpfen. Im hier präsentierten Projekt werden Videokameras verwendet, um einen dynamischen Prozeß aufzuzeichnen. Jede einzelne Kamera liefert eine Folge von 2D Bildern, die in einem einzigen Bildwürfel zusammengefaßt werden können. In diesem werden durch Kombination von Merkmalsextraktions-, Verfolgungs- und Matching-Algorithmen übereinstimmende Objektpunkte ermittelt und zu einer Bewegungskurve zusammengefaßt. Durch räumlichen Rückwärtsschnitt entsprechender Bewegungskurven aus verschiedenen Bildwürfeln erhält man die räumlichen 4D Koordinaten X, Y, Z und T des Bewegungsmodells.

RÉSUMÉ:

La possibilité de modeler des processus dynamiques est un domaine de recherches relativement récente. A la suite des grands progrès de la puissance des ordinateurs en dernier temps il est possible d'assembler les avantages d'un arpentage photogrammetrique d'objets statiques de haute précision avec la représentation de mouvement. Le projet présenté dans cet article se sert de camera vidéo pour enregistrer un processus dynamique. Chaque camera donne une série d'images 2D, qui peut être interprété étant une seule image 3D. En se servant de différentes méthodes pour trouver des éléments particuliers et d'algorithmes d'assimilation les points d'objet correspondant peuvent être déterminés dans l'image 3D et réunis dans une courbe de mouvement. L'intersection spatial de courbes correspondantes donne les coordonnées X, Y, Z et T du model qui représente le mouvement.

1. INTRODUCTION

The importance of modelling dynamical processes has grown rapidly in the last years. One reason for that development certainly is the great improvement of powerful computers. With their help it is possible to handle the data amount of dynamical processes in reasonable time. In that context there are different types of problems where it seems to be convenient not only to document a state at one certain moment but also to be able to describe and analyse dynamical events.

Such problems occur for example in the area of current mechanism, where it is of interest to be able to describe the spatial movement of particles in currents of air or in eddies of liquid. One concrete area of application is meteorology, where the movements of different zones of air towards each other are explored by describing the spatial movements of balloons passing these zones of air.

Another big area of application lies in medical research projects. For ergonomic investigations the ability to model the spatial movements of feet, ankle and knee during the process of walking is of special interest. In facial medicine the doctor wants to be able to analyse the movements of the upper and lower jaws while the patient is chewing.

That is why it seems useful to connect the advantages of high precision spatial measurement of static objects with the visualisation of movements as they occur in films.

2. SET-UP OF THE SYSTEM

Up to four video cameras (CV-235 monochrome, with a resolution of 752 x 582) and optional two pattern projectors are used in this project in order to register a dynamical process. The cameras and the projectors are connected with a frame-grabber (IC-P with AM-CLR from Imaging Technology). During the recording a pattern can be projected on to the object (head, knee) so that surface descriptions can be generated in a fully automatic way by using matching algorithms. Besides, targets are fixed on the object in order to provide an easy possibility to detect identical anatomical points in different images.

Over a certain period of time each of the four cameras records a sequence of 2D-images (= slices). This sequence can be interpreted as one 3D-image (= Space-Time-Cube, STC) with the image co-ordinate axes x, y and the time-axis T. The STC in figure 1 represents a hand which is clenched to a fist and then opened again.

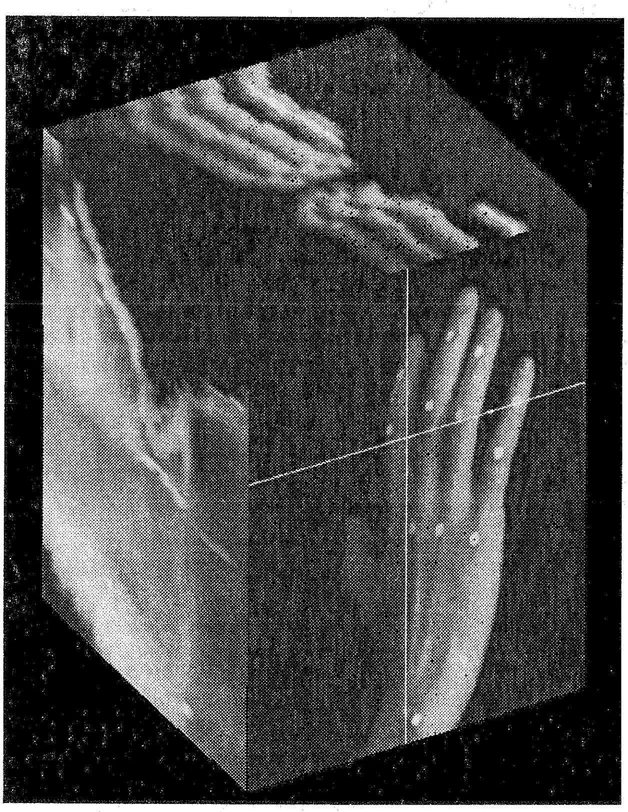

Fig. 1: The position in the STC of the xT-slice on the left is marked by the vertical white line in the last recorded image, while the top face of the cube shows the yT-slice marked by the horizontal line.

Concerning the axes the special meaning of the T-axis should be taken into account. Different to the Z-axis of conventional voxel-arrays where all three axes are equal, the T-axis has a special meaning because the recorded movement of points can only occur in the direction of the positive T-axis.

The four STCs can now be used to generate a motion-model with the axes X, Y, Z and T. The slices at different moments T = constant can be taken to generate surfaces using matching algorithms. All these surfaces should take into account the existence of correlation between slices adjacent in time.

For the following computation process first each STC is analysed separately. Then the 4D-points of the motion model are determined by spatial intersection.

3. COMPUTATION PROCESS

When computing the spatial points of the motion-model two different methods are being tested.

3.1 Point Tracking method

In the first approach one arbitrarily chosen slice is taken as initial position. In this slice points of interest are determined with the help of feature extraction operators (e. g. Förstner-Operator) [Förstner, 1987]. To select appropriate parameters for the thresholds of the feature extraction algorithm in a fullautomatical way, mean value and variance of the specified slice are used.

Next, corresponding points have to be found. This is done by tracking each of the feature points through the STC. A least-squares-approach [Jähne, 1993] is used to determine the direction to the next corresponding point. On the assumption that the direction of the gray value gradient changes in a local 3D-neighbourhood both components $\alpha 1$ and $\alpha 2$ of the optical flow can be determined (Fig. 2).

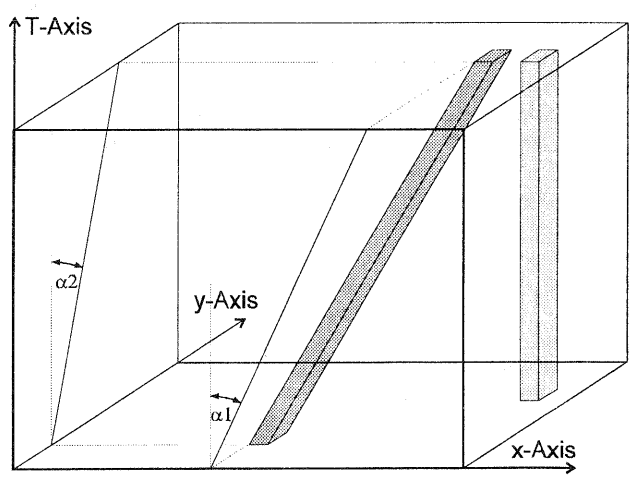

Fig. 2: Components $\alpha 1$ and $\alpha 2$ describing the local direction of a moving object element. The right object element is static.

The equation to be solved is

$$g_x \cdot \alpha 1 + g_y \cdot \alpha 2 = g_t ,$$

where g_x, g_y and g_t are the partial derivatives of the gray values. Using various points in the local 3D-neighbourhood the components can be determined by adjusting the overdetermined equation system by the method of least squares.

The computed direction is used to get an approximate position of the corresponding point in the adjacent slice. Then the high precision localisation of the point is done by Least-Squares matching [Gruen, 1985]. Whereas the size of the template can be kept fixed for the STC, the size of the search area is varied depending on the variance of the computed components. If the accuracy is high then the search area can be small and vice versa. When the new point is determined the tracking process goes back to the least-squares-approach, until all the slices have been checked.

In that way motion curves connecting corresponding object points, and their relations to one another can be found. The algorithm is applied separately to all the STCs. Then the relations between different STCs are checked in order to find the corresponding motion curves. In the course of this process also wrong parts of motion curves are detected and corrected.

Finally the spatial intersection [Kraus, 1993] of corresponding motion curves results in a spatial curve, where the point locations depend on the time T [X(T), Y(T), Z(T)]

3.2 Point Classification method

In the second approach the feature extraction algorithm is applied independently to all the slices of the STC. To classify corresponding points all feature points of one slice are compared to the points of the adjacent slices. The computed distances are taken to build the relations between the feature points (Fig. 3). So, continuous motion curves as well as incomplete ones can be determined step by step.

After this procedure has been applied to all the STCs the following steps are analogous to the point tracking method. The spatial intersection of the curve points for all the STCs results in the point co-ordinates X, Y, Z and T of the motion model.

If we make use of the pattern projector both described methods can be applied in the same way. The difference concerning the first two cases is that points of the pattern do not represent any more one single object point. In each of the slices the projected pattern is located at a different position on the object, because of the movement of the object. As a constraint every point of one motion curve have to lie in one plane in the STC. This plane is determined by the projection centre of the camera and the light ray of the observed pattern point.

This constraint can be used when searching for corresponding points. One further constraint can be introduced to the spatial intersection algorithm. Corresponding pattern points of the motion model have to be located on one straight line, namely on their light ray to the pattern projector.

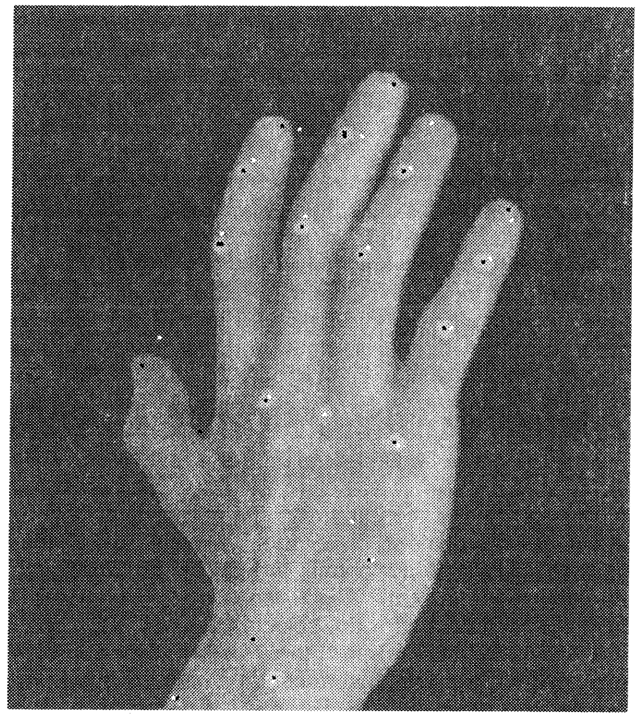

Fig. 3: Overlay of feature points in two adjacent slices. Feature points of the shown slice are marked as black dots, points of the adjacent slice as white dots.

3.3 Comparison of both methods

The computation of the second method is faster than the first one, but only points found by the feature extraction algorithm are being used for the classification process. So, if real feature points are not detected because of unfavourable thresholds settings, they cannot be classified and therefore will not appear in the motion model. In contrast, the point tracking method operates only in a local neighbourhood and can adapt itself more easily to different conditions of image contrast.

Concerning the thresholds settings, of course for the first method inadequate parameters may be computed too. But in this case the thresholds only need to be set once per STC. This circumstance allows the user, if necessary, to refine the parameters interactively. For the point classification method is not useful to check each slice interactively, because of the great number of slices.

The disadvantage of the point tracking method is that object points, which are not yet visible or not visible any more in the initial slice, due to the recorded movement, cannot be tracked and therefore also will be missed in the motion model. This problem can be overcome by choosing two or three slices as initial ones (e. g. at the beginning and at the end of the recorded STC) and track the points in two contrasting directions.

Besides the mentioned methods for modeling dynamical spatial processes it is also possible to use slices of different STCs taken at the same time and to build a spatial model using stereo matching algorithms [Förstner, 1986]. In that case different models has to be linked in object space with the help of surface matching. This approach needs synchronisation of the different cameras, otherwise no surface for one fixed moment can be determined.

Both methods described in this paper work even without synchronisation, because in a first step the STCs are analysed separately and then the motion curves of corresponding points are determined. Therefore, points at any moment can be interpolated if necessary, before computing the 4D co-ordinates of the points of the motion model by spatial intersection.

4. CONCLUSIONS

In each of the mentioned cases the result is a motion-model with the axes X, Y, Z and T. In a model of that type it is possible to obtain a surface for one fixed moment (T = constant). This is done by first computing the respective points for the selected value of T on each of the spatial curves and then building the surface description. This static surface can now be analysed visually and geometrically. Besides the selection of one fixed T it is also possible to analyse the motion and changes of one fixed co-ordinate level (e. g. Z = constant) by showing and analysing the contour lines at different times.

The possibility to visualise the movement of objects which has been determined by high precision photogrammetric measurement is rather new and offers totally new areas of application for photogrammetry.

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