PARTICLES FLOW DETERMINATION IN 4-DIMENSIONAL SPACE

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ABSTRACT

The purpose of the present study is to establish the kinematic description of the three dimensional evolution of projections of particles, in an automatic way.

Particles, which are numerous and fairly similar, are filmed by two cameras placed at two different points. Thus, two stereoscopic views of the scene, at any given time, are obtained providing three dimensional information. The succession of such stereopairs in a period of time then gives us an account of the information related to the movement.

To trace back the trajectory of each particle, we need to extract these two kinds of information, that is to solve a double matching of particles, both spatial and temporal.

Traditional stereo matching techniques can not be used here, for the space being observed does not have properties of continuity, which makes it impossible for local solutions to be propagated.

For these reasons special techniques of graphs have to be developed in which matching hypotheses, between right and left views, are progressively checked by the coherence of the trajectories deduced from them. To escape the complete combinatorial research, a kinematic model has to be use, which allows us to predict trajectories by Kalman filtering.

1. INTRODUCTION

The purpose of the present study is to establish the kinematic description of three dimensional evolution of projections of particles, in an automatic way.

To establish a kinematic balance, that is to trace back the trajectory of each particle, the data of two image sequences of the phenomenon are given, they are filmed by two synchronized cameras placed at two different points.

Consequently, two stereoscopic views A(T) and B(T) of the scene are obtained at any given time T, thus providing three dimensional information. The succession of such stereopairs in a period of time then gives us an accout of the information related to the movement of these particles.

To be able to find out these two kinds of information one needs to identify, for each particles and at any given time, corresponding projections from the two images, as well as to identify thoses which immediatly follow them.

Therefore the problem we are faced with consists of a double matching of particles, both spatial and temporal.

Practically, the task present some difficulties:

* Numerous, more or less similar particles are observed which may often be hidden by each others (figure 1).
* The problem of temporal matching is in itself quite a difficult one too because of temporal sampling which breaks the continuity of trajectories.
* Moreover the depth of the projections of particles is important enough to be

responsible for considerable disparities, which makes even human interpretation difficult. Thus it is impossible to take advantage of correlation techniques used in particular in the application of aerial photogrammetry <SMIT>. photogrammetry applications <SMIT>.

* Properties of continuity whithin the space being observed are not verified. In fact, the particles "float" in space, now hypotheses of the space continuity "almost everywhere", is a major point in most research on the shortcoming of stereoscopics, such as that by Marr and Poggio <MARR>, <MAY-1>, which allows the propagation of local solutions.
* Finally, every method using the matching of segments or points <LONG>, <CAST> makes the hypotheses of the uniqueness of matching. This hypotheses cannot be applied here since the particles can hide each other.

Since neither the continuity nor the uniqueness of matching can be verified, we will have to develop specific matching techniques whose computing cost is higher than those used usually in stereophotogrammetry (correlation methods <SMIT>, relaxation labeling <BARN>, <BERT>, <HWAN>, <MEDI>, testing of hypotheses <GRIM>, <AYAC>, dynamic programming <BAKE>, <BENA>, <LEGU>, <OTHA>, Hough transformation <MAY-2>)

For this reasons, special techniques of graphs have to be developed in which the interpretation in terms of path is researched. Matching hypotheses, between right and left views, are progressively checked by the coherence of the trajectories deduced from them.

To avoid the complete combinatorial research, heuristics as well as a detailed kinematic model have to be used which anables the trajectories to be predict by Kalman filters <SCHW>.

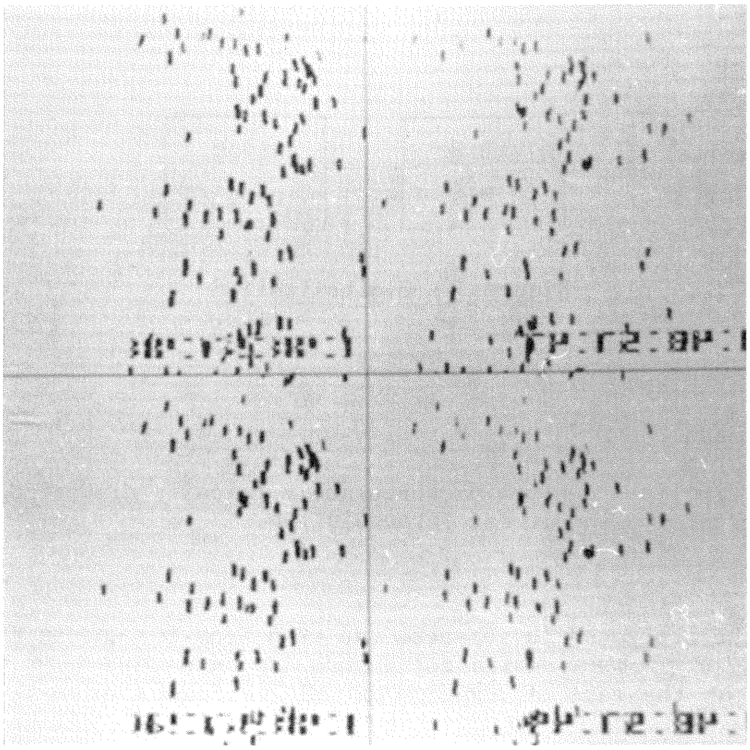


Figure 1: A stereopair exemple

2. Experimental set up

Image recording

The cameras used are standard video cameras fixed onto a bench which enable the focal distance, the distance to the subject to be adjust identically for each camera. In the same way the distance between the two cameras and the convergence angle can be modified <LAFO>.

Both cameras are synchronized and linked to a timer which numbers every frame produced.

Digitalization

Images are then digitalized and memorized according to the following way:

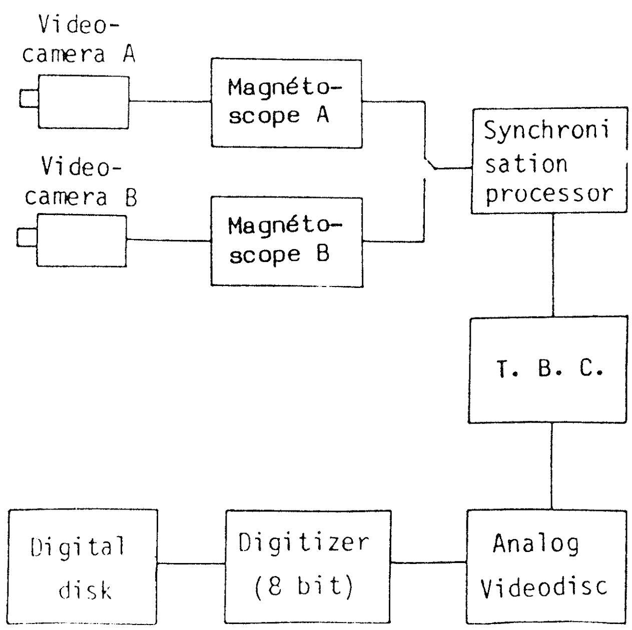


Figure 2: Digitalization

3. Preliminary picture processing

Systematical treatment

Because of the sampling, digital pictures are vertically distorted, this defect is systematically corrected using linear interpolation.

Frame separation

The images ar the processed to separate the even from the uneven frame in order to produce two different pictures which correspond to successive time intervals. Thus, we take advantage of the rate of acquisition of the frames which is of 1/50 th of a second.

Registration

By setting up the bench properly, it is possible to adjust the cameras in order to make the video lines correspond to the epipolar lines of the observed scene.

Eventually, digital registration techniques can be applied, if serious distortions appear <BONN>, <BENA>.

Particle extraction

A detection process of stains (that is the projected image of one particle on a view) is now used.

This process provides attribute vector (luminosity, surface, centre of mass, minimal box...) and a label for each stain which caracterizes them.

However, some ambiguities are left, due to the fact that one stain may include the projected images of different particles which hide one another.

4. Processing

Correspondances are to be identified between these stains, on the one hand, from a period of time to the following one, on the other hand, from one picture to the other picture of the same stereopair.

The trajectory of each particle will be represented by a graph which is sequentially developed. Simultaneously, the kinematic behavior of the particles is modelised by using Kalman filtering applied on the particles center of mass.

Representation of results

Every trajectory related to one particle is describe, by a tree such as:

* The depth of the tree gives us time
* Every node of the tree represents a possible position of the centre of mass of the particle in the 3-dimensional space at the given time T. A possible position corresponds to the association of two stains on the left and right views.
* The successive nodes represent the position of the same particle at the next time T+1. One particle can divide itself at any moment, so every node may have many successors.

There are, at least, as many trees as there are particles counted at the initial stage.

Sequential process

At the stage T-1, all the trees are developed down to the depth T-1. Then, at the stage T all the nodes of depth T are built. For that purpose <u>the subproblem of tracking</u> has to be solved for each final node of depth T-1.

Resolution of tracking subproblem

Let us consider a node at depth T-1. Kalman filtering is processed on the N upper node values, that is the N former positions of the particle in the 3-dimensional space. N being there the order of the model used for the Kalman filter. Thus the position of the particle at the given moment T can be estimated with some uncertainty.

Therefore, a research zone is defined in 3-dimensional space which projected onto the two pictures A(T) and B(T) provides two 2-dimensional research zones ZA and ZB.

Each of the zone ZA and ZB may or may not contain stains. If they does, only the pairs of these stains, one taken from ZA, the other from ZB, which can be associated with each others are retained. The stains can be associated to each other if they share some common epipolar lines together, and if they obey a criteria of similarity based on the attribute vectors of the stains. One stain can be used for several associations (case of hidden particles).

The location in 3-dimensional space which corresponds to each association which has been retained, constitute a new observation in the Kalman filtering process and a new node on the graph.

Then, for one given node, as many succesor nodes as the associations we retained are built, the position at the given moment T of the filtered trajectory corresponding to the new observation is attributed to all of them.

If no one couple has been retained, and if the particle is not outside of the field of view, it is considered that the corresponding branch of the tree doesn't represent any valid trajectory, and, therefore, must be suppressed.

remark:

> When for every tree all the nodes at depth T have been constructed, all unused stains in the two images A (T) and B (T) are examined. For every pair of those stains which can be matched a new tree is then constructed which begins at the depth T and which is initiated in the same way as the initial trees.

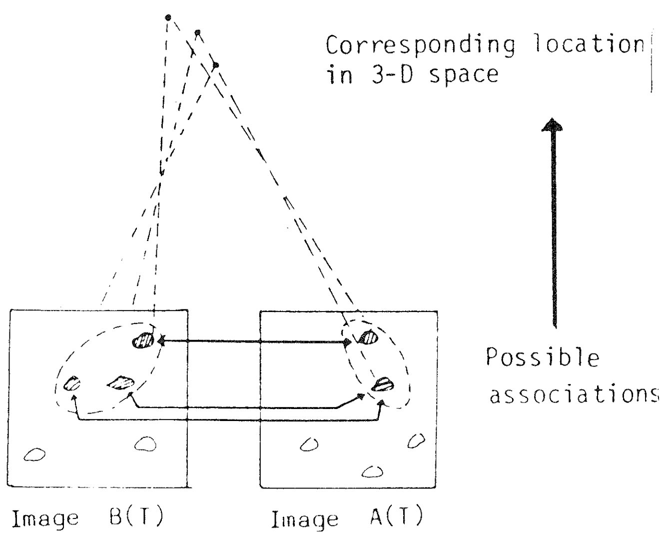


Figure 3: Stains association

Initialization

On the N first stereopair of images, a large number of combinations of the temporal and stereo associations is defined, in order to avoid missing any possible trajectory. These first element of trajectories make possible the initialization of Kalman filters though many of them may be rapidly suppressed.

5. Results

The use of the algorithm, in a simplified form is then introduced, in where the particles are not too numerous and quite well separate. Figure 4 represent some of the images from the sequence which has been studied. The images have been pretreated so that it is possible to extract and label the stains.

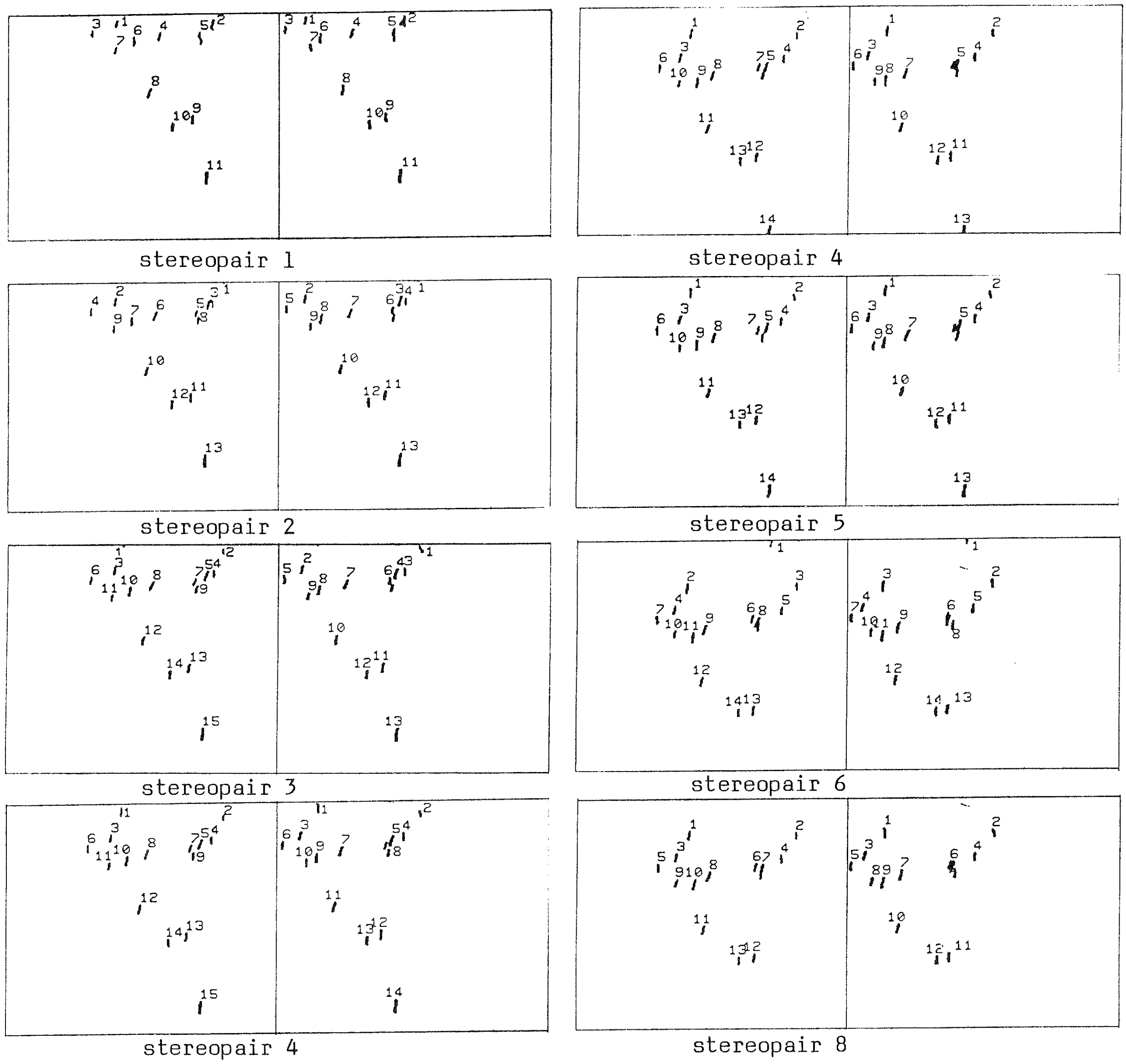


Figure 4: Exemple of stereoscopic sequence of images.

A kinematic model of the second order is used for this purpose. In fact, the particles which are subject to a certain amount of contact are filmed when their speed is more or less stabilised.

different kinds of trajectories are obtained:

*interrupted trajectories:

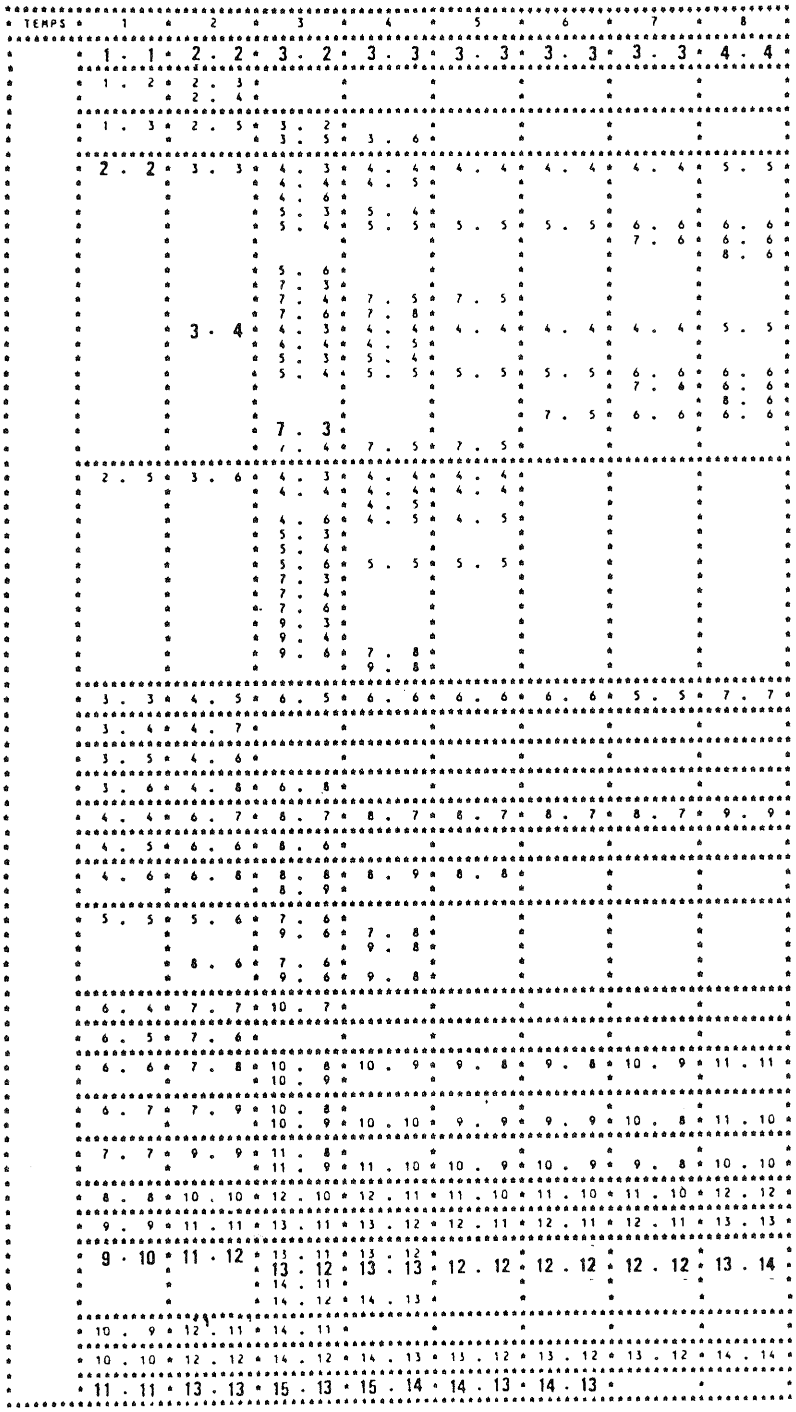
-if the particle went outside the field of view (figure 5 case 1)

-if the trajectory is not valid (figure 5 case 2)

* complete trajectories:

- when the trajectory is correct and correspond to real particle (figure 5 case 3).

-when the trajectory does not correspond to a real particle but is nethertheless valid. This appears for exemple when two particles are moving whit the same speed on parallel directions. (figure 5 case 4)



Case 1: trajectory 11/11, 13/13, 15/13, 15/14, 14/13, 14/13 correspond to a particle went out of the field.
Case 2: trajectory 2/2, 3/4, 7/3 is not valid and then has been interrupted.
Case 3: trajectory 1/1, 2/2, 3/2, 3/3, 3/3, 3/3, 3/3, 4/4 is complete and valid.
Case 4: Trajectory 9/10, 11/12, 13/12, 13/13, 12/12, 12/12, 12/12, 13/14, does not correspond to any real particle trajectory but nethertheless is a valid one.

Figure 5: Trajectories obtained.

6. Conclusion

The proposed solution is a suboptimal one, a more rigourous solution would use unique representation of all the possible associations of stains at every time T, and the research of all the existing trajectories in that array. The complexity of that problem isn't polynomial and leads to prohibitive computering costs.

By sharing the problem of each of the particle and by making a full use of knowledge of the process we are studying, we can considerabely reduce the complexity of the problem, which nevertheless still depends on such factors as: number of particle, ratio between speed of particles and speed of temporal sampling, distance between the two cameras.

To limit these costs, for the more reasonable exploitation of the method, is one of the aim of our study.

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