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3D RECONSTRUCTION OF PLANTS

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ABSTRACT

The reconstruction of plants which is relevant for evaluating the growth of plants according to the time is based on stereovision. Two methods of stereovision are presented.

INTRODUCTION

The description of geometrical structure of vegetation canopies in general, and in particular, of crops has today several applications :

1 - Crop simulating models need to enter, agronomical variables, at a given date, such as leaf areas, optical properties, ...

2 - The characterization of crop structure using non destructive methods (satellite remote sensing, field radiometry) needs to know structural parameters in order to modelize the radiative transfer inside the canopy [2,3,4].

Different attempts were made until now:

1/ to measure in situ structure parameters,using :

- some 3D digitizer, laser distance meter or 2D plant profiles [1]
- manual photogrammetric measurements [4,5]

2/ to reconstruct plant geometry from them [6]

The encounted limitations of these previous published methodologies are :

- time consuming when a handheld probe is used (sonic 3D digitizer)
- need to cut the plants (plant profile)
- limitations to canopies high enough to allow man movement inside it (corn)

The paper deals with in situ measurements of geometrical structural parameters of plants. We here present a stereovision approach adapted to plant geometry which is quite different from the classical polyedric space. This approach has been chosen because it does not have the previous drawbacks.

EXPERIMENTAL ENVIRONMENT

We will present a lab environment and a real environment. In the 2 cases, we use calibration grids. The grids are designed in order to cover the work volume where we want to find the 3D structure of the plants. The figure 1 shows the laboratory experiment.

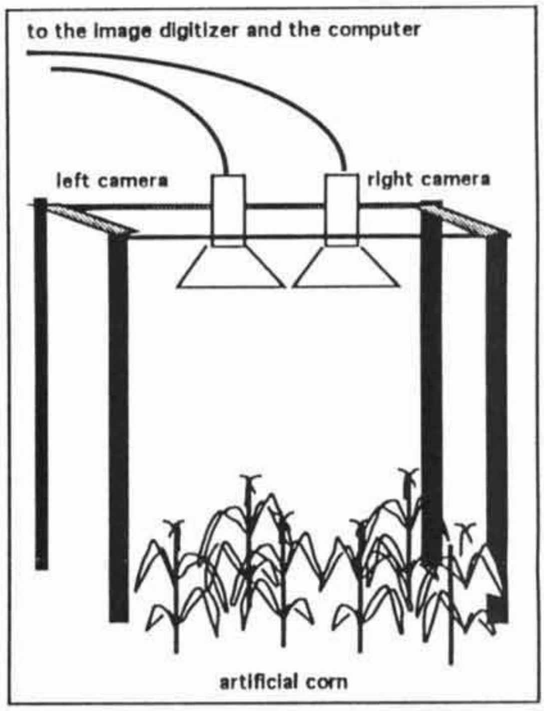

Figure 1 - Laboratory Experimental Device

PRESENTATION OF THE TWO METHODS IN A LABORATORY CONTEXT

First, the contours of left and right images are detected from Canny-Deriche's operator [7]. Then, the contours are approximated by line segments and the matching phase begins. This phase consists in finding homologuous features; the first and the second methods respectively use line segments and points as features. Finally, segments or points are reconstructed and drawed.

The steps of our processing appear on figure 2 :

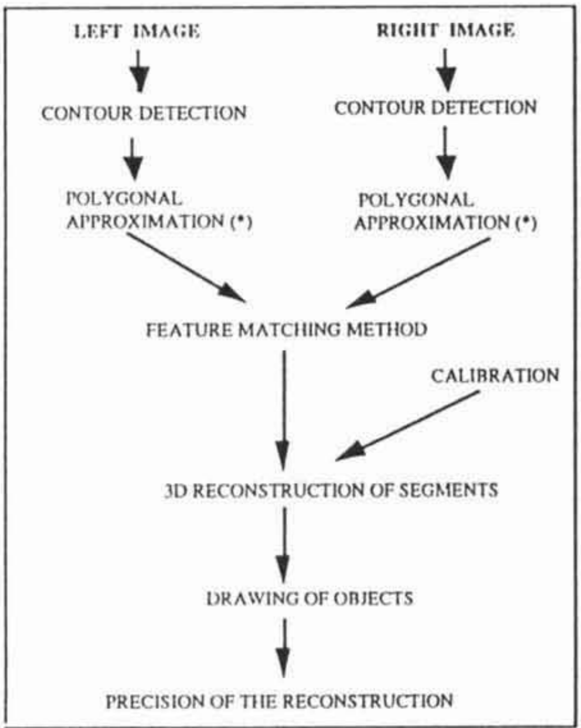

Figure 2 - The steps of 3D object reconstruction
(*) this step is not performed in the second method.

The calibration method is based on pin hole model, the mathematical modelling can be found in [8]. We distinguish intrinsic parameters which characterize the camera itself and extrinsic parameters which correspond to the rigid displacement between the coordinate system associated with the grid and the intermediate 3D coordinate system attached to the camera. At the end, we get the equation : $A=Bx$ (1)
where A is the column matrix of grid corner points coordinates in the image, B is a matrix composed of image and 3D coordinates of grid corner points. The solution x is equal to :

$$x=B^{+}A \quad (2)$$

B^{+} is the pseudo-inverse of matrix B, it minimizes Hilbert's norm. Greville's algorithm [9] gives B^{+}.

The precision of camera calibration depends on :
- the conditioning of B,
- the measure precision of the respective coordinates (X,Y,Z) of calibration grid points in the scene coordinates system and their image coordinates in digitized image coordinates system,
- the geometrical distortion.

Before examining the conditioning of B, let us recall that B must have a rank of 11. This implies that the calibration object must not be coplanar which is the case with a dihedral grid. [13] gives information about calibration camera accuracy.

1- FIRST STEREO MATCHING METHOD

The stereo matching processes can be distinguished according to 3 criteria [10] :
- the choice of image features (segment of the leave's contour),
- the constraints used for reducing the ambiguity matching and search space,
- the matching methods.

The chosen feature is line segment . Its attributes are its length and direction. Each line segment is defined as a vector and has four neighbourhoods which are on the left, on the right and at the ends of this vector. Each neighbourhood is characterized by the line segments which intersect it.

Among the constraints, the constraint used are :
- the epipolar constraint,
- the uniqueness constraint,
- the order constraint.

The matching method is based upon the probabilistic relaxation algorithm [11]. Before performing the matching method , preprocessings on the line segments such as concatenating small segments are carried out.

The proposed matching method follows the steps below

1. An initial probability value is given to the probability $p_{i\alpha}$ (probability of matching the line segment S_i of the left image and the line segment S_α of the right image) according to their resemblance,
2. the bilateral normalisation is performed and the value of $p_{i\alpha}$ is within the range [0,1],
3. $p_{i\alpha}$ is set to 1 if $p_{i\alpha}$ is near 1 and it gets 0 if it is near 0. It enables us to accelerate the matching process,
4. the entropy H is computed from all $p_{i\alpha}$ ($H=-\sum\sum p_{i\alpha}\log(p_{i\alpha})$),
5. if H equals 0 or doesn't vary, we go to the step number 7 otherwise we go to the following step,
6. the calculation of new values of all the $p_{i\alpha}$ are carried out according to the relaxation formula (6),
7. According to the value of $p_{i\alpha}$ the list of matched segments is updated.

At the step 1, the computation of pia takes into account the resemblance of the lentgh and direction of S_i and S_α and the distance to the epipolar line corresponding to the middle of S_i with the middle of S_α.

Bilateral normalization (step 2) consists in calculating : for each segment S_i of the left image :

$$p^{l}_{i\alpha}=\begin{cases}\dfrac{p_{i\alpha}}{norml} & \text{if } norml\neq 0 \\ 0 & \text{if } norml=0\end{cases} \quad \text{with } norml=\sum_{\alpha=1}^{m} p_{i\alpha}$$

m is the number of line segments in the right image; for each line segment of the right image :

$$p^{r}_{i\alpha}=\begin{cases}\dfrac{p_{i\alpha}}{normr} & \text{if } normr\neq 0 \\ 0 & \text{if } normr=0\end{cases} \quad \text{with } normr=\sum_{i=1}^{n} p_{i\alpha}$$

the bilateral normalization result is : $p_{i\alpha}=\min(p^{l}_{i\alpha}, p^{r}_{i\alpha})$

At the 6th step, the evolution of $p_{i\alpha}$ follows the relaxation iterative equation :

$$p_{i\alpha}^{(n+1)} = p_{i\alpha}^{n}(1+q_{i\alpha}^{n}) / \sum_{i=1}^{n} p_{i\alpha}^{n}(1+q_{i\alpha}^{n}) \quad (6)$$

n is the current iteration number

All the details concerning computing $q_{i\alpha}$ can be seen in [12]. This process works quickly because it takes into account the fact that some line segments do not have corresponding segments in the other image in a proper way.

2 - SECOND STEREO MATCHING METHOD

Instead of using a blind method for finding the homologuous points in the two images, we hereafter use knowledge about the plants we reconstruct. For example, we know that the corn leaves belonging to one given plant have their origin on a vertical stem. Furthermore, the stems are aligned in rows. So, it is easy to locate the extremity and origin of each leaf and to match leaves on the stereovision image pair using only these two points.

In our process, we can extract the the extremities of leaves either by mathematical morphology method or by using the curvilinear abscissa $\theta(s)$ and its derivative. Then, we locate the vertical segments which correspond to the stem of plants. After that, we follow the 2 half contours on each leaf and their homologuous half contours and compare their numbers of pixels. Usually, we do not get the same number of pixels on the two homologuous half contours. So, we resample after smoothing the half contour which is described by the smaller pixel number. Finally, the step matching consists in making a one to one correspondence between the 2 half homologuous contours.

Reconstruction step

In the first method, we reconstruct the scene segments from all the homologuous segments and in the second method we reconstruct scene points from homologuous points by using calibration parameters.

PRESENTATION OF THE FIELD EXPERIMENT

The methodologies above described are developped in order to be used on real plants. A field experiment was carried out to test the accuracy and performance of the stereovision technique in real conditions. Stereo photos were acquired using two Hasselblad electric cameras fitted with 100 mm lens and fixed to a vertical loom at 8 meter above the soil (stereobasis= 0.75 m, vertical optical axis). Two 3D calibration targets were located in the recovering field of the camera in order to calibrate the stereo system (photo6). This system was firstly used for estimating the height of corn leaves. Photographs were enlarged and digitized so as to measure the image coordinates of about 300 manually selected points on the leaves. The statistical analysis of results shows that the confidence interval (95%) is 4.3 cm for 2.50 m height which is good.

RESULTS

Photos 1 and 2 show the left and right contour images. Photos 3 illustrates the polygonal approximation got from the left contour image. Photo 4 shows the projection of the reconstructed segments obtained by the first stereovision method onto yz plane. We see that we have mistakes. Photo 5 presents a perspective image of contour points reconstructed by the second method, the results are very good. Photo6 illustrates the field experiment device.

CONCLUSION

We have experimented camera calibration, stereovision and reconstruction with standard hardware (cameras and image digitizer) on artificial corn canopy. Results show that a new simple method for matching homologuous objects can be proposed. It uses a limited knowledge of the plant structure and greatly improves the segment stereo matching algorithm based on relaxation. In addition, first results obtained in the field experiment on a real corn proves that stereovision is well suited to the problem of estimating structural parameters.

One important thing to be noticed is that this methodology can be applied to other types of plant structures changing acquisition parameters (scale factor) and moving to suited botanic knowledge associated with the crop.

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Photo 1

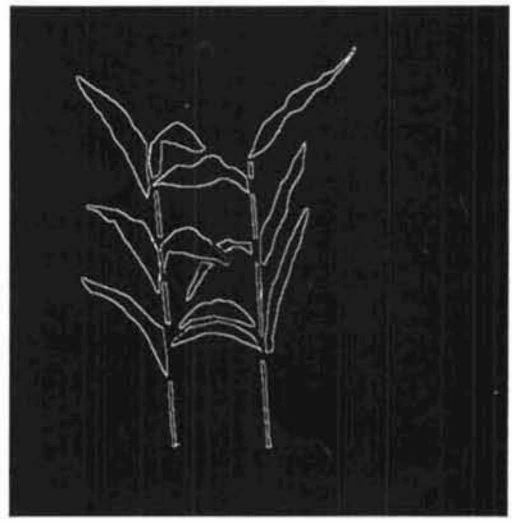

Photo 2

Photo 3

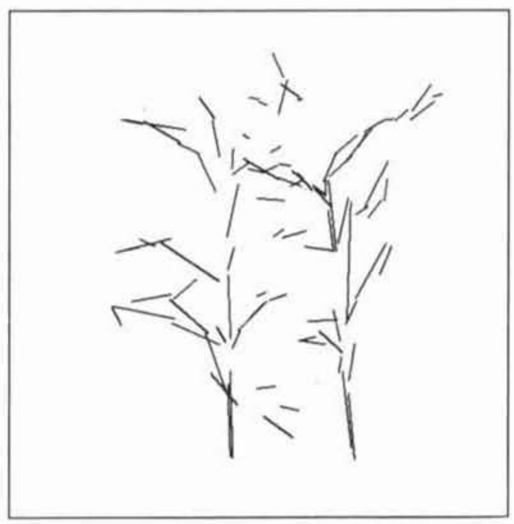

Photo 4

Photo 5

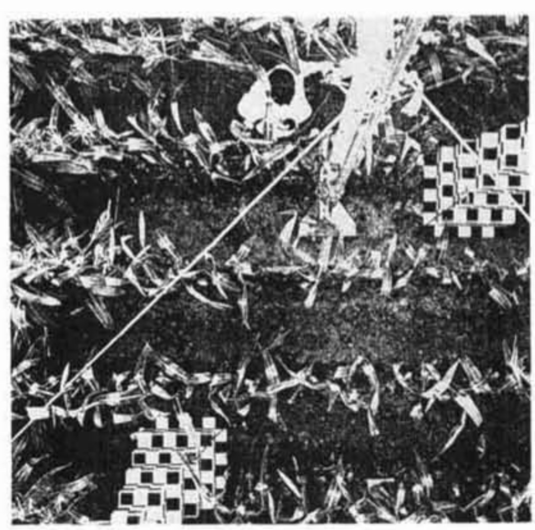

Photo 6