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LOCALIZATION OF AUTONOMOUS MOBILE ROBOTS BY MONOCULAR VISION IN MODELLED SITES. APPLICATION TO A NUCLEAR POWER PLANT

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ABSTRACT

This paper presents all the procedures up to now integrated in the "ULYSSE" software and designed for the automatic localization of a mobile robot in the area of the airlock of an "ELECTRICITE DE FRANCE" nuclear power plant. It is shown that if the initial pose of the robot is known, if a 3D geometrical model (even partial) is available, if a coarse estimation of each displacement is provided from odiometric devices, then the pose of the robot can be automatically determined by monocular vision and by matching the successive images and the CAD model. This matching occurs between the linear edges of the model and the image straight contours obtained after a polygonal approximation, and the attitude of the model is derived from the interpretation of the projection of at least three model edges.

INTRODUCTION

The potential applications of autonomous mobile robots using projective vision are numerous. The complexity of the problems to be solved depends on the available model of the world where the robot must move.

If this world is nearly not known, before any displacement it is necessary to acquire 3D information. Stereovision systems using two or three cameras [AYA-89] are now able to provide it. But for the moment the obtained range data is quite sparse and its accuracy is low in general even if it can be sufficient sometimes to solve some navigation problems. When the environment is measured, it is then necessary to analyze the data to find the robot path [LEB-89].

When a CAD model (even partial) of the world can be used, then the navigation problem is much simpler and is mainly reduced to the location one after each move. In this case it is possible to think about a monocular vision system to solve it.

The ULYSSE software is a set of modules designed for the automatic localization by monocular vision of a robot moving in an "ELECTRICITE DE FRANCE" nuclear power plant [DHO-90a], for instance in the area of one door of the airlock (images (a) and (b) of figure 1) for which a projection of the used partial CAD model is given in figure 2.

THE ULYSSE SOFTWARE

This software has been developed and implemented on a SUN 386i workstation. It is composed of two groups of programs : (i) for the preprocessings of the brightness images and (ii) for the localization of the robot "step after step".

The preprocessings consist in the extraction of the contour points [DER-90], the scheming of these contours [REI-90] and the polygonal approximation of the retained contours [DAG-89]. Figure 3 shows the results of these preprocessings when applied on the image (a) of figure 1.

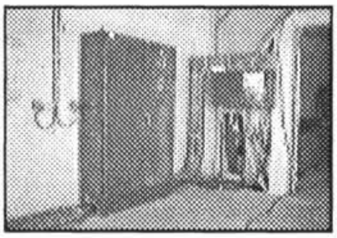
The second group of programs contains four modules for the accurate localization of the robot in the observed environment. They allow :

Module M1 : the determination of the space attitudes of the model deduced from the 3D interpretation of three straight contours when matched with three straight edges of the model [DHO-89],

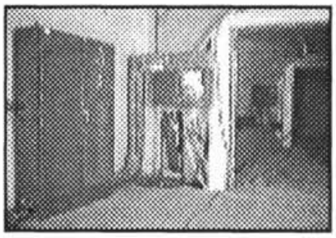
Module M2 : the determination of the space attitude of the model for more than three straight contours [LOW-85],

Module M3 : the automatic matching of the edges of the model and the image segments, and the calculus of the best point of view,

Module M4 : the automatic matching of the model and the image using module M2, and the determination of an accurate point of view.



(a)



(b)

Figure 1. Brightness images of the airlock from two different points of view.

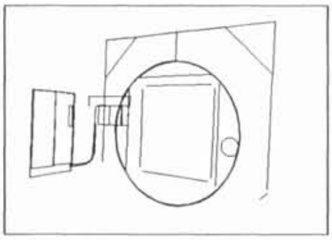


Figure 2. Projection of the CAD model of the area of one airloock door.

(a) (b) (c)

Figure 3. (a) Contour points; (b) Contour lines after scheming; (c) Polygonal approximation of the contour lines.

THE LOCALIZATION PROCEDURE

The whole procedure consists in an adapted linking of these four modules.

Finding the initial pose of the robot (modules M1 and M2) In the present state of the procedure, the initial pose of the robot must be provided at first. If at least three matchings between the straight contours and the straight edges of the model are known *(they can be manually obtained from the image and a projection of the model)*, then the initial attitude can be calculated with either module M1 or module M2.

But in the latter case, Lowe's algorithm gives the right pose only if good initial conditions are supplied for the iterative resolution of the involved non-linear equations. Thus it is better to initialize the execution of module M2 with the good but usually less accurate solution given by module M1 [DHO-89] [LOW-90].

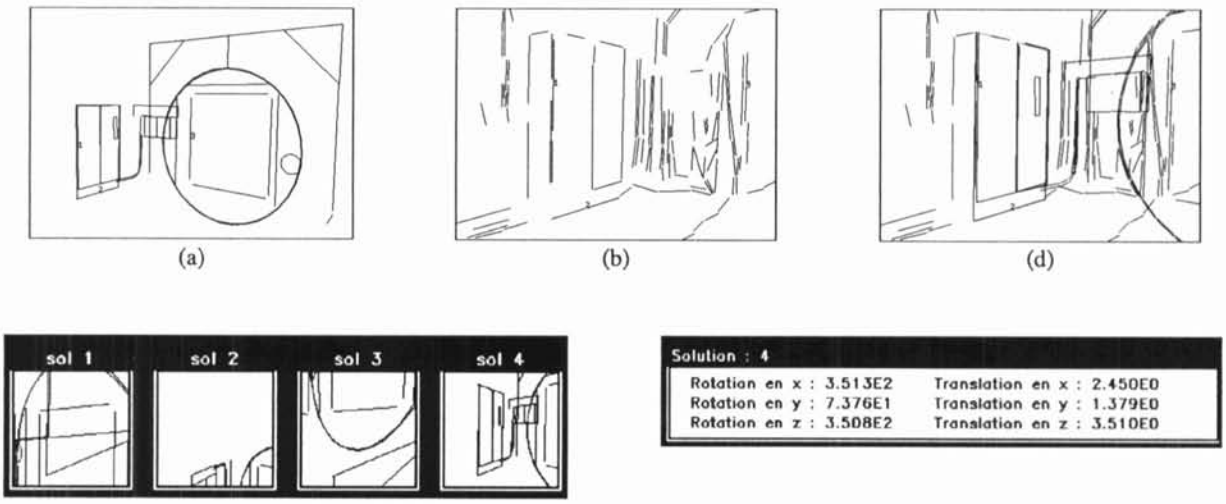
Figures 4a and 4b show three matchings manually chosen. Figure 4c shows all the possible attitudes given by module M1 and figure 4d gives the superimposition of the image and of the only correct model attitude selected with simple logical rules [DHO-89]. Figure 4e indicates the value of the space attitude parameters of the model (the rotations are expressed in degrees and the translations in meters).

The solution provided by module M1 (figure 5a) is then the initial condition for module M2. Figures 5a and 5b give the six manually chosen matchings, and figure 5c, the superimposition of the solution thus obtained from module M2, and of the image.

This accurate attitude is considered as the initial location of the robot in its world of displacement.

Determining the point of view after a move (module M3) It is considered that an estimation of the displacement is available since the robot movement which has been ordered at the preceding step is known and since odometric measures can be done.

This estimation allows to calculate the one of the robot attitude. The image of the model corresponding with this attitude is then matched with the observed image of the scene. In order to reduce the number of matchings, only the model edges matched at the preceding step are considered (cf sub-section *Refining the point of view after a move*).



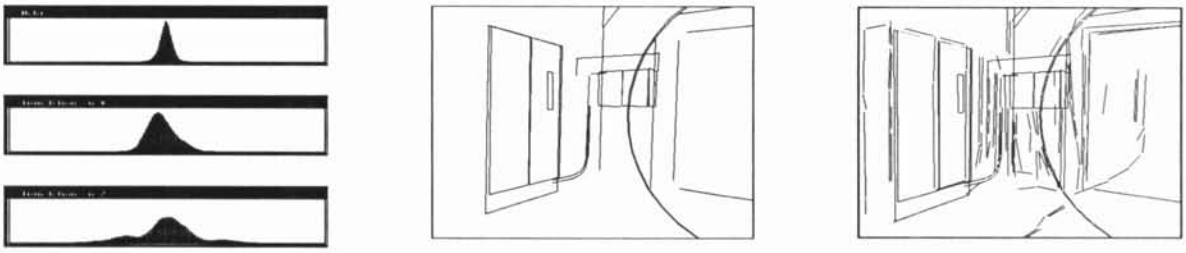
(a) (b) (d)

(c) (e)

Figure 4. Correct attitude from the interpretation of three matchings.

(a) (b) (c)

Figure 5. Attitude from the interpretation of six matchings.



(a) (b) (c)

Figure 6. Point of view after the accumulation process.

A matching between an model edge and an image segment is possible only if :
- the model edge has been matched at the end of the preceding step,
- the sum D of the distances between the extremities of the image segment and the support line of the projection of the model edge is less than a threshold *thdD* (current value : $thdD = 100$ *pixels*),
- the angle δA between the projection of the model edge and the image segment is less than a threshold *thd* δA (current value : $thd\ \delta A = 15°$),
- the length of the projection of the model edge and the one of the image segment are greater than a threshold (current value : 30 *pixels*),
- the gradient of the image at the middle of the image segment and the one at the middle of the segment of the preceding image which has been matched with the same model edge are similar (difference between their orientation : $\pm 45°$, and between their magnitude : $\pm 33\%$).

The matchings are ordered according to the criterion C :

$$C = 0.5(thdD - D)/(thdD) + 0.25(thd\delta A - \delta A)/(thd\delta A) + 0.25(R/L)$$

where L is the length of the projection of the model edge (Pme), and R is the length of the covering of the Pme by the orthogonal projection of the image segment on the support line of the Pme.

The higher C is for a matching, the more probable this matching is.

For each considered model edge, the three best matchings are retained. For each triplet of matchings, the possible attitudes of the model are computed with module M1. Those which are retained are such that :
- the three matched model edges are situated in front of the camera,
- their projection is visible,
- there exists a superimposition between the projection of a model edge and the corresponding image segment,
- the rigid transform between the space attitude of the model at the preceding step and the present one is of small magnitude. As the robot is moving on a horizontal plane, and as the vertical axis is the Y -axis, the thresholds which are currently used are : $\Delta R_x = \pm 5°$, $\Delta R_y = \pm 20°$, $\Delta R_z = \pm 5°$, $\Delta T_x = \pm 1m$, $\Delta T_y = \pm 0.15m$ et $\Delta T_z = \pm 1m$.

Due to the particular displacement of the robot, only three attitude parameters are variable. Then an accumulation on their value is done . When the matching process is achieved, the retained values for R_y , T_x and T_z are those corresponding with the maximum of each accumulator. Figure 6a presents accumulation results, figure 6b, the estimated attitude of the model (the displacement of the robot is estimated here with an error of 25%) provided to module M3, and figure 6c, the superimposition of the projection of the model in the attitude got from accumulation, and of the scene image.

Refining the point of view after a move (Module M4) The attitude given by module M3 results from matchings of the image segments and of the model edges which have been matched at the end of the preceding step.

But as the robot has moved and as consequently the scene image is modified, it is then necessary to determine all the model edges which are now visible, i.e. those which can be matched with the current contours. For that an automatic matching is done using the model attitude given by module M3 in a similar way as in module M3. But here :
- all the model edges are candidates for matching,
- for each model edge, only the best matching is retained.

A new attitude is calculated with module M2. After each group of 5 loops of Lowe's algorithm, a new matching is done in the same conditions. This procedure is stopped when the number of matched model edges becomes constant. At the end the final attitude of the model gives the attitude of the robot at the present step.

For summary, the modules involved during the localization procedure by monocular vision are :

- at the initial step : modules M1 and M2,
- at any other step : firstly, module M3, secondly, module M4 which uses module M2.

Figure 7 gives a result obtained with module M4. The number of matched model edges is 19, and the mean error which is the mean distance of the projection of the extremities of the matched model edges to the support line of the matched image segments, is less than 1.5 pixel.

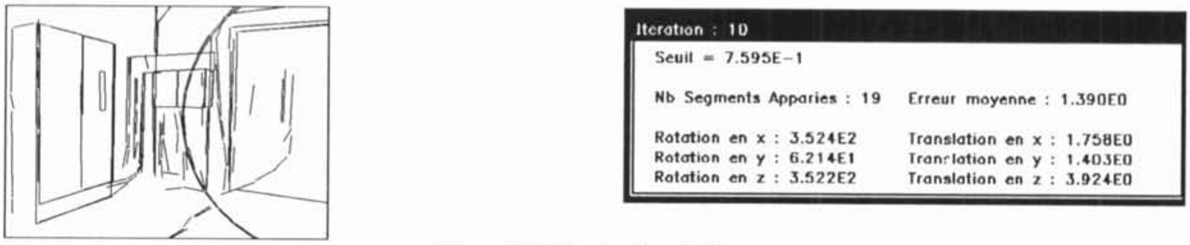


Figure 7. Refined point of view.

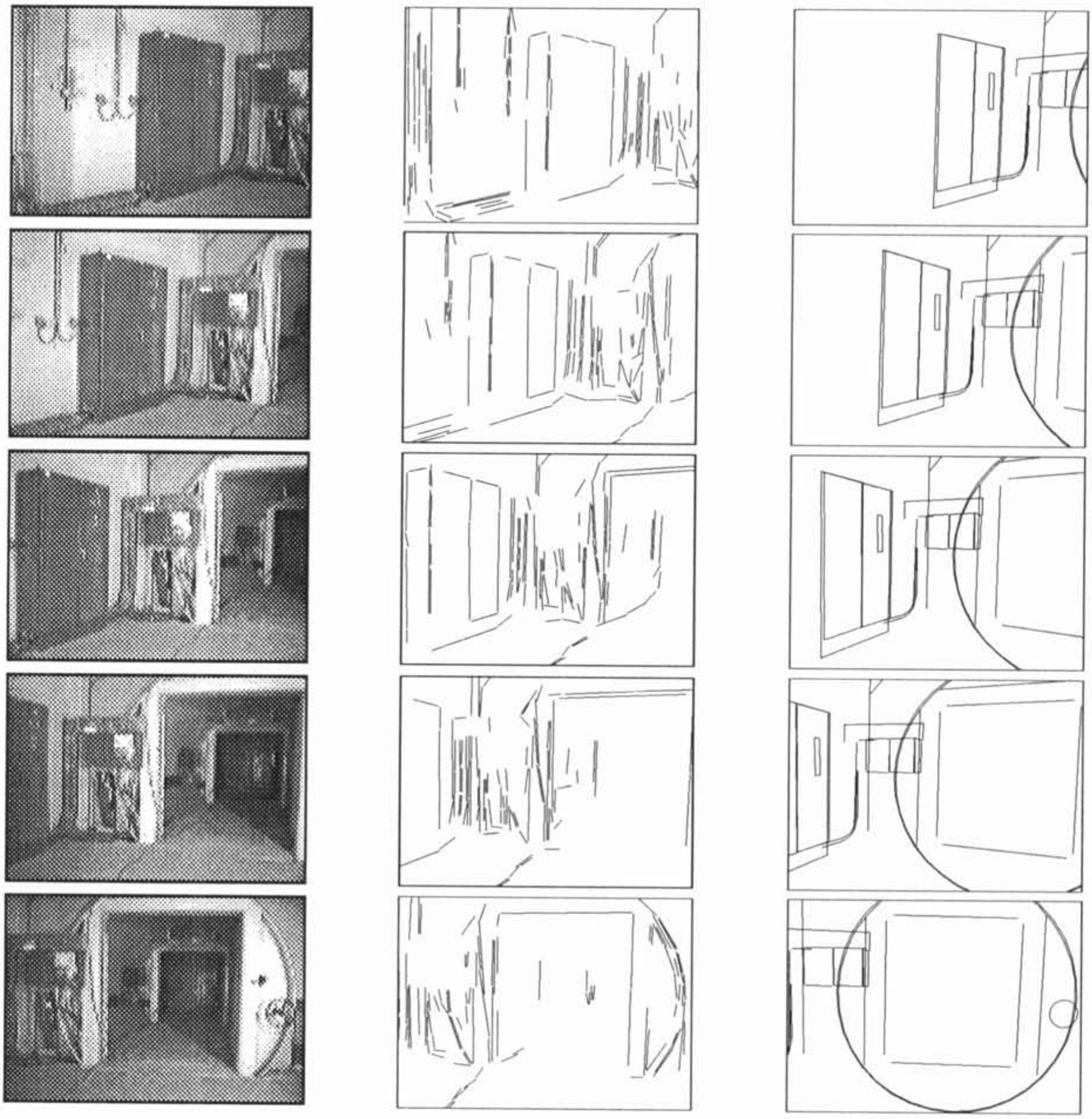


Figure 8. Localization results during a simulated "run" of the robot.

EXPERIMENTAL RESULTS

Figure 8 presents the localization results obtained for a sequence of 5 images. The images of figure 1 are the 2nd and the 3rd ones of the sequence. The images of the central column shows the extracted polygonal contours, and those of the right column, the projection of the model using the calculated attitude parameters.

At each step, the relative displacement has been evaluated by taking 75% of the difference between the initial and final values of each space attitude parameter. The number of matched model edges was respectively 15,18,20,17 and 31.

Despite the complexity of the images and the simplicity of the scene model, it can be observed that the localization problem has been successfully solved during a simulated navigation of the robot.

CONCLUSION

This work makes explicit the use of a geometrical model of the environment where an autonomous robot has to move, to locate it by monocular vision. The space attitude of the robot is accurately derived from a matching, even partial, of this model and of the scene image at each step. This results from a tridimensional interpretation of straight segments of the image contours, only possible if a geometrical model of the scene is available. This restriction is not strong in case of industrial sites whose structure is generally known or can be obtained by modelization from 3D data. The model which has been used here was determined in this latter way.

Improvements are in progress at this time : 3D interpretation of other geometrical features [DHO-90b] [RIC-90], less combinatorial procedure to find the point of view after a move by taking into account more restrictive matching conditions [HOR-89].

An next important aim will be the automatic localization of the robot at the initial step which is partly manual in the present state of the ULYSSE software. We intend to implement dynamic vision in order to get 3D information from a sequence of images.

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