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Mobile Robot Global Localization Using Just a Visual LandMark

Armida González Lorence[1,2], Mayra P. Garduño Gaffare[2] and J. Armando Segovia de los Ríos[2,3]
[1] Instituto Tecnológico de San Juan del Río
Av. Tecnológico No. 2 CP. 76800, San Juan del Río, Querétaro

[2] Instituto Tecnológico de Toluca
Av. Inst. Tec. s/n, Metepec, Edo. Tel. 01(722) 212-3197
[3] Instituto Nacional de Investigaciones Nucleares
Apdo. Post 18-1027, México, D. F. Tel. 01(55) 532-97-200

ABSTRACT

In this paper, is presented a mobile robot localization vision system that uses only just one artificial landmark, which is supported with the results of a strong analysis of diverse significant concepts of projective geometry.

Is widely known that even though a very promising matter for robot localization is the vision area, it has its weakness because the images are deformed due to the perspective view of the camera used, but with the system obtained with this investigation that uses projective geometric properties in the landmarks, it is possible to improve an adequate mobile robot localization. In this way, with the presence of just one landmark in the analyzed scene and with the support of its perspective views it is possible to obtain a satisfactory absolute localization of the mobile robot.

KEYWORDS: LandMark , Mobile Robot, Projective Geometry, Localization.

1 INTRODUCTION

In this paper is presented a novel visual system that uses just one landmark to evaluate the global localization of a P2-DX mobile robot [19] that uses as sensor only a PTZ CCD camera (Charge Coupled Device) [23].

Precedent researching works [1, 2, 3, 4] require the use of three or at least two Artificial Landmarks to improve the mobile robot localization. Additionally these Landmarks have to be distributed in the scene in an appropriated way [5, 6] and also have to be well selected [7, 8] to make an adequate localization [5, 6] of the mobile robot.

Due to the difficulty of doing a good selection of the landmarks involved in the localization process there exist other works [7, 8] that have propose the use of these landmarks but also combined with the use of other technologies as laser range finders [12], sonars [9, 10, 11], laser lines [17, 18] or ultrasonic and infrared sensors [13, 14, 15, 16].

In this work is evaluated the global localization of a mobile robot using a visual system, but to avoid the difficulties previously mentioned [5, 6, 7, 8], in this work it is needed the presence of just one passive landmark [1].

It is known, by the study of the past works [13, 14, 15, 16, 20], that it is impossible to acquire the robot configuration if it isn't use any other support, that's why, this research includes a strongly study of projective geometric proprieties [21, 22] applied the landmark design to obtain an adequate robot localization.

2 THE GEOMETRIC PROJECTIVE SUPPORT

In the Euclidean Geometry there are several proprieties that do not change under transformations [12, 24]; however, in the perspective views of an image process, the lengths and angles change and the parallel lines may intersect.

The Projective Geometry model well the imaging process because certainly there are not lengths, angles or parallelism preserved but the projective transformations preserve types (points remain points and lines remain lines), incidence (whether a point lies on a line), and also preserve the measure called Cross Ratio [24] .

The Cross Ratio is a ratio of ratios of distances; it is always preserved and is therefore a very useful concept for our project. If there are given four collinear points p_1, p_2, p_3 and p_4, where the Euclidean distance between two points p_i and p_j is denoted as Δ_{ij}. Then, the definition of the cross ratio appears in the equation 1.

$$Cr(p_1, p_2; p_3, p_4) = \frac{\Delta_{13}\Delta_{24}}{\Delta_{14}\Delta_{23}} \quad (1)$$

To improve the Cross Ratio it has to be selected a point p_1 as reference point and then compute the ratio of distances from that point p_1 to two other points p_3 and p_4; and then compute the ratio of distances from the remaining point p_2 to the same two points p_3 and p_4. The ratio of these ratios is invariant under projective transformations.

The Euclidean distance between two points $p_i = [X_i, Y_i, Z_i]^T$ and $p_j = [X_j, Y_j, Z_j]^T$ is computed from the 2D Euclidean points (equation 2) obtained by dividing by the third coordinate:

$$\Delta_{ij} = \sqrt{\left(\frac{X_i}{Z_i} - \frac{X_j}{Z_j}\right)^2 + \left(\frac{Y_i}{Z_i} - \frac{Y_j}{Z_j}\right)^2} \quad (2)$$

Independently of which coordinate is use as divisor (but always the same) the Cross Ratio is the same. However, the value of the Cross Ratio is different depending or the order chosen for the points involved, but once chosen one order, the Cross Ratio is always the same for that selected order.

Not surprisingly, since the lines and points are dual, there exists an equivalent Cross Ratio for lines and it is defined on four lines which are incident in a single point, also called pencil of lines [24], it can be computed by replacing the Euclidean distance between two points with the sine of the angle between lines. The cross ratio for lines will be the same no matter which line is used as reference, but one selected an order between the lines, it has to be preserved in the same way that was in the cross ratio for points.

Is imperative have knowledge of it is not required that the original points be collinear.

The cross ratio of lines is defined in terms of the angles between the four lines (see equation 3).

$$Cr(l_1, l_2, l_3, l_4) = \frac{\sin\alpha_{13}\sin\alpha_{24}}{\sin\alpha_{23}\sin\alpha_{14}} \quad (3)$$

Many areas of the computer vision have little to do with the projective geometry, but in some specific areas like camera calibration, scene reconstruction, image synthesis and object recognition the projective geometry is a mathematical framework much important in computer vision.

In this work are applied projective geometry's proprieties in the navigation process of a mobile robot, in order to evaluate the localization of the robot with respect to one artificial landmark of well known proprieties; those properties are well identified by involving in the localization process the projective geometry cross ratio property. By the use of that property it is possible identify the real position of the characteristic landmark points.

3. THE ARTIFICIAL LANDMARK DESIGNED

The design of the artificial landmark here proposed (see figure 1) was inspired from the work presented in [3], and also, here is considered that in [2] was mentioned that “if the landmark characteristics are efficiently recognized, then the artificial landmarks can develop an impressive geometric localization”.

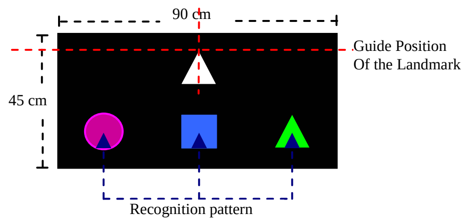


Fig. 1. Artificial landmark design, pattern figures area=63 cm^2 each, Euclidian distance between pattern figures centroids=23 cm.

The general color of the landmark is black which is a color of easy recognition in an office ambient; the landmark has a rectangular form which is deformed when it is appreciated from a perspective view [12, 21, 24, 25, 26].

The landmark size is adapted to be easily identified and for easy placement on flat surfaces (e. g. walls), it is tied to the horizontal vision field of the camera used and to the landmark location method used [27]. With all this, the robot’s camera always sees, at least, one artificial landmark, enough for the localization method here presented.

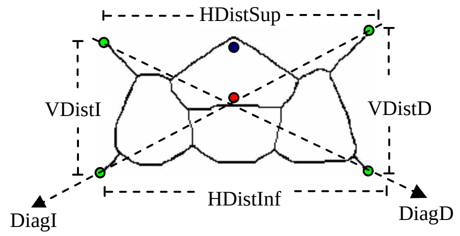
Each landmark contains a recognition pattern formed by a set of three geometric figures easily recognizable [23]; this pattern increases the reliability of the landmark identification process due to its horizontal orientation and the proportion of its areas; this pattern also helps to evaluate the robot orientation with reference to the landmark [21, 24].

There exists a database named "*Code Table*" with a one to one relation between each recognition pattern and a specific configuration (x, y, θ) of the associated metric map (see Fig. 2), in order to obtain the absolute configuration of the robot.

With this artificial landmark design it is possible to correct odometer deviations [8, 28] that any mobile robot accumulates during its navigation process.

3.1. The landmark properties

In the figure 2 are shown the landmark's special proprieties that allow obtaining the information that will be used to improve the robot localization.



	Position Guide
	Central point
	Extreme points
HDistSup	Superior vertical distance
HDistInf	Inferior vertical distance
VDistI	Left vertical distance
VDistD	Right vertical distance
DiagD	Right Diagonal distance
DiagI	Left Diagonal distance

Fig. 2. Characteristics extracted from the landmark

3.2. Information extracted to applied in the Cross Ratio property

Initially, previously to the mobile robot localization process, the camera has to be calibrated [23, 29]. In such camera calibration process are obtained the focal distance and *r1*, *r2*, *r3* and *r4* distances to the landmark. The distances *r1*, *r2*, *r3* and *r4* correspond to four vectors that go from the initial robot's configuration (0, 0, 0) to each point p_1, p_2, p_3 and p_4 of the landmark (see figure 3), also there are evaluated the three vectors (vectors painted in green in figure 3) that converge on each point p_1, p_2, p_3 and p_4. And finally the cross ratio of each group of green vectors that converge to *r1*, *r2*, *r3* and *r4* are also calculated.

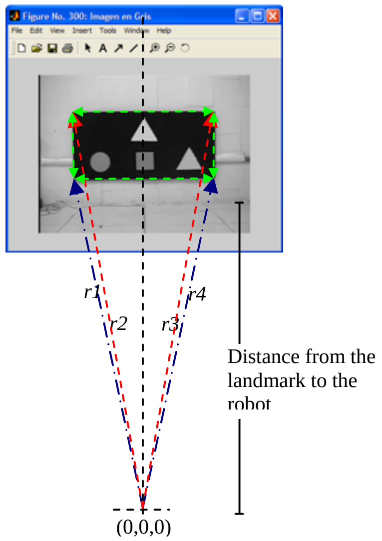


Fig. 3. Initial position of the robot (x=0, y=0, θ=0); *r1*, *r2*, *r3* and *r4* vectors

4. ROBOT'S LOCALIZATION ALGORITHM

The algorithm to evaluate the robot's global localization initially evaluates the robot orientation and then the robot position.

3.3. Orientation evaluation

Unlike the situation depicted in figure 3, where the robot's orientation coincides with the normal landmark, if the orientation angle changes, the view of the artificial landmark acquires a deformation (see figure 4) such information is used to evaluate the current robot's orientation with respect to the artificial landmark perceived at the moment.

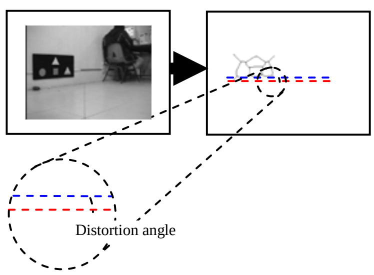


Fig. 4. Artificial landmark distortion

With the perspective deformation of the landmark is obtained the information (*HDistSup*, *HDistInf*,

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VDistI, *VDistD*, *DistDiag* and *AngVision*) used in the localization algorithm to acquire the robot orientation as it is illustrated in figure 5.

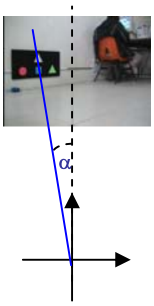


Fig. 5. Landmark perspective view with angle relation

3.4. Robot position evaluation

The figure 6 illustrates the geometric fundament of the algorithm. It is possible to recognize two triangular structures that are pointed towards the vectors *r1* and *r3* and are formed by the two oriented segments: $r1=[p1, p2, p4, VDistI, HDistInf]$ and $r3=[p3, p2, p4, HDistSup, VDistD]$.

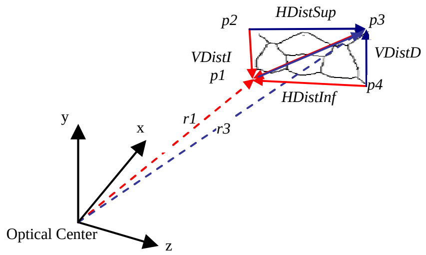


Fig. 6. Geometric fundament

With the points p_1, p_2, p_3 and p_4 defined in the artificial landmark and admitting certain system restrictions, the solution sensibility notably decreases and increases the measure range of *r1*, *r2*, *r3* and *r4*. These restrictions essentially imply the "a priori" knowledge of the artificial landmark geometry and the restriction of the camera pan and tilt angles, both to 0.

The physical geometry of the landmark is well known as was specified in section 3, and as mentioned before in section 3.1 it was extracted the image landmark geometry, so that the distances *VDistI*, *VDistD*, *HDistSup*, *HDistInf* and *DistDiag* and the points p_1, p_2, p_3 and p_4 are known; then, if it is applied the projective property of the Cross Ratio [21, 22, 25], where the distance proportions are kept, it is necessary to deduce only the values *r1* and *r3* where it is known only one of the points that conform these distances, these points correspond to p_1 and p_3 respectively. The following algorithm is derived from these considerations:

mr1= calculate_slope (p_1, UnknownLocation(x,y));
mVDistI= calculate_slope (p_1, p_2);
mDistDiag= calculate_slope (p_1, p_3);
mHDistInf= calculate_slope (p_1, p_4);
ang_r1_DistDiag= calculate_ang(r1,DistDiag);
ang_VDistI_HDistInf= calculate_ang(VDistI,HDistInf);
ang_VDistI_HdistDiag= calculate_ang(VDistI,HDiag);
ang_r1_HDistInf= calculate_ang(r1,HDistInf);

The computations developed before are used to obtain the Cross Ratio of the pencil formed with the lines *r1*, *VDistI*, *DistDiag* and *HDistInf*; the partial result that can be obtain until this moment is presented in the equation 4, such result depends of the unknown values (x,y) that correspond to the camera location, note that the rest of the values are known.

$$Cr1=\frac{Sin\left(\tan^{-1}\left(\dfrac{mDistDiag-\frac{p1.y-y}{p1.x-x}}{1-\frac{p1.y-y}{p1.x-x}\times mDistDiag}\right)\right)\times Sin(\alpha(mDistVI\_mDistHI))}{Sin(\alpha(mDistVI\_mDistDiag))\times Sin\left(\tan^{-1}\left(\dfrac{mDistHI-\frac{p1.y-y}{p1.x-x}}{1-\frac{p1.y-y}{p1.x-x}\times mDistHI}\right)\right)} \quad (4)$$

After that, obtain the Cross Ratio of the pencil formed with the lines *r3*, *VDistD*, *DistDiag* and *HDistSup* with the next computations:

mr3= calculate_slope (p_3, UnknownLocation(x,y));
mVDistI= calculate_slope (p_3, p_1);
mDistDiag= calculate_slope (p_3, p_2);
mHDistInf= calculate_slope (p_3, p_4);
ang_r3_HDistSup= calculate_ang(r3,HDistSup);
ang_DistDiag_VDistD= calculate_ang(DistDiag,VDistD);
ang_DistDiag_HDistSup= calculate_ang(DistDiag,HDistSup);
ang_r3_VDistD= calculate_ang(r3,VdistD);

Again, a partial result presented in the equation 5 is obtained, also such result depends of the unknown values (x,y) that correspond to the camera location and the rest of the values are known.

$$Cr3=\frac{Sin\left(\tan^{-1}\left(\dfrac{mDistHS-\frac{p1.y-y}{p1.x-x}}{1-\frac{p1.y-y}{p1.x-x}\times mDistHS}\right)\right)\times Sin(\alpha(mDisDiag\_mDistVD))}{Sin(\alpha(mDistDiag\_mDistHS))\times Sin\left(\tan^{-1}\left(\dfrac{mDistVD-\frac{p1.y-y}{p1.x-x}}{1-\frac{p1.y-y}{p1.x-x}\times mDistVD}\right)\right)} \quad (5)$$

The equation 5 represents the cross ratio of the pencil of lines that form the superior triangle of figure 7, in addition as previously mentioned, values *Cr1* and *Cr3* are known, because they were obtained after the calibration process, therefore if these known values are replaced in both equations (equations 4 and 5), then there are two equations (4 and 5) with just two unknown values (x and y), if this two equation system of two variable values is resolved then can be obtain the real values x and y that correspond to the position of the robot's camera with respect to the artificial landmark.

4. EMPIRICAL RESULTS

The figure 7 shows the user interface (a) of the visual robot localization system and the robot's environment (b).


(a)

(b)

Fig. 7. User interface (a) and robot's environment

The figure 8 shows that the artificial landmark is identified by the visual system in any situation of light, point of view or size.

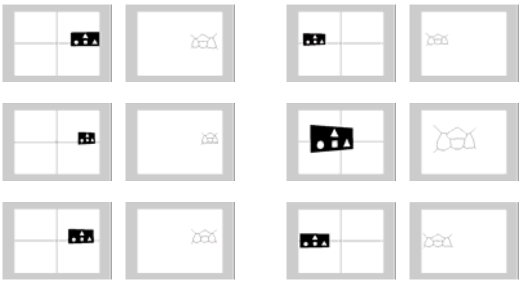
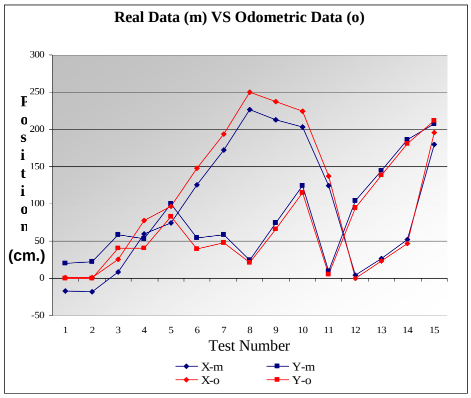


Fig. 8. Artificial landmark identified by the visual system

The figure 9 shows a sample of fifteen selected results that demonstrates that, the robot localization that is acquired with past works [8, 28] that use only odometer localization differs more of the real physical measure (a) than the data evaluated with this new system (b).

In the figure 9 (b) can be seen only the red results (evaluated data) that correspond to the real data, due to the similarity with the blue ones (behind the red ones), this figure demonstrates the efficiency of this new algorithm.

a)


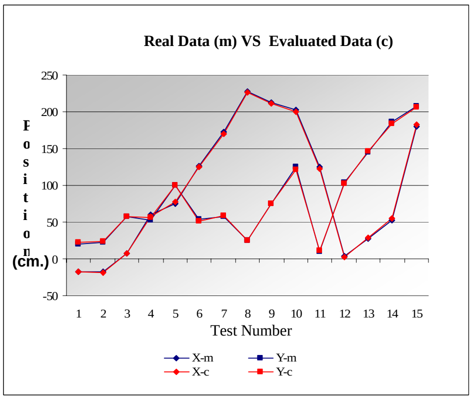
b)


Fig. 9. Graphical representation of results obtained in selected tests

CONCLUSIONS

In this work is assumed that the image distortion has relevant importance to successfully recognize symbols and figures; that's why here are used some proper concepts of the projective geometry to increase the robot's ability to recognize deformed figures by offering some knowledge of perspective perception.

The purpose was to make that the mobile robot could recognize deformed figures, right like the human beings do.

Because of this research, now there exists a new visual localization system that uses only one landmark to localize a mobile robot, that applies successfully basic concepts of the projective geometry and that could be applied to any mobile robot that has a vision system.

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