Abstract
The aim of this work is to determine the best landmark for its use in tasks such as precise positioning of AGVs or mobile robots in front of loading / unloading areas. The work developed aims at determining the precision that can be achieved with different pattern landmarks, of use in positioning systems, based on computer vision. Different computer vision algorithms have been tested from the images acquired from different camera configurations and bending angles with respect to the vertical axis. As a result of the evaluation of these errors, we extract the recommendation of the most favourable bicolour pattern to be used, as well as the bounding errors obtained from the segmentation and recognition methods most frequently used.

1 Introduction
Landmarks are frequently used both, for autonomous vehicles navigation and mainly in dead-reckoning operations, to reduce the positioning error when the vehicle is reaching its final goal. The methods most frequently used for landmarks detection and location are based either on laser detection systems, to measure the distance between the mobile and the target, or vision systems based on the detection and recognition of a given pattern. The landmarks are normally constituted by synthetic patterns.

We can distinguish two main kinds of patterns depending on two facts, whether they have to be used for absolute vehicle positioning, or they are designed to reposition the vehicle with precision with respect to a known reference location. In the first case the use of coded patterns enable the system to recognise some given absolute positions. In the latter case it is not necessary to rely on coded patterns since it is only necessary to detect the incremental error, that is, the deviation from the desired vehicle pose.

The study of the most adequate landmarks for robotic applications has been extensively discussed in the literature. In [1] the problem of viewing the image from different camera configurations is dealt with by designing a self-similar landmark pattern, bar-code like. The coded pattern design is conceived to be reliable even with some occlusions. The methods for landmark identification have also been a research topic, to select the most adequate patterns from a "natural" environment. Working in this direction, in [2] a landmark extraction and recognition framework based on projective and point-permutation invariant vector is described. The problem of adequately placing the landmarks in the environment to be identifiable, at least one at a time, by the mobile robot during its autonomous navigation, is tackled in [3]. The landmarks patterns and their location is also discussed in [4]. The discrimination of landmarks in environments with heterogeneous multi-robot system is described in [5].

The problem of tracking a landmark to position a vehicle and guiding its movement is dealt with in [6]. In this work the mark normally used on the back of vehicles in factories is used as a target to be tracked by another autonomous vehicle to form a convoy. With this strategy a convoy is formed from different autonomous vehicles joined by virtual, visual, links. This positioning principle, the detection of the deviation of a given mark with respect to the expected vehicle point of view, is extended for its use in helicopters. The vision system is used as a visual odometer [7].

This paper describes the study of the precision that can be obtained using different, non-coded, generic patterns. The aim is to determine the best landmark pattern for precise mobile robot positioning in applications such as loading and unloading. The usefulness of landmarks for such applications has motivated the study of the most adequate patterns. In [8] a study of the best shape of small fiducial marks for use
in parts positioning in an industrial process, optical lenses manufacturing, is described. In that application much emphasis was given to the size of the uncoded mark. The present work is oriented to find the most adequate mark without this size constraint.

2. The patterns considered

There is a wide range of marks commonly used in manufacturing and in storing / retrieval processes, used either in manual or autonomous robotic systems. Fig. 1 shows some of the most frequent marks used.

![Fig. 1 Some common landmarks used in factories](image)

In this work we have selected a set of them, which potentially can provide more precision in their location. Consequently better vehicle positioning can be obtained. Fig. 2 shows the four reference patterns evaluated and their complementary colours. These patterns have in common their separability from the background. In the former two, those with concentric structure, the precise position of the pattern centre point is not influenced by the noise that is normally produced in the segmentation process due to the background visible elements. This is due to the effect of the external circle that bounds the internal shape without ambiguity. On the other side, the geometry of the two later patterns, those having radial structure, is also insensitive to the background noise.

![Figure 2 Landmarks evaluated. a) original colours, b) complementary colours](image)

3. Landmarks detection and tracking

The study of the optimal landmarks starts with the detection process, followed by the location techniques and the analysis of the theoretical errors, which are afterwards evaluated by experimentation. This experimentation has been performed in a laboratory test bed as well as on a real environment.

3.1 Landmarks detection

The detection of the landmarks over the scene requires an algorithm able to detect the zone in the image where a landmark pattern can be found. Since the patterns used present the maximum image saturation, black and white, they appear with a significant contrast in the images. Additionally, and taking into account that the cameras are located in fixed positions in the reckoning area, the imaged landmarks will always have a known size. Therefore, the segmentation algorithm can use an observation window, adequate to the size of the pattern, that sweeps the whole image to locate the candidate landmark patterns. The positions in the image where the searching windows extract a bipolarised histogram verifying some predefined thresholds are considered to correspond to landmark candidates.

After the selection of the landmark candidates a second algorithm processes the binarised image, detects the central point of the areas that constitute the pattern and a further post-analysis of the candidate image areas finally verifies whether the segmented area can correspond, or not, to one of the patterns.

3.2 Landmarks location

A 3D location vision system is used in order to avoid the problem of viewing patterns with different sizes when the environment is composed of heterogeneous mobile robots or reference positions at different heights, as well as to compensate the vehicle height changes due to the possible variable load.

The location of the pattern in each camera image has been achieved by using two methods. The first one is based on the calculation of the centre of gravity of the segmented areas, while the second is based on the correlation with the geometrical model of the corresponding pattern. The method considered for each pattern has always been the one that has provided the best landmark location. As was previously foreseen, the patterns having a concentric structure have been detected more precisely when using the centre of gravity method, from the central elements. On the contrary, when the patterns having radial structure are used, correlation provides better results.

The fact that there are landmarks both on the vehicle and on the reception area enables us to perform a continuous recalibration of the cameras used in stereovision.

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The calibration consists of determining the \( x_0, y_0, \theta \) co-ordinates of the reference frame corresponding to the loading/unloading point, from the central point position \( x_1, y_1 \) and \( x_2, y_2 \) of the landmarks located over the arrival docking area.

### 3.3 Tracking

Once a pattern has been located over the scene, it is tracked by the tracking window. In the proposed application the precise positioning of a vehicle in front of the loading/unloading port is attained using landmarks. With the aim to reduce the relative position error some patterns are placed over the vehicle, while others, those that define the docking area, are placed in pre-defined reference positions.

The patterns placed in pre-defined positions, in this case the loading/unloading areas, remain static, while those located in the mobile robot change their position according to the vehicle trajectory.

The experimental environment is shown in fig. 3. It shows a typical loading/unloading process, an AGV feeding a machine. The landmarks on the vehicle and on the loading/unloading zone are visible during the vehicle manoeuvring. They are placed in such a way that they can be located by a pair of zenith cameras. Fig. 4 shows the segmented image, where the detected landmarks are shown within their respective tracking windows.

### 4. Errors as a function of geometrical parameters

The evaluation of the patterns, to determine those providing better precision, has required the design of a test bed for experimentation. The test must consider the effects of the pattern bending angles that generate perspective distortion of its shape, and can consequently affect its reliability. This distortion is due to the possible non-absolutely horizontal vehicle positioning and to the angle formed by the camera optical axis and the field of view.

In the experiment, the patterns are located in a known position in front of a pair of stereo cameras. The baseline of the stereo cameras can be modified precisely to change the disparity between the stereo images, and thus to determine the effects of the cameras configuration for every pattern.

With this experimental platform, the evaluated pattern is bent from 0 to \( \pm 90^\circ \), with respect to the axis perpendicular to both, the baseline and the optical axis. A set of images are acquired during this bending movement of the pattern. The centre point of the pattern is calculated for every acquired image and its location is compared with the real one. In this way, the location error is measured in a wide range of different viewing angles.

This process is repeated for each of the six proposed patterns and for different baselines. In the experimentation the diameter of the digitised landmarks is 50 pixels. With this resolution, fig. 5 shows the mean absolute position error obtained for the different patterns under test, varying for each one the bending angle and the baseline. In this figure, the ordinate axis is
represented in pixels, thus all the considered landmarks produce errors at the sub-pixel level.

These results have to be considered as a landmarks comparative study, so as to decide the best landmark to be used more than to obtain quantitative results, that are highly dependent on the system configuration.

The results obtained are not surprising since the position of the centre of the pattern is only explicitly defined in the patterns with a radial structure, and the definition of this central point is not affected by the periphery segmentation errors. The results show that the simpler of these two kinds of patterns is better. On the other hand, among the patterns with concentric structures, those providing better results are the ones whose segmentation allows them to operate with a bigger area. This is due to the fact that the computation of the centre of gravity gives a statistical value, an averaging value, that works better the higher the number of image points considered.

Let $\varepsilon_l$ and $\varepsilon_r$ be the location error of the pattern c.o.g. in the left and right image respectively. Let $D$ be the disparity of these c.o.g. Then, the relative error in the distance measure can be written as:

$$\frac{\varepsilon_z}{Z} = \frac{\varepsilon_l + \varepsilon_r}{D}$$

Theory recognises that the increase of the baseline improves the resolution but reduces the admissible bending angle of the pattern. The tolerance on the value of this inclination is evaluated from the experimental results. It is seen that the error is maintained very low in a range of angles between $\pm 30^o$, when working with baselines higher than 0.5 z.

The errors were computed experimentally using the best pattern. The resultant errors were 0.25 mm, operating over a working area of 50 x 50 cm and having the cameras located at a height of 2 m. The experimental error is less than the theoretical one when using the patterns with radial structures. On the contrary, when working with the concentric patterns, the experimental error is closer to the theoretical one due to the fact that the imprecision on the segmentation of the peripheral zone affects the computation of the patterns centre point.

Once the most suitable model was found, a theoretical study has been carried out to determine the effects of the error in the location of the centre point of the pattern, as well as the influence of the bending angle. These factors affect the measure of the distance from the landmark to the camera, the $z$ value. The different curves are computed operating with camera configurations where the baseline, $d$, is a given fraction of $z$, within the range of ratios: $0.1 \leq d/z \leq 0.9$. Fig. 6 shows the errors obtained as function of the pattern bending angle. These results can be used to determine the most suitable distance between the pair of stereo cameras, given a range of possible pattern-bending angles.

It is well known that the accuracy of the measure of distances, or depth, in stereo vision is directly related to the addition of the location errors of the two conjugated points in the left and right images, and inversely related to the magnitude of the measured disparity.

5. Results

The system has been tested with an AGV fleet. With the available vehicles the landmarks centre point can be located at a distance of 52 cm from one to each other, and the landmarks over the docking belt can be placed at a distance of 64 cm. The cameras are located on the ceiling, at a 3.20 m height and with a baseline of 80 cm.

With this configuration we got the best positioning results when the vehicle is located in the middle between the two stereo cameras. The error map shown in fig. 7 represents the data obtained for the different vehicle positions in the reckoning area.

These results show that the relative position of the vehicle with respect to the port produce localising errors
below the values required to ensure a correct loading/unloading procedure.

Using the different evaluated patterns it has been observed that with the best of them a precision with a ratio 3 to 1 with respect to the very common pattern with concentric structure is obtained.

![Error map obtained when the vehicle manoeuvres under the pair of stereo cameras](image)

**Fig. 7** Error map obtained when the vehicle manoeuvres under the pair of stereo cameras

### 6. Conclusions

The optical localizers used by the autonomous AGVs, that are necessary to cancel the odometric errors or to improve the limited resolution of a GPS, for dead reckoning operations, enable us to achieve resolutions better than 2,5 mm using camera configurations with d/z ratios higher than 0,3. This performance makes this sensor suitable for both indoor and outdoor environments.

In this paper different patterns have been experimented with and the results of the experimentation on their location errors have been compared with the theoretical ones. This study has shown that not all of them give the same location errors, but that the most advantageous are those formed by circular sectors, and specially those formed by 4 quadrants. The error obtained using this pattern is much better than that obtained using concentric patterns. In general, it has been observed that the real errors obtained are slightly lower than the theoretical ones. This is due to the fact that the theoretical value is computed for the most adverse situation.

### References


