

Using Barcodes for Robotic Landmarks

Armando Sousa^{1,2}, Catarina Santiago¹, Paulo Malheiros¹,
Paulo Costa^{1,2}, António Paulo Moreira^{1,2}

¹ FEUP – Faculty of Engineering, University of Porto, Portugal
Rua Dr. Roberto Frias, s/n 4200-465 Porto, Portugal

² INESC-P – Instituto de Engenharia de Sistemas e Computadores do Porto, Portugal
asousa@fe.up.pt, catarinasantiago@gmail.com, {paulo.malheiros, paco, amoreira}@fe.up.pt

Abstract. This paper presents an innovative vision “sensor”. The proposed method uses a vision system for recognizing distant barcodes. It is ideal for Real-Time Self Localization since the proposed algorithm uses light-weight processing of the image obtained by a multi-purpose vision system. The choice of the marker is discussed and the proposed solution uses the industrial barcode standard of Interleaved 2 of 5 to retrieve a measurement of relative position (x, y, z). The angle formed between the camera and the marker is obtained from the “perspective” of the seen image. The results section discusses the measurement data quality for the actual set of experiments. A maximum error of 0.2m was achieved for a camera of 1024x768 with a lens viewing angle of 60° and markers printed on a 14.8cm x 21cm plain paper for localization on a 4x4m world. Typical processing times are between 18 and 25 ms.

Keywords: Localization, Vision, Real Time Vision, BarCode.

1 Introduction

Autonomous mobile robotics is an important research area. True autonomy needs self localization, that is, a mobile autonomous system must find its own localization. Many real world robotic applications feature a semi-structured environment that is mostly unpredictable, possibly dynamic, but where some markers can be placed explicitly to allow robustness and accuracy in the complex task of robotic self localization. Frequent applications demand that the environment must be adequate for both humans and robots as they will share the same environment. This fact places constraints on what kind of markers are admissible for localization. Many other constraints exist for current day robotic applications like limited on-board computing power and Real Time constraints.

Most current robotic platforms feature vision systems because such systems are inexpensive and possess rich sensors from where a number of features can be extracted in the same measurement (a single frame from the image stream). Vision systems are also intrinsically safe to humans and allow for passive, easy to build markers. The task of Real Time image processing creates the need for careful design and implementation of the system hardware and the processing application.

1.1 Test Platform

The presented work is part of an experimental platform for a service cleaning robot, made of effective but inexpensive parts. The mentioned robot is shown in Fig. 1 and features a real consumer grade cleaning apparatus (pushed in front of the robot, yellow and black colours); the cleaning apparatus is passive, that is, the brushes spin upon the unit being pushed forward. Odometry for such a platform is even less reliable than in other applications because of variable friction forces to the ground - the spinning of the brushes on the floor causes the robot bump and twist occasionally. Self recovery from error situations makes clear the need of uniquely identifiable markers for sporadic global localization.

Fig. 1 shows the “CleanRob” platform. The robot features a differential drive, odometry and sonars sensors and a PC motherboard that uses firewire to link to the camera. The camera is meant to serve other purposes besides the localization method described. The robot is to perform autonomous cleaning missions in the faculty corridors that has significant dimensions (200 meters) and many hard-to-distinguish corridors (for additional information, visit the project's web site [17]).

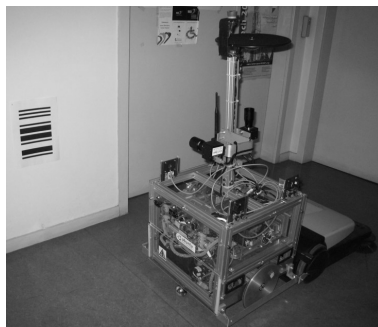


Fig. 1 Robot with front cleaning apparatus and a barcode sample of A4 size.

1.2 Objective

This work presents and characterizes an interesting, inexpensive, robust, and easy to implement global localization technique that uses a Real Time (RT) vision system. The proposed approach produces localization information adequate for RT self-localization on real mobile robotic platforms. The proposed methodology identifies markers and retrieves their relative (x, y, z) position. If the marker position on the world is known, then global localization is achieved.

The system is to be used by the “CleanRob” test platform presented in the previous section. The intent is to have a prototype for a real world autonomous service robot adequate for semi-structured environments of large complexity and size.

1.3 Structure

After the current introductory section that describes the test platform and the objectives, the second section addresses several works that are interesting and comparable to the one presented. The third section builds on the previously presented ideas to list some requirements that, in turn, justify the choices made for the marker design process and then the actual algorithm is presented. Section four presents actual experimental results that lead to the conclusions presented in the following section. Finally, some hints for future work are presented in the sixth and last section.

2 Related Work

The current section focuses on previous research that is related to (artificial) marker self-localization using vision based systems. The general overall goal is to gather as much information as possible from the seen image of the marker. The image is supposed to allow convenient (fast and real time) processing, robustness to false positives and provide accurate data.

Yoon & Kweon (2001) [15], [16] make use of colour image processing to find coloured markers. Scarce data is available about the precision of the resulting measurements but the method is tailored for small environments. This methodology is interesting because it tries to eliminate false positives by using colour combinations and seeks a number of different, identifiable markers.

A localization technique based on a pair of coloured rectangles is used by Jang et al (2002) [10]. The system uses colour processing and controlled pan and tilt to target the marker and minimize camera and lens distortions which is said to improve the accuracy of the measurements. Some results are shown on a 2.4m x 3m world with errors less than 20cm.

A feasible approach is to use industrial barcode readers to detect presence of markers. Distance reading is possible with industrial grade sensors but this technique has very limited usage for self-localization purposes as angles are unavailable.

Jörg *et al* (1999) [11] does, in fact, make use of barcodes to guide a robot based on the recognition but the authors don't present many results regarding the quality of the devised perception system but rather study the methodology of the readings.

Other approaches for visual markers include using coloured poles (Sousa et al. 2005) [13], balls, lines, corner lines, etc (Iocchi & Nardi 1999 [8]; Göhring & Burkhard 2006 [4]).

3 System Design

The proposed goal is to use a vision system to detect and identify markers and retrieve relative distance and relative angle of vision to the seen marker. If the camera is on-board the robotic system and marker's world position is known, then global localization information is available. Localization information has soft Real Time characteristics, that is, the usefulness of the information decays over time.

3.1 Vision System Hardware

The vision system is made by an Imaging Source Inc camera that is connected by firewire to the main board of the PC that consists in the brain of the robot. These cameras are adequate for real time measurements because they use very little internal buffering. The actual camera used is a DMK31AF03, with a resolution of 1024 x 768 pixels black and white camera where each pixel can have 256 grey levels.

3.2 Marker Design

Taking into consideration the application mentioned in the first section, the robot is to self-localize in a world of relatively large dimensions with a large series of hard to distinguish corridors and hallways. The idea of adding localization markers to the environment seems an interesting solution for current day real world autonomous robotic applications. The design of the marker structure itself must be carefully selected in order to solve the problem of localization adequately (Yoon & Kweon, 2002 [15], [16]).

Based on the experience taken from the robotic platform presented earlier, the marker design should be based on the following identified requirements: passive, inexpensive, unobtrusive (thin, etc.), human safe (eye safe, etc.), provide quality information, adequate for RT detection using the vision system and for reading with low computational cost, easy implementation (high repeatability) and deployment, standardized shape, provide robust measurements and allow for “many” different, identifiable, markers.

As mentioned earlier, colour image processing is prone to having problems with lighting changes and colour decaying through aging. Real world applications have to deal with a variety of lighting conditions ranging from artificial lights to different colours of the sun (or sun passing through coloured shades, etc.).

A large number of markers are essential to make up for possible partial or total occlusion on a dynamical world of large dimensions.

The mentioned issues lead to the conclusion that the marker should simply be a printed sheet of paper with adequate Black and White coding. Industrial barcodes may be easily shaped in such a way. Such systems use ingenious and proven methods to encode simple numeric information that points to a very interesting solution. Ad-Hoc barcodes for localization have previously been used by Costa *et al.* (2001) [3] where a radial “bar” code is used in order to produce external localization (position and angle) of a number of identifiable robots.

3.3 Select Barcode Technology

There are a number of industrial barcode standards available. For simplicity and robustness, a well known, unidimensional encoding technique was used as a base for the proposed system. The encoding technique is known as interleaved 2 of 5 code (for general knowledge see Wikipedia_i2of5 [14]) as defined by ISO/IEC 16390:2007 [9], [7] and ANSI / AIM [1], [2] in the Uniform Symbology Specification (for additional

barcode knowledge refer to Pavlidis *et al.* 1990 [12]). The mentioned standard encodes a decimal number into bars that are easy to read with a linear optical scanner, even in the presence of slight misalignments. The proposed technique achieves dense information encoding yet retaining robustness and flexibility. The name of the code derives from the fact that each encoded digit uses 5 bars of alternating colour (black/white), each of which can be either narrow or wide. The standard also stipulates quiet zones, start sequence and stop sequence that allow calibration of the size of the bars, thresholds on how to identify narrow or wide bars and still provide a high level of immunity to noise and partial occlusion. An example of such encoding is shown on Fig. 2 (Fig. 1 also showed a barcode marker placed on the wall).

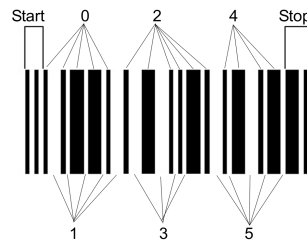


Fig. 2 Example of barcode showing individual digits for “012345” content

3.4 Application Strategy

Some elementary ground rules for Real Time image processing were obeyed in developing the measurement application such as zero copy and one pass processing. Only after all the processing is done, if time is still available, data is fed back to the user screen.

The goal of the image processing algorithm is to measure accurately and efficiently the relative position and angle to the top left of the barcode, as shown in Fig. 3.

3.5 Image Processing Algorithm

Vision systems produce a stream of images. In order to map bi-dimensional (u,v) image coordinates into real 3D world coordinates, the camera model has to be determined. The well known pin-hole camera model (Hecht, 2001 [6]; Gonzalez and Woods, 2007 [5]) is used to that purpose. There is also the non linear distortion commonly called barrel distortion that has to be modelled. Vision sensing systems include intrinsic and extrinsic parameters.

Intrinsic parameters to the vision system are: resolution, pixel size, focal distance, lens centre and barrel distortion. Extrinsic parameters are the position of the camera in the 3D world and the associated orientation angles. For simplicity, the camera is assumed to be in the origin, viewing axis aligned with x axis as shown in Fig. 3.

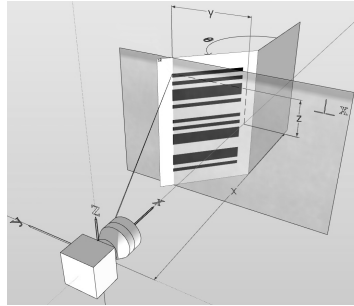


Fig. 3 Camera axes

The vision system model parameters were estimated using common calibration techniques that involve mapping real points in space and matching points on the screen and then optimizing model parameters.

For real world applications, it is interesting to use (inexpensive) wide angle lens that carry important distortion along the image. That distortion is called barrel distortion and a sample image is shown in Fig. 4.



Fig. 4 Test image showing barrel distortion (for the actual camera and lens used).

A few assumptions were made to speed up the barcode search: the barcodes are placed in a vertical wall with horizontal stripes, the camera horizontal optical axis is horizontal and the camera vertical axis is aligned with world vertical.

The full algorithm can be summed up as:

1. Cycle all the configured vertical *scan lines* to find *candidate regions* – a quiet zone followed by two elementary digits (n_1, n_2); if found a *candidate region*, then produce temporary additional *scan lines* for accuracy; for each *candidate region* with marker digits (n_1, n_2), keep start pixel and end pixel coordinates;
2. Group viable *candidate regions* into *markers* – for each of the found viable marker numbers (n_1, n_2), keep only the coordinates of the 4 outer corners;
3. For all *markers*, undistort the coordinates of the corners;
4. Calculate angles using pin-hole model and relative world distance and position using known marker dimensions;
5. Estimate angle information;

Additional information for these steps appears later on, in the current section.

The left image of Fig. 5 shows a barcode and configured scan lines (note that scan lines are more frequent in the interesting region) and the right image the grey levels for a single scan line, including the upper and lower bounds to allow for black/white threshold calculations. The actual threshold value is dynamically calculated to allow for shadows, etc..

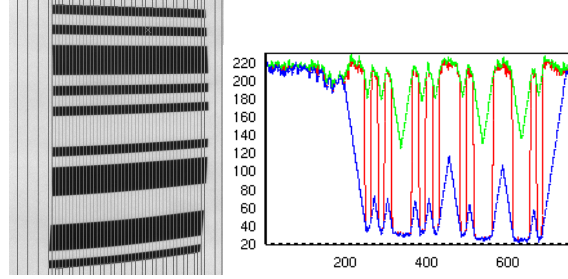


Fig. 5 Barcode maker and scan lines (left) and grey levels along one scan line (right)

The used code has a standard minimum quiet zone and a fixed start sequence that eases the recognition of a valid sequence of digits. The presented algorithm can be extended to accommodate for additional marker digits – to allow for a larger number of different marker numbers.

Once a *candidate region* is found, the coordinates of the barcode top left pixel (u_i , v_i) and bottom left pixel (u_b , v_b) are found, the world position, relative to the camera frame, of the barcode left point can be found. New coordinates (u_{tl} , v_{tl}) and (u_{bl} , v_{bl}) can be found applying the barrel un-distortion formula to eliminate the source of error.

$$\begin{aligned}
 \Delta_u &= u - u_c \\
 \Delta_v &= v - v_c \\
 d^2 &= \Delta_u^2 + \Delta_v^2 \\
 u_{nd} &= \Delta_u * (1 + K_b * d^2) + u_c \\
 v_{nd} &= \Delta_v * (1 + K_c * d^2) + v_c
 \end{aligned} \quad (1)$$

, where K_b is the barrel undistortion parameter; (u_c , v_c) is the centre of the lens that generates the barrel distortion; pixels of coordinates (u_{nd} , v_{nd}) make up an undistorted image from the original image.

Using equations (2) the world angles (α , β) of the half lines that start at the camera centre and pass over the points C_{tl} (u_{tl} , v_{tl}) and C_{bl} (u_{bl} , v_{bl}) can be found (see left image of Fig. 6).

$$\begin{aligned}
 \alpha &= \text{atan2}(I_w/2 - u, d_{eq}) \\
 \beta &= \text{atan2}\left(I_h/2 - v, \sqrt{(d_{eq})^2 + (I_w/2 - v)^2}\right)
 \end{aligned} \quad (2)$$

, where I_w and I_h are the image width and height; d_{eq} is the distance from the origin to the virtual image plane – these three parameters are intrinsic to the vision system.

The world position for point C_{tl} can now be found by

$$\begin{aligned} \Delta &= \tan(\rho_{tl}) - \tan(\rho_{bl}) \\ \Delta_\rho &= C_s / \Delta \\ \Delta_{xw} &= \Delta_\rho * \cos(\theta_{tl}) \\ \Delta_{yw} &= \Delta_\rho * \sin(\theta_{tl}) \\ \Delta_{zw} &= \Delta_\rho * \tan(\rho_{tl}) \end{aligned} \quad (3)$$

, where C_s is the marker vertical size (an input to this algorithm).

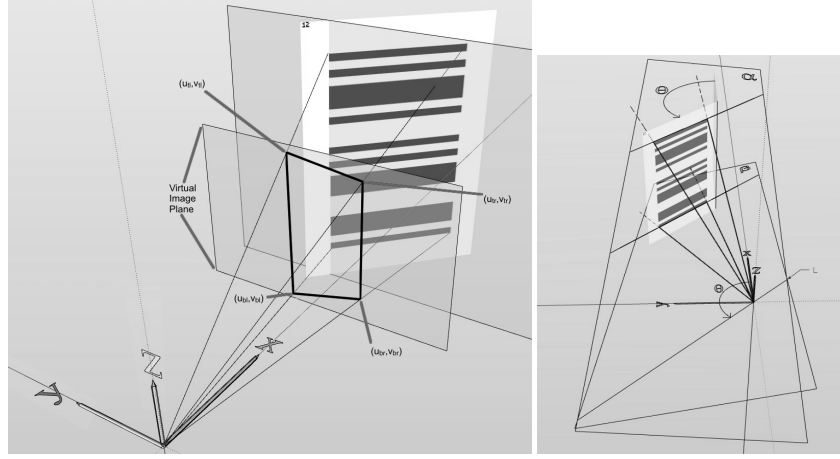


Fig. 6 Perspective of seen marker on virtual image plane (left image) and planes for angle estimation (right image)

To find the relative angle of vision between camera and barcode, “perspective” information is used. The planes α and β are defined by three points each: C_{tl} , C_{tr} and the origin for α and C_{bl} , C_{br} and the origin for β (see right image Fig. 6).

The intersection of these two planes is a line parallel to the line given by the intersection of the barcode plane and the horizontal plane. The angle between this line and the x axis gives us the barcode orientation. A vector v_l with the same orientation as this line can be found by

$$v_l = v_\alpha \times v_\beta \quad (4)$$

, where v_α and v_β are vectors orthogonal to the planes α and β .

Finding the estimate for the angle of the marker concludes the discussion of the algorithm.

4 Results

This section presents the experiments made and characterizes results.

4.1 Experimental Setup

The used setup is based on an Imaging Source DMK31AF03 camera with a resolution of 1024 by 768 with 256 grey scale levels. The camera with the fitted lens has a viewing angle of about 60 degrees with significant barrel distortion. The markers tested are simply sheets of paper with the barcode printed by a common consumer grade laser printer. The size of the marker (including mandatory quiet areas) is A5 (14.8cm by 21cm).

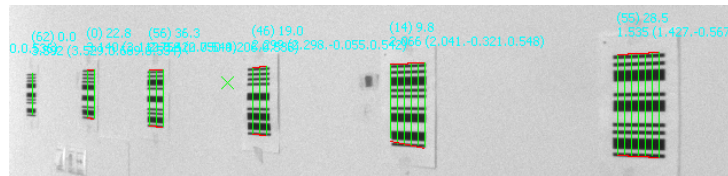


Fig. 7 Application showing 6 barcode markers with A5 size on the test wall

A partial screen shot from the localization application showing the image seen by the camera is on Fig. 7.

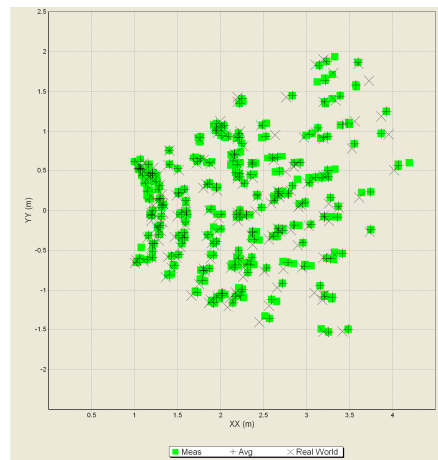


Fig. 8 Measurement dispersion for experiments: smallest and lighter arrows are individual measurements and intermediate sized blue arrows are the average of the readings; red arrows are real world poses.

Several barcodes are identified, from right to left, code numbers 55, 14, 46 and so on. Fig. 1 showed the robot with an A4 sized marker on the wall. To allow for

efficient data gathering the test landscape has 6 codes and the robot with the camera moves to several manually selected poses to gather data from the presented algorithm.

The robot is carefully hand placed with the help of measuring tools, such as civil constructor's laser line generators and a large size angle meter (a custom made protractor). Experimental data is obtained by moving the robot whilst the barcodes are always in the same position - the wall (as seen in Fig. 7). Each experiment has a different known camera position and angle such that barcodes are read at different relative distances and angles. For additional ease of interpretation of the data, the results are shown in the form of a camera situated at the origin and calculating the errors of the several seen barcodes.

Fig. 8 shows the global distribution of the entire set of results, also room space presenting limitations and consequences of the used methodology for data gathering.

Each experiment has its own robot pose and is 256 measurements were taken for each experiment. Each frame can have any number of seen markers but faraway markers may become unreadable typically due to the smallest bar of the marker becoming invisible. A total in the order of 22000 frames were analyzed and more than 80000 markers were found and measurements logged.

4.2 Analysis

Fig. 8 hints that accuracy for the proposed measurement is interesting. This fact can be further ascertained by Fig. 9 that presents the accuracy of the measurements taken as a function of the number of detected lines in a given marker measurement. For the tests at hand, the z position of the marker is known and is not useful for self localization. Some angle information is also available from the perspective of the seen image of the barcode.

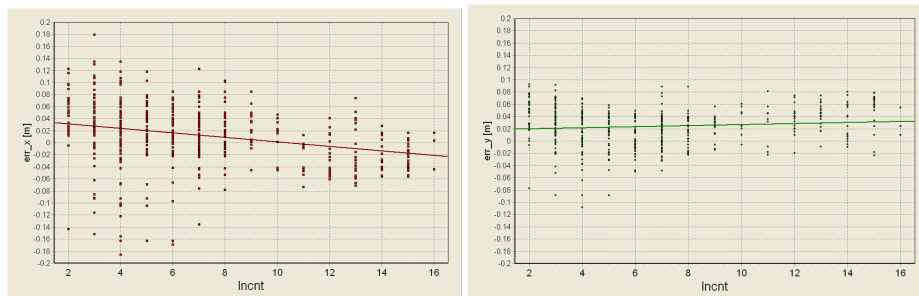


Fig. 9 Error in X over scan line counts (left) and error in Y over scan line counts (right)

For all measurements taken, the global accuracy of the proposed methodology is very interesting: all measurements have position errors in x less than 0.2m (over 4 meters), in y less than 0.11m (over 3.5 meters). Angle information is not as reliable and only 90% of the measurements have errors of less than 20° .

5 Conclusions

The presented work shows an innovative approach for landmark localization. The requirements that led to the development of the presented algorithm are discussed in detail because they are inspired in the operation of a real robotic testing platform.

The proposed methodology features inexpensive, unobtrusive, and simple to produce markers that carry numeric information. The presented system can handle 100 unique markers but the ideas presented can be easily extended to larger ranges.

Two applications were implemented: one produces the markers according to the industrial standard of Interleaved 2 of 5 barcode; the other runs in the embedded PC. Both applications can run in any common Linux distribution.

The system is naturally portable to other vision hardware but the used setup is based on an Imaging Source DMK31AF03 camera with 1024 by 768 resolution (256 grey scale levels) that connects via firewire link to a common PC motherboard with an AMD Athlon 3000+ MHz CPU. The camera with the fitted lens has a viewing angle of about 60 degrees with significant barrel distortion. The markers used for the experiments are simply sheets of white paper printed on a regular laser printer. The size of the marker (including mandatory quiet areas) is A5 (14.8cm by 21cm). The approach taken is to use Black and White image processing that is expected to handle well significant differences in lighting situations.

The test setup was a wall with 6 barcodes and the experiments were made moving the test robotic platform. During the experiments more than 80000 measurements were logged in an area of about 4x4m and the accuracy was always better than ± 0.2 meters. Most measurements (90 % of the times) have accuracy of ± 0.1 meter and ± 20 degrees. Any number of markers can be identified in a single image.

Processing times are around 18 ms and rise up to 25 ms when there are many barcodes candidates within the 40 scan lines. It is expected that the overall time lag from reality to result to be at most 0.07 second which is adequate for a normal paced service robot to be usable in real time self localization.

The proposed approach also detects the number encoded on each marker and by knowing the marker's world position, then, the presented system is able to do Global Real Time Self Localization as was stated initially.

6 Future Work

The quality of the measurements can be further improved with additional searching of the image, of course, at the expense of additional computing power/processing time.

Several techniques are to be studied further like implementing scan line adaptive density, get a better accuracy of the marker envelope using full sub pixel resolution and use a lens with a motorized zoom for additional precision.

Another issue is to study the effect of the rotation of the marker and other angular effects on the final accuracy of the measurements as well as the effect of shadows and alterations in ambient lighting in the accuracy of the measurements.

Taking into consideration that the final goal of the proposed approach is self-localization, it then appears that changing the marker size and shape will

probably impact heavily on the results so it would be interesting to test other marker sizes and derive a model for this kind of measurement. Additional work will also be dedicated to using data fusion techniques to a set of measurements that include various measurements of the approach proposed here.

Acknowledgments. This work has been partially funded by the Department of Electrical and Computer Engineering of the Faculty of Engineering, University of Porto (FEUP), under contract DEEC-2004 and partially by FCT under grant ACORD - Adaptative Coordination of Robotic Teams (PTDC/EIA/70695/2006). The authors wish to thank DEEC and Portuguese FCT for the financial support.

References

1. AIM – Association for Automatic Identification and Mobility, <http://www.aimglobal.org>
2. ANSI – American National Standard Institute, <http://ansi.org>
3. Costa P., Moreira A., Marques P., Costa P., Sousa A., Gaio S., 2001. 5dpo Team Description. In RoboCup games and conferences Andreas Birk, Silvia Coradeschi, Stoshi Tadokoro, RoboCup 2001: Robot Soccer World Cup V, pp.-, 2001
4. Göhring, D. & Burkhard, H., 2006. Multi Robot Object Tracking and Self Localization Using Visual Percept Relations. In: Proceedings of IEEE/RSJ International Conference of Intelligent Robots and Systems (IROS) 2006, pp 31-36
5. Gonzalez R. & Woods R., 2007. Digital Image Processing, (3rd Edition). Prentice Hall. ISBN 978-0131687288
6. Hecht, E., 2001. Optics (4th Edition), Addison Wesley, 2001, ISBN:0805385665
7. IEC – International Engineering Consortium, <http://www.iec.org>
8. Iocchi L. & Nardi D., 1999. Self-localization in the RoboCup environment. In Third International Workshop on RoboCup (Robot World Cup Soccer Games and Conferences)
9. ISO – International Organization for Standardization - <http://www.iso.org>
10. Jang, G., Kim, S., Lee, W. & Kweon, I., 2002. Colour Landmark Based Self-Localization for Indoor Mobile Robots. In the proceedings of the ICRA 2002, IEEE International Conference on Robotics and Automation vol. 1, pp. 1037 – 1042
11. Jörg, K., Torsten, G. & Weber, J., 1999. Supporting Mobile Robot Localization by Visual Bar Code Recognition. IASTED Conference on Robotics and Applications (RA'99) Santa Barbara, California, USA
12. Pavlidis, T., Swartz, J. & Wang, Y., 1990. Fundamentals of Bar Code Information Theory, IEEE Computer Journal, vol. 23, no. 4, pp. 74-86, Apr., 1990
13. Sousa, A., Costa, P., Moreira, A., Carvalho, A., 2005. Self Localization of an Autonomous Robot: Using an EKF to merge Odometry and Vision based Landmarks. In the proceedings of the 10th IEEE International Conference on Emerging Technologies and Factory Automation, pp.227-234
14. Wikipedia_i2of5 - Wikipedia BarCode Interleaved 2 of 5, http://en.wikipedia.org/w/index.php?title=Interleaved_2_of_5&oldid=200950623
15. Yoon, K. & Kweon, I., 2002. Landmark design and real-time landmark tracking for mobile robot localization. Mobile Robots XVI, Douglas W. Gage, Howie M. Choset, Editors, Proceedings of SPIE Vol. 4573 (2002)
16. Yoon, K. & Kweon, I., 2001. Artificial Landmark Tracking Based on the Colour Histogram. In the proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), vol. 4, pp. 1918-1923
17. CleanRob Project – CleanRob Project web site , <http://www.fe.up.pt/cleanrob>