Advances in Intelligent Systems and Computing 418

Luís Paulo Reis
António Paulo Moreira
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Robot 2015: Second Iberian Robotics Conference

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Preface

This book contains a selection of papers accepted for presentation and discussion at ROBOT 2015: Second Iberian Robotics Conference, held in Lisbon, Portugal, November 19th–21st, 2015. ROBOT 2015 is part of a series of conferences that are a joint organization of SPR – “Sociedade Portuguesa de Robótica/Portuguese Society for Robotics”, SEIDROB – Sociedad Española para la Investigación y Desarrollo de la Robótica/Spanish Society for Research and Development in Robotics and CEA-GTRob – Grupo Temático de Robótica/Robotics Thematic Group. The conference organization had also the collaboration of several universities and research institutes, including: University of Minho, University of Porto, University of Lisbon, Polytechnic Institute of Porto, University of Aveiro, University of Zaragoza, University of Malaga, LIACC, INESC-TEC and LARSyS.

Robot 2015 builds upon several successful events, including three biennal workshops (Zaragoza- 2007, Barcelona – 2009 and Sevilla – 2011) and the first Iberian Robotics Conference held in 2013 at Madrid. The conference is focussed on the Robotics scientific and technological activities in the Iberian Peninsula, although open to research and delegates from other countries.

Robot 2015 featured three plenary talks by:

- Manuela Veloso, Herbert A. Simon University Professor at Carnegie Mellon University, USA, on “Symbiotic Autonomous Mobile Service Robots”;
- Bill Smart, director of the Personal Robotics Group at Oregon State University, USA on “How the Law Will Think About Robots (and Why You Should Care)”; and
- Jon Agirre Ibarbia, co-ordinator of R&D projects at TECNALIA Research & Innovation, Spain, on “Applications in Flexible Manufacturing with Humans and Robots”.

Robot 2015 featured 19 special sessions, plus a main/general robotics track. The special sessions were about: Agricultural Robotics and Field Automation; Autonomous Driving and Driver Assistance Systems; Communication Aware Robotics; Environmental Robotics; Social Robotics: Intelligent and Adaptable AAL

Systems; Future Industrial Robotics Systems; Legged Locomotion Robots; Rehabilitation and Assistive Robotics; Robotic Applications in Art and Architecture; Surgical Robotics; Urban Robotics; Visual Perception for Autonomous Robots; Machine Learning in Robotics; Simulation and Competitions in Robotics; Educational Robotics; Visual Maps in Robotics; Control and Planning in Aerial Robotics, the XVI edition of the Workshop on Physical Agents and a Special Session on Technological Transfer and Innovation.

In total, after a careful review process with at least three independent reviews for each paper, but in some cases 4 or 5 reviews, a total of 118 high quality papers were selected for publication, with a total number of authors over 400, from 21 countries, including: Brazil, China, Costa Rica, Croatia, Czech Republic, Ecuador, France, Germany, Italy, India, Iran, The Netherlands, Poland, Portugal, Serbia, Singapore, Spain, Switzerland, United Kingdom, USA and Viet Nam.

ROBOT 2015 was co-located with the RoCKIn Competition 2015, which took place in the Parque das Nações, Lisboa, between 19 and 23 November, nearby the conference venue. RoCKIn is a Coordination Action funded by the European Commission FP7, and its main goal is to foster robotics research, education and dissemination through robot competitions. Thirteen teams from seven countries, including two teams from Mexico, were qualified and competed in RoCKIn@Home and RoCKIn@Work Challenges. Participants from both events had the opportunity to join in social events and to visit both venues, taking advantage of an extraordinary opportunity to follow presentations and actual robot systems showing recent results in this exciting field.

We would like to thank all Special Sessions' organizers for their hard work on promoting their special session, inviting the Program Committee, organizing the Special Session review process and helping to promote the ROBOT 2015 Conference. This acknowledgment goes especially to Vitor Santos, Angel Sappa, Miguel Oliveira, Danilo Tardioli, Alejandro Mosteo, Luis Riazuelo, João Valente, Antonio Barrientos, Luís Santos, Jorge Dias, Raul Morais Santos, Filipe Santos, Germano Veiga, José Lima, Guillermo Heredia, Anibal Ollero, Manuel Silva, Cristina Santos, Manuel Armada, Vicente Matellán, Miguel Ángel Cazorla, Rodrigo Ventura, Nicolas Garcia-Aracil, Alicia Casals, Elena García, José Pedro Sousa, Marta Malé-Alemany, Paulo Gonçalves, Jose Maria Sabater, Jorge Martins, Pedro Torres, Tamás Haidegger, Alberto Sanfeliu, Juan Andrade, João Sequeira, Anais Garrell, Andry Maykol Pinto, Aníbal Matos, Nuno Cruz, Brígida Mónica Faria, Luis Merino, Nuno Lau, Artur Pereira, Bernardo Cunha, Armando Sousa, Fernando Ribeiro, Eduardo Gallego and Oscar Reinoso Garcia.

We would also like to take this opportunity to thank the rest of the organization members (Carlos Cardeira, Brígida Mónica Faria, Manuel Fernando Silva, Daniel Castro Silva and Pedro Fonseca) for their hard and fine work on the local arrangements, publicity, publication and financial issues. We also express our gratitude to the members of all the Program Committees and additional reviewers, as they were crucial for ensuring the high scientific quality of the event and to all the authors and delegates whose research work and participation made this event a success. Last, but not the least, we acknowledge and thank our editor, Springer, that was in charge of these proceedings, and in particular to Dr. Thomas Ditzinger.

November 2015

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Nearest Position Estimation Using Omnidirectional Images and Global Appearance Descriptors

Yerai Berenguer, Luis Payá, Adrián Peidró, Arturo Gil and Oscar Reinoso

Abstract This work presents an algorithm to estimate the position and orientation of a mobile robot using only the visual information provided by a catadioptric system mounted on the robot. Each omnidirectional scene is described with a single global appearance descriptor. We have developed a description method which is based on the Radon transform. Our localization method compares the visual information captured by the robot from an unknown position with the visual information stored in a previously built map. As a result it estimates the nearest position of this map and the orientation of the robot. We have tested all the algorithms with a virtual database we have built. This database is composed of a set of omnidirectional images captured from different points of an indoor virtual environment. The experiments have allowed us to tune the main parameters and the results show the effectiveness and the robustness of our method.

Keywords Grid map · Omnidirectional images · Global appearance · Radon transform · Computer vision

1 Introduction

Nowadays there are countless kinds of robots with many configurations. Among them, mobile robots have extended due to their flexibility, as they are able to change their position during operation. Usually, these robots have to solve a task autonomously in an unknown environment, so the robot must estimate its position and orientation to be able to arrive to the target point avoiding obstacles. There are

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two main approaches to solve the localization problem. First, the robot may have a previously created map of the environment. In this case the robot has to estimate its position within this map. Second, the robot may not have any a priori knowledge of the environment thus it has to create the map and calculate its position simultaneously. This problem is named SLAM (Simultaneous Localization And Mapping).

These mapping and localization processes are possible thanks to the robot sensors, such as lasers, encoders, cameras, etc. They provide environmental information to the robot in different ways (e.g. lasers measure the distance to the nearest objects around the robot). This information is processed by the robot to build a map and to estimate its position and orientation. With these data, the robot must be able to carry out its work autonomously.

Along the last years much research has been developed about robot mapping and localization using different kinds of sensors and many algorithms have been proposed to solve these problems. A lot of these works use visual sensors to carry out the localization because this kind of sensors has many possible configurations, relative low cost and they provide the robot with very rich information from the environment. This images permit carrying out other high-level tasks. In this work we use the omnidirectional configuration [15]. We can find many previous works that use omnidirectional images in mapping and localization tasks, such as [3, 9, 14]. Valiente et al. [14] present a comparison between two different visual SLAM methods using omnidirectional images. Mohai et al. [9] propose a topological navigation system using omnidirectional vision. At last, Garcia et al. [3] make a survey of vision-based topological mapping and localization methods.

Traditionally, the developments in mobile robotics using visual sensors are based on the extraction and description of some landmarks from the scenes, such as SIFT (Scale-Invariant Feature Transform) [8] and SURF (Speeded-Up Robust Features) [1] descriptors. This approach presents some disadvantages: the computational time to calculate and compare the descriptors is usually very high thus these descriptors may not be used in real time, and it leads to relatively complex mapping and localization algorithms.

More recently some works propose using the global information of the images to create the descriptors. These techniques have demonstrated to be a good option to solve the localization and navigation problems on the ground plane. Chang et al. [2], Payá et al. [12] and Wu et al. [16] propose three examples of this. In [11], several methods to obtain global descriptors from panoramic scenes are analyzed and compared to prove their validity in map building and localization. The majority of these global appearance descriptors can be used in real time because the computational time to calculate and handle them is low, and they usually lead to more straightforward mapping and localization algorithms.

In this work we propose a solution to the localization problem using only the visual information captured by an omnidirectional system mounted on the robot. This system is composed of a camera pointing to a hyperbolic mirror and it provides the robot with omnidirectional scenes from the environment. We describe each scene using one global-appearance descriptor. Our starting point is a database of omnidirectional images captured on a grid of points in the environment where the robot has to navigate. We face the localization problem as an image retrieval problem.

Comparing to previous works, the contribution of this paper is twofold. First we define a new method to describe the global appearance of omnidirectional images. This method is based on the Radon transform. We have not found any previous work that uses this mathematical transformation in the field of robotics localization. Second we optimize the localization process in a previously built map.

The experiments have been carried out with our own images database that has been created from a synthetic indoors environment.

The remainder of this paper is structured as follows. Section 2 introduces the concept of global appearance and the description method we propose. Section 3 describes our localization method. In section 4 the experiments and results are presented. At last, section 5 outlines the conclusions.

2 Global Appearance of Omnidirectional Images: Radon Transform

Methods based on the global appearance of the scenes constitute a robust alternative compared with methods based on landmarks extraction. The key is that the global appearance descriptors represent the environment through high-level features that can be interpreted and handled easily, and with a reasonably low computational cost.

This section presents the transform we have employed to describe the scenes (omnidirectional images). Each scene is represented through a single descriptor that contains information of the whole appearance without any segmentation or local landmark extraction. We also present the distance measure we use to compare descriptors. Any novel global appearance description method should satisfy some properties: (a) it should make a compression effect in the image information, (b) there should be a correspondence between the distance between two descriptors and the metric distance between the two positions where the images were captured, (c) the computational cost to calculate and compare them should be low, so that the approach can be used in real time, (d) it should provide robustness against noise, changes in lighting conditions, occlusions and changes in the position of some objects in the environment, (e) at last, it should contain information of the orientation the robot had when it captured the image.

The description method we have developed is mainly based on the Radon transform.

2.1 Radon Transform

The Radon transform was initially described in [13]. It has been used in some computer vision tasks, such as shape description and segmentation, such as [5] and [4].

The Radon transform in 2D consists of the integral of a 2D function over straight lines (line-integral projections). This transform is invertible. The inverse Radon transform reconstructs an image from its line-integral projections. By this reason it was initially used in medical imaging (such as CAT scan and Magnetic Resonance Imaging (MRI)).

The Radon transform of a 2D function $f(i, j)$ can be defined mathematically as:

$$\mathcal{R}\{f(i, j)\} = \lambda_f(p, \phi) = \iint_{-\infty}^{+\infty} f(i, j)\delta(p - \overrightarrow{r}\,\widehat{\overrightarrow{p}})didj \tag{1}$$

Where δ is the Dirac delta function ($\delta(x) = 1$ when $x = 0$, and $\delta(x) = 0$ elsewhere). The integration line is specified by the radial vector $\overrightarrow{p}$ that is defined by $\overrightarrow{p} = \widehat{\overrightarrow{p}} \cdot p$ where $\widehat{\overrightarrow{p}}$ is a unitary vector in the direction of $\overrightarrow{p}$. p is the $\overrightarrow{p}$ magnitude:

$$p = |\overrightarrow{p}| \tag{2}$$

The line-integral projections evaluated for each azimuth angle, ϕ, produce a 2D polar function, λ_f, that depends on the radial distance p and the azimuth angle ϕ. $\overrightarrow{r}$ is a cluster of points which is perpendicular to $\overrightarrow{p}$.

The Radon transform of an image $im(i, j)$ along the line $c_1(d, \phi)$ (Figure 1) can be expressed more clearly by the following equivalent expression:

$$\mathcal{R}\{im(i, j)\} = \int_{\mathbb{R}} im(i' \cos\phi - j' \sin\phi, i' \sin\phi + j' \cos\phi)\, ds \tag{3}$$

where

$$\begin{bmatrix} i' \\ j' \end{bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{bmatrix} \cdot \begin{bmatrix} i \\ j \end{bmatrix} \tag{4}$$

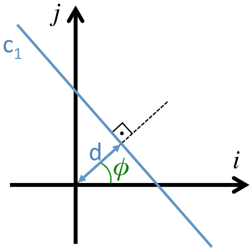
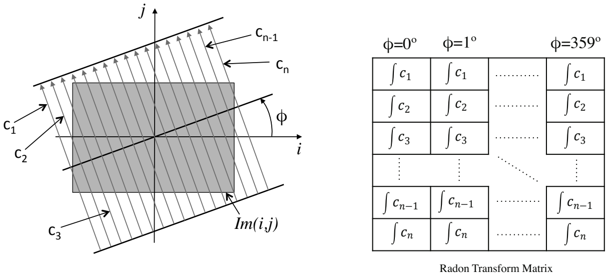


Fig. 1 Line parametrization through the distance to the origin d and the angle between the normal line and the i axis, ϕ.

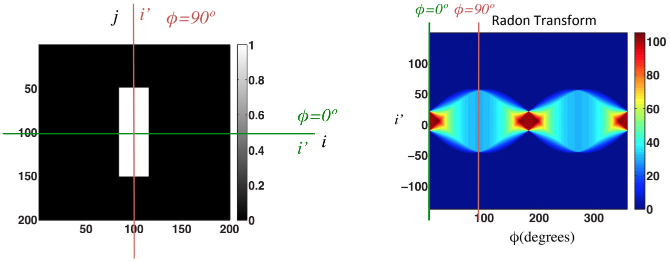
When the Radon transform is applied to images, it calculates the image projections along the specified directions through a cluster of line integrals along parallel lines in this direction. The distance between the parallel lines is usually one pixel. The Figure 2(a) shows the integration paths to calculate the Radon transform of an image in the ϕ direction, and the Figure 2(b) shows the value of each component of the Radon transform in a simplified notation.



(a) (b)

Fig. 2 (a) Integration paths to calculate the Radon transform of the image $im(i, j)$ in the ϕ direction. (b) Radon transform matrix of the image $im(i, j)$.

The Figure 3 shows a sample black and white image, on the left, and its Radon transform, on the right. Furthermore it shows graphically the process to calculate the Radon transform.



(a) (b)

Fig. 3 (a) Sample image. (b) Radon transform of the sample image.

Radon Transform Properties. The Radon transform has several properties that make it useful in localization tasks using images. These properties are the following:

- Linearity: The Radon transform has the linearity property as the integration operation is a linear function of the integrand:

$$\mathcal{R}\{\alpha f + \beta g\} = \alpha \mathcal{R}\{f\} + \beta \mathcal{R}\{g\} \tag{5}$$

- Shift: The Radon transform is a variant operation to translation. A translation of the two-dimensional function by a vector $\overrightarrow{r_0} = (i_0, j_0)$ has a translation effect on each projection. This translation is given by a distance $\overrightarrow{r} \cdot (\cos\phi, \sin\phi)$.
- Rotation: If the image is rotated an angle ϕ_0 it implies a shift ϕ_0 of the Radon transform along the variable ϕ (columns shift).
- Scaling: A scaling of f by a factor b implies a scaling of the d coordinate and amplitude of the Radon transform by a factor b:

$$\mathcal{R}\left\{f\left(\frac{i}{b}, \frac{j}{b}\right)\right\} = |b|\lambda_f\left(\frac{d}{b}, \phi\right) \tag{6}$$

2.2 POC (Phase Only Correlation)

In this subsection we present the method we use to compare the Radon transform of two images.

In general, a function in the frequency domain is defined by its magnitude and its phase. Usually, only the magnitude is taken into account and the phase information is discarded. However, when the magnitude and the phase features are examined in the Fourier domain, it follows that the phase features contain also important information because they reflect the characteristics of patterns in the images.

Oppenheim and Lim [10] have demonstrated this by reconstructing images using the full information from the phase with unit magnitude. This shows that the images resemble the originals, in contrast to reconstructing images using the full information from the magnitude with uniform phase.

POC (Phase Only Correlation), proposed in [7], is an operation made in the frequency domain that provides a correlation coefficient between two images [6]. In our case we compare two Radon transforms but this does not affect the POC performance because the Radon transform can be interpreted as an image.

The correspondence between two images $im_1(i, j)$ and $im_2(i, j)$ calculated by POC is given by the following equation:

$$C(i, j) = \mathcal{F}^{-1}\left\{\frac{\mathbf{IM}_1(u, v) \cdot \mathbf{IM}_2^*(u, v)}{\left|\mathbf{IM}_1(u, v) \cdot \mathbf{IM}_2^*(u, v)\right|}\right\} \tag{7}$$

Where $\mathbf{IM}_1$ is the Fourier transform of the image 1 and $\mathbf{IM}_2^*$ is the conjugate of the Fourier transform of the image 2. $\mathcal{F}^{-1}$ is the inverse Fourier transform operator.

To estimate the distance between two images we have used the following expression:

$$dist(im_1, im_2) = 1 - max\{C(i, j)\} \tag{8}$$

$max\{(C(i, j)\}$ is a coefficient that takes values in the interval [0, 1] and it measures the similitude between the two images.

This operation is invariant against shifts in the i and j axes of the images. Furthermore, it is possible to estimate these shifts Δ_i and Δ_j along both axes by:

$$(\Delta_i, \Delta_j) = argmax_{(i,j)}\{C(i, j)\} \tag{9}$$

If we use Radon transforms of omnidirectional images, the value Δ_i allows us to estimate the change of the robot orientation when capturing the two images.

This way, POC is able to compare two images independently on the orientation and it is also able to estimate this change in orientation.

3 Localization Method

In this section we address the localization problem. Initially, the robot has a map of the environment. It is composed of a set of omnidirectional images along with the position of the capture points (coordinates with respect to a reference system). Then, the robot captures an image from an unknown position (test image). Comparing this image with the visual information stored in the map, the robot must be able to estimate the nearest position of the map.

Since the positions where the map images were captured are known the method we develop is a pure localization method. Also, the robot has no information about its previous position neither its path, so we face the problem as an absolute localization.

This method allows us to know the nearest image of the map (the most similar to the test image). Thanks to this information we know that the robot is located in the surrounding of the point where the corresponding image was captured. The method is detailed in the following subsection.

3.1 Nearest Position of the Map (Image Retrieval Problem)

The operation consists of the following steps:

1. The robot takes an omnidirectional image from its current unknown position (test image). The objective is to estimate this position and the orientation of the robot on the ground plane.
2. This image is transformed using the Radon transform.
3. It is compared with all Radon transforms of the map using the POC comparison. As a result, we know which is the most similar image.
4. The position where this omnidirectional image was captured is the nearest neighbor.
5. Once the nearest position is known, we estimate the orientation of the robot. We compare the Radon transform of the test image with the radon transform of the image extracted at step 3. (Eq. (9)).

After this process we assume the robot is located around this position. The accuracy depends mainly on the distance between the capture points of the map images.

4 Experiments and Results

In this section we present the virtual database created to test our method, we use it to test the method and we show the results obtained.

4.1 Virtual Database

In order to check the performance of the proposed technique, we have created a virtual environment that represents an indoor room. In this environment it is possible to create omnidirectional images from any position. This is an advantage since it allows us to create a versatile database to test the localization algorithm. The Figure 5(a) shows a bird's eye view of the environment.

The omnidirectional images have 250x250 pixels and they have been created using a catadioptric system composed of a camera and a hyperbolic mirror whose geometry is described in Figure 4. The parameters used in the mirror equation are $a = 40$ and $b = 160$.

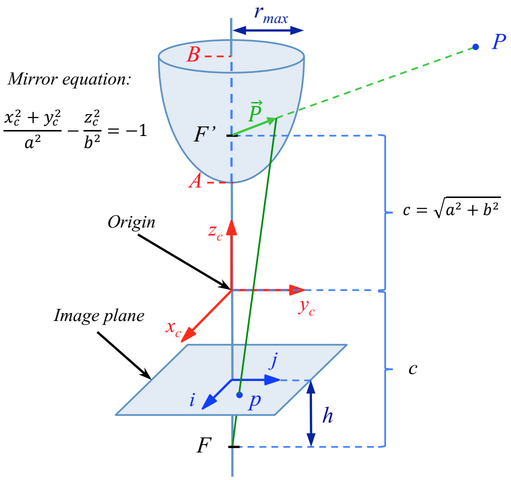
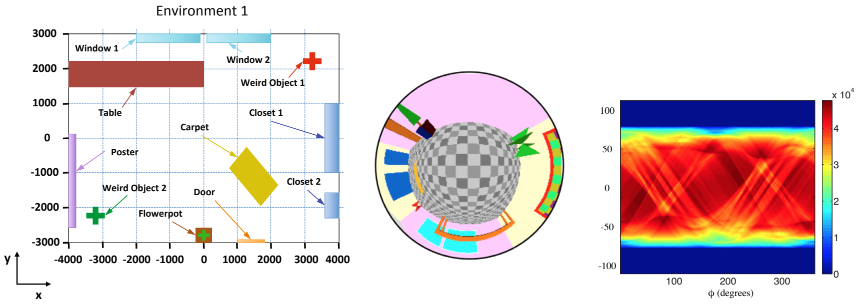


Fig. 4 Catadioptric system used to capture the synthetic omnidirectional images.

Several images have been captured in the environment to create the map from several positions on the floor. The map is composed of 4800 images captured on a 8x6 meters grid with a step of 10 centimeters between positions. To carry out the experiments we can change the number of map images to test the performance of the map when the distance between capture points increases. The Figure 5(b) shows one sample omnidirectional image of the environment created with our program.



(a) (b) (c)

Fig. 5 (a) Bird's eye view of the virtual environment. (b) Example of an omnidirectional image captured from the point x=1500 mm and y=1500 mm. (c) Radon transform of (b).

4.2 Results Obtained with the Virtual Database

The performance of our method depends on some parameters, such as the size of the map and the distance between images. In this subsection we compare the results of different tests changing the values of these parameters to test our method. We will study the influence of the distance between map positions in the same area of the environment (size of the grid), so the number of map images is different in each case.

Nearest Position. In this experiment we analyze 4 different step sizes between consecutive map positions. The distances that we will use are 100, 200, 300 and 400 mm. The size of the grid is 8m x 6m in all cases, so the number of map images depends on the step size.

The Figure 6 shows the distance (Eq. (8)) between the Radon transform of a test image and each image of the map (200x200). The position of the test image is x=-2239 mm and y=-1653 mm. And the corresponding position according to this figure (the minimum of the 2D function) is x=-2200 and y=-1600. As we can see, the distance decreases sharply around this position.

The average computation time per iteration in each case is shown in Figure 7. The 100 mm distance between map positions is not advisable because the computational time is much higher than the others.

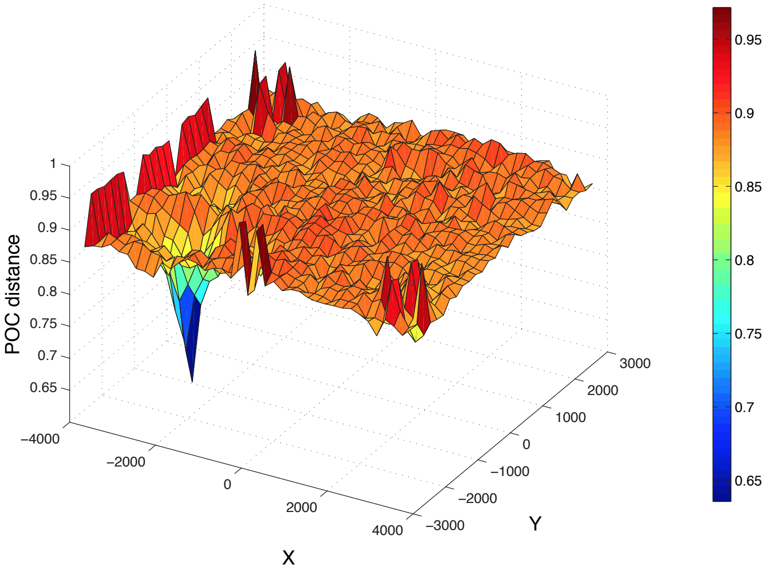


Fig. 6 Example of an iteration of our method in a random position. The position of the test image is x=-2239 mm and y=-1653 mm.

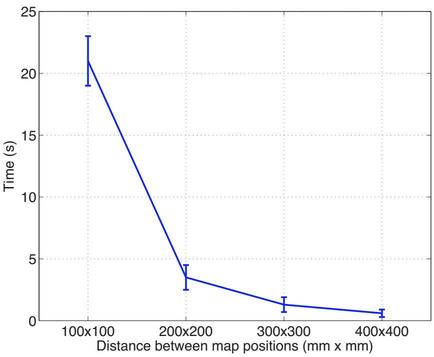


Fig. 7 Computational time for each iteration.

The Figure 8 shows the global results of this test. We have used 3500 test images captured from different random positions of the environment. In each bar, the blue part represents the proportion of correct localizations, the green part represents that the method localizes the robot around the second nearest position, i.e. the position calculated is not the nearest position but rather the second nearest position of the map, and the red part is the proportion of errors for each map size.

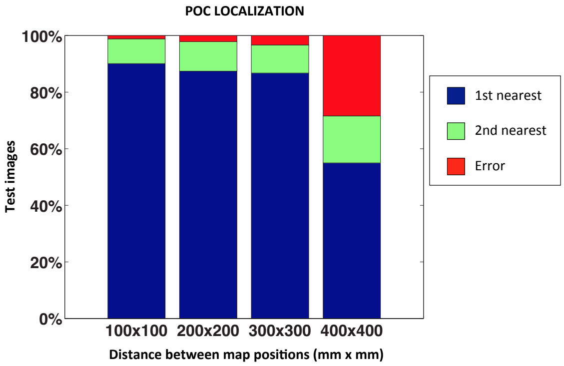


Fig. 8 POC localization experiment.

The average orientation versus the distance between map positions (Eq. (9)) is shown in Figure 9. This error increases when the distance between map positions is higher because the test image and the corresponding map image are less similar.

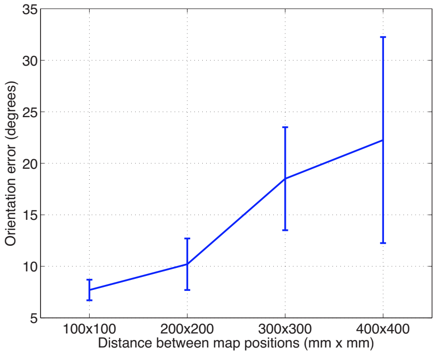


Fig. 9 Average orientation error of the experiment.

We can observe that the method is working properly with a distance between map positions not exceeding 300x300 millimeters.

5 Conclusions

In this paper we have presented a method to estimate the position and orientation of a mobile robot in an environment that has been previously mapped. We propose a solution to the absolute localization problem and we face it as an image-retrieval problem. We have also developed a novel description method for omnidirectional scenes based on the Radon transform. At last, all the algorithms have been tested with our own virtual database.

The results have demonstrated that it is a very reliable method to estimate the nearest position of the map. As for the values of the parameters, the distance between map positions is the main parameter to tune in this method. The best choice is 200x200 mm as it offers a good balance between accuracy and computational time.

The results presented in this paper show the effectiveness of the global appearance descriptors of omnidirectional images to locate the robot. We are now working to improve this method and we are trying to carry out the localization in a map with more degrees of freedom. We are also working to include the color information of the images as it can also provide useful information.

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