

Advances in Intelligent Systems and Computing

Volume 693

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ROBOT 2017: Third Iberian Robotics Conference

Volume 1

 Springer

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Preface

This book contains a selection of papers accepted for presentation and discussion at “Robot 2017: Third Iberian Robotics Conference,” held in Seville, Spain, November 22–24, 2017. Robot 2017 is part of a series of conferences that are a joint organization of Sociedad Española para la Investigación y Desarrollo de la Robótica/Spanish Society for Research and Development in Robotics (SEIDROB) and Sociedade Portuguesa de Robótica/Portuguese Society for Robotics (SPR). The conference organization had also the collaboration of several universities and research institutes, including University of Seville, Polytechnic University of Catalonia, University of Zaragoza, University of Aveiro, and University of Lisbon.

Robot 2017 builds upon several successful events, including three biennial workshops (Zaragoza–2007, Barcelona–2009, and Sevilla–2011) and two Iberian Robotics Conferences (Madrid–2013 and Lisbon–2015).

The conference is focused on the robotics scientific and technological activities in the Iberian Peninsula, although open to research and delegates from other countries.

Robot 2017 featured three plenary talks by:

- Oussama Khatib, Director of Stanford Robotics Lab, Stanford University, USA, President of the International Foundation of Robotics Research (IFRR)
- Dario Floreano, Director of the Laboratory of Intelligent Systems, EPFL, Switzerland, Director of the Swiss National Center of Competence in Robotics, Switzerland
- Alin Albu-Schäffer, Head of the Institute of Robotics and Mechatronics at the German Aerospace Center (DLR), Germany.

Robot 2017 featured 27 special sessions, four of them with two slots in the Conference Program, plus 5 sessions coming from the General Track. The conference had an industrial track with four sessions. The main purpose of this track is to present industrial needs and recent achievements in robotic industrial applications looking to promote new collaborations between industry and academia. Six papers of the industrial track have been included in this book.

The Special Sessions were about Aerial Robotics for Inspection, Agricultural Robotics and Field Automation, Autonomous Driving and Driver Assistance Systems, Challenges in Medical Robotics in the Frame of Industry 4.0, Cognitive Architectures, Communication-Aware Robotics, Cooperative and Active Perception for Robotics, Educational Robotics, Legged Locomotion Robots, Machine Learning in Robotics, Marine Robotics, Ontologies and Knowledge Representation for Robotics, Rehabilitation and Assistive Robotics, Robotics and Cyber-Physical Systems for Industry 4.0, Robotic and Unmanned Vehicles for Security, Robot Competitions, Robots Cooperating with Sensor Networks, Robots for Health care, Sensor Technologies oriented to Computer Vision Applications, Simulation in Robotics, Vision and Learning for Robotics, and Visual Perception for Robotics.

Additionally, the four industrial Special Sessions were about Application of Robotics to Manufacturing Processes in the Aeronautic Industry, Application of Robotics to Shipbuilding, Integration of Drones in Low Altitude Aerial Space, and Robotics Solutions for Flexible Manufacturing.

Finally, the sessions in the General Track were about the following topics: Aerial Robotics (double slot), Manipulation, Mobile Robotics, and Mobile Robotics Applications.

The Robot 2017 Call for papers received 201 papers. After a careful review process with at least three independent reviews for each paper, 141 of them have been selected to be included in this book. There are over 500 authors from 21 countries including Australia, Brazil, Colombia, Croatia, Czech Republic, Denmark, Ecuador, Finland, France, Germany, Ireland, Italy, Luxembourg, Macao, Mexico, Poland, Portugal, Spain, United Arab Emirates, UK, and USA.

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 2017 Conference. This acknowledgment goes especially to the members of the Program Committee, Organizers of the Special Sessions, and Reviewers for the hard work required to prepare this volume 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. The work of the Local Organizing Committee was also crucial to produce the Robot 2017 Program and this book.

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 2017

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Movement Direction Estimation Using Omnidirectional Images in a SLAM Algorithm

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Abstract. This work presents a method to estimate the movement direction of a mobile robot using only visual information, without any other additional sensor. This visual information is provided by a catadioptric system mounted on the robot and formed by a camera pointing towards a convex mirror. It provides the robot with omnidirectional images that contain information with a field of view of 360° around the camera-mirror axis. A SLAM algorithm is presented to test the method that estimates the movement direction of the robot. This SLAM method uses two different global appearance descriptors to calculate the orientation of the robot and the distance between two different positions. The method to calculate the movement direction is based on landmarks extraction, using SURF features. A set of omnidirectional images has been considered to test the effectiveness of this method.

Keywords: SLAM · Omnidirectional images · Vision systems · Image description

1 Introduction

Nowadays many robots can be found to solve some day to day tasks, and the number of them is increasing year to year. Many of these robots are mobile, 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. To solve this task, two fundamental steps must be carried out. On the one hand, it must create an internal representation of the unknown environment (map) and on the other hand it must be able to estimate its position within the map. The robot uses the information extracted from the environment by the different sensors that it is equipped with. This information is compared with the data stored in the map to estimate the position of the robot. There are many kinds of sensors that provide useful information to the robot, such as touch sensors, encoders, laser or vision sensors.

Vision sensors have some properties that make them very useful in mobile robotics because they have 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 [17].

In the field of the Simultaneous Localization and Mapping (SLAM), omnidirectional images have many advantages because they contain information with a field of view of 360° around the mirror axis. We can find many previous works that use omnidirectional images in mapping and localization tasks. For example, Valiente et al. [16] present a comparison between two different visual SLAM methods using omnidirectional images and Garcia-Fidalgo and Ortiz [6] make a survey of vision-based topological mapping and localization methods.

The classic developments in mobile robotics using visual sensors are based on the extraction and description of some landmarks from the scenes. These landmarks can be either natural or artificial and some methods are available, such as SIFT (Scale-Invariant Feature Transform) [12] and SURF (Speeded-Up Robust Features) [1].

More recently, some works propose using the global appearance to describe the scenes, creating a unique descriptor per image. These techniques have demonstrated to be a good option to solve the localization and navigation problems when the movement of the robot is contained in the floor plane. For example, Chang et al. [3] presents a vision-based navigation and localization system using the gist descriptor, Payá et al. [14] use a descriptor based on the Fourier signature in Monte Carlo localization tasks, and Wu et al. [18] propose an efficient visual loop closure detection method. In [13], several methods to obtain global descriptors from panoramic scenes are analyzed and compared to demonstrate 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.

Sometimes, the mapping process produces an error that tends to increase as new positions are added to the map due to the iterative calculation of new poses of the robot. This can be a big problem in extensive environments when the robot has to calculate many new poses. This uncertainty can be reduced by detecting loop closures and using optimization algorithms to relocate each previous pose. This problem is thoroughly studied in this work.

The contribution of this work is the creation of a method to calculate the movement direction of the robot using only visual information. Also, a SLAM method is presented to test this movement direction algorithm as a fundamental step of it. This SLAM method consists of three different steps: calculating the pose of the robot (position and orientation), detecting loop closures (by comparing global appearance descriptors) and optimizing the map. The optimization algorithm used in the presented paper is named G2O and it was presented by Kümmerle et al. [11].

The experiments have been carried out with a set of images captured while the robot traversed a real working environment. It has been captured following a real path including several rooms in a building.

The remainder of this paper is structured as follows. Section 2 introduces some preliminary concepts about image description and graph optimization. Section 3 describes our movement direction estimation algorithm and the SLAM method. Section 4 describes the database used to carry out the experiments and presents the experiments and results. At last, Sect. 5 outlines the conclusions.

2 Preliminaries

Along the paper, two methods are used to describe the global appearance of scenes: the Radon transform and the Histogram of Oriented Gradients (HOG). This section includes some information on them. Also, we present the fundamentals of the methods used to calculate the difference between two images captured from different locations. At last, we describe the optimization algorithm used to recalculate the previous map positions after detecting loop closures.

2.1 Global Appearance Descriptors

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.

When designing a new description method, we should take several features into account. This descriptor should have a compression effect in the image information. Also, there should be a correspondence between the distance between two descriptors and the distance between the two positions where the images were captured. The computational cost to calculate and compare them should be low, so that this descriptor can be used in real time. Furthermore, it should provide robustness against noise, illumination changes, occlusions and position changes of the objects in the environment. Finally, it should contain information on the orientation the robot had when it captured the image.

This subsection presents two different image descriptors we have used in the SLAM method to describe the omnidirectional images. Both of them are based on global appearance, without any segmentation or local landmark extraction. Also, a descriptor based on the landmark extraction is used to carry out the movement direction estimation.

Radon Transform. The Radon transform was initially described in [15]. It has been used in some computer vision tasks, such as shape description and segmentation, such as [7, 8].

The Radon transform in 2D consists in calculating the integral of a 2D function along a set of 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:

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

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 \vec{p} that is defined by $\vec{p} = \widehat{\vec{p}} \cdot p$ where $\widehat{\vec{p}}$ is a unitary vector in the direction of \vec{p} . p is the \vec{p} magnitude:

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

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 . \vec{r} is a cluster of points which is perpendicular to \vec{p} .

The Radon transform of an image $im(i, j)$ along the line $c_1(d, \phi)$ 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

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

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.

Histogram of Oriented Gradients (HOG). HOG has been used traditionally as a description method in the field of object detection. It was initially described by [4]. They used it in people detection tasks. However, there are several works in which this description method has been enhanced, such as [19], who improve the accuracy and the computational cost.

The basic implementation consists in dividing the image into small connected cells and the histogram of gradient orientations is calculated in each cell. Then, the descriptor is composed by arranging of these histograms in a single vector.

Fernandez et al. [5] analyze this kind of descriptor in outdoor localization tasks. Furthermore, they make a comparative analysis between several methods to describe outdoor panoramic images.

2.2 POC (Phase Only Correlation)

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

POC (Phase Only Correlation), proposed in [10], is an operation made in the frequency domain that provides a correlation coefficient between two images [9]. 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. In general, it permits obtaining both the relative orientation between two different Radon transforms and a similitude coefficient between them, as shown in [2].

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

$$C(i, j) = \mathcal{F}^{-1} \left\{ \frac{\mathbf{IM}_1(u, v) \cdot \mathbf{IM}_2^*(u, v)}{|\mathbf{IM}_1(u, v) \cdot \mathbf{IM}_2^*(u, v)|} \right\} \quad (5)$$

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:

$$dist(im_1, im_2) = 1 - max\{C(i, j)\} \quad (6)$$

$max\{C(i, j)\}$ 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 along 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:

$$(\Delta_i, \Delta_j) = argmax_{(i, j)} \{C(i, j)\} \quad (7)$$

If we compare the Radon transforms of two omnidirectional images using POC, the value Δ_i is proportional to the relative orientation α of the robot when capturing the images according to Eq. (8).

$$\alpha = \frac{\Delta_i \cdot 2\pi}{N} \quad (8)$$

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

2.3 Optimization Algorithm: G2O

G2O is an optimization algorithm described in [11]. This method was created for optimizing graph-based nonlinear error functions.

In the field of SLAM, the robot has to calculate its pose when it takes every new image with respect to the previous poses included in the map. This operation has an error associated that increases in each pose calculation, so we need to correct the poses to decrease this deviation. G2O is able to recalculate each pose

of the map using new pose restrictions. One of these restrictions can be obtained when loop closures between one pose of the existing map and the new pose of the robot occur. Then, G2O relocates each pose of the map gradually modifying them to fulfill the loop closure restriction. Then, the new pose is located in the same position than the equivalent pose stored in the map.

3 Movement Direction Estimation in a SLAM Method

In this section, we present our visual approach to estimate the movement direction of the robot inside a visual SLAM method. The robot goes through the environment and captures a set of images from some positions. Every time a new image arrives, the robot includes a new node inside the map. This map is formed by nodes. Then, the SLAM problem is solved, following these three steps:

First, the robot calculates two descriptors of the image: the Radon transform and the HOG descriptor; and stores them in the node. Then, the robot creates a new node and locates it inside the map calculating the position and orientation of the new node with respect to the previously added node, and both nodes are connected. This localization process is carried out by using only visual information.

Second, the robot checks the existence of possible loop closures comparing the new scene with the previous scenes stored in the map.

Finally, the map is optimized by using the G2O algorithm with the loop closures detected. This process is repeated in each new location. These steps are detailed in the next subsections.

3.1 Creating the Map

This subsection presents the method proposed to calculate the coordinates of each new node with respect to the previous one. The pose of the new node is estimated by calculating the distance, the orientation change and the movement direction. With this purpose, the Radon and the HOG descriptors of the omnidirectional images associated with the current and the previous node are used.

Figure 1 shows graphically the mapping process. It consist in calculating the (x_k, y_k) coordinates of each new node. These coordinates are calculated from the distance and the movement direction between poses.

The distance between consecutive locations is calculated using the Eq. 6. Which is an image distance, not a metric distance, i.e. this distance is expected to be proportional to the metric distance.

The orientation of the robot with respect to the previous node α_j , is calculated using the Eq. 8.

The calculation of the angle that forms the current node j with the x-axis β_j , is carried out following this process:

First, the robot calculates the orientation change α_j , between this image and the omnidirectional image of the previous node. Taking this orientation change

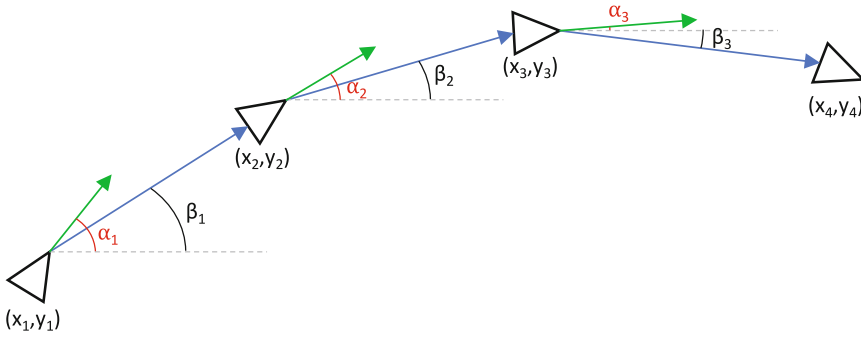


Fig. 1. Mapping process scheme.

into account, the previous image is rotated to have both images orientated in the same direction.

Second, both omnidirectional images are transformed into panoramic views.

Third, SURF features are extracted from both panoramic images and they are matched.

Fourth, the horizontal component of the displacement between matched features of both images is extracted. This ‘horizontal displacement’ is considered positive if it points towards the right of the image or negative otherwise.

Finally, a set of windows is defined. These windows have M rows and $0.5N$ columns, $W = \{W_1, W_2, \dots\}$, which horizontal distance between them is one pixel. The quantity of landmarks with negative displacement inside each window and the number of landmarks with a positive displacement outside is counted, resulting the vector $\mathbf{n} = [n_1, n_2, \dots]$. The maximum of this vector is extracted ($p_w = \text{argmax}(\mathbf{n})$). Then, the position p_w permits to estimate the searched angle using the Eq. 9.

$$\beta = \frac{p_w \cdot 2\pi}{N} \tag{9}$$

Figure 2 presents two different panoramic images superimposed, showing the matched SURF features between them. The red lines are the limits of the window of 180° . In that case the window is placed when the condition to calculate the movement direction of the robot is accomplished. It shows that all points inside the window have a negative displacement along the x axis and the points outside this window have a positive displacement along the same axis.

The new node coordinates (x_k, y_k) are calculated by these equations:

$$x_k = \text{dist}(im_{k-1}, im_k) \cdot \cos(\beta_k) \tag{10}$$

$$y_k = \text{dist}(im_{k-1}, im_k) \cdot \sin(\beta_k) \tag{11}$$

where $\text{dist}(im_{k-1}, im_k)$ is the POC distance between the Radon transform of the two consecutive images, calculated by using the Eq. 3, and β_k is the movement direction angle of the k node 9.

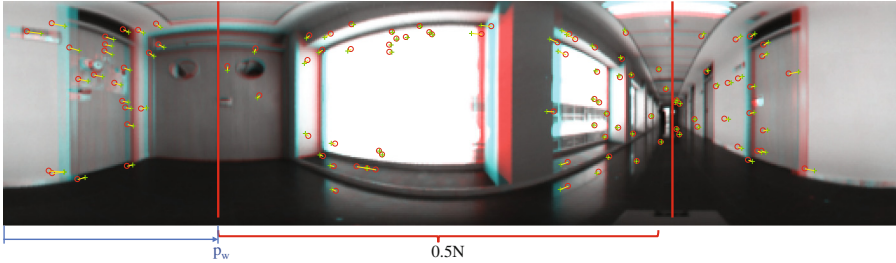


Fig. 2. Matches between SURF features of two consecutive panoramic images of the database.

3.2 Loop Closures

The next step of the algorithm consists in detect loop closures, i.e. comparing the HOG descriptor of the new image taken by the robot with the HOG descriptors stored in the map. To calculate the distance between HOG descriptors we use the cosine similarity between them to calculate the distance:

$$dist(\vec{d}_1, \vec{d}_2) = 1 - \frac{\vec{d}_1 \cdot \vec{d}_2^T}{\sqrt{(\vec{d}_1 \cdot \vec{d}_1^T)(\vec{d}_2 \cdot \vec{d}_2^T)}} \tag{12}$$

where \vec{d}_1 and \vec{d}_2 are the HOG descriptors of two different images.

The loop closures have to be determined by defining a maximum threshold of distance, S (Eq. 13). This threshold is defined as a constant in the beginning of the SLAM process. If the distance is lower than this threshold, the two poses compared will be considered as the same location (x, y) , but the orientation of the robot can be different.

$$if(dist(\vec{d}_1, \vec{d}_2) < S) \rightarrow loop\ closure \tag{13}$$

3.3 Optimization of the Map

Taking the detected loop closures into account, the robot uses this information to optimize the stored map. This optimization is made by using the G2O optimization algorithm.

When the robot detects a loop closure, it has to relocate all previous nodes to reduce the error associated to each node position. This process modifies all the node positions in the map to accomplish the new restriction calculated by the loop closure detection.

The modification of the position of the nodes is made by the G2O algorithm. It receive as input all the node positions of the map and the loop closure restriction. Then, G2O gives as an output the new recalculated node positions.

Therefore, the two nodes of the loop closure are localized in the same position and the coordinates of the rest of the map nodes are modified.

4 Experiments

This subsection presents the set of omnidirectional images used to test our method and the results obtained in these experiments.

4.1 Database

In order to check the performance of the proposed technique, a set of images captured by ourselves is used. This set was captured while the robot followed a tricky path through several rooms inside a building. Figure 3 shows a sample omnidirectional image of the environment.

This database has been created taking one new omnidirectional image every 40 cm approximately. It is formed by 515 omnidirectional images with 1280×960 pixels each one. The Fig. 4 shows the omnidirectional acquisition system used to capture the omnidirectional images, formed by the camera (model: DFK-41BF02) and the hyperbolic mirror (model: Eizo Wide70).



Fig. 3. Sample omnidirectional image of the database environment.



Fig. 4. Omnidirectional acquisition system

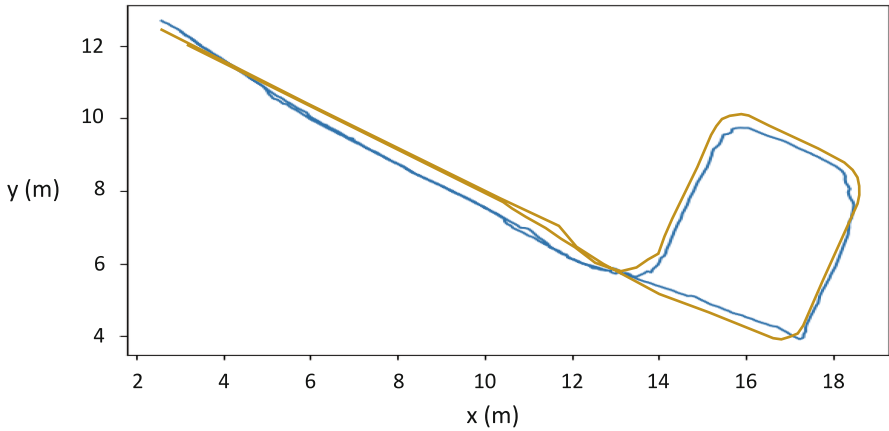


Fig. 5. Map created using the real path. The blue line is the map created using our SLAM algorithm. The yellow line is the ground truth.

4.2 Results

In this section the results of the experiments with our SLAM algorithm are shown. The database described in Sect. 4.1 has been used to carry out these experiments.

The maximum threshold of distance between HOG descriptors (Eq. 12) is an important parameter to tune. To do that, we have made some tests and chosen the best value to detect loop closures. After these tests we consider a threshold equal to 0.006 as a good value of distance between HOG descriptors.

Figure 5 shows the results of the SLAM algorithm after incorporating the final position of the first path. The blue line is the map created using our algorithm. The yellow line is the ground truth.

As for the computational time, the robot spends an average of 0.7 s in each iteration of the SLAM process. This time tends to increase in each iteration because the map is formed by larger amount of nodes and the loop closure detection needs to compare a higher number of HOG descriptors.

5 Conclusions

In this paper we have presented a SLAM method to estimate the position and orientation of a mobile robot in an environment estimating the movement direction of the robot using a method based on landmark extraction. We use two different global appearance descriptors and a method based on SURF features to carry out the SLAM process. The map is formed by these two global appearance descriptors of each image. At last, the algorithm has been tested with a set of images captured in an indoor environment.

The results have demonstrated the accuracy of the method, which is mainly thanks to the method to calculate the movement direction based on the behavior of the SURF features in both images.

The results presented in this paper show the effectiveness of the global appearance descriptors of omnidirectional images to do SLAM thanks to the richness of the information they contain. We are now working to test the method using new databases of different environments. Furthermore, we are implementing a clustering method to reduce the computational time to detect loop closures when the number of nodes considerably increases.

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