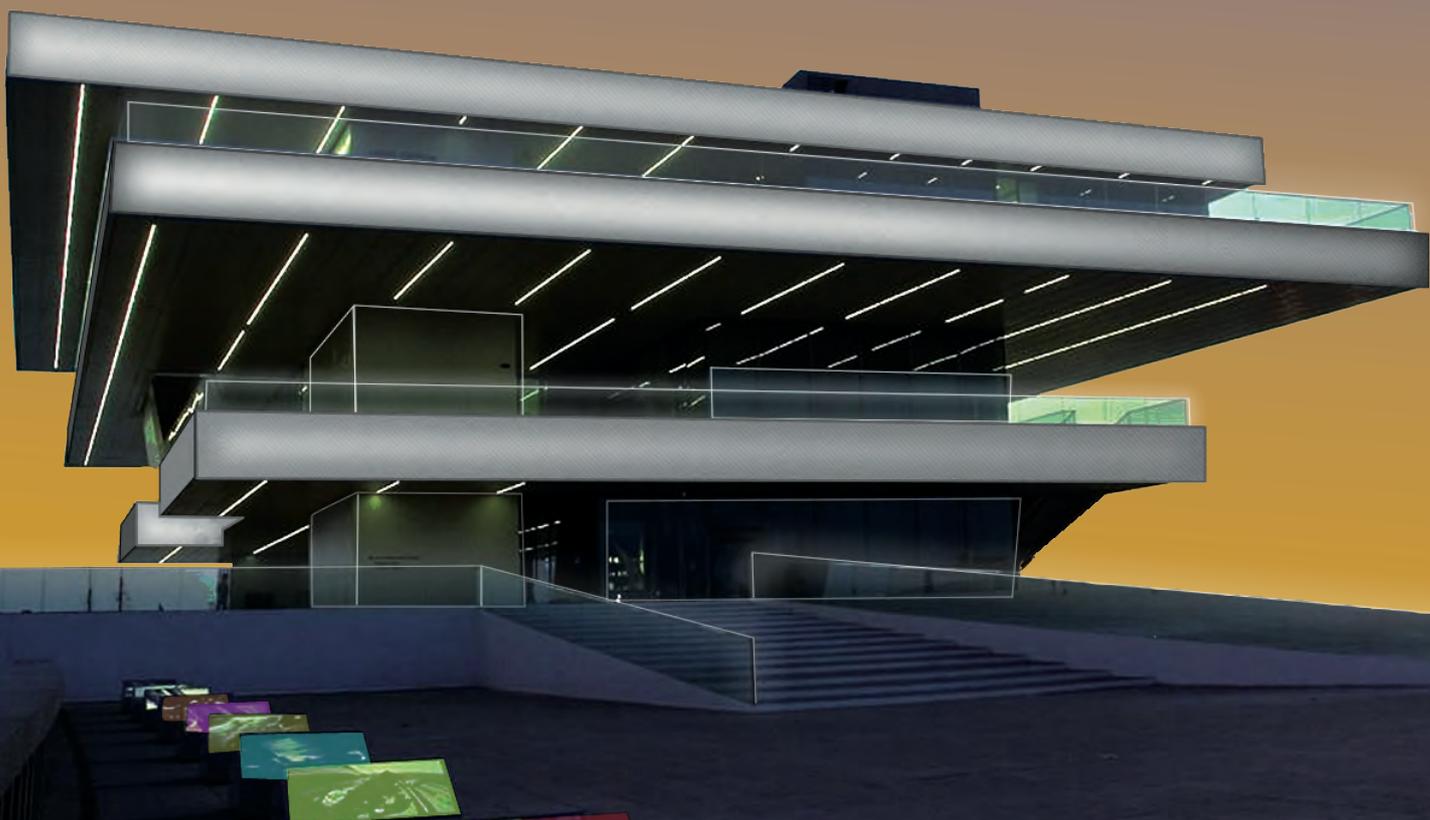


# INTED **2013**

**7th International Technology, Education and  
Development Conference**

Valencia (Spain), 4th - 6th of March, 2013.

# CONFERENCE PROCEEDINGS



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# A NEW RESOURCE IN THE TEACHING OF A COMPUTER VISION AND ROBOTICS SUBJECT

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## Abstract

In the field of mobile robotics, the task of building a map of the environment where the robot moves is a very important step during the design of any application that requires the robot to move autonomously. The most important features concerned in map building are deeply studied in advanced subjects about robotics. As this topic is currently being developed by many researchers and new methods are being implemented, it is necessary to provide students with a tool that allows them to understand how these methods work and how they can configure them to optimize the map built.

In this work, we present a tool we have developed to be used in a computer vision and robotics subject (in a PhD degree). Using this tool, the student will be able to test and understand many map building concepts in robotics, using visual information and appearance-based methods. This tool offers an easy and intuitive graphical interface that guides the student through the configuration of the algorithms. Some databases have been added to this tool. Each of them is composed of a set of real indoor images, captured in a real environment under realistic lighting conditions. Thanks to this software, the students can learn how this family of methods works and the importance of a good choice of the parameters to get accurate results.

Keywords: Computer vision, mobile robots, appearance-based methods, educational software, higher education.

## 1 INTRODUCTION. VIRTUAL LABORATORIES IN MOBILE ROBOTS AND COMPUTER VISION

Nowadays, the presence of robots around us is continuously increasing both in our houses and in the factories. They have appeared in such environments to carry out some tasks that are unpleasant for us. However, it is necessary these robots have a high degree of autonomy to be able to develop correctly in the environment where they have been designed to work.

Very often, it is necessary that the mobile robot is able to know where it is located and to calculate how to arrive to the target points to complete the task it is developing. With this aim, the robot must keep an internal representation of the environment where it evolves. We name this representation a 'map of the environment'. The use of computer vision to create a representation of the environment is very extended due to the good relationship quantity of information / cost that the cameras offer. The research developed during the last years in the topic of map creation using visual information is enormous, and new algorithms are published continuously. This way, both computer vision and robotics constitute two fields in engineering which are in a continuous development and that permit solving with robustness tasks that imply the autonomous movement of a robot in a real scenery [1].

In a subject of our PhD degree, in the Miguel Hernandez University (Spain), there is an optional subject where these topics are studied. Students learn how the information extracted from a set of images captured by the robot can be used during the map building and localization process. The students study some classical approaches to solve these problems and the practical sessions of this subject allow the students to put into practice the theoretical concepts studied in the classroom. Traditionally, these practical sessions have been developed in the robotics laboratory. The students are proposed some tasks they have to solve making use of a robot and the visual information it captures with a camera it carries on it. The students have to implement the necessary algorithms to solve them. The main problem of these sessions is the fact that the number of robots and cameras available in the laboratory to develop and test the algorithms is limited and so the available time in the laboratory.

Our objective is to overcome these difficulties and also, to make an adaptation to the new philosophy of the European Space for Higher Education, that must be centred in the learning and autonomy of the student; it should be a less rigid system with regards to the lectures and timetables. With this aim, we are encouraged to use some new methodologies to improve the autonomy of the students [2].

We have designed and implemented a software tool that facilitates the students to reach the objectives of the subject. This software constitutes a link between the data collected by the real robots and the task the student has to carry out. This way, after an initial presence practical session, where the teacher exposes the fundamentals of the robots and the cameras, the student can develop the rest of the sessions in his house, with a flexible timetable, making use of the software we have designed. When any problem or doubt arises, students can get in touch with the lecturer through a virtual tutoring system.

The remainder of the paper is structured as follows; section 2 presents the principles the students study in the theoretical classes. In section 3, we detail how the software tool works. Section 4 presents some implementation details and, at last, in section 4, we present the conclusions of the work.

## 2 APPEARANCE-BASED METHODS IN ROBOTICS. APPLICATION TO MAP BUILDING

In this section we present a summary of the theoretical background that students learn about appearance-based map building before starting to use this software tool.

From our point of view, the map building process consists of several phases, which will be presented along this section.

1. Capturing the images of the databases. In a real application, a robot with a camera mounted on it would travel along the environment to map. It would capture some images along this environment and this set of images would constitute the basic information to build a map or representation of the environment.
2. Computing an appearance descriptor per scene that contains the most relevant information of the image.
3. Extracting the topological or geometrical relationships between descriptors. It must be done by comparing the appearance descriptors.
4. Comparing the layout of the computed map with respect to the geometry of the original map. This final step is only necessary when we are testing a new algorithm to know if it leads to good results.

At the end of the process, the set of image descriptors and the topological or geometrical relationships between them will constitute the map of the environment. In the next subsections we develop these steps

### 2.1 Images databases

To test the map building algorithms, we have captured several databases with images from different environments. The image databases we have used to carry out the experiments belong to the Technique Faculty of Bielefeld University [3]. These databases consist in a set of omnidirectional images captured from a set of points situated on a regular grid. We have transformed these omnidirectional images into panoramic images. The main features of these databases are shown in table 1.

Table 1. Relevant parameters of the image sets used in the mapping experiments.

Environment	Size (images)	Resolution (pixels)	Grid step	Environment size
Laboratory	9x16	56x256	0.3 m	2.4x4.5 m
Main Hall	9x19	56x256	0.5 m	4x9 m
Kitchen	11x8	56x256	0.1 m	1x0.7 m
Living	21x10	56x256	0.1 m	2x1 m
Hall	35x10	56x256	0.1 m	3.4x0.9 m

## 2.2 Computing the appearance descriptor of each image

In the appearance-base approaches, all the necessary comparisons between images to build the map are implemented using the information of the whole images, without extracting any kind of landmark. However, working with the entire images presents a very high computational cost, and also large memory requirements. As an intermediate step, in the appearance-based approaches, it is necessary to build a descriptor that retains the most relevant information of the images in a lower dimensionality.

Fourier representations constitute a traditional way of describing the images when working with panoramic scenes [4, 5]. Among these representations, the Fourier Signature presents two interesting properties. The most relevant information concentrates in the low frequency components of each row, and it presents rotational invariance, what is very interesting in robot localization applications [6]. Further information can be found in [7].

When we work with the appearance of panoramic images, it is necessary to take into account the fact that appearance is influenced both by the position and shape of the objects and the illumination conditions. The appearance of an object in an image can vary strongly depending on the illumination systems and the lighting level of the scene (whether it is artificial or natural and the part of the day when the images were captured). It is therefore necessary to implement a mechanism that allows us to work independently of the lighting conditions of the environment.

The application of several kinds of filters to the images offers us invariance with respect to the illumination of the scene in object recognition tasks. In these applications, the student may choose to apply a homomorphic filtering. It has shown a good performance in removing the contribution of changing lighting conditions in the scenes [8].

After this process, each image is represented by a vector  $d_i, i \in \{1, \dots, n\}$  where  $n$  is the number of images of the environment to map. The size of each vector is  $s \times r$ , where  $s$  is the number of rows of the panoramic images and  $r$  is the number of Fourier components retained to build the descriptor.  $r$  is a configurable parameter. The larger is  $r$ , the most information is retained from the scenes but the higher is the computational cost.

## 2.3 Computing the topological or geometrical relationships between descriptors

In this application, we propose the students to use a mass-spring-damper model to build a topological map of the environment where the images' layout matches up with the original layout. Each image acts as a particle  $P_i, i \in \{1, \dots, n\}$  whose mass is  $m_i$ . Each pair of particles  $P_i$  and  $P_j$  are joined with a spring  $S_{ij}$  with elastic constant  $k_{ij}$  and a damper, with damping constant  $\kappa_{ij}$ . If the value of the elastic constants is proportional to the distance between image descriptors, then, when this particle system evolves freely to the balance, it is expected that the final layout of the particles is similar to the real layout where images were captured. In our experiments, we make the natural length of each spring  $l_{ij0} = D_{ij}$ , where  $D_{ij}$  is the Euclidean distance between the descriptors of images  $i$  and  $j$ .

Taking into account the resulting force on each particle, the position of this particle can be updated by applying iteratively the following expressions:

$$\begin{aligned}\vec{a}_i &= \vec{F}_i / \vec{m}_i \\ \vec{v}_i(t + \Delta T) &= \vec{v}_i(t) + \vec{a}_i(t) \cdot \Delta T \\ \vec{r}_i(t + \Delta T) &= \vec{r}_i(t) + \vec{v}_i(t) \cdot \Delta T\end{aligned}$$

Where  $\vec{a}_i, \vec{v}_i, \vec{r}_i$  are respectively the acceleration, velocity and position of the particle  $i$ , whose mass is  $m_i$ . The parameter  $\Delta T$  that appears in these equations has a significant relevance in the necessary time to tend to balance and in the accuracy of the final particle distribution. It is desirable this parameter to take a relatively high value along the initial steps, when the particles may be far from balance and they should move quickly. However, as the system tends to balance, this parameter should be given a lower value as the particles are expected to be nearer their final positions. We

propose to set a maximum number of steps,  $s_{tot}$  and we make  $\Delta T$  to change along the process. ( $s$  is the current step in this process):

$$\Delta T = \xi \cdot \left( 1 - \frac{s}{s_{tot}} \right)$$

A good choice of the parameters  $\xi$ ,  $k_{ij}$  and  $\kappa_{ij}$  is important for the convergence of the system and to arrive to a good distribution of the balanced particles. The elastic constants are important because they have influence in the speed of the particles while they tend to balance. On the other hand, the damping constants have an important role in the convergence of the mapping process. Thanks to them, the change in the positions of the particles between two consecutive iterations is not a sudden process and the system tends to balance gradually.

At last, the process followed to build the map depends strongly on how the images arrive along the process. When all the images are available before the mapping process begins and we have no information about the order they have arrived in, a batch mapping approach must be used. In this approach, all the particles are given random initial positions, and then we allow the system to tend to balance to form the final map (fig. 1). We consider the system has arrived to balance when the sum of movements of all particles is under a threshold. On the other hand, if the images are captured gradually and the mapping process must start before the whole set of images is available, an incremental approach must be implemented. In this approach, the map can be built online, as the robot is going through the environment. When we have a balanced set of particles and a new particle (image) arrives, first we allow this new particle to tend to balance, while maintaining the position of the other particles still, and when it arrives to balance, we allow the whole system to tend to balance (fig. 2).

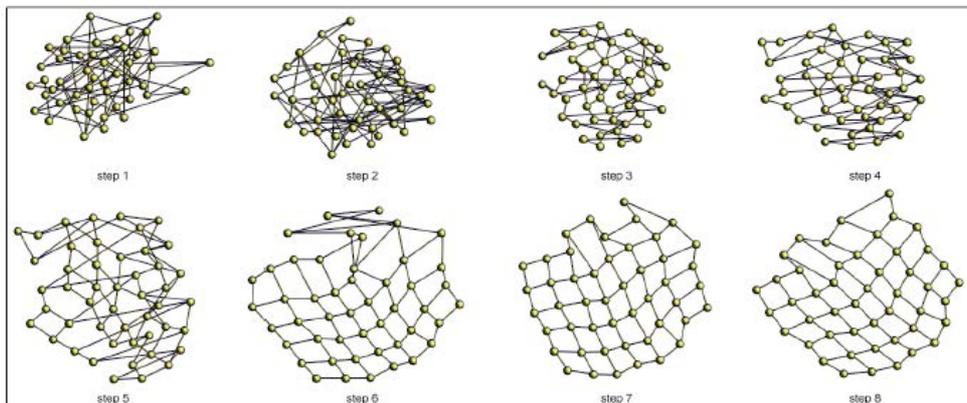


Figure 1. Example of some intermediate steps during the batch mapping process. In step 1, the particles are situated at random positions, and as the process advances and particles tend to balance, their distribution tends to be similar to the real one.

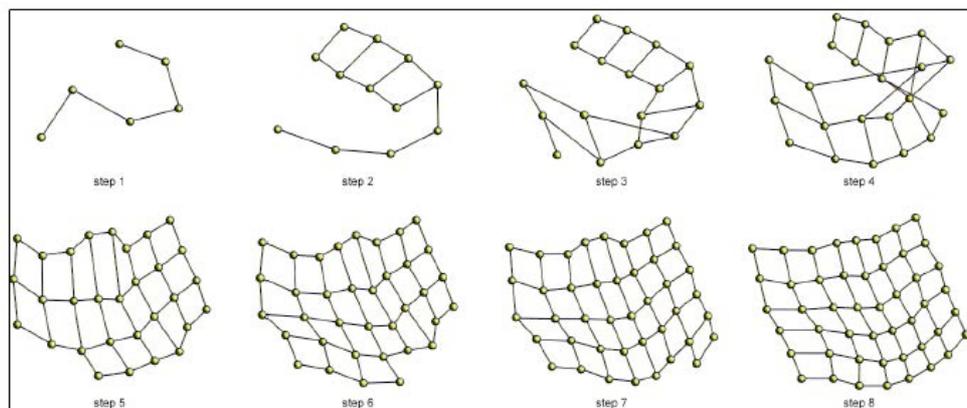


Figure 2. Example of some intermediate steps during the incremental mapping. In step 1, the new particles are added gradually to a previously balanced map in each step.

## 2.4 Shape difference between the original and the resulting map layout

Once the map is built, to test the accuracy of the algorithm we must evaluate how similar are the computed layout and the real layout of the captures. As the only information we have to build the map is the distance between Fourier descriptors, the resulting map is expected to have a similar shape comparing to the original grid but with a scale factor, a rotation and a possible reflection. Our tool makes use of a method based on the Procrustes analysis [7]. This analysis allows us to compare two sets of points while removing these effects and, as result, it provides a parameter  $\mu \in [0, 1]$  that is a measure of the shape correspondence between the sets of points. The lower is  $\mu$ , the more similar are the two sets. We name this parameter  $\mu$  'Topological error' [9].

## 3 DESCRIPTION OF THE TOOL

In this section we present a detailed description of the performance of our application. Our general philosophy while designing this tool was the simplicity of use. We try to guide the user during the whole process and take into account that it is possible that the user may not be an expert in the autonomous robot field. The final objective of the tool is to provide the students with a set of real databases of omnidirectional images to understand and test the feasibility of an appearance-based topological mapping approach using a spring-mass-damper system to create a map of the environment.

### 3.1 User's manual

We use MATLAB [10] to develop the application. It is necessary the student run first MATLAB in his computer because the application must be launched from this program. When it starts running, a graphical interface appears. All the necessary actions can be carried out through this interface. The appearance of the graphical interface is shown in fig. 3. In general, this figure shows all the necessary options to build the topological map, a bird's eye view of the real map distribution of the images, the final topological map obtained with the algorithm and the topological error. The topological map is updated step by step so that student can understand the method.

From now on, we describe the steps that must be carried out during a common sequence of use of the tool and the options it provides to the students. The first step consists in configuring the parameters of the database that the user wants to use to build the map. This step allows him/her to choose from five different images databases (table 1). Also, he/she can choose between the batch and the incremental options to build the map. Finally, it permits choosing between different distributions within a image database. To compute the distribution of the original map, the student must choose the number of images in each axis of the system and the distance between them (fig. 4).

In the second step of the process, the student has to choose the number of Fourier components ( $r$ ) used to compute the Fourier Signature of each panoramic image in the database. With this parameter the user will be able to understand the importance of the compression level in the final result of the experiment, and the necessity to find an appropriate number of Fourier components for the mapping process to work appropriately (fig. 5 a).

Finally, the student has to choose the parameters involved in the spring-mass-damper system. First, the user has to choose the maximum iterations per particle ( $s_{tot}$ ) and the mass of each particle ( $m_i$ ) and test the importance of this parameter both, in the time necessary to build the map and in the shape of the map obtained. Once the user has chosen that parameters it is necessary to adjust the time increment for the movement of the system ( $\xi$ ) and the value of the constant  $k_{ij}$  of the spring and damper ( $\kappa_{ij}$ ) to simulate the performance of each spring in the forces system (fig. 5 b).

Once all the parameters have been selected, the user will press the 'Start' button to begin the mapping process. During the process, the students can appreciate an interactive evolution of the spring-mass-damper topological mapping algorithm performance. The student can see the topological map (blue points in fig. 3) in each step of the process. When the student has chosen the incremental method, the process gradually adds new positions on the map and stabilizes them. In the opposite case (batch mapping), all poses are added in the first moment in random positions and then, the system is allowed to tend to balance. In addition the topological error in the map building ( $\mu$ ) is computed and shown at the end of the process (fig. 6b). Finally, the user can pause the process by

pressing the 'Pause' button and later continue with it by pressing the 'Continue' button, or reset the process by clicking on the 'Stop' button.

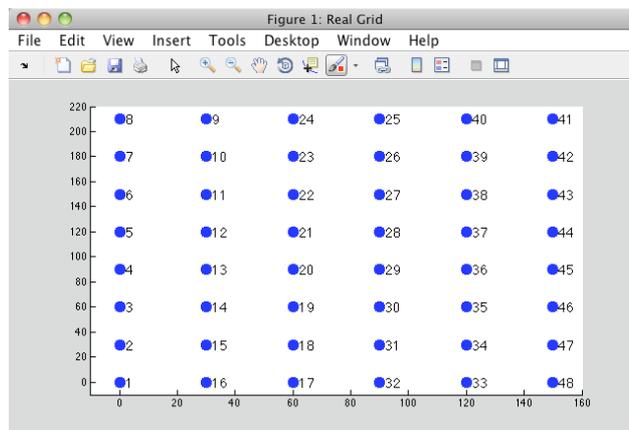
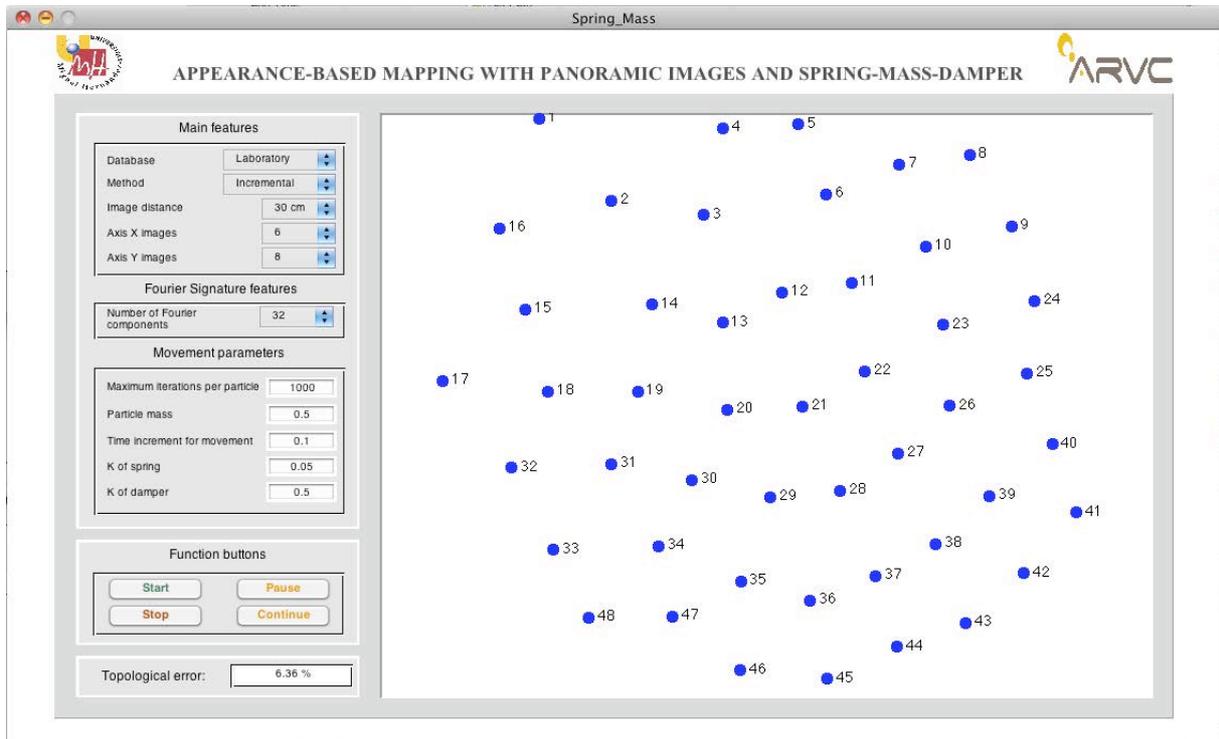


Fig. 3. Appearance of the graphical interface of the application.

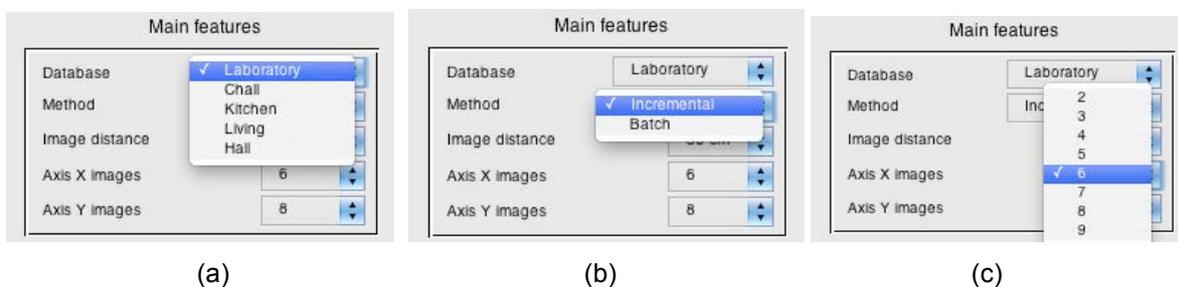
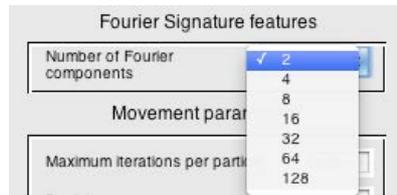
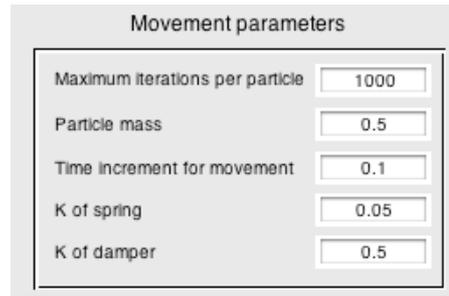


Fig. 4. (a) Databases the user can choose, (b) map building methods the user can use and (c) number of images in each axis the user can choose to do the experiment.

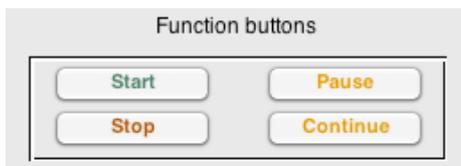


(a)



(b)

Fig. 5. (a) Number of Fourier components the user can use and (b) movement parameters the user can configure to do the experiment.



(a)



(b)

Fig. 6. (a) The function buttons the user can use during map building and (b) the topological error of the mapping problem the user gets at the end of the process.

## 4 IMPLEMENTATION DETAILS

The implementation of the application has been made by employing a mathematical software tool that allowed us to make complex mathematical operations in a short period of time, allowing us to develop a user interface that simplified the use of it. With this purpose we decided to use MATLAB (MATrix LABoratory), mathematical software that offers an integrated elaboration environment with its own programming language (M-language) [10].

### 4.1 MATLAB

MATLAB was created in 1970 by Cleve Moler. It is a high-level language and interactive environment that allows us to perform computationally intensive tasks. MATLAB can be used in an extensive range of applications such as communications, control systems design, signal and image processing, financial analysis and computational biology, etc. MATLAB includes vector and matrix operations that are primordial to solve scientific and engineering problems.

MATLAB incorporates a large number of graphic functions for visualizing data and also includes a large number of mathematical functions, such as those to solve linear algebra problems in an optimal manner, which enable us to perform Fourier analysis in a reasonable computational time.

### 4.2 GUI

We can design a graphical user interface in MATLAB through the tool GUIDE (Graphical User Interface Development Environment). With this tool we can add push buttons, radio buttons, selection lists, dropdowns, and sliders, as well as ActiveX controls and plots. The creation of a graphical user interface by GUIDE in MATLAB gives as a result two files, *matlabguide.fig* and *matlabguide.m*. The first one contains the graphical part and allows us to make the design of the appearance of the user interface. The second one is the program code, including the functions and command used by the application.

When we add a new push button or other object in the graphics window we have to write the code associated to that object in the suitable part of *matlabguide.m*. On the other hand we can also request the status of the properties of some objects in the graphics windows at each instant or change these properties if we need it.

### 4.3 Main functions

The objective of this section is to outline the most interesting MATLAB mathematical functions we have used in our code for the application. One important function is *imread.m*, which allows us to get an  $M \times N \times 3$  matrix of each image in the database and thanks to it we can work with the images as matrices. Another important function within the library of MATLAB functions correspond to *fft.m*, used to obtain the FFT (Fast Fourier Transform) of a sequence of numbers.

To filter the images we use *homofilter.m*. It has been developed by us, as it has not been found in the library of MATLAB functions. It returns a filtered image using a Homomorphic filter. With regards to the movement of poses in the map, we have used the function *random.m* to give a random initial location at each pose of the map.

In addition we have used a function that allows us to obtain the topological error between the real map and the map obtained with our methods. The function used is *procrustes.m* ( $\mu = \text{procrustes}(X, Y)$ ) and determines a linear transformation (translation, reflection, orthogonal rotation, and scaling) of the points in matrix  $Y$  to best conform them to the points in matrix  $X$ . The function returns the minimized value of this dissimilarity measure in  $\mu$ .

To finish, we have used two functions to make possible the interaction between the graphical interface and the application code, *get* and *set*. The first one obtains the status of any of the properties of an object in the GUI. The second one allows us modify any property of a GUI object. Thus, with both commands, the interaction with the user is performed.

## 5 CONCLUSIONS

This work presents a software tool we have designed to be used in a robotics and computer vision subject in a PhD degree. In this subject, the students learn techniques for map building and localization of mobile robots using the appearance-based information extracted from the images captured by the camera the robot carries on it.

Thanks this tool, the students can fully understand the appearance-based approach in robotics mapping and can experience the localization process with real data. The main features of the tool are:

- Some databases with panoramic images (both grey-scale and colour) of several real environments are included. With these images, the student can test the algorithms they have learned to build the map.
- We have implemented a method to compress the information of the images, based in the discrete Fourier Transform of images.
- We have implemented an algorithm to build a map using an approach based on a set of forces created by some virtual springs among the images the robot has captured along the environment. Students can test how some parameters affect the final map this algorithm computes.
- The student can test how the degree of compression of the visual information affects to the final map.
- The tool is fully interactive. It shows the map building process step by step graphically and, at the end, it shows the layout of the final map and it gives a measure of the error.
- As all the databases included have been captured in real environments under realistic lighting conditions, the tool allows the students to face a real problem and experience the troubles that would outcome in a real application.

This way, we provide students with a tool that allows them to freely test and improve the algorithms they learn in the classroom. The tool has demonstrated to be useful for the students to understand the mapping algorithms and other basic concepts in mobile robotics and computer vision. We expect that, thanks to this tool, the students are able to design and develop new algorithms in map building and localization.

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