PLANAR MAP AND 3D MODEL CONSTRUCTION USING A MOBILE ROBOT

Tommaso Gramegna, Giovanni Attolico, and Arcangelo Distante

Abstract— **Building the planar map and a 3D model of the environment is a fundamental task for a mobile robot that , using several and properly configured equipments and appropriate software modules, can reach these goals with high precision and in an automatic way. Such capability can increase the efficiency and the quality of 3D reconstruction not only in challenging environments (caves, mines, …) but also in reverse engineering in construction, useful also for monitoring and maintenance applications. An experimental session has been performed in corridor of the ISSIA–CNR institute. The mobile vehicle used is composed by a mobile robotic platform equipped with a laser range finder, sonar sensors, a video camera, inclinometers, a compass and an antenna for the wireless communication between the robot and a remote computer. Using all these devices, and suitably integrated software modules, by navigating in the laboratory it is possible to obtain two-dimensional planar reconstruction of the site and to recover the 3D structure of some zones of particular interest.**

Index Terms— **Autonomous Robot Navigation, Range Sensing, Planar Map Construction, 3D Reconstruction.**

I. Introduction

Mobile robot localization and environment mapping have been important research topics for the past years. Now, the state of the art is referred to as Simultaneous Localization And Mapping (SLAM), where a map of the environment is built and the robot is localized therein, simultaneously. Traditionally, most approaches use precise distance sensors, such as laser range finders. Often, due to the properties of the sensors localization, the environment is described in terms of 2D maps, restricting applicability to planar structured environments, such as offices and corridors.

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Vision sensors are capable of providing much more information and can be seen as the best sensing modality for mobile robots. The data provided by a single camera is essentially 2D but, using stereo cameras or monocular image sequences, full three-dimensional information can be reconstructed.

Reconstruction from images is a thoroughly investigated topic in computer vision. The major obstacle for extensive use of vision sensors is computational complexity. But with the increase in computing power we experienced in the past few years, full real-time spatial information from cameras seems to be within our grasp in the near future.

In this paper we present a technological solution using a properly equipped mobile robot that performs the 2D map building using a laser range scanner during the autonomous robot navigation and the three dimensional reconstruction of some zones of particular interest using a computer vision technique.

The mobile robot used for the experimental session performed in the corridor of the ISSIA–CNR institute is composed by a mobile robotic platform equipped with a laser range finder, sonar sensors, a video camera, inclinometers, a compass and an antenna for the wireless communication between the robot, with its sensors, and a remote computer.

The four tractor wheels can climb a 45% grade and sills of 9 cm. Sixteen forward and rear sonar sensors detect obstacles up to 7 m for and preserve the site and the vehicle. The robot case contains four motors, a local processor and the batteries. On the top of the robotic platform it has been installed a laser range finder able to sense objects at a distance up to 80 m with a resolution of 0.5° (360 readings on 180°). The all-terrain robotic platform is also equipped with a compass, inclinometers and one-hundred tick encoders with inertial correction recommended for dead reckoning to compensate for skid steering.

Above the vehicle has been placed a support with appropriate height carrying a pan-tilt-zoom camera. The structure is in aluminum in order to be, at the same time, light and robust. It is one meter high to acquire the image of interest from an appropriate viewpoint.

Using all these devices during the inspection of the site it is possible to obtain its two-dimensional planar reconstruction and to recover the three dimensional structure of some zones of particular interest.

Firstly the planar map of the inspected environments is obtained using the laser scanner mounted on the robot platform. The high accuracy of about one millimeter allows to build accurate planar maps especially when the robot moves on a plane.

Another application performed in this experimental site is the reconstruction of the full three-dimensional Virtual Reality Modeling Language (VRML) model of some zones of particular interest. We have used a computer vision technique for the 3D reconstruction of a scene starting from a set of three images of the scene. The only geometrical constraints are the correspondences between feature points in different images that must be acquired by the same camera with a fixed focal length.

The paper is organized as follows. Section 2 deals with the construction of the planar map of the corridor of the ISSIA–CNR institute. The section 3 presents the method used for the 3D reconstruction of the entry point of the institute using a set of three different images. Finally, some conclusions are drawn.

II. Construction of the Planar Map

Mapping environments is a fundamental task for the reverse engineering in construction and is useful also for monitoring and maintenance applications.

Due to the characteristics of the reverse engineering, maps of the environments are usually not available or not usable for robots, therefore a critical step is the generation of a map of the explored environment in order to both localize itself and recognize places that have already been explored.

This turns the problem of building a map in a problem of on line simultaneous localization and mapping (SLAM), since the robot has to concurrently estimate its position (in order to provide consistent maps) and build a map of the environment.

As many works on SLAM have shown [1]-[3], the best setting for building maps in indoor environments is to use a wheeled robot equipped with a laser range finder. The high accuracy of about 1 mm allows to build accurate planar maps especially when the robot move on a plane.

The platform used for these experiments was an Activmedia P3AT mobile robot equipped with a SICK LMS 200 laser scanner (Fig. 1).

Fig.1: Activmedia P3AT mobile robot exploring the corridor of the ISSIA–CNR institute.

In this system, the planar information of the site is obtained during a random tour in automatic way within the corridor of the ISSIA–CNR institute with the laser beam oriented towards the wall of the institute. People crossing the corridors of the institute during the experimental session don't cause errors in the planimetric reconstruction of the site because the robot it is able to separate moving obstacles from the structure of the corridors.

The largest map acquired by the robot is shown in Fig. 2. It is composed by 429 frames scanned by the laser in the building of the Italian National Research Council, located in Bari, and covering an area of approximately 23x15 m. The scan time has been less than 7 minutes.

The same robot platform is used for the inspection and the planar reconstruction of a cave [4]. When the robot does not move on a planar area, the solution of the SLAM problem becomes more complex.

The robot pose space comes from $R^2 \times SO(2)$ to $R^3 \times SO(3)$, that is from three to six dimensions. The laser range finder, that can be safely used in planar environments loses its effectiveness, since it is able only to detect obstacles lying on the scanning plane.

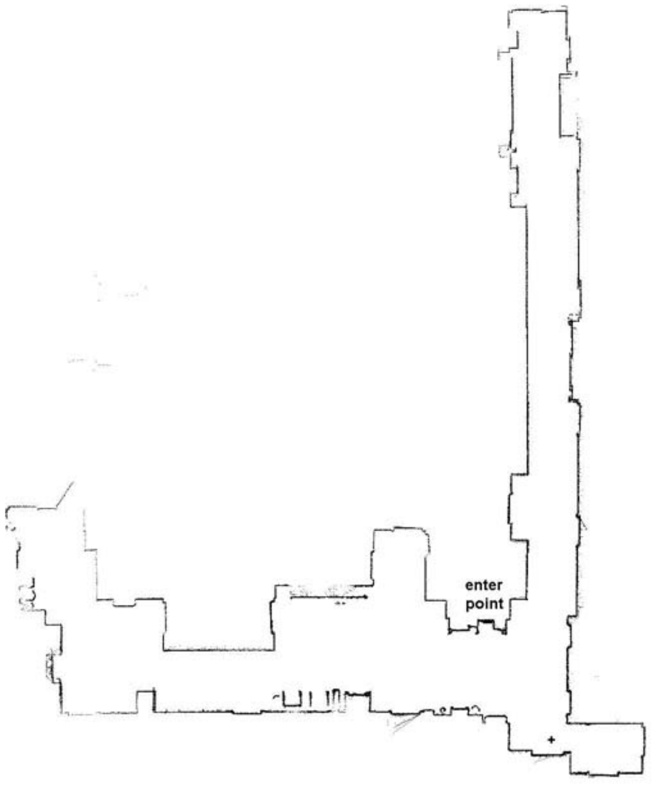


Fig.2 Planimetric map of the corridor of the ISSIA–CNR institute reconstructed during the robot navigation.

In this case due to the irregularity of the ground characterized by depression and bumps, it is necessary to integrate the laser data, supplying planar information, with the inclinometer data in order to obtain a 3D information about the environment scanned. The results obtained in this experimental session [4] can confirm the applicability of this technological solution even for the construction of the planar map in outdoor environments characterized by depression and bumps.

III. 3D MODEL RECONSTRUCTION TECHNIQUE

Another application tested during the experimental session in this site has been the reconstruction of full three-dimensional VRML models of the entry point of the institute using the mobile robot platform with a pan-tilt-zoom camera at one meter high to acquire the image from an appropriate viewpoint, as it is shown in Fig. 1.

Reconstruction of 3D models using computer vision techniques generally requires to extract features (point, lines, target objects) and to match them [5]-[7]. Moreover, it is important to determine the correspondences between points in different images since the accuracy of the resulting model depends directly on the accuracy of the feature correspondences.

The method used in this paper uses, as geometrical constraints, only the correspondences between corners in different images. A complex 3D scene is reconstructed using a set of three images acquired from three different viewpoints of the same scene. The only requirement on the images is to be acquired by the same camera with a fixed focal length.

The application requires the development of the following steps:

1. Image acquisition
2. Corners extraction
3. Sparse matching
4. Inliers determination
5. Camera calibration
6. 3D reconstruction
7. 3D model visualization

Let's go trough these steps to illustrate the main aspects of each one.

The first step consists of the image acquisition that has to be performed using the same camera with a fixed value of focal length.

Feature points corresponding to high curvature points are extracted for each image using the Harris corner detector [8]. The application of the Harris technique is suitable for the extraction of image points that correspond to strongly characterized features in the three images. For this reason the Harris method is preferable to most common edge detection methods such as Canny, Roberts etc. From each of the three images acquired a prefixed maximum number of corners is extracted using the Harris detector.

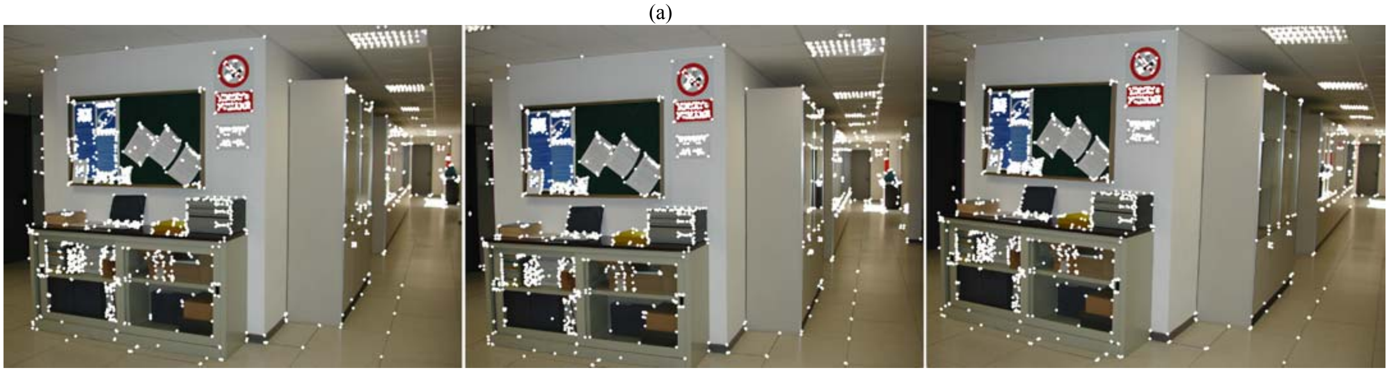
Once a set of feature points have been extracted from all the three images, a matching procedure must be performed to obtain the right correspondences between corners. The matching procedure is made up of two steps and works for each couple of images [9].

In the first step, a classical correlation technique is used to establish matching candidates between two images: a correlation score is computed for each couple of points; if the correlation score is higher than a given threshold, the couple of points is considered as a candidate match.

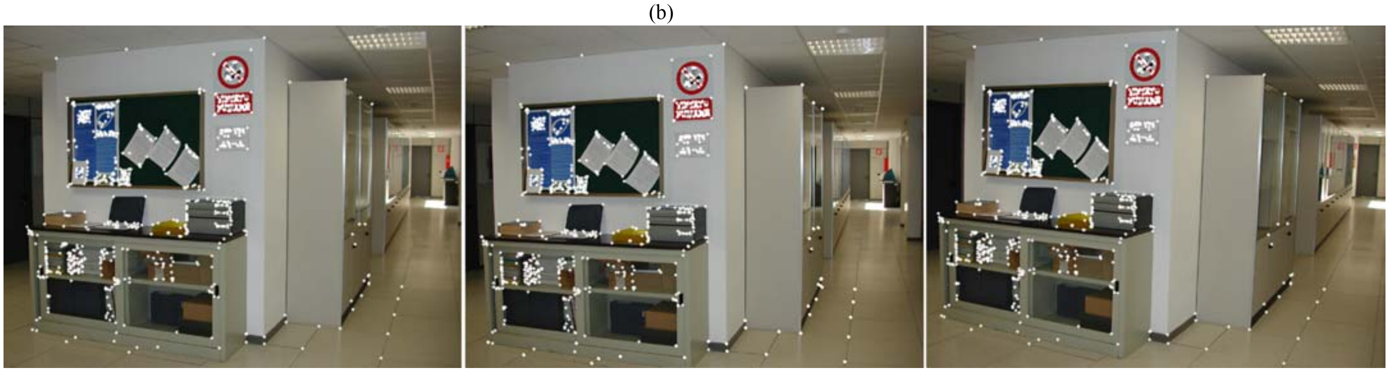
In the second step, it is necessary to disambiguate the candidate matches since a point in the first image may be associated to several points in the second image and vice versa. For this aim, a relaxation technique based on the computation of the parameter "strength of the match" can be used. It is determined on the base of the good matching of points in the neighborhood of the considered point. The strength of the match counts the number of similar candidate matches found in the neighborhoods. The minimization trough a relaxation technique of the energy function, defined as the sum of the strength of all candidate matches, solve the ambiguity problem [9].

After the determination of the corners correspondences for each couple of images, the set of corners belonging to all the three considered images is determined; these feature points are the inliers.

(a)



(b)



(c)

Fig. 3. Set of 3 images of the same scene from different points of view.
(a): 3 images of the entry point of the institute;
(b): the white points indicate the corner extracted;
(c): the white cross markers indicate the inliers extracted.

From the knowledge of the corresponding corners it is possible to determine the Fundamental Matrix and, consequently, the intrinsic parameters of the camera used [10], [11].

The Fundamental Matrix estimation methods can be classified into linear and non-linear ones; they are all based on the basic constraint set by the epipolar geometry. The methods differ for the technique used to cope with noise and outliers. For this application, the technique chosen consists in the resolution of the Kruppa equations [12], [13] through the application of genetic algorithms [14].

At this point, all the necessary data to reconstruct the 3D scene are given and the three dimensional model is reconstructed trough the application of the polygonal mesh technique.

The 3D visualization of the scene is performed using a VRML tool: a 3D surface model is obtained with a triangular wireframe and the texture is obtained from the images and mapped onto the mesh.

Here is presented an example of the reconstruction method applied to a set of images of the entry point of the institute shown in Fig 2. In the same figure the cross marker indicates the robot position.

In Fig. 3 (a) is illustrated the set of three images of the same scene from different points of view using the same camera with a fixed focal. The white points in Fig. 3 (b) indicate the corners extracted for each image using the Harris detector; the maximum number of corners to be extracted has been set to 2000. For each image 1848, 1815, and 1924 corners have been extracted, respectively. Fig. 3 (c) shows, for each figure, the 788 inliers extracted for this set of three images, indicated by the white cross markers.

Fig. 4. Textured and wireframe reconstructed scene of the three dimensional of the entry point of the institute.

The intrinsic camera parameters extracted with the calibration procedure are the followings: f_u= 3500, f_v=3500, u_0=-235, v_0=18, s=0 where f_u, f_v are the focal lengths in pixel along the (u, v) image axes, (u_0, v_0) are the coordinates of the principal point in pixel and s is the skew factor.

Fig. 4 shows the textured and wireframe reconstructed scene of the three dimensional model of the entry point of the institute.

IV. Conclusions

The application of a technological solution seems to be the best way to solve the problems of the two-dimensional map of a building and the three-dimensional model of some zone of particular interest.

A properly and equipped mobile robot platform can reach these goals with high precision and in a automatic way.

An experimental session has been performed in corridor of the ISSIA–CNR institute. The mobile vehicle used is composed by a mobile robotic platform equipped with a laser range finder, sonar sensors, a video camera, inclinometers, a compass.

Using all these devices, and suitably integrated software modules, during the navigation it is possible to obtain two-dimensional planar reconstruction of the site and to recover the 3D structure of some zones of particular interest. The map of the environment is obtained using the data provided by the laser range finder during the wandering navigation in the corridor. The points collected during the navigation using the laser scanner allow a plane map of the corridor to be reconstructed with a precision up to 1 mm.

The three-dimensional structure of particular zones of interest has been reconstructed using three pictures acquired from different viewpoints using a camera with a fixed value of the focal length.

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