LOCAL PATH PLANNING IN UNKNOWN ENVIRONMENT BY LOCAL 3D ELEVATION MAP CONSTRUCTION

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Abstract: The paper deals with the problem of computing a path for an autonomous mobile robot, provided by a stereovosion camera, trough obstacles in an unknown environment with rough ground. The planner makes use of a 3D map reporting the presence and the highness of obstacles together with the shape of the ground and its discontinuities, under the hypothesis of stationarity. A local solution, with an expanding algorithm, is proposed. Some experimental results are reported to validate the proposed technique.

1 INTRODUCTION

The path planning problem for autonomous robot platforms has been a widely investigate problem characterized by several possible approaches depending on the possible hypothesis on the environment and on the robot kinematics.

In fact, starting from the simplest problem of a robot without any kinematic constraints moving in a perfectly known and static environment, for which a global path plan for reaching any final goal stating form any initial position can be performed, for example using the Voronoi diagrams approach or techniques based on potential fields among the most famous approaches, the problem has been more and more complicated adding one or more of the following conditions: $i.$ non stationary environment, i.e. presence of moving obstacles (like other robots or humans) or different conditions on some part (like a door, that can be open or closed); $ii.$ unknown or only partially known environment, in which the presence of obstacles (moving or not) or even the possibility to reach the goal has to be autonomously discovered by the robot itself; $iii.$ the presence of some constraints on the robot motion, like nonholonomic ones due to the kinematic characteristics of the platforms (Voronets, 1901).

In the present work, the case of totally unknown environment and nonholonomic platform with unicycle-like kinematics is considered. So the problem here faced is the computation of a path (if any) between an initial position and a final one for which only the coordinates are known, without any initial knowledge on the presence of obstacles or discontinuities in the ground.

The solution of the problem involves two main aspects. The first is the choice of the robot sensors for the acquisition of the necessary information on the environment and subsequent analysis; the second is the strategy for the construction of a feasible path for reaching the goal.

Regarding the first aspect, the present choice for the sensors is to use a stereo vision system only. The hardware used in the present application is a commercial device by Videre Design, the stereo head STH-MD1. It is composed by two fixed cameras, with parallel axes, both using CMOS sensible device with 1.3 Megapixels resolution. In the used configuration, they have two lens whose focus length f is 7.5 mm. The main advantages of such a choice with respect to different ones often used, like the rangefinder (Iocchi et al., 2000) for example, is the absence of physical interaction with the environment and the similitude with the human behavior.

As far as the second aspect is concerned, since a visual system implies that only a part of the field, the visible part, at a time can be investigated, at each step of the learning approach only a local knowledge can be acquired; in addition, without a motion, such knowledge cannot be increased, since a change in the point of view is necessary to change the area in the visible field for investigation. Then, a local path planner for local motion, based on the construction of a local and iteratively expanded map, is presented.

On these basis, the first step in the proposed solution is the construction of a suitable map for rep-

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resenting the acquired information necessary for the computation of a feasible path. There are several kind of maps that can be constructed starting from distance measurements, depending also from the characteristics of the vision system used. Most of them work efficiently under the hypothesis of indoor motion. Among them there are the occupation maps, where only the position of obstacles are stored, assuming to be safe any other position on the ground (Herbert et al., 1989). But in case of unknown environment exploration it is not possible to satisfy the hypothesis of safety for unexplored areas: no regularity assumptions can be posed.

The most suitable kind of maps for the present application are the elevation maps, where the known portion of the environment is represented by the height of the ground and the objects present. On this basis, an obstacle is represented by an area whose height is significantly different from its accessible neighborhood. Such an information is enough for the determination of a possible safe path that the mobile robot can follow, since it can move in all that directions where the height is equal or a little bit different (greater or lower) according to the mechanical characteristics of the rover.

The path planning technique here proposed is based on the construction of an elevation map, according to the procedure presented in (DiGiamberardino and Usai, 2005), generated recursively on the basis of continuous image processing during the robot motion, which represents the acquired knowledge of the local environment in an increasing neighborhood of the robot.

The paper organization is then the following one. In section 2 a short description of the technique used for the construction of the elevation map is given. Section 3 is devoted to the description of the procedure proposed for the determination of a new connectivity map and, consequently, a local path: in 3.1 the map construction and in 3.2 the fina path.

2 CONSTRUCTION OF THE ELEVATION MAP

The basic algorithm adopted for the images analysis is a disparity map computation starting from a couple of stereo images. In such an algorithm the correspondence between the couples of conjugate points in the two images is achieved by means of an area-based correlation technique. It is well known that this kind of solution is very efficient for its computational aspects, but, on the other hand, it does not produce satisfactory results in presence of discontinuities in the distances of the objects present in the scene: it is sufficient that one object is partially covered and behind another one with respect to the point of view of the cameras to produce wrong results; in fact, the correlation of the area including parts of both the objects at different distances either associates the points of one object to the other or produces a false object at an intermediate distance between the two real ones. Some pre and post elaborations are needed in order to avoid such errors. In literature some techniques are proposed ((Murray and Little, 2000),(Fusiello et al., 2001)) based on a segmentation of the disparity map in order to manipulate in a different way the sections that potentially can produce the above described deformations. The result is a more clear and realistic reconstruction with the counterpart in a slower computation. In the present application we propose a different approach based on a standard (and pretty fast) edge detection algorithm, making use of the additional information coming from the motion of the robot and the continuous images acquisition. The accurate description of the algorithm for the construction of the elevation map and the measures filtering technic be found in (DiGiamberardino and Usai, 2005). In figure 4, a VRML model of an outdoor environment reconstruction is presented.

3 THE PATH PLANNING PROCEDURE

3.1 Chessboard construction

After the construction of the elevation map, in order to achieve the planning of a safe path in the environment, it is necessary to derive a new topological one, generated starting from the information stored in the elevation map and combining them with the knowledge of the mobile robot movement capabilities. Such a map is called *the chessboard*. The environment is divided into cells, storing several informations like the coefficients of the best fit plane, the obstacles presence in the cell and the fidelity of the elevation measures in the cell. Figure 5 shows an example of chessboard using a color code identification with the following meanings: light gray (green) for free cells with good measures, dark gray (red) when obstacle are present in the cell and the measures are good, darkest (blue) for cells that seems free but the measures are not enough, lightest (yellow) for apparently occupied cell associated to poor measures.

It is interesting to see how this coding is done. First of all, the best fit plane coefficients are computed by a least square approach. Then it is possible to say if there is an obstacle for the rover in the cell, comparing the founded fitting plane elevations with the ones of the true ground trend. In particular, the cell is free if the difference of the ground elevation and the fitting plane is always smaller than h_{max}, that is the height of the taller obstacle the rover is able to pass (figure 1). Note that a free cell has to be considered occupied if its slope is to high for the rover. Lastly, the fidelity of the elevation measures in the cell are computed thresholding the veridicity value corresponding to the measures of the cell.

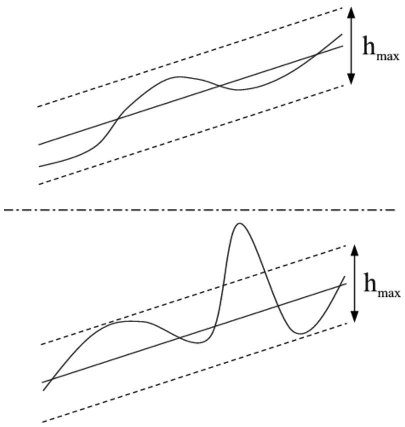

Figure 1: The cell obstacle detection condition.

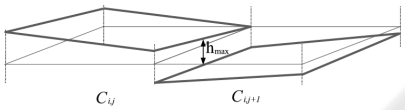

Figure 2: The cell connection condition.

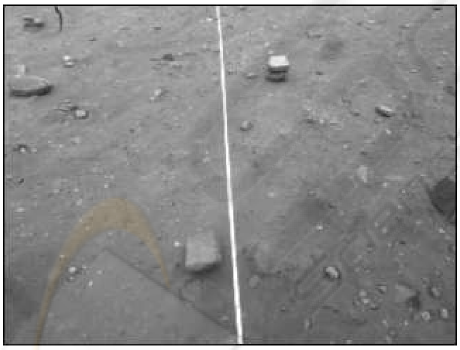

Figure 3: Example of an outdoor environment.

3.2 Path planning

After the chessboard is builded, it is possible to derive from it a connectivity graph, useful for the mobile robot path planning. In order to reduce the number of nodes of the graph, grouping similar cells, a third data structure is derived from the chessboard. Such a structure is a classical occupancy grid, where the "pixels" are marked occupied if:

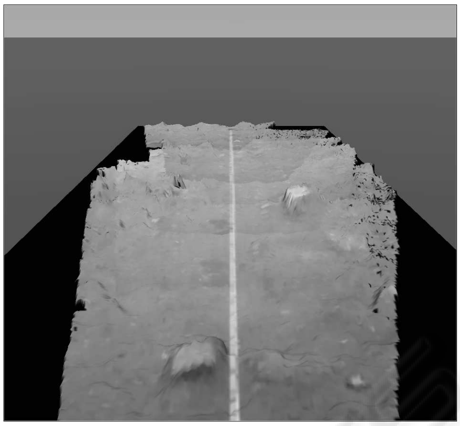

Figure 4: Example of an outdoor environment reconstruction.

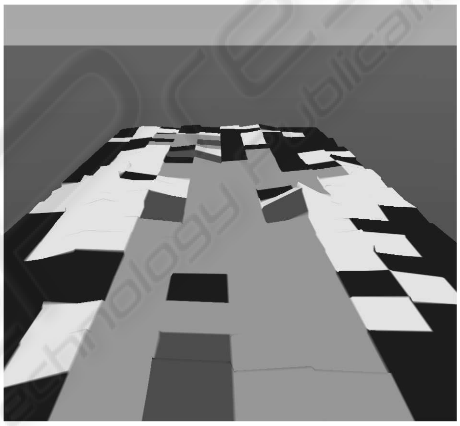

Figure 5: The Chessboard.

- The corresponding cell in the chessboard is occupied;
- The corresponding cell in the chessboard has not reliable measures;
- It corresponds to the frontier between two free cells with a too high difference in height to be passed by the robot (look at the connection condition in figure 5).

After this (binary) occupancy map is builded, it is necessary to augment the founded obstacles according to the robot dimensions and filling the possible "holes" left by the obstacle augmentation process (think at those regions that cannot be reacted by any other cells). In figure 6 it possible to see the planes approximation concerning a chessboard computed by the elevation map of an environment with two obstacles. As just noticed, from the chessboard we want to derive a simpler binary map. In figure 7, it is shown an example of this data structure. Note how the number of cells here is less than the one in the chessboard (figure 8). To divide the configuration space in "big"

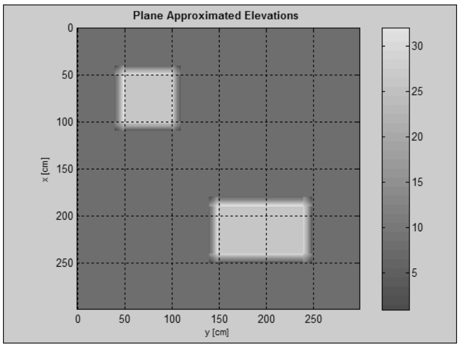

Figure 6: Example of planes approximation for an environment with two obstacles.

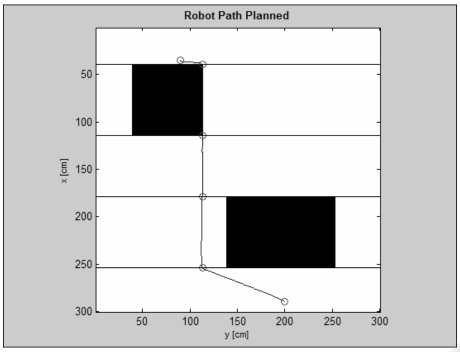

Figure 7: The path planned by the proposed method.

convex cells, the occupancy grid is scanned line by line and, whenever a "change in color" is found, a new horizontal frontier is marked. Once the new cells are found, a connectivity graph can be used to find which cells are involved in a specified path from P_{start} to P_{goal}. The path is then generated using splines that connect the border points of each cell. Such points are choose trying to minimize the distance from the previous via-point in order to keep the path as short as possible. In figure 7 and in figure 8, it is possible to see the planned path in the occupancy grid and in the chessboard. Note that we are interested in the exploration of the environment. So, in could be possible that some areas of the chessboard are unknown (or better, the measures are not reliable). As noted before, the not reliable cells (the ones with low veridicity rate) in the chessboard have to be considered not feasible for the robot motion. If a planning to a unknown area is required, the robot will plan until an auxiliary point, in the known area, is reached and then a new stereohead acquisition is done, pointing the direction of the desired destination point. The auxiliary point is chosen in order to stay at the minimum sight distance (about $50cm$, in our configuration) from the frontier of the unknown area. A new path is then planned from the actual point to the previously desired one.

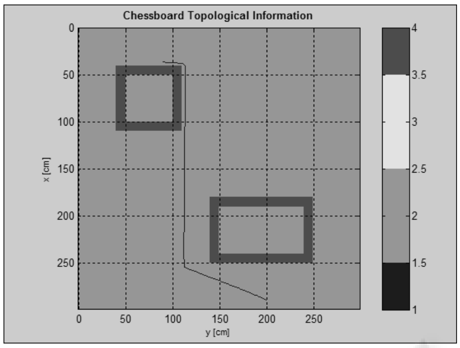

Figure 8: The path imposed over the chessboard.

4 CONCLUSION

In this paper a procedure for the determination of a local map and a feasible path for a robot moving in an unknown environment is presented. It consists of two main steps. Some figures show the results of each step and then the effectiveness of the procedure. Future work will focus on the evolution of the proposed technique for global path planning.

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