A CNN PATH PLANNING FOR A MOBILE ROBOT IN AN ENVIRONMENT WITH OBSTACLES

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In this paper a method for visual control based on images of a mobile robot in an environment with obstacles is proposed. Cellular Neural Networks are used here for path planning of a mobile robot, in real time.

1 Introduction

An important issue that can be found in robotics is the path planning for a mobile robot in an environment with obstacles, where the trajectory starts from an initial point in the workspace and it ends at the desired position called target. There are several solutions for this issue. These solutions are determined using, very often, one of the following methods [3,4]:

a) Path planning or robot navigation using a global method.

The global method is related with the superior hierarchical level in the robot control theory. Using this method, the optimal trajectory is obtained by avoiding the static and moving objects, known in the workspace. The global methods are often based on mapping the environment and they approach the problem only from a geometrical point of view.

b) Path planning or robot navigation using local methods.

The local method could be related to the inferior hierarchical level in the robot control theory. In this case the robot control could be obtained using the prescribed trajectory determined through a global path planning method. Using local methods, unknown static or moving obstacles are avoided, compensating the uncertainty of data sets given by the global method. Local planning or navigation takes into account, the kinematics and also the dynamics of a robot, because this planning is based on the information obtained from signals, which can be processed in real time. But, using only local information the optimal solution for the prescribed trajectory is not guaranteed and it cannot be started if the target is reached. These two approaches are often used together, namely the global planning is used for achieving a possible trajectory and local navigation is used for local optimization of the trajectory and for avoiding unexpected obstacles. For local navigation, "graph" methods or "fields of potential" methods can be used.

Cellular neural networks (CNN) can be successfully used in a wide spectrum of applications, starting with modeling of biological phenomena, image processing, navigation a mobile robot, etc., [1,2,5,6]. The environment with obstacles is put into a discrete image and this way it is possible to represent the workspace through a standard network having M*N cells. The values of pixels for gray-scale images are in the interval [-1,1], known as the standard domain in CNN. For binary images, these values could be only +1, for the black pixels and −1 for white pixels.

2 The visual control based on images of the mobile robot

In the current application, the mobile robot is in a plane workspace in which they are only static obstacles (Fig. 1). A single camera does the observations in the environment with obstacles.

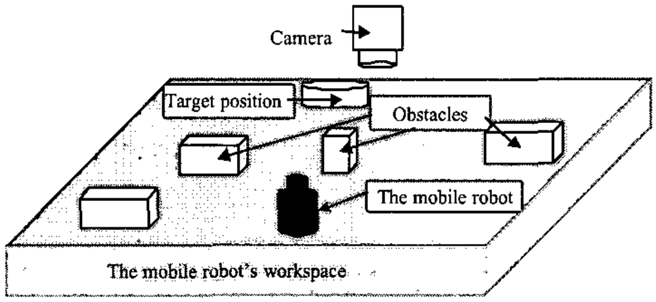

Figure 1. The workspace of the mobile robot with visual control.

The real images of the workspace are captured in discrete moments. (t_0+kT), beginning from the initial moment t_0, having a sampling step T and k being considered a natural number, $k \in N$. For a given input image, in between two successive sampling moments steps, all the processing steps of the algorithm must be done. Then, a new image of the workspace can be captured only if all the processing steps of the algorithm are made. If the environment contains static and also moving objects, then it is important that the processing of signals to be made fast, in real time. Namely, if the visual control of the robot is cyclically repeated by following the steps of the global algorithm, then the target position could be considered as fixed, and the start position could be related with the current position of the robot from the last image that was captured. Another case could be also considered, namely the case in which the target object changes position from one sample to another of the captured image, but only if image processing speed is high enough to obtain the control signal of the robot.

3 Path planning for the mobile robot moving in between two points from the environment with obstacles

In Fig. 2 the algorithm for path planning is described. The image processing steps of this algorithm are done using space-invariant cellular neural networks having templates of 3*3 dimension. The input image is considered as a binary image. This image is obtained through elementary CNN processing for a gray-scale image that represents the workspace. In the binary image obtained, the pixels having +1 values mean the forbidden positions in which the robot cannot move, and the pixels having -1 values are representing the positions in which the robot can navigate in the workspace.

3.1 Distance evaluation in between points from the workspace and the target point

In this step of the algorithm, in the image plane a wave is generated. The origin of the sources, which generates the wave, is the position of the target point. Through its propagation, the wave searches all the possible directions in the environment, starting from the target point (Fig. 3).

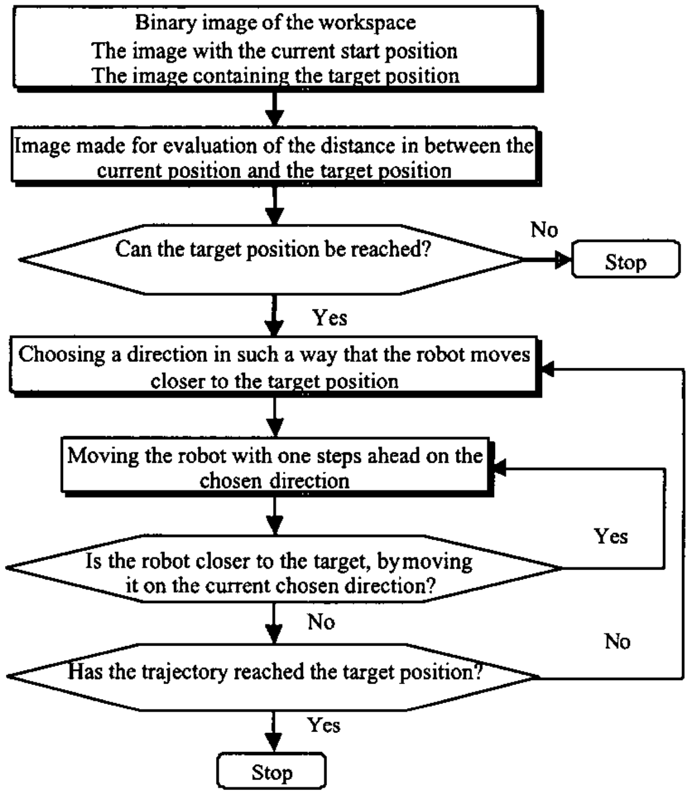

Figure 2. Algorithm for path planning of the mobile robot when it moves in between two points from the environment with obstacles.

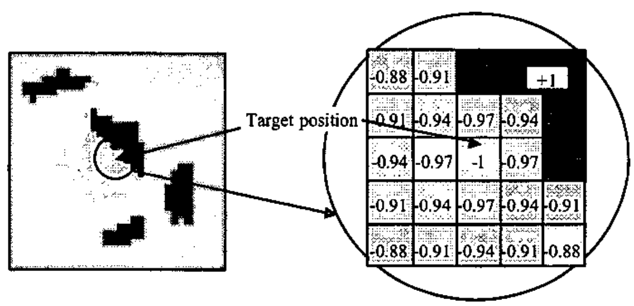

Figure 3. The principle of distance determination in between the target and a point from the workspace through wave propagation having the origin of the source in the target point. The values of pixels in the image are proportionally increasing with the distance, starting from the origin of the source.

An image in which all the pixels have the value +1, except a pixel, that corresponds to the target position having -1 value is put on the networks STATE, $x(t_0)$. This image is, in fact, the exactly opposite of the image that contains the target point. The current binary image of the workspace is used as a MASK image in this processing step. The image for distance evaluation in between two different positions in the workspace, one of them being the target position, could be achieved using the template explore.tem, "C S L-CNN

Software Library (Templates and Algorithms)" [8]. The pixels corresponding to the borders of the workspace, namely the pixels that are at the boundaries of the cellular neural network are considered always forbidden positions. As a result of this processing step, the value of the pixel corresponding to the target position in the output image remains unchanged at the initial value -1 and the pixels having the value +1 are going to be the forbidden positions through where the robot cannot pass. All the other pixels will have values that proportionally increase with the distance in between them and the target position.

Thus, starting from the center of wave source the value of pixels is approximately increasing with one measure unit of the distance β, when the wave radius having a circular propagation is increasing with 1. If there is at least one possibility to read the start position, starting from the target point, then in this output image, the value of the pixel from the position corresponding to the start position will be modified from +1 to a value that is directly proportional with the distance in between the start and the target point. The algorithm is able to show if there isn't a free path, without obstacles, from the start position to the target position, at each new cycle of the global algorithm.

3.2 Choosing the optimal direction through which the robot moves closer to the target position .

Choosing the optimal direction is a processing step, which is based on the possibility of extracting the value of a pixel from a gray-scale image if its position is given by an inactive pixel having the value -1, into a binary image, used as a mask image. The mask image has the same dimension as the initial image. In this processing step, a gray-scale image and a binary image are needed. The gray-scale image is the image obtained by evaluating the distances, the positions from the workspace and the target position. The binary image is an image in which all the pixels have the +1 value, except one inactive pixel –1, which gives the position of the start point or the current position needed for choosing a new direction. The binary image obtained in this way is the reverse of the image containing the start position. Using a local method, a neighbor cell from the 8 possible directions N, S, E, W, S-E, N-E, N-W, S-W, is chosen in such a way that the value of the cell is the smallest possible. The path followed by the mobile robot choosing the direction corresponding to this cell is the shortest to reach the target. Elementary processings is used for choosing the optimal path, "AMC-instructions" (Extended Analogic Macro Code and Interpreter [8]). The images are processed using the family of template shift.tem [8] corresponding to the eight directions. For exa mple (Fig. 4), the optimal direction for the robot to move starting from the initial point A is point B and from the turning point D the suitable direction is towards the point E.

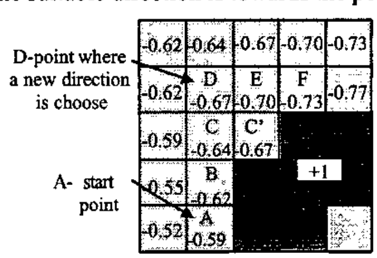

Figure 4. The principle of choosing the optimal direction.

3.3 *The continuos movement of the robot following the chosen direction*

The robot moves on the chosen direction that remains unchanged as long as the current direction allows the robot to move closer to the target. Starting from the current position, the next step of robot will be made on the same direction only if the value of the pixel corresponding to the following position is smaller then the value from the current position, as shown in Fig. 4 in between points C and D. Otherwise, if the value of the following pixel on the current direction is bigger then a new curve is taken or it follows a new step in choosing a new direction, as it happens in point D.

When a new direction is chosen, for every cycle of the algorithm, first it is checked if the target position was reached, the pixel corresponding to the target point being the only one that has the value -1. The group of templates select.tem extended for the 8 directions [8] is used for obtaining the image with the prescribed trajectory, image obtained after choosing the optimal direction, so that the robot can move closer to the target.

3.4 *The planning of the trajectory through the determination of optimal direction on each step*

According to the method presented in the previous paragraph, the choice of a new direction is achieved only if through the maintaining of current direction, the robot doesn't approach to the target position (Fig. 4). Thus, the number of turnings is minimized, but the planning trajectory is not the trajectory with the minimal length. In the presented example, between the two turnings, points A and D, there is the point B from which the optimal direction should be C' instead of C. Therefore, to obtain the optimal trajectory from the point of view of minimal length of the trajectory of robot, should be chosen at each step the optimal direction of evaluation of distance between the target position and the points of the workspace, corresponding to each pixel of the image with gray levels. The choice of optimal direction at each step is achieved based on the principle presented in the paragraph 3.2. The planning trajectory is thus resulting, as being optimal for the application presented in this paragraph (Fig. 5,g,h), from the point of view of length. The points of the arrows are indicating the fact that the choice of optimal direction is achieved at each step, corresponding to the pixels in image of the environment with obstacles.

4 Simulation of the algorithm for path planning

The algorithm for path planning of a mobile robot in an environment with obstacles using CNN was tested using the simulation environment "CadetWin-99", (CNN application development environment and toolkit under Windows-Visual Mouse Platform and Multi-layer CNN Simulator [8]), (Fig. 5).

The minimum time needed for the processing of the algorithm is obtained as a sum of the minimum times obtained for each step of the algorithm. The minimum processing time of the step in which the evaluation of distances in between points from the workspace and the target is made, depends on the distance in between the start and the target position because is absolutely necessary that the wave to reach, through propagation, the start position. In the following step, in which the robot moves on the chosen direction, the necessary time is increasing with the length of the path that must be followed. The total number of curves also must be taken into account when computing the total time, namely the number of points, in which a new optimal direction is chosen to get closer to the target, also must be considered.

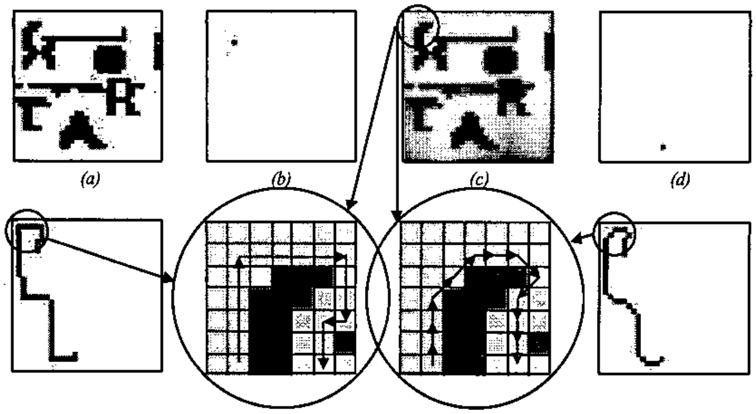

Figure 5. Results achieved through simulation of the CNN algorithm for planning trajectory of the mobile robot, that moves in between two points of an environment with obstacles: (a) image with the environment after the pre-processing step; (b) the given target position; (c) image obtained for evaluating the distance in between the start position and the target; (d) determination of the start position; (e) image with the achieved prescribed trajectory; (f) image representing the details of a part from the chosen prescribed trajectory; (g) the detailed image of a portion from the optimal planning trajectory; through the determination of optimal direction at each step; (h) the planning trajectory, optimal from the point of view of the length.

In Table 1, the estimated processing time of the path planning algorithm for a mobile robot in a discrete 32*32 pixels environment with obstacles is presented.

Table 1: Running time estimation of the CNN path planning for a mobile robot.

Processing steps	Mean processing time by simulation on a PC-866 [MHz]
Evaluation of the distance between the start position and the target using explore.tem	600 ms
Choosing the optimal direction	5 ms
Planning trajectory between two turnings using select.tem	25 ms
Planning trajectory at each step	1 ms
Total processing mean time for planning trajectory through the continuos moving of the robot following the chosen direction p	800 ms
Total processing mean time for planning trajectory through the determination of optimal direction at each step	800 ms

A value must be associated with each point from the workspace in the evaluation of distances in between points and the target position step. This condition is necessary so that the algorithm can run correctly. The CNN domain of values must be taken into account in this case and also the fact that, the minimum value of the distance β is limited. A necessary condition for the proposed algorithm to run correctly is that at each captured image, the start and target point can be identified. Putting this condition, the dimension of the image and the minimum sample step for spatial discrete representation of the captured image is obtained.

5 Conclusions

The results obtained testing the CNN algorithm, confirm that using the Cellular Neural Networks for image processing, the trajectory of a mobile robot in an environment with obstacles can be planned in real-time. Therefore, this planning method based on image represents an advantageous alternative to other methods used to navigate a mobile robot. The proposed CNN algorithm provide to robot the planning trajectory, optimal from the point of view of the length of the trajectory and from the point of view of the number of turnings, avoiding the obstacles from the environment and pointing out whether the target is not accessible. Between these two methods, it can be chosen the optimal method only after the knowledge and the evaluation of the imposed conditions and of the aim in the concrete application.

The precision of positioning the robot in the working environment based on visual information could be increased if the dimensions of acquired images are changing when the robot is approaching to the target. This purpose could be achieved by adjusting adequately the position and the focus of the camera in order to acquire only the region of interest from the image of the working environment. With this aim, a possible solution can be represented by the combination of the CNN algorithm for following an object with a video camera, with the algorithm for planning the trajectory [7].

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