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Application of a Blind Person Strategy for Obstacle Avoidance with the use of Potential Fields

E. P. Lopes**, Eliana P. L. Aude*, J. T. C. Silveira*, H. Serdeira*, M. F. Martins*

*Federal University of Rio de Janeiro, NCE
**Federal University of Rio de Janeiro, IM
P.O. Box 2324 - Rio de Janeiro - RJ 20001-970 - Brazil
Tel: +55 21 598-3164 Fax: +55 21 598-3156
e-mail: ernesto@cos.ufrj.br, elaude@nce.ufrj.br

Abstract

This paper proposes a new obstacle avoidance algorithm for the CONTROLAB AGV which uses a similar strategy adopted by a blind person to avoid obstacles while walking. The AGV moves within an office environment with a known floorplan and uses an "electronic stick" consisting of infrared sensors to detect unknown obstacles. Initially a global potential field function is defined for each floorplan room. While the AGV is moving, the original potential function is modified each time an obstacle is detected by the infrared sensors. This modification is simply performed by the addition of previously calculated potential field values on a grid which represents the room working area. The interesting aspects of the proposed approach are that the potential function adaptation involves very low computational burden, the algorithm is free from local minima, the obstacles can have any shape and low cost sensors can be used to detect obstacles.

Keywords: obstacle avoidance, potential fields, autonomous guided vehicles, trajectory planning

1. INTRODUCTION

This paper analyses the navigation problem of the CONTROLAB AGV [Aude99a] within a set of rooms in a building. It is assumed that the AGV displays circular symmetry and that the building floorplan is known a priori. Obstacles that may block the robot trajectory are detected as the robot moves.

With the floorplan information, the AGV may plan its trajectory from a starting position to any destination within the building, which may be in another room. The destination position is sent to the AGV, through wireless communication, by any user connected to the Internet [Carn99]. In this path planning problem, which will be called global planning, the AGV must find the best sequence of rooms to cross within the building in order to reach the desired destination room. The global planning problem is solved before the AGV starts moving.

After solving the global trajectory planning problem, the AGV has to solve the local trajectory planning problem in order to define the detailed trajectory to be followed from its current position within a room to the door that connects this room to the next one to be visited according to the pre-defined global trajectory.

While moving along the local trajectory, the AGV must avoid obstacles which it may eventually find on its way. This paper focuses on the local trajectory planning problem and proposes a new procedure for avoiding obstacles detected in real time. Practical solutions to the real time solution of the local trajectory planning problem are constrained by the following issues:

- the robot must be able to change its trajectory while it is moving, but the computational load for performing such changes must be small;
- although several variables can and must be controlled during the AGV navigation, its radial symmetry and the fact that the AGV position has little or no relation with the other variables to be controlled indicate that the configuration space to be considered must be a subset of R^2. The other variables are controlled by other systems which are not discussed in this paper;
- the sensor system to detect the presence of obstacles must be fast and simple;

Given these constraints, this paper proposes the use of an AGV which is equipped with an "electronic stick", implemented with infra-red sensors, which is able to detect collision points in a similar way as a blind person does when walking.

The paper goal is to update a global navigation function [Lato91], which is a harmonic potential function [Kim92], while the robot is moving. An initial navigation function is a priori determined considering the room without obstacles. For each detected collision point, this function is modified to represent the presence of the obstacle. The computational effort for this adaptation is very small because the function modification is performed by adding two set of values which can be pre-determined.

As a consequence, the proposed procedure can be used in real time.

It should be stressed that the global navigation function we are looking for is neither unique nor contains information on all the obstacles and depends on the trajectory followed by the AGV.

In Section 2 of this paper, the CONTROLAB AGV basic architecture is described. Section 3 discusses the global navigation function and its adaptation during the real time navigation. Section 4 presents simulation experiment results showing the behavior of the AGV Local Trajectory Subsystem. Finally, Section 5 presents the main conclusions and suggestions for future developments.

2. THE CONTROLAB AGV ARCHITECTURE

The CONTROLAB AGV is a tricycle drive with a cylindrical body. It moves autonomously within office environments and follows instructions issued by any station connected to the Internet as shown in Figure 1.

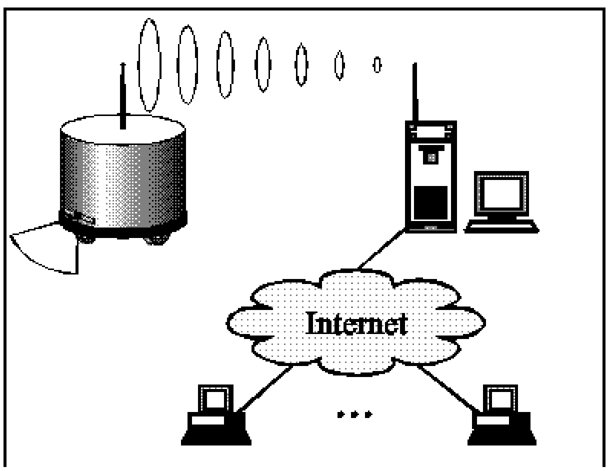

Figure 1: Basic Operation of the CONTROLAB AGV

The CONTROLAB AGV consists of the following hardware or software modules:

- **Autonomous Guided Vehicle**: a moving robot equipped with a radio transceiver, infrared sensors, and hardware/software resources for storing and processing information;
- **Control System**: responsible for commanding the direction and speed of the AGV movement;
- **Client/Server Subsystem:** the client stations use the Internet to issue orders to the AGV. The Request Server organizes the client orders received by the Internet and uses wireless communication to both send the floorplan description and the client requests to the AGV and to receive information which allows remote monitoring of the AGV operation. This information is sent to the clients by the Internet;
- **Architect:** a special client, implemented as an object-oriented software tool, which supports the editing of the environment floorplan to be sent to the AGV;
- **Trajectory Planner:** an on-board software module which is able to establish a trajectory to be followed by the AGV from its current position to the desired destination within the environment. It consists of a Global Trajectory Planner and a Local Trajectory Planner;

Figure 2 shows a block diagram of the CONTROLAB AGV architecture.

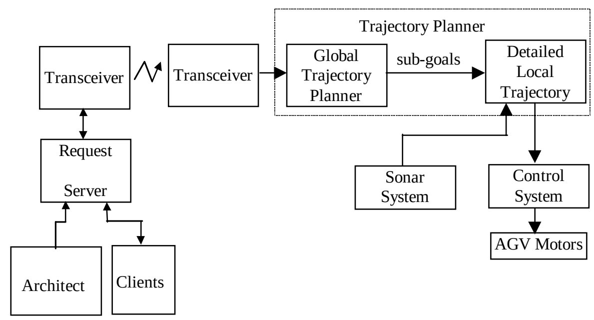

Figure 2: The CONTROLAB AGV Architecture

The AGV has a priori knowledge of the environment in which it should travel. It stores a description of this environment consisting of a floorplan and a derived Connectivity Graph. The floorplan description is produced by the Architect and is supplied to the AGV by the Request Server. At the start of its operation, the AGV also receives information on its initial position in a room within the floorplan.

In this application, the Request Server receives orders to be sent to the AGV from the several client stations connected to the Internet. An order is characterized by the identification of the destination room and by the desired final location within this room. Requests are stored in a queue and a new request is only sent to the AGV after completion of the previous one.

2.1 The Global Trajectory Planner

The Global Trajectory Planner is responsible for generating and analyzing all possible paths from the AGV original location to the final location within a known floorplan consisting of doors and free areas. The Global Trajectory Planner creates a Connectivity Graph to represent the floorplan as shown in Figure 3. Within the Connectivity Graph, nodes are associated with doors and there is an edge in the graph connecting two nodes whenever the doors associated with these nodes open to a common free area. The weight of each edge is given by the product of the distance between the centers of the doors and the common free area weight.

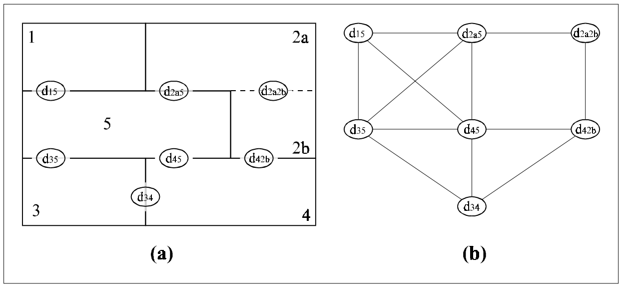

Figure 3: (a) Environment Free Areas and (b) Connectivity Graph

Let us consider that *S*(x,y) is the initial AGV location in the free area a_s, and that *G*(x,y), located in the free area a_g, is the destination point of a given request. The Global Trajectory Planner generates then the Connectivity Graph adding two nodes associated with *S* and *G* and then calculates the minimum-cost path between *S* and *G*. Figure 4 illustrates the previous floorplan with the inclusion of *S* and *G*, placed in the free areas 1 and 2b, respectively. The assigned weights indicate that free areas 1 and 3 should be avoided and that it should be given priority to using free area 5, which represents a corridor. All possible connections between doors are shown both in the topological scheme and in the Connectivity Graph. The best path - ***S***, $\mathbf{d_{15}}$, $\mathbf{d_{2a5}}$, $\mathbf{d_{2a2b}}$, ***G***, with a total cost of 294.3 - is emphasized.

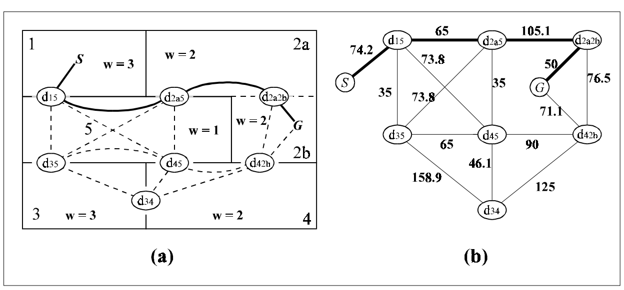

Figure 4: (a) Global Trajectory between *S* and *G* (b) Connectivity Graph including *S* and *G*

2.2.2 The Local Trajectory Planner

Each edge of the path defined by the Global Trajectory Planner in the Connectivity Graph defines the start and end points of a segment of the global trajectory. The precise trajectory to be followed by the AGV between each of these pairs of points is defined by the Local Trajectory Planner using the global navigation function in a particular room. This function is calculated a priori and its values are mapped on a grid which is laid out in the room area. During the AGV movement, the global navigation function is modified by the influence of detected obstacles. This adaptation of the global navigation function values is performed by adding its previous values on the grid to the values of the potential function associated with the detected obstacle which can also be determined a priori since every obstacle is modeled as a single point on the gird. The mathematical derivation of the global navigation function is discussed in detail in Section 3.

3. THE GLOBAL NAVIGATION FUNCTION AND ITS ADAPTATION

3.1 Some Results of the Potential Field Theory and Robot Motion Planning Concepts

Epstein [Epst62] has provided a very complete account on the potential field theory. The use of potential fields in the problem of robot motion planning has been analyzed in detail by Latombe [Lato91] and the importance of the harmonic potential functions in the generation of artificial potential fields has been thoroughly discussed by Kim and Khosla [Kim91, Kim92].

A set $\Gamma \subset R^n$ is a domain if it is open and connected.

A function f defined in a domain Γ and belonging to the class $C^2(\Gamma)$ is said to be harmonic in Γ if $\nabla^2 f = 0$, where $\nabla^2 = \partial^2/\partial x_1^2 + \ldots + \partial^2/\partial x_n^2$.

The harmonic functions have the following properties:

- any linear combination of harmonic functions is harmonic;
- a harmonic function minimum and maximum values within a domain are at the boundaries of this domain;
- by applying a transformation, such as $y_i = cx_i + b_i$, to the variables of a harmonic function, it continues to be harmonic.

The configuration space represents the robot as a point in an appropriate space where the obstacles are the constraints in the values of each coordinate.

A navigation function is a local-minimum free potential function ϕ such that the vector $-\nabla\phi$ gives the direction of the robot motion at any time [Khat86].

The advantage of harmonic functions on non-harmonic potential functions is that for the first one it is possible to avoid local minima, which can get the robot stuck.

3.2 Generation of the Global Navigation Function

As previously mentioned, the configuration space to be considered in this work is any rectangle in R^2. The AGV position is defined by the coordinates of its center of gravity in relation to a fixed referential. The construction of the global navigation function starts by calculating the initial navigation function F_0 which is a solution to the following Dirichlet problem for the Laplace equation:

$$\partial u^2/\partial x^2 + \partial u^2/\partial y^2 = 0$$

$$u(x,y) = 0 \text{ for } x = 0 \text{ and } 0 \leq y \leq b \text{ or}$$
$$y = 0 \text{ and } 0 \leq x \leq d \text{ or}$$
$$y = b \text{ and } 0 \leq x \leq d \qquad \text{(Equation I)}$$
$$u(d,y) = u_0 \quad \text{if } 0 < y_0 \leq y \leq y_0 + \Delta y \text{ or}$$
$$= 0 \quad \text{otherwise}$$
where $u_0 < 0$

Equation I has been derived considering a rectangular room with width equal to b, length equal to d and a door at (d, y_0) with width Δy. The potential value at the room door is u_0 and the potential value at the room walls was set to 0.

The function F_0 is the solution of Equation I, and it corresponds to an initial situation in which the only relevant information to the problem is the AGV position, the room length (d) and width (b) and the position of the target door (d, y_0). Since this information is available before the AGV starts its operation, F_0 can be determined and its values can be mapped on a regular grid, which is laid out over the room area, before the AGV starts moving. The solution of Equation I is given by:

$$u(x,y) = \sum E_n \sinh(n\Pi x/b) \sinh(n\Pi y/b), \text{ where:}$$

$$E_n=2u_0(\cos(n\Pi y_0/b)-\cos(n\Pi(y_0+\Delta y)/b))/\Pi n \sinh(n\Pi d/b)$$

The grid values of a radial harmonic potential function ϕ centered at any grid position are also calculated before the AGV starts moving. Its equation is given by:

$\phi = (\lambda/2\Pi) \log r$, where r is the Euclidean distance to the symmetry center of the potential function and λ is a negative constant.

This potential function is associated with any obstacle detected by the AGV while its moving, since it is always modeled as a single point on the grid.. When the AGV finds an obstacle, the closest obstacle point is identified and the potential function ϕ symmetry center is displaced to the grid position which is closer to this obstacle point. This displaced function is added to the global navigation function at the grid positions according to Equation II. Due to the first and third properties previously mentioned, the result is a new harmonic function which includes information on the presence of detected obstacles. At stage N, the current navigation function F_N is given by:

$$F_N = A_N F_0 + \Sigma A_c \phi_0 \quad \text{(Equation II)},$$

where A_N and A_c are multiplication factors which may change during the AGV movement.

A_N increases with the number of detected obstacle points (N). A_c is defined as a function of the current potential gradient at the obstacle point.

It should be stressed that the navigation function adaptation can be performed by simply adding two already known sets of values (the current global navigation function and the displaced potential function ϕ with its symmetry center on a grid position) associated with all the grid positions.

4. SIMULATION EXPERIMENTS

The Local Trajectory Planner controls the AGV navigation from any room position to a room door based on the general principle described in Section 3.

A simulation experiment has been performed considering a rectangular room with a single door. Figure 5 shows the initial potential field generated inside the room. A low value potential was set at the door (u_o = -1) and 0 was the higher potential value set at the walls, according to the mathematical development discussed in Section 3. The potential field values mapped on the grid positions are calculated before the AGV starts moving. The same is done for the values of a potential function ϕ which represents the charge field to be associated with the detected obstacles.

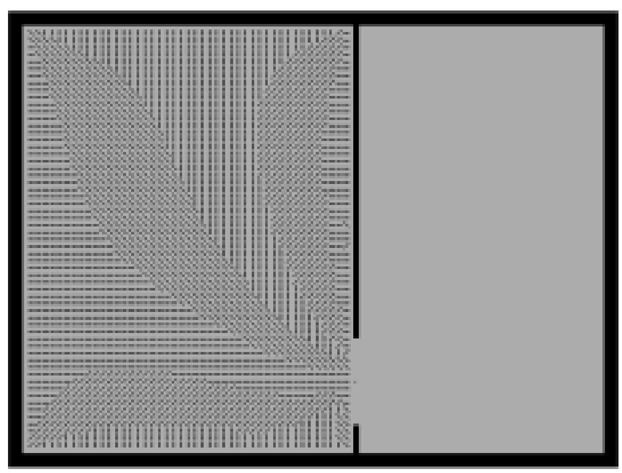

Figure 5: Initial Room Potential Field

The equipotential lines of the generated field are shown in Figure 6. The grid is represented by the dark dots. The AGV real time movement is shown in Figure 7. The AGV is represented by a circle and the "electronic stick" (infrared sensors) range is represented by a circular segment 40 cm ahead of the AGV. At the beginning, the AGV follows the field dictated by the room defined by the initial global navigation function. As soon as the presence of an obstacle is detected by the AGV "electronic stick", the global navigation function values are modified by the addition of a charge field associated with the detected obstacle point that is closer to the AGV.

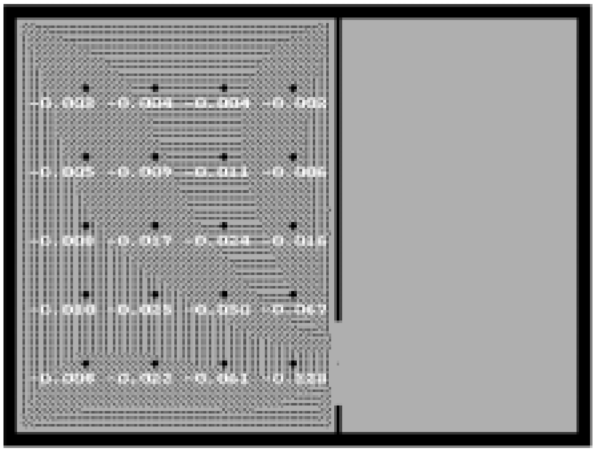

Figure 6: Potential Field Equipotential Lines

The global navigation function adaptation is performed by taking into consideration both the total number of charges previously added to the original room field and the current potential value at the position where a new obstacle was detected. As mentioned in Section 3, the multiplication factor A_N associated with the room potential field increases as the number of added charge fields increases. In addition, the actual value of the multiplication factor A_c associated with the charge field is defined in order to avoid the creation of a too big potential gradient value in a region where the current value is low. Otherwise the AGV could be pushed against the room walls, for instance, as a result of a global navigation function modification introduced by the detection of an obstacle close to a wall.

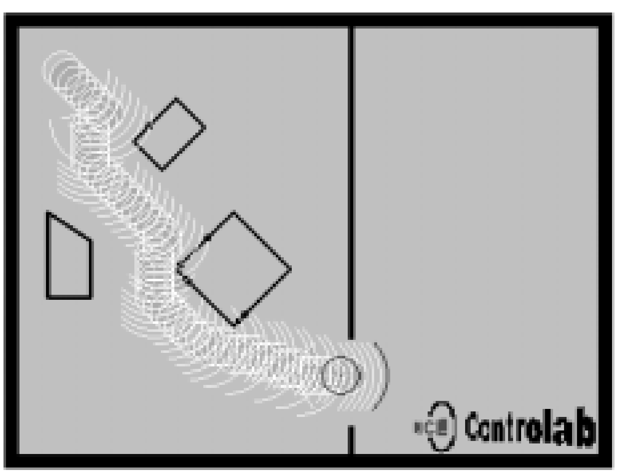

Figure 7: The AGV Real-Time Movement

5. CONCLUSIONS AND FUTURE WORK

An adaptive path planning procedure with real-time obstacle avoidance capability has been proposed. It works on a grid defined over the mobile robot working area. Updated values of the global navigation function are found by adding at the grid points the current value of the global navigation function to the potential function associated with the presence of a detected obstacle modeled as a point. Adjustable multiplication factors are applied to both functions before the addition. Both the initial room potential function and the potential function associated with an obstacle modeled as a point are calculated a priori for all the grid points. Therefore, the determination of the new values of the global navigation function at the grid points can be performed by simply doing a few multiplications and additions.

For this path planning procedure, obstacle detection is performed using infrared sensors in a similar way as a blind person detects obstacles with the use of a stick.

The main features of the proposed procedure are the following ones:

- it demands very low computational load;
- it is intended to be used to avoid any kind of obstacles;
- it requires low cost sensors;
- it is free from local minima.

Simulation experiments have shown promising results in the ability of the proposed procedure to be used in the implementation of mobile robots which are able to detect and avoid collisions with unknown obstacles while moving.

The convergence problems of this algorithm will be discussed in a future work. In addition, research will be done with focus in applying the proposed procedure to demonstrate the ability of a mobile robot to learn the position of obstacles which do not move frequently within an environment.

6. ACKNOWLEDGEMENTS

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