Hybrid technique using harmonic potential fields and evolutionary algorithms for path planning in mobile robots

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Abstract. The path planning is an important element in the process of navigation in various fields such as robotics, and particularly in mobile robotics, this can be accomplished by various techniques such geometric, probabilistic, computational or reactive and usually provides knowing everything the workspace of the agent. This article deals with the implementation in a simulator of the reactive technique that does not need the whole environment to find a solution to the path planning problem and converge in a first attempt, also in a new attempts of the test was implemented a evolutive algorithm that improved the initial solution and make it very similar to that obtained by this technique with the knowledge of the entire environment, but with significant savings in information dissemination and processing.

1 Introduction

Exist several definitions of the path planning problem, depending on the area where it applies, in mobile robotics can be defined as "*given a robot and information of its workspace find an collision free route between two specified points*" [1]. Various techniques are used to solve the problem, since the visibility graph [2], voronoi diagrams [3], grid cells [4], and potential fields [5].

Potential Fields can be found in the literature of many scientific disciplines, including mathematics, computing, physics and chemistry. The potential fields are associated with coordinates within an space with scalar or vector potential value, where these values are often energy levels (scalar field) or physical forces (vector field).

The artificial potential fields are similar to the potential fields of the real world, used primarily by the field of artificial intelligence to model a variety of problems. Among the various definitions that exist on artificial potential fields is: "A potential field function is a mapping in every possible coordinate is a n-D space to another with a scalar or vector value. The space coordinates can be discrete or continuous. If the value that is mapped to be a potential field is a scalar value, then the corresponding potential field is normal to a n-D surface in a continuous space (n+a)-D"[6].

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Khatib was the first in the use of potential field technique for application in robotics, presenting an algorithm easy to implement, but suffers from a major weakness on the convergence of the method due mainly by the effect of "local minimum" in the solution.

A lot of improvements to the Khatib's method have been proposed in order to convey the convergence problem [7]; Later, Conolly [8] began to work with the artificial harmonic potential fields (HPF) technique, that satisfy the Laplace equation, these techniques guarantee displacements in complex environments. Masoud [9,10,11] .

The evolutionary computation using iterative processes, such as growth or development in a population. This population was then selected as a random guide of search using parallel processes to find the desired end. Such processes are often inspired by biological mechanisms of evolution.

The evolutionary algorithms offer an important skill to cope with realistic goals and design objectives reflected in relevant fitness functions.

The first research on artificial fields with potential use of evolutionary algorithms was presented in 1998 by Dozier, et al. [12], then emerged the potential artificial evolutionary of Vadakkepat [13] to work in real path planning into robots.

In this paper is presented the use of a hybrid methodology to generate routes, called evolutionary harmonic potential field (EHPF), used in problems with partial knowledge of the environment. Masoud's method [9] starts with a definition of the goal point and the exterior boundaries of the environment. Then solve the boundary value problem (BVP) for an biharmonic potential and obtains the possible paths that lead to a mobile to achieve the goal. The planner manages to lay a trajectory to the target that avoids the obstacles relying only on the data its sensor provide. Each time that the sensors detects the presence of obstacles to adjust the steering field so that the presence of the newly acquired data is accomodate. Unlike the Masoud's method, the method presented here does not provide a cromprehemsive solution to follow, but that is base on the generation of local segments that are concatenated to form the total path from a starting point to a goal point free of collitions. The individual segments are the solutions of a local, with respect to the robot, harmonic potential field problem. The information needed to properly outline the local harmonic potential field problem is obtained by using a system of range sensors that recognize the environment that surrounds the robot. Thus establishing an evolutionary process of displacement of the mobile on a path to discover. Simulation has been carried out on cluttered environments and excelent results have been obtained.

This paper is divided as follows: Section 2 contains the problem formulation, Section 3 shows simulation results, and finally conclusions and recommendations are given in section 4.

2 Problem Formulation

2.1 Harmonic potential field

Conolly suggested the use of harmonic potential functions [8], [14] . This functions disappear the local minimun. The mathematical model is originated in fluid dynamics. Condider the flow lines of an incompressoble fluid, with sources (work-space and the obstacles boundaries) and sinks (the target) in the environment. The "fluid" has lines that allow flow away from the boundaries towards the target, without local minimum –which can represent that it is not allowed added sinks (fluid can be compressible).

Definition

A harmonic function in a domain $\Omega \subset R^n$ is a function that satisfies the Laplace equation:

$$\nabla^2 \phi = \sum_{i=1}^{n} \frac{\partial^2 \phi}{dx_i^2} = 0 \qquad (1)$$

where ∇ is the nabla operator, ϕ is the potential field function in Ω, and x_i is the cartesian coordinates .

2.1.1Implementation Conolly suggested derive the harmonic potential field using finite difference iterative methods (numerical analysis techniques) in a grid representation of the space. Boundaries Conditions are imposed on the grid in relation to the position of obstacles and the goal. The idea is to try to converge to a numerical approximation that satisfies the Laplace equation under the conditions imposed by the obstacles and position start/goal.

The values obtained for grids are used to navigate when has been iterate enough to ensure that there is no local minimum. The resulting function of navegation is the complete resolution.

2.1.2 General Boundaries Conditions The harmonic function are used to define the potential field and thus to define the path planning problem. The boundaries of Ω consists of the boundaries the starting point, goal point, the workspace and the all edges of the obstacles to analyze.

Solutions to the Laplace equation are examined regarding different types of BVPs as Dirichlet and Neumman.

In our case we used the Neumman conditions (Homogeneous Neumman), due to the robustness in the generation of field. The BVP to resolve is

$$\nabla^2 V(x) = 0,$$

subject to:

$$\frac{\partial V(x)}{\partial n} = c\big|_{x\in\Gamma},\ V(x) = 0\big|_{x=x_T} \ \text{ y } V(x_s)=1 \qquad (2)$$

where Γ is the boundaries of the forbidden zones, n is a unit vector normal to Γ, c is a positive constant, x_T is the goal point and x_s is the starting point. This approach is effective for point to point motion planning. The drawback of this technique is that obtained a path dangerously close to the obstacles, as shown in the Fig. 1.

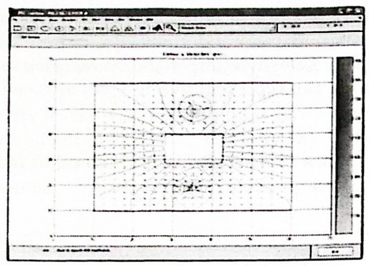


Fig 1. Homogeneous Neumann Condition

2.1.3 Evolutionary harmonic potential fields. The approach token to solve the path planning and managment problem is to cast it in terms of an optimization problem and to use a population-based stochastic search process, known as evolutionary computation, as the basis of moving along the problem's response surface. Briefly, the idea behind this approach is to develop a number of candidate solutions (e.g. the population) in parallel, each solution potentially exploring a different aspect or region of the search space. At each generation, those members of the population that show the highest potential relative to a cost function are selected and allowed to reproduce. Reproduction takes the form of exchange of genetic material between individuals, random mutation of individuals, or a combination thereof. This reproduction is the means through which solutions move through the search space.

About evolutionary harmonic potential fields contributions is only one, given by Masoud [10], stressing that his model as opposed to evolutionary traditional techniques that used the learning for selection of action ensuring convergence, not since the first attempt, since the idea of learning from previous attempts is very relief in this type of techniques. The Masoud planner converges from the first attept, making subsequent attempts resulting in improved performance of the planner. In our case, we present an idea similar to that Masoud, with the option that the first approach only works with local harmonic potential fields (LHPF) and subsequent attempts trying to make improving the path through evolutionary learning techniques.

2.2 Problem Outline

Different from the classical methods of HPF technique where full knowledge of the environment is a precondition to obtain a general solution, here the general solution is obtained by the joint of LHPF solutions that allow the mobile move to the target. The mobile uses a real time sensor recognition system to get the information of the local environment needed for resolve outline the HPF problem.

The environment: Let Ω be a space in which the agent is permitted to operate in an bidimensional region R^2 ($\Omega \in R^2$); let O be a set of unknown regions occupied by obs-tacles in R^2 ($O=R^2-\Omega$). Γ be the boundary of Ω, and O together $(\Gamma = \partial\Omega + \partial O)$.

The agent: It is cover by a circle $R(x)$ of radius δ with boundary $\gamma(x)$.

Assume the agent starts at location $q_s \in \Omega_s$ and its target is $q_g \in \Omega$. Then, using a set of sensors located on the agent, with maximum range ε, a local space $\Omega_s \in \Omega$ is re- cognized. Let Γ' be a subset of Γ inside Ω_s, with boundary $\partial\Omega_{s}, = \Gamma'' + \Gamma'$ where Γ'' are the boundaries free of obstacles on Ω_s and let q_p be the projected point, along the line of sight between the starting point and the goal point, on the boundary of Ω_s. Fig. 2 shows the workspace, and the definition of the local conditions needed for the outline of the local evolutionary harmonic potential field problem.

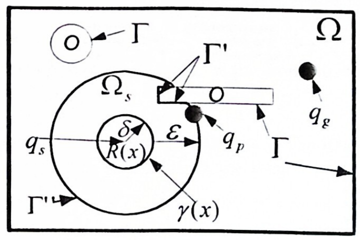


Fig. 2. Local conditions stablished.

Now the local BVP to solve for the local HPF is posed as follows:

$$\nabla^2 V_1(x) \equiv 0 \qquad x \in \Omega_s$$

subject to:

$$\frac{\partial V_1(x)}{\partial n} = 0\Big|_{x=\partial\Omega_s} \qquad V_1(x) = 0\Big|_{x=q_t} \qquad (3)$$

$$V_1(x) = 1\Big|_{x=q_s}$$

Assuming that there is any obstacle between q_s and q_p and using the gradient of the local potential field, a segment of the path is obtained and the agent can move from q_s to q_p. Now, the point q_p is taken as the point for recognition ($q_p = q_s$) of the new local environment and new boundary conditions are derived together with a new projected point q_p, establishing the conditions for the next LHPF problem. This process is repeated until the agent reaches the target point.

2.2.1 Local Planning Algorithm. Given the local conditions of movement, the proposed algorithm (see Fig. 3.) a-llows to generate a path since the starting point to the goal point in a first attempt, more details can be found at [15].

Once developed a first plan is to use the obtained information by the q_p points where the robot is placed in every local path, seeking to remove repetitive partial movements, to smooth the movements curvilinear and seek possible moves straight to reduce the distance between points, all of this based on evolutionary how no evo-lutio-nary techniques.

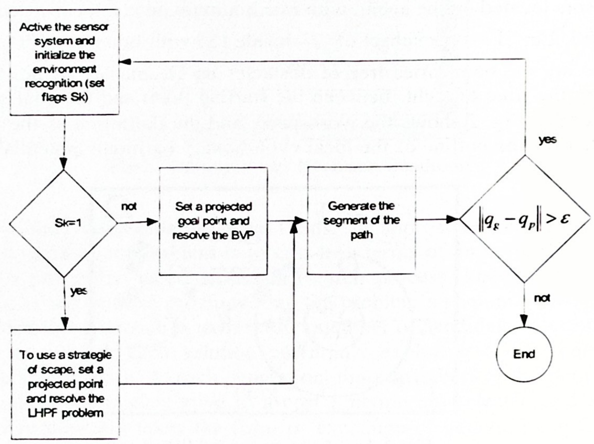


Fig. 3. Local Planning Algorithm.

2.2.2 Evolutionary Applications. In some cases, to real applications, it is difficult to put the projected point q_p in the line of sight of the mobile with respect to the target point, because the sensing action does not ensure you can locate this point in $\partial\Omega_s$, in this case the search for the best position on $\partial\Omega_s$ is based on a genetic algorithm (GA), which uses as the population at all free points of the boundarie of Ω_s (divided in relation a quadrants refers to the mobile see Fig. 4). The fitness function is obtained based on the shortest distance between the mobile and the target point. Once obtained the best position, is placed q_p and solves the LHPF.

Given a pair (q_s, q_g), of a starting and goal positions, the algorithm first generates a population R of M_r candidate routes from q_s to q_g with random via points on the arc generated in each quadrant of the $\partial\Omega_s$.

$$R=\{R_1, R_2, \ldots, R_{Mr}\} \tag{4}$$

Where $R_i = \langle q_s^i, r^i, q_g^i \rangle$ is the ith route with one via point r.

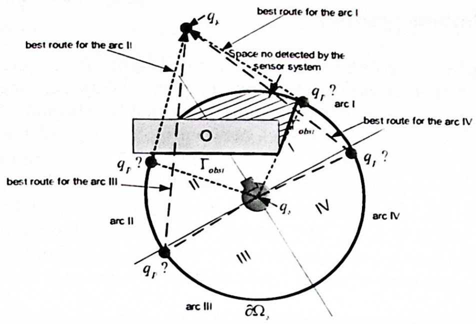


Fig. 4. q_r location on the frontier of Ω_s in the presence of an obstacle.

Each route is evaluated on its fitness. The fitness of the ith route is defined as the sum of the lenghts of the both two segments on the route:

$$F(R_i) = \sum_{j=0}^{1} \left\| r_j^i - r_{j+1}^i \right\| \tag{5}$$

with $r_0^i = q_s^i$ and $r_{n+1}^i = q_g^i$

This is done in each quadrant, obtaining the best route to each of them, then select which generated less distance to the target and the location of the via point r is chosen to put the projected point q_p.

In the same way, finding a better position of q_p, is used another GA in which the population depends on the arc generated in $\partial\Omega_s$ where q_p is initially. The fitness function is obtained based on the shortest Euclidian distance generated between q_{p-1} and q_{p+1}, in addition to adding the proximity of the obstacles that limit the arc, to establish a secure position.

In this case, the fitness is obtained by:

$$F(R_i) = \sum_{j=0}^{1} \left\| r_j^i - r_{j+1}^i \right\| + \frac{1}{\left\| r^i - r_{obst} \right\|} \tag{6}$$

where r is the position of the via point and r_{obst} is the position of the Γ'.

For experimental results was used GA toolbox of Matlab introducing a population of 50 (no matter arc size is considered 50 positions on it), a crossover rate of 70% and a mutation of 0.001.

The changes of direction and extent of the local workspace are not based on evolutionary techniques, which are described in more datail in [15].

3 Simulations results

The propossed algorithms were tested in Matlab. There were several tests in diffe-rent environments both simple and complex workspaces, seeking to contrast the results regarding the overall planning presented by Masoud. The first simulation considers two walls as obstacles between the mobile and the goal point. The mobile and the target points are stablished in (8.75, 7.9, 42°) and (1.01, 1.35, 40°) respectively with respect to an inertial frame (the x,y dimensions of the workspace are in meters). The obs-tacles (walls) are located, the first to 1.1m. from the goal point, with a length of 3.4m. The second, is 2.6m. from the starting point with a length of 3.8m. Likewise, it is considered for this case, the robot has an array of sensors around it, generating a scan of 1.5m. in a circle shape as is shown in Fig. 5.

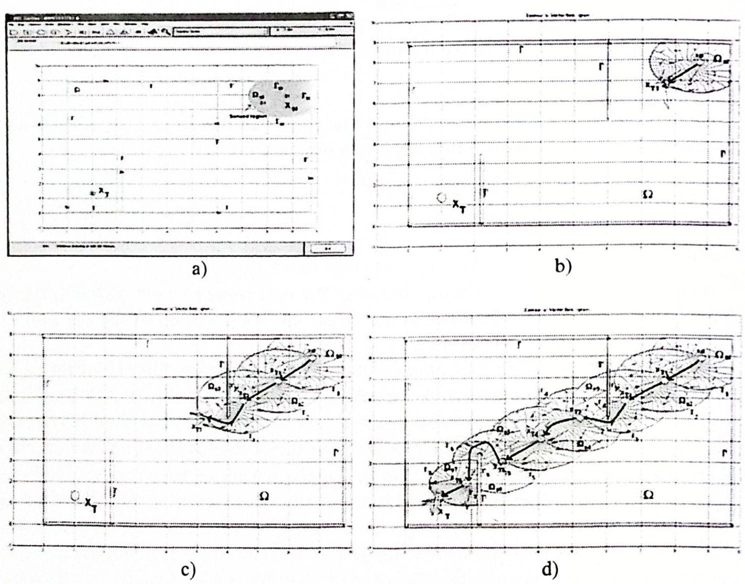
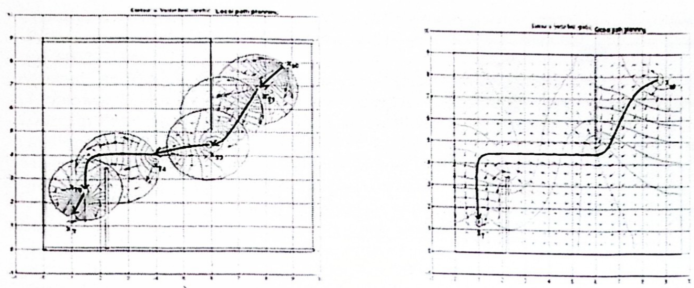


Fig. 5. Applying the local planning algorithm. a) Local conditions stablished; b) first LHPF solution; c) moving to an obstacle; d) final path in a first attempt.

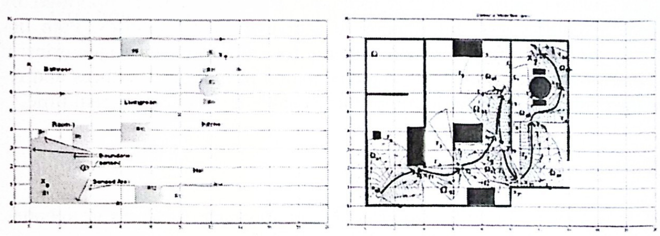
For this first problem 6 surfaces were scanned before to be seen the target point, as shown in Fig. 5. With the use of the evolutionary algorithms in following attemps of the experiemt is obteined an improvement in the final route, which is presented in Fig. 6a. In the Fig. 6b is show the path obtained by applying the technique used by Masoud. In comparing the two results is that the routes are very similar.



a) b)

Fig. 6. a) Final path obtained by the EHPF b) path obtained by Masoud technique.

Simulation on more complex environments were carried out. The problem is to move the robot from the room-1 to the kitchen as shown in Fig. 7a, taking a semicircular scanning of 3m. The action of generating the complete path in a first attempt is shown in Fig. 7b.



a) b)

Fig. 7. a) one scan on the room; b) general result in first attempt

Applying the evolutionary algorithm to the followin attempts to improve the path, it come to get the path that is presented in the Fig. 8a; as in the example above, the result is contrasted with the overall technique (see Fig. 8b).

As can be seen in both cases, the results obtained in the local planning are very similar to those that are generated with the technique overall, but with the advantage of not needing to know the whole environment, which is difficult to obtain in many real-life applications. Moreover, in this way, it takes the principle of the reactive methods, which allows subsequently use the information obtained to generate the corresponding trajectory.

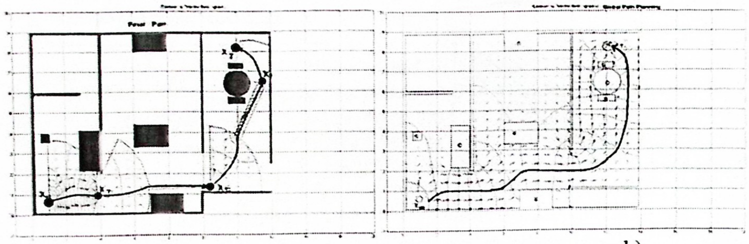


Fig. 8. a) Final path obtained by the EHPF b) path obtained by Masoud technique.

4 Conclusion and directions for further research

In this paper was submitted the path planning problem using a harmonic potential field technique with evolutionary algorithms techniques yielded a route similar to that obtained by techniques global planning, without knowing the whole environment . The method can be used for the case of workspace with changing environments. The authors believe that this technique is better to that submitted by Masoud, since it requires less information to achive similar responses. Path improvement may give as result paths more suitable for smooth, faster trajectories of the agent. Future work are aimed at its implementation in mobile structures and refinement of the evolutionary variable compnent to enable it to operate in real time.

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