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Integrating Directional Constraints in Intelligent, Hybrid, PDE-ODE Motion Controllers

by

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Abstract

This paper addresses an important problem that has remained, to the best of the authors' knowledge, neglected in the motion planning literature. That is the incorporation of directional constraints along with obstacle avoidance in steering a robot to a target zone. In this paper Harmonic field motion planners which can only deal with isotropic workspaces are generalized to incorporate anisotropic workspaces with pre-imposed directional constraints. Theoretical developments along with simulation results are provided.

1. Introduction

Despite the diversity of motion planning methods [1] ,all existing techniques, to the best of the authors' knowledge, are unified in considering isotropic workspaces. Such a class of workspaces places no restrictions on the direction the agent can assume in its interior. Unfortunately, realistic workspaces are highly likely to impose directional constraints on the behavior of an agent. Such constraints may appear in the form of "Traffic" signs requiring the agent to restrict its direction of motion in accordance with the posted sign. While there are many planning approaches from which one may choose a candidate to modify in order to incorporate directional constraints, the authors believe that the Harmonic Potential Field approach to motion planning [2-3] is an ideal candidate for such a choice. Harmonic planners are a subset of a more general class of planners that are called Hybrid PDE-ODE motion planners (Figure-1). When set to operate in the context of a Hybrid, Discrete-time, Continuous-time system this class of planners transform into an interesting and powerful class of motion planners that is called Evolutionary, Hybrid, PDE-ODE motion planners [4,5] (Figure-2). Evolutionary, Hybrid, PDE-ODE planners are situated, embodied, intelligent, and emergent mechanisms for behavior generation. They require no a priori knowledge of their multi-dimensional environment to guarantee that a mobile agent with an arbitrary shape will converge to its target from the first attempt (First Attempt Completeness). Moreover, in such class of planners the range of the sensors has no influence on convergence where even local sensing such as tactile sensing, or a bumper switch can guarantee convergence in a multidimensional environment. The range of the sensors only controls the rate of convergence. Figure-3 shows three attempts of a point agent to reach its target in a maze. Despite the total lack of a priori knowledge about the maze and the use of proximity sensing the agent managed to reach its target every attempt, each time enhancing its performance till it totally converged along an optimal path to the target.

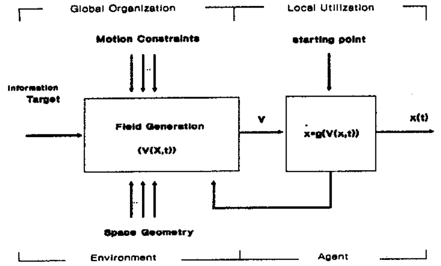

Figure-1: Sturctuer of a Hybrid, PDE-ODE Planner

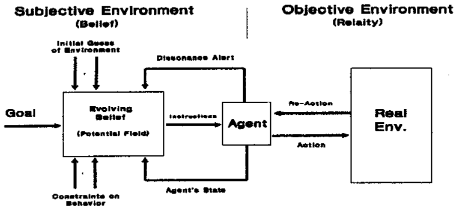

Figure-2: Sturctuer of an Evolutionary, Hybrid, PDE-ODE Planner

In this paper Nonlinear, Anisotropic, Potential Fields are suggested for the construction of motion planners that are capable of incorporating directional constraints along with obstacle avoidance in a motion planning process.

2. The Planner

The modified planner generates a safe, constraint-satisfying trajectory to the target using the gradient dynamical system:

$$\dot{X} = -\nabla V(X,\Psi(X),\Gamma,X_t) \ , \qquad X\in\Omega.$$

$$\textbf{such that} \quad \lim_{t\to\infty} X(t)\to X_t, \ X(t)\cap O\equiv\phi \ , \ \dot{X}^t\Psi(X)>0 \quad X\in\Omega'.$$

where V is a scalar potential field. The Potential field is conditioned for navigation using the BVP: solve

$$\begin{array}{lll} & \nabla^2 V(X)=0 & X\in\Omega-\Omega', \\ \textbf{and} & \nabla\cdot\Sigma(X)\nabla V(X)=0 & X\in\Omega', \\ \textbf{subject to} & V(X_t)=0, \ V(\Gamma)=1 \ . & \end{array}$$

where X and $\dot{X}$ are the N-D position and velocity vectors respectively, Γ is the boundary of the forbidden regions (O, Γ=∂O), X_t is the target state, Ω is the workspace of the robot, Ω' is a subset of Ω (Ω'⊂Ω),

$$\Sigma(X) = \begin{bmatrix} \sigma_{x_1}(\Psi(X)) & 0 & \ldots\ldots & 0 \\ 0 & \sigma_{x_2}(\Psi(X)) & \ldots\ldots & 0 \\ . & & & \\ 0 & 0 & \ldots\ldots & \sigma_{x_N}(\Psi(X)) \end{bmatrix},$$

Ψ(X) is a unit vector field that is defined in Ω' to mark the direction along which motion is to proceed, and $\sigma_{xi}(\Psi(X))$ is defined as:

$$\sigma_{x_i}(\Psi(X)) = \begin{cases} \sigma_f & \Psi^t(X)\nabla V(X) > 0 \\ \sigma_b & \Psi^t(X)\nabla V(X) \le 0 \end{cases},$$

σ_f and σ_b are positive constants ($\sigma_f \gg \sigma_b$) depicting the permissibility of the associated part of the workspace.

3. Results

The capabilities of the planner are demonstrated using the simple example shown in figures 4,5 of a road with two unidirectional lanes. At each lane the agent is required to restrict its direction of motion in accordance with the large arrows shown to mark the admissible directions. Also, the agent can only switch lanes at either the beginning or end of the road and is forbidden from doing so along the solid line separating the two lanes. First, an isotropic, harmonic potential field planner is used for steering motion from the initial starting point to the target point. As can be seen from figure-4a the planner totally disregarded the constraints on direction and proceeded to the target along the shortest path (a straight line). Figure-4b shows the corresponding gradient navigation vector field that the agent is using to steer itself. In Figure-5a a nonlinear, anisotropic, harmonic planner is used for steering motion. As can be seen, the planner enforced the

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Figure-3a: First Attempt.

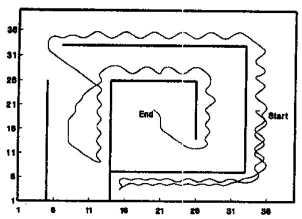


Figure-3b: second attempt.

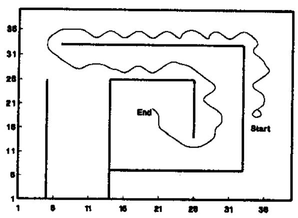
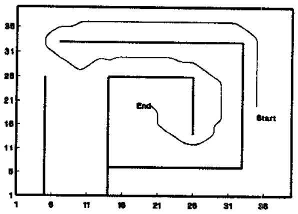


Figure-3c: third attempt.



directional constraints, avoided the obstacles, and drove the agent to its target. Figure-5b shows the corresponding gradient field.

4. Conclusions

In this paper a novel and complete motion planner that is capable of integrating directional constraints along with obstacle avoidance constraints in the navigation process is suggested. The proposed planner is an important addition to the motion planning literature enabling the utilizing agent to enforce the important directional constraints which realistic workspaces often present. It also demonstrates the effectiveness of the harmonic potential field approach to planning, not only as an effective motion planner, but also as a prototype for generating other planning techniques that realistically address the needs of agents operating in real world environments.

References

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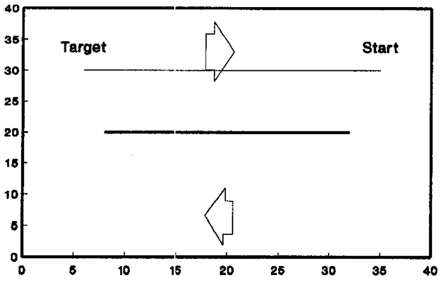

Figure-4a: Harmonic Potential Field Planner.

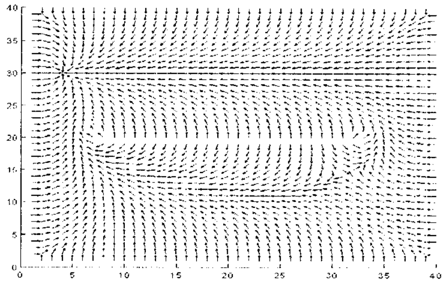

Figure-4b: Corresponding Gradient Field.

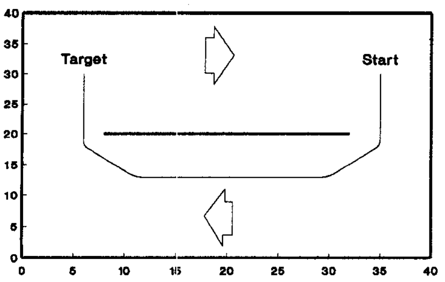

Figure-5a: Modified Harmonic Planner

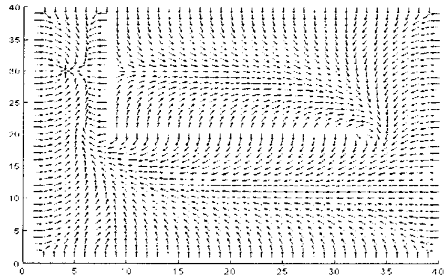

Figure-5b: Corresponding Gradient Field