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Application of artificial neural networks to the robot path planning problem

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Abstract

Robot path planning is a problem largely addressed within the field of Artificial Intelligence (AI) since its exact optimal solution given by Computational Geometry is unfeasible to be implemented in real time. However most of classical AI methods are still unimplementable in real time. Artificial neural networks appear to be a promising paradigm to tackle this problem. We discuss how neural networks may contribute to improve the performance of robot path planners. Three types of artificial neural networks are distinguished in their application to the robot path planning problem: self-organizing feature maps, optimization neural networks and pattern classification neural networks.

1 Introduction

Path planning is a well-known and one of the most important problems in Robotics. This problem involves finding a continuous path between initial and goal robot configurations which avoids collisions with obstacles in the robot workspace. Many algorithms have been proposed to solve this problem in the fields of Computational Geometry and Artificial Intelligence. We can find a thorough survey of existing path planning approaches in [5]. Other recent state-of-the-art works for review are [17] and [16].

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The time complexity of exact geometric approaches grows exponentially with the number of degrees of freedom (dof) [3]. Consequently, its implementation is only feasible for a robot with very few dof. The artificial neural networks paradigm appears to be promising for accomplishing real-time collision-free path planning. The tasks which neural networks can be applied to can be grouped into five classes: pattern reproduction, optimization, pattern association or classification, feature discovery or clustering and reward maximization. Kung & Hwang [7] argue that most robotic processing tasks can be formulated in terms of optimization or pattern reproduction/classification. As a matter of fact, neural networks are being investigated and used in practically every domain of Robotics [1].

2 Neural networks and path planning.

The task of motion planning in the way human beings perform it can be approximately divided into three stages. In the first stage, they recall the complete global environment from the local line of sight [6]. Secondly, they address the global motion planning - the real motion planning problem- by determining a sequence of movements which define a path between their current and goal location taking into account the map of the global environment recalled in the first stage. The environment is considered at a coarse enough level of detail to be assumed fixed and known. These two first stages take place before the actual execution of the planned movements, so they are off-line activities. In the last stage, they have to deal with the actual environment which is partially unknown a priori and dynamic. The goal now is to follow the path previously generated while avoiding collisions with static or mobile entities whose presence was not taken into account in the previous stage. This task is classically assumed to be tackled with local motion planning methods and it has to do more with motion control than with planning. Motion control is a real-time activity in which an actual motion is made to adjust as closely as possible to a commanded motion through the use of sensory feedback while avoiding collisions with obstacles.

In [17] it is argued that motion planning and control involve two different types of processing. It is stated that global planning involves symbolic sequential processing, whilst motor control involves massive parallel pattern

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processing. Nevertheless, artificial neural networks appear to be also appropriate for global motion planning [9][13].

3 Self-organizing features maps

The three approaches reported here share the idea of using a self-organizing neural network to develop a graph - for free space or the frontier between free space and obstacles - that constitutes the main tool of the path finding algorithm (see table 1).

Approach	**Kurz 1992**	**Morasso et al. 1992**	**Najand et al. 1992**
Contribution	passive (free-space graph)	passive (graph for free space and obstacles)	passive (free-space graph)
Workspace	2D	2D	2D
No. of Robots	1	1	1
Robot type	mobile	mobile	mobile
Robot shape	circular	point	point
Scope	global	global	global
Obstacles	arbitrary	arbitrary	arbitrary
Environment	static	static	static
Discretization	no	no	no
Theo/Sim/Imp	implemented	simulated	simulated
On/Off line	off line	on line	off line

Table 1.Self-organizing feature maps.

Kurz [8] proposes a method for a mobile robot to built up a free-space graph while exploring the environment. The free-space graph is developed from a Kohonen's self organizing feature map.

Morasso et al. [12] propose another path planning approach which relies on a self-organizing neural network designed by them: SOC. The main idea is to consider on-line navigation as a two-class classification problem where the goal is to learn the decision boundaries between the class of free-space and the class of obstacles. As on-line planning is addressed, an incremental classifier, i. e., a classifier that is able to refine its knowledge as new samples from the sensors become available and, possibly, it can support time-varying decision classes, namely moving obstacles.

Najand et al. [13] also proposed a self-organizing method to represent the free space of the environment that is slightly inspired on the skeletal representation of the Voronoi diagram approach. The free space is represented with a Kohonen topology preserving map. This approach is very similar to Kurz's but a known environment is assumed.

Approach	Jorgensen 1987	Lee & Bien 1989	Bersini et al. 1992
Contribution	active (Boltzman machine)	active (Hopfield neural network)	active (Attractor dynamic)
Workspace	2D	2D	2D
No. of robots	1	multiple	1
Robot type	mobile	mobile/ multiple dof manipulator	mobile
Robot shape	point	circular/lines	point
Scope	global	global	global
Obstacles	arbitrary	circular	circular
Environment	dynamic	static	static
Discretization	yes	yes	no
Theo/Sim/Imp	implemented	simulated	simulated
On/Off line	on line	off line	off line

Table 2. Optimization neural networks.

4 Optimization neural networks

These methods normally used a Hopfield-like neural network and formulate path planning as an optimization problem. Two different types of approaches can be distinguished in this trend (see table 2). The most largely applied type relies on using a Hopfield-like neural network with continuous outputs [6] [9]. Some of these take advantage of simulated annealing techniques in order to avoid the local optima problem. In these type of methods, the constraints of minimal path length and safe distance to obstacles, together with some other constraints, are usually collected in an energy function to be minimized. Then the neural network is used as a state-space mechanism by exploiting its attracting memory feature to achieve a solution which minimizes the energy function of the system. Because of the state-space search, these methods require discretization

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of the robot configuration space; this fact is their main drawback. However they have proven to be suitable for global motion planning in static environments.

On the other hand, the recent tendency of dynamic attractors comes up [2]. This kind of methods takes advantage of attractor dynamic features of the Hopfield-like neural networks to implement the optimization instead of exploiting the attracting memory feature.

5 Pattern classification neural networks

Methods reported in this section do not utilize pattern classification neural networks as an active part of the path finding algorithm but as an assisting system (see table 3).

Approach	**Chen & Chung 1992**	**Meng & Picton 1992**
Contribution	passive (forbidden areas mapping)	passive (collision penalty computation)
Workspace	3D	2D
No. of Robots	1	1
Robot type	3 dof manipulator	mobile
Robot shape	lines	point
Scope	local	global
Obstacles	arbitrary	rectangular
Environment	dynamic	static
Discretization	yes	yes
Theo/Sim/Imp	simulated	simulated
On/Off line	on line	off line

Table 3. Pattern classification neural networks.

The contribution of Meng & Picton [11] is an improvement to Park & Lee [18] path planning algorithm. Park & Lee approached the path planning problem by using Hopfield's neural network optimization concept. The constraints of avoiding collision and minimizing the length of the path are quantified by a neural network representation of the penalty function associated with an obstacle. Meng & Picton propose the use of only a three-layer neural network to implement the global collision penalty function rather than one for each obstacle, and they designed a learning method based on the backpropagation algorithm.

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Chen & Chung [4] designed a path planner for 3 dof nonredundant robot in a 3D discretized environment. The robot has two revolute joints for the forearm and shoulder and one prismatic for up and down movement. A three-layer backpropagation network is proposed to determine the relationship between the location of a unit obstacle and its corresponding forbidden regions in one of the possible configurations of the robot. To plan a path between starting and goal points, they utilize the Back Trace algorithm. This path finding algorithm makes alternatively use of the two global forbidden maps to make the manipulator try one configuration to reach a point, if it can not succeed with the other.

6 Conclusions

It has been argued that the path planning problem can be addressed in three stages like human beings do it: recalling of the environment from sensory information, global path planning and motion control (local motion planning). Three types of artificial neural networks applied to the robot path planning problem have been distinguished - self-organizing feature maps, optimization neural networks and pattern classification neural networks- and different approaches have been reported for each type.

Other type of artificial neural networks that we have not discussed in this paper is reinforcement based neural networks. These approaches perform the search of the path on line and rely on local qualitative information in terms of punishment or reward. They can allow a robot to acquire goal- and environment-independent obstacle-avoidance reflexes. A detailed discussion of these methods can be found in [10].

The neural networks methods reported here, except for the ones which use sensory information, represent the obstacles in a very simple and unrealistic way, e. g., circles for mobile robots and obstacles, and lines for the links of manipulators. Thus to apply these approaches in the real world, they should take advantage of good object representations. As circular or spherical objects have proven to be very easy to handle, a method that allows every object to be represented as a set of circles or spheres [14][15] would be very useful to avoid adding excessive complexity to neural networks path finding approaches when applying to realistic environments.

Most of the research in this field has been focused on mobile robot path planning. There is little research done in applying neural networks to the path planning problem for manipulators.

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