Applied Soft Computing 21 (2014) 352–364

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

A two level real-time path planning method inspired by cognitive map and predictive optimization in human brain

Yeganeh M. Marghi[a], Farzad Towhidkhah[a,*], Shahriar Gharibzadeh[b]

[a] Biological System Modeling Lab, Faculty of Biomedical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
[b] Neuromascular Systems Lab, Faculty of Biomedical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

ARTICLE INFO

Article history:
Received 11 August 2012
Received in revised form 18 January 2014
Accepted 20 March 2014
Available online 3 April 2014

Keywords:
Sensory-motor map
Global level
Local level
Model-based prediction
Variable prediction horizon

ABSTRACT

A biologically inspired two level method is proposed for real-time path planning in a complex and dynamic environment, employable in ground vehicles. This method takes the advantage of both global and local path finding procedures. In the first level, i.e., global level, the planner utilizes a neural network architecture as a sensory-motor map, similar to the cognitive map used by humans, and an optimization algorithm to produce a coarse path. In the second level, i.e., local level, the global path is improved by employing a model-based prediction method with a finite prediction horizon in a way that future information about the environment is involved in the planner's decision making. In the suggested method, the prediction horizon is variable and is adjusted in each step of the planning in agreement with the kinematic features of the closest obstacle in the visual field of the planner. We considered four different path planning tasks in a virtual dynamic environment to evaluate the performance of the proposed method against the human path planning strategy. The results demonstrate the ability of the method to plan a strategy comparable to the driving scenarios chosen by most subjects and to generate a real-time collision-free path in a dynamic environment with obstacles.

1. Introduction

Over the past years, path planning has attracted significant attention by researchers in different areas including robotics, vehicle guidance, artificial intelligence, and biological systems modeling; each studying the issue from their own point of view. In robotics and vehicle guidance, movement path planning is generally defined as the system's ability to perform automatic path planning in any simple or difficult situation. In biological systems however, the focus is on the functions of different parts of the human and animal brains for better understanding and modeling the behaviors of the cognitive centers [1–7]. Path planning is a complicated cognitive process based on the estimation of the future representation of the environment for the human beings. The most important factors in the path planning process in the human includes: mental map creation from the external world; estimation of the current and future statuses of free spaces located in visual field (environment's dynamic prediction); estimation of free spaces statuses that are not in visual field but will be evident in future (spatial associative memory); estimation of the current state of the body and movement trajectory according to body dynamic (internal model) and the optimal path selection (optimization) [8–12].

Most of the research indicates the critical role of the frontal area in the human brain, especially the prefrontal cortex (PFC), in behavioral planning [1,2,6–9,12,13]. The PFC has a critical function in constituting a map among sensory inputs, thoughts and actions [8]. It is revealed that the frontal patients have unfortunate performances and strategies in complex behavioral tasks [1]. To plan a movement path, the PFC assembles and processes information from cortical and subcortical regions in the brain to represent internal states and goals required for establishing rules which are used in the planning procedure [2]. Pisapia [8] interpreted this representation of assembled information as a function of the dorsolateral PFC to conserve information in an active state. The evidence shows that this is attained by constructing on-line internal models of the external zone.

Through recent years, different models and methods have been suggested for real-time path finding in a dynamic environment. Most of these approaches are presented according to the conditions and restrictions within a specific application. For instance, in

* Corresponding author at: Faculty of Biomedical Engineering, Amirkabir University of Technology, 424 Hafez Ave., P.O. Box: 15875-4413, Tehran, Iran.
Tel.: +98 21 64542363; fax: +98 21 66468186.
E-mail address: towhidkhah@aut.ac.ir (F. Towhidkhah).

http://dx.doi.org/10.1016/j.asoc.2014.03.038

path finding a ground-vehicle, a planner encounters a large volume of information processing. The planner should be aware of its own position, the condition of other objects in the environment, and road geometry. Thus, motion path planning is a collection of some active and adaptive processes that requires a frequent interaction between planner and environment [14,15]. Since the understanding of the environmental configuration and information about its objects is an important phase of path planning, many strategies have been proposed to represent the environment map. A key point in this regard is to consider the nature of the environment in the representation. One of the well-known groups of maps which are employed in map-based path planning is "cognitive map". Many studies have shown that the strategy used by the brains of primates and rodents are based on employing a cognitive map [16–19]. Generally, the cognitive map is a robust representation of an external environment and its objects within their spatial relations, which gives the ability to handle the uncertainty of the environment. This issue was presented over sixty years ago by Tolman [16]. After two decades of studying the function of the hippocampus, O'keefe [17] realized the existence of place cells (as pyramidal cells), which play an important role in determining objects' places and kinematic features of their movement (e.g., velocity and direction). Later, several studies have been done on the hippocampal function in path finding [19–21].

Some research studies in animals' behaviors indicated the mapping of sensory inputs to motor commands in their navigation procedure [22]. For human, spatial information (e.g., perception of action, geometric shapes, and symbols) is instructed based on the sensory-motor experiences. Cognitive map provides a supervised planning that simplifies the path planning for the planner to generate a short path between observation and goal place even in complex environments [22]. Usually, the cognitive map is assumed as a collection of basic geometric features and landmarks, which represents physical aspects and spatial relations in an environment. Moreover, this cognitive structure helps the planner to recall efficient information of the external environment and eliminate insignificant features to establish a near optimal and safe motion trajectory. Inspired by human cognitive map, Kuipers [23] proposed a spatial semantic hierarchy model of environment representation. The introduced model consists of different sensory, processing, learning and control levels to provide a successful navigation in a large-scale space. In this work, navigation through an unknown environment has been made possible by using locally distinctive cells in a grid map over the environment. Yeap and his colleagues [24] proposed cognitive mapping for a mobile robot in path finding tasks for mapping and estimating positions for robot home way finding.

One of the major groups of path planning approaches, which uses a grid-based map for path finding is a neural network model. Many neural networks have been proposed for real time and collision free path generation in static and dynamic environments [25–28]. A group of these networks employs a learning process while others do not use any learning and previous knowledge. Most of the neural network models which work in the dynamic environment utilize a grid-based representation of the environment [26,27]. The functional performance of this group of networks is similar to how humans make decisions based on the mental map. Glasius et al. [25] proposed a Hopfield type neural network with nonlinear dynamic for collision free path finding in both static and dynamic environments. In another work, Glasius et al. [26] introduced a bio-inspired two-layered neural network that was able to produce a smooth path in dynamic place. Yang and Meng [27] suggested another bio-inspired neural network with a continuous dynamic based on the shunting equation of Grossberg. This model was developed to generate a real time collision free trajectory in both static and dynamic areas. Lebedev et al. [28] proposed a parameter-free model based on a dynamic wave expansion neural network (DWENN) for path finding in a dynamic environment. The principle of this network is based on wave propagation from a target to other neurons that convey information of the distance to the target place. However, most of these models suffer from computational efforts when facing fast dynamic objects in the environment.

From another point of view, there are two main strategies for path planning: global and local path planning. The global path planner makes decision by employing a map of the surrounding environment. The generated path in this method is formed according to exploration among free spaces in an arranged map, based on the past and current information of the environmental configuration. A drawback of this group of planners is the weakness in path finding in dynamic environments. In contrast, the local path planners benefit from a proper operation in dynamic and clutter environments. This group locally performs the planning based on the goal position. However, a drawback of local planners is the poor performance in an expanded environment. To improve the performance of planners in both dynamic and wide environments, a combination of the two groups has been suggested by some researchers [28–33]. A primary model introduced in this respect is a hierarchical path planning method suggested by Miura and Shirai [29]. This hierarchical method consists of local and global levels. At the local level, the planner abstracts an environmental graph and searches locally for the optimal trajectory. At the global level, path smoothing is done through replacing locally optimal trajectory by straight lines, which is globally optimal. Sequeira and Ribeiro [30] proposed a two level path finder for underwater autonomous vehicles. In this approach, a rough path produced in the first level was optimized based on minimum energy in potential field. Bortoff [31] proposed a real-time two-step path planner for unmanned autonomous vehicles (UAVs) that Voronoi graph and a local exponentially stable solution are utilized in each step respectively to compute an optimal path. Another two-step structure for the motion path planning is recommended by Garrido et al. [32]. They utilize a two level planning for a safe and fast path generation for a mobile robot. Similarly, at the first level, a global route was produced based on the wave front planning strategy on Voronoi diagram. At the second level a fast marching technique was applied to develop the global and suboptimal trajectory in the settled graph. Dolgov et al. [33] suggested a novel approach for path finding for autonomous vehicles. The proposed method is attributed to the global and local path planner for producing a smooth path in an unknown environment. Some of the reviewed studies exhibit proper performance only in static environments, while the others perform well in dynamic conditions. However, since the prediction part of planning is disregarded in the latter type, they might encounter trouble in certain dynamic situations. Another challenging issue in motion path planning is complexity and spread of an environment. Most of the aforementioned works have weak performance in these states.

This paper is focused on using a two-level motion path planning with the artificial intelligence approach as a convenient method in motion path generation. A biologically inspired model is proposed for real-time path planning in complex and dynamic environment applicable in ground vehicles. The proposed method consists of two phases of path generation. In the first phase, by using a sensory-motor map which is analogous to the human cognitive map, a coarse path is produced. A bio-inspired neural network based on the network suggested by Yang and Meng [27] is used to form the sensory-motor map. In the second level, the produced rough path is locally enhanced by using a model-based predictive strategy. In model-based predictive strategy the rough path is modified by applying the future presence of an environment and the model of all obvious obstacles in a finite prediction horizon. In this approach, the prediction horizon is variable and is adjusted in each step of