Path planning in the hippocampo-prefrontal cortex pathway: An adaptive model based receding horizon planner

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Summary

Four characteristic properties of human path planning strategy are course and fine planning, supervised planning, adaptation and robustness, and complexity reduction. These four characteristics are also observed in "model predictive controller" and its modified version, "receding horizon planner". We hypothesize that the human brain performs path planning tasks, literally like a receding horizon planner.

The similarities between human brain and a receding horizon planner are: (1) hippocampus contains the course model and the parietal cortex is responsible for the fine model. (2) Replanning and trajectory tuning using the visual data in parietal cortex and prefrontal cortex is exploited in an adaptive restricted receding horizon. Prefrontal cortex plays the role of the supervisor. (3) Adjusting the sampling time of the planner is implemented based on changes in the complexity of the environment and tasks. This is in fact, the adaptation, which exists both in human behavior and in receding horizon planner. (4) The brain simplifies path-finding problems to reduce computational loads, exactly similar to what engineering controllers intend to do. The visual data is smoothed by clustering of obstacles, before performing any computational task.

Finally, we have discussed the consequence of our hypothesis in Alzheimer disease as an optimal planning disorder. Based on some experimental data, Alzheimer patients have a reduced predictive horizon, making the system less robust and exposed to hazardous conditions in sophisticated environments.

Patients with mild Alzheimer disease have little trouble with simple optimization problems; working memory of the prefrontal cortex is sufficient for this purpose. However, in complicated tasks, the brain needs huge extended memory. This memory is available through hippocampo-prefrontal pathway, which is to some extent disturbed in Alzheimer patients. We suggest that this fact may be a basis for future experimental diagnosis tests. We predict that Alzheimer patients should have problems with planning for far future; because they have a weak memory, insufficient for heavy optimization tasks, such as moving through moving obstacles in a dynamic environment. Alzheimer disease could be early detected by designing new tests in which the ability of patients to predict the future events is checked. These
Introduction

In this study, we focus on human path planning strategy. Four characteristic properties of this process are as follow:

1. Coarse and fine planning: Two types of neuronal activities exist in the lateral prefrontal cortex of monkeys performing a path planning task in a maze in which the monkeys are obliged to plan motor actions in multiple steps [1]. The first type reflects the position within the maze to which the animal intends to reach within an initial step (an immediate goal) and the second type reflects the position within the maze that is to be captured as the final goal. However, neither type activated motor areas of the brain, indicating that the mentioned mechanisms are involved in path planning strategy rather than the motor activity. Therefore, it is concluded that the human has two types of path planning strategies: coarse and fine.

The information from parietal cortex, prefrontal cortex and hippocampus is important in navigation and guidance [2]. The brain uses a model of the environment which is both static and dynamic. Hippocampus plays the role of an associative memory which can retrieve the scenes learned before [3] as a static map of the environment. Hence, these data are used for coarse map generation in the hippocampus. On the other hand, the interactions between prefrontal and parietal cortices are used for dynamic mapping and fine tuning of the rough path.

2. Supervised planning: Crowe et al. claim that path tuning in parietal cortex is not due to the lower level visual features of the maze stimulus, but rather is associated with maze solution in prefrontal cortex, and as such, reflects a cognitive process applied to a complex visual stimulus [4]. This is the remapping which is done due to dynamic changes in the environment and suggests the upside-down planning, which is the role of prefrontal cortex as a supervisor of the planner. Klingberg et al., have shown that the area in the inferior parietal cortex is co-activated with the dorsolateral prefrontal cortex in several working memory tasks involving planning, irrespective of the sensory modality of the stimuli [5]. This evidence shows the increased activation of both the prefrontal and the parietal cortices in a planning task.

3. Adaptation and robustness: It is also shown that visual sampling of the environment is increased when there is a potential hazard in the travel path [6]. So the planning horizon in prefrontal cortex is adaptive due to complexity of the environment. Obstacle avoidance do influence the visual sampling time, proportional to the magnitude of environmental changes. This can be considered as a robust behavior in humans.

4. Complexity reduction: It is believed that during path planning, the brain uses the visual information for clustering of obstacles. Then, the prefrontal cortex uses these clusters to identify a safe corridor to plan a route between obstacles [7]. In other words, the brain reduces computing effort and simplifies decision making process by clustering of obstacles, and optimizes the path through finding the safe corridor.

Engineering background

In this section, we discuss some properties of model predictive controller (MPC) and its modified version, receding horizon planner (RHP), in order to see whether some similar behaviors exist between human path planning strategy and these engineering methods.

MPC generates control actions based on the output prediction of the system to be controlled using optimization techniques [8]. The basic structure of the MPC is shown in Fig. 1. The controller has two major parts: (a) a model of the process for estimating the future behavior (the predicted trajectory) of the system and (b) an optimizer that computes the future errors (collisions...
or hazardous routs) by tuning the rough estimated trajectory.

In an RHP, some major properties are observed:

1. Coarse and fine planning: There are two tuning factors in the RHP algorithm: (a) The prediction horizon. It refers to the time duration in which the output of the model is studied and used in the optimization. (b) The control horizon. It is the number of future control signal steps applied to the model to produce the predicted trajectory. Indeed, the desired trajectory, which is the set point of the system and included in the prediction horizon, can be considered as the coarse path. However, the tuned path, which is computed during the optimization process (in control horizon), is in fact the fine planning.

2. Supervised planning: By changing the model parameters, an adaptive MPC is capable of adapting itself with the dynamic changes of the model and disturbances. An added supervisor module in the adaptive MPC or RHP tunes their parameters due to these changes.

3. Adaptation and Robustness: In RHP, the prediction horizon may be either fixed or adaptive due to the complexity of the system. Because of restricted computing capabilities, more sophisticated environments need shorter prediction horizons and reduced moving steps. Prediction horizon should be large enough to accommodate the system transient dynamics. Although increasing the value of prediction horizon increases the system stability and moderates the control signals, it also increases computing time. When the model is imperfect or time variant, it is important to adopt suitable horizons, both for prediction and for control. The most important advantage of MPC is that

in the case of observing undesirable behavior in the plant or violating the operating constraints, the recursive optimization algorithm improves the control signals, which could cause "robustness of the controller", i.e. sustaining the stability of the total system.

4. Complexity reduction: For linear systems, the step response or the impulse response of the system are used for modeling the plant. These models could be obtained simply by using standard identification methods. They have few identification parameters and lead to simple linear optimization problems, consequently reducing the computation time. On the other hand, nonlinear models can reduce the model mismatching, but cause a nonlinear optimization problem with heavy computation time. In addition, most of RHPs use a smoothed reference trajectory in order to ease the control process. A smoothed reference trajectory has limited frequency components, i.e. it has no jump or fast variation. Therefore, a simple model like a step response could follow it easier.

The hypothesis

Based on the above mentioned topics, we hypothesize that the human brain performs path planning tasks, literally like an RHP.

The similarities between human brain and an RHP are summarized as follow:

1. The model of the static and learned environment retrieved from hippocampus is used to select the strategy of movement in the prefrontal cortex. On the other hand, parietal cortex tunes the coarse model of the environment. It means that, hippocampus contains the coarse model and the parietal cortex is responsible for the fine model.

2. Replanning and trajectory tuning using the visual data in parietal cortex and prefrontal cortex is exploited in an adaptive restricted receding horizon. Prefrontal cortex plays the role of the supervisor.

3. Adjusting the sampling time of the planner is implemented based on changes in the complexity of the environment and tasks. This is in fact, the adaptation, which exists both in human behavior and in RHP. This is in essence, a kind of robust behavior.

4. The brain simplifies path-finding problems to reduce computational loads, exactly similar to what engineering controllers intend to do. The
visual data is smoothed by clustering of obstacles, before performing any computational task.

**Alzheimer disease: an optimal planning disorder**

A "Traveling Salesman Problem" (TSP), promised as a test for early detection of the Alzheimer disease, shows that nearly none of the Alzheimer patients could find the optimal solution. In this test, a random array of 30 points is generated. The task consists of drawing the shortest continuous path, passing through each point once and only once, and returning to the starting point [9]. This test is an engineering benchmark too. Failing to pass this test means a poorly designed planner and optimizer. This evidence supports the idea that the planning and optimization needs extra memory to be allocated to the short term memory (STM), because the STM can facilitate only 7 memory spaces concurrently in TSP test. From an engineering point of view, Alzheimer patients have a reduced predictive horizon, making the system less robust and exposed to hazardous conditions in sophisticated environments.

In another research, the drivers with mild Alzheimer Disease (AD) made significantly more incorrect turns, got lost more often, and made more at-fault safety errors than control subjects, although their basic vehicular control abilities were normal [10]. This shows some problem in more complicated tasks needing planning. This research is consistent with our hypothesis, claiming that adaptation and robustness are two features of RHP and the brain.

Rizzo et al. have studied important factors in car crashes included visuospatial impairment, disordered attention, reduced processing of visual motion cues, overall cognitive decline and reduced 3-dimensional perception [11,12]. They have shown that these factors are more pronounced in Alzheimer patients. It seems that a reduction in perception ability (modeling of the environment) in AD is the main cause of these disorders. On the other hand, a reduction in the useful field of view has been reported in AD, indicating the shortening of the predictive horizon in these patients, which is in accordance with our hypothesis about the model based behavior of human path planning.

Patients with mild AD have little trouble with simple optimization problems. The short term memory provided as working memory of the prefrontal cortex is sufficient for this purpose. However, in more complicated tasks, the brain needs huge extended memory. This memory is available through hippocampo-prefrontal pathway which is to some extent disturbed in Alzheimer patients. We suggest that this fact may be a basis for future experimental tests, trying to diagnose mild AD.

**Consequences of the hypothesis**

In RHP, for longer prediction horizons, we need more memory to fulfill prediction and optimization tasks. We predict that Alzheimer patients should have problems with planning for far future, as they have problems with past events; because they have a weak memory, insufficient for heavy optimization tasks, such as moving through moving obstacles in a dynamic environment.

Alzheimer disease could be early detected by designing new tests in which the ability of patients to predict the future events is checked. These tests could be accompanied by a multi-step optimization problem. We believe that paying attention to this opinion may provide a good help in diagnosing AD in earlier stages. Surely, experimental studies are needed to validate our hypothesis.

**References**


