Chapter XIV
Towards Autonomic Computing: Adaptive Neural Network for Trajectory Planning

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ABSTRACT

Cognitive approach through the neural network (NN) paradigm is a critical discipline that will help bring about autonomic computing (AC). NN-related research, some involving new ways to apply control theory and control laws, can provide insight into how to run complex systems that optimize to their environments. NN is one kind of AC systems that can embody human cognitive powers and can adapt, learn, and take over certain functions previously performed by humans. In recent years, artificial neural networks have received a great deal of attention for their ability to perform nonlinear mappings. In trajectory control of robotic devices, neural networks provide a fast method of autonomously learning the relation between a set of output states and a set of input states. In this chapter, we apply the cognitive approach to solve position controller problems using an inverse geometrical model. In order to control a robot manipulator in the accomplishment of a task, trajectory planning is required in advance or in real time. The desired trajectory is usually described in Cartesian coordinates and needs to be converted to joint space for the purpose of analyzing and controlling the system behavior. In this chapter, we use a memory neural network (MNN) to solve the optimization problem concerning the inverse of the direct geometrical model of the redundant manipulator when subject to constraints. Our approach offers substantially better accuracy, avoids the computation of the inverse or pseudoinverse Jacobian matrix, and does not produce problems such as singularity, redundancy, and considerably increased computational complexity.

INTRODUCTION

Current research areas on theories and applications of Cognitive Informatics (Wang et al., 2005; Chiew, 2003; Wang, 2005) have demonstrated a consistent effort at applying cognitive informatics to real world problem domains such as autonomous computing. Almost all of the hard problems yet to be solved in this discipline are stemmed from the fundamental constraints of the brain and the understanding of its cognitive mechanisms and processes (Wang et al., 2002; Wang et al., 2003).
Towards Autonomic Computing

The autonomic computing (Wang, 2003) derives from the body’s autonomic nervous system, which controls key functions without conscious awareness or involvement. Autonomic controls use motor neurons to send indirect messages to organs at a sub-conscious level. These messages regulate temperature, breathing, and heart rate without conscious thought. The implications for computing are immediately evident; a NN, which computes joint positions for a robot and adapts itself under varying conditions without considerably increased computational complexity. In recent years, artificial neural networks have received a great deal of attention for their ability to perform nonlinear mappings. In trajectory control of robotic devices, neural networks provide a fast method of autonomously learning the relation between a set of output states and a set of input states (Guez et al., 1989; Kieffer et al., 1991; Hunt et al., 1992; Ramdane-Cherif et al., 1995).

In (Jung et al., 2000; Fang et al., 1993; Fang et al., 1998) several neural network inverse control techniques are applied for trajectory tracking of a PD controlled rigid robot and (Kawato et al., 1990) look ahead planning based on neural networks is successfully applied to real time control of a robot arm. The task is to touch a rolling ball with a robot arm.

Traditional approaches to control redundant manipulators have centered on the Jacobian pseudoinverse (Klein et al., 1983) which is non intuitive, tiresome to compute and generates arbitrary joint position vectors in the neighborhood of singularities. These solutions are often inappropriate and result in unacceptable large joint velocities and accelerations.

Many methods have therefore been developed to solve this problem. Some of them extend the pseudoinverse (Liegeois, 1986; Klein, 1993 et al.; Chen et al., 1993) so as to use the kinematic redundancy for optimizing an objective function or to directly solve the redundancy by including some constraints into the direct kinematic model. Other works are oriented towards real time application like the gradient projection scheme proposed in (Dubey et al., 1991) or the decomposition of the jacobian matrix into two squared matrices found in (Chevallereau, 1988). The computational complexity is partly reduced. The globally optimal resolution has also been proposed. This approach converts the redundancy resolution to an optimal control problem using the necessary conditions of optimality given by the Pontryagin’s principle (Nakamura et al., 1987) or by the optimal control theory (Kim et al., 1994). This work is however inappropriate for real-time control. These solutions generate arbitrary joint positions in the neighborhood of singularities and when target positions are out of reach.

Since a neural network can certainly learn to generalize and learn relationships that were not present in the training set, it will give an approximated solution near singularity points. As a result, a neural network will be able to solve the singularity problem which has long been the major difficulty in implementing Resolved Motion Rate Control. A neural network will also be able to give solutions that work well even when target positions are out of reach.

Another problem that arises when studying the kinematic aspects of a robot manipulator is the so-called inverse geometrical problem. When using a position controller to operate a robot manipulator, trajectory planning is required in advance or in real time. The desired trajectory is usually described in Cartesian coordinates and needs to be converted to joint space for the purpose of analyzing and controlling system behavior. The inverse geometrical model can generally be approached by a numerical solution. The geometric method using (Hunt, 1987; Kircanski et al., 1993) derives a closed-form solution from the direct kinematic equation. For manipulators that do not have a closed-form solution like kinematically redundant manipulators, standard numerical procedures (Featherstone, 1994; Bestaoui, 1991) solve the nonlinear differential equation at a discrete set of points. Moreover, for redundant arms, one solution has to be chosen from an infinite number of inverse kinematic solutions obtained for a given workspace position. This leads to increased numerical complexity.

In this chapter, we use the Modified Memory Neural Network (MMNN) to solve both the redundancy and singularity problems of the inverse geometrical model in a more effective manner than the standard methods. Specifically, we use the MMNN to find solutions to the inverse geometrical model which are required for operating the position controller of a redundant robot manipulator. We demonstrate that the MMNN-based position controller is better able to track straight line trajectories than standard methods, especially when the trajectories involved singularities. We show that the MMNN-based position controller can also be trained to honor problem specific constraints. This neural network controller is able to successfully track more challenging cyclical trajectories when certain constraints were enforced.
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