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Robot manipulator control using neural networks: A survey☆

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ABSTRACT

Robot manipulators are playing increasingly significant roles in scientific researches and engineering applications in recent years. Using manipulators to save labors and increase accuracies are becoming common practices in industry. Neural networks, which feature high-speed parallel distributed processing, and can be readily implemented by hardware, have been recognized as a powerful tool for real-time processing and successfully applied widely in various control systems. Particularly, using neural networks for the control of robot manipulators have attracted much attention and various related schemes and methods have been proposed and investigated. In this paper, we make a review of research progress about controlling manipulators by means of neural networks. The problem foundation of manipulator control and the theoretical ideas on using neural network to solve this problem are first analyzed and then the latest progresses on this topic in recent years are described and reviewed in detail. Finally, toward practical applications, some potential directions possibly deserving investigation in controlling manipulators by neural networks are pointed out and discussed.

1. Introduction

In recent decades, robotics has attracted more and more attention from researchers since they have been widely used in scientific researches and engineering applications, such as space exploration, under water survey, industrial and military industries, welding, painting and assembly, and medical applications, and so on [1,2]. Much effort has been contributed to robotics, and different types of robot manipulators have thus been developed and investigated, such as serial manipulators consist of redundant manipulators [3] and mobile manipulators [4], parallel manipulators [5], and cable-driven manipulators [6]. A redundant manipulator is often designed as a series of links connected by motor-actuated joints that extends from a fixed base to an end-effector while a mobile manipulator is often designed as a robotic device composed of a mobile platform and a redundant manipulator fixed to the platform [7]. Different from these serial manipulators, a parallel manipulator is a mechanical system that usually uses several serial chains to support a single platform, or end-effector. Besides, a cable-driven manipulator is a special parallel manipulator, in which the moving platform is driven by cables instead of rigid links [8]. Using these manipulators to save labors and increase accuracies are becoming common practices in various industrial fields. As a consequence, many approaches have been proposed, investigated and employed for the control of robot manipulators [9]. Among them, thanks to many advantages in parallel distributed structure, nonlinear mapping, ability to learn from examples, high generalization performance, and capability to approximate an arbitrary function with sufficient number of neurons, the neural-network-based approach is a competitive way to control movements of robot manipulators [1]. Generally speaking, neural networks can be classified into different types according to different criterions. For example, in terms of the structure of the network, they can be classified into two categories: feedforward neural networks and recurrent neural networks [10,11]. A feedforward neural network is an artificial neural network with no cycles or feedback signal inside while a recurrent neural network allows bi-directional information

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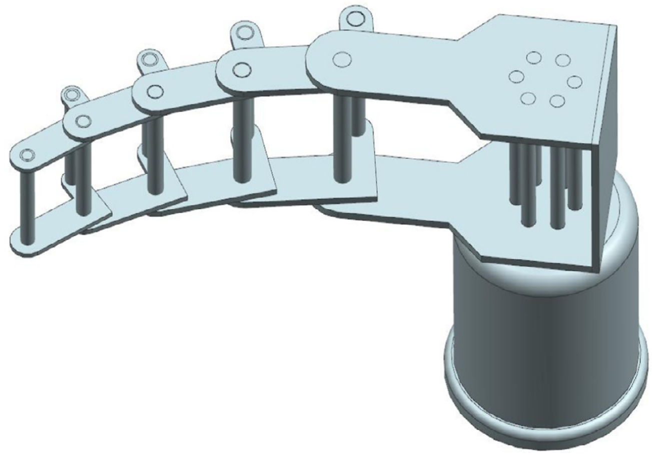

Fig. 1. An example of redundant manipulators.

flow, which means the information inside flows from a successive node to a previous one (or called feedback) or forms a closed cycle within a single node. In this paper, we make a relatively comprehensive review of research progress on controlling these robot manipulators by means of neural networks. The overall organization of the paper is as follows. After the introduction, we present preliminaries on the control of robot manipulators based on neural networks in Section 2. Section 3 presents and reviews different types of robot manipulators in detail with the corresponding schematics being illustrated. In addition, Section 4 revisits applications of different neural networks to the control of robot manipulators. Moreover, two possible future research directions on control of robot manipulators using neural networks are pointed out in Section 5. Finally, Section 6 concludes the paper with final remarks.

2. Preliminaries

The purpose of controlling manipulators is to achieve a specific task like payload carrying, trajectory tracking and so forth [12]. In order to accomplish those tasks, we have to send orders to the manipulators to let them achieve the desired velocity, acceleration or force at specific time [13]. The behavior of manipulators can be deemed as a function since the output given by a manipulator would be different with the change of inputs. Taking the redundant manipulator illustrated in Fig. 1 as an example [14], with inputs of manipulators being angles of joints often expressed as $\theta(t)$ at a specific time t, we have the following general expression [15]:

$$r(t) = f(\theta(t)), \tag{1}$$

where $r(t)$ indicates the end-effector's position and $f(\cdot)$ represents the differentiable nonlinear function. Actually, the output value could also be velocity, acceleration, and force applied on end-effectors, which just needs further calculation. The purpose is to design a controller that could send appropriate inputs when the desired output is given, sometimes with various kinds of constraints. In this paper, we mainly investigate controllers based on neural networks, which have already shown to have powerful capability in solving nonlinear problems [16–21].

An intuitive working flow of controlling a manipulator with neural network based controller is given in Fig. 2. Generally speaking, according to the extent of the knowledge on the manipulator dynamics as well as external disturbance, neural network based controllers for the motion generation and control of manipulators can be classified into three categories: full knowledge, partial knowledge, and no knowledge on the model dynamics and external disturbance of manipulators. With known structure and parameters, recurrent neural networks can be developed to control manipulators such that a performance index under extra constraints can be optimized [22–28]. A control scheme based on recurrent neural networks is presented in [26], which is able to maximize the manipulability of a robot manipulator with known model dynamics effectively in an inverse-free manner. The involved recurrent neural network solves the problem recursively and does not need to be trained in advance. In addition, under certain conditions, it has been proven that feedforward neural networks are capable of approximating various nonlinear functions to any desired degree of accuracy [29]. Thus, the adaptive neural network is designed to compensate uncertainties due to modeling errors or disturbances in the control of manipulators with partial knowledge on model dynamics [29,30]. Besides, the model-free control scheme aided with neural networks is able to address the learning and control of manipulators simultaneously in a unified framework, with the model dynamics of manipulator unknown [31].

In order to command manipulators to finish a specific task, users only need to input a desired output to the control system in practical cases [32]. Then the controller would automatically send a processed signal including commands to manipulators to achieve the final outputs. The crucial task here is to design a controller able to minimize the difference between the desired outputs and the actual outputs, in order to simulate the dynamics of target manipulators.

3. Various robot manipulators

In this section, we start a discussion from a perspective of the variety of mainstream manipulators that involved in controlling problem tackled by neural networks.

3.1. Redundant manipulators

Redundant manipulators are those manipulators that have more domain of freedom (DOF) than required by tasks, which enable some improvements on performance like avoiding collision, optimizing specific criteria like torques or velocity at joints. Different form the non-redundant manipulator, as illustrated in Fig. 1, a robot manipulator with extra redundancy could move in a wider range, have better dexterity and also work more efficient in coordinate manipulation task [33]. The optimization of redundant manipulators is frequently treated as a quadratic programming problem. To remedy the joint-angle drift phenomenon for control of two redundant manipulators, a scheme is proposed in [34] and solved by a special case of dual network termed piecewise-linear projection equation based neural network. This work can be deemed as a follow-up work on the motion planning of redundant manipulators based on neural networks. More related works done on the control of redundant manipulators include [15,35–41].

3.2. Parallel manipulators

A parallel manipulator as shown in Fig. 3 is a mechanism that an end-effector, usually a platform, is supported by several serial chains, which could be applied to the area of medication, industrial manufacturing, deep sea exploration [42,43] and flight simulators [44]. One of the most famous example is Stewart platform, consisting of six linear actuators and two platforms, one of which is the base to support actuators and the other would be the end-effector supporting by those controllable actuators [45]. Compared with serial manipulators, parallel manipulators have better stiffness and are more convenient to reconfigure. In addition, parallel manipulators may avoid the error which may be amplified by each joint