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Reliability-based approach to the inverse kinematics solution of robots using Elman's networks

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Abstract

The solution of inverse kinematics problem of redundant manipulators is a fundamental problem in robot control. The inverse kinematics problem in robotics is the determination of joint angles for a desired cartesian position of the end effector. For the solution of this problem, many traditional solutions such as geometric, iterative and algebraic are inadequate if the joint structure of the manipulator is more complex. Furthermore, many neural network approaches have been done to this problem. But the neural network-based solutions are not much reliable due to the error at the end of learning. Therefore, a reliability-based neural network inverse kinematics solution approach has been presented, and applied to a six-degrees of freedom (dof) robot manipulator in this paper. The structure of the proposed method is based on using three networks designed parallel to minimize the error of the whole system. Elman network, which has a profound impact on the learning capability and performance of the network, is chosen and designed according to the proposed solution method. At the end of parallel implementation, the results of each network are evaluated using direct kinematics equations to obtain the network with best result.

Keywords: Robotics; Recurrent networks; Elman networks; Inverse kinematics solution; Reliability; 6-dof robots

1. Introduction

The trajectory to be followed and the task to be performed during motion planning by an industrial robotic manipulator is mostly important in real-time systems. The motion takes place in Cartesian space, but most of the industrial robots, especially the articulated ones, are controlled in their own joint spaces. Because of this, in order to perform a motion, a kinematics transformation between the Cartesian space and joint space is necessary. Computation of joint variables is also needed in computing the required joint torques for the actuators. The kinematics problem in robotics can be divided into two main sections: forward and inverse kinematics problems. Forward kinematics problem, that is, given the joint variables, determination of the end effector position and orientation in the Cartesian space, can easily be solved in closed form. On the other hand, inverse kinematics problem, which consists of determination of each joint variable by using the Cartesian space data, does not guarantee a closed-form solution. The inverse kinematics transformation is configuration and structure dependent, and is also nonlinear. For other robot models, which do not have a closed-form solution, inverse kinematics solution gets much too difficult and different types of approaches for the solution like neural network approach are mostly needed (Balkan et al., 2000).

The inverse kinematics problem for a robotic manipulator is obtaining the required manipulator joint values for a given desired end-point position and orientation. The inverse kinematics problem is usually complex for robotic manipulators. There are three traditional methods used to solve inverse kinematics problem: geometric (Featherstone, 1983; Lee, 1982), algebraic

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(Duffy, 1980; Manocha and Canny, 1994; Paul et al., 1981; Manocha and Zhu, 1994) and iterative (Korein and Balder, 1982) methods. Every method has some disadvantages. The algebraic methods do not guarantee closed-form solutions. In case of using geometric methods, closed-form solutions for the first three joints of the manipulator must exist geometrically. The iterative methods converge to only a single solution and this solution depends on the starting point. For simple manipulator geometry, the problem is solved using trigonometric approaches involving tedious mathematical steps. If the joint structure of the manipulator is more complex, the inverse kinematics solution by using these traditional methods is a time-consuming study. The computation of inverse kinematics using artificial neural network is particularly useful where less computation times are needed, such as in real-time adaptive robot control (Clark and Mills, 2000). In other words, for a more generalized m-degrees of freedom (dof) manipulator, traditional methods will become prohibitive due to the high complexity of the mathematical structure of the formulation. To compound the problem further, robots have to work in the real world that cannot be modeled concisely using mathematical expressions (Grudic and Lawrange, 1993).

Fast algorithms are needed for inverse kinematics solution of robot manipulators particularly in real time control. The traditional solution methods take much time in solution. Therefore, artificial neural networks-based inverse kinematics solution has received a great deal of attention from researchers because of the online and fast working feature (Chen et al., 1996; Köker et al., 2001). Many papers have been published related to the neural networks-based inverse kinematics solution of robot manipulators (Hahala et al., 1991; Bao and Ito, 1995). Tejomurtula and Kak (1999) have proposed a solution for inverse kinematics solutions based on structured neural networks that can be trained quickly. Their algorithm overcomes the disadvantages of back-propagation algorithm, like training time and accuracy. Karlik and Aydin (2000) has presented a study of inverse kinematics solution based on finding the best configuration of neural network model by using the same 6-dof robot model in this study. They have tested the solution for two configurations. In the first configuration the neurons are fully connected to each output with one hidden layer. In the second configuration, for each output a neural network is designed with two hidden layers. They stated that the result of the second configuration is better than that of the first configuration.

A neural network-based inverse kinematics solution method yields multiple and precise solutions with an acceptable error and it is suitable for real-time adaptive control of robotic manipulators. Therefore, the main aim of this paper is focused on improving the reliability of the neural network-based solution of inverse kinematics problem. In other words, it is focused on minimizing the acceptable error stated above. It is a well-known fact that in parallel implementation the error decreases from the viewpoint of a whole system. Here, to obtain the inverse kinematics solution, Elman network, which is from the recurrent networks family, has been chosen. It has feedback loops, which have a profound impact on the learning capability and performance of the network (Haykin, 1999). Three Elman neural networks, which are parallel implemented, are used in the solution. The aim of using three different Elman networks is to minimize the error from the viewpoint of the whole solution system. If one network gives results with many errors, the other one may give better results. The results of each network are evaluated by using direct kinematics equations to obtain information about their error. In other words, the angles obtained for each joint are used to compute the Cartesian coordinate for end effector, and then, using Euclidian distance equation, the error in the metric can be computed for each obtained result. This will help us to select the best results among the results of the three neural networks. The training data of each neural network have been selected very precisely. Especially, unlearned data in each neural network have been chosen, and used to obtain the training set of the last neural network.

2. Kinematics analysis of a 6-dof robot

A robotic manipulator can be modeled as an open-loop articulated chain with several rigid links connected in series by either revolute or prismatic joints, which are driven by actuators. Robot kinematics deals with the analytical study of the geometry of the motion of a robot with respect to a fixed reference coordinate system as a function of time without regarding the forces/moments that cause the motion. Therefore, it deals with the analytical description of the robot as a function of time, in particular, relations between the joint-variable space and the position and orientation of the end-effector of a robotic manipulator (Fu et al., 1987). Fig. 1 shows the structure of the robotic manipulator used in this study.

In robotics, the kinematics analysis is done in two ways: forward (direct) kinematics and inverse kinematics analysis. The solution of inverse kinematics problem, which is mainly solved in this paper, involves the determination of the end-effectors position and orientation and their rate of change, as a function of given positions and speeds of the axes of motion (Koren, 1987).

Denavit and Hartenberg (1955) proposed a matrix method of systematically establishing a coordinate