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An evolutionary approach for solving the multimodal inverse kinematics problem of industrial robots

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Abstract

The inverse kinematics solution of an industrial robot may provide multiple robot configurations that all achieve the required goal position of the manipulator. In the absence of obstacles, multiplicity resolution can be achieved by selecting the robot configuration closest to the current robot configuration in the joint space. An evolutionary approach based on a real-coded genetic algorithm is used to obtain the solution of the multimodal inverse kinematics problem of industrial robots. All the multiple configurations obtained by this approach can be displayed using a 3D modeler developed in MATLAB for the purpose of visualization. The multiple configurations are then compared on the basis of their closeness in joint space to the current robot configuration. Simulation experiments are carried out on a SCARA robot and a PUMA robot to illustrate the efficacy of the approach.

Keywords: Robot inverse kinematics; Real-coded genetic algorithm; Multiplicity resolution

1. Introduction

The kinematics equations of an industrial robot are non-linear and transcendental in nature. Their inverse kinematics solution provides the joint angles that are required to attain a particular position of the robot wrist in the robot workspace. The inverse kinematics solution may provide multiple robot configurations that all achieve the required goal position of the manipulator. In the absence of obstacles, the robot configuration closest to the current robot configuration in the joint space may be selected. This process of obtaining a unique solution can be referred to as a 'multiplicity resolution'.

Paul [1] proposed the use of homogeneous transformation matrices to obtain the inverse kinematics solution. The solution is obtained in a sequential manner, isolating each joint variable by pre-multiplication by a number of homogeneous transforms in each equation. Geometric intuition is suggested at certain points of the solution for certain manipulators. Multiple solutions for an elbow manipulator corresponding to 'elbow up'

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and 'elbow down' configurations are obtained trigonometrically. The issue of multiplicity resolution is also not addressed by the author.

Details of research work done in the area of obtaining the inverse kinematics solution of industrial robots can be found in the robotics book by Fu et al. [2]. Fu et al. [2] have presented the inverse transform technique of determining the joint solution of a manipulator. This technique is based on the paper by Paul et al. [3]. The technique does not give a clear indication of how to select an appropriate solution from the several possible inverse kinematics solutions for achieving a particular goal position. A geometric approach based on the work of Lee and Ziegler [4] has also been presented in Fu et al. [2]. This approach utilizes arm configuration indicators which have to be pre-specified by a user for finding a particular configuration out of the multiple configurations available from the inverse kinematics solution.

Iterative solutions for finding the inverse kinematics solution of industrial robots have been proposed by Uicker et al. [5]. Recently, Nearchou [6] has proposed an evolutionary approach based on a modified binary-coded genetic algorithm (GA) to obtain a unique solution for the inverse kinematics problem of non-redundant industrial robots and redundant robots. The issue of multiplicity resolution of an industrial PUMA robot has been solved through the minimisation of total joint displacement and the closest solution in the joint space relative to the current configuration is evaluated. The superiority of the evolutionary approach over the well-known pseudo-inverse method and the simple binary-coded genetic algorithm is established in this work. Moreover, the evolutionary approach does not require the computation of the Jacobian matrix so that any problem related to the inversion of this matrix, like singularities, is overcome. However, the proposed approach suffers from certain limitations. A two level binary-coded GA is proposed wherein potential solutions are evaluated by the high level GA and incremental changes are evaluated by the low level GA until a global optimum is achieved. It has been shown by Deb and Agrawal [7] that real coded GAs are more suitable for continuous search spaces than binary coded genetic algorithms. Further, the fitness function used by Nearchou [6] is a weighted sum of the total joint displacement required to achieve a desired end-effector position and the positional error of the robot. This is equivalent to the use of a penalty parameter for satisfying the robot kinematics equations. Although genetic algorithms do not use any gradient information, they may not be free from the distortion effect caused due to the addition of the penalty term with the fitness function. Moreover, the multiple configurations of an industrial robot existing due to the multimodal nature of the inverse kinematics problem are not available at the end of the search since only the best solution based on the minimisation of total joint displacement is evaluated.

The inverse kinematics problem solution of an arbitrary robotic manipulator based on a binary-coded genetic algorithm has been presented by Khawaja et al. [8]. The approach is used for computing the motion of a n–R robotic manipulator following a specified end-effector path. Since GAs search the whole solution space in parallel they may come up with multiple satisfying solutions. The sum of the squares of the discrete joint velocities is introduced as an additional fitness function to guide the evolutionary process to a single solution. The multiple configurations of a robot existing due to the multimodal nature of the inverse kinematics problem are thus not available at the end of the search. A neural network approach using backpropagation algorithm was used by Bingul and Ertunc [9] to solve the inverse kinematics problem of an industrial robotic manipulator not having an analytical inverse kinematics solution. The disadvantage of the approach is the large errors in the joint angles and the inability of the approach to provide the multiple solutions of the inverse kinematics problem. A kinematic model is formulated and solved as an optimization problem for ABB robot manipulators by Wang and Lienhardt [10]. The objective is to analyze and evaluate the performance of the GA in optimizing robot kinematic accuracy. In this algorithm, small changes in the kinematic parameters values represent the parent and offspring population and the end-effector error represents the fitness functions. A numerical example has been used to demonstrate the convergence and effectiveness of the given model. The multiple solutions of the inverse kinematics problem are again not provided by this approach.

In the present work, an evolutionary approach based on a single level real-coded genetic algorithm is used to obtain the solution of the multimodal inverse kinematics problem of industrial robots. The fitness function is defined in a manner which requires the evaluation of the positional error of the robot and the total joint displacement separately. The multiple robot configurations that achieve a desired goal position of the robot are available at the end of the search. No arm configuration indicators need to be pre-specified by the user. Only the number of multiple robot configurations needs to be input by the user. All the available multiple con-