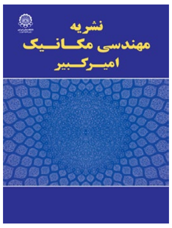

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Solving the Forward Kinematic Problem of Under-Constrained Cable Driven Robots for Online Control Purposes

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ABSTRACT: In this paper, a method is proposed which allows computing the position of the end-effector based on neural networks approach by taking into account external forces applied to the end-effector. As in under-constrained robots kinematics and statics are intrinsically coupled together, and they simultaneously should be considered, the forward kinematic problem of the robot can be made equivalent to an optimization problem. Solving the optimization problem is time consuming and not suitable for practical purposes. Therefore, in order to solve the forward kinematic problem a SimMechanics model based on the robot geometry and dynamic is designed and presented. By means of this method, the forward kinematic problem is solved offline and is used for online purpose. Moreover, an analysis of workspace is performed which reveals that the solution of the forward kinematic problem of the under-constrained cable robots can be calculated uniquely. By resorting to a neural network method, a position control is performed and the proposed method is validated. The comparison of the operated and desired path is shown for a helical trajectory. Maximum error in the assumed workspace is 0.4 percent. Finally, the proposed method was implemented experimentally and the results confirm the efficiency of the foregoing method.

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1- Introduction

Cable Driven Parallel Robots (CDPR) are similar to parallel actuated robots structurally with the fundamental distinction that cables cannot push the End-Effector (EE) but only pull it. Kinematic analysis is essential for the practical application of CDPRs, which contains three majors, namely, the workspace analysis, the Inverse Kinematic Problem (IKP) and the Forward Kinematic Problem (FKP). For parallel mechanisms, FKP is more challenging and it is worthful because of its practical importance [1]. FKP of a CDPR can be regards as finding the geometrical pose of the EE for a given set of cables lengths. For the over-constrained and fully-constrained robots, all Degree Of Freedoms (DOFs) of end-effector can completely be determined by the lengths of cables. However, for the third category, only some of the DOFs can be exactly determined. For the under-constrained robots, the platform is not stable and some of the DOFs can only be determined [2]. The EE in this group of robots, even with fixed length of cables, continues to preserve some DOFs and the final pose should be determined by the applied forces to the EE. Hence, kinematics and statics simultaneously should be considered which increases the complexity of determining robot pose [3]. Lots of efforts in order to present a simple high precision model of CDPR that could work in an online manner have been done [4-10]. In this paper, the use of neural networks to the end of solving the FKP of under-constrained CDPRs is proposed. The main contribution of this paper, compared to similar researches conducted in the literature, consists in finding the EE's position of under-constrained CDPRs and using in a control algorithm.

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2- Methodology

In this paper, a SimMechanics dynamic model of CDPR under study is designed. The inverse kinematic problem of the robot is solved and the cable lengths are obtained for a set of paths that span the workspace of the robot. Assigned cable lengths are applied to the model and the position of the EE is obtained. A neural network is trained by considering the length of cables as inputs and the position of the EE as outputs. A novel approach based on a neuro-fuzzy algorithm, the so-called "LoLiMoT" algorithm, is used as the neural network. LoLiMoT is a type of neuro-fuzzy algorithm which compared to other neuro-fuzzy networks has proven its efficiency in pattern recognition and learning the nonlinear system. The algorithm divides the input space into local linear models. It needs lower neuron count compared to normal neural networks and has a higher performance in terms of learning a mapping of the input space to one output. Fig. 1 illustrates the structure of a LoLiMot neural network with m neurons and p inputs.

Moreover, an analysis of workspace is performed which reveals that the solution of the forward kinematic problem of the under-constrained cable robots can be calculated uniquely. The workspace of robot for a given set of assigned cable lengths can be obtained by intersecting the workspace of all taut cables. As shown in Fig. 2, the workspace of each taut cable is a spherical shell.

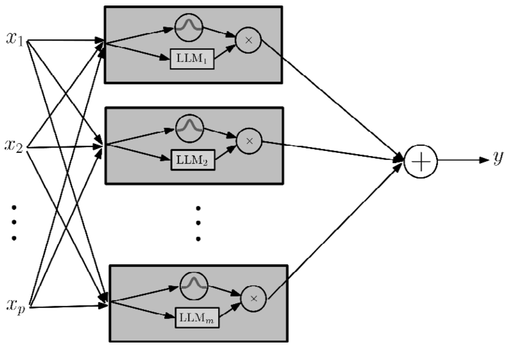

Fig. 1. The structure of a LoLiMot neural network with m neurons and p inputs.

In the latter figure, l_i is the length of the i_{th} cable and b_i is the distance between the EE's center of gravity and the cable's attachment point to the EE. The lower and upper bounds of the radius of sphere, are determined as $l_i + b_i$, when the EE's center of mass point is in line with the unit vector along the ith cable and $l_i - b_i$, when the EE's center of mass falls on the cable's unit vector.

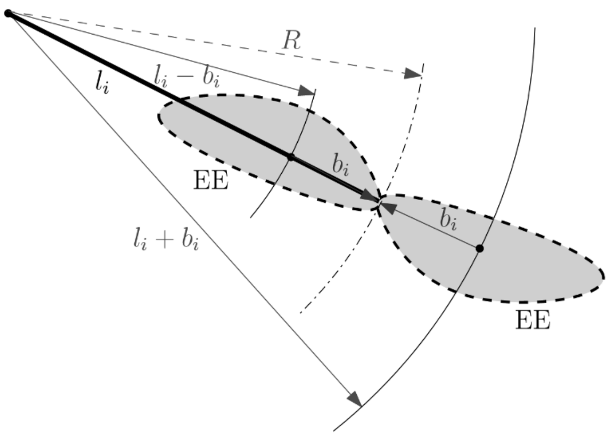

Fig. 2. The workspace of each taut cable

In this paper, a position control approach is performed and validated for the under-study CDPR. In this method, as aforementioned, given a set of cable lengths the pose of the EE is obtained by means of the neural network method. The comparison of operated and desired path is shown for a helical trajectory. Maximum error in the assumed workspace is 0.4 percent and the obtained results confirm the efficiency of the proposed method. The schematic of kinematic control algorithm is shown in Fig. 3.

3- Conclusion

This paper presented a study on the modeling and control of under-constrained CDPRs. Main conclusions of the paper are as follows:

• The kinematics of cable robots was introduced in general form.

• The workspace analysis was performed in order to show the uniqueness and global minimum answer of FKP solution for under-constrained CDPRs.

• The effect of EE's size is studied by using numerical examples.

• In order to solve the FKP of the robot a neural networks method base on the LoLiMoT algorithm is used.

• The data sets are obtained by the designed SimMechanics model of the robot which represents the dynamic and kinematic model of the robot.

• By means of the neural network method a position control is performed and the proposed method is validated

• The comparison of operated and desired path is shown for a helical trajectory and the maximum error is 0.4 percent.

The proposed method was implemented experimentally. The results demonstrated the effectiveness and correctness of the algorithm.

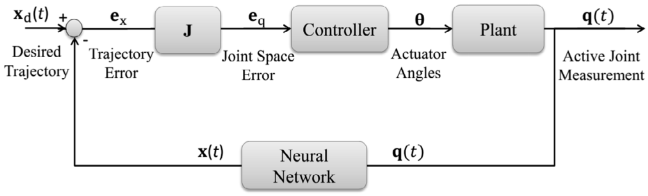

Fig. 3. The schematic of kinematic control algorithm

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