A NEW INVERSE KINEMATIC ALGORITHM FOR DISCRETELY ACTUATED HYPER-REDUNDANT MANIPULATORS

A. MOTAHARI†, H. ZOHOOR‡ and M.H. KORAYEM§

† *PhD student, Department of Mechanical and Aerospace Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran, POB: 14155-4933, Corresponding author. a.motahari@srbiau.ac.ir*

‡ *Professor, Center of Excellence in Design, Robotics and Automation, Sharif University of Technology; Fellow, The Academy of Sciences of IR Iran, zohoor@sharif.edu*

§ *Professor, Center of Excellence in Experimental Solid Mechanics and Dynamics, Iran University of Science and Technology, hkorayem@iust.ac.ir*

***Abstract*— The term *discretely actuated hyper-redundant manipulator* is applied to a kind of manipulators which consists of serially connected modules. Such modules are composed of discretely actuated joints having finite stable states. Since the previous studies have rarely offered satisfactory results regarding the problem of inverse kinematics of discretely actuated hyper-redundant manipulators, the present study is attempting to develop and investigate an effective algorithm to solve this problem. To achieve this, the current research intends to solve the problem of 2D and 3D inverse kinematics of manipulators with many modules, by considering both position and orientation of end frame in real-time with fairly high accuracy. The main ideas of the proposed method are: using mean workspace, breadth-first search with two non-adjacent modules in each step and improving the results by iterating the process. The effectiveness of the presented method is verified through different numerical analyses for various case studies.**

***Keywords*— Binary manipulators; Discrete actuation; Hyper-redundant manipulators; Inverse kinematics.**

I. INTRODUCTION

A hyper-redundant manipulator can be produced by cascading serial and/or parallel manipulators –as modules– on top of one another with a fixed base. This way, the manipulator is like a serial robot in a macroscopic view (Ebert-Uphoff and Chirikjian, 1996). In the present article, whenever we use the term ‘hyper-redundant manipulator’ we are, in fact, referring to the manipulator type that was introduced above. The serial connection of modules in these manipulators causes their workspace to be large. Furthermore, their large degree of freedom results in high dexterity and the ability to avoid obstacles by their snake-like motions. However, it also causes complexity in control. To overcome this limitation, the discrete actuators are proposed instead of traditional continuous ones. A discrete actuator has only a few stable states. For example, a binary prismatic actuator has only two possible states, either fully extended or fully retracted. A Discretely Actuated Hyper-redundant Manipulator (DAHM) is a hyper-redundant manipulator with all of its active joints actuated discretely. The joint level control in DAHMs is very simple because of the simple mechanism of the discrete actuators. So the control does not require feedback sensors (Sujan and Dubowsky, 2004). It makes DAHMs cheaper and lighter than the hyper-redundant manipulators which contain continuous actuators. High task repeatability and high reliability are the other advantages of DAHMs developed by simplicity of their joint level control. In fact the application of discrete actuators is not restricted to hyper-redundant manipulators. For some examples readers are referred to Proulx and Plante (2011), Chen *et al.* (2011) and Petit *et al.* (2010).

Since the actuators of a DAHM have only a few stable states, possible configurations of a DAHM are limited to several states. The number of possible configurations grows exponentially by increasing the number of modules. For example, if each module contains three binary actuators, then the number of configurations of each module will be eight. Now if five of these modules are connected serially, then the constructed manipulator will have 8^5=32,768 configurations. The position of the end frame related to each configuration specifies a point of the manipulator workspace, so the workspace of a DAHM is a cloud of discrete points.

One of the most important issues in kinematic analysis of DAHMs is the inverse kinematic problem. Since the solution of forward kinematics of these manipulators is clarified, the first idea for solving the inverse kinematic problem that comes to mind is to solve forward kinematic of all possible configurations offline, saving all positions of the end frame of the manipulator with their corresponding configurations, and using them online. But due to the exponential growth of the number of the possible configurations, this method is not feasible for the manipulators which contain a high number of modules, both in terms of the solution time and the required memory.

On the other hand, a DAHM will be practical only if the number of modules is high. Thus, finding an efficient method for solving the inverse kinematic problem of DAHMs is essential.

Until now, many efforts have been made to solve this problem. Chirikjian and Lees (1995) approximate macroscopic feature of the manipulator by a special curve which they named as “backbone curve”. They solved the inverse kinematic problem in two steps; calculating the parameters of the curve was done at first