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Generating human-like movements for robotic arms

Jing Zhao, Biyun Xie *, Chunyu Song

The College of Mechanical Engineering & Applied Electronics Technology, Beijing University of Technology, 100124, China

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ABSTRACT

In this paper, the generation of trajectories of both end-effector and joints for human-like reaching and grasping motions is studied. In reaching movement, the human-like end-effector trajectory is obtained based on the minimum jerk model. A total potential energy criterion is constructed to resolve the kinematic redundancy of human arm in the target position. Gradient Projection Method (GPM) is adopted to trace the human-like end-effector trajectory while minimizing the total potential energy to generate the human-like joint trajectory. In grasping movement, the total potential energy and wrist discomfort are synthesized to resolve the kinematic redundancy of human arm in the target position and orientation. A new planner, Gradient Projection Method based Rapidly-exploring Random Tree (GPM-RRT) algorithm, is proposed to generate the human-like end-effector trajectory by goal biasing and the human-like joint trajectory by minimizing the synthesis of the total potential energy and wrist discomfort. The criteria and algorithm are verified by simulations and experiments.

1. Introduction

Generating human-like movements for robotic arms has gained interest in recent years [1,2]. It has significant application values to humanoid service robot, advanced industrial robot and assistive robot [3]. Humanoid service robot with a body shape built to resemble that of the human body is being developed to perform human tasks like personal assistance. The most promising robots seem to be those with human-like characteristic not only in their structural types but also in their intelligence and motions [4,5]. Besides, the advanced industrial robot is a potential new application area. Because of the fast rising labor costs, a new class of industrial robots is being developed. Unlike the traditional industrial robots, they can work in the spaces ergonomically designed for human workers and are safe enough to work together with them. Human-like motion can give people a sense of security and comfort and enhances the efficiency [6,7]. The assistive robots such as the wearable exoskeleton robot can support or enhance natural body movements for the disabled people [8]. Generating human-like natural movements becomes even more important to the assistive robots, which affects the treatment outcomes.

In this paper, the methods to plan human-like reaching and grasping movements for robotic arms are studied. Human arm movement is a very complicated process due to the redundancies in task space, joint space and muscle space [9]. In the field of ergonomics and robotics, many studies have been performed on the analysis of human arm postures and movements. The main purpose in ergonomics is to predict the arm postures and movements for computer-aided ergonomic evaluation. In robotics, the main purpose is to generate human-like movements for robotic arms. In general, their methods are similar and can be classified into two categories: criteria based methods and motion characteristic based methods. The relevant literature on these topics will be reviewed in the following sections.

* Corresponding author. Tel.: +86 10 67391684.
E-mail address: xiebiyunyun@gmail.com (B. Xie).

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1.1. Arm posture and movement prediction based on criteria

Jung et al. [10–12] suggested a psychophysical cost function to describe the joint discomfort. This cost function indicated that the farther from the center angle, the more discomfort human feels. First, the cost function was used to predict the static arm posture. Then a resolved motion method was applied to predict the motion through optimization. Further, a regression model was constructed to predict the perceived discomfort with respect to the joint movement. Yang et al. [13–15] constructed several human performance measures and used multi-objective optimization method to predict human postures and motions. The human performance measures included joint displacement, discomfort, delta potential energy and visual displacement. The concept of the first two human performance measures is analogous to the discomfort cost function constructed by Jung et al, and they are all defined in terms of the joint angle. Also, Lee et al. [16] defined another discomfort measure in terms of the joint torque. Yang et al. [17] adopted it to simulate human arm movement. Wang et al. [18] proposed a geometric inverse kinematic algorithm to predict arm reach postures based on the criterion of minimization of the norm of joint angular velocities. Later, they extended the algorithm to a seven Degrees of Freedom (DOFs) arm model to predict arm prehension postures [19].

It can be seen that discomfort is the most widely used criterion. However, there still exist some problems. First, the ranges of shoulder joint motion are much larger [18], so they are insensitive to discomfort. Second, only using this criterion is not sufficient to explain the redundancy resolution of human arm. As for the multi-objective optimization method, it is important to determine the weights of measure to represent the relative importance which is not fully addressed [9]. In [18], the predicted pointing-to-nose arm postures with the starting posture being fully extended arm pointing laterally is questionable.

1.2. Arm posture and movement prediction based on motion characteristics

Zhang et al. [20] predicted the reaching movements via a weighted pseudo inverse. Through a numerical optimization procedure based on simulated annealing, the optimal weighting parameter values are estimated to describe the relative movement contribution of individual DOF. Further, they developed a general model by statistically synthesizing the movement specific parameter values [21].

In these studies, it's not obvious how to choose the accurate initial posture. Besides, the process of this method includes optimization and regression, which introduces two sources of errors.

1.3. Human-like control of robotic arms based on criteria

Lenarcic [22] presented some kinematic properties of a humanoid manipulator. Then, Gams and Lenarcic [1] generated human-like movement based on the manipulability index, but the results were far from human-like. Almasri and Ouezdou [6] generate human-like motion based on an energetic criterion including gravitational potential and kinetic energies of the arm. Zacharias et al. [7] used the Rapid Upper Limb Assessment (RULA) [23] criterion from ergonomic research to determine the naturalness of robot arm configurations. Hyunchul et al. [8] resolved the redundancy of a seven DOF wearable robotic system by combining both kinematic and dynamic criteria.

In comparison with the criteria constructed in ergonomics, the criteria for human-like control in robotics are incomplete. As for the multiple criteria, the determination of weights is still a problem.

1.4. Human-like control of robotic arms based on motion characteristics

Some studies directly borrow the research findings from other fields, such as neurophysiology, and integrate it into the inverse algorithm [24]. Some studies extracted very simple features through observations or experiments and used them for human-like control. Caggiano et al. [25] observed human writers and recognized that the joints at the shoulder and elbow should have higher mobility with respect to the joints at the wrist. Tian et al. [26] built a lookup table to give the redundant joint reasonably and calculate the remaining six joint angles by traditional inverse kinematic algorithm. Xie et al. [27] proposed a hypothesis named target arm pose to interpret the natural motion of human arm. Based on it, a new inverse kinematic algorithm was developed to plan the human-like reaching movements. Besides, other studies adopted more complex methods to obtain more accurate features. Seungsu et al. [4] characterized human arm movements with the elbow elevation angle using the respond surface method. However, this method may not satisfy a desired orientation of the hand fully. Zanchettin et al. [2] improved this method by using a least-squares algorithm to derive the relationship between the hand pose (position and orientation) and the swivel angle. Kuo et al. [28] introduced the fuzzy approach to obtain the elbow height in different behaviors and solved a unique pair of the inverse kinematics solution. Ga-Ram et al. [5] used the evolutionary algorithm based imitation learning to train the motion primitives so as to reflect both the properties of human and robot. Artemiadis et al. [29] used a Bayesian network to describe the dependencies among the human joint angles and control a robot arm using electromyographic (EMG) signals from the upper limb. A mathematical model was trained to decode upper limb motion form EMG recordings [30].

In the field of robotics, there are diverse methods for extracting the features of human arm movements. However, the accuracy of some features needs to be further verified. Besides, comparing with the criteria, these features may lack clear physical interpretations [2].