Mechanism and Machine Theory 129 (2018) 51–69

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Research paper

Grasp configuration planning for a low-cost and easy-operation underactuated three-fingered robot hand

Shuangji Yao[a,*], Marco Ceccarelli[b], Giuseppe Carbone[b], Zhikui Dong[c]

[a] College of Material Science and Engineering, Yanshan University, Qinhuangdao, PR China
[b] LARM: Laboratory of Robotics and Mechatronics, University of Cassino and South Latium, Cassino Frosinone, Italy
[c] School of Mechanical Engineering, Yanshan University, Qinhuangdao, PR China

ARTICLE INFO

Article history:
Received 29 November 2017
Revised 27 March 2018
Accepted 23 June 2018

Keywords:
Robotic hand
Underactuation
Grasp configuration planning
Simulation
Experimental testing

ABSTRACT

This paper proposes a method for modeling and planning the grasping configuration of a robotic hand with underactuated finger mechanisms. The proposed modeling algorithm is based on analysis and mimicking of human grasping experience. Results of the analysis is preprocessed and stored in a database. The grasp configuration planning algorithm can be used within a real time online grasp control as based on artificial neural networks. Namely, shapes and sizes of task objects are described by taxonomy data, which are used to generate grasp configurations. Then, a robot hand grasp control system is designed as based on the proposed grasp planning with close-loop position and force feedback. Simulations and experiments are carried out to show the basic features of the proposed formulation for identifying the grasp configurations while dealing with target objects of different shapes and sizes. It is hoped that the well-trained underactuated robot hand can solve most of grasping tasks in our life. The research approach is aimed to research low-cost easy-operation solution for feasible and practical implementation.

1. Introduction

Self-adaptive envelope grasping can be conveniently obtained by means of underactuated finger mechanisms in a robotic hand. This solution provides convenient features for grasping objects of unknown shapes and sizes. However, it gives indetermination in the finger position during the grasping. In the last decades several researchers have been investigating multi-fingered robotic hands aiming to mimic the human hand. Many studies focus on the issues of grasp planning for target objects and related control planning. Research works are undertaken from different views in order to analyze grasp planning and establish grasp strategy models, as referring to grasping configuration planning, grasping position planning for fingers and palm, contacting point selection, kinematic and torque computation for each joint, grasping operation and stability [1].

Geometry method is an initial solution to build grasp planning which is based on the theory of form-closure and force-closure. Nguyen presented a simple algorithm in [2] to construct force-closure grasps directly based on the grasped objects' shape. An efficient algorithm for grasp planning synthesis is reported in [3] as based on bounded polyhedral/polygonal objects. In paper [4], computation method for stable grasps of three-dimensional polyhedral objects is formulated. A sufficient and necessary condition to achieve form-closure grasp is demonstrated in [5] for multi-fingered robot hands. An improved

* Corresponding author.
E-mail addresses: buaayaoshuangji@163.com (S. Yao), ceccarelli@unicas.it (M. Ceccarelli), carbone@unicas.it (G. Carbone).

https://doi.org/10.1016/j.mechmachtheory.2018.06.019

approach by using a ray-shooting algorithm is reported in [6] to test force-closure for 3D frictional grasp. Optimization methods are also reported to be used in designing grasp planning for multi-fingered robot hands. The evaluation optimal criterions are related to grasping capabilities such as manipulating space, grasp forces and torque, grasp stability. When an optimum criterion reaches the maximum or minimum solution, the grasping parameters can be calculated as optimal results. Form-closure optimum problem for stable grip has been formulated and solved as in [7]. An optimality criterion based on decoupled wrenches is presented in [8], in which the algorithms for achieving force-closure grasps of 2-D and 3-D objects are developed. In [9] two general optimality criteria are introduced and discussed by considering the total finger force and the maximum finger force. An approach of quantifying the effects of compliant grasps is reported in [10], in which the grasping stiffness is defined and used as an optimal criterion. A general algorithm with two computing phases is presented in [11] for optimum dynamic force distributions in multi-fingered grasping. The considerations are based on optimum function for grasp planning as focused on optimum evaluation. A dimension reduction method for dexterous hand grasping is proposed in [12]. It is possible to apply a control algorithm to dexterous hand models and obtain consistent results. However, for most of multi-contact grasp systems, it is complex to provide a suitable formulation that can express the evaluation function. In addition, an optimal iteration need mass computation to converge. This computation process always costs a lot of time. Thus, it is difficult to apply in a real time control system.

Target objects are variable in different shape, size and grasping environment. It may be complicated to describe the objects' parameters and translate them into a mathematical model. Thus, a hand control system usually cannot be programmed for universal grasp tasks. In this paper, grasp planning is proposed with 6 configurations for an underactuated multi-fingered robot hand. With the ability of passive compliance self-adaptation, the underactuated robot hand can grasp most of the objects in daily life. The artificial intelligence algorithm for grasp configurations modeling is proposed as based on human knowledge. The simulations and experiments show feasibility and practicality with the feature of low-cost easy-operation.

2. Grasp configuration planning based on artificial intelligence

Human hand can grasp different objects with several finger configurations. The rule for choosing human hand grasp configuration is based on daily experiences and intelligence considerations. For example, a human can use two finger tips to pinch a hammer handle, but it is easy to slide off. However, the grasp is stable if all the fingers and palm envelope the hammer together. Thus, it can be concluded that human experience and artificial intelligence can provide the basic information for a successful planning of robot hand grasp configuration. The grasp planning is possible to be generated by some algorithms with human knowledge process and analysis.

Grasp planning of multi-fingered robot hand based on human knowledge and artificial intelligence technology is a significant challenge. There are two mainly issues that should be studied: i) the methodology and representation for grasp selection on known and unknown objects; ii) learning from human experience to grasp similar objects. Many research works have been developed in this field in recent years. The grasping algorithms proposed in [13,14] can figure out grasp type and establish ideal contact points and define metrics, even for uncertainty shape object and complex environment. A method of demonstrated grasp sequence for five-fingered robot hand is reconstructed and proposed in [15], which is based on hybrid fuzzy modeling. A reinforcement learning algorithm is proposed in [16] to enable service robot hand to grasp daily objects with many contact points. The algorithm is evaluated by simulation with three-fingered robot hand. Comprehensive knowledge for grasping is learned by referring to the geometrical and physical knowledge of grasping in [17]. The simulation work with the Barrett Hand shows that it can find suitable grasp solutions for a novel object quickly. A method is presented in [18] to acquire robust motion primitives for uncertain object grasping. Grasping algorithm based on template is reported in [19] to find suitable grasp configuration for given tasks. Some approaches of machine learning from demonstration are discussed in [20–22]. The robot hands can be trained to perform the desired grasp according the tasks. A fast KNN-based method of objects categorization is proposed in [23] for grasp planning by human experience. A neural networks evolution and probabilistic inference approach for robot hand grasping novel objects are introduced in [24] and [25]. A method for grasping planning generated by recognizing and estimating the objects with image is developed in [26] and [27]. The acquired grasping data is used for learning the best grasping strategy.

In retrospect, a planning algorithm for grasping configuration is used in control system to establish the relationship between target objects and grasp configurations. The grasp analysis with human knowledge can be carried out when the objects' characteristics such as shape and size are known. It would be applied in a real-time control system with some necessary characters:

- Robot hands can perform stable grasp configurations.
- The experiences with human knowledge can be studied as an artificial intelligence to build a model for grasp configuration planning algorithm.
- The grasp configuration planning algorithm has the character of rapid calculation speed.

We proposed a grasp configuration planning algorithm for the three-fingered underactuated robot hand in this paper. The possibility of realizing the grasp configuration planning algorithm according human experiences is discussed in the first and second sections. In the third section, several available grasp configurations are introduced for the proposed three-fingered underactuated robot hand. The algorithm is obtained in the fourth section based on human experience and knowledge. The artificial intelligence data analyzing and modeling is processed by rough set mixed neural networks. In the fifth section, the