Intelligent Computation in Grasping Control of Dexterous Robot Hand

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Dexterous robot hand is an important integrated product of bionics and robotics. In modern life, it has gradually become the focus and hot spot. This paper introduces various types of famous dexterous robot hand and its development. The intelligent computation of robot hand also improves to adapt the more complicated using environment. The paper focuses on the study of the theoretical calculation in grasping control. The theoretical characteristics of intelligent computation are analyzed. In the end, the conclusion of grasping control is summarized.

Keywords: dexterous robot hand, grasping control, intelligent computation, computational development.

1. INTRODUCTION

With the rapid development of science and technology, robots' application continues to expand. From industry to family, robots are no longer confined to the simple repetition works. They gradually become intelligent and dexterous. Due to the further research in intelligent learning and bionics, humanoid robot is entering into a high-speed development, which is becoming the most popular and cutting-edge. The reasons why people are willing to develop humanoid robot are as follows: First, the robot has biological structure which can be deeply improved. Second, the study on humanoid robot increases human's creativity. Third, humanoid robot gets positive feedback to extend human abilities. At the same time, humanoid robot has the light weight, small energy consumption, strong adaptability, friendly appearance and other advantages. Especially, the gait performance of humanoid robot is excellent. Humanoid robot is one of the most important objects in contemporary research[1-3].

Compared with other robots, humanoid robot can adapt to a variety of human environments better, such as family hosting, hospital caring, school teaching, restaurant servicing and other aspects. Humanoid robot can't develop without its various implementing parts, such as dexterous robot hand. Humanoid robot can be used in rehabilitation medicine and it provides good conditions for the cure of autism or depression[4].

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The upgrade of intelligent manufacture, the high quality of sensor and new technology of remote sensing makes it possible for robots to do housework in everyone's home. And this relies on flexible and stable end actuator. Contrary, flexible and stable end actuator improves humanoid robot's applications in more aspects. It cannot be easy to make a precise surgery[5], provide power for amputation or paralysis patient movement without a controllable end actuator, namely the dexterous robot hand[6].

The development of dexterous hand relates to manufacturing and intelligent control technology[7]. The robot's hand evolves from splint type to multi-fingered type with the function enhanced. Dexterous hand is a highly integrated device, which contains reception and execution parts. But the most important is grasping control system.

2. COMPUTATIONAL DEVELOPMENT

The industry of dexterous robot hand grows fast. Mechanical construction designs and action instruction methods influence the development of dexterous hand[8]. From literatures[9-14], it can be seen that dexterous hand has developed many types and sizes since 16th century. Also, the intelligent computation develops many thinking. More efficient algorithms appear in dealing with the problems when robot hand grasps objects. In complex environment, dexterous robot hand needs a stable intelligent control to finish the work, such as surgery or arm rehabilitation.

The first multi-fingered robot hand is developed in

Japan which is named Okada[15]. The mechanical structure uses the combination of pulley and steel wire. This transmission system provides the stability in hardware. The intelligent computation in this hand proves that it screws bolt, which means this computation provides the stability in software. But screwing bolt is the basic function for a dexterous robot hand. The algorithm used in this hand is based on the coordinate positioning. Correspondingly, this algorithm leads to the scarcity of applications.

Over the next decades, many flexible dexterous hands appear. Stanford/JPL hand is a typical dexterous hand which is developed by Stanford University[16]. DLR-I is composed of 4 same fingers with 16 degrees of freedom in German[17]. NASA also develops NASA hand in 1999[18]. At the beginning of 21 century, the British Shadow Robot Company developed a new type of humanoid dexterous hand, named Shadow hand[19].

During these years, some algorithms are updated. The research in force-closure algorithm and form-closure algorithm is deeper. In the study of force-closure grasping, Nguyen proposes the concept of fully-constrained rigid body motion in independent contact region. He points out that in force-closure grasping, contact points of finger and the object must be in independent contact area. The ligatures between the contact points must be contained within the friction cone of the contact points. In the study of form-closure grasping, it is proved that it needs 7 contact points to construct the force-closure without friction for a general object. This solution makes the intelligent computation of dexterous hand more reasonable and applicable. But it is complicated for a robot hand to be designed to get 7 contact points.

Now, the developing of dexterous hand in Europe and the United States has reached a high level. The research of dexterous hand in China is relatively late. Until 1980s, it is carried out by part of universities and robot research institutions. BH hand is the first generation of Chinese dexterous robot hand[20]. Harbin Institute of Technology and German Aerospace Center cooperate to develop a generation of HIT series hand[21].

Though the starting is late, the research on the intelligent computation or algorithm is very deep. Xiong describes the form-closure and relative form-closure in the respect of grasping matrix. He establishes the equivalent distinguishing theorem of the form-closure grasping. It provides an easy and straight way to compute the force.

3. INTELLIGENT COMPUTATION OF GRASPING

Grasp theory contains the theory of grasping stability, operability and optimal grasping. The optimal grasping theory is the main direction of capture theory research. For example, the optimal grasping method of meeting static friction constraint is proposed by Buss in 1995[22-23]. This method solves the problem of optimization grasp with point contact and soft finger contact. Then, the domestic and foreign scholars try to use autonomous grasp theory in solving the problem. Subsequently, R.Cutkosky applies the artificial intelligence into the dexterous hand grasp study[24]. This theory works out the problem of inaccurate grasp action by adjusting the hand posture in multiple feedback information. After that, Iberall trains dexterous hand control system by neural network[25]. And T.N.Nguten inspires grasping planning by topological network[26]. All these methods break through the traditional control ways, but autonomous control and stability of the dexterous hand needs to be further strengthened in complex environment.

The purpose of research on dexterous hand is to develop the dexterous hand to realize the objects grasping of any shape, using variety of tools and completing the grasping tasks. At present, the developed dexterous hand lacks multi fingers coordination technology and multi fingers control technology which is important in micro-operation[27].

Study on the stability of grasping is the exploration the grasping theory. It needs to analyze fine movements and force of grasping. The stability analyzing is the basic work of grasping control.

Autonomous grasping planning of dexterous hand is the system that autonomy planning and deciding with the information collected by sensors[28]. The process is out of manual operation. For example, the local autonomy processing system can determine the posture and position between the target and hand gripper, which is installed in the extravehicular special hand gripper sensor.

When the dexterous hand asked to grasp an irregular object or non-model object, the local autonomy processing system can improve the intelligence of the dexterous hand and reduce the communication between hand gripper and main controller[29]. This can reduce the communication time to decline the errors and delays.

On the basis of stability analysis and grasp planning study, the gripper control strategy needs to be studied[30]. Because the tendon and rod transmission mode is used in dexterous hand, the control is still complex. The complex control strategy is the biggest obstacle when robot uses multi finger dexterous hand. It has a closed chain polycyclic characteristics, non uniqueness of control and coordination problems of motion. The main idea to control the gripper now includes the impedance control, force control, damping control and position control[31].

The task of dexterous hand is to grasp and manipulate objects, so the problem of coordination control can be divided into two main aspects:

Control the movement of an object to track a given trajectory. And maintain the appropriate contact force between the fingers and the object to ensure a stable grasp.

In order to achieve the above purposes, the position and force control are usually separated, called position / force hybrid control[32]. Many researchers have studied in coordination control for a long time and they get some useful methods, such as master-slave, screw theory and so on[33].

Nakano and Arimoto use a master-slave mode in two hands grasp controlling. They use position control in master hand grasp and force control in slave hand. Then, Luh and Zheng take minimum energy consumption in joint torque controlling as an optimization index. They use non linear programming method to solve the force distribution[34].

The dynamics equations are expressed as:

$$D({}^{i}q){}^{i}\ddot{q}+H({}^{i}q,{}^{i}\dot{q})+G({}^{i}q)={}^{i}T+({}^{i}J)^{Ti}F, i=1,f \quad (1)$$

Among number 1 refers to master hand, f refers to slave hand, q refers to the position of joint, T refers to joint torque and J refers to Jacobi matrix[35].

When two hands operate an object, the following kinetic equations are met:

$$\begin{bmatrix} M & 0 \\ 0 & I \end{bmatrix}\begin{bmatrix} x \\ \varpi \end{bmatrix}+\begin{bmatrix} 0 \\ \varpi \times I\varpi \end{bmatrix}+\begin{bmatrix} M_g \\ 0 \end{bmatrix}=-{}^{1}F-{}^{f}F \quad (2)$$

Among ϖ refers to angular velocity, x refers to the object's position in base coordinate system, M refers to inertial force, g refers to gravity acceleration[36].

And combination of two equations is:

$$({}^{i}E)^{-i}({}^{i}J)^{i}T+(fE)^{-i}(f_J)^{f}T=({}^{i}E)^{-i}({}^{i}J)^{i}B+(fE)^{-i}({}^{f}J)^{f}B-F \quad (3)$$

Among ${}^{i}B$ refers to the left equation of (1), F refers to the right equation of (2). ${}^{i}E=({}^{i}J)({}^{i}J)^{T}, i=1,f$.

A unique solution can be got by adding some constraints in the upper equation. The optimal joint torque can be obtained by setting the minimum energy consumption as an optimization index and using linear or nonlinear programming method[37].

Many researchers use the generalized inverse method to divide the fingertip force into two parts to satisfy the contact constraint conditions, such as Kerr Roth, Yoshikawa et al and so on[38].

The fingertip force and the object force connect as:

$$F_{up}=W^{+}\times F_b+[I-W^{+}\times W]\times Y \quad (4)$$

Among W^{+} is W pseudo inverse, $Y\in R^{9}$ is an arbitrary constant vector. The right part of (4) is a part of the movement in a fingertip force. The internal force can be made by adjusting the internal force. Through adjusting the internal force can satisfy the contact constraint conditions. The usual method is to calculate the internal force of the former one, and then determine the internal force by linear or nonlinear programming method. This method of calculating internal force involves a large number of numerical calculations[39].

Park and Starr propose a fingertip force calculation method. The optimization of fingertip force is calculated during the mission planning phase. In the process of object manipulation, screw theory is used in calculating to the new object of internal force[40].

The force and torque requires to be applied is F_b, M_b.And the friction of fingertip is point contact. Fingertip forces are $f_i=\lfloor f_{xi}, f_{yi}, f_{zi}\rfloor, i=1,2,3$.

Formulas are as follows:

$$f_i=F_b-f_2-f_3 \quad (5)$$

$$(f_2 f_3)^{T}=G_m^{T}(G_m\times G_m^{T})^{-1}\times(M_b F_b)^{T} \quad (6)$$

Among

$$G_m=\begin{bmatrix} 0 & z_1-z_2 & y_2-y_1 & 0 & z_1-z_3 & y_3-y_1 \\ z_2-z_1 & 0 & x_1-x_2 & z_3-z_1 & 0 & x_1-x_3 \\ y_1-y_2 & x_2-x_1 & 0 & y_1-y_3 & x_3-x_1 & 0 \\ x_2-x_1 & y_2-y_1 & z_2-z_1 & x_3-x_1 & y_3-y_1 & z_3-z_1 \end{bmatrix}$$

The rotation quantity theory is used to calculate the object rotation matrix R. Contact normal N and grasping force f_g is obtained by initial contact normal N_0 and the initial grasping force f_{g0}[41].

$$N=R\times N_0 \quad (7)$$

$$f_g=R\times f_{g0} \quad (8)$$

4. INTELLIGENT COMPUTATION OF CONTROLING

Dexterous hand is used to grasp and operate objects. The control problem divides into two parts: 1. Control the motion trajectory of operated objects, namely the position control of the object. 2. Control the contact force of operated objects, namely the internal force of the object.

After years of research, the control methods of dexterous hand develops from junior to senior, from simple to complex. The scholars use master-slave control, hybrid control, nonlinear control, neural network and impedance control in early studies. Arimoto takes the master-slave control system into dexterous hand control[42]. The master finger takes the position control and slave finger takes force control. But the constraint between fingers and objects is one way only, making the error easily and fail to grasp. Craig takes hybrid control in dexterous hand grasping[43]. This method is to divide the object motion into free motion space and constraint space and uses position control and force control in these two subspaces. Z. Li proposes a nonlinear feedback compensation system to control[44]. It turns nonlinear problems into linear problems and analyzes to process. Hanes uses neural network to train and learn[45]. J. Lu studies in impedance relationship between position and force to make a control[46].

Recent years, many foreign and domestic scholars study and use the hybrid control system, such as self-adaptive hybrid control, robust hybrid control and learning control[47-48]. The self adaptive hybrid control system estimates uncertain parameters of the dexterous hand through the self adaptive loop. But this method is only suitable for the precision known system model. Robust hybrid control system stabilizes uncertain factors, but it cannot offset the uncertain effect completely. Learning control is a method that improves the control performance by learning. And it has strong robustness for uncertainties. But most of learning methods are off-line learning with uncertain precision shortcomings that cannot be adjusted online.

It can be seen from the review that it has made remarkable achievements in the grasping planning and coordination control of dexterous hand study. Some has been applied in engineering practice. But the control system of multi finger hand still has the shortcomings that the intelligent and integrated degree of the system is not ideal[49].

5. CONCLUSION

The robot dexterous hand has the appearance of human hand and strong applicability. This paper summarizes the processing in research on some intelligent computation of dexterous hand and analyzes its development direction. The design of it becomes more precise and the control of it becomes more intelligent. The developed dexterous hand has a mature algorithm. This is the key in the movement and gesture changing of dexterous robot hand. A success algorithm helps robot hand in dealing with difficulties in various environments.

The movement of dexterous hand is flexibility and adaptability. It is generally redundant or hyper redundant and the structure is complex. The reliability is hard to ensure. In the future development, improving the reliability of dexterous hand is a major part[50]. It drives researchers to develop a new algorithm to deal with the problem.

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