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The SKKU Hand: Work in Progress

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Abstract— **This paper presents on-going research of the SKKU Hand. The purpose of the development of SKKU Hand is for delicate dynamic grasp. To design a dexterous robot hand driven by motor, we studied a human hand analysis. And customized fingertip force/torque sensor and joint torque sensors are integrated each finger as well as brushless DC motors and harmonic drivers. The rest of the paper presents a control strategy of SKKU Hand. For robust grasp, we implemented classical impedance control.**

Keywords— **Multifingered Robotic Hand, Impedance Control**

1. Introduction

For many years, research of robotics has been advanced significantly and robots are widely used in the industrial field that would replace human to work. However, development of service robot is still in the laboratory level, despite the positive benefits for many purposes. Especially, multi-fingered robotic hand was difficult challenges because it is needed flexibility and adaptability like a humans hand.

Basic problems for multifingered robotic hand are mechanism design, control of hand and motion planning. The mechanism of the robot hand is very important because it determines possible actions of the robot hand. However, mechanical joint has a kinematic constraint and actuator also has many limitations. In general, there are two types of method to drive the robot hand; tendon driven type and motor driven type. The tendon driven type robot hand has benefit that it can be made small and similar with human hand. But, it is difficult to control a robot hand by elasticity of tendon cable. The output force of fingertip is limited. The motor driven type is possible to precision control of each joint by using a gear. Also, it can be made to finger modules. But, the motor driven robot hand has drawback that many actuators are need to make robot hand and there is limits to reduce the size of robot hand[1].

Also, many researchers focused on the robot hand control and motion planning problems. Salisbury [2] implemented Cartesian stiffness control with fingertip force sensors. This approach allows someone to specify stiffness of fingertip. But, stiffness control has disadvantage because it cannot actively control the complete system dynamics. Liu[3] proposed a novel Cartesian impedance control for DLR Hand based on joint torque measurement. The fingertip appears as mechanical impedance when it contact with an object. Impedance parameters M, B, K determine the dynamic behavior of the grasp. Yoshikawa[4] presented hybrid position/force control approach for the simple case of moving the grasped object in free space.

To grasp a fragile object, a compliant behavior should be required for a robot hand. In this case, an impedance control can be good solution. For this reason, we implemented impedance control for our newly designed multi-fingered robotic hand. This paper introduces the SKKU Hand and shows our plan for implementing an impedance controller.

2. The SKKU Hand

2.1 *Overview of the Hand Design*

The purpose of this work is to develop an anthropomorphic Robot hand for the delicate dynamic grasp. For this, we performed a design optimization to improve a problem of existing robot hands. Because multi-fingered robot hand is different to human hand, we focused on a job with robot hand. Our design parameters are manipulability, size of workspace, opposition angle between fingertips. Using these parameters, we modified a length between joints and rearranged fingers. Newly designed robot hand is shown in Figure 1. Each fingers have a 3dof, including differential bevel gear and passive joint. The thumb is designed for a 4dof considering adaptability to grasp different objects. Besides each fingers can be equipped a force torque sensor or a tactile sensor.

2.2 *Electrical System*

The three active joints (one additional passive joint) of each finger are connected BLDC motor. And harmonic drive,

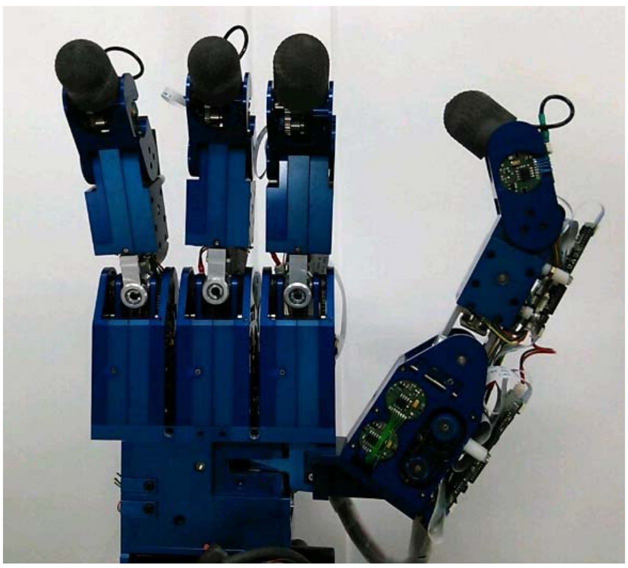

Fig. 1. The SKKU Hand

belt, bevel gear are also equipped as a part of the actuator system. Each motor is connected with incremental type encoder for the purpose of position control. Also potentiometer is installed at each joint because we want to know absolute joint position. In order to force control, a six dimensional force torque sensor is developed. This sensor is equipped at each fingertip. Beside the fingertip is able to replace force torque sensor with a tactile sensor. All of these sensors are connected to CAN bus network. A main controller is based on PowerPC chip and contains 8 channel CAN bus. In order to control with real time, we implemented RTOS Xenomai that is a real-time development framework cooperating with the Linux kernel. This controller performs a motion planning and sends a position command to a motor driver.

3. Impedance Control

In order to robustly grasp an object, it is needed not only precise position control but also compliance to external forces. As a solution, Hogan[7] suggested the impedance control scheme which will improve system dynamics characteristic.

First, we can derive the equations of motion of a robot hand. This equation is well known[11]:

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) = \tau + \tau_{ext}, \tag{1}$$

where $M(q) \in \mathbb{R}^{3\times 3}$ is the inertia matrix, $C(q,\dot{q}) \in \mathbb{R}^3$ is the Coriolis/centrifugal matrix, $G(q) \in \mathbb{R}^3$ is the vector of gravity torques, and $\tau, \tau_{ext} \in \mathbb{R}^3$ is the vector of external torques. Also $q \in \mathbb{R}^3$ is the joint angles and the Coriolis/centrifugal matrix $C(q,\dot{q})$ is shown as following equation.

$$C(q,\dot{q})_{ij} = \sum_{k=1}^{2n} C_{ijk}(q)\dot{\hat{q}}_k, \tag{2}$$

$$C(q)_{ijk} = \frac{1}{2}\left(\frac{\partial M_{ij}(q)}{\partial \hat{q}_k} + \frac{\partial M_{ik}(q)}{\partial \hat{q}_j} - \frac{\partial M_{kj}(q)}{\partial \hat{q}_i}\right). \tag{3}$$

The following derivation is based on the work of Hogan[7], [8], [9], and [10]. For the cartesian impedance controller, end-efffector coordinates $x \in \mathbb{R}^3$ is often preferred. Then we can derive the desired dynamic behavior in terms of $x, \dot{x}, \ddot{x}$. And the relation of the motion can be written with Jacobian as follows.

$$\dot{x} = J(q)\dot{q}, \tag{4}$$

$$\ddot{x} = J(q)\ddot{q} + \dot{J}(q)\dot{q}. \tag{5}$$

In order to spectify the desired impedance behavior, we can shows the dynamical relation of the form

$$M_d\ddot{\tilde{x}} + B_d\dot{\tilde{x}} + K_d\tilde{x} = F_{ext}, \tag{6}$$

where M_d, B_d, K_d are the desired inertia, stiffness, and damping matrix. $\tilde{x}$ is the position error between x and the desired position x_d.

$$\begin{aligned} &J(q)^{-T}M(q)J(q)^{-1}\ddot{x} + J(q)^{-T}C(q,\dot{q})J(q)^{-1}\dot{x} \\ &-J(q)^{-T}M(q)J(q)^{-1}\dot{J}(q)J(q)^{-1}\dot{(x)} + J(q)^{-T}G(q) \\ &= J(q)^{-T}\tau + F_{ext} \end{aligned} \tag{7}$$

This equation can be written in the form

$$\begin{aligned} &M_x(x)\ddot{x} + C_x(x,\dot{x})\dot{x} + J(q)^{-T}G(q) \\ &= J(q)^{-T}\tau + F_{ext}, \end{aligned} \tag{8}$$

where the matrices $M_x(x)$ and $C_x(x,\dot{x})$ are given by

$$\begin{aligned} M_x(x) &= J(q)^{-T}M(q)J(q)^{-1}, \\ C_x(x,\dot{x}) &= \\ J(q)^{-T}&\left(C(q,\dot{q}) - M(q)J(q)^{-1}\dot{J}(q)\right)J(q)^{-1}. \end{aligned}$$

Then the Cartesian impedance control law can be written from (8) and the desired closed loop system (6).

$$\begin{aligned} \tau &= J(q)^T\left(M_x(x)\ddot{x}_d + C_x(x,\dot{x})\dot{x}\right) \\ &-J(q)^T M_x(x)M_d^{-1}\left(K_d\tilde{x} + B_d\dot{\tilde{x}}\right) \\ &+J(q)^T\left(M_x(x)M_d^{-1} - I\right)F_{ext} + G(q) \end{aligned} \tag{9}$$

The external force F_{ext} can be measured by means of a force/torque sensor at the finger tip of the robot hand.

4. Future Work

The next step in our work is a experiment that evaluate the robot hand and an impedance controller. An implmentation of a sensor fusion algorithm that utilize many type of sensors is also our objective. Furthermore we are working on redesign of the SKKU Hand for improving quality and size issue, because we need more human like hand.

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