Proceedings of the 2003 IEEE
International Conference on Robotics & Automation
Taipei, Taiwan, September 14-19, 2003

The HIT/DLR Dexterous Hand: Work in Progress

X.H. Gao, M.H. Jin, L. Jiang, Z.W. Xie, P. He, L. Yang, Y.W. Liu, R. Wei, H.G. Cai,
H. Liu[a] , J. Butterfass[a], M. Grebenstein[a], N. Seitz[a] , G. Hirzinger[a]

Robot Research Institute, Harbin Institute of Technology (HIT), Harbin 150001, P.R. China
[a] Institute of Robotics and Mechatronics, German Aerospace Center(DLR), 82230 Wessling, Germany
Email: ljiang_hit@yahoo.com.cn, gxh1113@yahoo.com.cn, Hong.Liu@dlr.de

Abstract

This paper presents the current work progress of HIT/DLR Dexterous Hand. Based on the technology of DLR Hand II, HIT and DLR are jointly developing a smaller and easier manufactured robot hand. The prototype of one finger has been successfully built. The finger has three DOF and four joints, the last two joints are mechanically coupled by a rigid linkage. All the actuators are commercial brushless DC motors with integrated analog Hall sensors. DSP based control system is implemented in PCI bus architecture and the serial communication between the hand and DSP needs only 6 lines(4 lines power supply and 2 lines communication interface). The fingertip force can reach 10N.

Keywords: dexterous hand, multisensory, serial communcication

1 Introduction

The development of dexterous robot hand is a very challenging endeavor, which has been pursued by many researchers. Many dexterous robot hands have been built over the past three decades[1][2][3][4][5]. These devices make it possible for the robot to grasp and manipulate objects.

Since 1997 DLR has developed two generation of multisensory dexterous robot hands: DLR Hand I[4] and II[6]. Both hands are highly integrated multisensory mechtronic hands. Based on the experience of DLR Hand I, the DLR Hand II was designed toward stronger and more reliable. The number of cables between the hand and main microprocessor has been greatly reduced from more than 400 to only 8. The optimal combination of BLDC motors, harmonic drives, belt transmission and differential bevel gear transmission makes the fingertip force up to 30N. The extra degree of freedom of thumb enables the hand not only for power grasping but also for fine manipulation. It is well recognized that the DLR Hand II is one of the

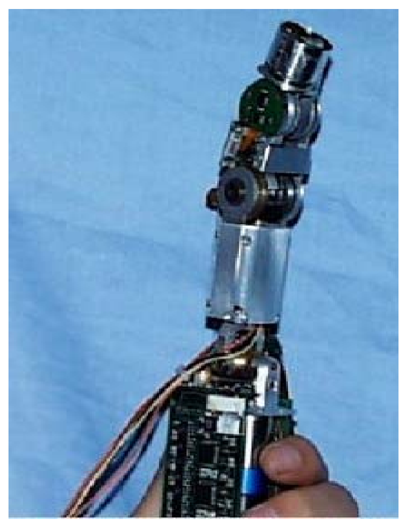

Fig.1: One finger of the HIT/DLR Hand

best robotic hand in the world. On the other side, however, because of its high integration it is not easy to manufacture such hand, especially for the actuator system where all the motors are specially designed and the analog hall sensors must be adhesived and calibrated carefully. Since 2001, based on the DLR's experience, DLR and HIT have been developing a smaller human-like dexterous robot hand. The goal will be to build a robot hand with less difficulty to reproduce it. To achieve this goal, several issues have to be considered, such as the fingertip output force, actuators and sensors. If the fingertip force must be greater than 30N, then it would be very difficult for other commercial motors to realize it in the same space occupation. For many cases one third of 30N fingertip force will be enough for many fine manipulation. Based on this basic understanding DLR and HIT are jointly engaged in developing a low-cost and easy manufacturing robot hand.

This paper presents to date progress on this project. The paper is organized as follows: Section 2 gives an overall description about the system. Section 3 describes the multisensory system. Integrated electronics and hand controller hardware are introduced in section 4 and section 5, respectively. Finally, section 6 addresses conclusion and future work.

2 Overall system description

To achieve a high degree of modularity, all four fingers are identical. A prototype of one finger of the HIT/DLR hand is shown in Fig.1. All actuators are integrated in the finger's base and the finger's body directly, the electronics and communication controllers are fully integrated in the finger's base in order to minimize weight and the amount of cables needed for a hand.

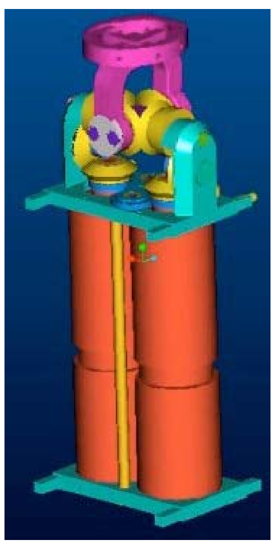

Fig.2: Base joint unit and its actuation system

The effectiveness of bevel gear differential transmission has been successfully demonstrated in the DLR Hand II. In order to save the work for special motors assembly with adhesive and calibration of analog Hall sensors, the first important issue is to select appropriate commercial motors with the power for 10N fingertip force. Through strict comparison the brushless DC motor (1628 BLDCM) with planetary gears transmission from Faulhaber Co. have been chosen for the base joint's actuators. And the motor itself has been applied in the finger's body. The motor measures 16mm in diameter and 28mm in length. There are 8 cables including three drive signals, three analog Hall sensors and corresponding power and ground.

Fig.2 shows the 3D structure of one base joint unit. The base joint with two degrees of freedom is of differential bevel gear type, the planetary drive gears are directly coupled to the BLDCM, and the bevel gears are connected to planetary gears via additional gear reduction of 2:1. For curling/ extension motion the motors apply a synchronous motion to the bevel gears using the torque of both motors. For abduction/adduction the motors turn in contrary directions. This causes a curling motion on the fingertip using the torque of both motors and means we can use small motor and reducer while reaching bigger output force on the fingertip.

The middle link is actively actuated by a BLDCM in combination with a tiny harmonic drive gear. The harmonic drive measures 20mm in diameter and 13.4mm in length and the reduction ratio is 1:80. The motions of middle phalanx and distal phalanx are not individually controllable, they are connected by means of the linkage, whose structure and parameters are optimized by simulation. The finger unit is shown in Fig.3.

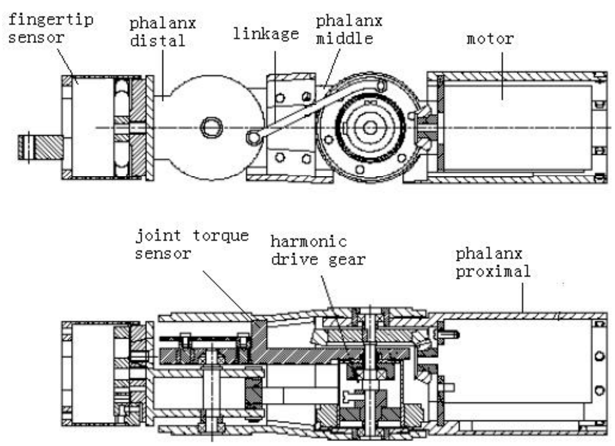

Fig.3: Finger unit with one integrated actuator and two coupled joints.

Kinematic design of multifingered hand shows that the motion of the thumb and the fourth finger is absolutely necessary to improve the grasping performance in case of precision and power grasp. Therefore the hand will be designed with an additional degree of freedom in order to realize motion of the thumb relative to the palm. This enables to use the hand in different configurations.

3 Multisensory System

A dexterous robot hand needs as a minimum a set of force and position sensors to enable control schemes like position control and impedance control in autonomous operation and teleoperation. Compared to DLR Hand II, there is some improvement in the sensor system. Instead of contact potentiometer in each joint a contactless Hall sensor based joint position sensor has been developed. Also, base joint torques have been designed in flat form so that the whole height could be reduced. Sensor equipment of the HIT/DLR hand is shown in Table1.

Table1 Sensor equipment of one finger

Sensor type	Count/finger
Joint torque	3
Joint position	3
Motor position	3
Force/torque	1
Temperature	2

3.1 Joint torque sensor

Each joint is equipped with strain gauge based joint torque sensor. To reduce the length of a finger a new type base joint torque sensor with two degrees of freedom is designed (Fig.4). The torque sensor located in middle joint is integrated into the connecting part and can precisely measure the external torque.

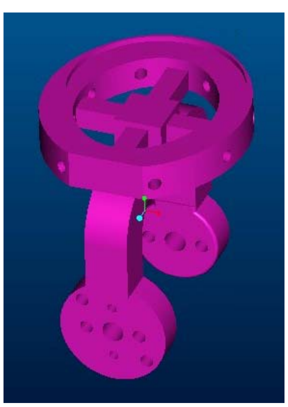

Fig.4: Base joint torque sensor

3.2 Joint position sensor

Since we can calculate the joint position from the motor Hall sensors, the joint position sensor would not be absolutely necessary. However, in the presence of the elasticity and hysteresis of the transmission system, joint position sensor can provide with a more accurate information of joint position, and it can eliminate the necessity of referencing the fingers after power up.

A new integrated 2-axis hall effect sensors, replacing conventional contact potentiometer and contactless incremental encoder, are integrated in every active joint of the HIT/DLR hand in order to measure joint position and meet the requirement. The heart of the sensor is a cross-shape Vertical Hall Sensor(VHS) featuring a total of five supply contacts and four signal contacts. The active zone of the device measures about 0.2 to 0.3mm in size. A permanent magnet mounted on the axis of a rotating shaft generates the magnetic field required for the measurement, working principle of the measuring system is shown in Fig.5. The magnetic field created by the permanent magnet is parallel to the sensor surface. With a rotation of the axis, the angle of the magnetic field rotates in the sensor plane. After offset compensation and pre-amplification, the two output signals are processed to yield absolute angular position or velocity.

Since base joint is of differential type , we have to calculate the joint position of the base joint from the hall element output values. Since there was no way to measure the joint position directly due to space restriction, we have to add a special measuring module.

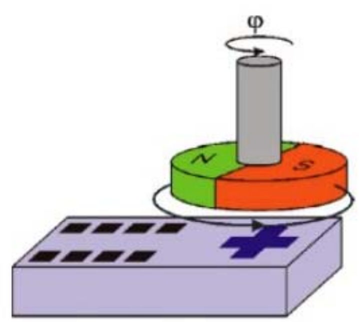

Fig.5: Principle of measuring system by using integrated hall sensor

3.3 Motor position sensor

Each BLDCM is equipped with three linear Hall effect sensors which are used for commutation of the motors. These sensors supply three sinusoidal signals with a constant phase shift of 120° . The position within the magnetic cycle of the motor can be calculated from arbitrary two sinusoidal signals. By additionally counting the cycles the relative position of the motor can be calculated, while the speed can be calculated by differentiation of the position signal.

3.4 Force/torque fingertip sensor

Besides the torque sensors in each joint we have integrated a miniaturized six dimensional strain gauge-based force/torque sensor with fully digital output into the fingertip. Signals from foil strain gauge bridges are amplified and converted to digital representations of the force and torque applied to the sensor. Signal processing circuit and A/D converter are mounted within the sensor body in order to achieve the integration of the sensor and improve the behavior of the signals. It needs only 6 wires including power supply.

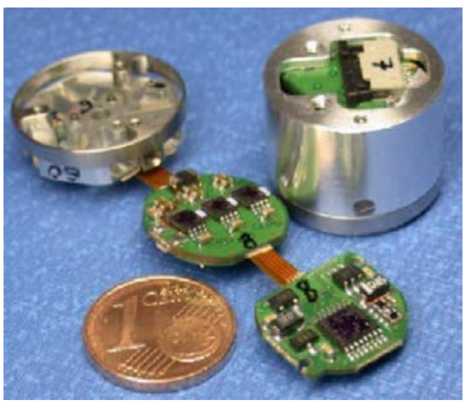

Fig. 6, full digital 6dof fingertip force sensor

The force and torque measure ranges are 30N for F_x, F_y and F_z, 200*Nmm* for M_x, M_y and M_z, respectively. A 200% mechanical overload protection is provided in the structure. Fig. 6 shows an integrated fingertip sensor with electronics.

3.5 Temperature sensor

Several precision integrated-circuit temperature sensors are integrated into the finger. These sensors have small size and low quiescent circuit. Information from these temperature sensors are used to compensate for outputs of the above sensors and protect the system.

4 Integrated electronics

One major goal of the design of the HIT/DLR Hand was to achieve full integration of the electronics needed in the finger and the palm for minimizing weight and the amount of wires and enhancing the system reliability.

In finger unit we achieved the integration of electronics by using flexible printed circuit board(PCB) with appropriate bending space and shape(Fig.7). One end of the board is connected to the fingertip force/torque sensor, another is connected to the communication controller in the finger. Signal processing circuits of joint position sensor, joint torque sensor and base joint torque sensor and A/D converter are included in this board.

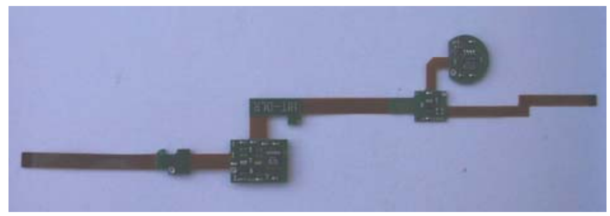

Fig.7 Flexible printed circuit board in the finger

In accordance with mechanical structure of the base joint, the base joint position sensor circuit board is compactly designed , which is connected with the communication controller in the finger and the power converter via board-to-board interfaces composed of headers and board stackers. The power converters for driving three motors in a finger are located directly beside the motors and they are galvanically decoupled from the sensor electronics in order to minimize the noise induced by the running motors.

A serial ADC with 8 analog channels and 12 bit resolution is used to convert the sensor signals as near as possible to the sensor conditioning circuitry into digital data. There are in total 23 sensor signals in a finger, in consideration of both the mechanical structure design and the fact that two signals from a joint position sensors and two signals from a motor must be collected at the same time for the best measuring accuracy, a 5 serial ADC are used. These distribution is as follows: one converter is located in the fingertip sensor, two in the base joint torque sensor circuitry and two in the power converter board.

5 Hand controller hardware

The design of control system has been greatly conditioned by the large amount of sensory information which is needed to be acquired and elaborated at run-time, thereforc a DSP(Digital Signal Processor)-based real-time control system has been built. Electronics and communication architecture in a finger are shown in Fig.8. The kernel of the system is a commercially available processor board with a TMS320C6711. Some characteristics of this board are: 150MHz clock, floating point arithmetic unit, 2Mbyte of synchronous burst memory and 512K bytes flash program memory. This board is plugged in a PCI slot of a industrial computer via PCI bridge controller. The DSP board and industrial computer communicate via the Dual Port RAM (DPRAM).

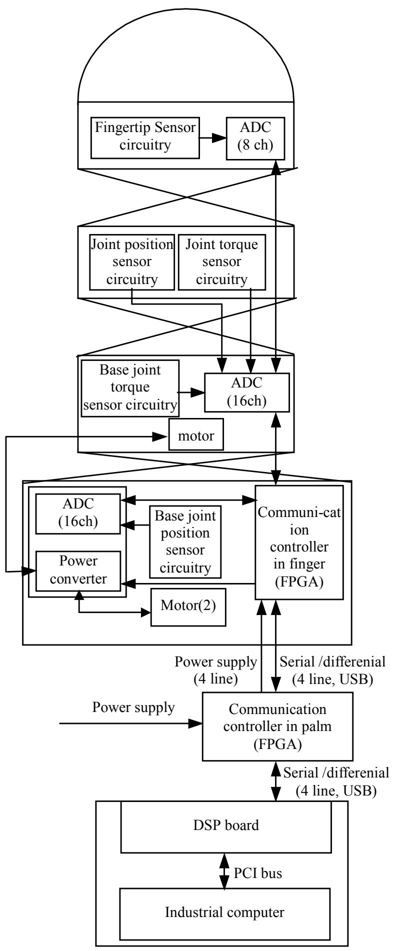

Fig.8: Electronics and communication architecture

In order to use the hand freely on different robot manipulators, reduce cables and the possibility of noise in the sensor signals, a fully integrated serial communication system, based on FPGA(Field Programmable Gate Array) has been developed.

Each finger holds one FPGA-based communication controller, which is responsible for the collection of all sensory information in the finger, the distribution of the data from the control scheme to three actuators for finger control, and the communication with the communication controller in the hand base. Furthermore this controller performs some signal processing task like digital filtering and calculating the motor speed. The communication controller in the hand base links the serial data stream of each finger to the data stream of the DSP board. Besides a four power supply the number of external cables of HIT/DLR hand is an four line communication interface since the data is transmitted via LVDS(Low Voltage Differential Signal).

The whole control architecture has been freshly tested. From a PC manual operator can command the finger's movement and also read the sensor data simultaneously.

6 Conclusion and Future work

A prototype of HIT/DLR Hand's finger and it's control architecture have been presented. The initial experiment proves the fingertip output force up to 10N. Future work will be concentrated on the redesign of the prototype and control algorithm.

Reference

[1] S.C.Jacobsen,J.E.Wood,D.F.Knutti,K.B.Biggers. The UTAH/MIT Dextrous Hand: Work in Progress. The International Journal of Robotics Research. 1984,3(4):21-50

[2] J.K.Salisbury,J.J.Craig. Articulated Hands: Force Control and Kinematic Issues. International Journal of Robotics Research. 1982,1(1):4-17

[3] J.Butterfass,G.Hirzinger,S.Knoch,H.Liu. DLR's Multisensory Articulated Hand, Part I: Hard-and Software Architecture. Proceedings of the IEEE International Conference on Robotics andAutomation. Leuven, Belgium. 1998:2081-2086

[4] H. Liu, J. Butterfass, S.Knoch, P.Meusel, G. Hirzinger. A New Control Strategy for DLR's Multisensory Articulated Hand. IEEE Control Systems. 1999,19(2)：47-54

[5] C.S.Lovchik,M.A.Difler. The Robonaut Hand: A Dextrous Robotic Hand for Space. Proceedings of the IEEE International Conference on Robotics and Automation. Detroit, Michigan. 1999：907-912

[6] J. Butterfass, M. Grebenstein, H. Liu, G. Hirzinger: DLR-Hand II: Next Generation of a Dextrous Robot Hand, Proceedings of the IEEE ICRA, Seoul, Korea, 2001