

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

4,800

Open access books available

122,000

International authors and editors

135M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.

For more information visit www.intechopen.com



Development of Tendon Based Dexterous Robot Hand

Chung-Hsien Kuo and Chun-Tzu Chen
*Department of Electrical Engineering
National Taiwan University of Science and Technology
Taiwan*

1. Introduction

Dexterous robot hand development is a very challenging and interesting research topic. A dexterous robot hand may serve as a prosthesis hand for disabled patients or to serve as a gripping device for robotic arms. In most of previous studies, the dexterous robot hands are developed based on the directed gear train controls and tendon wired controls. The directed gear train control based design (Lin et al., 1996; Namiki et al., 2003) directly coupled the gear train in the finger module mechanisms. In such a configuration, the weight of the dexterous robot hand is quite heavy because of using numerous gear parts and motors. At the same time, the mechanical design and the assembly of the directed gear train dexterous robot hand are much complicated. Meanwhile, the heats resulted from high reduction of gear trains as well as the high speed rotation of motors are also challenging issues of directed gear train based dexterous robot hands. Consequently, the weights and heats are major concerns when applying this configuration to the prosthesis hand for amputees.

On the other hands, the tendon wire control based dexterous robot hand allocates the gear trains and motors at a distance location (Jacobsen et al., 1986; Kyriakopoulos et al., 1997; Chaloo et al, 1994). In this manner, the weights and heats produced from motors and gear trains are resolved when compared to the directed gear train based configuration. Nevertheless, the non-rigid characteristics and frictions of the tendon wires are also important to the precise control of a dexterous robot hands.

In this chapter, a dexterous robot hand with tendon wired control is proposed to perform the characteristics of compact size and low weight. According to this purpose, the dexterous robot hand size is defined as the hand size of a twenties male. In order to reduce the weight of the dexterous robot hand, the ABS engineering plastic material is used in this study. Additionally, to emulate the hand motions of a human, the dexterous robot hand is designed as a five-finger mechanical structure. Consequently, the proposed dexterous robot hand is composed of 16 joint motions. To reduce the control complexity, 12 active joints are independently controlled; and the remaining four joints are manipulated depending on four corresponding active joints.

At the same time, five FSR pressure sensors are attached on the tips of all fingers to detect external forces applied on the corresponding fingers. Therefore, the robot hand is capable of

gripping objects with different gripping force setting. In addition to the mechanical design and sensor deployments, the motion trajectories for different gripping behaviors (Parka et al., 2006) are also constructed. These motion trajectories are desired to synchronously control the finger joints for achieving various gripping behaviors. Consequently, the tactile force sensing (Kawasaki et al., 2007; Kawasaki et al., 2002) may combine with the motion trajectories to perform force feedback based gripping control systems. Finally, the proposed dexterous robot hand prototype is developed to demonstrate its motion behaviors.

2. System architecture

In this section, the system architecture is described. The proposed system architecture is composed of the mechanical design, behaviour based gripping motion planning with tactile force sensing, and system integrations, as shown in Fig. 1. The mechanical design specifications include the size and skeleton of robot hand, degree-of-freedom, range of motions of each finger, and orientation of each finger. These specifications are defined according to the hand profile and various gripping postures of a twenties male student in our laboratory. Therefore, the proposed dexterous robot hand may demonstrate similar motions with the human beings. In addition, a tendon wired control configuration is proposed in this study to reduce the weight and heat of the hand. Especially, the ABS engineering plastic material is used to further reduce the weight of the robot hand.

Development of Tendon Based Dexterous Robot Hand	Mechanical Design	Design Specifications
		Tendon Wired Actuators
	Gripping Motion Planning	Gripping Behavior Modeling
		Tactile Sensing
		Gripping Trajectory Planning
	System Integration/ Test	Motion Control System
		Parameter Setting and Training System

Fig. 1. System development architecture

The gripping motion planning module acts the supervisory controller of the proposed dexterous robot hand. It is responsible of modelling gripping motions in terms of setting the initial and final postures of fingers, acquiring the tactile sensor data from the tips of all fingers, and planning the gripping trajectory based on the gripping models, maximum allowable tactile forces and maximum allowable joint angles. Note that the gripping motion planning module may just model simple gripping motions in the current stage. Finally, the system integration and test module is desired to cooperate with the motor controller to manipulate the robot hand. At the same time, the operation parameters such as the maximum tactile force and grip model selection can be also desired.

3. Mechanical design


In this study, a dexterous robot hand is proposed based on the design concepts of light weight, compact size, similar to human's hand gripping motions, gripping force restriction, and low cost. In order to meet these design concepts, the following design issues and directions are discussed before this research project.

1. **Light weight:** Most of dexterous robot hands are designed based on directed gear train controls and tendon wired controls. Because of the distance motor and gear train configurations of the tendon wired control robot hand, the weight of the robot hand can be reduced. At the same time, an ABS engineering plastic material is also used to fabricate the hand to further reduce the weight of the robot hand. In this manner, the light robot hand may reduce the loads of the robot arms for service robots as well as the loads of the upper extremity for hand amputees.
2. **Compact size:** One of the study purposes of this dexterous robot hand is to produce a prosthesis hand for hand amputees preliminarily. Therefore, in addition to the robot hand weight reductions, the hand size and profile must be similar to the human beings. In this study, the proposed dexterous robot hand is designed referring to a twenties male student in our laboratory. Consequently, a five-finger robot hand with 16 degree-of-freedom is presented.
3. **Emulating human's hand gripping motions:** In addition to similar hand structures, the range of motions of human's hand is also evaluated. The range of angles of the joint is defined via physically measuring the angle of finger joints. In addition, several gripping motions such as gripping apples, eggs and pens are simulated using the computer aided design (CAD) software.
4. **Gripping force restriction:** Gripping force restriction is important to the robot hand. The maximum force restriction may provide a sufficient gripping force when the finger tip touches the objects, but the force will not damage the gripped objects. At the same time, the maximum allowable tactile force may also protect the wire and motors of the robot hand.
5. **Low cost:** In general, the cost of a dexterous robot hand is quite expensive because of using high performance DC/ AC servo motors. In recent years, the advance RC (radio servo) techniques provide a simple and low cost position servo control solution. Therefore, the RC servo motors are used in this work to reduce the cost of motors.
6. **Other concerns:** In addition to the previous considerations, the tendon wired control robot hand may also eliminate the heats resulted from the motors and gear trains when compared to the directed gear train control robot hands. At the same time, the distance actuated robot hand can be applied in more strict environments such as water. Finally, to reduce the control complexity, the joint motions of distal interphalangeal joints of the index finger, middle finger, ring finger and little finger are designed to be dependent on the joint motions of the proximal interphalangeal joints of the corresponding fingers. As a consequence, the motor number is reduced as 12 in this study.

Mechanical design of the proposed dexterous robot hand uses the Pro/E CAD software tool. As described before, the robot hand profile and structure is referred to the hand of a twenties male student in our laboratory. Fig. 2 shows the hand photo of the volunteer. Design parameters of this robot hand follow the hand structure of this hand profile. In order to increase the producing efficiency of mechanical parts, geometries of these mechanical parts are modified and designed as several uniform specifications, as shown in the right-

hand-side of Fig. 2. Note that the little finger just designed as a two-phalanx structure because of infrequent uses of this finger as well as reduction in the length of this finger when these uniform mechanical parts are used.

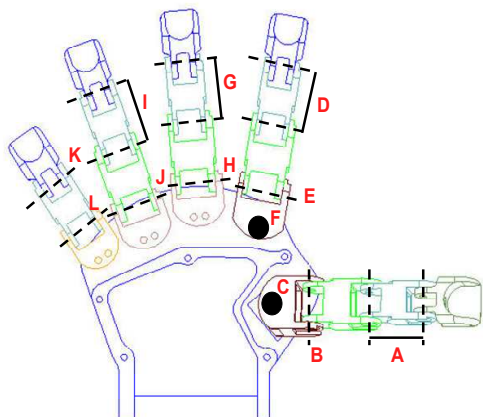
Unit: mm



	Thumb Finger	Index Finger	Middle Finger	Ring Finger	Little Finger
Distal Phalanx	24.1	24.2	24.2	24.2	24.2
Distal Phalanx	23.5	23.5	23.5	23.5	23.5
Distal Phalanx	24.86	24.86	24.86	24.86	N/A

Fig. 2. Hand photo of volunteer and design parameter of robot hand mechanical structure

Unit: degree



Joint Symbol	Range of Angle	Joint Symbol	Range of Angle
A _{Distal}	89	G _{Distal}	75
A _{Proximal}	87	G _{Proximal}	103
B	75	H	93
C	45	I _{Distal}	67
D _{Distal}	75	I _{Proximal}	101
D _{Proximal}	101	J	91
E	90	K	80
F	32	L	93

Fig. 3. Mechanical structure design and ranges of joint angles of the proposed robot hand

In addition to design a similar structure with human being, range of joint motions are also discussed in this study. The ranges of joint motions of fourteen volunteers are evaluated as shown in the right-hand-side of Fig. 3. The joint symbols are referred to the left-hand-side CAD model. These parameters are mean-values measured from fourteen volunteers. Especially, to reduce the control complexity, the joint motions of distal interphalangeal joints and proximal interphalangeal joints of A, D, G and I (referred to Fig. 3) are designed as dependently actuated. The joint angles of distal and proximal joints are correlated in terms of the ranges of joint motions. In practice, different diameters of pulleys and cable wires are used to produce synchronous actuations of distal and proximal joint within the defined angle ranges. Fig. 4 shows the design details.

The mechanical parts of this robot hand are produced in the machining shop of our university. Bearings are used in all rotary parts to reduce the frictions, as shown in the left-hand-side of Fig. 5. In addition, the tactile sensor socket is also desired at the distal phalanx part of each finger, as shown in the right-hand-side of Fig. 5.

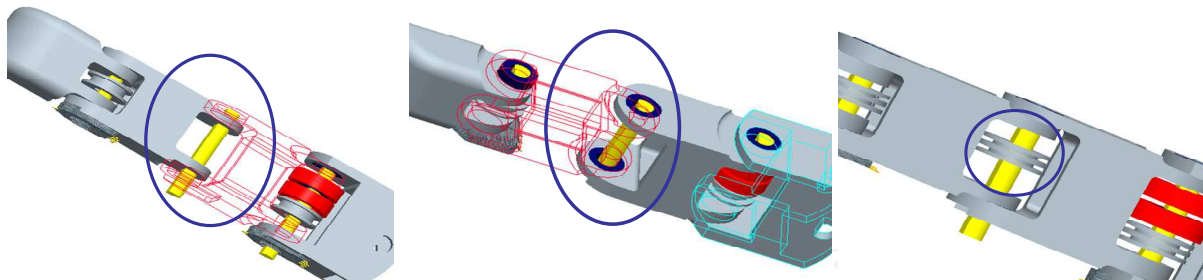


Fig. 4. Design details of a finger CAD model

In order to reduce the weights of mechanical parts, the ABS engineering plastic material is used, and all mechanical parts are shown in Fig. 6.

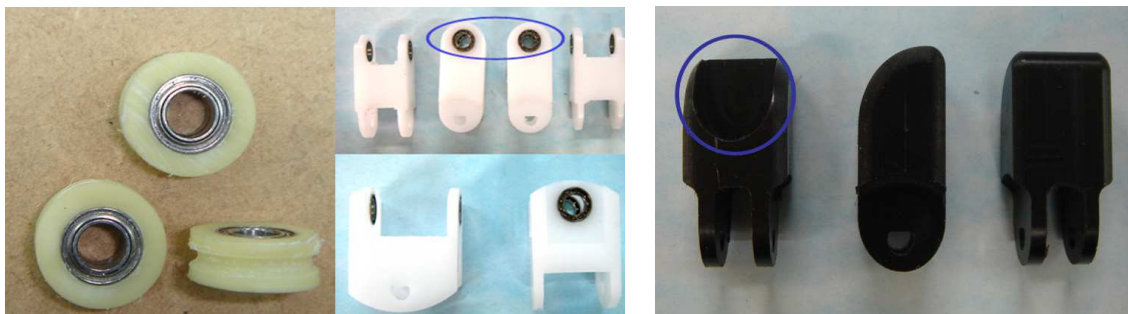


Fig. 5. Parts with bearings and tactile sensor socket



Fig. 6. Photos of produced mechanical parts and assembly of the hand

Because of referring the hand profile of a twenties volunteer, the size of the fingers are evaluated as shown in Fig. 7. In this figure, the index finger of the volunteer are compared with the robot hand. Apparently, they are in a similar finger profile. Finally, because of using the ABS engineering plastic material, the weight of the hand can be reduced. The weight for each finger is summarized in Table 1. To investigate the mechanism performance, several hand postures of human beings are simulated using the 3D CAD tool, as shown in Fig. 8. As a consequence, these hand postures can be properly desired using the proposed mechanical structure of this robot hand.



Fig. 7. Finger profile comparisons for a twenties volunteer and the proposed robot hand

Unit: gram

	Thumb Finger	Index Finger	Middle Finger	Ring Finger	Little Finger
Distal Phalanx	4	3.5	3.5	3.5	3.5
Middle Phalanx	4	4	4	4	4
Proximal Phalanx	3.5	4.5	4.5	4	3
Metacarpal Phalanx	N/A	3.5	3.5	3.5	N/A
Weight of a Finger	11.5	15.5	15.5	15	10.5

Table 1. Weights of fingers of the robot hand

Finally, the tendon wired control configuration is introduced. In this study, a multi-cord steel wire with 0.8 mm diameter is used. In addition, the tendon wire is surrounded with a spring cord as shown in Fig. 9. In addition, the assembled tendon wired control robot hand is also presented in Fig. 10. The photo of the wire actuated robot hand is shown in the left-hand-side of Fig. 10; and the photo of the distance motor site is shown in the right-hand-side of Fig. 10. All RC servos are mounted at the motor platform, and it can be installed off the hand and arm so that the load of the arm can be reduced.

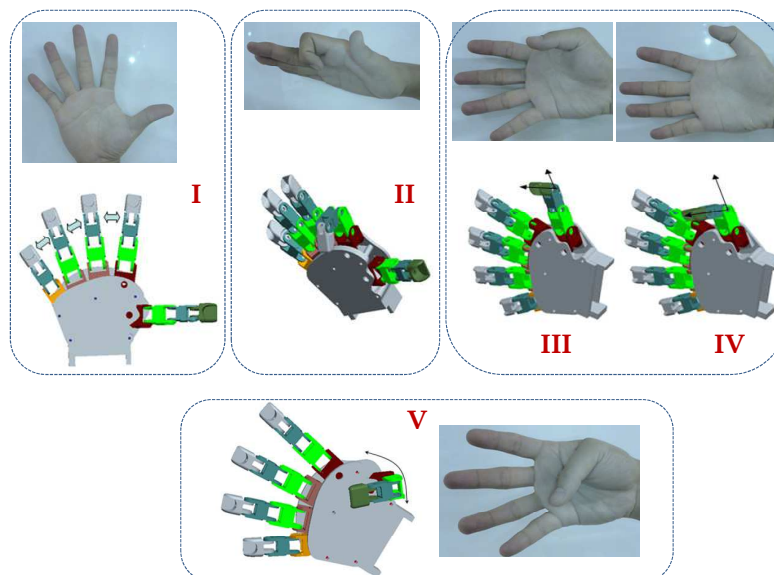


Fig. 8. 3D CAD hand posture simulations

For example, the motor platform can be installed inside the body of a wheeled robot or a humanoid robot to increase the carry loads of the arm and hand. Note that the motor platform is just installed under the robot hand for demonstrations in this chapter.

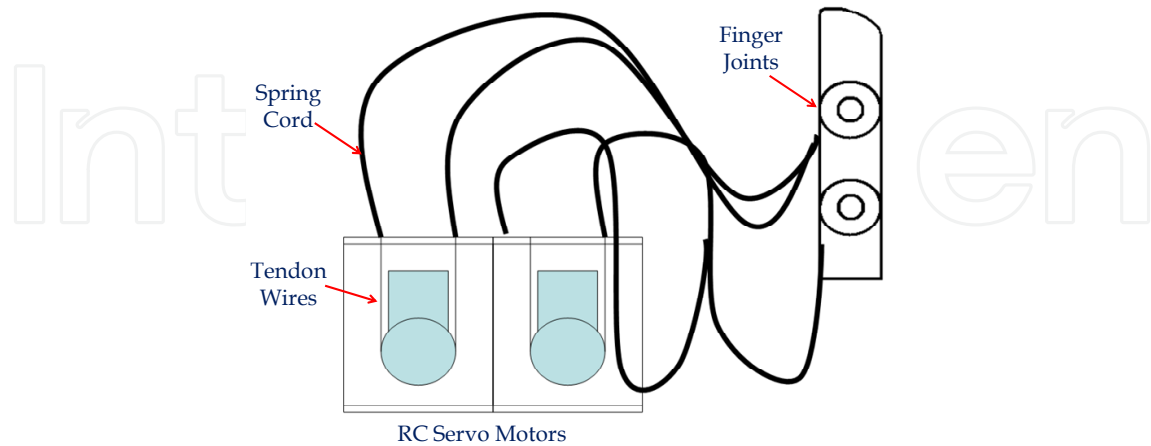


Fig. 9. Tendon wired control configuration

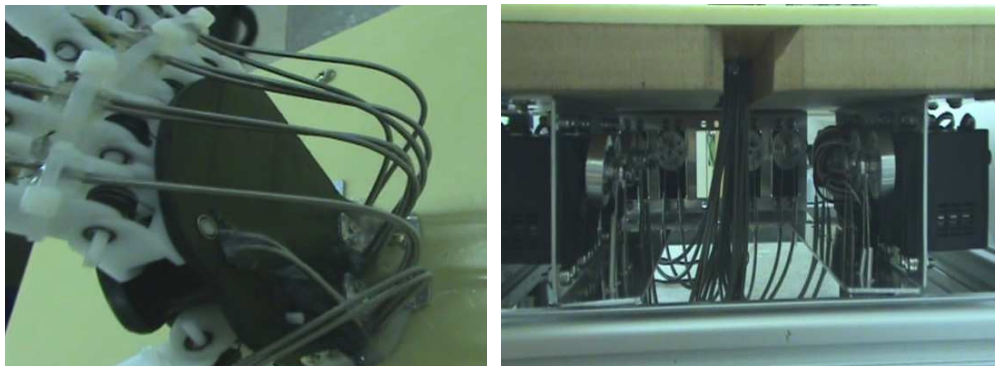


Fig. 10. Photos of wire actuated robot hand (robot hand site and distance motor site)

4. Behavior based gripping motion planning with tactile force sensing

In this study, the developments of a dexterous robot hand do not focus on the mechanical structure design, but also on the gripping behavior modelling. In order to simplify the gripping model as well as to perform more realistic approach, only simple and frequent gripping behaviors are discussed such as gripping an apple, cylinder, egg, etc. It is noted that the precise position controls of all finger tips using inverse kinematics are not the focus of this study due to the difficulties of getting a precise spatial position and orientation of the gripped object in this study. Instead, this study investigates the joint motions from an initial posture to a final posture of a hand for each interested gripping motion. Fig. 11 shows the initial and final postures of a robot hand for gripping an egg and an apple, respectively.

All joint angles of the initial hand and final postures are recorded. The gripping motion can be synchronously desired according to the interpolations of the joint angles of the initial and final postures. Therefore, the gripping model is formed based on the initial and final joint angles as the synchronous interpolations of these joint angles.

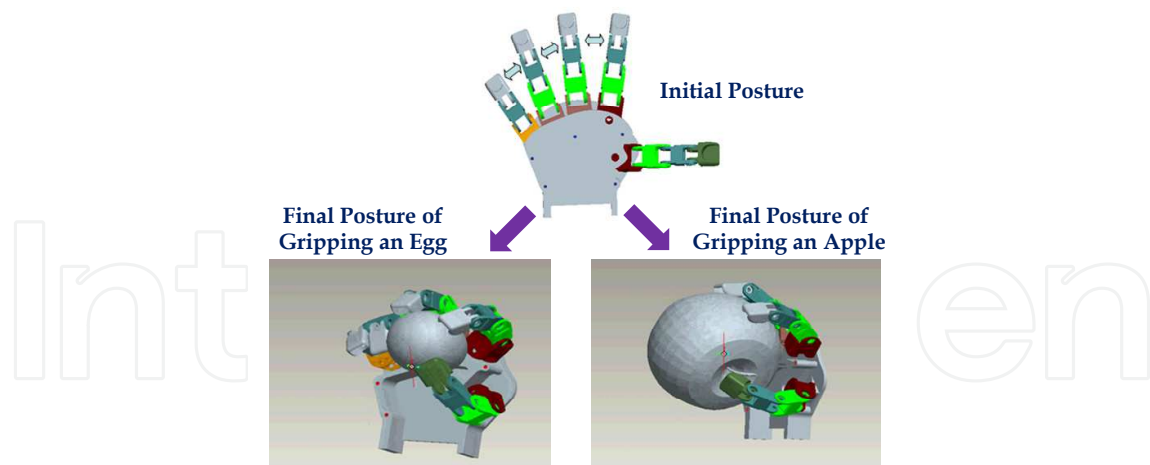


Fig. 11. Gripping postures simulations of an apple and an egg

Most of initial postures are the same (complete extraction of all fingers, as shown in the top figure of Fig. 11). However, the final postures are quite different for various gripping models. Equation (1) shows the gripping model for a specific gripping motion.

$$n = \frac{T}{\Delta T} \quad (1)$$

$$\Delta \theta_k = \frac{\theta_{k,f} - \theta_{k,i}}{n} \quad (2)$$

$$\theta_k(t) = \theta_{k,i} + t \Delta \theta_k \quad (3)$$

where T is time required for the gripping motion; ΔT is angular position command time interval for joint motors; n is theoretical count of position commands for a specific gripping motion; $\theta_{k,i}$ is the initial joint angle for joint motor k ($k = 1$ to 12); $\theta_{k,f}$ is the final joint angle for joint motor k ; $\Delta \theta_k$ is the angle increase of joint motor k ; t is the index (from zero) of position commands.

Especially, the gripping model just defines the synchronous joint angle increase for all joint motors in each operation command with a pre-defined time interval. The actual final (stop) joint angles will not be identical to the pre-defined final posture because it is difficult to get the actual positions and orientations of the gripped object online. That means the real final postures will not refer to the pre-defined final postures; instead, they depend on the maximum allowable tactile sensor force as well as the maximum allowable joint angles to meet practical gripping situations. Hence, the actual operation commands for a whole gripping motion may be smaller or greater than the theoretical count of operation commands, as shown in Fig. 12. Consequently, based on the tactile sensor data feedback and maximum allowable joint angle mechanisms, the final (stop) joint angles are determined finger-by-finger.

Note that the tactile sensor used in this study is a conventional force sensing resistor (FSR). On the other hand, the maximum allowable joint angle is desired for the finger being not damaged during gripping. At the same time, the maximum allowable joint angle may also prevent the collisions and intersections of the hand mechanism for tactile sensor failures and gripping position uncertainties.

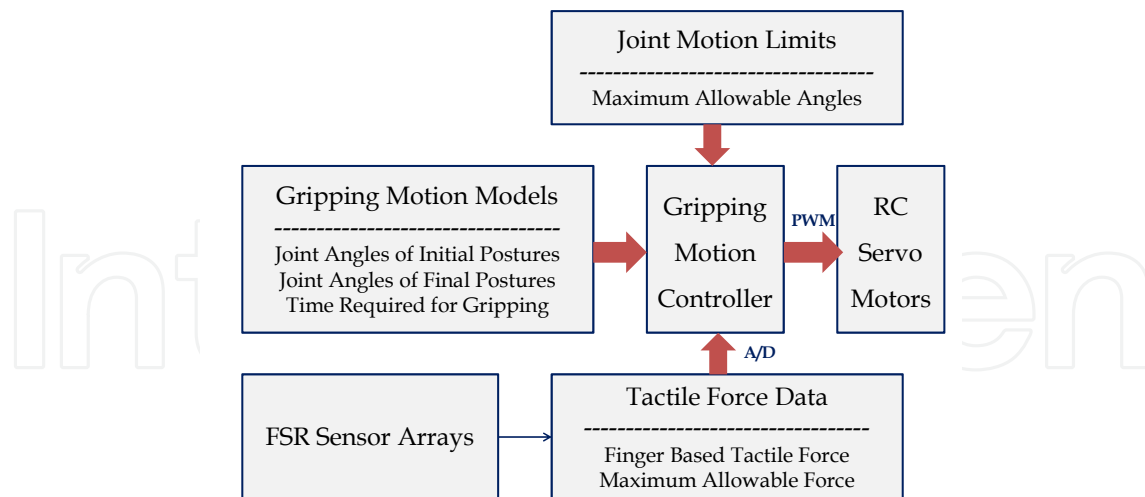


Fig. 12. Behavior-based gripping motions control architecture

The algorithm of the proposed behavior-based gripping motion control system is described in Fig. 13. At the beginning of gripping operations, a gripping model is selected. The angle increase of all joint angles is calculated according to the angular position (operation) command time interval and the time required for such a gripping motion. The operation command index (t) is set as zero at the startup. The joint angles are further updated to get closer to the object. The maximum allowable tactile forces and joint angles are examined finger-by-finger.

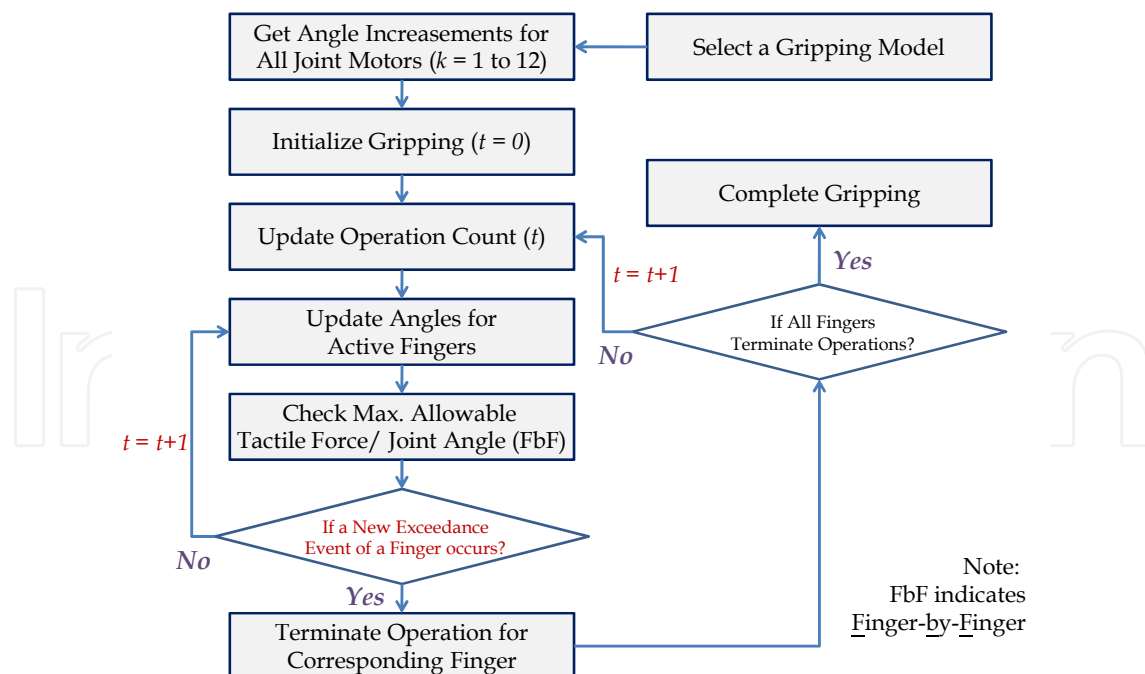


Fig. 13. Algorithm of behavior-based gripping motion control system

The active finger is defined as a finger with neither the tactile force being below the maximum allowable force nor the joint angles belong to this finger being within the

maximum allowable joint angles. The system is running for all active fingers in terms of updating operation command index (t) as well as calculating new joint angle commands for active fingers. Finally, the gripping motion is completed when no active fingers existed in this system.

5. System integrations and experiments

The system integration and test module is desired to cooperate with the motor controller to manipulate the robot hand via implementing the behavior based gripping motion control algorithm. The control system of the proposed dexterous robot hand is constructed using the PSoC (Programmable System on a Chip) processor. The PSoC is a mixed-signal array microcontroller, and it is a product of Cypress Semiconductor. The core of PSoC is built based on a very-small Harvard architecture machine, named M8C. In addition to the core of firmware, the most important feature is that PSoC provides reconfigurable integrated analog and digital peripherals. Therefore, the PSoC is very suitable to integrate the sensing and actuation devices of the dexterous robot hand. In addition, the analog multiplexer is also desired to extend the analog-to-digital channels of the FSR sensing. At the same time, the gripping models are stored in an EEPROM and the data is accessed via the I²C communications.

In order to justify the tactile force variations among these five FSR sensors, the calibrations of FSR sensor are also desired in this study. At the same time, the operation parameters such as the grip model selection, maximum allowable tactile force for each finger, maximum allowable joint angles, theoretical operation time required for each gripping motion, and operation command time interval are downloaded from a host computer via RS 232 communications. Fig. 14 shows the control circuit boards and the photo of gripping an egg. Ideally, only the fingers of thumb and index and middle fingers are used for gripping. Therefore, the terminations of the thumb, index and middle fingers should be done via checking the maximum allowable tactile forces.

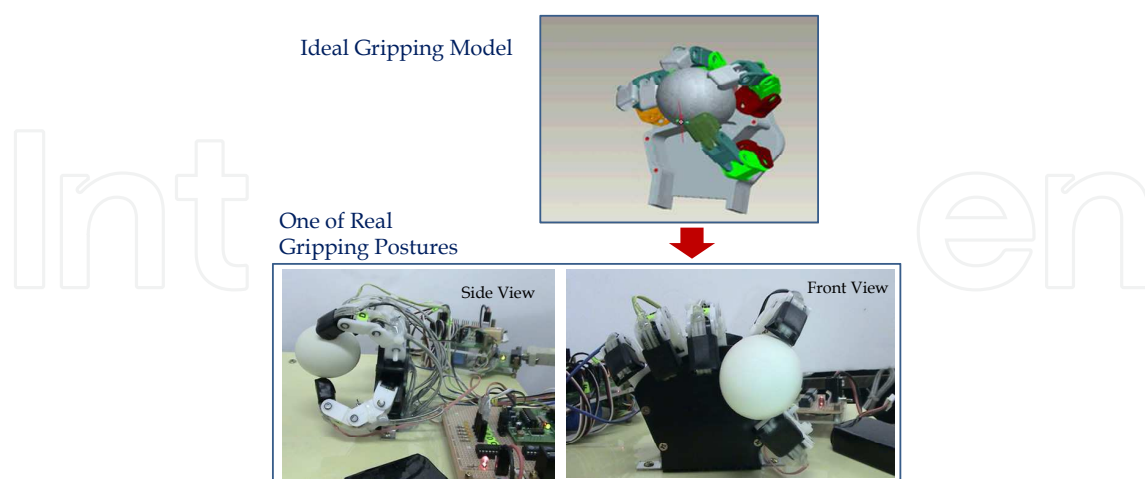


Fig. 14. Egg gripping experiment with inconsistent egg posture (middle finger cannot touch the egg, and this finger is terminated via maximum allowable joint angle of the egg gripping model)

However, due to inconsistent spatial position and posture of the egg, only the thumb and index can touch the tactile sensors in this experiment, and middle finger are terminated via the maximum allowable joint angle for this egg gripping model. Additionally, the terminations of the ring and little finger are also done in terms of the exceedances of their maximum allowable joint angles. It is important that the maximum allowable gripping joint angles of different gripping models must be determined carefully according to practical considerations.

In addition to gripping an object, the proposed dexterous robot hand may perform several hand postures. These hand postures are done via only using the maximum allowable joint angles. Fig. 15 shows several typical hand postures for presenting one-digit numbers, clenched hand, OK symbol, and YA symbol.

6. Conclusions

In this chapter, a dexterous robot hand is proposed based on the design concepts of light weight, compact size, similar to human's hand gripping motions, gripping force restriction, and low cost. The robot hand prototype is produced in this study. Especially, complicated kinematics models and position control of joint angles are not constructed due to unpredictable object orientations and positions in this study. Instead, the gripping motion behavior models for different gripping motions cooperating with maximum allowable tactile forces and joint angles are constructed to simplify the control architecture as well as to improve the practical gripping compatibility. This chapter just represent a pilot study of a low cost dexterous robot hand; however, most of design and control parameters are not well justified to perform perfect performance. On the other hand, the selection of tendon wire as well as the mechanical properties and dynamics of the tendon wire are still the major interests of the future works.

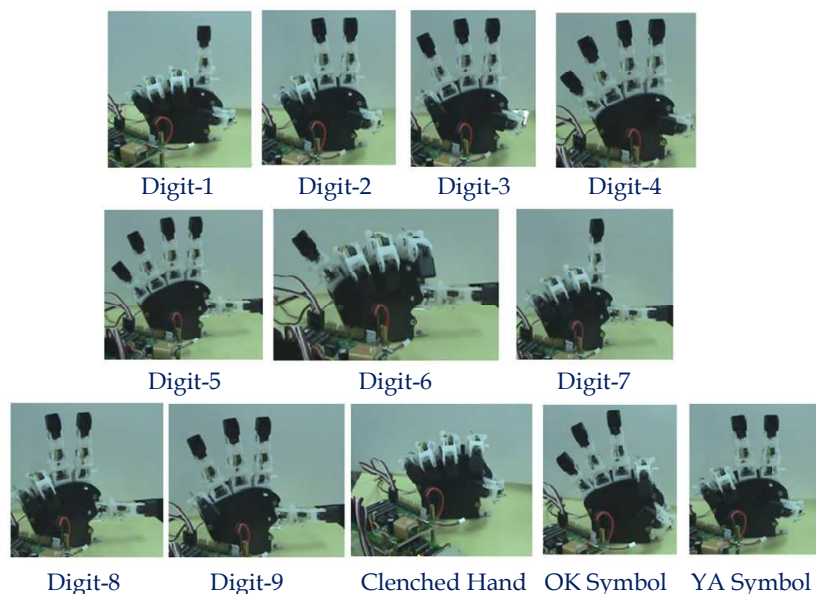


Fig. 15. Several hand posture demonstrations

7. Acknowledgement

This work was partially supported by the National Science Council, Taiwan, R.O.C., under Grants 95-2221-E-011-226-MY3.

8. References

- Chaloo, R.; Johnson, J.P.; McLauchlan, R.A.; & Omar, S.I. (1994). Intelligent Control of a Stanford JPL Hand Attached to a 4 DOF Robot Arm, *Proceedings of IEEE International Conference on Humans, Information and Technology*, Vol. 2, pp. 1274 - 1278.
- Jacobsen, S.; Iversen, E.; Knutti, D.; Johnson, R.; & Biggers, K. (1986). Design of the Utah/M.I.T. Dexterous Hand, *Proceedings of IEEE International Conference on Robotics and Automation*, Vol. 3, pp. 1520 - 1532, San Francisco, U.S.A.
- Kawasaki, H.; & Mouri, T. (2007). Design and Control of Five-Fingered Haptic Interface Opposite to Human Hand. *IEEE Transactions on Robotics*, Vol. 23, No. 5, pp. 909 - 918.
- Kawasaki, H.; Komatsu, T.; & Uchiyama, K. (2002). Dexterous Anthropomorphic Robot Hand with Distributed Tactile Sensor: Gifu Hand II. *IEEE/ASME Transactions on Mechatronics*, Vol. 7, No. 3, pp. 296 - 303.
- Kyriakopoulos, K.J.; Van Riper, J.; Zink, A.; & Stephanou, H.E. (1997). Kinematic Analysis and Position/Force Control of the Anthrobot Dexterous Hand. *IEEE Transactions on Systems, Man, and Cybernetics, Part B*, Vol. 27, No. 1, pp. 95 - 104.
- Lin, L.R; & Huang, H.P. (1996). Integrating Fuzzy Control of the Dexterous National Taiwan University (NTU) Hand. *IEEE/ASME Transactions on Mechatronics*, Vol. 1, No. 3, pp. 216 - 229.
- Namiki, A.; Imai, Y.; Ishikawa, M.; & Kaneko, M. (2003). Development of a High-speed Multifingered Hand System and its Application to Catching, *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*, Vol. 3, pp. 2666 - 2671.
- Parka, N.H.; Oh, Y.; & Oh, S.R. (2006). Behavior-based Control of Robotic Hand by Tactile Servoing. *International Journal of Applied Electromagnetics and Mechanics*, Vol. 24, pp. 311-321.



Advances in Robot Manipulators

Edited by Ernest Hall

ISBN 978-953-307-070-4

Hard cover, 678 pages

Publisher InTech

Published online 01, April, 2010

Published in print edition April, 2010

The purpose of this volume is to encourage and inspire the continual invention of robot manipulators for science and the good of humanity. The concepts of artificial intelligence combined with the engineering and technology of feedback control, have great potential for new, useful and exciting machines. The concept of eclecticism for the design, development, simulation and implementation of a real time controller for an intelligent, vision guided robots is now being explored. The dream of an eclectic perceptual, creative controller that can select its own tasks and perform autonomous operations with reliability and dependability is starting to evolve. We have not yet reached this stage but a careful study of the contents will start one on the exciting journey that could lead to many inventions and successful solutions.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Chung-Hsien Kuo and Chun-Tzu Chen (2010). Development of Tendon Based Dexterous Robot Hand, *Advances in Robot Manipulators*, Ernest Hall (Ed.), ISBN: 978-953-307-070-4, InTech, Available from: <http://www.intechopen.com/books/advances-in-robot-manipulators/development-of-tendon-based-dexterous-robot-hand>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2010 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](#), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.

IntechOpen

IntechOpen