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Development of a 3-Fingered Hand and Grasping Unknown Objects by Groping

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Abstract— This paper addresses the development of a three-fingered hand and discusses a strategy for grasping unknown objects by groping. In the former part of the paper, the design of the developed robot hand is presented. The robot hand has thumb, index finger and middle finger with a total of eight degrees-of-freedom. The location of thumb is designed considering opposability of human hand. Eighty-seven touch sensors are distributed over the surface of palm and fingers of the robot hand. In the latter part of the paper, a strategy for grasping unknown objects by groping using the developed hand is discussed. Groping is a kind of "active sensing." When the system does not have any models of objects to grasp, active sensing becomes inevitable. The aim of the groping is to find a grasping configuration for unknown objects. A can, a ball, a cone, a plate, and a cube are chosen for the unknown objects in the experiments. Experimental results demonstrate the capability of the strategy for grasping unknown objects. This strategy needs neither models of objects nor complicated computation, and therefore, useful especially for assembly tasks in the real world.

1. Introduction

For flexible and agile assembly and manufacturing, dextrous robot hands are expected to play a major role. Especially sensor-based reactive handling objects by robot hands will be a key technology for flexible assembly. Since the beginning of robotics research, a considerable number of studies have been made on robot hands. In the beginning, stable prehension [1], force control in grasping [2] and object recognition by tactile sensors [3, 4] were hot research subjects.

In the last decade, a lot of dextrous robot hands [5, 6] and tactile sensors [7, 8] have been developed. Jacobsen et al. have developed the Utah/MIT Dextrous Hand (UMDH) [5], which uses two antagonistic polymeric tendon tapes to actuate each joint. Jacobsen et al. have also developed the 9-DOF, 3-fingered force-reflecting hand which is attached to the 7-DOF TOPS robot arm [6]. The hand is actuated by hydraulic actuators to achieve high performance force control and force reflection.

In recent years there has been renewal of interest in active sensing by robot hands[9, 10]. Kaneko and Tanie proposed a contact point detection strategy using self-posture change [9]. Namiki and Ishikawa proposed an idea of *shaping*, which is a behavior of changing finger configuration for optimal grasping after once grasping an unknown object [10]. Finger tip tactile sensors were used for the shaping. A human can grasp an unknown object by groping even with eyes closed, although the complete object shape can not always be recognized. It means that in order to grasp unknown objects, active sensing for finding grasping points of the object is needed rather than precise object recognition.

This paper addresses the development of a 3-fingered hand and discusses a strategy for grasping unknown objects by groping. Eighty-seven touch sensors are distributed over the surface of palm and fingers of the robot hand. The criteria and design of the hand are illustrated in Section 2. In the latter part of this paper, an grasping strategy of unknown objects by groping is discussed. Conceptual idea of the grasping strategy is similar to the idea of *shaping* [10]. However, the grasping strategy discussed in this paper uses a more simple algorithm and uses distributed touch sensors on the surface of the robot hand, therefore, robustness can be expected. The grasping strategy is outlined in Section 3. Experimental results that demonstrate the capability of this strategy are also presented in Section 4.

2. Development of a three-fingered robot hand

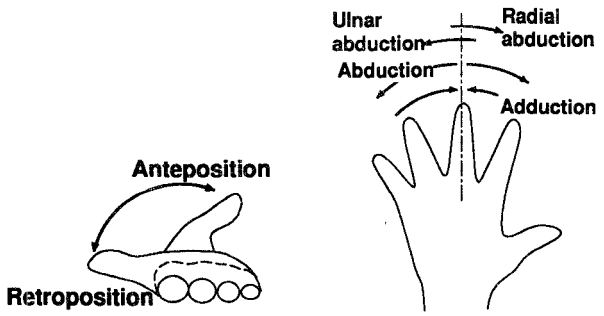
A 8-DOF, 3-fingered robot hand with distributed eighty-seven touch sensors is developed in this work. The robot hand is designed as an imitation of human hands, although the number of fingers is reduced to three in order to lighten the hand. The design of the robot hand and the touch sensor are presented in this section.

2.1. Human hands

Human beings have a thumb and four fingers: index finger, middle finger, ring finger and little finger for each hand. For stable prehension only three of them are needed, however, the redundant two fingers enable human hands to do dextrous manipulations. Opposability between the thumb and the other fingers (Figure 1 (a)) also helps stable prehension of objects and dextrous manipulation.

Thumb has two phalangeal joints: IP (Inter-Phalangeal) joint and MP (Metacarpo Phalangeal), while other fingers have DIP (Distal InterPhalangeal) joint, PIP (Proximal InterPhalangeal) joint and MP (Metacarpo Phalangeal) joint for each. The joints' rotation for flexion/extension of each finger are coupled to each other.

Abduction and adduction of index finger, ring finger and little finger center around middle finger [11]. The MP joint's movement of middle finger is called radial abduction or ulnar abduction [11] (see Figure 1



(a) Anteposition and retroposition

(b) Abduction and adduction of fingers

Figure 1. Joint movements of human hands (modified from [11]).

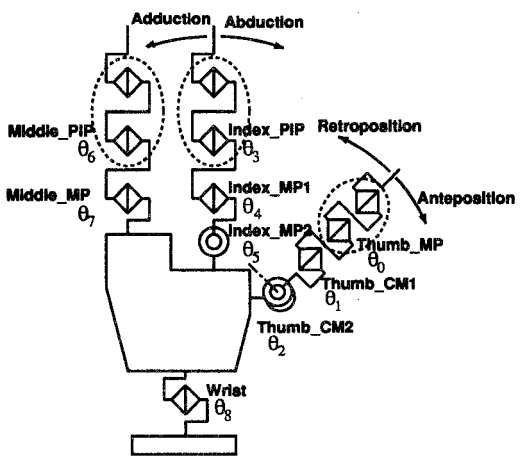


Figure 2. Distribution of degrees-of-freedom of the robot hand.

(b)). Abduction, adduction and opposition (anteposition) of thumb are achieved by the carpo-metacarpal (CM) joint's movement.

In the next subsection, considering the features of human hands described above the design criteria are illustrated.

2.2. Design criteria

The features which enable human hands the dextrous manipulation were discussed above. Borrowing some of the features, design criteria of the robot hand are summarized as follows:

1. The robot hand is designed to have the similar dimension of a human hand.
2. To reduce the weight of the robot hand, the number of fingers is reduced to three: thumb, index finger and middle finger.
3. Radial/ulnar abduction (see Figure 1 (b)) is not considered here, therefore, MP joint of the middle finger is designed not to have the DOF for abduction/adduction
4. Considering coupled movement of human fingers, PIP and DIP joints of the index and middle finger are designed to be coupled. IP and MP joints of the thumb are designed also in the same way.

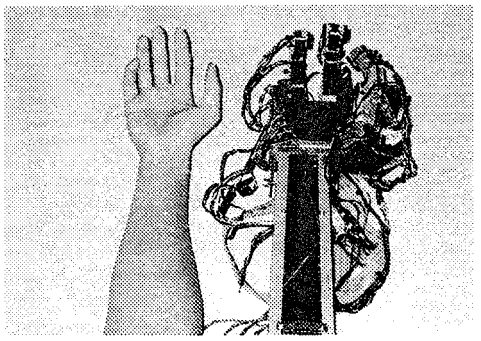


Figure 3. Outward appearance of the developed hand.

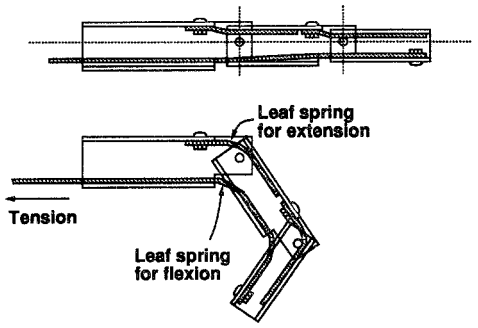


Figure 4. The coupled driving mechanism.

5. Borrowing the opposability of human hands, the location of the DOFs of the thumb should be designed.
6. Control system should be installed inside the forearm.
7. Touch sensors should be distributed over the surface of the palm and fingers.

From those criteria, the distribution of DOFs of the robot hand is designed as shown in Figure 2. The joints circled by dotted lines are coupled as described in criterion 4.

2.3. A three-fingered robot hand

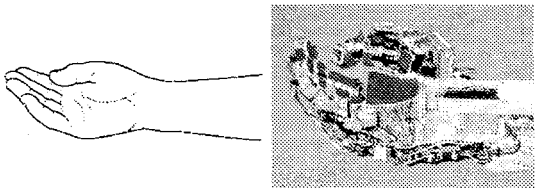
The outward appearance of the developed 3-fingered robot hand is shown in Figure 3. For the coupled driving of PIP and DIP joints of the index and middle finger, and IP and MP joints of the thumb, the mechanism using thin leaf springs is developed as illustrated in Figure 4

Eight actuators are used for driving fingers and one for the wrist. In order to reduce the weight of the hand, DC motor servo modules supplied by FUTABA are chosen. The modules were originally for radio controlled toy cars. The specification of the servo modules used for the hand is presented in Table 1. The servo module has a position feedback circuit inside. Once a reference position is commanded by correspond pulse width, rotation of the motor axis is controlled by the internal hardware position servo.

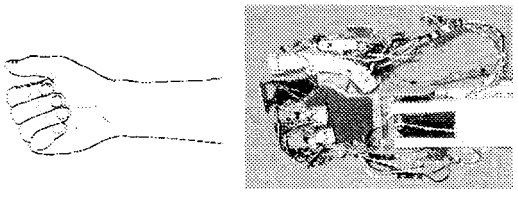
Napier indicated that the function of the hand of primates is characterized by following five aspects: (a) convergence, (b) prehensility, (c) opposability and (d)

Table 1. Specification of the FUTABA actuators.

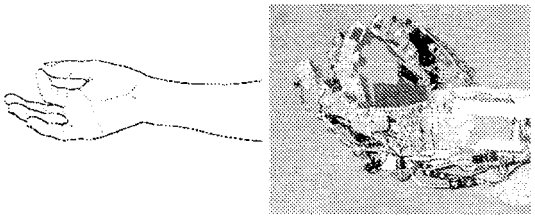
Type	Dimension [mm]	Weight [g]	Max. Vel. [rad/s]	Torque [kgm]
FP-S5102	28×13×29	22	4.76	0.021
FP-S3002	31×16×30.2	35	5.24	0.033
FP-S3801	59.2×28.8×49.8	107	4.03	0.140



(a) Convergence



(b) Prehensility



(c) Opposability

Figure 5. Three configurations imitating human hand (the figures on the left are from [12]).

divergence [12]. Imitating a human hand, three configurations of the robot hand which demonstrate the convergence, prehensility and opposability are shown in Figs. 5 (a), (b) and (c).

2.4. Touch sensors

Touch sensor units with simple structure are developed for the robot hand. An unit of the sensor has four layers as shown in Figure 6. The first layer is a shock absorber made by urethane sponge. Electrically conductive fabric of the second layer is separated from the three rows of contact points on the circuit of the fourth layer by spacers of the third layer. Only a +5V power supply always have a contact with the electrically conductive fabric.

Once the urethane sponge is pressed, the sponge deforms, and thus, the electrically conductive fabric has some contacts with the contact points on the circuit. The number of the contacts depends upon the pressing force. Sensibility of the developed sensor against the loads which press the whole surface of the urethane sponge is illustrated in Table 2, which shows the actual output of five trials at each load. As described above, there are three rows of contact points, and thus, ●○○ in Table 2 indicates that only left row of the sensor has

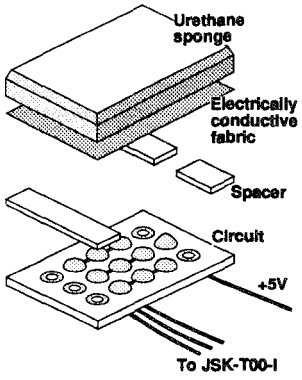


Figure 6. Developed touch sensor.

Table 2. Sensibility of the touch sensor (●: On, ○: Off).

load	1st trial	2nd trial	3rd trial	4th trial	5th trial
20 [gf]	○○○	○○○	○○○	○○○	○○○
21 [gf]	○○○	●○○	○○○	○○○	○○○
22 [gf]	●○○	●○○	●○○	●○○	●○○
⋮			⋮		
27 [gf]	●●○	●●○	●●○	●●○	●●○
⋮			⋮		
32 [gf]	●●●	●●○	●●●	●●●	●●○
33 [gf]	●●●	●●●	●●●	●●●	●●●

a contact.

Distribution of the sensor on the surface of the palm and fingers is illustrated in Figure 7.

2.5. Control system

Transputer-based control system is developed for the robot hand. The control system consists of a transputer-based processing board JSK-T00-M and two kinds of interface boards JSK-T00-P and JSK-T00-I.

The JSK-T00-M board has the 16 bit transputer INMOS T225 and 64 kbyte SRAM, and controls the interface boards JSK-T00-P and JSK-T00-I.

The JSK-T00-P which has a universal-pulse-processor chip (HITACHI HD63140) is used to generate pulse width motor commands corresponding to reference motor angles and used to obtain the motor angles. The JSK-T00-I, which has a capability to deal with 128 bit on-off data, is used to obtain the touch sensors' information. The JSK-T00-P and JSK-T00-I are mounted on the JSK-T00-M.

The stack of the boards is installed inside the forearm. The connection is shown in Figure 8.

3. A strategy for grasping unknown objects

Napier has classified static prehension into two basic patterns: power grip and precision grip [12]. Kamakura has more precisely classified static prehension into fourteen patterns [13], which is an extension of Napier's classification.

The term "power grip" is used to refer to a prehension pattern which flexes fingers around an object and presses the object on the palm, while the term "precision grip" is used to refer to a prehension pattern which

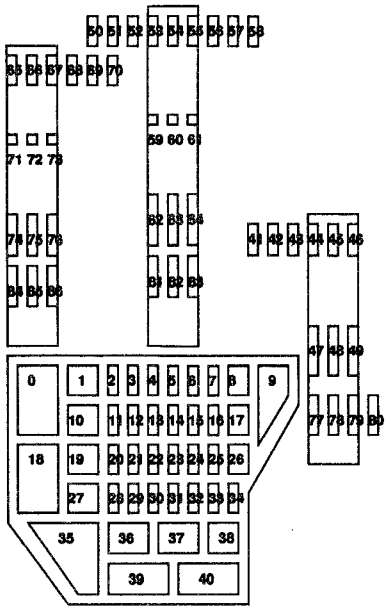


Figure 7. Distribution of the sensors.

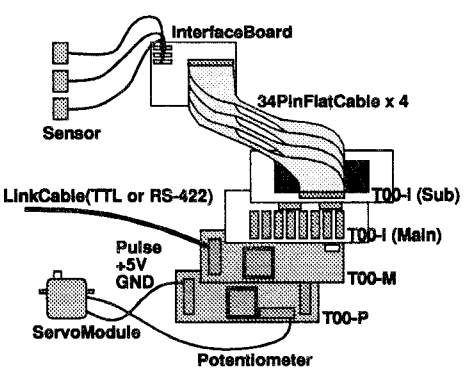


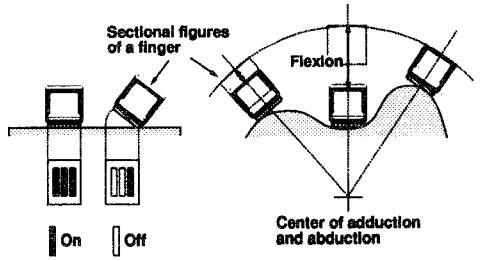
Figure 8. Hand control system.

does not use the palm and grasps an object using pulp of fingers accompanied with mild flexion.

The aim of the strategy is to achieve an artificial power grip without having any models of the grasping object. The strategy is composed of two behavioral processes: (I) active abduction or adduction of the thumb and the index finger in order to find the optimal grasping configuration (Figure 9 (b)), and (II) mild flexion round the object (Figure 10). Both behavioral processes of (I) and (II) utilize the touch sensory information.

In the strategy the following two criteria are considered:

1. The thumb and the index finger should be placed on the grasping object as squarely as possible. The squareness of the grip is estimated by touch sensors' on-off information (see Figure 9 (a)).
2. The CM joint of the thumb (Thumb_CM1 shown in Figure 2) and the MP joint of the index finger (Index_MP1 shown in Figure 2) should flex as much as possible to make the pressing of the object on the palm easy (see Figure 9 (b)).



(a) Squareness on an object (b) Flexuosity

Figure 9. Conceptual sketch of the grasping strategy.

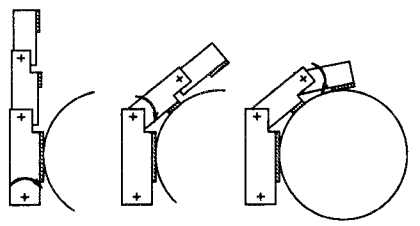


Figure 10. Mild flexion around an object.

The squareness of the thumb and the index finger on the object are estimated by the numbers of contact points detected by the set of touch sensors 47, 48, 49, 77, 78, 79 mounted on the surface of the proximal phalange of the thumb and 62, 63, 64, 81, 82, 83 mounted on the proximal phalange of the index finger (see Figure 7), respectively. In order to find the maximum contact configuration, active abduction and adduction of the thumb and the index finger are performed. During this abduction and adduction behavior, phalangeal joint angles for flexion of Thumb_CM1 and Index_MP1, which respectively correspond to θ_1 and θ_4, are memorized.

A performance index $J(\theta_i)$ to estimate the above criteria is given by:

$$J(\theta_i(t)) = N(\theta_i(t)) + \alpha(\theta_{i-1}^{contact}(t) - \theta_{i-1}^{div}) \qquad (i = 2, 5). \tag{1}$$

The subscript i takes either 2 or 5, where $\theta_2(t)$ and $\theta_5(t)$ correspond to the abduction/adduction of the thumb and the index finger, respectively, while $\theta_1(t)$ and $\theta_4(t)$ correspond to the flexion. $N(\theta_i(t))$ $(6 \geq N(\theta_i(t)) \geq 0)$ is the number of contact points obtained by the set of touch sensors when $\theta_i = \theta_i(t)$. $\theta_1^{contact}(t)$ and $\theta_4^{contact}(t)$ are the phalangeal joint angles of Thumb_CM1 and Index_MP1 when the control system detect the contacts between the object and fingers. Contact is detected by seeing the touch sensory information, however, if the touch sensors do not detect the contact with the object the system judges by the difference between the reference position command θ_{i-1}^{ref} and current position θ_{i-1} detected by the potentiometer. The threshold $\theta_{i-1}^{threshold}$ is set to be 10 [°] in the experiment. θ_{i-1}^{div} is the preshaping divergence configuration before grasp and is given here by

$$[\theta_1^{div} \quad \theta_4^{div}] = [-40 \quad 0] \ [°]. \tag{2}$$

The first term of the right hand side of Eq. (1) cor-

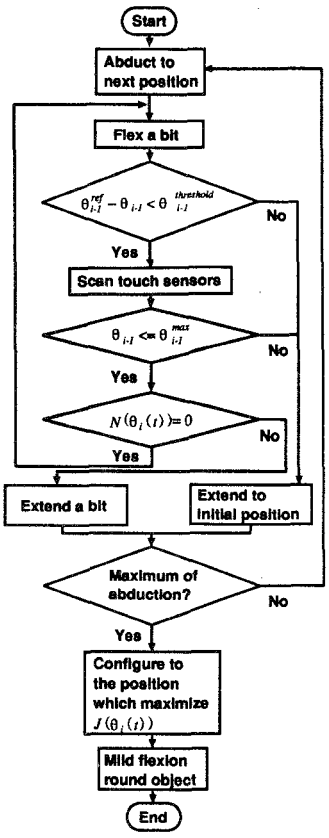


Figure 11. Strategy flowchart.

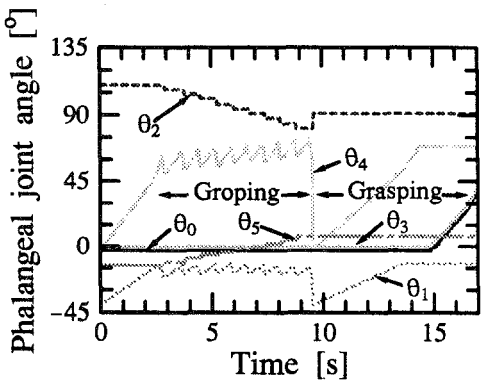


Figure 12. Joint trajectory of fingers.

responds to the criterion 1 described above, while the second term corresponds to the criterion 2. α in Eq. (1) is a weight to give a priority for estimation. α is set to be 1/90 in the experiment which gives the number of contact points high priority (because the second term of the right hand side of Eq. (1) becomes less than 1.0).

In this strategy, after finding the configurations of θ_2 and θ_5 which maximize the performance index $J(\theta_i(t))$ given by Eq. (1), mild flexion round the object (Figure 10) is performed. To clarify the discussion, the strategy is illustrated in the flowchart (Figure 11).

4. Experiments of grasping unknown objects

A can, a ball, a cone, a plate, and a cube are chosen as unknown objects to grasp in the experiments. Once the robot hand detects contact with an object, it starts grasping following groping.

To begin with, experiment of grasping a can is performed. Figure 12 plots the phalangeal joint angle trajectories during groping and grasping behavior. Saw-edged trajectories of θ_1 and θ_4 indicate groping.

Detected contact points for variety of $[\theta_2 \quad \theta_5]$ during groping a can are illustrated in Figs. 13 (a) $\sim$ (j). From the result of groping optimal configuration which maximize the performance indices $J(\theta_2(t))$ and $J(\theta_5(t))$ is given with $[\theta_2 \quad \theta_5] = [91 \quad 7]$ [°]. Figure 13 (k) shows the contact points when the robot hand grasp the can in the obtained optimal configuration.

Finally, experiments of grasping various unknown objects are performed to demonstrate the capability of the strategy. Figs. 14 (a) $\sim$ (f) show the shapes of grasping for the various objects.

5. Conclusion

The design of a 8-DOF, 3-fingured robot hand is presented. The location of DOFs of the robot hand is decided based on human hands. Especially, the location of thumb is designed carefully to satisfy the opposability. Eighty-seven touch sensors are developed and distributed over the surface of the palm and fingers of the robot hand. The control system is installed inside the forearm to make it easy to attach to the humanoid in the lab.

A strategy for grasping without any models of objects is also discussed. To find the optimal grasping configuration the robot hand gropes the object, which is a kind of "active sensing" behavior. A can, a ball, a cone, a plate, and a cube are chosen among unknown objects to grasp in the experiments. Experimental results demonstrate the capability of the strategy for grasping of unknown objects.

The strategy needs neither models of objects to grasp nor complicated computation, therefore, useful in the real world.

Acknowledgment

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References

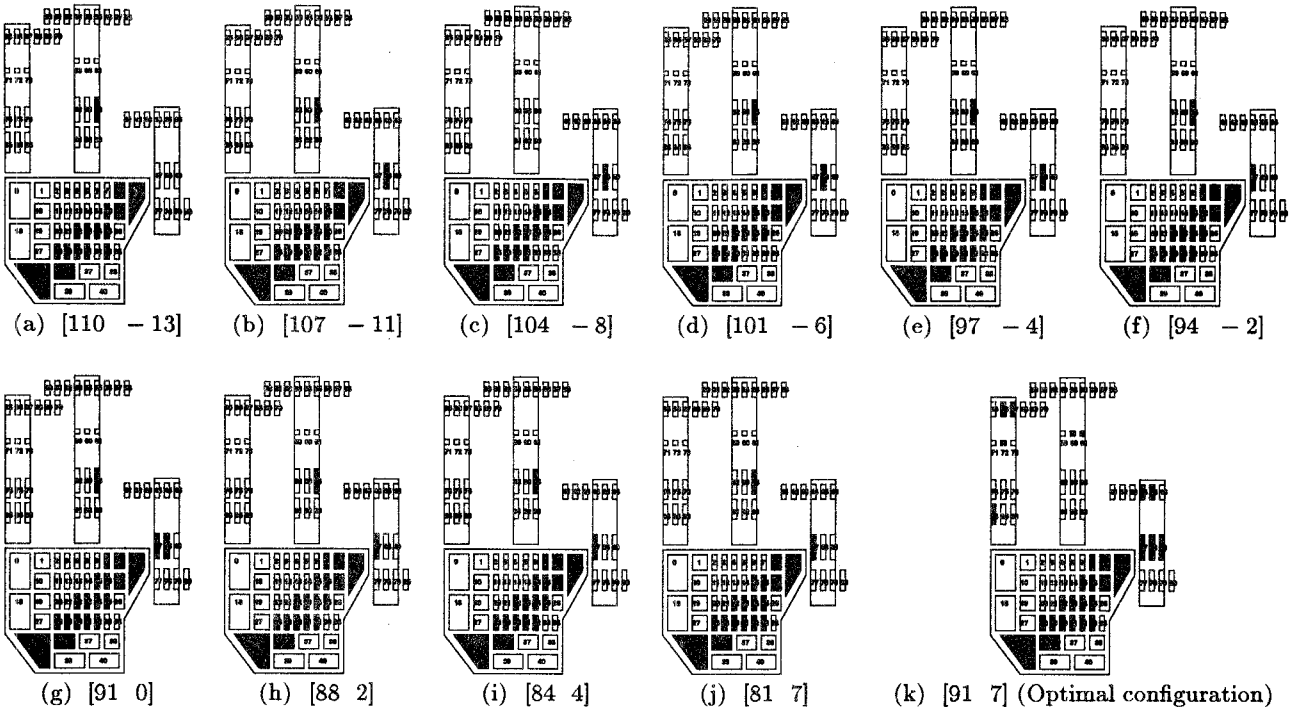
[1] H. Hanafusa and H. Asada. Stable Prehension by a Robot Hand with Elastic Fingers. In *Proc. of 7th Int. Symp. on Industrial Robots*,, pp. 361–368, 1977.

[2] J. K. Salisbury and J. J. Craig. Articulated Hands: Force Control and Kinematic Issues. *Int. J. of Robotics Research*, Vol. 1, No. 1, pp. 4–17, 1977.

[3] S. Aida G. Kinoshita and M. Mori. A PATTERN CLASSIFICATION BY DYNAMIC TACTILE SENSE INFORMATION PROCESSING. *Pattern Recognition*, Vol. 7, pp. 243–251, 1975.

[4] H. Ozaki, S. Waku, A. Mohri, and M. Takata. Pattern Recognition of a Grasped Object by Unit-Vector Distribution. *IEEE Trans. on Systems, Man and Cybernetics*, Vol. 12, No. 3, pp. 315–324, 1982.

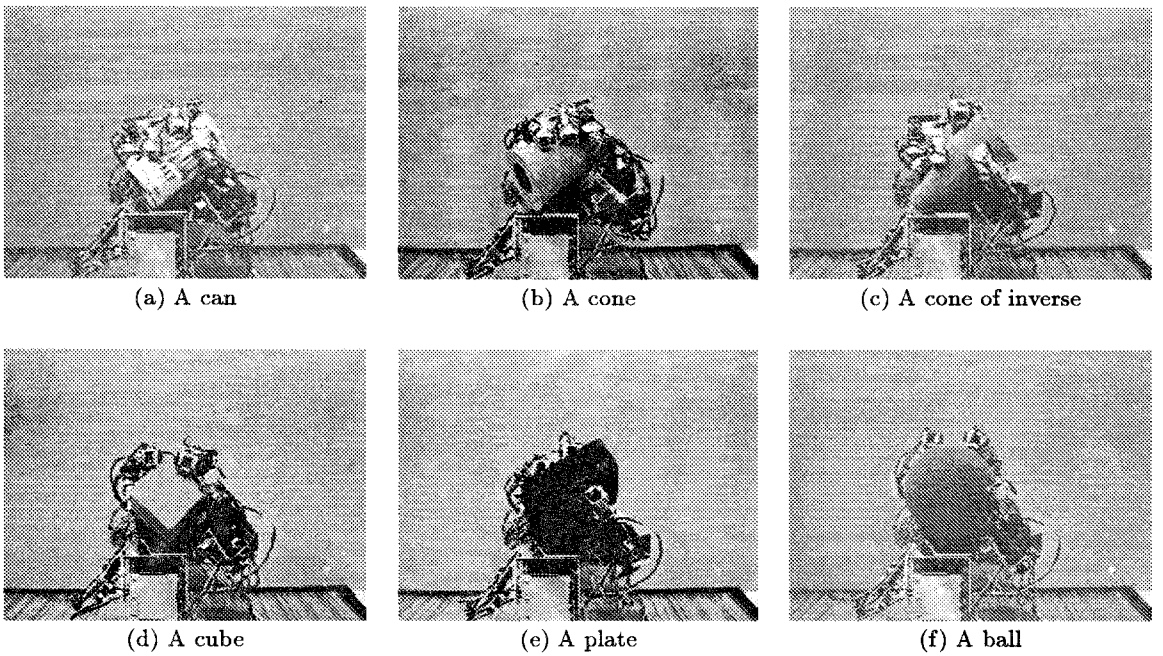
[5] S. C. Jacobsen, E. K. Iversen, D. F. Knutti, R. T. Johnson, and K. B. Biggers. Design of the UTAH/MIT Dexterous Hand. In *Proc. of IEEE Int. Conf. on Robotics and Automation*, pp. 1520–1532, 1986.



(a) [110 −13] (b) [107 −11] (c) [104 −8] (d) [101 −6] (e) [97 −4] (f) [94 −2]

(g) [91 0] (h) [88 2] (i) [84 4] (j) [81 7] (k) [91 7] (Optimal configuration)

Figure 13. Contact points for the variety of $[\theta_2\ \theta_5]$ (°) during groping a can. (■: On, □: Off)



(a) A can (b) A cone (c) A cone of inverse

(d) A cube (e) A plate (f) A ball

Figure 14. Grasping of unknown objects.

[6] S. C. Jacobsen, E. K. Iversen, C. C. Davis, D. M. Potter, and T. W. McLain. Design of a multiple degree of freedom, force reflective hand master/slave with a high mobility wrist. In *3rd Topical Meeting on Robotics and Remote Systems*, 1989.

[7] P. Dario and G. Buttazzo. An Anthropomorphic Robot Finger for Investigating Artificial Tactile Perception. *Int. J. of Robotics Research*, Vol. 6, No. 3, pp. 25–48, 1987.

[8] H.Maekawa et al. Development of a Finger-Shaped Tactile Sensor and its Evaluation by Active Touch. In *Proc. of IEEE Int. Conf. on Robotics and Automation*, pp. 1327–1334, 1992.

[9] M. Kaneko and K. Tanie. Contact Point Detection for Grasping of an Unknown Object Using Self-Posture Changeability. In *Proc. of IEEE Int. Conf. on Robotics and Automation*, pp. 864–869, 1990.

[10] A. Namiki and M. Ishikawa. Optimal Grasping Using Visual and Tactile Feedback. In *Proc. of Int. Conf. on Multisensor Fusion and Integration for Intelligent Systems*, 1996.

[11] American Society for Surgery of the Hand. *The Hand.* Examination and Diagnosis. 2nd Ed., C.Livingstone, New York, 1983.

[12] J. R. Napier. The Evolution of the Hand. *Scientific America*, pp. 56–62, 1962.

[13] N. Kamakura, M. Matsuo, H. Ishii, and F. Mitsubosi Y. Miura. Patterns of Static Prehension in Normal Hands. Vol. 34, pp. 437–445, 1980.