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Research on intelligent motorized prosthetic hand by functional analysis of human hand at near future

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Abstract. It has become possible to have common mechanism of electrical prosthetic hand for infant and grown-ups. For the grasping, the thumb, the index and the middle fingers pinch the object mainly. And the ring and little fingers drive supplementary to support the object. Five fingers have some mechanical compliance for grasping object more surely. The grasp function of this hand will be reinforced in the near future, that will approach to human grasping form (22 modes of gasping). In this report, we describe about the materialization (design and trial manufacture) of 17 kinds of hand mechanism and these control system.

Keywords. *Prosthetic hand, Recognition of tactile sensor, Command of EMG, Infant prosthetic hand,*

I. INTRODUCTION [1][2][3]

Looking back at the development of electrical prosthetic hands from 1968 up to date, there have been three problems.

(1) The first problem is that electrical prosthetic hands for infants are difficult to develop their mechanisms.
(2) The second problem is that electrical prosthetic hands are not well fitted to the end of their lost parts.
(3) The size and shape of electrical prosthetic hands were not adaptive to their growth.

To solve these problems, we made it our basic policy to build up a CAD system that is capable of printing out machining drawings of prosthetic hands from the information available from two basic design conditions that we set up for our research focus.

(1) One is that prosthetic hands for infants should be modified in proportion to the growth of their hands.
(2) Another is that, for the patients 20 years and older, prosthetic hands adaptive to their age and body shape should be provided.

To meet these design conditions, it is imperative to design mechanisms commonly applicable to all patients, regardless of whether they are infants or grown-ups and whether they are male or female.

General information of our electrical prosthetic hand;

(a) Infants with congenital deficient's has little recognition for grasping objects.
(b) Adults with congenital deficient’s are able to recognize the position of object.
(c) The merits and demerits of the grasp function depend on the prosthetic hand mechanism.
(d) Electrical prosthetic hands for infants, requires that its highly resembles a real hand.

It is expected that motion variety of electrical prosthetic hand will increase in the near future. New feature motion will be classified into 22 modes of grasping and 12 modes of arm form. These two configurations will be selected under optimum conditions. For example, in the case of electrical prosthetic hand for forearm amputating, we expect 22 degrees of freedom including bending, stretching and rotation fingers.

But the control signal by electromyogram sensor is only 4 channels by using pronator and supinator (2 channels), triceps brachii muscle (1 channel) and triceps muscle (1 channel). In the second part of this study, we propose the method of fine classification of grasping and arm form by software using electromyogram.

In this research, we explain mechanism and control system of electrical prosthetic hand.

II. FUNCTIONAL HAND AND ARM

2.1 Our hand model [4][5]

In this research, we completed one 3D model by superposing laminations from two directions, sectional outline lamination of horizontal projection and that of inside. We compared hand-shape model with secondary model measured in order to check how close completed model is to actual outline.

Morecki and others proposed a structural model of human upper limb based on its anatomic structure, which has 27 DOFs in total, 20 DOFs in hand excluding wrist joint.[4]. Most of conventional robot hands and prosthetic hands have been developed on this proposal.

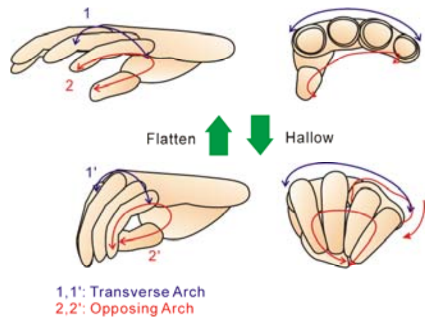


Fig. 1 Arch structure in the hand and the 4th and 5th CM joint movement in the palm

However, there is a problem in this hand model. Edge of thumb cannot face fingers and therefore, fourth and fifth finger make insufficient flexion that prevents realization of grasping function of human. Fukuda[5] and Shimonaka focused their attention on carpal-metacarpal joint (CM joint) and they set up model with 25DOFs giving one DOF to each CM joint of four fingers (except thumb) and adding pronation and supination DOFs of metacarpophalangeal joint (MP joint).[6] However, this model is not representing human hand correctly as the second and third CM joint of human hand seldom moves. 25-DOF model of Fukuda and others cannot be realized as it includes unnecessary functions as actual hand.

Fig. 1 shows arch of hand. Movement of CM joints directly participated in opening and closing hand as grasping function. In grasping condition, CM joints shape the arch and thumb and four fingers get near making grasping operation secure. This is close to a human grasping operation.

Many prosthetic hands on the current market have grasping operation by lateral pinch with thumb and the second finger or three-point picking adding the third finger. Such grasping operation is not sufficient depending upon the shape of the object. Especially, fingers of child hand can cover less area of the object and grasping capability is reduced.

Functional classification of the hand is shown in Fig. 4. Lateral pinch with two or three fingers is 30% or less of the total grasping movements. By contrast, grasping with five fingers reaches 60% or more. This tells how important the arch function shown in Fig. 1 is. Mechanism of our prosthetic hand satisfies the points mentioned above.

2.2 Prosthetic hand realized by analysis

The behaviours of human hands are verified to understand the rules in the relevance of the design parameters. The classification of the human hand has been conducted, but the subject is not in balance for proposing a five-digit artificial hand design. Thus, we classified the dynamic and static usage of human hand and arm to perceive the movements and poses required in the hand. The classification is intended to be simple and limited to practical activities.

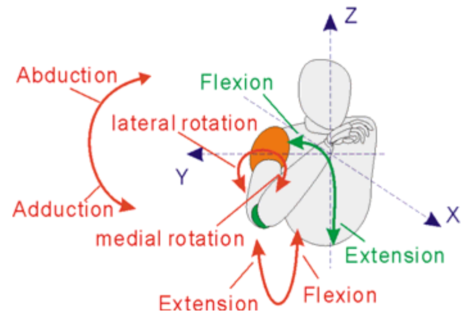


Fig. 2. Joint movement of the upper arm

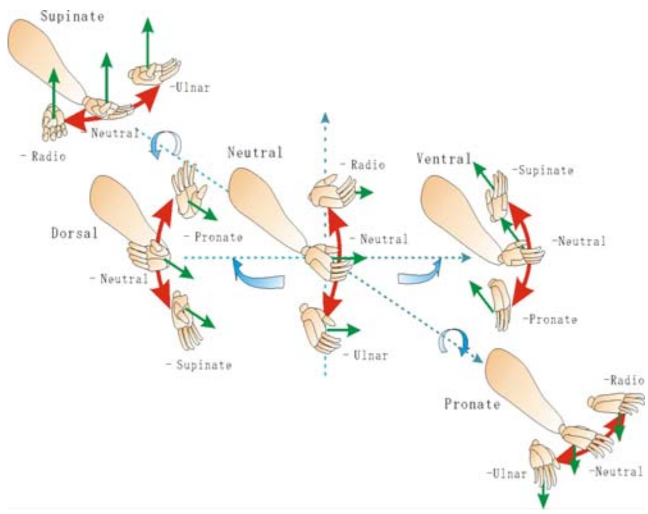


Fig. 3. Classification of the postures of the forearm

The arm movement is classified into 14, wrist and forearm movement to 6, hand movement to 14, finger movement to 12, thumb movement to 12. The arm pose is classified into 10, and wrist pose to 12. The hand pose is organized as neutral, prehension, non-prehensile contact, and gesture. Prehension mode is further classified into 22, and non-prehensile contact mode into 41 as shown in Fig.4 and Fig.5. The movements and poses are categorized by discussing the position and orientation of the regions in the arm and digits in relation to the dorsal or palm. The motions of hand are further classified on the direction of acceleration created at the proximal end of the finger element. The poses of hand are sorted by the orientation of the elements of finger in relation to the dorsal or palm.

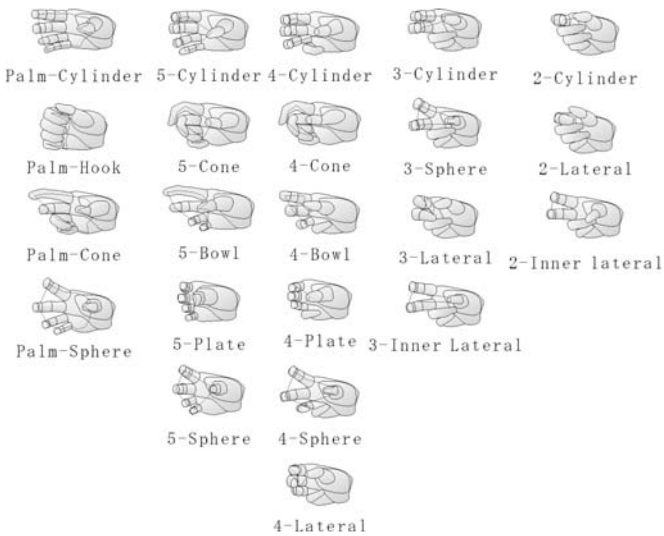


Fig. 4 Prehension modes classified into 22 types.

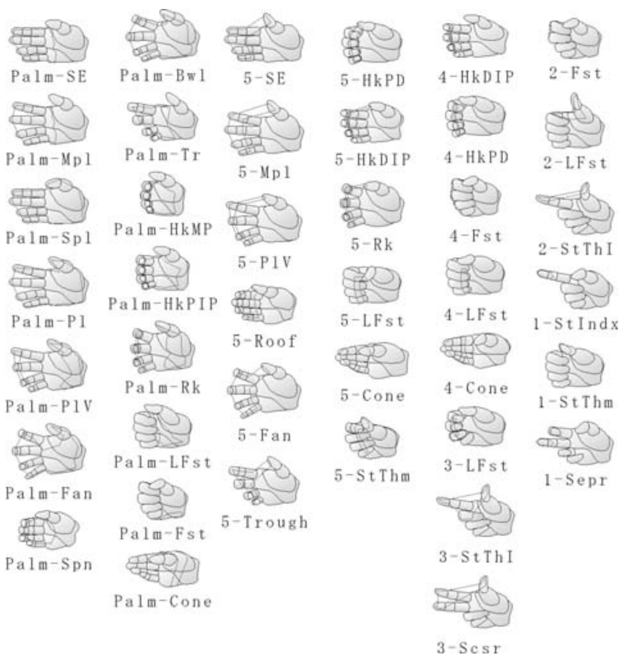


Fig. 5 Non-prehensile contact modes classified into 41 types

The prehensile and non-prehensile postures are organized by the direction of the force that is applied to the object, palm and number of digit involved, and the distribution of the surface area in contact.

The classification of Fig.4, Fig.5 are synthesised by relating the prehensile and non-prehensile modes with the arm and hand movements that are required for performance. The wrist pose and arm pose are linked as well. The link mechanism describes a series of hand mode where the input is the movement and the output is the mode of hand action. The differentiation of adding and subtracting the joint is set as an evaluation value of design assessment for dexterous hand. Thus, the series of hand mode describes a solution for modifying the mechanical structure effectively.

The hand modes are utilized to assemble the mechanism, sensor layout, and control sequence for determining the intelligent hand design in future. We designed prosthetic hand with 22 joints and 15 DOFs aiming at human hand . Our prosthetic hand developing now has 2degrees of freedom and one motor such as opening and closing of hand in Fig.6. However, MP, PIP and DIP joints of 4 fingers correspond to 5 degrees of freedom from appearance as they are grasped to fit for the shape by spring back action of material.

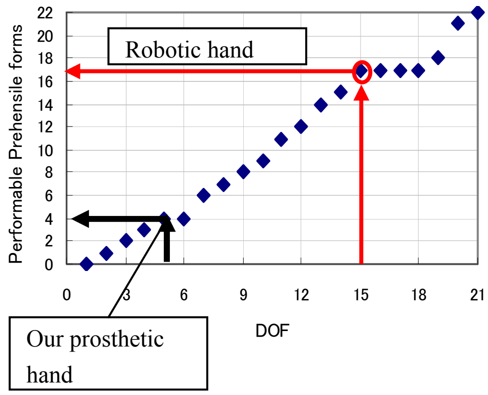


Fig.6 DOFs of finger and prehensile

Ⅲ. THE CHARACTERISTICS OF OUR ELECTRICAL PROSTHETIC HANDS STYLE AND FORMAT

The usage of electrical prosthetic hands in Japan is very low, one percent or less. This is because Japanese patients rely for their electrical prosthetic hands mostly on imports from Germany prosthetic hand. The sizes and shapes of the imported goods do not fit them. There is the case where Japanese male patients who are short in height select electrical hands for female use, but electrical hands for female use are not various. As a result, if they have healthy hand, they select electrical hands slightly smaller than the size of their healthy hand. Accordingly, it is most unlikely for Japanese patients to select electrical prosthetic hands adaptable to their age and body shape. Such situation is commonly seen not only in Japan but also in other countries.

The objectives of our research are to integrate the design and manufacture of electrical prosthetic hands adaptive to the age, body shape and sex of our patients, into a system.

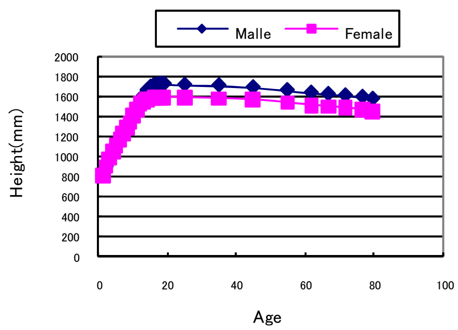


Fig.7 Relationship of the age with the height of Japanese

Fig. 7 shows the relationship of the age with the height for Japanese.

Here, we see that, for periods from 16 to 18 years old, their height changes in proportion to their age. As an exception, there are children who grow faster. But, generally, a proportional growth is observed. We also observed that the shape of the residual hand of the children with congenital defect is larger by comparison with the height of normal children. We guess that this may be due to frequent use of their residual hand.

To design electrical hands adaptive to age and body shape, we had to satisfy six requirements.

(1) It is necessary to develop such mechanisms that can be commonly applied for all electrical prosthetic hands for infants and grown-ups.

(2) Electrical prosthetic hands for grown-ups must be provided with the moving functions that satisfy their needs.

(3) Electrical hands for infants must be provided with different functions that adapt to their age and behavior.

(4) The holding function of electrical hands for infants should be provided with a sliding detection mechanism based using a touch sensor.

(5) Basically, electrical hands should have the shape that fits the shape of the residual hand of the disabled. To achieve this, It is necessary to measure the shape of the residual hand and work out cosmetic gloves.

(6) After fixing electrical hands, it is necessary to enhance the functions of the electrical hands as the users become more familiar with the operation of the electrical hands and wish to have different functions.

Concerning the No.1 requirement, we have developed the mechanisms that can be commonly applied for all electrical prosthetic hands for infants and grown-ups. The above mechanism is shown in chapter 4.

Concerning the No.2 requirement, we have modified the conventional three-point holding mechanism to a four-finger compliance holding mechanism to expand the holding capabilities. The four fingers of the new mechanism can hold an object as a human does.

Concerning the No.3 and No.6 requirements, a microcomputer was built into electrical prosthetic hands to control their functions. The software on the computer is capable of pattern recognition by multi sensors. Especially, it is difficult to recognize grasp function for infant. Then it makes a difference by adding the grasp meet general-purpose requirements of the users.

Concerning the No. 4 requirement, we have adopted a microcomputer that is able to recognize with three patterns from multi sensors.

Concerning the No.5 requirement, we were able to make models for each person.

This has become possible by forming a three-dimensional shape on the basis of the contact less image processing and making positive models, using rapid prototyping.

Therefore, our development point is to provide an make a difference adapting to each handicapped person.

Ⅳ. FUNCTION OF THE MOTORIZED PROSTHETIC HAND

4-1 Size of two or three year-old child

Fig. 8 show sizes of two- to three- year-old child for prosthetic hand. Size of three year-old child we measured was 50mm wide, 90mm long and 60mm high. We referred to the shape as well as the size.

Our basic design places emphasis on hand shape fit to body shape considering not age but height and weight of the child. We are aiming at custom-made prosthetic hand as the finish.

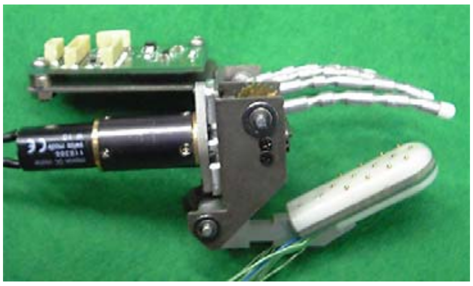


Fig.8 Prosthetic hand for 3 year old

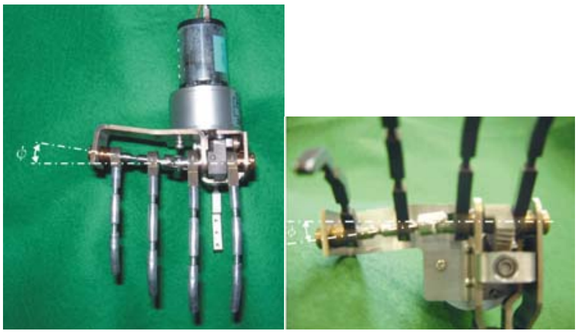


Fig. 9 Hand mechanisms in the palm structure

3D measurement system (OPTOTRAK) measures 3D coordinate data in real time tracking infrared LED (infrared marker) placed on finger edge of the hand. Sampling speed is 3KHz and RMS accuracy is 0.1mm.

Roll-in of the fourth and fifth fingers toward thumb is confirmed by measurement results. Measurement result is virtually-united in calculation result as to the fifth finger.

As for the fourth finger, 1.5mm difference is observed. Mounting-angle error of the finger to axis and processing accuracy could cause this difference.

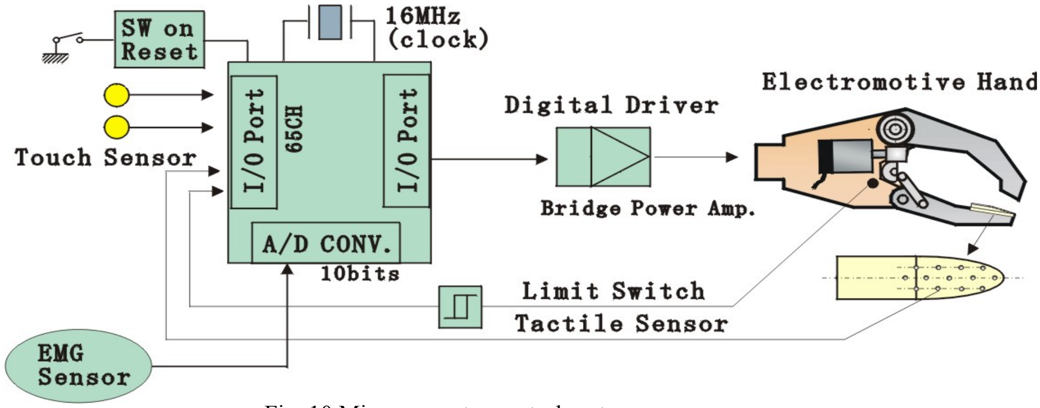


Fig. 10 Microcomputer control system

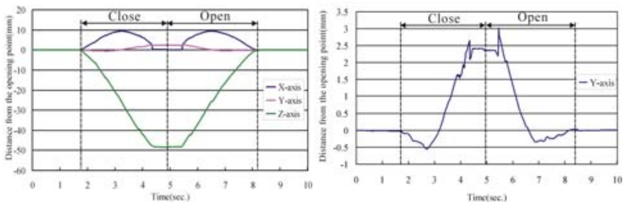


Fig. 11 Movement of 3 axis finger edge (a) and Y-axis measurement result (b) - 4th finger

Grasping capability results from antagonistic movement of five fingers as shown in Fig. 9. This mechanism has a great effect on child's grasping capability as length of their fingers is short.

Opening and closing of each finger is one DOF movement centered on knuckle (MP joint section). This opening and closing is shown on XZ plane and YZ plane. (Fig.11)

Finger-edge-to-finger-edge compliance mechanism by measurement results of the fourth and fifth fingers are shown in Fig. 11 (a) (b) .

Intelligent Hand, Fig. 9 is an anthropomorphic hand with four fingers and thumb. DC micro motor is installed in the hand. Each digit is designed with a compliance mechanism to simultaneously flex and extend the joints in the digit. The arrangement and number of the joints in the digits are designed to partially resemble the human hand. The suitable characteristics in achieving the flexibility of gripping forms fingers are priory applied.

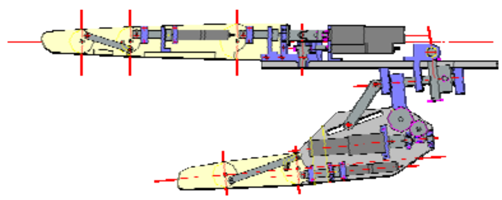
The palm is designed to compose a transverse arch and the fingertips of the ring and little fingers are arranged to spread out shown in Fig.9.

Thirteen tactile sensors are mounted on the inner surface layout in a continual diamond pattern. The digit is controlled by the changes of sensor response.

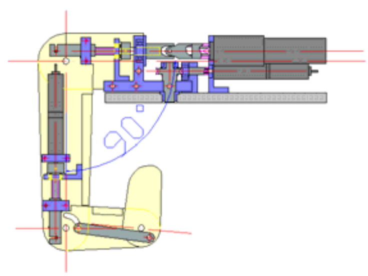
The change of sensor response in the pattern is detected as slippage of the target object in the holding condition. The object movement on the finger surface is limited to vertical, transverse and rotational movements. Thus, observing the sensor condition and recognizing these pattern changes to trigger actions can stabilize the object condition in the hand.

Approach to tactile sensor by elevated muscles detecting rubber is used as tactile sensor and is loaded in a socket.

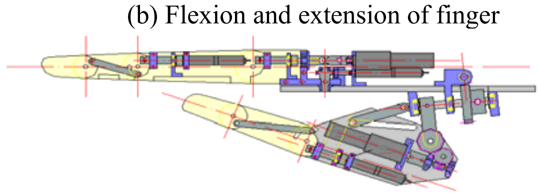
This tactile sensor can produce ON/OFF signal surely more than low myoelectric signal controlled by microcomputer as shown in Fig.10.



(a) Opposition movement



(b) Flexion and extension of finger



(c) Abduction and adduction of thumb

Fig.12 Structure of phantom prosthetic hand

This hand has the functions shown in Fig.13. The degrees of freedom of palmar and dorsal flexions are added. The mode of hand is selected in relation to the form of arm in order to control 22 kinds of grasping motions. The mode of arm form and grasping (or non-grasping) form are selected by detecting a posture of arm by inclinometer. Electromyogram signal is also taken into account in order to correct the hand form. These motions need operational training. [7][8]

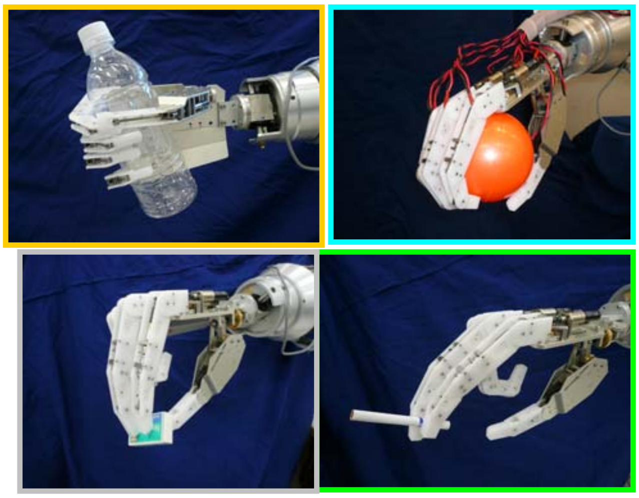


Fig. 13 Application of robotics hand

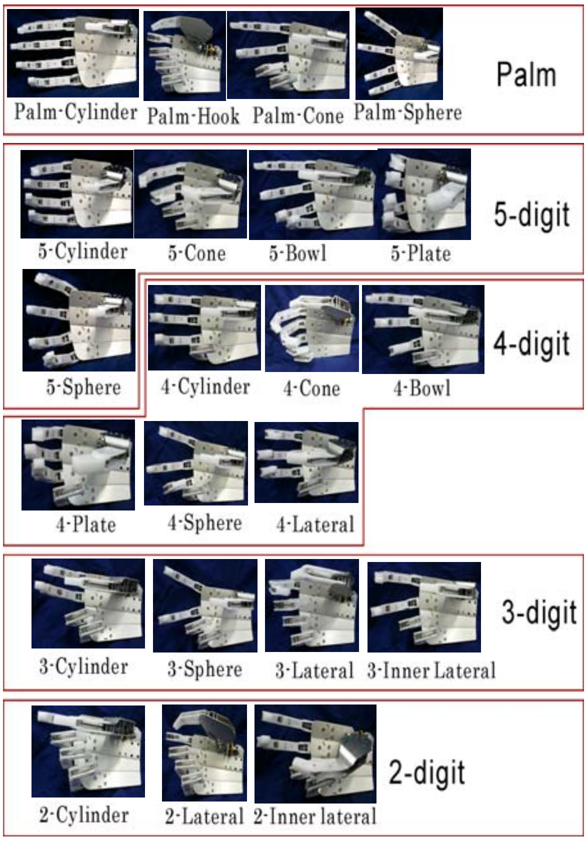


Fig. 14 77% of achievement ratio of prehension modes

In this training, according to the manipulation skills of handicapped person, the grasping form will approach close to the real human grasping form. The mechanism and tactile control system of artificial hand is successful while the target object is limited. The difficulty of operating the hands rises when the object is not captured on surface with tactile sensors. Therefore, the arrangement of the tactile sensor and degree of freedom in the hand for active sensor usage is the topic. Cooperative control of the arm is an associated subject.

V. CONCLUSION

It has become possible to have common mechanism of electrical prosthetic hand for infant and grown-ups. The grasp function of this hand will be reinforced in the near future, that will approach to human grasping form (22 modes of gasping).

We report following four items;

(1) We achieved 77% of prehension modes that we proposed.
(2) We realized the mechanism which has 17 DOF by using 14 micro motors in the robotic hand.
(3) In the near future, we expect that DOF of phantom prosthetic hand will increase in 22 DOF.
(4) Especially, the method of phantom prosthetic hand has the evaluation functions from the arm motion and the posture.

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