DEVELOPMENT OF AN ANTHROPOMORPHIC HAND (Mark-1)

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ABSTRACT

As a part of the national R&D program to develop "Advanced Robot Technology" research is progressing on sophisticated robot technology to be used in fields such as nuclear energy, deep sea operations, and fire-fighting. The authors are now in the process of developing an "Anthropomorphic Robot Hand" which has the form and functions of human hand, and which is a part of the research on a robot hand that is controlled by the master-slave method widely usable in these fields. We developed an anthropomorphic robot hand (Mark-1) which is provided with 22 degrees of freedom comprising the metacarpus, wrist and forearm.

1. FOREWORD

A huge amount of research is now being conducted on robots and manipulators, but only very little research is being done to develop a robot hand which can function like a human hand. One reason is that in the traditional development of the industrial robot, emphasis has had to be put on making the robot capable of grasping and operating on manufactured products rather than on making it duplicate human activity.

In the large-scale project "R&D of Advanced Robot Technology", research is being conducted on advanced robotics for applications in such fields as nuclear power, undersea operations, and fire-fighting. As part of the research on tele-existence technology for the "Advanced Robot Technology" research and development project for intelligent machinery of the future, the authors have been working to develop an anthropomorphic robot hand, that is, a robotic hand which resembles a human hand. In order to research tele-existence technology, a master unit which monitors human operations and gives command signals, a slave unit with anthropomorphic hand and arm, and a controller must be developed. This report discusses the basic concepts of research on the anthropomorphic robot hand, the structure of the anthropomorphic robot hand (Mark-1), whose palm and wrist components have been test made, the master unit and the controller.

2. BASIC CONCEPT OF THE ANTHROPOMORPHIC ROBOT HAND

The anthropomorphic robot is one which performs work instead of humans in dangerous or extremely uncomfortable environments, such as those related to atomic power, undersea operations or fire-fighting. As tele-existence technology is a control method of advanced operability and presence at a remote distance, the research aims to develop a total system comprising master, controller and slave. Research is also progressing in parallel with manipulator on functions of the human head, that is, on the eyes(seeing), the ears (hearing), the mouth (sound producing) and so on. The term anthropomorphic implies that the robot not only resembles the human being in size and configuration, but also possesses functions similar to operations of human activity.

A. Morecki et al 1) explained that the human upper extremity has 27 degrees of freedom, and of these 20 degrees of freedom are concentrated at the hand, especially at the fingers, and the remaining degrees of freedom are distributed over the rest of the extremity from the wrist to the shoulder. In developing a robotic arm resembling the human upper extremity, it is extremely important to confine all joint mechanisms of the hand, especially the fingers, within a limited size and configuration. In addition, the robotic arm must be reduced in weight as much as possible because the human upper extremity is supported only by the shoulder.

In order to overcome the aforementioned obstacles, the following points were considered.

1) Size and weight reduction of the actuator and reduction gears,
2) Actuators should be placed at the forearm, the upper arm, or the body trunk as far from the hand as possible, so that moment at the shoulder and elbow can become small.
3) A pulley/wire method should be used as much as possible for trans mitting drive power from the actuator to each joint of the hand so that maximum weight reduction can be achieved.
4) When the wire/pulley method is used to transmit drive power, there must not be any interference between each degree of freedom.
5) The structural material must be light in weight, and yet strong enough.

Consequently Prototype models 1 and 2, resembling the structure of the human hand have been designed and developed, and based on these results, the anthropomorphic robot hand Mark-1 has been designed and developed.

3. DEVELOPMENT OF AN ANTHROPOMORPHIC HAND MECHANISM (Prototype-1, 2)

The model hand of the slave is of the same size as the human hand and has five fingers; the structure of the four fingers other than the thumb is shown in Figure 1. In the figure, the mechanism for motion in lateral direction of the MP joint is omitted, but in the developed finger model (Prototype-1), one finger has four degrees of freedom. Finger joints are moved by wire drive method. The unique feature of this scheme is that since the wire always passes through the axis of the finger joint, the wire length is kept constant during finger movement and there is no interference with other joints. The DIP and PIP joints are driven by wire in the direction for grasping the object, then returned by a spring for ungrasping. Other joints are driven in shaking motion by wire and pulley. The driving DC motor is equipped with an encoder having a resolution of 300 P/R and an zero position sensor. The developed anthropomorphic hand mechanism of Prototype 1 is shown in Figure 2.

Prototype 2 is aimed at application in many types of industries. It is twice as large as the human hand but of the same configuration, and it has the same number of degrees of freedom as that of Prototype-1. A new design concept was applied to the mechanism for driving the four degrees of freedom of the finger. The structure of the four fingers other than the thumb in Prototype 2 is shown in Figure 3. In Figure 3, cross section A-A shows the center of the MP joint axis. To not make the figure complicate mechanism of two degrees of freedom in a joint are drawn separately. A pulley is installed to the axis of each joint, the actuator is placed near the wrist, and the wire drive method is employed. The wire driving the DIP joint passes through the rotation axis of the MP joint and the wire driving the PIP joint passes through the rotation axis of the MP joint, so none of the joints is affected by the motion of any other joint. Furthermore, the route of wire which executes flexion and extension of three joints including the MP joint, is fixed by guide roller. The three actuators that perform flexion and extension in response to radial flexion or ulnar flexion motions perform bi-directional movement in the direction of the arrow shown in Figure 3; by means of a link mechanism which is a special feature of Prototype 2 the length of wire is always kept constant. Consequently, the movement of one joint does not interfere with the motion of any other joints.

The fundamental model of the master unit (Figure 2), which detects the motion of human fingers and issues command signals, has five fingers, each with two degrees of freedom. Its structure employs the link-type goniometer method. The master is fixed to the palm of the operator's hand by rubber bands, and metal rings are attached to the fingers. Motions of the PIP joint and the MP joint of the finger are monitored.

A controller for the aforementioned hand mechanism was developed and operated experimentally. Shown in Figure 4 are recordings of potentiometer output of the master hand when fingers of the master have been moved by 70 - 80 degrees, and movement of the actuator the slave hand in response to the movement of master hand. Although there was a slight problem in installing the master to the human hand, movement of the slave hand in response to that of the human hand was obtained.

The developed Prototype 2 is shown in Figure 5. Some of the components have been omitted so that the internal structure can be seen. The hand is twice as large as the human hand, so it can grasp relatively large objects as compared with Prototype 1. Concerning the structure of Prototype 2, a wire passes through the rotation axis, and it is confirmed in operational tests that three actuators slide in response to radial flexion and ulnar flexion, and that the wire length is kept constant.

4. DEVELOPMENT OF AN ANTHROPOMORPHIC ROBOT HAND (Mark-1)

Through development and performance test of the prototype hand mechanism whose shape and function resemble those of a human hand, a forearm type anthropomorphic robot arm (Mark-1) which has five fingers and freedom for the wrist was designed and developed.

The Mark-1 is a forearm type anthropomorphic hand having a forearm, a wrist and, like the prototype hand mechanism, five fingers (thumb, index finger, middle finger, fourth finger and little finger). As shown in Figure 6, the Mark-1 is similar in size and shape to the hand and forearm of an adult male. Each finger of the hand has four degrees of freedom.

The thumb can perform not only flexion and extension, but adduction and abduction. The other four fingers perform adduction, abduction, flexion and extension of the MP joint, and flexion and extension of the PIP and the DIP joints. The DIP joints of fingers other than the thumb are designed so as to move in proportion to movement of the PIP joint. The reason is that in the movements of four fingers of the human hand other than the thumb, the DIP joint normally moves in conjunction with the movement of the PIP joint, except for special movements. For this reason, the number of the actuators and the gross weight of the robot arm can be reduced by reducing the number of degrees of freedom. Consequently, whereas there are 20 joints in the hand of the Mark-1, there are only 16 actuators; and the Mark-1 has 18 actuators in total, including two wrist joint actuators.

A pulley is installed at the axis of each joint, and the actuator located at the forearm employs the wire drive method. If the wire drive one joint(e.g. PIP joint) passing through another joint(e.g. MP joint), it has no interference on the movement of this joint(MP joint) because it always passes through the rotation axis of the joint. Moreover, the route of wire from joint to actuator is fixed by a guide roller. In the human hand, one joint can perform both dorsi-flexion and palmar-flexion, at the wrist, but in the Mark-1, two joints for these movements are located as shown in Figure 6 because of mechanical limitations.

The angles of movable range of the fingers and wrist of the Mark-1 hand are as shown in Figure 7. In developing robotic hands and arms, the selection and positioning of actuators is extremely important. In the design of the Mark-1, the weight of the actuators is over 65% of the gross weight; then the methods of positioning and fixine the actuators are the subjects of design. For the Mark-1, a method of positioning was designed so that all the actuators would be located in the forearm. The specifications of the actuators used are given in Table 1. The actuators installed into the forearm have been arranged in a truss configuration opposing the axis of 8 actuators on the wrist side and that of 10 actuators on the elbow side. The wire which transmits power passes through the central portion of the truss of the actuators on the wrist side. The central portion of the truss configuration in the elbow side becomes empty space, so an actuator has been placed for wrist dorsi-flexion and palmar-flexion; that is, 9 actuators are in truss configuration and one actuator is in the center. As reduction gear harmonic drive system is employed and the wire used for power transmission is 0.45mm in diameter.

The developed Mark-1 is shown in Figure 8 and the hand portion of the Mark-1 is shown in Figure 9. For the hand and part of the forearm, a high-molecular material of light weight and low friction coefficient was used as the structural material. In the part of the forearm where relative strength is required, aluminum alloy is used. Furthermore, a new globe equivalent to human skin has been omitted from the figure so that the interior of the hand component can be easily seen. When this globe is put on, the hand looks even more like a human hand in exterior appearance.

The weight of each component of the Mark-1 is shown in Table 2. The total weight of the motors, including the reduction gears and encoders, is 2,180g, and is about 65% of the gross weight of the robotic hand (3340g). When the weight of the forearm component (790g) is added, the total forearm weight is 2,970g, about 89% of the gross weight of the robotic hand. A self-lubricating, and light weight high-molecular material is used for the fingers and no metallic bearings are used. The thumb weighs 45g and each of the other four fingers weights only 29g. The gross weight of the hand component, including wrist joint, thus becomes only 370g, so a large amount of reduction in weight is achieved.

Shown in Figure 10 is a block diagram of the control component of the Mark-1. Two types of master units for monitoring the actions of human upper extremities and issuing command signals were developed: one type uses the above mentioned potentiometer is for the hand component(Prototype-1) shown in Figure 2; the other type uses a strain gauge. The latter type master unit also uses metallic hooks on the rubber band and magic tape. In addition to these master units, a control box was fabricated which enables off-line control.

5. AFTERWORD

We developed the Anthropomorphic robot hand Mark-1, a master unit for operating the Mark-1, a controller, and software for enabling graphic display. In operating the Mark-1 with a master unit that employs a potentiometer, favorable results could be obtained at speeds equivalent to that of useual activities by human beings. Figure 11 shows monitoring display by line drawing of performance of the hand. Although there is a slight problem in the computer processing speed, the monitoring function yielded favorable results.

In the future, efforts will be directed toward developing an anthropomorphic mechanism with sensors, resembling the entire human upper extremity much more closely. Progress will be also made in the development of a master for the entire upper extremity.

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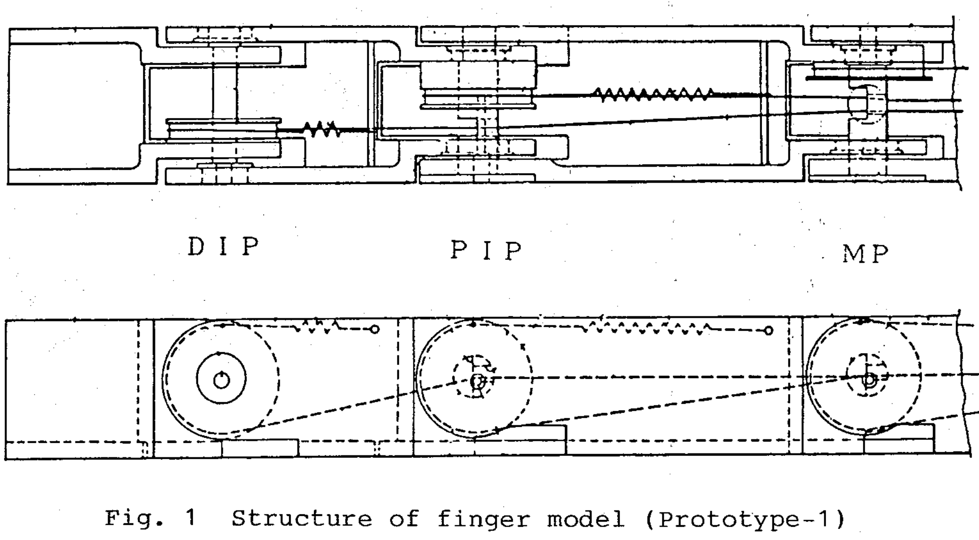

Fig. 1 Structure of finger model (Prototype-1)

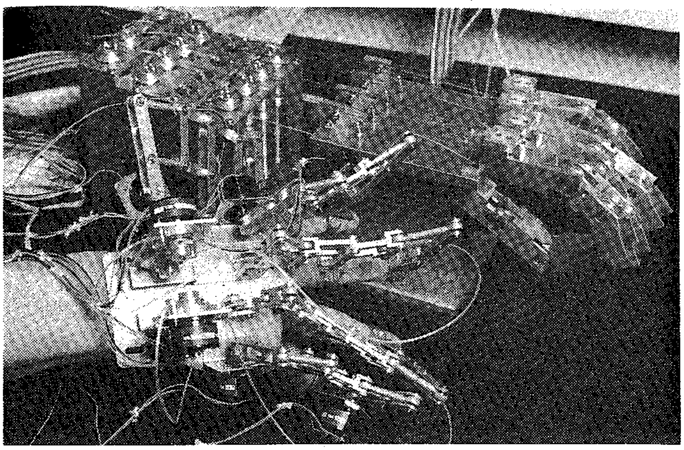

Fig. 2 Master and Prototype-1

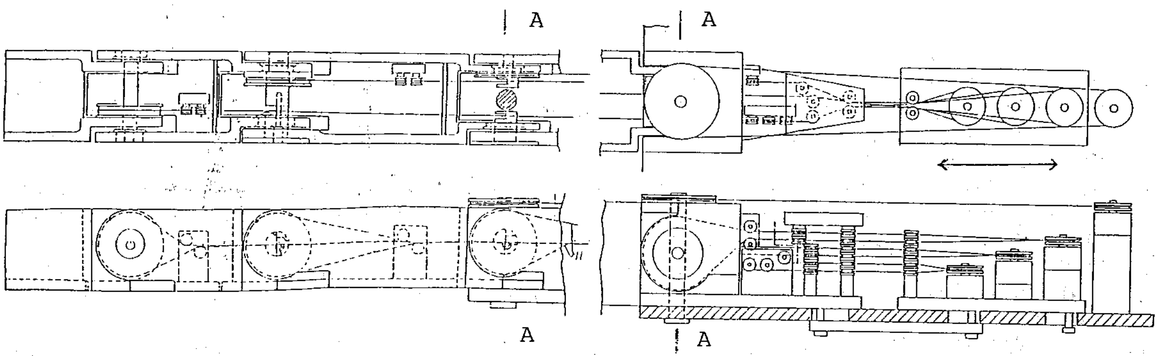

Fig. 3 Structure of finger model (Prototype-2)

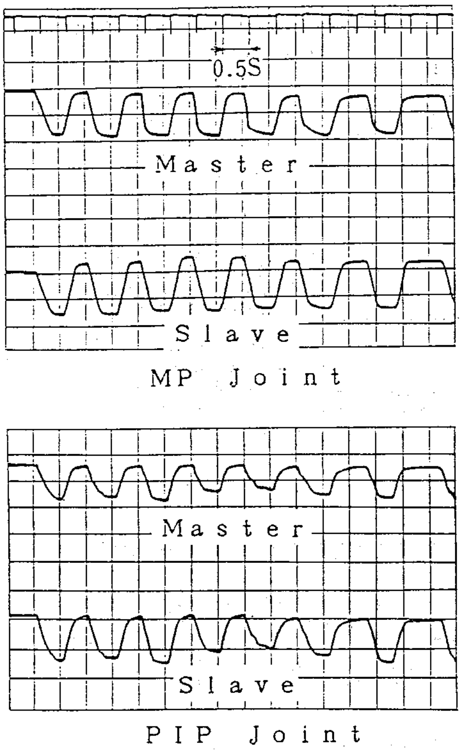

Fig. 4 Data of motion (prototype-1)

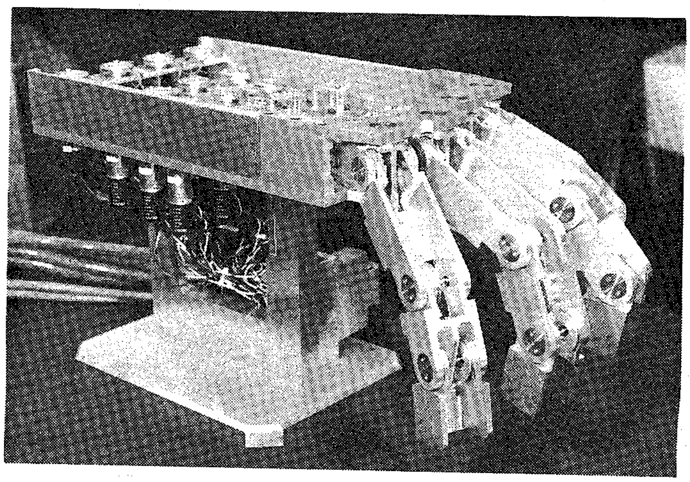

Fig. 5 Finger model (Prototype-2)

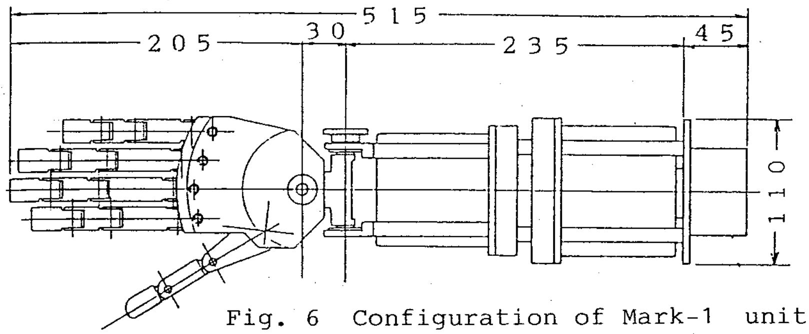

Fig. 6 Configuration of Mark-1 unit:mm

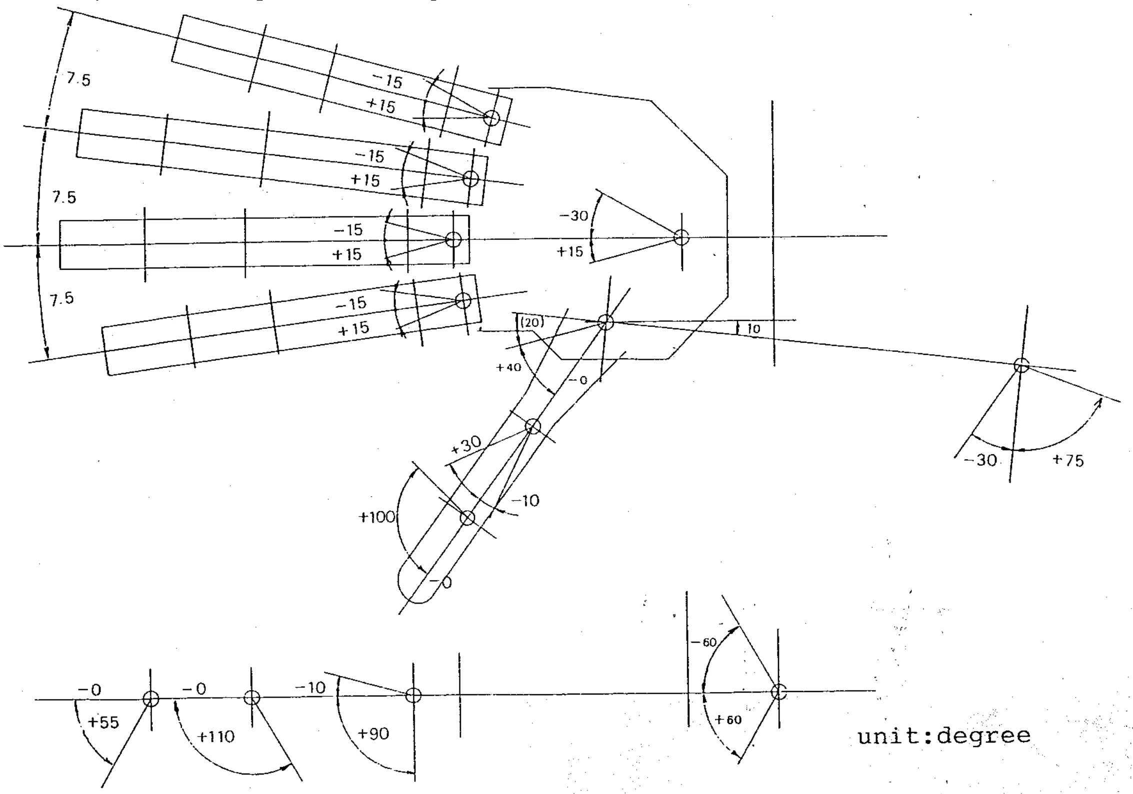

Fig. 7 Operating angle of Mark-1

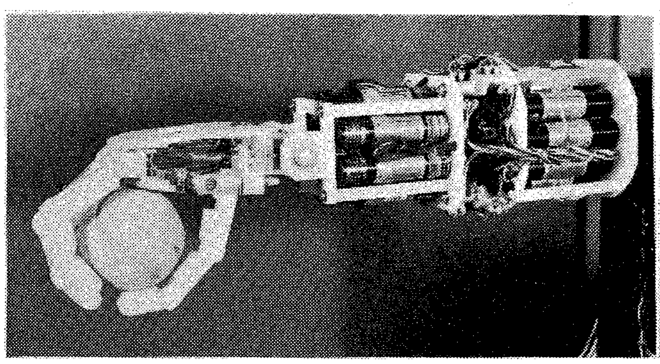

Fig. 8 Mark-1

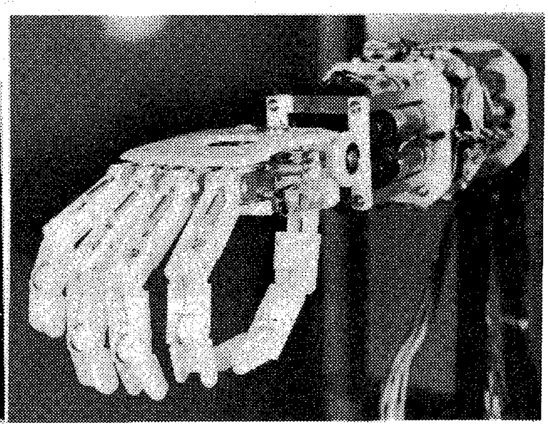

Fig. 9 Fingers of Mark-1

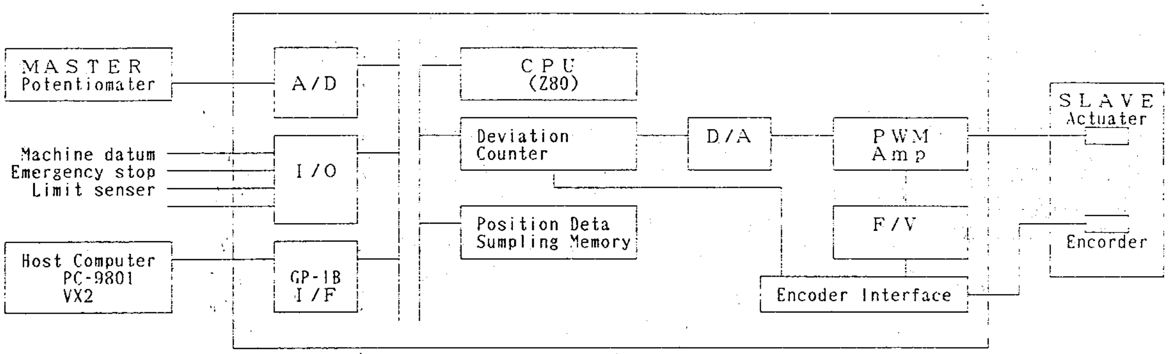

Fig. 10 Block diagram

Table 1 Specification of Actuator

Actuator		Fingers and Wrist[1] Joint	Wrist joint[2]
Rated Output Power	W	1.7	8.6
Rated Output Torque	Ncm	30	140
Rated Voltage	V	12	24
Rated Current	A	0.5	1.0
Rated Output Speed	rpm	55	60
Reduction Ratio	1 : R	1 : 80	1 : 50
Encoder	P/rev	200	200

(1) Radial-Flexion and Ulnar-Flexion
(2) Extension and Flexion

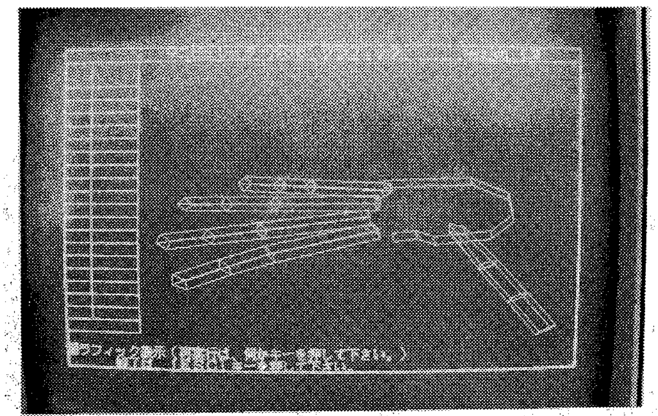

Fig. 11 Graphic display of hand shape

Table 2 Weight of parts
Unit : g

Hand	370
Forearm	790
Actuator	2180
Total weight	3340