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Design of a Humanoid Hand for Human Friendly Robotics Applications

Naoki Fukaya, Shigeki Toyama[a] and Tamim Asfour, Rüdiger Dillmann[b]

[a]Department of Mechanical System Engineering, Tokyo University of Agriculture and Technology, Japan. Email: {fukaya,toyama}@cc.tuat.ac.jp

[b]Department of Computer Science, Institute for Control and Robotics, University of Karlsruhe, Germany. Email: {asfour,dillmann}@ira.uka.de

In this paper the mechanism and design of a new, single-motor-driven hand with human-like manipulation abilities is discussed. The new hand (called TUAT/Karlsruhe Humanoid Hand) is designed for the humanoid robot ARMAR that has to work autonomously or interact cooperatively with humans and for an artificial, lightweight arm for handicapped people. The new hand is designed f or anatomical consistency with the human hand. This includes the number of fingers, the placement and motion of the thumb, the proportions of the link lengths and the shape of the palm. It can also perform most part of human grasping types. The hand possesses 21 DOF and is driven by one actuator which can be placed into or around the hand.

1. INTRODUCTION

Humanoid robots are expected to exist and work in a close relationship with human beings in the everyday world and to serve the needs of physically handicapped people. These robots must be able to cope with the wide variety of tasks and objects encountered in dynamic unstructured environments. Humanoid robots for personal use for elderly and disabled people must be safe and easy to use. Therefore, humanoid robots need a lightweight body, high flexibility, many kinds of sensors and high intelligence. The successful introduction of these robots into human environments will rely on the development of human friendly components.

The ideal end-effector for an artificial arm or a humanoid would be able to use the tools and objects that a person uses when working in the same environment. The modeling of a sophisticated hand is one of the challenges in the design of humanoid robots and artificial arms. A lot of research activities have been carried out to develop artificial robot hands with capabilities similar to the human hand. The hands require many actuators to be dexterously moved [6,7]. However, the control system of the humanoid robot becomes more complicated if more actuators are additionally used for the hand design. This is a key aspect for the artificial arm because a handicapped person might not be able to control a complex hand mechanism with many actuators. For this reason, we propose to develop a lightweight hand driven by a single actuator. To this end we adopted a new mechanism for the cooperative movement of finger and palm joints.

2. HUMANOID ROBOT AND ARTIFICIAL ARM

At the Forschungszentrum Informatik Karlsruhe (FZI) we develop the humanoid robot ARMAR, which will be able to assist in workshops or home environments [1]. The research group of the Tokyo University of Agriculture and Technology (TUAT) developed an artificial arm for handicapped people [3]. The humanoid robot has twenty-five mechanical degrees-of-freedom (DOF). It consists of an autonomous mobile wheel-driven platform, a body with 4 DOF, two lightweight anthropomorphic redundant arms each having 7 DOFs, two simple gripper and a head with 3 DOF. Main focus of our research is the programming of the manipulation tasks of ARMAR by a motion mapping between the robot and the person, who demonstrates the task [2]. Since the robot should support a simple and direct cooperation with the human, the physical structure (size, shape and kinematics) of the arm is developed as close as possible to the human arm in terms of segment lengths, axis of rotation and workspace. The mobile platform is equipped with ultrasonic sensors, a planar laser-scanner, and sufficient battery power to allow for autonomous operation.

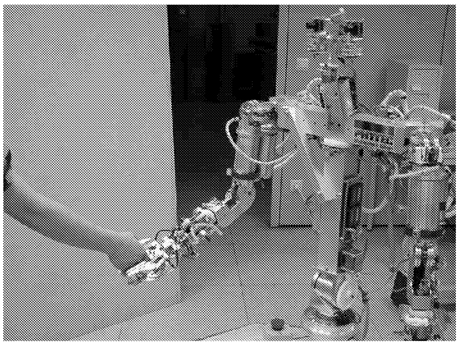

Figure 1. The humanoid robot ARMAR

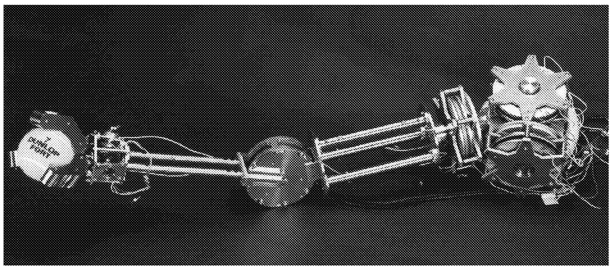

Figure 2. The artificial arm using a spherical utlrasonic motor

We also developed an artificial arm using a spherical ultrasonic motor [3]. The spherical ultrasonic motor has 3 DOF in one unit, which is similar to the human joint [4]. We have also developed a sandwich type ultrasonic motor, it produce twice as high torque output as the same size conventional ultrasonic motor. The arm has one spherical ultrasonic motor for the wrist joint, one sandwich type ultrasonic motors for the elbow and the shoulder joint. These motor are suitable to use for an artifical arm for handicapped people. Consequently, the artificial arm has 7 DOF and represents a good approximation of the human arm. The advantages of the arm are small size, lightweight and high torque at low velocity compared with conventional ones. With a few assignments about output characteristics, it is enough for a handicapped person

3. THE NEW HUMANOID HAND

3.1. Human hand movement

One of the main characteristics of the human hand is the capability of conformably grasping objects with various geometries. Figure 3 clearly shows the typical grasping types of various objects [5].

We do not think about the position of fingers and palm when we grasp objects, because we already know instinctively which position is the best for stable grasp and for saving grasping force. This matter has an important meaning, namely our hand and fingers are automatically moved when we want to stable grasp an object, and the grasping force of each finger becomes even. We simultaneously make adjustments of the position of every finger and of the contact position of the palm. From the above discussion we can conclude that the design requirements for the hand may be satisfied with each finger and the palm acting together in a coordinated group, being independently controlled and making self-adjustment of the position of fingers and palm.

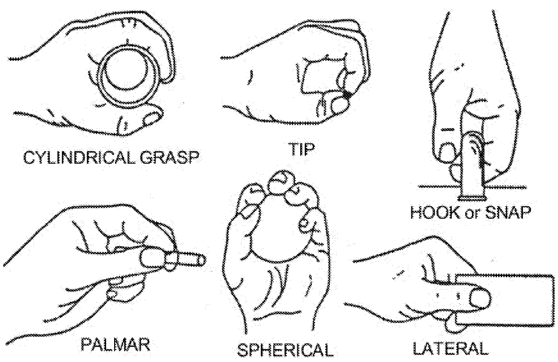

Figure 3. Typical human grasping.

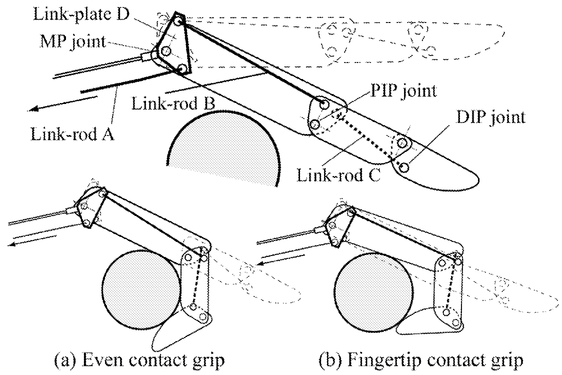

Figure 4. Mechanical works on the finger.

3.2. Study of the grip form

The type of human grip figure 3 shows can be classified into 2 categories: a grip achieved by the fingertips and an even contact grip carried out by the whole surface of the hand (i.e. cylindrical or spherical grip). However the even contact grip may change into the fingertip grip. During some actions like squeezing an object or holding heavy objects, we can observe that the fingertip stays in contact with the object surface by flexing the DIP and PIP joints, while the MP joint remains straight and the middle phalanx leaves the object. The even contact grip needs to flex all the joints of a finger around the surface of the object. Specifically it is necessary for the realization of both grip types that the IP and the MP joints move independently. Figure 4 shows the way this link mechanism works to achieve independent movements of each joint. To grasp an object, the link-rod A pulls the link-plate D and the finger moves and keeps its form. If the proximal part touches an object, the following happens: the link-plate D moves independently, while the middle proximal part is moved by the link B. The link C attached to the proximal part pulls the distal proximal part. Finally, the finger curls around the object with a small grasping force.

We studied this structure by using the mechanical analysis simulator A1 MOTION. It is difficult to analyze the contact condition, therefore we decided to place springs in the center of gravity of each block to represent the contact with the object. The rotational moment M on the link-plate D contains the grip force. P1, P2 and P3 are tensions applied on each spring in order to generate contact force with the object. In the analysis model of the fingertip grip we removed the spring on the middle phalanx because the latter has no contact to the object in this case.

Figure 5 shows the analysis results performed by A1 MOTION. We can observe remarkable difference at P1. The even contact grip is better than the fingertip grip to grasp breakable objects when the rotational angle is small. Indeed when using the even contact grip, P1 decreases as the rotational angle increases and it becomes the half when the angle is 40 degrees.Therefore the fingers might drop the object if the object is heavy. On the contrary in the case of the fingertip grip, P1 increases as the rotational angle increases, therefore it is possible to firmly hold the object.

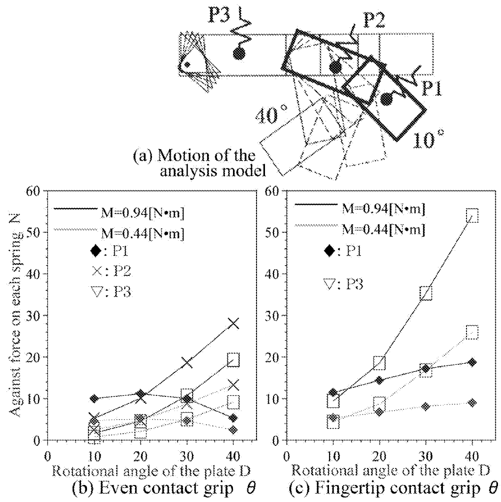

Figure 5. Motion of the analysis model and analysis results

This mechanics has several good characteristics similar to the human being movements and it can automatically change the grip shape in response to the object condition. Therefore it can be very useful to control systems.

3.3. Humanoid hand mechanism description

Based on this research work we constructed an experimental model of the humanoid hand. Its weight is 125 g. We take the size from 27 yeas old Japanese man, his height is 165 cm, and weight is 55 kg. Figure 6(a) shows a clear, rather complex picture of the skeletal structure. We constructed a palm using a ball-joint rod with 2 DOF. The index and middle metacarpal rods are rigid on the base of a plate which is connected to the wrist. The metacarpal rods of the ring and little fingers are free movable like the human palm and are connected with short ball-joint rods like tendons. Thus, each metacarpal joint has 2 DOF (figure 6(b)). The thumb finger has a simple structure: it has only one degree of freedom, which is fixed on the basic plate. The rotational axis is set at an angle of 6.5 degrees to the vertical line of the basic plate. We deem this is sufficient in order to grasp many objects because the hand can already grasp a wide variety of objects if the thumb finger only operates to fix the object position as a fulcrum.

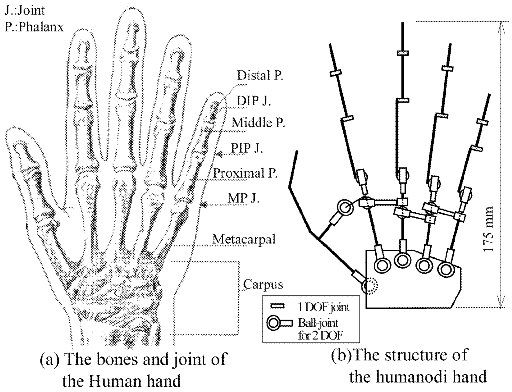

Figure 6. Structure of the human hand and the humanoid hand

Figure 7 shows the linkage system of the finger motion. The four fingers and the thumb finger are connected with some links by the link-plate E to H and every joint is free movable. By using weak springs or rubber bands, each finger can easily return to its index position. Each link starts working by itself with the strain of the link-rod A when the link-rod J is pulled. Every finger will be moved because link-rods A pull each finger through the link-plate D. The link-plate E starts a rotation centered on a joint point of the link-rod A of the little finger when the little finger touches the object to be grasped.

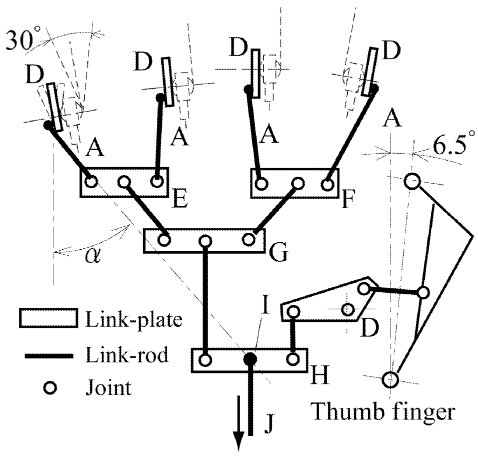

Figure 7. Link mechanism

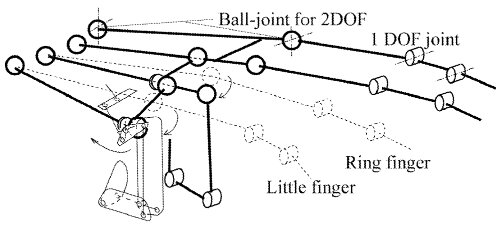

Figure 8. Movement of the palm part

The link-plate G also starts a rotation centered on a joint point from the link-plate E when the ring finger touches the object, while the index, middle and thumb fingers keep moving. Thus, every link keeps being moved by the link-rod J until every finger touches the object. Therefore, each link moves to keep the balance of the strain force on every link when the contact force of some finger becomes suddenly weak. Finally, the contact force becomes evenly again. The link-plate E affects the palm rods towards the object if the ring and little fingers touch the object (figure 8). Since the fingers and the palm are capable of evenly touching the object, a more stable and safety grasping and holding of the object can be achieved. The link-plate D of the index and little fingers is located at an angle α to the link-rod J (figure 7). Therefore, both fingers can grasp the object with an adduct force and it can be touched with the side surface like as a human being.

4. RESULTS AND EXPERIMENTS

Figure 9 shows grasping experiments performed by the humanoid hand with the grasping types mentioned above. It is evident that every grasp type is sufficiently well holding. This shows that the link mechanism, the adduction/abduction function of the MP joints and the palm motion ability are effectively working in grasping and holding the objects. We appreciate that extra devices should be employed in order to accomplish the special cases of the Palmar and Lateral grasps. For instance, it is difficult to execute a pick-up operation of a pen and then to change the grip style, because independent movements of every finger are necessary to change the grip style. However, we retain that it is possible to control easily each finger to a certain extent by using simple devices like an electrical brake or an electromagnet pin control on the link-rod of every finger.

5. CONCLUSION

In this paper we presented the mechanical design concept and experimental results of a new humanoid hand for human friendly robotics applications. The humanoid hand is able to grasp and hold objects with the fingers and the palm by adapting the grip to the shape of the object, through a self-adjustment functionality. The hand is driven by only one actuator. Therefore, it is not necessary to use feedback sensors in the hand because the griping force adjusts the grasp position and the posture of the five fingers. This is greatly useful to simplify the hand control system. As a further result, we confirmed that with the humanoid hand, it is possible to fulfill the demands for typical manipulation tasks of humanoid robots in the human everyday world such as offices, homes or hospitals.

6. ACKNOWLEDGMENT

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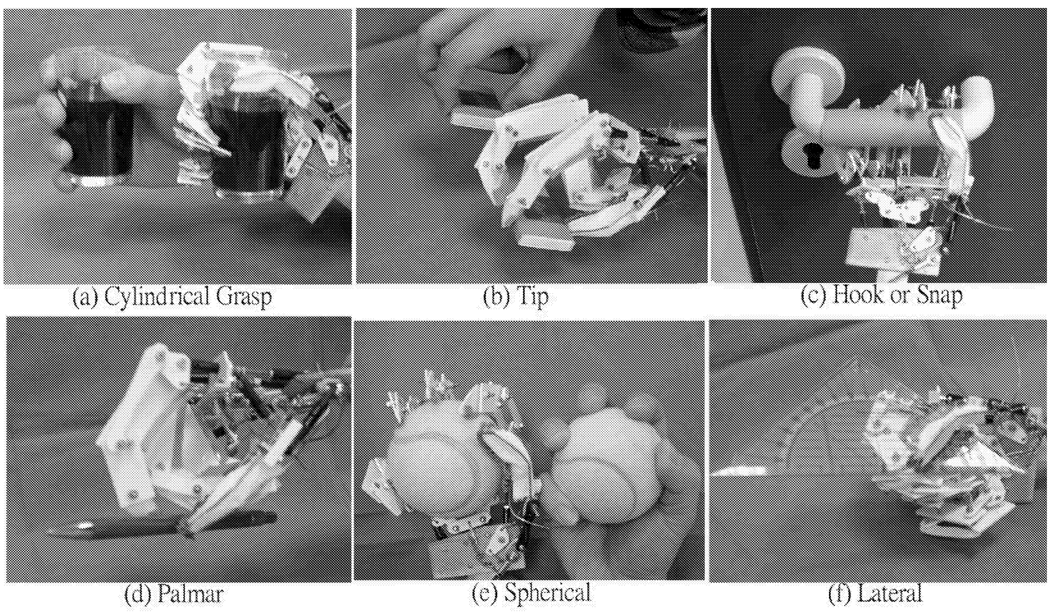

Figure 9. Grasping examination by the TUAT/Karlsruhe humanoid hand