Development of Humanoid Hand with Cover Integrated Link Mechanism for Daily Life Work

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***Abstract*—many people are expecting for robots to support home work. However, in order to actually do such work, it is necessary for the robot to acquire the complex functions of human hands. Therefore, we developed a humanoid type hand that can be used for humanoid robot and prosthetic hand, and verified various actions of daily life to prove its function. As a result, this robot hand could grab eggs and vegetables, pour water into the cup, grasp the plastic wrap and cover the dishes.**

Keywords—robot hand, prosthetic hand; life support robot

I. INTRODUCTION

As represented by cleaning robots, robots acting on household work are gradually increasing. From this, expectations for robots are increasing more and more. Ideally, it would be ideal if work such as preparing meals and drying laundry could be realized, but in order to do so, the robot must overcome many problems. One of big problem is to improve the performance of manipulators. Since the home environments are optimized for the structure of the human body, it is desirable that the robot also fits the environment. However, the hands of conventional robots are insufficient for performing complicated tasks, and even if robot hands have excellent functions, many sensors and large systems and advanced it was necessary to use a program [1,2]. Therefore, we have been developing robot hands that realize various motions of daily life with concise operation using know-how of artificial arm and robot hand [3,4]. By using a unique link mechanism, we called a harmonic link mechanism, this hand can easily realize various operations with a single actuator. However, these link mechanisms are composed of a large number of parts, and simplification of the structure is required for commercialization. Therefore, we developed a structure that integrates the link mechanism with the exterior using a 3D printer. As a result, we have greatly reduced the number of parts and built a robot hand that is lightweight and suitable for living environment.

II. CONVENTIONAL HUMANOID HAND

We have been developing a robot hand that can realize various motions with a single actuator called a TUAT/ Karlsruhe Humanoid Hand. The size of this conventional humanoid hand is similar to that of a human hand [3,4]. Fingers of this hand have a complex link mechanism (Fig.1).

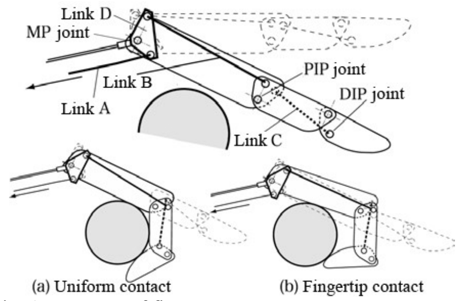

Fig. 1 Structure of finger

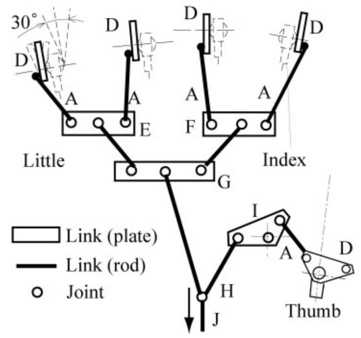

Fig. 2 Link mechanism for operating each fingers

To grasp an object, the link A pulls the link D and the finger moves and keeps its form. If the proximal part touches an object, the following happens: the link D moves independently while the middle proximal part is moved by the link B. Each finger is coupled with link-plates working independently (Fig. 2). Link-plate D turns through a link-rod A when I pull link-plate J. Because link-plate E, F, G and I turn independently, power of motor branches at H and are transmitted to four fingers and thumb. As a result, each finger keeps the contact force's balance automatically. In addition, the function of the palm is important to grasp of a delicate object. Palm of this hand has self-bend function when it tries to grasp an object.

The number of parts of this hand exceeds 300. This is due to the necessity of an exterior for stably gripping an object, in addition to the structural problem of realizing all operations by a link mechanism. The exterior is also an important part to realize a human appearance. This is not only an appearance, it is a necessary function to adapt to various environments and to operate tools.

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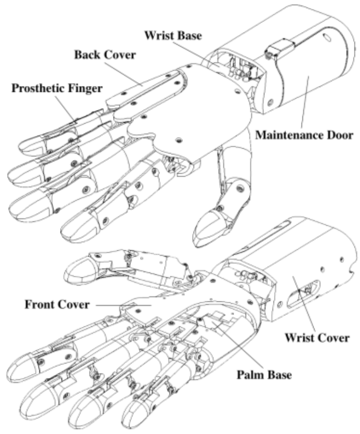

Fig. 3 Structure of F-hand

Fig. 4 Comparison of conventional humanoid hand and F-hand

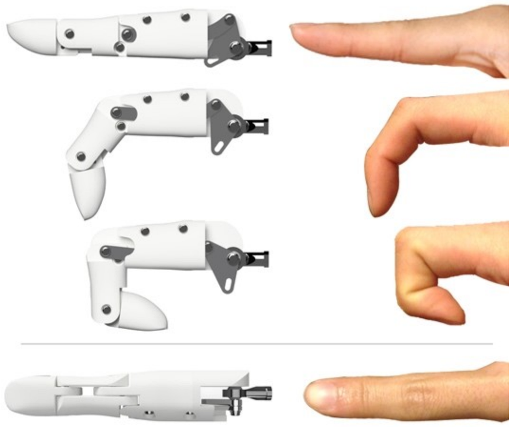

Fig. 5 New design finger of F-hand

TABLE I. NUMBER OF PARTS OF BOTH HANDS

	Index	Middle	Ring	Little	Thumb	Palm	Whole
Con. Humanoid hand	32	32	32	32	63	159	350
F-Hand	24	24	24	24	30	87	213
Reduction rate	75.0%	75.0%	75.0%	75.0%	47.6%	54.7%	60.9%

III. NEW DESIGN MODEL BUILD BY 3D PRINTER

A. Basic Strcture of a New Design Hand

In order for the robot hand to grip the object stably, it is desirable that the finger and the palm contact uniformly. Human hands have meat cushions and realize uniform contact with objects. Also, as everyday objects such as cup or door knob are optimized for the shape of a human hand, it is preferable that the fingers of the robot hand are also close to the shape of this human's hand. In order to realize such a function, we built a robot hand using a link mechanism constructed of metal and a large number of frames, film sheets and urethane gel, so we needed a lot of parts. Therefore, we developed a structure to solve both problems by constructing with ABS and PLA resin by 3D printer (UP Plus2) the exterior itself close to the shape of a human finger with a link mechanism (Fig. 3). All fingers and palm are structured to operate in conjunction with same link mechanism which we shown in Fig. 2, and operate with one motor (Futaba RS405CB). When grasping an object, it is sufficient to instruct the rotation angle of this motor feedforward in view of the size of the object and the task. While realizing the same operation as in Fig. 1, the exterior was integrated to realize a large reduction in the number of parts. The other four fingers also have different length, but the basic structure is the same. The palm is important for stable gripping of objects. For this reason, we constructed a structure in which metacarpals of the ring finger and little finger integrated with the exterior are bent. This hand is hereinafter referred to as F-hand.

Fig. 4 shows a comparison of our conventional humanoid hand and F-hand. All fingers and palm are structured to operate in conjunction with same link mechanism which we shown in Fig. 2, and operate with one motor (Futaba RS405CB). When grasping an object, it is sufficient to instruct the rotation angle of this motor feedforward in view of the size of the object and the task. Fig. 5 shows the behavior of a new design finger. However, since the thumb has a very complicated structure, the MP joint in this model has only one degree of freedom structure like Fig. 1. About this joint, we plan to build it in the future to have the same function as conventional humanoid hand.

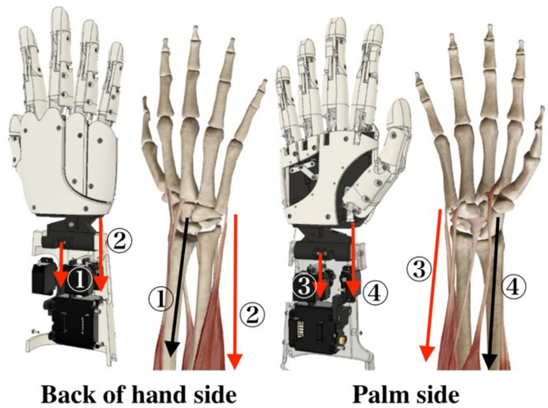

Fig. 6 Structure of wrist joint of F-hand

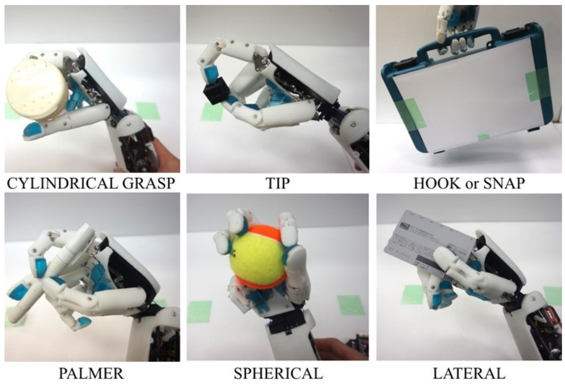

Fig. 7 Six basic holding pattern of ADL by F-hand


(a) Egg (b) Vegetables (green pepper and petit tomato) (c) Pour water into the cup (d) To wear socks (e) Grasp the plastic wrap

Fig. 8 Experimental result of grasping object in daily life by F-hand

B. Comparison of the Number of Parts Between a Conventional Humanoid Hand and a New Design Hand

As an example showing the effect of reducing the number of parts, Table 1 shows the number of parts of each of the conventional humanoid hand's finger and F-hand's finger in Table 1. As shown in Table 1, the number of parts of four fingers other than the thumb having the same structure could be reduced to 75%. As for the thumb, the MP joints are not two degrees of freedom, so there is a big difference in the number of parts, however if we can construct the same structure for this joint as well, the reduction rate of the number of parts is about the same as the other fingers We believe that it will become. n particular, the rate of decrease of palm was large and conspicuous. This is complicated by using many parts to bend the metacarpal born of the ring finger and little finger in the conventional humanoid hand, whereas with the 3D printer, these multiple parts are combined into one It is because it can be put together. As a result, with the whole hand, the number of parts can be reduced to about 60.9% by using 3D printer. By new structures, we were able to drastically reduce the number of structural parts themselves as well as screws and nuts.

C. Wrist Structure with Emphasis on Applicability to the Residential Environment

In an environment where people live, the wrists need to move flexibly. For example, in order to open the door by turning the door knob, it is necessary to rotate the wrist and passively bend and extend the wrist. Also, when a robot's hand hits a person, if the wrist is fixed, it also becomes a factor of big injury. The conventional humanoid hand has been realized such a passive structure, but we have not developed about the wrist structure. So we developed a soft moving passive wrist. For the wrist joint, it was constructed so as to operate in two directions: palmar flexion and dorsi-flexion, radial flexion and ulnar flexion. As for the motion, we adopted the structure which antagonizes with two actuators (E-max ES08MDII) like human. Since the shape is prioritized and a small motor is used, the output is as small as 0.16 Nm, and the work that can be done at the present time is mainly light work (Fig. 6).

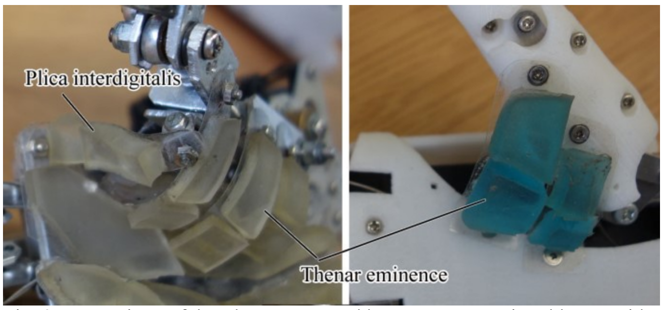

Fig. 9 Comparison of thumb structure and between conventional humanoid hand and F-hand

IV. Experimental results

A. Grasping Typical Objects Under the Living Environment

An experimental result of F-hand is shown in Fig. 7. In order to confirm the operation of the hand, we made six typical daily lives, and we were able to do it without problems. And then, we tried to experiment of grasping various objects in our daily life. We grasped the fragile raw egg, vegetables, tableware such as cups, clothes such as socks and plastic wraps (Fig. 8). Everything was easy to carry out, but it was not possible to manipulate tools such as pliers or kitchen knife. This is due to the fact that it was impossible to build a complicated and flexible structure of human hand such as a soft palm, plica interdigitalis (first web space of hand) and thenar eminence like conventional hand with 3D printer.

B. Effects of the Plica Interdigitalis and the Thenar Eminence

Fig. 9 shows thumb part of the conventional humanoid hand and the F-hand. In our conventional humanoid hand, urethane gel cushions and film sheets were used to construct a plica interdigitalis and thenar eminence. Although these part are rarely used in conventional robot hands, it is important parts for stabilizing the gripping of a plier, a kitchen knife and the like [4]. We could not make such a part in F-hand because we could not produce such a structure demonstrating flexibility and strength with our 3D printer. For this reason, F-hand could not stably grasp these tools as compared with conventional robot hands. Also, since the MP joint has one degree of freedom, the thumb of F-hand could not fully operate scissors and chopsticks. This is because the structure of the thumb is quite complicated, so we could not build a satisfactory structure with 3D printers at the moment.

C. Evaluation of 3D-printed Humanoid hand's functions using Kamakura's Taxonomy

In order to confirm the influence due to the lack of a structure such as a flexible sheets and urethane gel cushions possessed by a conventional humanoid hand, we used a Kamakura's taxonomy once used again [4,5]. As a result of verifying the grasping ability of F - hand for Kamakura's taxonomy, we could realize all 14 kinds of grasping movements with conventional robot hand, but F-hand could be done only 11 kinds (Fig. 10). The achievement rate was 78%. The action which could not be grasped is 3 actions of grabbing kitchen knives (Pos), operating scissors (PoD), operating chopsticks (T-III). The reason why the scissors could not be

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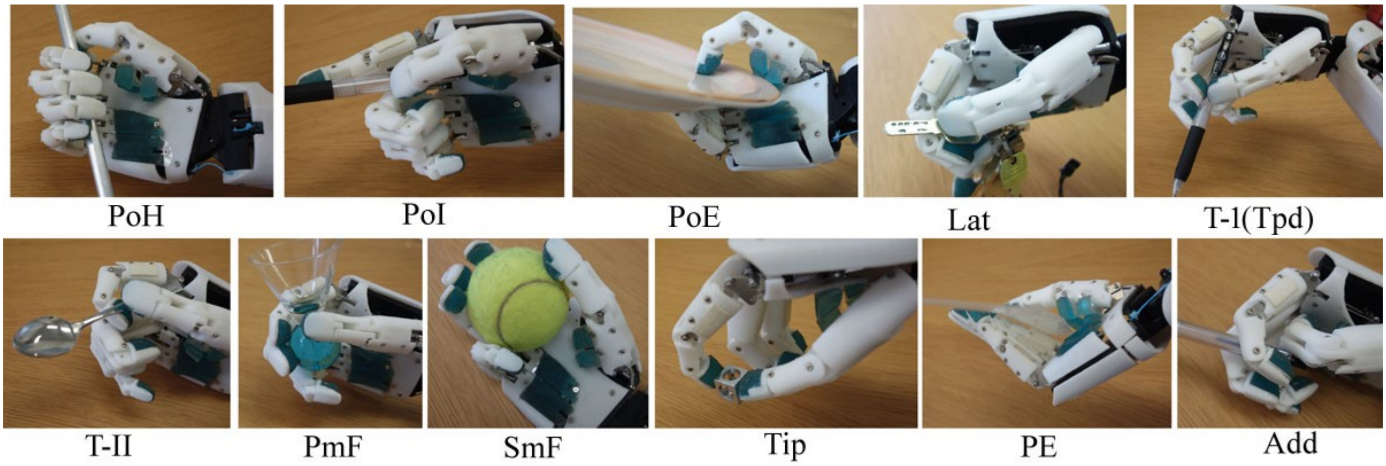

Fig. 10 Experimental results of Kamakura's taxonomy with F-hand

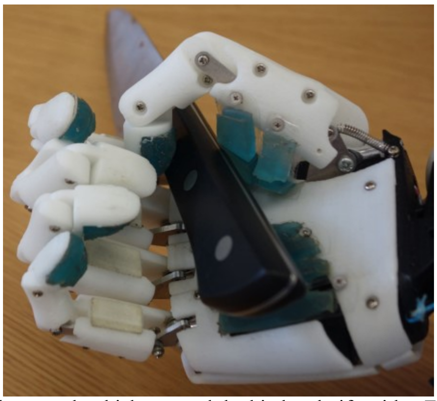
Fig. 11 Failure result which grasped the kitchen knife with a F-hand (surface of the palm and the thenar eminence does not lift and so many gaps were made and it was not able to contact stably against the knife. The biggest problem is the plica interdigitalis.)

operated is because the MP joint of the thumb has only one degree of freedom, but the reason why the other two movements could not be done is because the thumb finger and palm do not function sufficiently. Fig. 11 shows the situation when grasping the kitchen knife with F-hand. You can see that there are many gaps between palm and kitchen knife. In the case of a human being, when the palm skin, plica interdigitalis and thenar eminence are raised and brought into contact with each other, such gaps are eliminated, and stick-like objects like knife handle can be stably gripped. However, as this model was constructed with a 3D printer, the palm was hard and because it was poor in flexibility, it was not able to stably hold the knife handle.

V. CONCRUSIONS AND FUTURE WORKS

Humanoid hands we have developed have been constructed with over 300 parts. And it was manufacturing by researchers who have special skills, knowledge and experience. For this reason, it was difficult to accurately duplicate hands with the same performance. Therefore, we tried to develop a new hand which can greatly reduce the number of parts and simplify the structure by using 3D printer which is excellent in shape reproducibility and can freely produce complicated parts. As a result, it became possible to reduce the number of parts to 60.9%. Moreover, since it became possible to reproduce parts easily with high precision, it became easy to prepare many prototype models easily. However, our 3D printers could not produce flexible parts, so some of the gripping actions that were possible with conventional hands could not be reproduced.

Therefore, we plan to respond to these problems by using a 3D printer that can print flexible materials in the future. We also believe that if we can build a structure for converting the MP joint of the thumb to 2 degrees of freedom with a 3D printer, we can further improve the grasping ability. For people who dislike appearance like a robot, if this robot hand attaches a cosmetic glove like human, the size looks unnatural because it is too large. When using the robot hand for such use, it is necessary to develop a slim structure.

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