DeMaMech 2005

Report

Yutaro Takahashi

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1. Personal Data

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Supervisor	Prof. Dr. Takeshi Maeno

2. Executive Summary

As my name suggest, I am Japanese. I have Japanese parents and therefore the Japanese nationality. I was born however, in the Netherlands, and spend my life living in the Netherlands. I visited Japan a couple of times for a short vacation, but I always wanted to live in Japan for a longer period. The DeMaMech Exchange Program gave me the opportunity to fulfill my wish. I stayed in Japan from the 24th of March until the 26th of September and joined the BioRobotics Laboratory of professor Maeno during that period.

The BioRobotics Laboratory of prof. Maeno, or Maeno-lab is part of the Mechanical Engineering department of the Faculty of Science and Technology of the Keio University. In that laboratory, I did my research on robotic hands. My objective was to design and build a prototype of a five-fingered underactuated dexterous hand. Underactuation means that the hand has less actuators then joints. Dexterous means that the fingers adjust to the grasped object.

My research included the trajectory of problem analysis, literature survey, (computer aided) design and fabrication. There was, however, a difference in thinking and designing methods between my home university (Delft University) and hosting lab.

The prototype that was built has five fingers with three phalanges each. The hand is made to be actuated by one actuator. The actuator is connected to the thumb and to a mechanism that equalizes the forces over the remaining four fingers. Each finger is cable driven. Different pulley diameters in the finger joints are used to obtain a more equal force distribution over the phalanges.

The finished prototype however did not function as was expected. Little inaccuracies during fabrication resulted in too much friction. Correct finger motion was confirmed for the fingers each, but not for the whole hand.

My life in Japan can be called typical for a Japanese master student, which means in my opinion, long days at lab, joining lab activities and having drinking parties with friends once in a while. On the other hand, I did not have an job or many social obligatories. Instead, I did some typical Japanese things like going to Kabuki(Tradition Japanese theater), Taiko(Traditional Japanese drums) and Sumo wrestling.

During my stay, I had a lot of discussions about Japanese culture with many people like my labmembers, my professor, fellow exchange students, relatives, Japanese friends, drunk people in izakaya and last but not least, my Dutch girlfriend. Hearing theories from foreigners and explanations from Japanese, together with my prior knowledge about Japanese culture formed my view on Japanese. I feel that I understand Japanese much better then I used to, still I realize that my understanding only involves a little part of the whole Japanese culture.

3. Travel Schedule

To Japan:

24 March 2006 (Arrival in Tokyo, 25 March 2006)
British Airways

Schiphol Airport, Amsterdam	–	Heathrow Airport, London
Heathrow Airport, London	–	Narita International Airport, Tokyo

From Japan:

26 September 2006
British Airways

Narita International Airport, Tokyo	–	Heathrow Airport, London
Heathrow Airport, London	–	Schiphol Airport, Amsterdam

4. Research

4.1 Introduction

The hands are the main tools for humans to physically interact with their environment. With its multiple degrees of freedom and high dexterity, the hands are used to perform many functions concerning grasping and manipulating objects. Grasps can roughly be divided into power grasps for firm and robust grasps and precision grasps for fine manipulation.

A lot of research is being done to develop a robotic hand with the same functionality as the human hand. This results in complex prototypes with many actuators and sensors, requiring a large amount of control effort. However, for many applications, the artificial hand only needs to perform power grasps and no fine manipulation is required. It is confirmed that underactuated dexterous grippers can be used to perform firm power grasps with large reduction in control complexity. With careful, task-oriented mechanical design, cheap and lightweight design can be achieved.

The objective of this research is to design and build a prototype of a five-fingered underactuated dexterous hand (from up the wrist) with human proportions, which is able to perform power grasps on apples and tomatoes.

The hand will be lightweight and have human proportions to make the hand applicable as prosthesis. The human-like shape will make the hand fit in the long term research goal of building a biologically inspired humanoid robot.

4.2 Design

To reduce control complexity, the robotic hand will be actuated by one actuator. This part will discuss the design of three essential parts in the robotic hand: the design of a finger, the design of a mechanism to equalize the forces in all four fingers (flexion mechanism), and the design of the extraction mechanism

Finger actuation
The mechanism for actuation of a finger is shown in figure 1. Figure 1a shows the mechanism for flexing the finger and figure 1b shows the mechanism for finger extension. When force T is applied on the mechanism, the cable tension will be equal over the whole cable length. However, due to the different pulley diameters, the torque on each phalange is different. The torque for extending the finger is equal for all phalanges. With the proper choice of pulley diameter, the closing sequence and the force distribution over the phalanges can be determined.

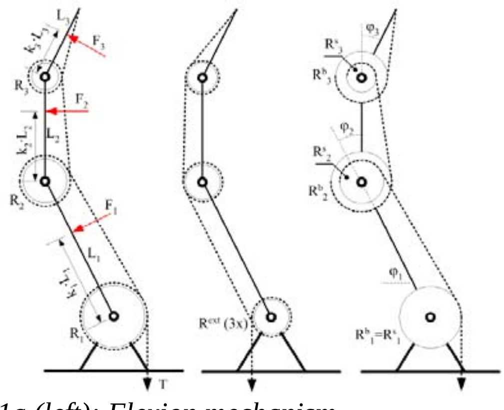


Figure 1a (left): Flexion mechanism
Figure 1b (middle): Extension mechanism
Figure 1c (right): Alternative flexion mechanism

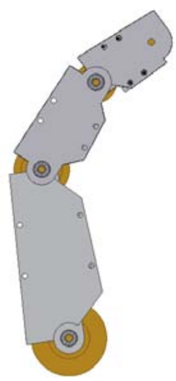


Figure 2: CAD drawings of designed finger

For manufacturing reasons an alternative flexion setup, the double pulley setup that is shown in figure 1c will be used. This setup has the same force characteristics as the setup of figure 1a, but the pulleys can be kept larger.

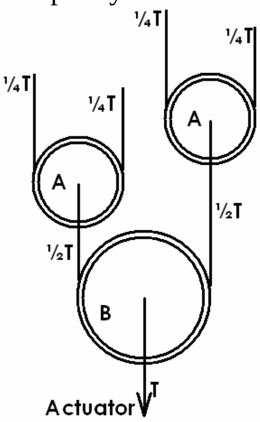
The actual design is shown in figure 2. The finger is dimensioned according to a two dimensional optimalization done by Schuurmans [1]. The length distribution of the phalanges are [0.5:0.3:0.2] from proximal to distal. The flexion pulleys have diameter [22, 6.8, 14.2, 4.6][mm] from proximal, middle inner, middle outer to distal. The extensions pulleys have all a diameter of 10 mm.

Force equalizer for four fingers

In order to keep the number of actuators small, the four fingers of the hand (excluding the thumb) will be controlled by one actuator. The amount of force has to be equal for all fingers, but the position of fingers can vary. Therefore, a mechanism is needed to apply the same amount of force on each finger, without fixing the position. The mechanism proposed is shown in figure 3.

All pulleys can rotate and translate in vertical direction. The actuator applies a tension force T in the direction shown. Pulley B will equalize the forces applied on the pulleys A. Pulleys A are connected to the fingers by cables. When the applied tension force is T and the friction is negligible, the force on the pulleys A is 0.5 T and the force on the fingers will be 0.25 T.

Because of the small available space, the pulley configuration is slightly changed for the actual design (figure 4). The two pulleys on the bottom of the figure have fixed positions.



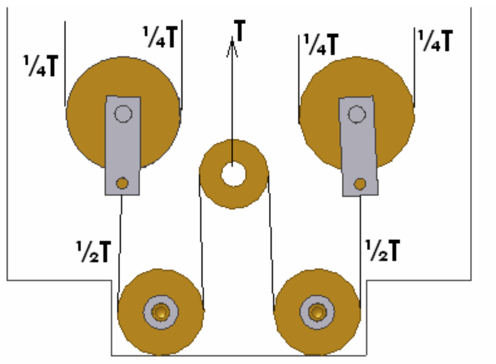


Figure 3: Mechanism to evenly distribute forces over four fingers
Figure 4: CAD drawing of mechanism to evenly distribute forces over four fingers (reconfigured)

Extension mechanism

The extension mechanism has less strict requirements than the flexion mechanism. The difference is that for flexion the finger motion is force controlled. The extension mechanism is position controlled. Therefore it is not needed to vary the pulley diameters for the extension pulleys (figure 1b), and there is no need for a force equalizer. Instead, all extension cables are connected to one axis. A schematic representation of the extension mechanism is given in figure 5.

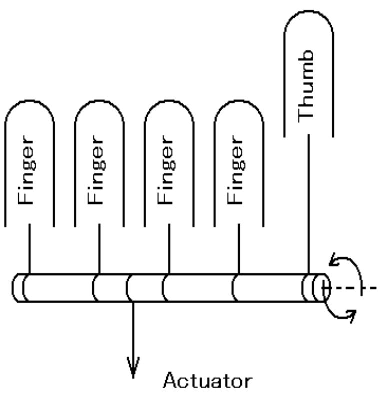


Figure 5: Extension mechanism

A CAD drawing of the whole hand is shown in figure 6. The hand has 4 fingers and a thumb, and contains the force equalizer and the extension mechanism.

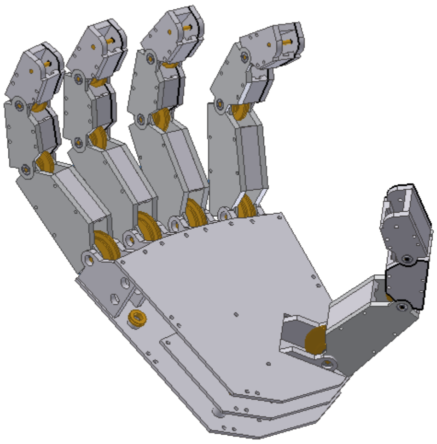


Figure 6 CAD drawing of robotic hand

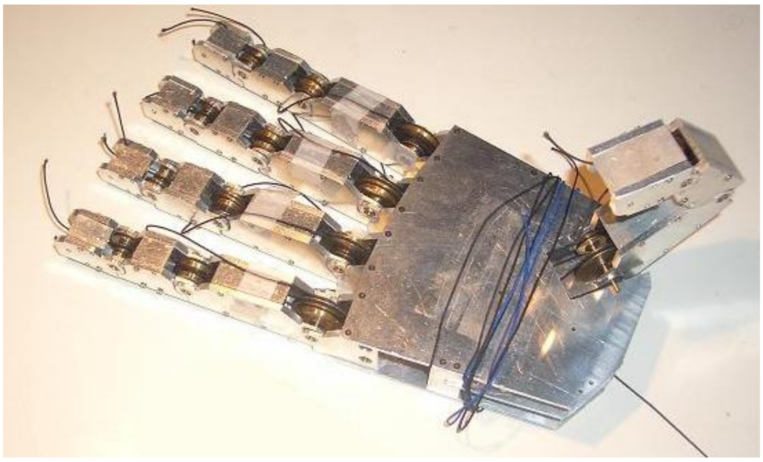


Figure 7: Fabricated prototype

4.3 Prototype

The prototype was build with the machines available in the laboratory. These machines included a CNC milling machine, a normal milling machine, a jigsaw, a lathe and a drill. The pulleys are made off brass, the cable is made off nylon and the other parts are aluminum.
A picture the fabricated hand can be seen in figure 7.

4.4 Conclusion and Discussion

A prototype was designed and fabricated. The prototype has 5 fingers (4 fingers and a thumb), all finger with 3 phalanges each. The hand is designed to be actuated by 1 actuator, and therefore underactuated. It is cable driven with the principle presented by Hirose and Umetani [1]. The hand has the proportions of a big human hand.
However, the hand did not work as expected. Due to mistakes in the design and fabrication irregularities, friction occurred. This friction was different for each finger and had a large influence on the closing sequence of the fingers, as well on the closing sequence of the phalanges. Therefore, the actuation cables were not connected onto the actuator and the grasping performance could not be tested.

To enable testing of the prototype some adjustments have to be made. The adjustments are aimed to reduce friction. There are two main groups of friction in this prototype. One is the friction of the phalanges at the point of rotation. The two side plates of the phalanges are fabricated with an CNC milling machine and have a negligible error. The two plates connecting the two side plates are less accurate and at some phalanges, the axis of rotation of the two side plates do not coincide. Forcing the two side plates to rotate around one axis results in an angled axis of rotation, causing friction with another phalange while rotating. This can be solved by refabrication of some of the connecting plates. Other friction is caused by the wire. The parts of material that causes the friction with the wire can be removed by rasping.

The prototype weights 450 grams without actuator. One of the most common Otto Bock prosthetic hand weights 470 gram. In order to make the prototype attractive as a prosthesis, the hand needs to be redesigned. Mass reduction can be achieved by reducing the thickness of the finger plates. The thickness of plates of the fingers are 3 mm. For most parts, this plate thickness can be reduced to 1.5 mm or 1 mm. On some of those parts, the acting force is so low that different materials like acryl can also be considered for further mass reduction.

For a second prototype not only mass reduction should be considered. In a practical point of view, the robustness of the hand should be increased. The cable fall of the pulleys very easily. In other words, the reliability of the hand is very low and it is time consuming to put the cable back on the pulley.
To prevent the cable to fall of the pulley and thus to assure the correct working of the hand, there should always be some amount of tension in the cables. The present prototypes loses tension at the switching point between flexion and extension. In order to keep tension in the cable, the extension mechanism should be revised.

It is also advised to make the grooves of the pulleys a little wider and deeper. The thickness of the nylon cable was not taken enough into consideration by the first prototype. A wider and deeper groove in the pulleys should increase the robustness of the hand.

As a future plan, it might be useful to reconsider the placement of the fingers and hand dimensions. The dimensions of the fingers are based on a two dimensional optimalizaion for a two fingered gripper. For a gripper with more than two fingers, the optimalization should be done in three dimensions. This will inevitably lead to more variables, amongst some of then are really vague variables like humanlikeness. However, optimalization of the angle between the fingers and the placement of the thumb could result into improvement of the grasping performance.

Although the hand did not work as expected, working on the prototype gave me much insight and feeling about the topic. This is the advantage of the research at the BioRobotics Laboratory of Keio university. There is much freedom and you have to make most of your decisions yourself. Afterwards, the decisions that you had taken sometimes turn out not to be the most logical ones. You will however really develop your own way of researching.

References

[1] J. Schuurmans. Optimization and design in underactuated robotic grasping. February 2005

5 Exchange Student Life

The day that I arrived, my tutor and two other labmembers picked me up from the station. After taking me to the dormitory, they immediately took me to lab. They gave a key of the lab, a password for computer access, they assigned me a desk and I had an opportunity to speak with the professor. The first thing that I noticed was the amount of trust and freedom that was given me. The professor said to me that I could come to lab whenever I wanted and if I needed some time to get used to the time difference and new environment, I was allowed to stay away for one week or even more.

This freedom is in my opinion typical for research at Keio University. The professor approves most ideas as long it is interesting, new and realistic. Also the budget is sufficient to obtain most hard-, or software that is required for the research. Only the lab-sessions were obligatory. If you can handle this freedom, Japan is a very nice place to study. For me it was hard to make my own schedule and to keep my own deadlines. The professor is available for advice and guidance, but is usually quite busy. Therefore most problems are solved together with other labmembers.

The lab is a place to do research. Student will enter a lab in the last year of their bachelor (4^{th} year => B4 students). The choice of the lab is usually based on the professor leading the lab and the research done at the lab. The BioRobotics laboratory of professor Maeno had 19 students.
A student stays at the lab for one or three years, depending on if the student quits after his bachelor or continues with his master. The B4 students are guided through the research process by a tutor who is a first year master student (M1). A second year master student (M2) is available for help for both B4 and M1 students. Passing on knowledge is considered very important. It even happened a couple of times that an already graduated student(OB) comes to lab to explain parts of research or how to use some software. More then in Europe, time is spend in helping other labmembers. Also during the obligatory labsessions, where a student has to give a presentation about his progress, the other students are encouraged to give comments and feedback. Therefore, most feedback and guidance is obtained from other labmembers, rather then from the professor, who is more a supervisor of the whole process.

The lab is also a place for social labactivities. There are weekly sportsessions, drinking parties, eating parties, lab trips, etc. In a way, the lab is a second home for students. Most students stay at lab for 10 till 12 hours a day on average for six days a week. It is always open and there are always people. Although research is central, students sometimes also eat, read comic books, play games and sleep at lab. For example , the Maeno lab has a water boiler, a microwave, a refrigerator and some blankets, enabling students stay in the lab for a couple of days when they are really busy.

For me, I never stayed in lab for sleeping. That was because the dormitory was very close (less than 10 minutes walking distance). The dormitory was very fine. The resident managers were very friendly, the rooms were clean and well equipped and both the university and the train station were within walking range. All rooms had their own refrigerator, air conditioner, telephone and fast internet connection. The kitchen, toilet, bath and shower was shared with one house mate. I had a really nice house mate, so sharing was not a problem, in contrary, I enjoyed the contact with my house mate. Although the air conditioner was quite essential for night rest during the hot, humid summer nights, the other equipment was luxury when considered that the room was mainly used for sleeping and showering. The kitchen was seldom used, because eating was usually done at the university, or somewhere else.

Eating is an essential part of Japanese culture. Each prefecture has one or two food specialties. For example, when I said to my labmembers that I would go to Kyoto, they advised me to eat Tsukemono and Kaiseki ryori (traditional Japanese menu). When I told them I would go to Sendai (in the North), they advised me to eat Gyutan (Beef tong) and Kaki (Oysters) and when we went to Nikko for lab trip, we all ate Yuba (soya milk curd) because it was a regional specialty. Besides the regional specialties, there is also the normal Japanese food, like sushi, ramen, Yaki-tori, shabu shabu, etc. There is also foreign food like fastfood, steak, pizza, pasta, paella, indian food, etc. The large variation in food made every meal something to look forward to. An appealing Japanese concept that I would like to mention is the izakaya. An izakaya is something in between a bar and a restaurants, where portions of food can be ordered to eat while drinking. The portions are shared with the whole group, so going to an izakaya with a large group results in eating a lot of different food.

The izakaya is excellently suited for drinking parties. Most izakaya's have 'nomihoudai', which means all-you-can-drink, for a certain amount of time. Students often take the 'nomihoudai' to get drunk in a not too expensive way. Usually, a nomihoudai drinking party is accompanied with drinking games, which results in large alcohol consumptions in a short time. This inevitably leads to drunk groups and openhearted talks within the group, but strangely interaction with other (drunk) groups rarely occurs. Working people usually do not take 'nomihoudai' since they are supposed to have enough money to drink better alcoholics without too much haste. However, in Japan, your glass is supposed to be filled by others. Drinking and getting drunk is therefore a real group process, playing a important role in group bonding. My Japanese uncle even said: ”In Japan, business is done during drinking!”.

6. Remarks/Summary/Conclusion

Looking back to my period in Japan, I can say it was a wonderful time. It really feels strange to be back. In Japan, every day felt special. People are very different. They act different, they dress different and even think different. It is a nice experience to live a life in a different culture then you are used to. You realize that there are more ways of thinking and that not one of them is necessary right or wrong.

The Japanese culture is also very deep and broad. Although I did many things, like going to Sumo, Kabuki, Taiko, Karaoke, clubs, playing soccer and softball and made some touristic trips within Tokyo, Yokohama and went to Kyoto, Osaka, Nikko and Sendai, there are also plenty of things that I still want to do. Looking back, it all seemed only blink of a second.

Studying in Japan was also very nice. For me, my laboratory was a great motivation and the way of studying at the BioRobotics Laboratory of professor Maeno was very appealing. Everybody in the lab really act as a group and are eager to help you. I felt very comfortable in the laboratory, also because the lab is always open and there are always people. I prefer to wake up late, and stay working until late. It was all possible.

I am sure that I will go back to Japan someday...

Remarks for students going to Japan

Studying in Japan means a lot of freedom. Be prepared for that freedom. It is useful to know what you want to do by forehand. Finding a research topic can be quite time consuming. Most labmembers are very helpful, but only when you ask them for help. They can do something for you, but important decisions during research have to be taken by yourself. With a good preparation, you will be able to enjoy Japan much more!