DeMaMech: Study Report

Exchange student life in Holland and Belgium

From 1st Sep 2004 to 31st Jan 2005

Osaka University

Akio Morita

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2. Executive Summary

I studied in Technical University of Delft from 1st of September 2004 to 3rd of January 2005. I worked on the research about "Design of a compensation mechanism for voluntary closing hand prosthesis". Though I worked alone till the beginning of October, Emanuele Antonucci, an Italian exchange student, cooperated with me to deal with the same project from the middle of October. Since then, we worked together and gave presentation about our work for 4 months in the monthly meeting of Man-Machine-Systems on 21st of December 2004.

Besides this research, I took several courses in TU Delft, "Introduction Man-Machine-Systems", "Biomedical Engineering Design" and "Intermediate English Course". In the course of Introduction Man-Machine-Systems, the researchers or PhD students introduced their research. I could broaden my knowledge about various kinds of applications. Biomedical Engineering Design consists of two parts of lectures. In the former, the teachers just gave us the lecture, and we had to design a specific prosthesis with group mates in latter part. We gave the presentation of our idea about the prosthesis twice.

Apart from study, I played football as a member of an official amateur team in the Netherlands. I played every weekend and did training every Tuesday and Thursday. Since I should communicate with the local Dutch people with Dutch language, I took Dutch language course once a week from ING group. ING Group is an international community in Delft.

I stayed in Leuven from 3rd of January to 31st of January. I belonged to the department of production engineering, machine design and automation. I studied about Electroactive polymer actuator there. On arriving at Leuven, the University registration office was closed because it was still in holiday. I worked o n the design a setup for the measurements of the simple characteristics of IPMC (displacement and force). And I tested whether the actuator is promising or not.

Apart from study, I stayed with foreign exchange students in the same flat for the first time. I could get knowledge of other culture people not only in Belgium but all over the world

<Travel Schedule>

T.U. Delft: from 1st of September 2004 to 2nd of January 2005

K.U. Leuven: from 3rd of January 2005 to 31st of January 2005

3. Research and Lectures

(T.U. Delft)

"Design of a Cosmetic Glove Compensation Mechanism"

<Introduction >

In prostheses design three key requirements play fundamental roles: comfort, controllability and cosmesis. The voluntary closing hand prostheses which are dealt with in this research have the main advantage over external powered devices; intuitive controllability. However, the voluntary closing hand prostheses are not still common in the market of this application because of poor cosmesis. For example, the Lite Touch hand by TRS (shown in Fig. 1), company from United States, made the voluntary closing hand of which the hinge and the operating cable are visible. For attacking this issue, flexible covering, and cosmetic gloves are needed in order to improve their appearance. Implementation of them does not come without further problems. In facts, these gloves counteract the movement of the prostheses fingers with non-linear force that make trouble with the proprioceptive feedback with the prostheses. Therefore design for the mechanism which can balance the elastic part of the glove counteraction is to be the purpose of the present research.

We, from now on, define the glove characteristic as the moment of the elastic force from the glove with respect to the thumb axes as a function of the thumb opening angle. The problems of glove characteristic are the non-linearity of their own hysteresis and different characteristics.

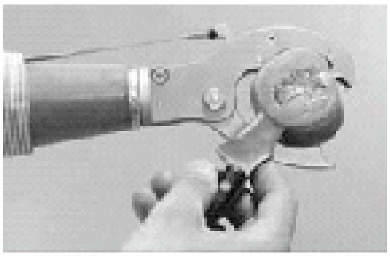

Fig. 1 Voluntary Closing Hand (TR

Fig. 2 Glove characteristics which we must design torque and angle of thumb

The statically balanced system is supposed to be sufficient for compensation mechanisms. Especially four bar linkage with spring mechanism should be useful because this mechanism is able to generate the torque which increases progressively.

<Four bar linkage>

(1) Concept of four bar linkage for compensation mechanism

The four bar linkage which we deal with for compensation mechanism is shown in Fig.3 schematically. We should point out that several methods exist for the synthesis of four bar linkages, from the historical Hrones & Nelson book to modern computer techniques. Nevertheless, all these methods are oriented to problems different from the one we are willing to solve. The classifications of the methods are; function, motion, and path synthesis methods. None of the categories fulfilled out needs, thus a different approach should be taken for analysis of four bar linkage. What we have to do is to find the configuration for fit with the glove characteristics.

Due to the various restrictions (position, spring stiffness, length and so on), we find the configuration by trial and error.

Fig.3 Four bar linkage for compensation mechanism Fig.4 Four bar linkage

(2)Analytical calculation

The four bar linkage is shown in Fig.4. Each joint of the four bar linkage is defined as 1, 2, 3, and 4 counter clockwise from left bottom point respectively. The joint 1 is connected with the thumb, thus the moment of the link between joint 1 and 2 (M) should be calculated. Note that the spring is not ideal spring, but real spring. M is

$$M = k \cdot (l - l_0) \cdot \frac{\sin(\theta_4 - \beta)}{\sin(\theta_4 - \theta_3)} \cdot \sin(\theta_2 - \theta_3) \cdot r_2 \qquad (1)$$

where k is spring stiffness, $\beta = \arctan[\frac{c + r_4 \sin\theta_4}{b + r_4 \cos\theta_4}]$, $l = \sin\alpha \frac{\sqrt{b^2 + c^2}}{\sin(\theta_4 - \beta)}$, l_0 is initial length of spring.

The moment M can be calculated based on two angles θ_3 and θ_4. These two angles can be calculated with Newton-Raphson method. The vector loop equation of the four bar linkage provides the set of functions that defined the two unknown link angles θ_3 and θ_4.

$$f_1 = r_2\cos\theta_2 + r_3\cos\theta_3 - r_4\cos\theta_4 - r_1 = 0$$
$$f_2 = r_2\sin\theta_2 + r_3\sin\theta_3 - r_4\sin\theta_4 = 0 \qquad (2)$$

where f_1 and f_2 are vector loop equations.

<Design the mechanism>

(1) Space constraint

The dimensions of the operating mechanism are very important factor for design. Roughly measurement on an existing closing hand prosthesis for toddlers resulted in an area of about 40mm and 30mm. And the presence of the real spring is also is to be considered. The real springs are standardized and have rest length and the limitation to be taken into account. Therefore the range of the spring is depended on the configuration as shown in Fig. 5.

The real extension spring can be selected from Tevema's catalogue.

Fig. 5 Limited area for spring attachment

Fig.6 The selected mechanism

(2) Selected mechanism

From the afore-seen considerations, Fig. 6 shows the selected layout for the mechanism in the initial and final positions and the dimensions of the mechanism. The mechanism should be as simple as possible, to meet the dimensional constraints and of course to make possible the match between the glove characteristics. Our approach is based on considerations on the glove characteristics and on the simulated characteristics for the balancing mechanism.

(3) Regulation

In order to adjust the compensation spring characteristic to the glove, we should know how the regulation parameters can influence the characteristics of compensation mechanism. The length of linkage, the attachment position of spring, and can be regarded as the regulation parameters shown in Fig.6.

(length of linkage)

We change only r2 and r3 when the total length (r2+r3) is constant 28mm. The moment of the thumb is shown in Fig.7 when r2 changes from 12mm to 15mm. The largest moment is when r2 is 15mm.

(stiffness of spring)

With the catalogue of extension spring from Tevema, we selected the three springs. These springs' stiffness (k) are 5.27N/mm, 24.56N/mm, and 30.06N/mm. The moment is shown in Fig.8. The largest moment is when k = 30.06N/mm.

(position of spring)

Fig. 9 shows the moment when the position attached with linkage changes; horizontal line on linkage1 (b = 8, 10, 12 mm), and vertical line on linkage1 (c = 8, 10, 12 mm). The largest moment is when b (and c) is 12mm

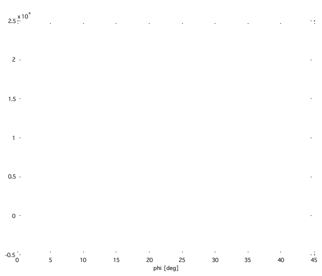

Fig.7 length of linkage

Fig.8 spring stiffness

(a) horizontal line

(b) vertical line

Fig.9 position of linkage

<Decision of final configuration>

The sum of the two lengths of linkage remain constant, that is to say r2+r3=28 mm. The final configuration of the mechanism is kept the same as above. When regulating the mechanism, the overall potential energy required to compensate for the glove elasticity is calculated. This will be equal to the area beneath the characteristic curve. Once done that, a configuration of the r2/r3 links is selected in order to provide the same amount of energy through the scope of the mechanism. Finally, the attachment point of the spring is positioned along a rail in order to match the torque required at the top of the curve.

The rail is shaped in such a way that the potential energy provided by the four bar through is motion is independent from the attaching point of the spring, as long as this point lies on the rail. Fig.10 compares the simulated resultant torque from the compensation mechanism with the given glove

Fig.10 simulated torque and glove characteristic

characteristic.

(K.U. Leuven)

"Electroactive Polymer Actuator experimental data"

<Introduction>

In recent years, Electroactive polymers are investigated by many researchers because they have a lot of attractive characteristics. They are lightweight, inexpensive and soft, and have low excitation voltage. Since they behave similar to biological muscles, they are called 'artificial muscles'. The aspects of EAPs which is similar to that of animals and insects can lead to design some innovative applications in medical and engineering area.

Generally, EAPs can be classified into two categories based on their activation mechanism: electronic and ionic. The electronic polymers require high activation fields (>150V/μm). However, they can be made to hold the displacement under activation of DC voltage, so that they are useful for robotic applications. For instance, piezoelectric polymer (PVDF and PVF2) can be obtained commercially. On the other hand, the ionic polymers require drive voltage only 1-5 V. However, it is needed to be in wetness.

IPMC (Ionomeric Polymer-Metal Composites) is focused on in this report. IPMC bends in response to an electrical activation as a result of mobility of cations in the polymer network. A relatively low voltage is required to stimulate bending in IPMC, where the base polymer provides channels for mobility of positive ions in a fixed network of negative ions on interconnected clusters. There are two types of base polymers which are used to form IPMC: Nafion (erfluorosulfonate) and Flemion (perfluorocarboxylate). This report focuses on the IPMC which consists of Nafion membrane and Platinum as electrodes on its surface. Measurements are performed to find out how the IPMC can be applied for many kinds of applications. In order to know the characteristics of IPMC, at first, the bending displacement and the force were measured under a low voltage. Subsequently, the time dependent behavior of IPMC was measured simply.

<Ionic Polymer-Metal Composites>

IPMC as bending actuators and sensors are referred to as 'soft actuators-sensors' or 'artificial muscles'. IPMC consists of a polymer membrane and metal electrodes plated on both faces. The polyelectrolyte matrix is neutralized with an amount of counter-ions and to balance the charge of anions fixed to the membrane. When an IPMC in the hydrated state is stimulated with a small voltage, both the fixed anions and mobile counter-ions are subjected to an electric field. Only the counter-ions are able to diffuse toward one of the electrodes charged negatively. As a result, the composite undergoes a bending deformation toward the anode. The schematic principle of such a bending mechanism of IPMC is shown in Fig.1.

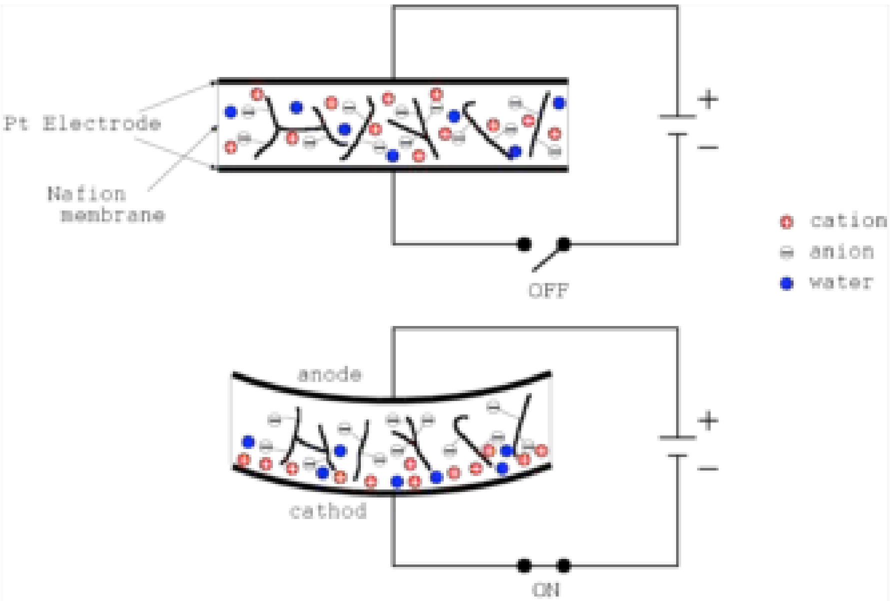

Fig.1 Schematic of bending model with migrating cations due to an imposed electric field

The IPMC strips were composited with a Nafion membrane and Platinum as electrodes. Nafion is a perfluorinated polymer that contains small proportions of sulfonic or carboxylic ionic functional groups.

<Experiment (static situation)>

In this section, the aspects of electroactivation of IPMC are presented. The displacement and the force of a sample IPMC of Enivironmental Robots Inc. are measured when this polymer responds to applied voltage. These experimental data are shown in this section as a fundamental characteristic of IPMC.

(A) Theory

(1) Displacement

IPMC bends when it is subjected to a voltage between the electrodes. The displacement is divided into two parts, electroactivation and IPMC's own weight. The displacement from only electroactivation can be measured as the difference between the current position and the initial one without any voltage.

(2) Force

The force is calculated by the mass which can keep shape of IPMC staying initial position as $F_e = Wg$ where F_e is the force fro electroactivation, W is mass of loading weight and g is gravity.

(B)Experimental setup

In order to determine the aspects of electroactivation, IPMC strip was set up as a cantilever-shaped actuator. IPMC bends when subjected to a voltage between its electrodes, and then the tip displacement can be measured by the ruler. On the other hand, the force can be measured when loading weight keeps the tip of IPMC strip staying the initial position. In this experiment, I measured all data every 30 seconds after applied voltage changes.

This IPMC of which thickness t is 0.3mm and width w is 6.5mm has parameters of where is the second axial moment of IPMC.

(1) Young's Modulus

Young's Modulus of IPMC can be calculated from experimental data. The displacement is measured directly based on some weights without any applied voltage. The displacements were measure 5 times by 5 kinds of weight.

The displacement with a single load f_w is derived as $f_w = \dfrac{Wgl^3}{3EI_y}$. Thus, the difference between two displacements Δf can find Young's Modulus of IPMC as described $E = \dfrac{(F_1 - F_2)l^3}{3\Delta f EI_y}$.

where F_1 and F_2 are the force when loads are W_1 and W_2 respectively.

The Young's Modulus are calculated by the difference of displacement between neighbors as shown in Table 1, where $l = 25.4mm$.

Table1 Young's Modulus

(E1-2)	418.3 [MPa]
E2-3	763.9[MPa]
E3-4	702.8[MPa]
E4-5	798.6[MPa]

Ave E2-5	755.1[MPa]

E_{1-2} is especially different from others. All data were measured by the ruler of which resolution is 1.0mm. I calculated the Young's Modulus as the average of data except E_{1-2}.

(2) Result

The experimental data are the distribution of 5 measurements.

(a)Displacement

The tip displacement of IPMC is shown in Fig. 12 when applied voltage changes from 0V to 4V.

(b) Force

The force was measured with loading weight which kept IPMC straight. The force is shown in Fig. 13 when applied voltage changes from 0V to 4V.

From Fig.13 the biggest force was 10mN. Therefore, the applications need to be designed accordingly and limited.

Fig. 12 Tip displacement vs applied voltage

Fig.13 Force vs applied voltage

<Experiment (dynamic situation)>

Fig. 14 shows how the tip displacement changes for 3 minutes after input voltage 4V is applied. The experimental data include 3 measurements.

The slow movement of the tip displacement are observed and there is no relaxation after bending toward anode. Herewith, the counter ion should be a large cation. The tip of IPMC was still bending 3 minutes after the applying voltage. The material of which response is very slow is not useful for applications.

Fig.14 The response of IPMC

4. Exchange student life

Football is one of the most popular sports in Europe. I wanted to communicate local people in the Netherlands, so I decided to take part in a local football team. I was a member of the football team of Osaka University, so, the difference between teams of Osaka and the Netherlands is also my interest. Anyone can play football in any club teams in the Netherlands. There are no official school teams different from Japanese school.

TU Delft has a sport center, where everyone can enjoy many kinds of sports. If you are a student, you can play more than 40 sports after paying 50 euro for one year. I belonged to one football club in the sport center, Ariston80's, which has seven teams and one woman team. This club is now at the 4th class in national amateur league in the Netherlands. I played the official match every Saturday and did training every Tuesday and Thursday from 20.00 o'clock. Many of the teammates have their own work and therefore we always do training in the evening. The most different part of football in Japan and in the Netherlands is an environment. The facilities for sports in the Netherlands are very good, for instance, I played always football on the grass ground, while on the soil ground in Japan. Not only the field where the Netherlands is better than Japan, but also that there are locker rooms, shower rooms, and a bar next to the every soccer ground. Why can they keep them being good conditions? The reason is that every team has its own sponsors. You can see a lot of advertisement of the sponsors in the pitch side of the ground, on the uniform, bag and so on. Dutch people really like a football.

I could play official amateur football league. I had a lot of opportunities to communicate with Dutch people. From these experiences with Dutch teammates, I am describing the personality of Dutch people. Dutch people are very lively and always talk to someone even he/she is a stranger. With such character of them, I could play with them easily as soon as I got to the Netherlands. Other character of them should be that they have unyielding opinion. The Dutch people always did their best performance earnestly for everything though they play only the small game, running, and training. Thus, they are very excited in the official game. They sometimes have a very big quarrel with opponents in the match of football. They really wanted to win.

If we win the match, they are very excited. The atmosphere after winning the game was very good. The Dutch people try to enjoy everything truly. There is a specific Dutch word "gezellig". The meaning is something like cozy. It is not completely same. I could experience "gezellig" through the football. The atmosphere in locker room after training or the match was very comfortable. The football in the Netherlands was my precious experiences.

5. Suggestions to the Project

It was too short that to complete one task for the project. I arrived at Leuven on 3rd of January2005 though the school was opened in the daytime; the registration office was closed because the New Year's holiday was till 10th of January. I suggest that I should have made my plan more clearly before coming to Leuven. If you make plan to go to Leuven as a second University for short time, you should consider about registration. And all students of Leuven are very busy because they have to take examination in January. I couldn't spend much time with Belgium students. Most of the students studied in their own home or library, so that the opportunities which I can communicate with Belgium students.

There are a few constant working spaces for the master students in Delft. The system of laboratory in Europe is different from Japan. I often saw some students who wrote master thesis in the shared computer room. However, you have a lot of opportunities for discussing with foreign students. There are many courses as group works.

6. Summary

From 1st of September to 31st of January, I studied in TU Delft .and KU Leuven. The research theme was different from my research in Japan. However, thanks to supervising from Prof. Plettenburg in TU Delft and Prof. Reynaerts, and also the discussion about design of compensation mechanism with my research fellow, Emanuele Antonucci, I could study a lot of knowledge for mechanical engineering.