Report
on the
DeMaMech EU-Japan Exchange Program
2004 – 2005

Paarthiban Purushothaman

Contents

1. Personal Data and University Information

1.1 Personal data

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1.2 Home institute information

Faculty: Machine and Transportation Systems
Department: Mechanical Engineering
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Konstruktionstechnik und Entwicklungsmethodik
Fakultaet fuer Verkehrs- und Maschinensysteme
Strasse des 17.Juni 135
D-10623 Berlin
Germany

Supervisor: Prof. L. Blessing

1.3 Host Institute Information

Faculty: Science and Technology
Department: Design Engineering
Lab: Ohnishi Lab

Address: Keio University
Department of Design Engineering
Faculty of Science and Technology
Hiyoshi 3-14-1, Kohoku
Yokohama 223-8522
Japan

Supervisor: Prof. K. Ohnishi

2. Executive Summary

After being accepted as a member of the *DeMaMech* exchange program in spring 2004, I had to choose a host university and host professor in two weeks. After choosing Prof. Ohnishi in the department of system design, I contacted the international center of Keio University to receive the certificate of eligibility for my visa application and to arrange accommodation in a dormitory. In the meanwhile, I also booked a flight to Japan and contacted my host lab in Japan.

In September, I attended a two-week preparation seminar at the Technical University of Delft in the Netherlands. We heard lectures about history, culture and industry of the Netherlands and Japan and took part in a beginners' Japanese course. In the end, we also prepared a report about our expectations of life and work in Japan. This seminar introduced us to the Netherlands and also prepared us for our stay in Japan.

After arriving in Japan, getting over my jetlag and going through registration formalities in the university and the city hall, I started work in the lab. My professor advised me to look into the current projects in the lab in detail before choosing a topic. I spend the first few weeks reading literature on motion control and examining the projects of my lab-mates in the fields of bilateral control, biped walking, vibration control, etc. Since I was specialized in design, I had a lot to learn in the field of motion control. First, I reviewed some fundamentals of motion control while learning the C++ programming language. Then, I programmed a simulation in C++ to simulate the bilateral control of two linear motors with force feedback using PD control together with a "disturbance observer" technique. By the time I finished programming the simulation, my understanding of motion control had increased, and I had understood some of the peculiar problems in motion control.

After some time, I decided to contribute to the research goals of the lab by redesigning a mechanism with control performance improvement in mind. One of the mechanisms in Ohnishi Lab, which was used to test control algorithms for bilateral control with force feedback, could not be controlled due to various problems in the mechanical design. I decided to redesign it completely, using a different mechanical structure and improving details such as joints and bearings.

In the next step, I analyzed the existing mechanism to understand its advantages and disadvantages and to derive requirements for a new mechanism. Then, I developed a concept for this new mechanism. At this time, I also learned to work with the CAD software SolidEdge® and the word processing software LaTex® in the Japanese language. After presenting my concept to my professor, I designed it in CAD. I tried to use catalogue parts as far as possible and made my parts easy to manufacture. I learned how to order parts from companies using web order systems, telephone and fax, which was a good opportunity to improve my Japanese.

With my CAD design almost finished, I started making parts in the university workshop. Since I had had very little experience operating tool machines, I asked the mechanics at the workshop to teach me how to use them. Besides learning many words and expressions in Japanese, my skill increased with every part I made, even though I made some mistakes once in a while. I learned to use band saw, milling machine, turning machine, and drilling machine as well as many tools used to handle metal. Experience in manufacturing parts led to changes in the design, and finally, after a few months, I was able to assemble the structure. It worked quite well, with static balance, reduced friction and reduced play.

In the lab, I presented the results in Japanese and gave suggestions for further improvements. Unfortunately, I was not able to perform experiments with actuators and a control program. However, my professor was pleased with the mechanism, and another student is currently continuing to work on the mechanism I designed. On August 8, 2005, I returned from Japan with the technical drawings of all parts and assemblies, a technical report on my project as well as photographs and a movie of the mechanism.

3. Travel Schedule

3.1 Trip to Tokyo

Departure from Berlin	05.10.04	
Flight SK1676	Berlin (Tegel)	→ Copenhagen
Flight SK0983	Copenhagen	→ Narita (Tokyo)
Limousine Bus	Narita	→ YCAT (Yokohama City Air Terminal)
Arrival in Yokohama	06.10.04	

3.2 Return trip to Berlin

Departure from Yokohama	08.08.05	
Limousine Bus	YCAT	→ Narita
Flight SK0984	Narita	→ Copenhagen
Flight SK1677	Copenhagen	→ Berlin (Tegel)
Arrival in Berlin	08.08.05	

4. Technical Report

Mechanical Redesign of Bilaterally Controlled Forceps Robot for Control Performance Improvement

4.1 Introduction
All robot systems consist of mechanical, electronic and control components. Weaknesses in one of these areas limit the performance of the entire robot system. For example, even a good control system cannot substitute for a bad mechanical structure. This research focuses on the improvement of the mechanical structure of a bilaterally controlled forceps robot in order to improve control performance. In this research, an existing master robot is analyzed to identify weaknesses in the mechanical structure. These weaknesses lead to requirements for an improved design concept. The functions of the robot system are analyzed to visualize energy and signal flows in the robot system. A new design is proposed on the basis of the requirements and the function analysis. Then, the merits and demerits of the design are discussed. Finally, work remaining to be done is described.

4.2 Requirements for new design
To be able to find an optimal solution for the redesign of the forceps robot, design requirements for the task have to be clarified. The research goals of the institute, the shortcomings and problems of the existing robot and working experience with the existing robot yield design requirements.

Figure 1 shows the existing robot with four degrees of freedom (DOF). The master consists of a mechanism, actuators and sensors. The mechanism includes a cage connected to three linear actuators through universal joints (parallel mechanism). The cage can move back and forth horizontally (DOF1). The parallel mechanism enables two rotational degrees of freedom. A slider-crank mechanism inside the cage used to open and close the slave forceps is connected to a fourth linear actuator. The actuators are stationary.
The advantage of this mechanism is its low moving mass. However, there are many disadvantages which lead to difficulties in control:

- complicated kinematics and dynamics
- high joint play and friction
- lack of static balance in the structure

Figure 1: Master, Actuators and Slave Forceps

The mechanism is parallel, which makes kinematics and dynamics complicated. Even if the operator moves the handle in only one direction, the shafts of all other actuators move as well. Joint play creates redundancy in the structure and makes small motions impossible to control. Friction increases energy loss and makes it more difficult to accurately control the slave and feel force feedback, especially if the friction is not reproducible to a certain extent. Due to the lack of static balance in the structure, the handle falls on the table as soon as the operator lets go. Therefore, gravity compensation is needed in the control system which increases the complexity of the control system and calls for larger actuators.

From the disadvantages presented above and the geometry of the existing robot, the following requirements can be derived:

- 4 degrees of freedom:
- translation on x-axis ±20 mm
- rotation on y- and z-axis ±30°
- master scaled to typical human hand dimensions
- easily controllable kinematics and dynamics
- no redundancy in mechanism
- low play in mechanism joints
- max. force applied by human hand: 40N
- max. force feedback: 40N
- statically force balanced structure
- high stiffness in mechanism
- low friction in mechanism

These requirements form the basis for a new design.

4.3 Analysis of Forceps Robot System

The forceps system includes five main elements: human operator, master, computer, slave and environment. The human operator manipulates the master. The master measures and sends kinematic data to the computer which uses it to control the movement of the slave. The slave receives control information from the computer and converts external electrical energy to manipulate the environment. The environment resists this manipulation through reaction forces which affect the movement of the slave. The computer evaluates kinematic data sent by the slave to calculate control commands as well as force feedback values for the master. The master uses electric energy to give mechanical force feedback to the operator, who in turn uses the resistance he feels to adjust his operating movements.

The robot is required to have four degrees of freedom (DOF). In the current design, the movement of the actuator for each DOF is a function of the movement of all the DOF of the operator. The current mechanism is redundant due to joint play, thereby causing additional unpredictable movements which do not move the actuators. If the movement of each actuator depends only on the movement of one operator degree of freedom, it would be a major improvement.

4.4 Working Principles

To fulfill the function of the robot master mechanism, working principles have to be chosen from the wide array of available possibilities. This section describes the reasons for choosing the particular combination of working principles in the proposed mechanism.

The actuator transforms electrical energy into mechanical energy to apply a controlled force on the robot mechanism. This function is fulfilled by feedback controlled electric motors, which can supply mechanical energy in two forms: rotation and translation. Motors with different working principles are used as actuators in robotic applications. It follows from the function description that the following criteria should determine the choice of the best motors for each actuator.

- energy conversion quality
- controllability
- suitability for force application on the mechanism

After considering all the possibilities available for actuators, therefore, a subset of these has been chosen to bear in mind while designing the mechanism. The working principle used is that of the AC linear motor and brushless DC rotational motor.

Mechanisms are used to transform and transmit movements and forces from one system to another. The master mechanism should connect the operator with the master actuators in such a way that the quality of movement and force transformation is as high as possible. All working principles used for these conversions must have the property of back drivability for the purpose of force feedback and should be as simple as possible.

From the different solutions available for force transformation and transmission, the ones most likely to achieve maximum performance must be chosen. Different common mechanisms likely to be used were considered taking advantages and disadvantages into account. For this project, friction gears and slider-cranks are considered for use with linear motors because they seem to be least prone to disturbances. For rotational motors, either a direct drive (without transmission mechanisms) or a combination with the harmonic drive is considered because of its high gear ratio. The friction gear is also a feasible solution for the rotational motor. These combinations are used to prepare a conceptual solution for the forceps robot.

4.5 New Design Proposal

This paper proposes the following design as an improvement of the exiting design. *Figure 2* shows the complete mechanism assembly modeled in the 3D-CAD program Solid Edge. It is composed of the

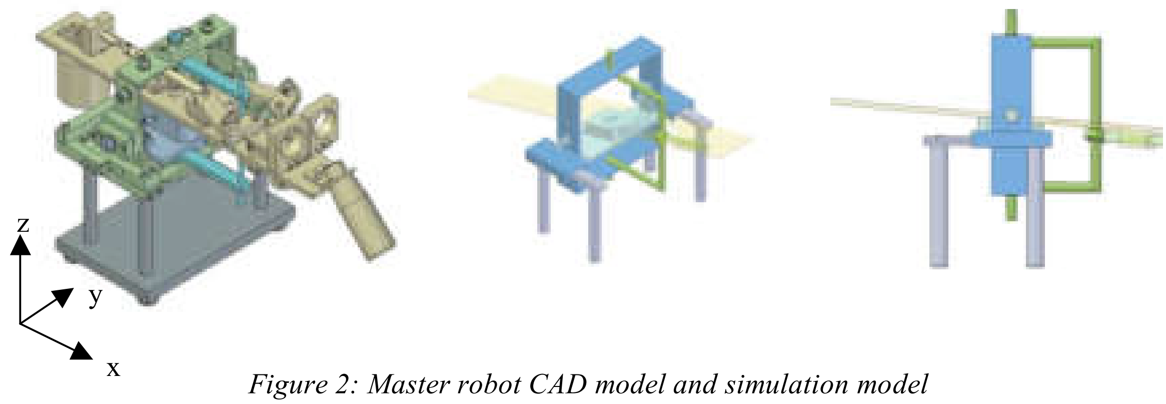


Figure 2: Master robot CAD model and simulation model

following basic components: the base, the frame, the y-axis, the z-axis and the grip. The base is fixed on a table. The frame is connected to the base on a linear slider and move can back and forth on the x-axis. The frame contains bearings which carry the y- and z-axis components. These components can rotate around their respective axes. The y-axis assembly contains a radial-axial bearing in its center which supports the grip. The grip can rotate inside this bearing. The grip is also connected to the z-axis assembly through a rod-end-bearing (universal joint) and slider combination. By rotating the z-axis assembly, the grip is rotated at the bearing. The rod-end-bearing and slider combination compensates for position and orientation differences between grip and z-axis. The grip assembly contains the forceps grip, which uses a slider-crank mechanism to convert the rotational handle movement to a translational movement for an actuator. It also contains the handles used to move the mechanism.

This mechanism is designed to be actuated with a linear motor for the x-axis and the grip, and rotational motors for the y- and z-axis.

4.6 Merits of the Proposed Mechanism

The proposed mechanism has been built without actuators as shown in *Figure 3,* but already shows many benefits compared to the existing mechanism. The merits include the following:

- low friction and play
- static force balance
- rotational axes of actuation do not rotate around another axis
- simple modeling

The proposed mechanism uses ball bearings, linear sliders and linear bushings in joints. It also includes components with a good surface finish for sliding components. This strategy minimizes friction and play. This can be clearly felt while handling the prototype. The mechanism is designed to be symmetrical. The grip assembly is counterbalanced so that the center of gravity and the center of axis rotation are in the center of the mechanism. Therefore, no gravity compensation is required in the control system. Only a small force is required to move the mechanism.

The rotational axes which are to be connected to the actuators do not rotate around another axis. Therefore, the actuators, which are the heaviest part of the system, only perform translational movement. This reduces inertia in the system.

Figure 3: Mechanism prototype

The previous design uses a parallel mechanism which has a complex physical model. Moreover, the parts used in the mechanism were of low accuracy and caused large play and friction in the mechanism. Since the mechanism proposed in this paper avoids these difficulties by mechanically decoupling the axes from each other, the resulting physical model is comparatively simple.

The grip is designed as an improved version of the crank-slider mechanism used in the previous design. In addition to the decrease of friction and play, the ratio of the cranks and the beginning and end angles of movement have been designed to use a larger percentage of the linear actuator force for the movement instead of for bearing load and friction.

4.7 Demerits of the Proposed Mechanism

In the proposed mechanism, the following aspects could be improved in the future: range, size, ergonomics, and connection to actuators. The basic principle of the mechanism works well. However, the prototype is designed to make use of some readily available catalog parts, thereby increasing the size of the mechanism. Substitution of custom-made parts for these could help optimize dimensions and increase the range of the movements in each DOF. The handle as well is designed making use of a standard grip. A more ergonomic grip would make handling easier.

The prototype has not yet been fitted with adapters to hold actuators. This will have to be done to make a fully working model. Preliminary testing has been done with a camera release fitted to the shaft on the grip assembly. The camera release does not work well because the spring inside the tube does not follow the movement of the grip. A new version of the release will use a stiffer spring running in a teflon-lined tube to minimize friction and enable better conversion of the grip shaft movement to the actuator.

4.8 Conclusion and Future Works

This paper proposes a new design for a bilaterally controlled robot master. Requirements are derived from the analysis of the existing master, and a function analysis is performed as a starting point for a new concept. A new concept is proposed which includes improvements such as reduced friction and play, symmetry, axes of rotation which do not rotate around another axis and a simpler, non-redundant force transformation from operator to axis coordinates.

A prototype built according to the design concept shows low friction and play, good static force balance and ease of movement. Improvements have to be made to increase the range of the mechanism, optimize dimensions and increase ergonomics. Further, adapters have to be designed to connect motors to the axes which are to be actuated.

5. Life in Japan

5.1 Introduction

From 2004 to 2005, I spent ten months studying at Keio University in Yokohama, Japan. During this time, I visited some parts of Japan and experienced life at the university and in the international dormitory. I made many friends outside the university and also took part in a two-week home stay with a family in a rural part of Kagoshima in southern Japan. Every day in Japan, I had the chance to improve my skills in the Japanese language and to get to know Japan and its people better.

5.2 Daily life and sightseeing

Daibutsu in Kamakura

I spent the first few weeks getting adjusted to daily life and sightseeing. Since my daily life in Japan was not that different from my life in Germany, I got adjusted to it very quickly. The friendliness and politeness of the Japanese made it easy for me to get through the formalities and get adjusted to life in Japan. In the course of my stay, I visited most of the important sites in Tokyo and Yokohama. I also visited the beautiful old capital Kamakura, the hot spring resort area Hakone, the old capital Kyoto and the large metropolitan area Osaka. After reading about many of these places and seeing them in documentaries, I was thrilled to see them with my own eyes. A few weeks before my return, I climbed Mt. Fuji, stood at the summit and watched the sun rise above the horizon of clouds below us, an experience I will never forget.

5.3 University life

My Mechanism

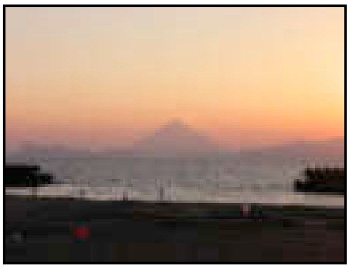
At the university, at the higher bachelor and master level, students are organized in lab groups with a professor in which they spend time between lectures to prepare their master thesis. Each lab has different traditions, habits and rules. The students in our lab had a large amount of freedom to choose their working times, the direction of their research, and the way they use lab resources. However, the students are also known to be particularly earnest and serious about their work. This environment enabled me to do research without any restrictions, and I received help whenever I asked for it. Because of the tense, busy atmosphere, work sometimes tended to be tedious, and some days seemed to last forever. I was impressed, however, with the way students work together, how the older students teach the younger ones, and how they survive meetings which sometimes last seven (!) hours without a break. The international center gave me friendly and efficient help in all bureaucratic matters, and the mechanics at the workshop patiently taught me how to use machines to manufacture parts for my research. Finally, my professor encouraged and motivated me, and thanks to him, I was able to design and manufacture my mechanism. Keio University certainly provides a good study environment.

5.4 Life outside the university

Celebrating Hanami

Outside the university, I used my free time to make friends and intensify contact with them. I got to know students from all over the world in the international dormitory as well as Japanese resident assistants living there. I also made many other friends in Tokyo, Yokohama and other parts of Japan. With them, I went exploring, sightseeing, hiking, eating and shopping. I took part in some traditional festivals such as *hanami* (watching cherry blossoms), *hanabi* (fireworks), *sotsugyoushiki* (graduation ceremony) and *houji* (Buddhist memorial ceremony) and a few *nomikai* (drinking parties) as well. I especially enjoyed singing and listening to karaoke. I had many interesting conversations with Japanese and foreign friends and learned a lot about the way Japanese express themselves, attitudes and opinions about different aspects of life, and cultural similarities and differences. I hope to be able to stay in contact with some of the friends I made in Japan for a long time.

5.5 Home stay in Kagoshima



Mt. Kaimondake

During spring break, I took part in a two-week home stay in a rural part of Kagoshima, which turned out to be my best experience in Japan. The purpose of the home stay was to develop international ties by living with a Japanese family as a family member. After a warm welcome, I quickly adjusted to family routine, waking up, eating, working and talking with them.

My host father worked for a package delivery service, so I went with him quite often to remote places in the hills or along the coast, enjoying the scenery on the way, and met and talked with people from the country I would never have the chance to meet otherwise. Standing on the beach near my host parents' house, I could see the sea in front, two volcanoes, Kaimondake and Sakurajima, in the distance and hills behind me. Driving through the hills, I once saw a group of monkeys running beside the road. On some days, I went with my host mother to feed chickens, collect eggs, pick vegetables and share some with neighbors. When I visited neighbors, they often invited me to have some tee and chat with them for a while. I realized that people in the country were much more open, direct and warm-hearted compared to people I knew in Tokyo and Yokohama, and much more so compared to many students at the university. According to my host parents, what I had experienced in the country as opposed to the city was the *real* Japanese culture. During my stay, I also took part in ceremonies and festivals and built an *irori* (traditional fireplace) with concrete, cement and clay. I had the chance to meet a Buddhist monk who had been to India on a pilgrimage, a car mechanic who had been to Ecuador as part of a development aid program, a retired calligraphy teacher who taught me some basic calligraphy, a geologist who had spent five years in Burma and many other interesting people. On some evenings after dinner, I listened to *enka* (old Japanese songs) with my host parents and even learned one of them for karaoke.

Dinner with host family

For two weeks, this home stay and my host parents brought me completely out of my normal university environment and introduced me to a way of life I couldn't really imagine before, and I'm very glad to have this extraordinary experience. I will stay in contact with my host parents and hope I will have a chance to visit them again in a few years.

5.6 Japanese language study

All the experiences I have written about wouldn't have been half as interesting without the Japanese language. I had studied Japanese as a hobby for some years before going to Japan, and I tried to improve my skills every day. I used Japanese in daily life and at the university. I learned the names of items in stores and expressions needed to talk to people about them. I learned technical terms in the university and held the last two presentations in Japanese. I spent a large amount of time talking to friends in Japanese, and I borrowed and watched Japanese DVDs once in a while. I took a Japanese course at the university and also studied Kanji and vocabulary at home. During my home stay, hardly anyone could speak English, so I had to survive with my Japanese and also learn some expressions in Kagoshima dialect. I like the Japanese language very much, so I enjoyed being in an environment in which I could practice it daily. I hope my Japanese has improved a little in the past ten months, and I hope I can increase my skills in the future or at least keep up my current level until I have another chance to go to Japan.

5.7 Conclusion

I spent my time in Japan working in the lab and going out with friends in my free time. Time flew by very quickly, and I suddenly found myself on an airplane somewhere over Siberia thinking about all that had happened. However, somehow, short time periods have their advantages. I concentrated many unique experiences into the few months I had and enjoyed my stay.

6. Summary

From October 2004 to August 2005, I spent ten months as a *DeMaMech* exchange student in Japan. First, I attended a two-week preparation seminar in Delft, The Netherlands, to learn about The Netherlands and Japan and to attend a language course. After taking care of the formalities and arriving in Japan, I settled in the international dormitory and met my professor and my lab mates. In the lab, I examined the current projects and searched for a topic for my own. After deciding to redesign a forceps robot master, I learned to use the necessary software and prepared a concept. Then, I modeled this concept in CAD and manufactured it in the faculty workshop. In the end, I presented my results and prepared a report.

As well as studying at the university, I also enjoyed life outside the university. I went sightseeing, made friends and went out with them, and took part in a home stay program. I especially enjoyed speaking Japanese and improving my skills through practical usage. I am very glad to have been able to go to Japan with the EU-Japan exchange program and hope others will also have a nice experience there as I did.