1. Personal Data

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Supervisor: Associate Prof. Takayuki Tanaka

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Faculty: Engineering

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2. Executive Summary

I studied at Katholieke Universiteit Leuven (K.U.Leuven) from September to December 2004 and Technical University of Denmark (DTU) in January 2005 as a DeMaMech exchange student.

At K.U.Leuven, I worked on the mobile manipulator LiAS (Leuven intelligent Autonomous System). Through this research, I showed necessity to vary impedance of the manipulator during the task process or in each task condition and to quantify the operational feel. At the end of the project at K.U.Leuven, I handed in a paper and made a presentation entitled "Investigation into the subjective operational feel with a multiple-degree-of-freedom manipulator"

At DTU, I took an intensive course, "Laboratory Course in Process Simulation". In this course I learned how to use some of the most important computer programs for simulation of metal casting, die casting of plastics as well as mechanical forming of metal.

During this project, I enjoyed the European life style, that is I did my best when I had to do and I used my fee time well when I took days off. Besides, I positively communicate with many people from various countries and travel around Europe. Through this precious experience, I realized that it's important to talk with people from different countries in person and to know their cultures.

As a suggestion to the project, I pointed to enough preparations for taking in students.

I hope this project will be expanded and more students can get precious opportunities to study abroad through this project.

3. Travel Schedule

- ✧ 6 – 7, September, 2004
  Sapporo – Tokyo – Munich – Brussels – Leuven
- ✧ 1, January, 2005
  Leuven – Copenhagen
- ✧ 31, January, 2005
  Copenhagen – Leuven
- ✧ 7 – 8, February, 2005
  Leuven – Brussels – Frankfurt – Tokyo – Sapporo

4. Research or Lectures

- Research (At K.U.Leuven)

I. Introduction

In the recent past, to develop a human-centred system and a human interface is emphasised when computers and mechanical devices including robots are designed. In this context, as one way to develop robots that move in human-centred environments, the behaviour-based paradigm became rapidly very popular. When one further analyses these applications, one discovers a striking grab in the application area, namely manipulation. However, very few successful applications were devised using the behaviour-based approach. Therefore, the mobile learning robotics group of K.U.Leuven has implemented several behaviour-based controllers on the mobile manipulator LiAS (see Figure1).

On the other hand, in the social context of aging population and declining birthrate, behaviour-based robots which move in human-centred environments are expected to develop into robots which assist humans.

As a first step to develop robots that assist humans, we need to survey the operational feel or comfort when humans touch end effectors of robots.

In this study, I investigated operational feel based on variable impedance parameters in Skill-assist with the manipulator of LiAS. LiAS has a high-level behaviour-based system and the manipulator is well-controlled, therefore I believe that it is useful for developing robots in human-centred environments to try to evaluate operational feel of the manipulator in Skill-assist.

II. Impedance model of the manipulator

The industrial robot arm I used has a 6-degree-of-freedom (6-DOF) CRS manipulator (see Figure2). The impedance model which has a mass-spring-damper system shown in Figure3 is defined on joint level to emulate human manipulation in LiAS system. This model provides adjustable stiffness and basically implements a natural low-pas filter on the force action on the joint. Moreover, by adding an extra damper to the system, switch between velocity control and force control can obtained. If the mass is free to move, i.e. there is no contact, the source controls the velocity of the mass. On the other hand, if the mass is free to move, i.e. the mass is in contact, the movement of the source regulates the interaction force.

III. Experiments

III-1 Experimental conditions

As a pilot study, I surveyed characteristic of the operational feel based on various impedance parameters and I chose a standard combination of impedance

parameters. Based on the pilot study above, I investigated the subjective operational feel in order to get a basic understanding of the relation between the impedance parameters and the subjective operational feel of maneuvering by asking the subjects i.e. Start up responsiveness, Controllability of the motion speed and Ease of positioning, to answer the questionnaire.

When I decided the desirable impedance parameters variation patterns in a positioning task in this study, I experimentally determined them. Here, to keep the model mechanically plausible, the mass m is taken constant. The variables k, c_1, c_2 are left to be used for control. The variable k can easily be used to achieve the desired stiffness and generally c_1 will be used to damp the mass-spring system. c_2 will be used to tune the velocity/force control. Therefore I fixed c_2 when I chose combinations of impedance parameters. To evaluate the difference of the operational feel clearly and easily, I temporarily classified the joints into 2 groups; joints which were used to move the manipulator in a longitudinal direction and up-down direction: Joint2, 3, 5 (Group1), and which were used in a transverse direction: Joint1, 4, 6 (Group2) when I changed the parameters.

The combination of impedance parameters(a) (Comb(a)) was a standard combination which was decided based on the results of the pilot study. Comb(a) had low c_1 and stiffness, but the manipulator were stable to some extent. In Comb(b), each joint had larger c_1 than in Comb(a). In Comb(c), Group1 had lager stiffness, and in Comb(d), Group2 had lager stiffness than in Comb(a). In all combinations of impedance parameters, the manipulator was stable to some extent. Besides, I asked the subjects to do the positioning task in the two types of motion speed i.e. Speed(1) - Operate the manipulator as fast as possible, Speed(2) - Operate the manipulator at a comfortable speed, because the operating speed relates to the operating efficiency deeply.

Therefore, the subjects had the eight experimental conditions that were combinations of the two positioning task speeds and the four types of joint impedance. In what follows, Experimental condition(a-1) means a condition which is combination of Comb(a) and Speed(1), and the other combinations are described by the same way. The subjects were asked to do a positioning task with the manipulator, i.e. a subject grasped the end of the manipulator, moved it and touched the circles on the targets with a brick that was fixed on it. The subject repeated the task. Experimental setup in this task is below (Figure4, 5).

III-2.Experimental results and discussion

The experimental results are shown in Table1 - 8. Comparing each result, I'll

discuss the relation between the impedance parameters and the subjective operational feel. Distinctive trends that I could grasp from the tables are below.

(a) In set up responsiveness;

1. The operational feel didn't depend on difference in motion speed very much. I guess this is because the speed were almost the same both in Speed(1) and Speed(2) when a subject started the task.

(b) In controllability of motion speed;

1. The subjects felt better in Experimental condition (a-1) than in (b-1), however they felt good in (b-2). That is because they feel more resistance while they are operating the manipulator as fast as possible and they feel more comfortable when they operate it at a comfortable speed in the case c_1 is large to some extent.
2. They felt good in (a-1), (c-1) and (c-2). This means it is easy to move the manipulator when c_1 and stiffness are low.

(c) In ease of positioning;

1. The subjects felt bad in Experimental condition (a-2) and (d-2). This means Group1 needed a measure of stiffness when the manipulator was operated at a comfortable speed.
2. They felt better in (b-2) than (a-2). This means the manipulator is more stable in the case the joints had large c_1 in Speed(2) when the end of manipulator touches the circle. Besides, I guess these two mentions above greatly depend on the stiffness of the environment (the targets) which the end of the manipulator (the brick) touches.

These results indicate the following.

1. Low values of damper and stiffness are not always comfortable for workers in the Skill-assist task, especially in the case the end effecter touches stiff environments.
2. It is necessary to vary impedance of the manipulator during the task process and in each task condition.

As I mentioned above, however, though there were some trends depended on impedance during the task, there were also differences in the operational feel among individuals. For example, in Experimental condition(b-1) and (c-2), some of them felt comfortable, the others felt uncomfortable in Ease of positioning. Moreover, when a subject brings a heavier object or gets tired, he/she must feel more uncomfortable during a task in the same experimental condition. Considering these, we need to investigate the relation between the individual operational feel and impedance of the manipulator in more detail. To realize it, I believe that

quantification of the operational feel is necessary.

IV. Conclusions

1. There are distinctive trends between impedance of the multiple-DOF manipulator and the subjective operational feel, i.e. it is necessary to vary impedance of the manipulator during the task process or in each task condition.
2. There are differences in the operational feel among individuals.

Figure1: LiAS

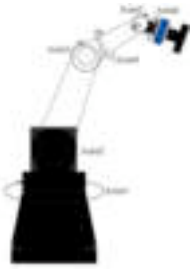


Figure2: CRS manipulator

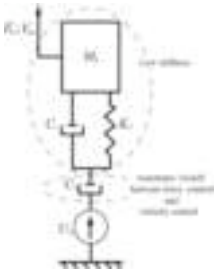


Figure3: Impedance model

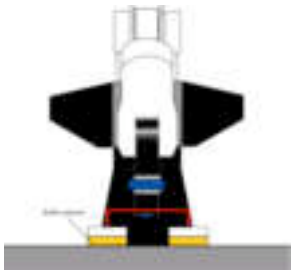


Figure4: Experimental Setup- Front view

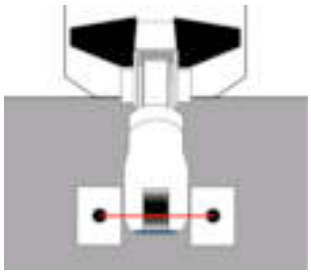


Figure5: Top view

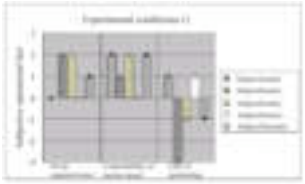


Table1: (a-1)

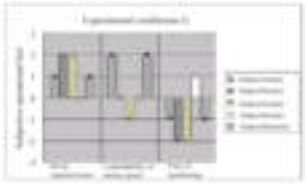


Table2: (a-2)

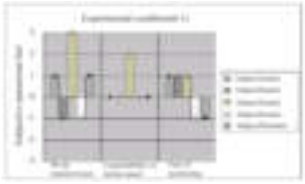


Table3: (b-1)

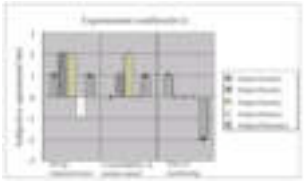


Table4: (b-2)

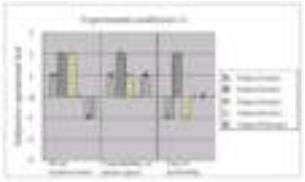


Table5: (c-1)

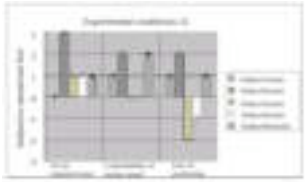


Table6: (c-2)

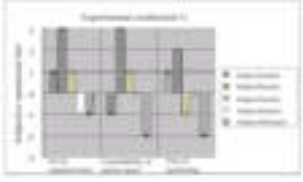


Table7: (d-1)

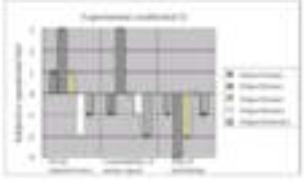


Table8: (d-2)

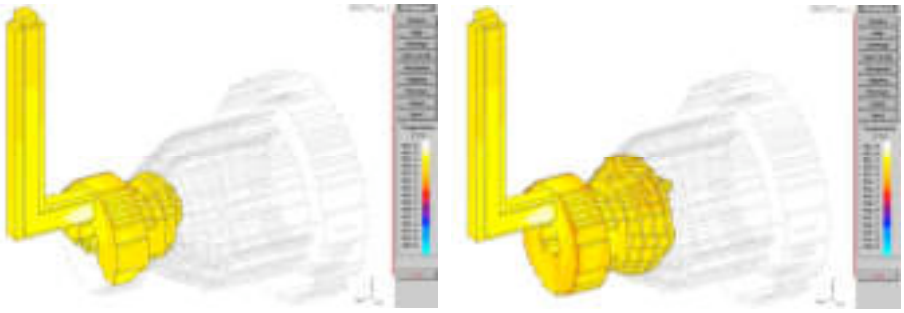
- Lecture (Laboratory Course in Process Simulation at DTU)

In this course, we learned how to use some of the most important computer programs for simulation of metal casting, die casting of plastics as well as mechanical forming of metal.

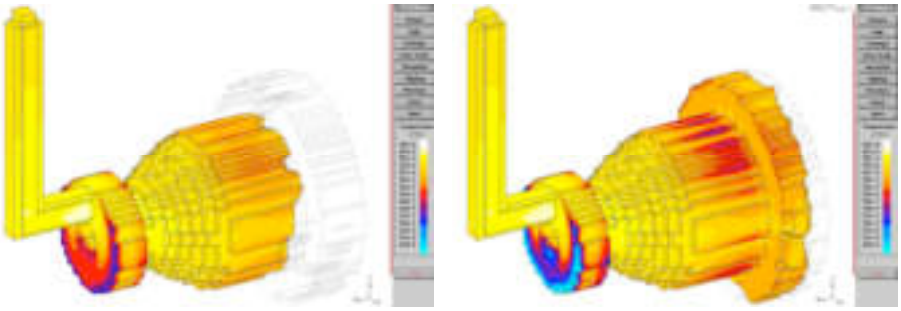
This course was divided into three parts covering simulation of plastics casting, metal forming and metal casting.

1. Plastics casting

In this section, we investigated the filling pattern in the process of the plastics casting with a computer simulation program called “SIGMASOFT”.



(a) 20% filled (b) 30% filled



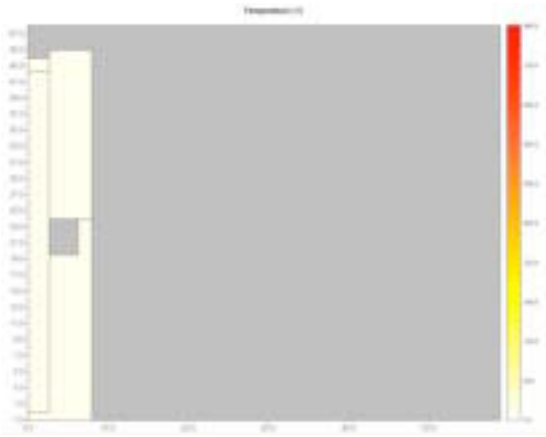
(c) 80% filled (d) 90% filled

Figure1: An example of filling pattern

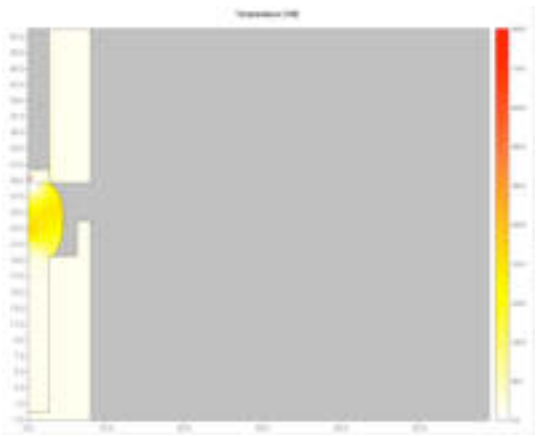
2. Metal forming

In this section, we tried to find a suitable process of forging a screw by investigating temperature, stress and strain of the product. The simulation program we used is “Deform”.

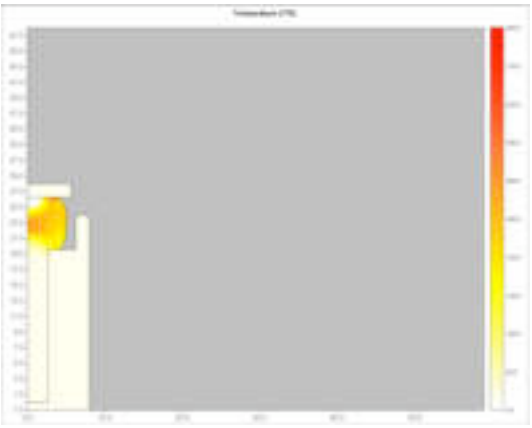
Besides, by using a 3-D simulation program called “Deform 3D”, we checked up strain and the load curve in the process of forging a screw.



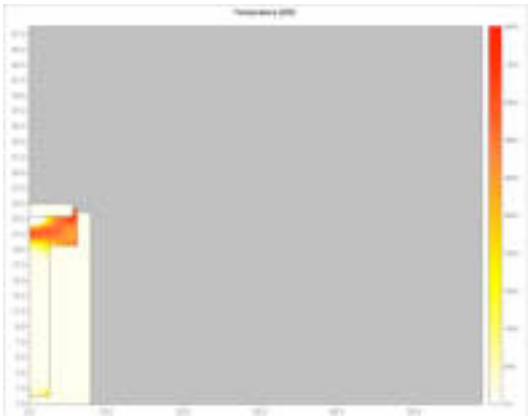
(a) STEP 1



(b) STEP 2



(c) STEP 3



(d) STEP 4

Figure2: The process of forging a screw

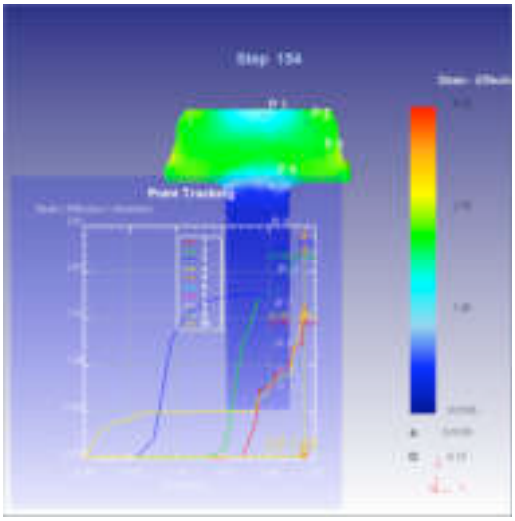


Figure3: Relation between time and strain

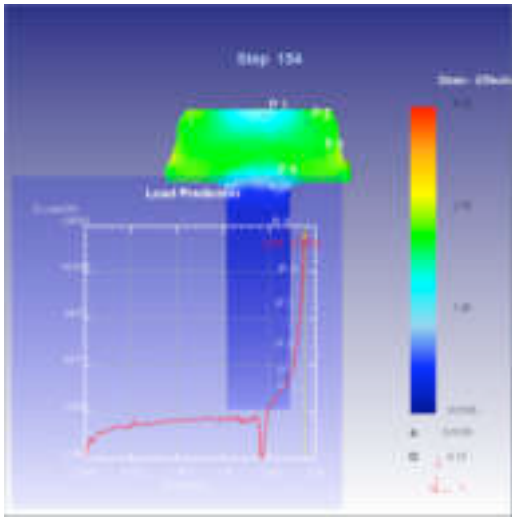


Figure4: Load curve

3. Metal casting

In this section, we investigated the filling pattern and how to reduce porosities in the product in the process of the metal casting with a simulation program called

“MAGMASOFT”.

Especially we focused on the location and shape of the feeder, and we made a suggestion of a feeder design.

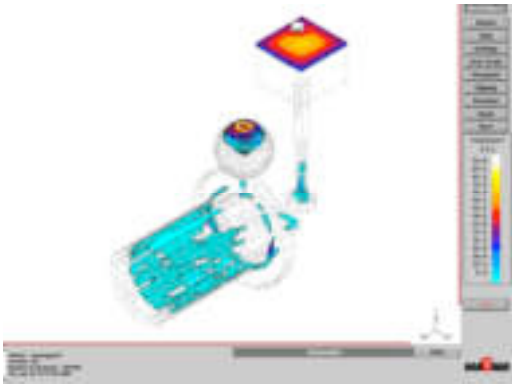


Figure5: Porosities in the product

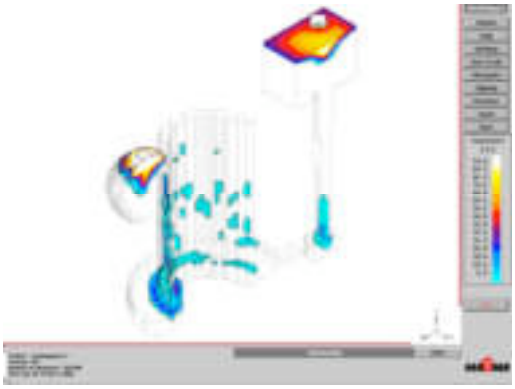


Figure6: Design that we suggested

4. Exchange Student Life

Leuven where I stayed from September to December 2004 is a beautiful city that has medieval atmosphere. Whole of the city is dotted with hundreds of facilities of Katholieke Universiteit Leuven where I studied, and I felt the city was in the university.

During my stay in Leuven, basically, I worked on my research in my laboratory weekdays, and I took days off on Saturday and Sunday. I loved this European life style, that is I did my best when I had to do and I enjoyed my fee time when I took days off.

In my laboratory, I belonged to the Mobile Learning Robots group and worked on a mobile manipulator with several co-workers of the group. When I worked on my research, autonomy was strongly required of me, i.e. I was told, “Do what you want when you want to do. ” Of course, I discussed how I should improve my research with my co-workers, and they helped me kindly and gave me good advices when I asked them. The most important thing was, however, to think and to do by my self and express my own ideas. When I had a break, I chatted cheerfully and drank a coffee with my co-workers. Moreover, I sometimes introduced Japanese culture to my Belgian co-workers and also learned their culture and language. I really had a pleasant time with them.

Besides, K.U.Leuven is well-known that many students from various countries are studying, therefore I was surrounded by international atmosphere in the city. This city gave me a good opportunity to communicate with many international students

and to learn the importance to accept the different cultures from ours. For example, at the beginning of the semester, I joined the international orientation days. During the orientation days, we learned how to live in the city, attended lectures on international awareness, introduction to Dutch and history of K.U.Leuven, and joined a party for international students. The international orientation days gave me a precious chance to make friends with people who have different backgrounds and specialties from various countries. Another example, in my apartment, many Arabic people lived there, so I could communicate with them in daily life. They were really kind and friendly to me. Chatting and having dinner with them, and being exposed to their culture that is quite different from ours, I felt in my bones that it's important to talk with people from different cultures in person.

In the evening, I sometimes went to cafes with my friends. Drinking Belgian beer – Belgium is famous for beer, and Leuven has Oude Markt that is called the longest bar in the world! – I shared pleasant time with them. Students of K.U.Leuven drink much and study well.

When I took some days off, I positively went out and visited other countries. Because Belgium is located at the heart of Europe, it was convenient for me to travel around. Visiting places that I had seen only in books, seeing glorious building, chatting with local people and looking at precious paintings in museums, I got interested in cultures and history of the countries I visited. Everything I saw, heard and felt there was flesh and exiting for me.

At the end of the program at K.U.Leuven, we handed in a paper and made a presentation about our research in front of our supervisors and co-workers. Writing a paper and making a presentation in English were arduous but challenging works for me, and thanks to this experience, I felt confidence in my English ability than before.

After finishing the project at K.U.Leuven, I went to Denmark in order to take an intensive course at Technical University of Denmark (DTU). The course theme was computer simulations of casting and forging process, and I worked on exercises in a group from morning to evening weekdays. It was really busy but fulfilling days. During my stay in Denmark, I had a homestay in an elderly Danish lady's house. She was always gentle, and I had a really good opportunity to know daily life in Denmark through communication with her.

The day when we finished our project, we Japanese exchange students of this project in Denmark gathered and cerebrated the completion of our project. My sense of achievement was special. My five-month stay in Europe past in a twinkle, and it

was a constructive, precious and dream-like life for me.

5. Suggestions to the Project

I think the greatest advantage of this project is that we can study abroad, communicate with people from various countries and feel the outside world of Japan early on as an engineer. Through this project, I believe I could make a big step to become an engineer who has global view.

Besides, this project gave me an opportunity to communicate not only with many international students but also with Japanese students whose major is the same as mine from other universities. Communication with them was really stimulative and constructive. This is also a good point of this project.

My suggestions to the project are the following:

1. Host institutes should fully prepare for taking in students in terms of their research theme and experimental setup because their stay at the host institutes in Europe is too short if the preparation is not enough.
2. Their research theme should match their major, preferences and interests to the possible extent, or it should be decided as early as possible so that they can learn at least the background of their research in advance.

I hope this project will be expanded and more students can get precious opportunities to study abroad through this project.

6. Summary

In this project, I studied at two institutes, Katholieke Universiteit Leuven and Technical University of Denmark. At K.U.Leuven, I investigated the subjective operational feel with a multiple-degree-of-freedom manipulator in order to develop robots that move in human-centred environments. At DTU, I worked on the exercises in computer simulations of casting and forging process.

This project also gave me an opportunity to make many international friends, communicate with people from various countries and see thousands of interesting things.

I believe these experiences through the project will lead me to become an engineer who can contribute to society of the world widely in the future. Besides, I hope the cooperation between Japan and European Union nations will be promoted in the field of exchange students through this project.