Report for exchange program

Osaka University Takanori HASEGAWA

1. Personal Data

Name: Takanori Hasegawa
E-mail: hasegawa@watt.mech.eng.osaka-u.ac.jp
Home institute: Osaka University
Department of Computer-Controlled mechanical systems
Ikeda/Asai libratory
Address: 1-2, Yamadaoka, Suita, Osaka, Japan

Host institute1: Delft University of Technology
Faculty of Mechanical Engineering and Marine technology
Systems and Control Group
Address: Mekelweg 2, 2628CD Delft, The Netherlands
Supervisor: C.W. Scherer

Host institute2: Technical University of Denmark
Faculty of Mechanical Engineering and Management
Address: Anker Engelundsvej 1, 101A, DK-2800 Kgs. Lyngby
Theme: Three weeks course

2. Executive Summary

I stayed the Netherlands from 1st September 2005 to 22nd December 2005 and Denmark from 22nd December 2005 to 31st January 2006.
In TU Delft I studied my project for my master thesis with Prof. C.W. Scherer. I had studied control engineering in my own university for two years. I would continue this project as my master thesis.
I also took two English courses and three lectures corresponding to my project. I have never taken these kinds of English courses in Japan, so I think I could improve my English skill for these courses. The Level of another three lectures is not so difficult, but there are a lot of group works with my classmates. It was very useful for me to learn these subjects and how to discuss with foreign students. I hope I could pass all of the lectures.

In DTU I took three weeks course “Advanced Modeling –Applied Mathematics”. This was my first time of taking like this three weeks course. This course was very tough for students. However I could meet a good partner from Austria, so this course was enjoyable for me because of the interesting topic and the good partnership with him.

The life in the Netherlands and Denmark was comfortable because my roommates were friendly and had different customs and opinions from mine. So at the beginning I was very confused, but I could understand their behavior and mind gradually. I will show my normal life there.

In this report, the first part is Personal Data, the second part is Executive Summary, the third part is Travel Schedule, the fourth part is Research and Lectures, the fifth part is Exchange student life and the final part is Summary.

Finally I would like to express my appreciation for all of the people who gave me good experiences in my life and officers who prepared this exchange program.

3. Travel schedule

TU Delft : From 1st September 2005 to 22nd December 2005

DTU : From 22nd December 2005 to 31st January 2006

4. Project and lectures in TU Delft

In this section I will show my project and two English lectures and three lectures corresponding to my project.

I researched control engineering which is my major in my own university. Especially, I paid attention to the analysis of stability with constrained system. The content is as following.

4.1 Analysis of Systems with Saturation via Polynominal Programming

4.1.1 Problem formulation

Let us consider a continuous-time linear system subject to actuator saturation

$$\dot{x}(t) = Ax(t) + B\sigma(u(t))$$

where $x \in \mathbf{R}^n, u \in \mathbf{R}^n$ are the state vector and the control inputvector. The function σ is the vector-valued standard saturation function, where for i = 1,…,s

$$\sigma(u_i) = \mathrm{sign}(u_i)\min\{1, |u_i|\}.$$

Note that it is without loss of generality to assume a unity saturation level.

The purpose of this paper is to estimate the domain of attraction of system under a given linear state feedback law $u(t) = Fx(t)$.

In my research, we will propose a Polynomial Lyapunov function to estimate the domain of attraction for the closed-loop system.

Let f_i be the ith row of the matrix F. We define the symmetric polyhedron

$$L(F) = \{x \in \mathbf{R}^n :| f_i x |\leq 1, i = 1, ..., s\}$$

If the control input $u(t) = Fx(t)$ does not saturate, that is $x \in L(F)$, for all $t \geq 0$, then the nonlinear system admits the following linear representation:

$$\dot{x}(t) = (A + BF)x(t)$$

Let E be the set of $s \times s$ diagonal matrices whose diagonal elements are either 1 or 0. There are 2^s elements in E. Suppose that each element of E is labeled as E_j, $j = 1, ..., 2^s$, and denote $E_j^- = I - E_j$. Clearly, E_j^- is also an element of E if $E_j \in E$.

Lemma 1 Let $F, H \in \mathbf{R}^{s\times n}$ be given. For an $x \in \mathbf{R}^n$, if $x \in L(H)$, then

$$\sigma(Fx) \in \mathbf{co}\{E_j Fx + E_j^- Hx : j \in [1, 2^s]\},$$

where $\mathbf{co}\{\cdot\}$ denotes the covex hull of a set. Therefore, $\sigma(Fx)$ can be expressed as

$$\sigma(Fx) = \sum_{j=1}^{2^s} \eta_i (E_j F + E_j^- H)x$$

where $\sum_{j=1}^{2^s} \eta_j = 1, 0 \leq \eta_j \leq 1$.

We denote that the parameters η_j are functions of the state. For all the state and time, there exists some continuous function $\eta_j(t)$. To decide $\eta_j(t)$ uniquely, let us consider the norm minimization problem for the current state. This problem is a convex problem with linear constraints. Therefore, this problem is formulated in

terms of linear matrix inequalities (LMIs).

4.1.2 Polynomial Lyapunov funtion

In the previous research, Chesi et al. (2002) introduced the construction of homogeneous polynomial Lyapunov function (HPLFs) for linear systems with time-varying structured uncertainties. In my research, let us consider a polynomial Lyapunov function which is extended from HPLFs. The basis of monomial forms can be described as following:

$$\dot{x}^{\{m\}}(t) = A_{\{m\}}x^{\{m\}}(t)$$

where $A_{\{m\}}$ is an $d \times d(d := \sum_{k=0}^{m}(n+k-1)!/(n-1)!k!.$

There is no method for finding the closed trajectory exactly in general Lyapunov function. Hence, in this paper, we will estimate the domain of attraction via a polynomial Lyapunov function. In the following, we will denote the level sets of

v_{2m} as $\mathbf{E}(V,M) = \{x \in \mathbf{R}^{\mathrm{n}} : v_{2m} = x^{\{m\}'}(V+M)x^{\{m\}} \leq 1\}.$

By using the extended matrix for the closed-loop system, a sufficient condition for establishing the existence of a polynomial Lyapunov function of the highest degree 2m for the system as follows.

Theorem 1 Let $A_{\{m\}},(BE_jF)_{\{m\}},(BE_j^{-}H)_{\{m\}}, j = 1,\ldots,2^s$ denote the extended matrix of $A, BE_jF, BE_j^{-}H, j = 1,\ldots,2^s$ respectively. If the problem

$$\min_{x,\eta,V,M,H} \gamma \text{ s.t. } x^{\{m\}'}(V+M)x^{\{m\}} > 0 \text{ where } x^{\{m\}'}Mx^{\{m\}} = 0$$

$$x^{\{m\}'}[A_{\{m\}} + \sum_{j=1}^{2^s}\eta_j\{(BE_jF)_{\{m\}} + (BE_j^{-}H)_{\{m\}}\}]'Vx^{\{m\}}$$

$$+x^{\{m\}'}V[A_{\{m\}} + \sum_{j=1}^{2^s}\eta_j\{(BE_jF)_{\{m\}} + (BE_j^{-}H)_{\{m\}}\}]x^{\{m\}} - x^{\{m\}'}Mx^{\{m\}} < 0$$

$$\text{for all the state trajectory } x(t) \neq 0,$$

$$(h_ix)'(h_ix) - x^{\{m\}'}(V+M)x^{\{m\}} \leq 0 \text{ for all } x \neq 0,$$

$$\begin{bmatrix} (E_1 F + E_1^- H)\tilde{x} \cdots & (E_{2^s} F + E_{2^s}^- H)\tilde{x} \\ 1 \quad \cdots & 1 \end{bmatrix} \eta(t) = \begin{bmatrix} \sigma(F\tilde{x}) \\ 1 \end{bmatrix},$$

$$\eta \geq 0, \quad \gamma - \eta' \eta > 0$$

admits a feasible solution

$H \in \mathrm{R}^{s \times \mathrm{n}}$, positive definite $V = V' \in \mathrm{R}^{\mathrm{d} \times \mathrm{d}}$, a scalar η for the current state, then $v_{\{2m\}} = x^{\{m\}'} V x^{\{m\}}$ is a polynomial Lyapunov function for the closed-loop system.

4.1.3 Summary

In my research, I introduced a LMI condition by using a polynomial Lyapunov function based on a set invariance condition. I will make simulation by this analysis condition for the certification of this effectiveness.

4.2 Lectures in TU Delft

I took three lectures (“Control Theory”, “Optimization in system and control” and “Discrete systems”) in TU Delf and two English courses. In this subsection, I will show these lectures briefly.

In Control Theory, there are two lectures per week in one quarter. The teacher’ s lecture and handout are very intelligible. And the teaching assistant is also kind. I had some background on Control Theory, but it was good for me to learn it, for this approach was different from the content which I learned before. There were a lot of exercises and one practical exercise to understand the lecture. These were very hard, but I made a lot of discussion with my colleagues. So, this experience was very interesting. I could get the 10 points in this extermination.

In Optimization in system and control, there was one lecture per week. This lecture was a little bit complicated because the teacher usually didn’t teach students details of the contents, just the essence. There was also a practical exercise to optimize a problem. I studied a lot with my colleagues. This examination was very difficult and the practical exercise took much time. So I made a lot of effort, then I could get the second best point in this lecture.

In Discrete systems, this lecture was how to make a program about Discrete event systems. In the first quarter, there was one lecture per week and in the second quarter I made groupwork with three Dutch students. I had never experience this kind of programming. However, our group cooperated with our programming about “Lift system”. We made some model of lift and described it as PDL. Then, we made

some programming by using “Delphi”.

I took two kinds of English lecture. One was the English lecture in TU Delft and the other one was in ING (International Neighbor Group Delft), which gives the members some lectures and activities. The style of two lectures were very practical. The main pint was conversation and how to express my opinion. I could meet some students who were different faculty and of course different nationality. The contents of conversation were sophisticated and big issue in the world. I didn’t usually talk about these contents. I made one presentation about the difference between Osaka University and TU Delft.

4.3 Three weeks course in DTU

I took three weeks course “Advanced Modeling –Applied Mathematics” because I was very interested in modeling by using Mathematics. In control engineering, which is my major, we have to model some practical things by applying Mathematics. I cannot show my paper in this report, so I will show only the abstract and conclusion of this project as following.

4.3.1 Abstract

To study the properties of polymers in good solvents the Self-Avoiding Walk (SAW) on a lattice is often used. At first we dealt with the creation of SAWs on the 2-dimensional and 3-dimensional cubic lattice. We used the pivot algorithm which is a dynamic Monte Carlo method to construct SAWs. To measure the entangleddness of a SAW we calculated the writhe. By doing this for a large number of samples we could look on different statistical properties. To determine whether a SAW is knotted or not, knot invariances can be calculated. We computed the knot determinant by using the Alexander polynomial for knots on the 3-dimensional cubic lattice.

4.3.2 Conclusion

- Creating self-avoiding (random) walks

  Our first approach to create a SAW was a step-by-step method: TO an existing SAW one step in a randomly chosen direction is added to get a longer SAW. But if the new step intersect the existing SAW, the whole SAW is detected and the iteration starts at the beginning. This leads to very long computation times and therefore this method is not useful to create long SAWs.

  Our second approach, the pivot algorithm, is much faster and we were able to get a large number of SAWs for future studies.

- Universal scaling coefficient ν for 3-dimensional SAWs

  Using R_e (end-to-end distance) of 40 samples for different walklength N, we made the approximation of ν by using a least square method. We got values for ν in the range 0f 0.57 to 0.63 by doing the approximation several times.

- Writhe computation

  We had to realize that computing the writhe on a computer leads to numerical problems if we make an in principle mathematical correct procedure. To avoid these numerical problems we check if two line segments lie in one plane and set the writhe for these two line segments to zero.

  To make the statistical analysis we calculated the writhe of SAWs for 5000 samples of different N. To get the results in an acceptable computing time we had to make sure that our program is fast enough. A big improvement was to put vectors together in a matrix and do calculations like crossings for the whole matrix at one time instead of using loops to do it for each vector separately.

- Writhe scaling

  After calculating the mean value of absolute writhe $\langle |W_r| \rangle$ for 5000 SAWs of length $N = 50, 100, ..., 600$ we looked at the scaling behavior. Using a least square method we found that the writhe scales as $\langle |W_r| \rangle \sim N^{\alpha}$ with $\alpha = 0.5599$.

  The maximization of the writhe was about four to five times larger than $\langle |W_r| \rangle_N$ for each N.

- Writhe distribution for a fixed N we looked at the distribution of the writhe. As expected it is symmetric about zero, the most values lie near to zero.

- Relation of writhe and extension of SAWs

  For each SAW exists a sphere with minimal radius where the SAW can lie in. For a fixed N we made a group for each radius with integer value and took the mean value of the absolute writhe of the SAWs that lie within one group. Since the writhe gives the writhe is larger according to SAWs which lie in a smaller sphere.

- Computation of knot determinant

  To determine if a SAW is knotted or not, our purpose was to compute knot invariants numerically. We introduced a projection of a knot onto a plane with additional information concerning over- and under-crossings. In the numerical implementation we considered all of the possibilities about crossing between horizontal and vertical line segments. After that, we decided if the crossing is

over- and under-crossing by comparing the decimal part of two coordinates. We got the sign of the crossing based on the right-hand rule. After sorting the crossings we were able to divide the projected walk into different arcs going from one under-crossing to the next. With this information we were able to compute the Alexander matrix and the knot determinant which is the absolute value of the Alexander polynomial evaluated in –1. To confirm our implementations we computed the knot determinant for different standard knot types.

5. Exchange student life

5.1 Life in TU Delft

At first I talk about my life in the Netherlands. I lived at a students' flat near TU Delft. The flat has nine floors. There are fifteen rooms, common bathroom and kitchen. On my floor, one roommate is Indian, two are Polish and others are Dutch. At the beginning of my stay, I was bewildered because there were some different customs and life styles. However, gradually I got used to the life style and shared dinner with some roommates. Sometimes I cooked dinner for them and vice versa. They usually organized their party or fun by themselves. This kind of activities was sometimes alarming for me because I had never experienced like this activity. One of the most amazing activities was the flat party. Our flat was very crowded, so we couldn't walk there as usual.

My normal life style was as following. I usually woke up at 7:30 a.m. and I watched BBC in common space while eating breakfast. I went to my faculty before 9:00 a.m. Then I took some lectures and studied my research and exercises until 5:00 or 6:00 p.m. In the morning I cooked my lunch, and I brought it to university. After going back to my room, I ate dinner with my roommates at 7:00 or 8:00 p.m. and sometimes watched some movies and studied my work at my room.

The research style in TU Delft was totally different from the style in Japan. In Japan almost master students study their research in their own laboratory. We usually share the common room and spend the same time. So we can make good friendship with our member of the same laboratory. However, in TU Delft there was no specific place and PC for my research. I made some appointment with my supervisor. If I had a question about my research, I asked a Ph. D student about it. Sometimes I felt lonely because there was no colleague like in Japan. However, my supervisor and Ph. D student were very kind and usually paid attention to my

opinion. So I had to express my opinion clearly and could learned a lot of things.
I could make friends with some friends who had the same major (System and Control) because I took some lectures in TU Delft. I made a lot of discussion about our lectures and exercises. The level of students was a little bit different, but each of them had their own opinion and vision of their future. The vision was more clear than one of Japanese students. I feel admiration for it. On the other hand, since they had a practical thinking, they want to study more practical things, not more mathematical things.

5.2 Life in DTU

Secondly I talk about my life in Denmark. I lived in Campus Village, which is made from a container. There was no shop around campus. If I go to some shops to buy something to eat, it takes 20 minutes by walking. So the place is not so convenient. However, the facilities were good. I usually cooked meals by myself. And Roommates were friendly.
In three weeks course, students usually study this course almost from 9:00 a.m. to 5 p.m. This course was very tough for all of the students. In the first lecture, students had to choose one project among three projects. I selected Project A, "A biopolymer's random walk". Biopolymer is very attracted topic in these days, so I selected it. Students could study this project within two people. Fortunately I could meet a very good partner from Austria.
We calculated these contents by Matlab and wrote our report by Latex in Solaris OS. If students have their own student card, they can use Data-bar, where there are a lot of workstations, every time. The supervisor and course assistants are very kind. Hence, I think the situation for studying was very comfortable.

6. Summary

This project gave a lot of precious experiences to me. I would like to sum up my experience into three remarkable points. The first point is the importance of friendship. The second point is the style of research. The third point is to search my conscience.
In this stay, I could meet a lot of friends all over the world. Sometimes I made discuss about each countries and opinions. The discussions were very exciting because their view were different from mine. They were more practical and reasonable. They usually searched what is best for them considering long interval. I

knew not only these different viewpoints and also different activities and customs which I had never seen. I actually feel a lot of diversities and the common sense. I think I could experience these because they had good friendship.

In my research, my supervisor usually told me that I should understand and explain what is the problem in my research as precisely as possible. He made a lot of discussions and advices. These were very helpful in my research and how to research.

Some people asked me about Japan, but I couldn't answer almost questions easily. Sometimes I missed Japanese food and culture. So, I felt that in Japan there are a lot of good things which we can be proud of. I confirmed that I didn't know so many Japanese things. I thought I should learn not only latest technologies and also Japanese traditional things. I also should search my conscience deeply.

Finally I would like to express my appreciation for this project.