1. Personal Data

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2. Executive Summary

The title of my research / master thesis is as follows:

A mathematical analysis and synthesis framework for attenuating disturbance responses due to control switching in a discrete, finite time context.

In operating practical control systems, parts of control systems are often switched. Examples are switching between controllers, sensors, actuators, plant dynamics and so on. The reason for this switching is that it enables to overcome the fundamental limitations of linear time invariant systems and by consequence switching thus improves the transient performance significantly.

However the improved performance can be degraded by disturbances injected before switching. Degrading means that undesirable bumpy responses may be caused due to switching. Next to degrading the control system its performance, these responses may even damage the control systems physically. Hence, switching in realistic control systems is necessary, but methods are required to suppress undesired responses.

Prof. T. Asai wrote papers of the subject in a continuous, infinite time domain. Because the use of these results in a practical computer added environment is not efficient, the research translates these publications to a discrete (infinite) time context. This first approach gives the necessary knowledge to eventually consider the discrete, finite time context.

In the first months my research mainly consisted of reading related papers concerning practical applications on the subject. Studying more theoretical papers and books gave me the necessary insight into the used tool of LMIs (Linear Matrix Inequalities).

The practical use of the result of the research is that the theory gives a more practical method to analyse the switching effects and secondly the proposed mathematical framework offers the ability to attenuate these effects by synthesizing a periferical control system.

3. Travel Schedule

- Workshop

August 2005 Köln – Berlin
August 2005 Berlin – Köln

- Exchange

18 September 2005 Brussels – Helsinki
Helsinki – Osaka

23 February 2006 Osaka – Helsinki
Helsinki – Brussels

4. Research

As said in the executive summary, it is a problem that when switching occurs, closed-loop systems may reveal undesirable responses.

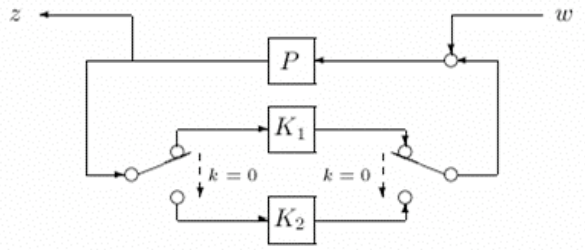

Figure 1.1: Switching of controllers

To observe or analyse the switching effects, so far, many methods have been proposed. However, the effectiveness and the limitations of those methods are not clear enough in the theoretical sense, since performance in terms of ability to attenuate undesirable responses has not been defined precisely and/or robustness for uncertainty has not been considered. On the other hand, a mathematical approach has been proposed in a previous paper of Prof. Asai [1] where disturbance and uncertainty are explicitly dealt with. More concretely, this paper [1] has proposed to use the L2 gain of the operator from disturbance injected before switching to output produced after switching, and has given analysis conditions in terms of LMIs.
Unfortunately, the analysis condition given in [1] is a sufficient condition. In other words, since the necessity of the condition is not proved, the method gives upper bounds for the gain and the results thus can be conservative. Moreover, since no results to find lower bounds have been proposed, the extent of conservatism is not clear. The problem dealt with in [1] is corresponding to robust performance problems. This suggests that, if we consider the corresponding nominal problem, less conservative or even necessary and sufficient conditions may be obtained. A more recent paper of Prof. Asai [2] showed necessary and sufficient conditions for the analysis of the L2 gain defined across switching, i.e. the gain from disturbance before switching to disturbance output after switching.
This research translates the continuous-time domain results of [2] to the discrete-time domain equivalent. As the use of a computer added environment demands a discrete approach of the system, this contributes the first step toward practical implementation of the results.
Moreover the results of [2] are, in addition to the consideration in discrete time domain, extended to a finite time interval. This means that the time interval considered before and after switching is bounded to limited duration. Regarding a computer added environment, this is the second step toward practical implementation of the results.

Once we have a framework to analyze the switching effects, we now need a method to alter them. This report proposes a discrete-time mathematical framework to compose or synthesize a periferical control system to attenuate the undesirable responses due to switching. The method used in this report is similar to paper \cite{Asai:Auto:2002} by T. Asai; while the existing frameworks do not deal with disturbances explicitly, the proposed framework in this report will deal with this by reducing the L2 gain across switching. The periferical control system to be synthesized is composed of a feed forward controller, a filter and matrices to assign initial states. This system can be synthesized efficiently by solving Linear Matrix Inequalities (LMIs).
Analogous to the analysis conditions, the synthesis framework is again considered in both infinite and finite discrete time interval.

In order to deal with the undesired responses mathematically, this report considers (in the variety of switched parts in practical control systems) the specific case of switching between controllers (as in figure 1.1). The technique of controller switching is often involved in tracking problems, however for the clarity of the proposed methods, we will only consider regulation problems.
Concretely this means that we do not consider reference signals. Since we will deal with linear systems, the results of this report can easily be extended to tracking problems by super positioning of the reference signal to the disturbance input (property of linearity).

An example of practical application to control switching lies in the search of a specific file on a computer hard disk. First the plant tries to find the corresponding track using a first controller in a rather fast but inaccurate way. After finding the right track the system switches to a second controller which enables the reading head to find the specific location of the wanted file on the track. The second controller is typically less fast, but more accurate. The switching between these two controllers introduces unwanted bumpy responses. In order to attenuate these disturbance responses the proposed mathematical framework can be applied and the negative effects of controller switching can be reduced.

5. Exchange student life

In Japan, many many things are different from the Belgium, European standard.
Concerning campus life, first of all, students are assigned to a laboratory after their second bachelor. Instead of following lectures and seminars as a main preoccupation, they spent most of the time doing their personal research in the laboratory. Where Belgium students do their work at home, Japanese engineering students have their own workplace in their laboratory. By consequence the atmosphere in the laboratory is very domestic and this makes it a nice place to study.

Osaka University has many international students from all over the world. One of the largest exchange programs is called OUSSEP. Since DeMaMech is a smaller program, we had the chance to take part in the activities that were organized for OUSSEP and thereby meet many foreign students.
Next to the OUSSEP activities there are many other things to do on the university site; festivals, sports, student events are part of this.

Next to campus life, as a foreigner interested in Japanese culture and landscape, Japan is a superb country for travelling around. Since Osaka is situated in the centre of Kansai region, travelling to famous cities like Kyoto, Kobe and Nara is easily done as weekend or day trip. Next to these cities, Tokyo is of course also definitely worth a visit. For this trip it is advisable to take the night bus since the Bullet Train can be quite expensive. In the somewhat more south of Japan, Hiroshima and Miyajima are easy to reach spots. Something definitely not to miss in Japan is an onsen, a Japanese style outdoor spa.

Osaka itself also is an interesting place. In Japan people of Osaka are know for their extensive eating culture. Another remark is that they are also said to be more friendly compared to people in Tokyo, but friendly has to be interpreted in a Japanese context here. Compared to Europe (in some occasions) everybody is friendly in Japan.

Concerning the accommodation, we lived in an international dormitory. In our case international mend that the main population was Chinese. In general the physical state of the dormitory was quiet poor. The rooms itself were okay, but the common places were of rather low quality. Since I spent most of the day in the ‘multi-use’ laboratory this was not a very big concern for me.

6. Summary

Concerning my research I'm very satisfied about what I accomplished. Since my knowledge of the subject was limited before I went to Japan, the effective guidance of my host professor T. Asai was crucial and enabled me to finish my master thesis.

In general the experience of staying and studying abroad has a priceless value. Spending 5 months in a culture so different from ours is a unique opportunity and has a good effect in different ways on both personal and professional future. In particular as an engineer Japan has a lot to offer. Students who are considering doing something alike, I can only encourage them to do it. I hope that this pilot exchange program of two years has enough influence to set up an elaborated exchange program for the future.

Last but not least I want to thank everybody that was involved in the organisation of this program and again that they can continue doing their work.