Travel Report from Australia and China

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Abstract

The report gives a summary of Björn Wittenmark's visits to China and Australia during the academic year 1986/87. An overview of the research is given together with a summary of impressions during visits at different universities.

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1. INTRODUCTION

During the academic year 1986/87 I had the privilege to visit the Department of Electrical and Computer Engineering at University of Newcastle, Newcastle, N.S.W., Australia. On the way to Australia I visited Tsinghua University, Beijing, China and East China Normal University, Shanghai, China. On the return to Sweden I visted University of California, Santa Barbara, USA. The travel was possible to make thanks to support from:

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I want to express my sincere gratitude for this support.

Section 2 contains a description of the research done during the year. Section 3 gives a short description of the visits I did in Australia. The visit in China is summaried in Section 4 and a summary is given in Section 5. A list of reports is given in Appendix A and seminars and lectures are listed in Appendix B.

2. RESEARCH

During the visit in Australia my main duty was research in the areas of adaptive control and design of controllers. In the research I mainly cooperated with Graham Goodwin, Rob Evans, Rick Middleton, Y C Soh, and David Hill.

Identification based on data with sampling delay

The report Wittenmark and Olsson (1986) is based on Olsson (1986). In many situations it is not possible to measure the input and the output of a process simultaneously. For instance if the sampling rate is fast the effect of this delay cannot be neglected. If the raw data is used to make a direct identification then there will be bias in the estimated parameters if we are interested in the process model without delay. See Sridharan et al. (1985). In our work it is shown how data with sampling delays can be used to obtain the model corresponding to the process without sampling delay. The modification is simple and can be made after the estimation is finished. The result is based on Wittenmark (1985). It is only required that a suitable structure is used in the estimated model and that the delay is known.

Constrained pole-placement using transformation and LQ-design

The optimal linear quadratic (LQ) design method has several good properties. For instance the closed loop system is stable and has some robustness properties provided the weighting matrices satisfy certain positivity conditions. The transient behaviour of the closed loop system is, however, difficult to determine since there is a complex relation between the weighting matrices and the closed loop poles. This implies that the weighting matrices have to be determined through trial and error. Pole-placement methods have the advantage that the closed loop poles can be specified. The drawback is the non-uniqueness of choice of feedback variables when the system has several inputs. Further it is too restrictive to place the poles in pre-determined locations. It would suffice to have the poles placed within a specified region. Some design methods have been proposed to make pole placement into regions. Anderson and Moore (1969) show how the poles can be restricted to the left of a vertical line in the left half plane. This idea is used in Shieh, Dib and McInnis (1986) to make pole placement within a vertical strip in the left half plane. Pai et al (1979) give a procedure to make pole placement within a sector using nonlinear optimization. Kawasaki and Shimemura (1983) propose a method to place the poles inside a hyperbola in the left half plane. Their method has the drawback that it is iterative. It can, however, be shown that the design objectives are fulfilled after a limited number of steps.

In the report Wittenmark, Evans and Soh (1986) we give a new method, which places the closed loop poles within a circle in the left half plane. The location of the poles within the desired region is obtained without any iterations. This is achieved by making a transformation and then applying linear quadratic design to the transformed system. The state feedback controller for the transformed system is then transformed back into the original variables. The transient properties of the closed loop system are thus determined by selecting a circle in the left half plane. The linear quadratic design in the transformed variables will then guarantee that the closed loop poles are placed within the desired region. The proposed method combines the advantages of both pole placement and linear quadratic design. The transient response is easily predicted by specifying the region for the eigenvalues of the closed loop system. The resulting controller has the robustness properties of LQ controllers. The method can be used for multivariable systems and will significantly decrease the number of trials compared to designing linear quadratic controllers. After the publication of the report a similar approach with pole-placement within a circle has been published by Fututa and Kim (1987).

Adaptive decoupling of multivariable systems

Most control systems for industrial processes are designed from a single-input-single-output point of view. This is appropriate only if the couplings between the different loops are weak. There are, however, many multivariable processes where there are strong couplings between the loops. It is then of importance to consider this coupling when designing the control system. Further it may be desirable to control the different loops individually. To do this a decoupler must be designed to separate the different control loops. The design of a decoupler requires good process models since the decoupler critically depends on the internal structure and parameters of the system. The problem of decoupling using linear state feedback has been given large attention. An overview based on geometric concepts is given in Morse and Wonham (1971) and using frequency domain methods in Wolovich (1974). The decoupling problem is also discussed in Pernebo (1981 a, b). The fundamental questions are the priori knowledge that is needed about the system and what closed loop systems that are achievable. These problems are discussed in Desoer and Gündes (1986). They give a parameterization of all achievable stable decoupled systems using dynamic output feedback. In Wittenmark, Middleton, and Goodwin (1986) adaptive decoupling is discussed. This implies that the design has to be made based on input-output models. The adaptive decoupling problem is solved approximately in McDermott and Mellichamp (1986). Adaptive decoupling and prior knowledge is discussed in Singh and Narendra (1984). The parameterization issues are discussed in Elliott and Wolovich (1984).

How is decoupling done in the process industry today? The usual approach is to design a precompensator such that the new system essentially becomes decoupled. A survey of different ways to measure the interaction in a system is given in Jensen, Fisher and Shah (1986). Procedures for designing the precompensators are discussed in Wolovich (1974) and Wolovich (1981). The first reference gives a design procedure that can be used if the process has a stable inverse. In Wittenmark, Middleton, and Goodwin (1986) an adaptive decoupling procedure based on a precompensator is proposed. The precompensator is designed such that no unstable pole-zero cancellations occur. The decoupling precompensator will separate the controller design into a number of single-input-single-output design problems. A design procedure along these lines is hinted at in Johansson (1983, p44).

The contributions relative to earlier works are:

- An adaptive decoupling algorithm for a large class of systems is suggested. The decoupling is done without any unstable pole-zero cancellations.
- The convergence of the design scheme is established under the assumption that the input signals are persistently exciting.

On the role of filters in adaptive control

Adaptive controllers are now more and more used in industrial applications, see the surveys Åström (1983b) and Seborg et al (1986). The convergence and stability issues for some classes of adaptive controllers were solved in the late 1970's for ideal cases such as known orders and delays of the process. The robustness properties of adaptive controllers have been debated intensively during the last years. The concencus of these discussions seems to be that adaptive control can be useful, but that extreme care must be taken when implementing the controllers. Different fixes have been suggested based partly on experience and partly on analysis. The implementation and robustness issues are therefore of great importance. In Wittenmark (1986) some of these aspects are discussed. The signal processing, i.e. the choice of different filters, in adaptive controllers is treated. An attempt is made to quantify some of the "folklore" around the implementation issues. The report concentrates on discrete time adaptive controllers. Some of the signal processing issues are then the same as for implementation of fixed parameter sampled data controllers. The problems are for instance the choices of the sampling period, the antialiasing filters and the specifications. These choices are, however, also influenced by the process, which now is unknown. The estimator part of the adaptive controller is also of great importance since it must produce accurate process models in appropriate frequency bands. Finally the interaction between the estimator and the controller may cause problems. Practical issues have been discussed for instance in Åström (1983a,b), Rohrs et al (1984) and Wittenmark and Åström (1984). The following quotations give some general advices and statements about the implementation.

Quote 1 (Ljung and Söderström (1983), p 139-140)
"... even if the true system is more complex than our models, the identification procedure will pick the best approximation of the system. ... The recursive algoirthm converges to that approximation that is best under the input signal used during the experiment."

Quote 2 (Ljung and Söderström (1983), p 267)
"It is thus good practice to choose an input for the identification experiment that as far as possible is similar to inputs to be used for the system at later occasions."

Quote 3 (Åström (1983a), p 986)
"Do not estimate unless the data is good."

Quote 4 (Åström (1983a), p 986)
"... beneficial to use a design method which gives a high gain at low frequencies and use adaptation only to find the characteristics around the cross-over frequency."

Quote 5 (Rohrs et al (1984), p 653)
"Keep the adaptation gain of the system small and let the adaptation proceed slowly."

Quote 6 (Rohrs et al (1984), p 653)
"Design the nominal control loop so that it is robust and that approximate model matching can be achieved even in the presence of unmodelled dynamics."

These quotations and references pinpoints some of the fundamental issues when implementing adaptive controllers. In Wittenmark (1986) these advices are quantified and an overall view of the implementation problem given. The results are based on ideas in Gevers and Ljung (1986) and Wahlberg and Ljung (1986).

The contributions of the report relative to previous work are:

- An overall treatment of the implementation problem.
- Quantitative rules of thumb are given to help the implementor.
- Both analysis and examples are used to illustrate the different points.

Adaptive stability augmentation

Most adaptive controllers are based on a "black box" approach. In many applications there is an extensive emperical knowledge about the process model. This a priori knowledge about the process model has so far only been used to a very limited extent. The knowledge has for instance been used to determine possible structures of the controller and desired closed loop responses. However, as soon as the structure of the adaptive controller has been determined all a priori knowledge is abandoned. It is expected that the use of a priori knowledge will improve the performance compared to adaptive controllers based on a black box approach. There are some references where a priori knowledge has been used in adaptive controllers. Clary and Franklin (1984) estimate the unkown part of the process. The adaptive controller is then designed in a conventional way for the full process model. Bai and Sastry (1986) use a more general process model for the a priori knowledge. Dasgupta et al (1985) and Dasgupta and Anderson (1986) derives a parameterization for identification of physical parameters in a model. The papers referred above mainly discuss how the a priori knowledge can be used in the estimation part of the adaptive controller. The controller design is then done based on the full process model. A different approach to the design is taken in Wittenmark (1987). The inspiration for the new class of adaptive controllers comes partly from design of power system stabilization equipment and design of autopilots for airplanes. These systems contain what sometimes is called stability augmentation. The idea is that a nominal control signal is augmented by an additional signal, which increases the stability properties of the closed loop system. The Adaptive Stability Augmentation (ASA) controller in the report is based on the idea to divide the controller into a fixed nominal part and an adaptive stability augmenting part. The report concentrates on the design principles. We discuss the improvement in performance that can be obtained if additional information is obtained about the system. Some of the motivations for the approach in this paper are:

- Computational aspects. We don't want to resolve the full design problem at each step.
- Safety aspects. The stability augmentation can be disconnected to obtain graceful degradation of the system.
- Use available process knowledge. The a priori knowledge give an indication how the controller should look like.

The contribution of the report relative to previous works are:

- A new design principle for control of partially known systems. The a priori knowledge is used in the estimation as well as in the design of the controller.
- The design and the analysis are simplified by the separation into a nominal controller and the adaptive stability augmentation.

An adaptive pole placement controller based on pole-zero parameterization

Most adaptive controllers can be regarded as a parameter estimator combined with a design procedure. The parameters are updated regularily, mostly at each sampling interval. The design problem is also resolved as soon as new parameters are obtained. To simplify computation, the models are sometimes reparameterized such that the new model contains the regulator parameters explicity. Such approaches are called direct adaptive control schemes. The advantage is a simplification of the design step. The disadvantage of these methods is that they are usually restricted to systems with a stable inverse i.e. minimum phase systems, because the zeros of the open loop system are cancelled in the design. See for instance Goodwin and Mayne (1987) for a discussion of continuous time model reference adaptive control. The pole placement design principle is an indirect method based on the solution of a Diophantine equation, see Åström and Wittenmark (1984). The solution of the Diophantine equation is essentially the same as solving a set of linear equations. The numerical properties of the calculations are highly dependent on the order of the system and the location of the open loop poles and zeros. If there are multiple poles or zeros close to the unit circle (in the discrete time case) then the solution is sensitive to changes in the estimated parameters, which leads to robustness problems.

In Wittenmark and Evans (1987) an attempt is made to avoid the sensitivity problem and the computational burden of general pole placement design. The approach is to introduce a new parameterization of the model of the process. The model is parameterized into poles and zeros instead of a shift form model. This implies that the estimated model is no longer linear in the parameters, which up till now has been regarded as an almost essential property. The pole-zero parameterization will of course complicate the estimation part of the algorithm, but it is argued in the paper that there will be a total gain because of the simplification in the design step. The pole-zero parameterization has been discussed in connection with digital signal processing, see Jackson and Wood (1978) and Orfanidis and Vail (1986). With the plant parameterized in the poles and zeros it is possible to make a parameterization of the controller such that the solution of the Diophantine equation corresponds to the solution of a linear triangular system of equations. The controller parameters can thus be computed recursively without extensive computations. It is also shown that the new parameterization can be used for implementing the controller. This makes it possible to avoid calculation of the shift form of the process model or the controller and consequently to avoid the sensitivity problems associated with the shift form. The advantages with the proposed parameterization are obtained by abandoning the linear in the parameters concept. The proposed estimation procedure is not much more complex than the conventional extended least squares method that can be used for the shift form. The recursive prediction error method, see Ljung and Söderström (1983), will converge to a local minimum of the loss function. There exist several local minima which corresponds (at least in the noise free case) to permutations of poles and/or zeros. It is, however, irrelevant to which of these minima the estimator converges. There are still many unanswered questions when using the proposed algorithm adaptivley. Convergence and stability properties and the numerical robustness issues are under investigation.

3. VISITS TO UNIVERSITIES

During my time in Australia I visited:

Prof Rod Bell, Macquaire University, Sydney (August 1, 1986)
Prof Peter Lee, University of Queensland, Brisbane (October 21, 1986)
Prof Brian Anderson, Australian National University, Canberra (January 29-30, 1987)
Prof Nevil Rees, University of New South Wales, Sydney (March 3, 1987)

The control group at Macquaire University is quite small. I had discussions with Rod Bell and Warren Moore. They are interested in design of expert systems. Warren Moore is making an application for power system dispatch. The system is going to be tested at a local power network. The group is also working control of a small radio telescope. The purpose is to follow a satellite and recieve and process picture data for weather forecast.

I visited the Chemical Engineering Department at University of Queensland. That department has a strong interest in process control and has much interaction with different industries. The process control group is involved in reseach, consulting, training, and continued education programs in cooperation with the industry. Some of the industries involved are: sugar milling, waste water treatment, minerals processing, and oil refining. I had also the opportunity to discuss with Lou Westphal at the Department of Electrical Engineering.

The Department of Systems Engineering at Australian National University (ANU) has a very strong group in control. The head of the department is Brian Anderson. Some of the other faculty members are John Moore, Bob Bitmead and Darell Williamson. ANU is a graduate school, although it is planned to start an undergraduate program in engineering in the near future. The main research areas for the group are: identification and modelling, adaptive systems, control system design, Riccati equations, digital filters, and array processing.

The control activities at University of New South Wales are concentrated towards modelling and simulation of boilers and other components in power systems. There is also some activities in biomechanics.

University of Newcastle

University of Newcastle was founded in 1965. The total number of students is about 6000 and 815 graduated in 1987. The number of employees is about 1000. Engineering is one of the largest faculties with a yearly intake of over 1000 students. Many of the students, especially in the Masters and PhD programs, are coming from overseas, with the largest number of overseas students coming from Malaysia, Singapore and Hong Kong. The engineering program is 4 years leading to a Bachelor degree. The number of students in electrical and computer engineering is slightly over 100 per year. The staff at electrical engineering consists of 2 professors, 1 associate professor, 4 senior lectures, and 4 lecturers. There are 25 graduate (Master and PhD) students.

The research interests at Electrical Engineering are:

- Adaptive control (Graham Goodwin, Rick Middleton, Carlos de Souza)
- Telescope control (Rob Evans, Bob Betz, Brian Cook)
- Power system stability (David Hill)
- Stability of nonlinear systems (Peter Moylan, David Hill)
- Motor drives (Bob Betz, Brian Cook, Rob Evans)
- Controller design (Graham Goodwin, Rick Middleton)
- Radar systems (Rob Evans)
- Telephone systems (Peter Moylan)
- Digital design (S W Chan)
- Computer programming and design (Peter Moylan, S W Chan)
- Adaptive signal processing (Tony Cantoni)

One interesting part of the university is Tundra. Tundra is a financially self-supporting company, which is founded to transfer knowledge, research, and education to industry, commerce and the community. For instance the telescope project and part of the motor drive project are done through Tundra. The income of Tundra (1986) was AUD 700 000, which corresponds to SEK 3 000 000.

4. VISIT TO CHINA

During July 10-28, 1986 I visited China. The purpose of the visit was a lecture series at East China Normal University in Shanghai. During the visit I also had the opportunity to visit Tsinghua University, Beijing and Shanghai University of Science and Technology. I had plenty of time to discuss with the staff and the students at these universities.

Tsinghua University, Beijing

Tsinghua University was visited during July 10-13, 1986. I was mainly discussing with Professor Zhan Zhaoying and his students at the Department of Precision Instruments. They are working in the area of control and adaptive filtering. One main application project is control systems for laser discs. The servo mechanism must have very high precision to allow high density storage of data. At the Department of Computer Science I visited one group working with control of industrial robots. Visual and sound control of the robots were studied on an experimental system.

East China Normal University, Shanghai

During the period July 14-25, 1986 I visited the Department of Mathematics at East China Normal University. The main purpose with the visit was to give a series of lectures and to discuss with staff and students participating in the lectures. The organizer of the visit was Professor Z.D. Yuan. The East China Normal University has no regular education in automatic control at the under-graduate level. At the Masters and Ph.D. levels fundamental and advanced courses are given within the Department of Mathematics. During the visit at East China Normal University I also gave a lecture at Shanghai Automation Society.

Shanghai University of Science and Technology, Shanghai

A one day visit was done July 23, 1986. This university has a regular engineering curriculum. I visited Professor Xie Xianya and his group. They have an active group in the area of digital control and adaptive control.

Summary

The visit to China was very interesting both professionally and personally. I gained a greater insight into the conditions and atmosphere at some Chinese institutes. The staff and the students are very eager to learn and understand the scientific development in other parts of the world. Several students and researchers that I met were very interested in to continue their studies abroad. This is something that is strongly supported by the unversities and the government.

5. SUMMARY

The travels during 1986/87 have had a great influence on me both professionally and personally. The possibility to change environment and get inspiration through contacts with other people and groups is very valuable and essential to be able to continue active research and to develop new courses at the department. Once again I want to express my gratitude to the funds and organizations that have made it possible to get this inspiration. Finally I hope that this can inspire others to make the effort to get similar experiences.

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Wittenark B., R. J. Evans, and Y. C. Soh (1986): Constrained pole-placement using transformation and LQ-design. Accepted for publication in Automatica

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APPENDIX A: LIST OF REPORTS

List of reports written during the visit in Australia.

Wittenmark B. and P.-O. Olsson (1986): Identification based on asynchonously sampled data. EE8634, September 1986. Accepted for publication in Automatica.

Wittenmark B. (1986): A property of the extra zeros due to sampling. EE8635, September 1986

Wittenmark B., R. J. Evans, and Y. C. Soh (1986): Constrained pole placement using transformation and LQ-design. EE8651, October 1986. Accepted for publication in Automatica.

Wittenmark B., R. H. Middleton, and G. C. Goodwin (1986): Adaptive decoupling of multivariable systems. EE8656, November 1986. Accepted for publication in International Journal of Control.

Wittenmark B. (1986): On the role of filters in adaptive control. EE8662, December 1986. Submitted for conference.

Wittenmark B. (1987): Adaptive stability augmentation or How to use a priori knowledge. EE8713, March 1987. Preliminary accepted for 1988 IFAC Symposium on Identification and System Parameter Estimation, Beijing.

Wittenmark B. and R. J. Evans (1987): An adaptive pole placement controller based on pole-zero parameterization. EE8719, May 1987. Preliminary accepted for 1988 IFAC Symposium on Identification and System Parameter Estimation, Beijing.

APPENDIX B: LECTURES BY BJÖRN WITTENMARK

1986

July 12	Adaptive control - An overview. Tsinghua University, Beijing
July 12	Adaptive Systems in Control and Signal Processing - A report from the workshop in Lund. Tsinghua University, Beijing
July 15	Digital control systems. East China Normal University, Shanghai
July 15	Design methods for digital controllers. East China Normal University, Shanghai
July 16	Adaptive control - An overview. East China Normal University, Shanghai
July 17	Self-tuning regulators. East China Normal University, Shanghai
July 18	Applications of adaptive control. Shanghai Automation Society, Shanghai
July 21	Adaptive Systems in Control and Signal Processing - A report from the workshop in Lund. East China Normal University, Shanghai
July 24	Dual control theory. East China Normal University, Shanghai
September 9	Adaptive control - An overview. University of Newcastle, Newcastle
October 7	Basic ideas in adaptive control. University of Newcastle, Newcastle
October 13	Model reference control. University of Newcastle, Newcastle
October 20	Self-tuning regulators I. University of Newcastle, Newcastle
October 21	Some applications of adaptive control. University of Queensland, Brisbane
October 27	Self-tuning regulators II. University of Newcastle, Newcastle
November 3	Stochastic adaptive control. University of Newcastle, Newcastle
November 10	Practical aspects and implementation of adaptive control. University of Newcastle, Newcastle

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January 29	Self-tuning regulators - An overview. Australian National University, Canberra
January 30	Some applications of adaptive control. Australian National University

March 3	Some application of adaptive control. University of New South Wales, Sydney
March 5	Adaptive stability augmentation or How to use a priori knowledge. University of Newcastle, Newcastle
May 27	Some applications of adaptive control. University of Newcastle, Newcastle
June 17	Basic ideas in adaptive control. University of California, Santa Barbara
June 18	Model reference control. University of California, Santa Barbara
June 19	Self-tuning regulators. University of California, Santa Barbara
June 22	Stochastic adaptive control. University of California, Santa Barbara
June 24	Practical aspects and implementation of adaptive control. University of California, Santa Barbara