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Objectives and skills

I am strongly interested in doing a postdoctoral research in the Process Systems Engineering area in order to apply my analytical and programming skills whilst completing my education. During the course of my education, I have gained experience in the process systems engineering field including process modeling, simulation, optimization and control aspects. In particular, this involved a large amount of programming in the `Fortran`, `C/C++`, `Visual Basic` and `Matlab` languages and has allowed me to develop strong problem solving, mathematical and programming skills. In addition, I have had opportunities to develop my communication skills as a result of significant teaching and presentational elements.

Education

Nov. 1998/Dec. 2001 : Ph.D. (Dr.-Ing.) in Chemical Engineering, Laboratory for Chemical Engineering Sciences (LSGC – CNRS) in Nancy, France, supervised by Profs. M.A. Latifi and N. Roche : "*Optimal control of small-size activated sludge treatment plants*". Awarded best Ph.D. thesis of year 2001 by the *Lorraine National Polytechnic Institute* (INPL).

1998 : Post-graduate diploma in Engineering Science, Louis Pasteur University in Strasbourg, France.

1995/1998 : Graduate diploma in Environmental Engineering, ENGEES National Engineering School in Strasbourg, France.

1992/1995 : Classes preparing to the *Grandes Écoles*, Alphonse Daudet High School in Nîmes, France.

June 1992 : Baccalauréat, French equivalent of A-level.

Professional experience

Oct. 2002/Sept. 2003 : Associate researcher in Automatics at INRIA (Comore goup) in Sophia-Antipolis, France, on the topic "*Observation and estimation of uncertain biological processes*".

Oct. 2001/Aug. 2002 : Associate researcher in Process Systems Engineering at the Laboratory for Chemical Engineering Sciences (LSGC – CNRS) in Nancy, France, on the topic "*Global optimization of chemical and biochemical processes*".

March/Sept. 1998 : Engineering and research training period at Cemagref in Lyon, France, on the topic "*Treatment of highly concentrated effluents through gravel media filters – Experimental and modeling aspects*".

July 1996 : Practical training period at General Utility Project society (GUP, Vivendi Water Co.) in Watford, U.K., on the performance improvement of water supply networks.

Teaching experience

I worked as a teaching assistant at *IUT de Nancy-Brabois* (a 2-year practical course in Chemical Engineering, after the A-level) and ENSIC (a 3-year French Engineering School educating Chemical Engineers) in Nancy, France, from 1998 to 2002.

2001/2002 :

- Tutorial class in advanced process synthesis on the use of sofwtare Pro/II.
- Tutorial class in process optimization on the use of mathematical programming techniques.
- Tutorial class in computing on the use of computer languages and softwares Fortran90, Visual Basic and Matlab.
- Kinetics and chemical engineering projects on the study of catalytic and non-catalytic pure dehydrogenation of methanol to formaldehyde.
- Computing projects on the programming of optimization algorithms (Rosenbrock and Quasi-Newton/BFGS methods).

2000/2001 :

- Practical work in chemical engineering and fluid mechanics.

1999/2000 :

- Practical work in object-oriented programming (Visual Basic) and data acquisition.
- Dynamic optimization projects on the optimization of chemical and electrochemical processes using CVI and BCI methods.

1998/1999 :

- Tutorial class in chemical Engineering on solid-fluid separation processes.

Doctoral studies at LSGC (Nancy, France)

I have pursued doctoral studies in Chemical Engineering at the *Laboratoire des Sciences du Génie Chimique* (LSGC – CNRS) in Nancy, France, and I got my Ph.D. in December 2001. The Ph.D. research topic was entitled “Methodology for dynamic optimization and optimal control of small-size activated sludge treatment plants” and was supported by the French *Ministère de l'Enseignement Supérieur et de la Recherche* (a 3-year grant from October 1998 to September 2001).

The aim of this work was to apply optimal control theory in order to improve the activated sludge process performances and to meet the tight discharge requirements defined by the European Union. Two optimization problems have been stated in order to minimize the nitrogen discharges and to reduce the energy consumption. Both are large-scale non-linear dynamic optimization problems, and are very challenging since (*i*) they involve discrete integer variables and (*ii*) the associated dynamic models (based on the ASM1 general model) exhibit hybrid discrete/continuous behavior.

For more insight, parameter estimation of the dynamic models has been performed for an existing treatment facility in collaboration with an industrial partner (Anjou-Recherche, a Vivendi Water Co. research center). It was shown that the application of optimal aeration policies provides large and durable improvements (up to 30%) with respect to usual operating modes in terms of either effluent quality or energy consumption.

Although the resulting optimal aeration profiles can be directly used as set-point profiles in an open-loop control strategy, such a control strategy would be inadequate due to the large influent variations as well as the inherent model mismatch. The design of efficient closed-loop control schemes was therefore addressed to deal with robustness.

- A simplified model with suitable observability and identifiability properties was first extracted from the ASM1 general model in order to reduce the computational times.
- Then sensitivity analysis of optimal control policies was carried out in order to evaluate how far the perturbed trajectories deviate from the nominal ones in case of model mismatch (an extension of the traditional sensitivity analysis theory was proposed to deal with a particular class of hybrid systems with explicit transition conditions).
- At last, closed-loop optimal control was implemented according to a two-step procedure : (*i*) joint observation/estimation of both unmeasured states and time-varying parameters using an extended-Kalman filter along with a non-recursive least squares algorithm ; (*ii*) application of non-linear model predictive control (NMPC) algorithms to update the optimal aeration policy. Such a control scheme was found to be particularly efficient to deal with large process disturbances and uncertainties.

From a practical point of view, the main outcome of this work was to demonstrate that improved performance of the activated sludge process and substantial financial gains can be realized upon the application of optimal control theory. At the theoretical level, I implemented during the course of the project complex dynamical models into `Fortran` simulation packages, performed model reduction, parameter estimation and optimization and sensitivity analysis of hybrid discrete/continuous dynamic systems, and designed and implemented efficient closed-loop control schemes involving non-linear observation/estimation and NMPC.

This Ph.D. thesis was accepted on December 18$^{\text{th}}$ 2001 by the following international committee :

Prof. C.S. Adjiman	Imperial College of Science, Technology and Medicine, U.K.
Prof. D. Dochain	Université Catholique de Louvain, Belgium
Prof. J. Ragot	Ecole Nationale Supérieure de Géologie de Nancy, France
Dr. J.M. Audic	ONDEO Company, France
Prof. M. Fikar	Slovak University of Technology in Bratislava, Slovak Republic
Prof. M.A. Latifi	Ecole Nationale Supérieure des Industries Chimiques de Nancy, France
Prof. C. Prost	Institut Universitaire de Technologie de Nancy-Brabois, France
Prof. N. Roche	Institut Universitaire de Technologie de Marseille, France

Post-doctoral studies at LSGC (Nancy, France)

As a teaching assistant of Chemical Engineering at the *Laboratoire des Sciences du Génie Chimique* in Nancy, France, from October 2001 to August 2002, I worked on the development of deterministic global dynamic optimization methods for (bio)chemical processes.

In chemical, biochemical and pharmaceutical industries, many products are manufactured in processes that are operated in an inherently transient manner. Examples include batch and semi-continuous processes, periodic processes that operate at a cyclic steady-state (such as PSA processes or some chromatographic processes) and campaign continuous processes (*i.e.* flexible continuous processes producing a variety of different but related products or grades of product). Strong economic, environmental and safety incentives exist for operating these processes in the most efficient manner possible.

The problems of designing and operating inherently transient processes can be referred to as dynamic optimization problems or open-loop optimal control problems. It has been known for years that dynamic optimization problems encountered in (bio)chemical engineering applications often exhibit multiple local optima. Because of models nonlinearities and functions nonconvexities, reaching the global optimum of a given problem by using existing dynamic optimization methods such as variational calculus or discretisation techniques is by no way guaranteed. But despite suboptimality can induce hazardous or even serious situations with respect to the aforementioned economical, environmental and safety issues, there is still no general deterministic global optimization algorithms for nonconvex dynamic optimization problems.

Two approaches have been investigated :

- Based on modern methods for deterministic global optimization of algebraic problems (*e.g.*, the αBB framework), deterministic global optimization of simple transient processes can be achieved by applying complete discretisation techniques (*e.g.*, orthogonal collocation on finite elements). The conception of general `Fortran` codes enabling dynamic global optimization this way has been considered. However, it was found that this approach performs poorly for problems which are nonlinear in the states, even failing to achieve convergence.
- More recently, an alternative approach to the deterministic global optimization of problems with ordinary differential equations in the constraints has been developed. The algorithm uses a spatial branch-and-bound approach combined to a novel procedure to build convex underestimation for nonconvex implicit defined state-dependant functionals, based on either the sensitivity or the adjoint methods (provided the functionals are twice-continuously differentiable). The method has been implemented in `Fortran90` (`GDO` program) and applications to simple parameter estimation and optimal control problems have been considered which demonstrate the tractability of the approach within reasonable computational times. Current investigations aim at improving the underestimation procedure in order to deal with larger dynamic optimization problems, and applications to PSA processes are being considered.

Post-doctoral studies at INRIA (Sophia-Antipolis, France)

Since September 2002, I have been working as a post-doctoral researcher at INRIA (French National Institute for Research in Computing Science and Control) in Sophia-Antipolis, France. This work deals with the problems of observation and estimation of uncertain biological processes, and is supported by the European Union (Telemac project, contract IST-2000-28256).

Strong incentives exist for conducting industrial anaerobic digesters in the most efficient manner possible, and the development of robust advanced monitoring and control procedures is therefore of great importance. The aim is twofold : (*i*) the depollution capability of industrial digesters must be improved to cope with the tight effluent standards, and (*ii*) the anaerobic digestion process must be efficiently stabilized since it is inherently unstable (wash-out).

- The first part of this work is concerned with the parameter estimation of uncertain biological processes described by general mass-balance based models. From a practical point of view, the objective is to calibrate and validate existing anaerobic digestion models based on experimental data provided by industrial partners. Two classes of methods are used : (*i*) general identification procedures based on dynamic optimization methods, and in particular on global dynamic optimization ; (*ii*) more specific approaches which attempt to take advantage of the special structure of the mathematical models (mass-balance based models). By combining both approaches, it was shown that accurate estimates of the yield and kinetic parameters can be obtained.
- A significant part of my research activities is also devoted to the observation of uncertain biological processes. Since rather limited information can be obtained, at a reasonable cost, for most biological processes, the design of robust observers (or software sensors) is indeed of major interest. Such processes are however inherently uncertain and the classical nonlinear observers (*e.g.*, the high-gain observer) often fail miserably to estimate the unmeasured state variables. These considerations have motivated the design of interval observers, which provide guaranteed bounds on the estimates, based on known bounds on the uncertainties (unknown inputs, uncertain parameters,...). Current investigations aim at extending the concept of interval observers in order to deal with problems where probability density functions (p.d.f.) are known for the uncertainties. A method providing the p.d.f. of the estimate rather than simple upper and lower bound has been developed for general mass-balance based process models. Applications to the anaerobic digestion process have been considered by taking adavantage of the confidence intervals given by the aforementioned parameter estimation procedure.

This post-doctoral position at INRIA gives me the opportunity to apply my skills in the process systems engineering area, and to gain knowledge in the field of automatics and applied mathematics. On the other hand, this work is closely linked to the field of biological processes, which was already the focus of my Ph.D. thesis.

Scientific communications

- **Articles in Journals with Peer Review**

– Fikar M., Chachuat B. and Latifi M.A., Optimal operation of alternating activated sludge processes, *Water Research* (**submitted**).

– Chachuat B., Roche N. and Latifi M.A., Optimal aeration strategies of small-size wastewater treatment plants : influence of optimisation time horizon, *Chemical Engineering & Processing* (**submitted**).

– Chachuat B., Roche N. and Latifi M.A., Reduction of the ASM 1 model for optimal control of small-size activated sludge treatment plants, *Journal of Water Science*, **16**(1) :5-26, 2003.

– Chachuat B., Roche N. and Latifi M.A., Dynamic optimisation of small-size wastewater treatment plants including nitrification and denitrification processes, *Computers & Chemical Engineering*, **25**(4/6) :585-593, 2001.

– Chachuat B., Roche N. and Latifi M.A., A new approach for optimal control of small-size activated sludge wastewater treatment plants (in French), *L'Eau, l'Industrie, les Nuisances*, **240** :53-59, 2001.

- **Articles in International Books**

– Chachuat B. and Latifi M.A., A new approach in deterministic global optimisation of problems with ordinary differential equations. C.A. Floudas and P.M. Pardalos, Eds. *Frontiers in Global Optimization*, series in Nonconvex Optimization and Its Applications, Kluwert Academic Publishers (**to appear**).

- **Articles in Conference Proceedings**

– Chachuat B. and Bernard O., Design of probabilistic observers for mass-balance based bioprocess models. *9th International Symposium on Computer Applications in Biotechnology (CAB9), 28-31 March 2004, Nancy, France* (**submitted**).

– Fikar M., Chachuat B. and Latifi M.A., Dynamic optimisation of alternating activated sludge processes. *European Control Conference ECC'03, 1-4 September 2003, Cambridge, UK* (**accepted**).

– Chachuat B. and Latifi M.A., A new approach in deterministic global optimisation of problems with ordinary differential equations. *4th Int. Conference on Frontiers in Global Optimization, 8-12 June 2003, Santorini, Greece.*

– Chachuat B. and Latifi M.A., Theoretical and practical aspects of dynamic optimisation of chemical processes (plenary lecture). *14th Int. Conference on Process Control, 8-11 June 2003, Strbske Pleso, High Tatras, Slovak Republic.*

– Fikar M., Chachuat B. and Latifi M.A., Optimal control design for an alternating activated sludge process. *5th Int. Scientific-Technical Conference Process Control, 9-12 June 2002, Kouty nad Desnou, Republique Chèque* (CD-ROM paper R-244).

– Chachuat B., Roche N. and Latifi M.A., Réduction du modèle ASM 1 pour la mise en œuvre de la commande optimale d'un procédé de traitement à boues activées. *4ème Congrès International GRUTTEE, 22-23 November 2001, Limoges, France.*

– Chachuat B., Roche N. and Latifi M.A., Optimisation dynamique des petites stations de traitement des eaux usées – Une étude de cas. *8ème Congrès francophone de Génie des Procédés SFGP, 17-19 October 2001, Nancy, France.*
In : *Récents Progrès en Génie des Procédés*, **15**(82) :269-276, 2001.

– Chachuat B., Roche N. and Latifi M.A., Minimisation of nitrogen discharges for small-size wastewater treatment plants. *3rd European Congress of Chemical Engineering ECCE'3, 28-30 June 2001, Nuremberg, Germany.*
In : *Chem. Ing. Tech.*, **73**(6) :590, 2001.

– Chachuat B., Roche N. and Latifi M.A., Dynamic optimisation of small-size wastewater treatment plants including nitrification and denitrification processes. *10th European Symposium on Computer Aided Process Engineering ESCAPE-10, 7-10 mai 2000, Florence, Italy.*
In : S. Pierucci, Ed., *Computer Aided Chemical Engineering 8*, Elsevier, Amsterdam, 2000.

– Chachuat B., Pons M.-N., Latifi M.A., Corriou J.-P. and Roche N., Simulation et optimisation d'installations de traitement des eaux, *Colloque Automatique et Environnement, CRAN, 9-10 March 2000, Nancy, France.*

– Chachuat B., Latifi M.A., Roche N. and Pons M.-N., Simulation et optimisation dynamique en traitement des eaux. *Récents Progrès en Génie des Procédés*, **13**(72) :205-212, 1999.

- **Technical Reports**

– Chachuat B. and Latifi M.A., `GDO` *: a `fortran90` program for global optimization of problems with ordinary differential equations.* Technical Report, LSGC-CNRS, Nancy, France (**in preparation**).

– Chachuat B. and Bernard O., *Estimation of the yield coefficients in mass-balance based models for bioprocesses – Applications to the anaerobic digestion process.* Technical Report, Telemac EU project IST-2000-28256, INRIA Sophia-Antipolis, France, 22p., 2003.

– Chachuat B. and Latifi M.A., *User's guide for `fortran` global optimisation code* `NLPGLOB`. Technical Report, LSGC-CNRS, Nancy, France, 62p., 2002.

– Chachuat B., Roche N. and Latifi M.A., *Identification et optimisation dynamique d'une station d'épuration de petite taille.* Technical Report, "Collaboration sur les échanges techniques en modélisation des stations d'épuration, LSGC / Anjou Recherche", 144p., 2000.

Referees

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