INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team CONGE

Contrôle géométrique des systèmes non linéaires

Lorraine

THEME 4A

Activity Report

2003

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1. Team

CONGE is a joint team with the LMAM (Laboratoire de Mathématiques et Applications de Metz) which is a laboratory recognized by the CNRS (UMR 7122).

Head of project-team
Jean-Claude Vivalda [DR INRIA (since October 2003)]

Administrative assistant
Christel Wiemert [AI]

Staff member INRIA
Abderrahman Iggidr [Junior research scientist]
Frédéric Mazenc [Junior research scientist]

Staff member Metz University
Philippe Adda [Associated professor]
Rachid Chabour [Associated professor]
Gauthier Sallet [Professor]

Staff member Nancy University
Edouard Richard [Associated professor]

Visiting scientist
Boris Kalitine [Minsk University – Bielorussia (1 month)]

Project technical staff
Ourida Chabour [until April, 30th 2003]

Ph. D. student
Sabeur Ammar [French-Tunisian scholarship (until june 2003)]
Samuel Bowong [Joint PhD with Ngaoundéré University (Cameroon)]
Jean-Luc Dimi [Joint PhD with Brazzaville University (Congo)]
Ismaïl Gourragui [INRIA-LGIPM scholarship, Joint PhD with LGIPM]
Mohamed Mabrouk [Tunisian scholarship]
Jean-Claude Kamgang [Joint PhD with Yaoundé University (Cameroon) – French ministry of Foreign Affairs scholarship]
Papa Ibrahima N'Diaye [regional scholarship, Joint PhD with Saint-Louis University (Senegal) and INRA]

Research scientist (partner)
Gabriel Abba [Professor (Metz University), LGIPM]
François Léonard [Associated professor (ENIM), LGIPM]

2. Overall Objectives

The CONGE project is a joint team with INRIA and Metz University through the LMAM (Laboratoire de Mathématiques et Applications de Metz) which is recognized by the CNRS (UMR 7122).

The research topics are in the framework of the nonlinear systems theory. More specifically, the team deals with the study of the stabilization and the theory of observers and observability. Moreover, modeling and simulation are parts of the issues of the team.

Stabilizing a system about an equilibrium point consists in finding a static or dynamic feedback which makes the equilibrium asymptotically stable. Several tools are used to achieve this task: backstepping, feedforwarding, positive semi-definite functions...

An observer is an additional dynamical system which aims at providing a state estimation. The observer makes use of the known variables of the system, i.e. the inputs and the outputs. The design of observers is a well mastered technique in the case of linear systems but is a more delicate task for nonlinear systems.

3. Scientific Foundations

3.1. Feedback stabilization

We consider des finite-dimensional systems written as:

$$\begin{cases} \dot{x} & = & f(x,u) \\ y & = & h(x) \end{cases}$$

The problem of stabilization consists in finding a command law $x \mapsto u(x)$ depending on the state x such that the closed-loop system $\dot{x} = f(x, u(x))$ is asymptotically stable about an equilibrium point of interest. One can also find a feedback law which depends only on the output y.

3.1.1. *Backstepping and feedforwarding*

Participants: Mohamed Mabrouk, Frédéric Mazenc, Edouard Richard, Jean-Claude Vivalda.

The basic result of the backstepping technique is as follows: consider the system

$$\begin{cases} \dot{x} & = & f(x) + g(x,y)y \\ \dot{y} & = & u + h(x,y) \end{cases} \tag{1}$$

where $x \in \mathbb{R}^n$, $y \in \mathbb{R}$, $u \in \mathbb{R}$ is the input, f and g are C^2 functions and $f(0) = 0$. If there exists a command law $x \mapsto v(x)$ that stabilizes the subsystem $\dot{x} = f(x) + g(x,v)v$ (with input v), then system (1) is globally asymptotically stabilizable by a C^1 command law. Many stabilizing command laws can be designed thanks to this technique and one has to choose those which give the best result in view of a given specification.

The feedforwarding technique has been invented by L. Praly and F. Mazenc. It can be applied to this kind of systems:

$$\begin{cases} \dot{x} & = & Mx + h_1(y) + h_2(x,y,u)u \\ \dot{y} & = & f_1(y) + f_2(x,y,u)u \end{cases} \tag{2}$$

Due to the term in u in the first equation, the backstepping technique cannot be applied; then we adopt an approach which is the opposite of the backstepping: first, we stabilize the subsystem in y, secondly we try to stabilize the whole system. Notice that the forwarding technique allows us to get bounded feedbacks, which is quite interesting for practical applications.

3.1.2. *Positive semi-definite functions*

Participants: Boris Kalitine, Rachid Chabour.

A well known theorem due to Lyapunov allows us to conclude to the asymptotic stability of an equilibrium: consider a system of differential equations $\dot{x} = f(x)$ (with $f(0) = 0$), if there exists a positive definite function V such that $\nabla V \cdot f(x)$ is negative definite, then we can assert that 0 is an asymptotically stable equilibrium point. The knowledge of such a Lyapunov function is often necessary for the design of a stabilizing feedback (cf. §3.1.1) but it is quite difficult to find such a function.

A little-known result in Occident, due to Kalitine and Bulgakov [28] [29] [30], allows us to make use of *semi-definite* positive functions in the investigation of the stability of an equilibrium. Searching such functions is obviously easier and their use simplifies the design of stabilizing feedback laws. Notice that, on this subject, there exists a great amount of works in the literature of the countries of Eastern Europe: the original result has been extended to discrete-time systems, to PDE, to non autonomous periodic systems, etc. The team is working to extend these results to non-autonomous systems and stochastic systems.

3.2. Observers

Participants: Sabeur Ammar, Ismaïl Gourragui, Abderrahman Iggidr, Mohamed Mabrouk, Gauthier Sallet, Jean-Claude Vivalda.

Consider a real system modeled by the differential system:

$$\begin{cases} \dot{x} &= f(x,u) \\ y &= h(x) \end{cases} \tag{3}$$

where the observation function h represents the set of measures made on the physical system. An observer is an auxiliary dynamical system:

$$\begin{cases} \dot{z} = \Phi(z,y,u) \\ \hat{x} = \theta(z) \end{cases} \tag{4}$$

which provides at any time t an estimation $\hat{x}(t)$ of the real state $x(t)$. More specifically, we have:

$$\lim_{t\to\infty} \parallel \hat{x}(t) - x(t) \parallel = 0$$

If every parameter of system (3) is known with enough precision and if it is possible to design an observer, a differential equation solver can give an estimation of the state of system (3).

The team investigates the theory of observability and observers for finite dimensional systems. More specifically, a current subject of interest is the design of observers for some mechanical systems (Ph.D. thesis of M. Mabrouk) or for the switched reluctance motor (Ph.D. thesis of I. Gourragui).

Another subject is the design of observers for biological systems, more specifically for systems which model the evolution of fishes populations submitted to a fishing effort. In this case, our aim is to stabilize the size of the population around an equilibrium point but, since it is not possible to measure all the state variables, it is necessary to design an observer which gets an estimation of the sizes of the different age classes. Before designing an observer, it is necessary to investigate the observability property. One definition of this last concept is as follows: system (3) is said *observable* if, given two initial conditions $x_0 \neq \overline{x}_0$, there exists an input u such that the solutions $x(t)$ and $\overline{x}(t)$ starting from x_0 and $\overline{x}_0$ satisfy the inequality $h(x(t)) \neq h(\overline{x}(t))$ for all t in a set of nonzero measure. If we are concerned with the construction of observers that converge with an arbitrary speed, the observability condition is necessary. From a theoretical point of view, it is then important to know “how many” systems are observable, that’s why we study the problem of the genericity of the observability for discrete-time systems.

4. Application Domains

4.1. Panorama

Here are some fields of application of the team:

- modeling and control of fluidpower systems;
- modeling and control of switched reluctance motors;
- epidemiology and biological systems.

4.2. Fluidpower

Key words: *Fluidpower systems.*

Participants: Edouard Richard, Jean-Claude Vivalda, Frédéric Mazenc.

In this field, our aim is to apply the techniques of nonlinear control to fluidpower systems. We carry out an activity of modeling and analysis of the mathematical properties of the model. The main problems that we plan to study are:

- the modeling and the improvement of the waterjet cutting machine;
- the design of command laws for the automatic control of hydraulic presses.

These works are made within the HYDRAULYCA resource center for fluidpower industry.

4.3. Switched reluctance motor

Participants: Gabriel Abba, Ismaïl Gourragui, François Léonard, Jean-Claude Vivalda.

High-speed Machining experienced a considerable development these last years. Under the impulse of a keen demand of the aircraft industry, high-speed machining centers have been developed to manufacture parts of high degree of accuracy out of aluminium, titanium, and their alloys. This technology makes it possible to machine very hard materials (glass, ceramics). Moreover, specific cutting conditions lead to obtain a better surface quality at lower cost. The mechanical engineering industry then largely attempted to develop the high-speed machining for the manufacture of more conventional parts. In collaboration with the LGIPM (Laboratoire de Génie Industriel et Production Mécanique), a thesis on the subject of the modeling and the automatic control of switched reluctance motor is in preparation. As far as we are concerned with this question, there are several problems of interest:

- there does not exist any precise mathematical model for all the operating range of these motors;
- at very high speed, we have to deal with the problem of command saturation;
- the measure of the angular position can be made only through an observer.

4.4. Epidemiology

Participants: Philippe Adda, Abderrahman Iggidr, Gauthier Sallet, Jean-Luc Dimi, Jean-Claude Kamgang, Samuel Bowong.

Epidemiology is a new research topic in our team. Emergent diseases led to a renewed interest for the study of the infectious diseases, so that the mathematical models become significant tools in the analysis of the propagation and the control of infectious pathologies. The understanding of the characteristics of the transmission of an infectious disease in a community or a country can lead to better approaches to decrease the transmission of this disease. The mathematical models can be used to compare, plan, set up, evaluate and optimize various programs of detection, prevention, therapy and control of a disease. We hope to obtain some significant results concerning the intra-host models for paludism and tuberculosis, and more particularly the understanding of the feedbacks implying two classes of auxiliary lymphocites Th_1 and Th_2.

4.5. Application of the geometric control to telecommunications

Participants: Ourida Chabour, Jean-Claude Vivalda.

This section is about the dynamical control of polarization. The PMD (Polarization Mode Dispersion) has been pointed out as a limitation to the velocity of communications through optical fibers. This explains why the industry of telecommunications is interested in the development of powerful controllers of polarization. The problem is as follows:

- the PMD controller must be able to reach any wanted state of polarization, whatever the initial state of polarization;

- the speed of the controller must be greater than the the maximum speed of variation of polarization in optical fibres; these variations can be natural (thermal variations, vibrations) or can have a human origin (fibre handling in the terminals);
- the accuracy of the state of polarization at the output of the device must be large.

Controling polarization amounts designing an algorithm of continuation of trajectory on the sphere of Poincaré.

6. New Results

6.1. RNRT Copoldyn

The RNRT Copoldyn ended in April 2003. The device developed by Thales together with the tracking algorithm designed in the team has been tested against a standard PMD controller. These tests show performances that are three times better in both static and dynamic cases.

6.2. Stabilization of finite dimensional nonlinear systems

Participants: Samuel Bowong, Frédéric Mazenc, Abderrahman Iggidr.

We obtained some new results about the stabilization of finite dimensional systems. We pointed out the extension of the backstepping technique to time-varying systems [14] and the design of strict Lyapunov function for some class of time-varying systems. As far as we are concerned with time-delay systems, we pointed out the extension of the technique of adding integrators for systems with delay in the input.

6.3. Semi-definite positive functions

Participants: Boris Kalitine, Rachid Chabour.

A generalization of the works of B. Kalitine to the case of non autonomous differential equations has been made by introducing semi-definite time-varying functions.

6.4. Observers

Participants: Jean-Claude Vivalda, Sabeur Ammar, Mohamed Mabrouk, Frédéric Mazenc.

We studied the genericity of the observability for discrete-time systems written as:

$$\left\{ \begin{array}{rcl} x_{k+1} & = & f(x_k, u_k) \\ y_k & = & h(x_k, u_k) \end{array} \right.$$

where x_k belongs to a compact manifold and y_k is in $\mathbb{R}^p$. In his PhD thesis [7], S. Ammar proves that if the number of outputs is greater than the number of inputs, the property of strong observability is generic (se also [27]). To be more precise, consider the following mapping:

$$\begin{array}{rccl} \Theta: & M & \rightarrow & (\mathbb{R}^p)^{2n+1} \\ & x & \longmapsto & (h(x, u_0), h(f^1(x, \underline{u_1}), u_1), \cdots, h(f^{2n}(x, \underline{u_{2n}}), u_{2n}) \end{array}$$

where

$$\begin{array}{rcl} f^1(x, \underline{u_1}) & = & f(x, u_0) \\ f^{k+1}(x, \underline{u_{k+1}}) & = & f(f^k(x, \underline{u_k}), u_k) \\ \underline{u_k} & = & (u_0, \cdots, u_{k-1}) \end{array}$$

There exists a residual set of mappings (f, h), where f is a parametrized diffeomorphism and h is a smooth mapping from M to $\mathbb{R}^p$, such that Θ is one-to-one for every $(2n+1)$-tuple $(u_0, \cdots, U_{2n})$. Another subject of interest is the design of observers for mechanical systems: for some systems with two degrees of freedom, we are able, under some conditions, to exhibit a change of variables which makes the system triangular and allows the construction of an observer which converges exponentially for bounded feedback. A paper on this subject is in preparation.

6.5. Biological systems

Participant: Abderrahman Iggidr.

In the field of halieutics, a command law bearing on the fishing effort which stabilizes the size of a fishes population around an equilibrium point has been designed, see [18].

6.6. Epidemiology

Participants: Philippe Adda, Abderrahman Iggidr, Gauthier Sallet, Jean-Luc Dimi, Jean-Claude Kamgang, Samuel Bowong.

The team studied global stability conditions for a class of epidemiological models; this class includes models for diseases like dengue, malaria, tuberculosis, etc. A new criterion for the global asymptotic of the free equilibrium of the model has been proposed (see [8]).

7. Contracts and Grants with Industry

The RNRT COPOLDYN has ended on April 2003 (see above).

8. Other Grants and Activities

8.1. Regional initiatives

A fluidpower center has been created by the team CONGE and the team ACS (member of the laboratory CRAN) in 1997. Recently, this pole was transformed into a center of resources which we called "HYDRAULYCA". This center is a structure without legal personality but which exists under the terms of an agreement in which the goals of HYDRAULYCA are described and which regulates the relations between the various partners. This agreement was signed between the UHP (Nancy 1), the INRIA Lorraine, the CNRS and the University of Metz. The main objectives of HYDRAULYCA are the services to the companies and the applications of the modern theory of automatic control in an industrial context. The center presented a 3 years-action plan. At the end of this time, it will be brought to change (CRITT, service company?) if it has shown its capacity to be self-financed. The center will be subsidized, next year, by the DRIRE (Délégation Régionale à l'Industrie, la Recherche et l'Enseignement).

8.2. National initiatives

The team CONGE is one of the founder members of the GDR 1107 (Methods and models of automatic control in the study of the dynamics of ecosystems and renewable resources) of the program environment program and takes part regularly in its work.

8.3. International relations

8.3.1. Algeria

We have signed an agreement with the center of seismological engineering of Algiers. Our cooperation bears on the active and passive control of systems related to earthquake-resistant construction.

8.3.2. Tunisia

A CMCU project of co-operation between CONGE and the University of Sfax was filed in.

8.3.3. Europe

The members of the team are also members of the Control Training Site (CTS). Gauthier Sallet is a member of the editorial board of the CTS.

8.4. Visiting scientists

- Bielorussia : B. Kalitine (University of Minsk), June 2003 (1 month).

9. Dissemination

9.1. Leadership within scientific community

The team is one of the founders of the ‘ GDR CNRS 1107” : Methods and models of automatic control in the study of the dynamics of ecosystems and renewable resources.

9.2. Conferences and workshops committees, invited conferences

Participants: Rachid Chabour, Frédéric Mazenc, Gauthier Sallet, Jean-Claude Vivalda.

- R. Chabour was invited to the SMT Convention at Hammamet (Tunisia) in March 2003;
- R. Chabour and G. Sallet taught a course in control theory at the spring school “Nonlinear control and applications” held in Tlemcen (Algeria) in May 2003;
- G. Sallet was a member of the scientific committee of the above-mentioned spring school;
- F. Mazenc was a member of the international program committee of the IFAC Workshop on time-delay systems (TDS ’03) held in September 2003 at Rocquencourt ;
- F. Mazenc was chairman of a session of the CDC’03;
- J.-C. Vivalda was invited to a control workshop by the Hong-Kong University in December 2003.

9.3. Teaching

J.-C. Vivalda, R. Chabour and E. Richard taught a course on control theory in the DEA of applied mathematics of the University of Metz (academic year 2003-2004).

9.4. Organization of seminars

The team organized a regular seminar during the academic year 2002-2003; in this framework 5 external researchers was invited to give a talk.

10. Bibliography

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