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Project-Team Metalau

Méthodes, algorithmes et logiciels pour l'automatique

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THEME NUM

Activity Report

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2. Overall Objectives

Keywords: *DAE*, *DEDS*, *Scicos*, *Scilab*, *active failure detection*, *diagnosis*, *dynamical systems modeling and simulation*, *hybrid systems*, *implicit systems*, *linear system theory and control*, *max-plus linear systems*, *modeling and simulation software*, *passive failure detection*, *plant growth modeling and simulation*, *robust control*, *robust estimation*, *robust filtering*, *scientific software*, *stochastic control*, *transportation systems*.

2.1.1. Research fields

The project-team is particularly active in the following areas:

- classical theory of dynamical systems
- optimal deterministic, stochastic and robust control
- failure detection in dynamical systems (both passive and active)
- network control and monitoring for transportation systems
- hybrid systems, in particular the development of Scicos
- maxplus linear systems: applications to transportation systems
- numerical matrix algebra and implementation in Scilab

2.1.2. Objectives

The objectives of the project-team are the design, analysis and development of new methods and algorithms for detection, identification, simulation and control of dynamical systems and their software implementations.

These methods and algorithms are usually implemented in Scilab which is an open-source scientific software package originally developed in the project-team. This task has been facilitated thanks to the creation of the new development project-team SCILAB which has taken over the engineering tasks such as maintenance, porting, testing, etc.

The project-team is actively involved in the development of control, signal processing, optimization and simulation tools in Scilab, in particular Scicos, a modeler and simulator for dynamical systems which is based on research on hybrid systems. Encouraged by the interest in Scicos, expressed both by the academia and industry, developing a robust user-friendly Scicos has become an important objective of the project-team. A lot of effort is put on the development of Scicos within the project-team.

As theory and applications enrich mutually, many of the objectives of the project-team can be seen through the applications:

- modeling and simulation of physical systems (mechanical, electrical, fluids, thermodynamics,...) based on the theory of implicit systems
- modeling, simulation and code generation of control systems based on the theory of hybrid systems
- modeling, analysis and control of transportation systems using the maxplus algebra
- modeling of the growth of plants as linear systems of varying state size and with delay in agronomy
- using robust control theory, and finite element models for identification purposes in the framework of failure detection and default localization for space systems, civil structures and other dynamical systems.

3. Scientific Foundations

3.1. Classical system theory

3.1.1. Systems, Control and Signal Processing

Systems, control and signal processing constitute the main foundations of the research work of the project-team. We have been particularly interested in numerical and algorithmic aspects. This research which has been the driving force behind the creation of Scilab has nourished this software over the years thanks to which, today, Scilab contains most of the modern tools in control and signal processing. Scilab has been a vehicle by which theoretical results of the project-team concerning areas such as classical, modern and robust control, signal processing and optimization, have been made available to industry and academia.

Ties between this fundamental research and Scilab are very strong. Indeed, even the design of the software itself, elementary functions and data structures are heavily influenced by the results of this research. For example, even elementary operations such as basic manipulation of polynomial fractions have been implemented using a generalization of the the state-space theory developed as part of our research on implicit systems. These ties are of course normal since Scilab has been primarily developed for applications in automatics.

Scilab has created for our research team new contacts with engineers in industry and other research groups. Being used in real applications, it has provided a guide for choosing new research directions. For example, robust control tools in Scilab have been developed in cooperation with industrial users. Similarly, Scilab's LMI toolbox has been developed with the help of other research groups. It should also be noted that most of the basic systems and control functions in Scilab are based on algorithms developed in the European research project Slicot in which METALAU has taken part.

3.1.2. Implicit Systems

Implicit systems are a natural framework for modeling physical phenomena. We work on theoretical and practical problems associated with such systems in particular in applications such as failure detection and dynamical system modeling and simulation.

Constructing complex models of dynamical systems by interconnecting elementary components leads very often to implicit systems. An implicit dynamical system is one where the equations representing the behavior of the system are of the algebraic-differential type. If ξ represent the "state" of the system, an implicit system is often described as follows:

$$F(\dot{\xi}, \xi, z, t) = 0, \tag{1}$$

where $\dot{\xi}$ is the time derivative of ξ, t is the time and the vector z contains the external variables (inputs and outputs) of the system. Indeed it is an important property of implicit systems that outside variables interacting with the system need not be characterized a priori as inputs or outputs, as it is the case with explicit dynamical systems. For example if we model a capacitor in an electrical circuit as a dynamical system, it would not be possible to label a-priori the external variables, in this case the currents and voltages associated with the capacitor, as inputs and outputs. The physical laws governing the capacitor simply impose dynamical constraints on these variables. Depending on the configuration of the circuit, it is sometimes possible to specify some external variables as inputs and the rest as outputs (and thus make the system explicit) however in doing so system structure and modularity is often lost. That is why, usually, even if an implicit system can be converted into an explicit system, it is more advantages to keep the implicit model.

It turns out that many of the methods developed for the analysis and synthesis of control systems modeled as explicit systems can be extended to implicit systems. In fact, in many cases, these methods are more naturally derived in this more general setting and allows for a deeper understanding of the existing theory. In the past few years, we have studied a number of systems and control problems in the implicit framework.

For example in the linear discrete time case, we have revisited classical problems such as observer design, Kalman filtering, residual generation to extend them to the implicit case or have used techniques from implicit system theory to derive more direct and efficient design methods. Another area where implicit system theory has been used is failure detection. In particular in the mutli-model approach where implicit systems arise naturally from combining multiple explicit models.

We have also done work on nonlinear implicit systems. For example nonlinear implicit system theory has been used to develop a predictive control system and a novel nonlinear observer design methodology. Research on nonlinear implicit systems continues in particular because of the development of the “implicit” version of Scicos.

3.2. Failure detection in dynamical systems

3.2.1. Acctive failure detection

Failure detection has been the subject of many studies in the past. Most of these works are concerned with the problem of *passive failure detection*. In the passive approach, for material or security reasons, the detector has no way of acting upon the system; the detector can only monitor the inputs and the outputs of the system and then decides whether, and if possible what kind of, a failure has occurred. This is done by comparing the measured input-output behavior of the system with the “normal” behavior of the system. The passive approach is often used to continuously monitor the system although it can also be used to make periodic checks.

In some situations however failures can be masked by the operation of the system. This often happens in controlled systems. The reason for this is that the purpose of controllers, in general, is to keep the system at some equilibrium point even if the behavior of the system changes. This robustness property, desired in control systems, tends to mask abnormal behaviors of the systems. This makes the task of failure detection difficult. An example of this effect is the well known fact that it is harder for a driver to detect an under-inflated or flat front tire in a car which is equipped with power steering. This tradeoff between detection performance and controller robustness has been noted in the literature and has lead to the study of the integrated design of controller and detector.

But the problem of failures being masked by system operation is not limited to controlled systems. Some failures may simply remain hidden under certain operating conditions and show up only under special circumstances. For example, a failure in the brake system of a truck is very difficult to detect as long as the truck is cruising down the road on level ground. It is for this reason that on many roads, just before steep downhill stretches, there are signs asking truck drivers to test their brakes. A driver who ignores these signs would find out about a brake failure only when he needs to brake going down hill, i.e., too late.

An alternative to passive detection which could avoid the problem of failures being masked by system operation is *active detection*. The active approach to failure detection consists in acting upon the system on a periodic basis or at critical times using a test signal in order to detect abnormal behaviors which would otherwise remain undetected during normal operation. The detector in an active approach can act either by taking over the usual inputs of the system or through a special input channel. An example of using the existing input channels is testing the brakes by stepping on the brake pedal.

The active detection problem has been less studied than the passive detection problem. The idea of injecting a signal into the system for identification purposes has been widely used. But the use of extra input signals in the context of failure detection has only been recently introduced.

The specificity of our approach for solving the problem of auxiliary signal design is that we have adopted a deterministic point of view in which we model uncertainty using newly developed techniques from H_∞ control theory. In doing so, we can deal efficiently with the robustness issue which is in general not properly dealt with in stochastic approaches to this problem. This has allowed us in particular to introduce the notion of *guaranteed failure detection*.

In the active failure detection method considered an auxiliary signal v is injected into the system to facilitate detection; it can be part or all of the system inputs. The signal u denotes the remaining inputs measured on-line just as the outputs y are measured online. In some applications the time trajectory of u may be known in advance but in general the information regarding u is obtained through sensor data in the same way that it is done for the output y.

Suppose we have only one possible type of failure. Then we have two sets of input-output behaviors to consider and hence two models. The set $\mathcal{A}_0(v)$ is the set of normal input-outputs $\{u, y\}$ from Model 0 and the set $\mathcal{A}_1(v)$ is the set of input-outputs when failure occurs. That is, $\mathcal{A}_1(v)$ is from Model 1. These sets represent possible/likely input-output trajectories for each model. Note that Model 0 and Model 1 can differ greatly in size and complexity but they have in common u and y.

The problem of auxiliary signal design for guaranteed failure detection is to find a "reasonable" v such that

$$\mathcal{A}_0(v) \cap \mathcal{A}_1(v) = \varnothing.$$

That is, any observed pair $\{u, y\}$ must come only from one of the two models. Here reasonable v means a v that does not perturb the normal operation of the system too much during the test period. This means, in general, a v of small energy applied over a short test period. However, depending on the application, "reasonable" can imply more complicated criteria.

Depending on how uncertainties are accounted for in the models, the mathematics needed to solve the problem can be very different. For example guaranteed failure detection has been first introduced in the case where unknown bounded parameters were used to model uncertainties. This lead to solution techniques based on linear programming algorithms. But in most of our works, we consider the types of uncertainties used in robust control theory. This has allowed us to develop a methodology based on established tools such as Riccati equations that allow us to handle very large multivariable systems. The methodology we develop for the construction of the optimal auxiliary signal and its associated test can be implemented easily in computational environments such as Scilab. Moreover, the online detection test that we obtain is similar to some existing tests based on Kalman filters and is easy to implement in real-time. The results of our research can be found in a book published in 2004.

3.2.2. Passive failure detection: Modal analysis and diagnosis

We consider mechanical systems with the corresponding stochastic state-space models of automatic control. The mechanical system is assumed to be a time-invariant linear dynamical system:

$$\begin{cases} M\ddot{\mathcal{Z}}(t) + C\dot{\mathcal{Z}}(t) + K\mathcal{Z}(t) &= \nu(t) \\ Y(t) &= L\mathcal{Z}(t) \end{cases}$$

where the variables are : $\mathcal{Z}$: displacements of the degrees of freedom, M, C, K: mass, damping, stiffness matrices, t: continuous time; ν: vector of external (non measured) forces modeled as a non-stationary white noise; L: observation matrix giving the observation Y (corresponding to the locations of the sensors on the structure).

The modal characteristics are: μ the vibration modes or eigen-frequencies and ψ_μ the modal shapes or eigenvectors. They satisfy:

$$(M\mu^2 + C\mu + K)\Psi_\mu = 0 \qquad , \quad \psi_\mu = L\Psi_\mu$$

By stacking Z and $\dot{\mathcal{Z}}$ and sampling at rate $1/\delta$, i.e.,

$$X_k = \begin{bmatrix} \mathcal{Z}(k\delta) \\ \dot{\mathcal{Z}}(k\delta) \end{bmatrix} \quad , \quad Y_k = Y(k\delta)$$

we get the following equivalent state-space model:

$$\begin{cases} X_{k+1} &= FX_k + V_k \\ Y_k &= HX_k \end{cases}$$

with

$$F = \exp(A\delta) \quad , \quad H = \begin{bmatrix} L & 0 \end{bmatrix} \quad and \quad A = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix}$$

The mechanical systems under consideration are vibrating structures and the numerical simulation is done by the finite element model.

The objectives are the analysis and the implementation of statistical model-based algorithms, for modal identification, monitoring and (modal and physical) diagnosis of such structures.

For modal analysis and monitoring, the approach is based on subspace methods using the covariances of the observations: that means that all the algorithms are designed for in-operation situation, i.e., without any measurement or control on the input (the situation where both input and output are measured is a simple special case).

The identification procedure is realized on the healthy structure.

The second part of the work is to determine, given new data after an operating period with the structure, if some changes have occurred on the modal characteristics.

In case there are changes, we want to find the most likely localization of the defaults on the structure. For this purpose we have to do the matching of the identified modal characteristics of the healthy structure with those of the finite element model. By use of the different Jacobian matrices and clustering algorithms we try to get clusters on the elements with the corresponding value of the "default criterion".

This work is done in collaboration with the INRIA-IRISA project-team SISTHEM (a spin-off of the project-team SIGMA2) (see the web-site of this project-team for a complete presentation and bibliography) and with the project-team MACS for the physical diagnosis (on civil structures).

3.3. Exotic systems

3.3.1. Hybrid dynamical systems

Originally motivated by problems encountered in modeling and simulation of failure detection systems, the objective of this research is the development of a solid formalism for efficient modeling of hybrid dynamical systems.

A hybrid dynamical system is obtained by the interconnection of continuous time, discrete time and event driven models. Such systems are common in most control system design problems where a continuous time model of the plant is hooked up to a discrete time digital controller.

The formalism we develop here tries to extend methodologies from Synchronous languages to the hybrid context. Motivated by the work on the extension of Signal language to continuous time, we develop a formalism in which through a generalization of the notion of event to what we call *activation signal*, continuous time activations and event triggered activations can co-exist and interact harmoniously. This means in particular that standard operations on events such as subsampling and conditioning are also extended and operate on activation signals in general paving the way for a uniform theory.

The theoretical formalism developed here is the backbone of the modeling and simulation software Scicos. Scicos is the place where the theory is implemented, tested and validated. But Scicos has become more than just an experimental tool for testing the theory. Scicos has been successfully used in a number of industrial projects and has shown to be a valuable tool for modeling and simulation of dynamical systems.

Encouraged by the interest in Scicos, expressed both by the academia and industry, beyond the theoretical studies necessary to ensure that the bases of the tool are solid, the project-team has started to invest considerable effort on improving its usability for real world applications. Developing a robust user-friendly Scicos has become one of the objectives of the project-team.

3.3.2. Maxplus Algebra, Discrete Event Systems and Dynamic Programming

In the modeling of human activities, in contrast to natural phenomena, quite frequently only the operations max (respectively min) and $+$ are needed (this is the case in particular of some queuing or storage systems, synchronized processes encountered in manufacturing, traffic systems, when optimizing deterministic dynamic processes, etc.).

The set of real numbers endowed with the operation max (respectively min) denoted $\oplus$ and the operation $+$ denoted $\otimes$ is a nice mathematical structure that we may call an idempotent semi-field. The operation $\oplus$

is idempotent and has the neutral element $\varepsilon = -\infty$ but it is not invertible. The operation $\otimes$ has its usual properties and is distributive with respect to $\oplus$. Based on this set of scalars we can build the counterpart of a module and write the general (n, n) system of linear maxplus equations:

$$Ax \oplus b = Cx \oplus d,$$

using matrix notation where we have made the natural substitution of $\oplus$ for $+$ and of $\otimes$ for $\times$ in the definition of the matrix product.

A complete theory of such linear system is still not completely achieved. In recent development we try to have a better understanding of image and kernel of maxplus matrices.

System theory is concerned with the input (u)-output (y) relation of a dynamical system ($\mathcal{S}$) denoted $y = S(u)$ and by the improvement of this input-output relation (based on some engineering criterium) by altering the system through a feedback control law $u = F(y, v)$. Then the new input (v)-output (y) relation is defined implicitly by $y = S(F(y, v))$. Not surprisingly, system theory is well developed in the particular case of linear shift-invariant systems. Similarly, a min-plus version of this theory can also be developed.

In the case of SISO (single-input-single-output) systems, u and y are functions of time. In the particular case of a shift-invariant linear system, S becomes an inf-convolution:

$$y = h \Box u \stackrel{def}{=} \inf_s [h(s) + u(\cdot - s)]$$

where h is a function of time called the impulse response of system $\mathcal{S}$. Therefore such a system is completely defined by its impulse response. Elementary systems are combined by arranging them in parallel, series and feedback. These three engineering operations correspond to adding systems pointwise ($\oplus$), making inf-convolutions ($\otimes$) and solving special linear equations ($y = h \otimes (f_1 \otimes y \oplus f_2 \otimes v)$) over the set of impulse responses. Mathematically we have to study the algebra of functions endowed with the two operations $\oplus$ and $\otimes$ and to solve special classes of linear equations in this set.

An important class of shift-invariant min-plus linear systems is the process of counting events versus time in timed event graphs (a subclass of Petri nets frequently used to represent manufacturing systems). A dual theory based on the maxplus algebra allows the timing of events identified by their numbering.

The Fourier and Laplace transforms are important tools in automatic control and signal processing because the exponentials diagonalize simultaneously all the convolution operators. The convolutions are converted into multiplications by the Fourier transform. The Fenchel transform ($\mathcal{F}$) defined by:

$$[\mathcal{F}(f)](p) = \sup_x [px - f(x)],$$

plays the same role in the min-plus algebra context. The affine functions diagonalize the inf-convolution operators and we have:

$$\mathcal{F}(f \Box g) = \mathcal{F}(f) + \mathcal{F}(g).$$

A general inf-convolution is an operation too complicated to be used in practice since it involves an infinite number of operations. We have to restrict ourselves to convolutions that can be computed with finite memory. We would like that there exists a finite state x representing the memory necessary to compute the convolution recursively. In the discrete-time case, given some h, we have to find (C, A, B) such that $h_n = CA^nB$, and $y = h \Box u$ is then 'realized' as

$$x_{n+1} = Ax_n \oplus Bu_n, \;\; y_n = Cx_n.$$

SISO systems (with increasing h) which are realizable in the min-plus algebra are characterized by the existence of some λ and c such that for n large enough:

$$h_{n+c} = c \times \lambda + h_n.$$

If h satisfies this property, it is easy to find a 3-tuple (A, B, C).

This beautiful theory is difficult to be applied because the class of linear systems is not large enough for realistic applications. Generalization to nonlinear maxplus system able to model general Petri nets is under development.

Dynamic Programming in the discrete state and time case amounts to finding the shortest path in a graph. If we denote generically by n the number of arcs of paths, the dynamic programming equation can be written linearly in the min-plus algebra:

$$X_n = A \otimes X_{n-1},$$

where the entries of A are the lengths of the arcs of the graph and X_n denotes the matrix of the shortest lengths of paths with n arcs joining any pair of nodes. We can consider normalized matrices defined by the fact that the infimum in each row is equal to 0. Such kind of matrices can be viewed as the min-plus counterpart of transition matrices of a Markov chain.

The problem

$$v_x^n = \min_u \left[\sum_{i=n}^{N-1} \varphi(u_i) + \psi(x_N) \mid x_n = x \right], \ x_{i+1} = x_i - u_i$$

may be called dynamic programming with independent instantaneous costs (φ depends only on u and not on x). Clearly v satisfies the linear min-plus equation:

$$v^n = \varphi \Box v^{n+1}, \ \ v^N = \psi$$

(the Hamilton-Jacobi equation is a continuous version of this problem).

The Cramer transform ($\mathcal{C} \stackrel{def}{=} \mathcal{F} \circ \log \circ \mathcal{L}$), where $\mathcal{L}$ denotes the Laplace transform, maps probability measures to convex functions and transform convolutions into inf-convolutions:

$$\mathcal{C}(f * g) = \mathcal{C}(f) \Box \mathcal{C}(g).$$

Therefore it converts the problem of adding independent random variables into a dynamic programming problem with independent costs.

These remarks suggest the existence of a formalism analogous to probability calculus adapted to optimization that we have developed.

The theoretical research in this domain is currently done in the MAXPLUS project-team. In the METALAU project-team we are more concerned with applications to traffic systems of this theory.

4. Application Domains

4.1. Transport

Traffic modeling is a domain where maxplus algebra appears naturally : – at microscopic level where we follow the vehicles in a network of streets, – at macroscopic level where assignment are based on computing smallest length paths in a graph, – in the algebraic duality between stochastic and deterministic assignments.

We develop free computing tools and models of traffic implementing our experience on optimization and discrete event system modeling based on maxplus algebra.

4.1.1. Microscopic Traffic Modeling

Let us consider a circular road with places occupied or not by a car symbolized by a 1. The dynamic is defined by the rule $10 \rightarrow 01$ that we apply simultaneously to all the parts of the word m representing the system. For example, starting with $m_1 = 1010100101$ we obtain the sequence of works (m_i):

$$\begin{array}{ll} m_1 & = 1010100101, \\ m_2 & = 0101010011, \\ m_3 & = 1010101010, \\ m_4 & = 0101010101, \\ m_5 & = 1010101010, \\ \text{etc.} & \end{array}$$

For such a system we can call density d the number of cars divided by the number of places called p that is $d = n/p$. We call flow $f(t)$ at time t the number of cars at this time period divided by the place number. The fundamental traffic law gives the relation between $f(t)$ and d.

If the density is smaller than $1/2$, after a transient period of time all the cars are separated and can go without interaction with the other cars. Then $f(t) = n/p$ that can be written as function of the density as $f(t) = d$

On the other hand if the density is larger than $1/2$, all the free places are separated after a finite amount of time and go backward freely. Then we have $p - n$ car which can go forward. Then the relation between flow and density becomes

$$f(t) = (p - n)/p = 1 - d \; .$$

This can be stated formally: it exists a time T such that for all $t \geq T$, $f(t)$ stays equal to a constant that we call f with

$$f = \begin{cases} d & \text{if } d \leq 1/2, \\ 1 - d & \text{if } d \geq 1/2. \end{cases}$$

The fundamental traffic law linking the density of vehicles and the flow of vehicles can be also derived easily from maxplus modeling : – in the deterministic case by computing the eigenvalue of a maxplus matrix, – in the stochastic case by computing a Lyapounov exponent of stochastic maxplus matrices.

The main research consists in developing extensions to systems of roads with crossings. In this case, we leave maxplus linear modeling and have to study more general dynamical systems. Nevertheless these systems can still be defined in matrix form using standard and maxplus linear algebra simultaneously.

With this point of view efficient microscopic traffic simulator can be developed in Scilab.

4.1.2. Traffic Assignment

Given a transportation network $\mathcal{G} = (\mathcal{N}, \mathcal{A})$ and a set $\mathcal{D}$ of transportation demands from an origin $o \in \mathcal{N}$ to a destination $d \in \mathcal{N}$, the *traffic assignment* problem consists in determining the flows f_a on the arcs $a \in \mathcal{A}$ of the network when the times t_a spent on the arcs a are given functions of the flows f_a.

We can distinguish the deterministic case — when all the travel times are known by the users — from the stochastic cases — when the users perceive travel times different from the actual ones.

1. When the travel times are deterministic and do not depend on the link flows, the assignment can be reduced to compute the routes with shortest travel times for each origin-destination pair.
2. When the travel times are deterministic and depend on the link flows, Wardrop equilibriums are defined and computed by iterative methods based on the previous case.

3. When the perceived travel times do not depend on the link flows but are stochastic with error distribution — between the perceived time and the actual time — satisfying a Gumbel distribution, the probability that a user choose a particular route can be computed explicitly. This probability has a Gibbs distribution called logit in transportation literature. From this distribution the arc flows — supposed to be deterministic — can be computed using a matrix calculus which can be seen as the counterpart of the shortest path computation (of the case 1) up to the substitution of the minplus semiring by the Gibbs-Maslov semiring, where we call Gibbs-Maslov semiring the set of real numbers endowed with the following two operations :

$$x \oplus^{\mu} y = -\frac{1}{\mu}\log(e^{-\mu x} + e^{-\mu y}) \ , \ \ x \otimes y = x + y \ .$$

4. When the perceived travel times are stochastic and depend on the link flows — supposed to be deterministic quantities — stochastic equilibriums are defined and can be computed using iterative methods based on the logit assignments discussed in the case 3.

The purpose of this research is double :

1. To study an engineering example of quantization. By quantization we mean the application of a morphism changing a deterministic optimization problem into a linear system of equations for modeling improvement by analogy with the way we obtain the Quantum Mechanics Equation from the Hamilton-Jacobi Equation of a system. This quantization can be seen as an application of what we have called previously “the duality between probability and optimization” introduced in the section 4.1.2
2. To develop a toolbox in Scilab dedicated to traffic assignment indeed it does not exist any free toolbox for this kind of application.

4.2. Modal analysis and diagnosis

We have used the techniques developed for modal analysis and diagnosis in many different applications: rotating machines, aircrafts, parts of cars, space launcher, civil structures. The most recent examples are:

- Eureka (FLITE) project: exploitation of flight test data under natural excitation conditions.
- Ariane 5 launcher: application to a ground experiment (contract with CNES and EADS Space Transportation)
- Steelquake: a European benchmark for a civil structure.

4.3. Plant Growth Modeling

Mathematical models on tree architecture principally concern the step by step algorithms depending on a genetic program, that insure the organ production during the growth process. Adding geometrical rules, one can obtain nice tree shapes that are used mainly in the world of computer graphics.

This pure morphogenetic approach has given in particular a formalism based on grammar called L-System or on Automata.

In agronomy, the vegetable matter production is the main goal. Simulation of the photosynthesis (biomass production and biomass allocation) is then performed, thanks to crude plant models mainly divided in compartments (leaves, branches, roots,...). No specific formalism has been developed in these last cases.

Recently new kind of tree models arouse, named “structural functional tree”. These models endeavor to combine both aspects: organogenesis and photosynthesis. The L-System approach has, then, also incorporated interactions with environment. In all the cases the principle of the growth starting from seed and the parallel simulation of numerous buds can make the computing time of a big tree quite long.

A new approach of tree computation has been implemented in the dynamical model GreenLab. Thanks to the physiological Ages notion and the botanical description, it is possible to divide a tree according to substructures that can be retrieved frequently inside the main architecture. Computing only one time these substructures improves dramatically the speed of the computation.

5. Software

5.1. Advanced software

- Scilab scientific software package (open source software available from Scilab)
- Scicos object oriented modeler, simulator and code generator included in Scilab (Scicos)
- CiudadSim Scilab Traffic Assignment toolboxes
- COSMAD Output modal analysis and diagnosis
- Greenlab plant growth simulation
- MAXPLUS Maxplus arithmetic and linear systems toolbox by the Maxplus Working Group
- SLICOT Interface with SLICOT library for computations in systems and control theory
- LIPSOL Linear-programming Interior-Point SOlvers for Scilab
- FSQP Interface Scilab-FSQP optimization tool
- CUTEr testing environment for optimization and linear algebra solvers
- LMI optimization for robust control applications (included in Scilab)

The above software packages are all available freely from Scilab.

5.1.1. Prototype software

- Implicit Scicos: new extension of Scicos for modeling more naturally physical systems based on Modelica language
- Digiplant extension of Greenlab with new modeling techniques

6. New Results

6.1. Plant growth modeling

The improvement of the GreenLab model in phase III concerns the interaction between the Organogenesis and the Photosynthesis during the plant growth. It needs to improve the dynamical equations of the Growth Process. The breakthrough has been to modelize the bud functioning and to take account of the ratio Supply/Demand.

Paul Henry Cournède, young professor in ECP, is developing a code to simulate the plant growth and the plant architecture. Calibration tools have been carried out to make the model able to fit real plants.

Amélie Mathieu student in Digiplante team does her Phd on that subject in ECP. The behaviour of the model is the main goal of her study. General results have been proved on the conditions of the stability of the Plant functioning. Complex interactions are carried out between the climate conditions and the plant endogenous functioning.

Another student of ECP Veronique Letort begins to write the interface between GreenLab and the current model of Genetic based on QTL. The result of this work is to be applied by the geneticians of Inra.

About the phase I of Greenlab model the Chinese student Wulin has solved the problem of the application of the Control methods on the dynamical equations. The goal of this study is to optimize the water supply in limited condition for the Sunflower. This issue is of a great interest for Agronomy. The Phd is supervised by professors Ledimet, Goursat and Quadrat.

Work with Liama is of high intensity. I supervise 5 Pdh there. The GreenLab model is fitted to real plants. Phd on Tomato and Maize carry on very well. Two computer scientists Qiao Xue and Xiao Ma have written good codes of GreenLab model for these plants. The action of light on plant growth is studied. A link with Inria to apply radiosity is realised.

6.2. Computer aided control system design

6.2.1. Scicos

Participants: R. Nikoukhah, S. Steer, A. Azil, M. Najafi, C. Bourcier.

The development of Scicos continues. This work is financed mainly through the RNTL projects Simpa, Eclipse and Metisse. A new more efficient compiler has been developed. This work was done by C. Bourcier, an intern supported through the Eclipse project in collaboration with the AOSTE project team.

The extension of Scicos to allow for “implicit blocks” in the framework of the RNTL Simpa project has been pursued. It is now possible to define implicit blocks in Scicos using (a subset) of Modelica language. This new extension is being tested using application examples from EDF.

In the context of the Metisse project, work has been done to allow the import of Amesim diagrams into Scicos. Closer integration between Scilab/Scicos and Amesim is being considered.

Scilab code generator has been extended and can now accept continuous-time blocks. The stand-alone usage of the generated code however requires the implementation of a fixed step size solver which is not yet available. This latter is also needed in the context of the Eclipse project and in particular the test examples from PSA.

A book on modeling and simulation in the Scilab/Scicos environment is in progress. This book contains a complete documentation for Scicos.

6.2.2. Scilab

Participants: R. Nikoukhah, F. Delebecque, J. Ph. Chancelier, S. Steer.

Metalau project continues to support the development of Scilab through both fundamental research and specific developments. The team has been working on defining the future extensions of the Scilab language and their implementations. These extensions which must be in line with applications in sytems and control, will be developed to facilitate the use of Scilab. These extensions include in particular new types of objects.

The work on the development of Matlab compatible mexfiles utilities has been pursued and is now pratically complete. This utility facilitates the work of the Matlab-Scilab translator which is being developed by the Scilab project team. The main purpose of this utility however is to make possible simultaneous development of toolboxes for Matlab and Scilab. To make these mexfiles operational in Scilab a number of new functionalities have been added to Scilab kernel, in particular those concerning the cells and structure objects. These objects can now be manipulated in Scilab similarly to Matlab.

The Metalau project continues to support and maintain the toolboxes it has developed in the past: LMITOOL, control, signal processing, etc.

6.3. Control and signal processing

6.3.1. Active failure detection

Participants: R. Nikoukhah, S.L. Campbell.

We develop a novel theory of robust active failure detection based on multi-model formulation of failures. The results of years of research have been published in a book in 2004.

We have continued also to work on the extension of our approach to more general situations. We started the study of active failure detection in continuous-time dynamical systems with sampled observations and obtained some interesting results last year. We have pursued this work and we now have a complete and efficient solution which is a subject of a journal paper accpeted for publication.

We have also examined numerical aspects of the implementation of our technique. This work is done in close collaboration with a PhD student of S.L. Campbell at NCSU.

6.3.2. Modal analysis and diagnosis

A comprehensive and consistent methodology in terms of covariance driven subspace for identification and modal detection of changes in case of output only measurement leading to a Scilab toolbox COSMAD has been developed. This toolbox is currently in an industrial evaluation process at EADS Space Launchers and CNES.

Significant results obtained for the physical diagnosis and defect isolation. The COSMAD toolbox includes a prototype version for this purpose.

6.4. Discrete event systems, Maxplus algebra and dynamic programming

6.4.1. Maxplus algebra and projective semimodule

Participants: G. Cohen, S. Gaubert, J.P. Quadrat.

In maxplus algebra, linear projectors on an image of a morphism B parallel to the kernel of another morphism C can be built under transversality conditions of the two morphisms. The existence of a transverse to an image or a kernel of a morphism is obtained under some regularity conditions. We have shown, this year, in [42] that those regularity and transversality conditions can be expressed linearly as soon as the space to which $\mathrm{Img}(B)$ and $\mathrm{Ker}(C)$ belong is free and its order dual is free. The algebraic structure $\overline{\mathbb{R}}^n_{\max}$ has these two properties. This result improves previous works using a maxplus Hahn Banach theorem to characterize linear projectors.

Moreover, the understanding of the duality between projective and injective semimodules and the links between idempotent semimodules and module theories has been improved. This work will be a contribution to a reference paper on the characterization of projective semimodules that we are continuing to write.

A popularization paper on maxplus algebra and discrete event systems has been also written [26].

6.4.2. Stochastic Control with Incomplete Observation

Participants: N. Farhi, J.P. Quadrat.

We have solved numerically optimal control problem of finite Markov chains in the case of incomplete observations. By quantifying the possible optimal filters we have obtained an approximation of the support of the probability law of the optimal filter. We have solved the dynamic programming equation on this space of quantified states. On two examples we have shown that this point of view is effective : – a secretary job problem, – a standard optimal renewal problem, in spite of the high à priori complexity of the problems considered. Indeed, on this two examples, the support of the probability law of the optimal filter, which belongs to a space of large dimensionality, can be approximated easily. In the first case the optimal filter has only a recurrent state. In the second case we can easily paramatrize this law using only two parameters. The results have been published in [61].

6.5. Transport

6.5.1. Microscopic Traffic Modeling

Participants: N. Farhi, M. Goursat, P. Lotito, E. Mancinelli, J.P. Quadrat.

In a starting thesis work we continue previous works done by P. Ndong and Tao Zhenyu on determining the fundamental traffic law for a road system with crossings. The fundamental traffic law gives the relation between the average flow and the density of vehicles in the system. After having obtained the equations for a general Petri Net and have applied it to a the modeling of a crossing with or without traffic lights in the previous works, by numerical experiments, we have identified the different phases and the macroscopic parameters from which depend these phases. We will try to analyze mathematically in the thesis of N. Farhi the observed results. First we have to justify the existence of the macroscopic variable and of their relations which is true only asymptotically when the number of places in the street go to infinity. We will try, in future work to determine the influence of the traffic lights on this law and optimize it with respect to the parameter of the traffic light controls.

Moreover the work on the derivation by maxplus methods of the fundamental traffic law, in the case of a unique circular road, is accepted in the IEEE-AC journal [9].

6.5.2. Optimal Pricing

Participants: P. Lotito, E. Mancinelli, J.P. Quadrat, L. Wynter.

This work is concerned with the bi-level optimization problem where we want, at the upper level, optimize the prices of some resources of a traffic network taking into account the impact of this pricing on the traffic assignment defined by an optimization problem (the lower level). This kind of problem is non concave. In previous work we have given heuristics to solve this non concave problem. We have continued this work by implementing in the Ciudadsim toolbox of Scilab the resolution of these two levels problems. An INRIA report is in preparation on this heuristic.

The upper level, in the simpler case, is piecewise quadratic with a paving done with convex polyhedra. We have tried to characterize the convex polyhedron on which the optimum is achieved without success. But the improvement in the understanding of the shape of the upper level criterion has given some improvement for the starting point of the heuristic discussed previously. The discussion about the mathematical properties and shape of the upper level criterion has been accepted in [32].

7. Contracts and Grants with Industry

- Eureka (FLITE) project: exploitation of flight test data under natural excitation conditions (Dassault Aviation, Airbus France and SOPEMEA are the French industrial partners)
- RNTL Project SIMPA. Main objective: extend Scicos capabilities to allow the usage of “implicit blocks”. Examples from EDF and IFP.
- RNTL Project ECLIPSE. Objective: provide Scicos with real-time multiprocessor code generation capabilities through an interface with the SynDEx software. Examples from PSA.
- RNTL Project METISSE. Objective: provide Scicos with the capability to import models constructed using the software AmeSim. Partner : the company Imagine.
- RAPL: Trucks automated traffic. Partners : LIVIC, Cofiroute, Renault...

7.1.1. Other funding

- Project transportation pricing (PREDIT)
- ACI Constructif: the ACI is leaded by the project-team SISTHEM and the partners are the project-team MACS, the MSSMat laboratory from ECP and the LCPC.

8. Other Grants and Activities

8.1. International Actions

- F. Delebecque, M. Goursat, B. Pinon, S. Steer.
  Organization of a Scilab Workshop with ENSAM Meknès. This workshop has been held (1-6 March 2004) at the University Moulay Ismaël (Meknès, Morrocco). The attendees of this workshop were teachers and Ph D. Students from different universities of the country.
- F. Delebecque, M. Goursat, R. Nikoukhah
  Organization of a Scilab-Scicos session at IEEE-CACSD Conference Taipei-Taiwan (August 2004).

8.2. National Actions

- F. Delebecque, M. Goursat, H. Perdereau.
  Organization of the first Scilab Conference with the Scilab project-team. This conference has been held (2-3 december 2004) at Rocquencourt.

8.3. Cooperations

- University of Rosario (Argentina): on optimal control problems and application with the research team of R. Gonzales under the coordination of E. Rofman.
- North Carolina State University (USA): on failure detection and numerical solution of hybrid DAEs under the coordination of R. Nikoukhah.
- LIAMA (Equipe associée): on plant modeling under the coordination of Ph. de Reffye.
- CIRAD: on plant modeling under the coordination of Ph. de Reffye.
- ECP: on plant modeling under the coordination of Ph. de Reffye.
- ENPC Cermics: on maxplus algebra under the coordination of G. Cohen, and on future of Scilab with J. Ph. Chancelier.

9. Dissemination

9.1. Scientific Committees

- R. Nikoukhah.
  - Member of the International Program Committee of the Meditteranean Control and Automation Conference 2004 and 2005.
  - Member of IFAC Technical Committee on Fault Detection, Supervision and Safety in Technical Processes (SAFEPROCESS TC).
  - Member of International Program Committee for SAFEPROCESS 2006.
  - Senior Member of IEEE.
- F. Delebecque
  - Member of the French national board of “Agrégation de Mathématique”.

9.2. University Teaching

- R. Nikoukhah
  - Ensta: Systems and Control, 2nd year, Dynamic Programming, 3rd year.
  - Pulv: Systems and Control, fifth year, Stochastic processes, forth year.
- J.P. Quadrat
  - Paris 1 : Introduction to optimal stochastic control: DEA.
- F. Delebecque
  - Ensta: Systems and Control, 2nd year.
  - Essi: Financial Math, DESS.
- Ph. de Reffye
  - ECP: Plant growths modeling.

9.3. Ph.D. Thesis supervision

- M. Najafi, supervised by R. Nikoukhah.
- A. Azil, supervised by R. Nikoukhah.
- A. Mathieu, Supervised by Ph. de Reffye.
- N. Farhi, supervised by J.P. Quadrat and M. Goursat.

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