# Chapter 5

# Project of "pôle SIS" (Signal, Images, Systèmes)

## 5.1 Permanent members (01/2012)

| | position | pedr or pes | teaching dpt | A/D | administrative duties |
|---|---|---|---|---|---|
| Allibert Guillaume | MCF 61 | | GEII.IUT | | |
| Antonini Marc | DR2 CNRS | | | | In charge of VIM speciality of Master IFI (2008/-) |
| Barat Christian | MCF 61 | | GEII.IUT | | |
| Barlaud Michel | PREX 61 (Emerit.) | PEDR 2007 | | | |
| Blanc-Feraud Laure | DR2 CNRS | | | | |
| Comon Pierre | DR2 CNRS | | | | |
| Comport Andrew | CR2 CNRS | | | | |
| Debreuve Eric | CR1 CNRS HDR | | | | |
| Deneire Luc | PR2 61 | | elec.EPU | | In charge of SICOM Master |
| Descombes Xavier | DR2 INRIA | | | | |
| Ducard Guillaume | MCF 61 | | elec.EPU | | |
| Favier Gerard | DR2 CNRS | | | | |
| Hamel Tarek | PR1 61 | PEDR 2007 | GEII.IUT | | |
| Icart Sylvie | MCF 61 | | elec.EPU | | |
| Lebrun Jerome | CR1 CNRS | | | | |
| Lopez Dino | MCF 27 | | info.EPU | | |
| Mathieu Pierre | MCF 61 | | R&T.IUT | | Head of dept R&T IUT |
| Menez Gilles | MCF 61 | | info.UFR | | |
| Meste Olivier | PR1 61 | PEDR 2008 | GEII.IUT | | |
| Payan Frederic | MCF 61 | | R&T.IUT | | Head of 2nd year of R&T.IUT |
| Pronzato Luc | DR1 CNRS | | | | |
| Rix Herve | PR1 61 (Emerit.) | | | | |
| Sassatelli Lucile | MCF 61 | | R&T.IUT | | |
| Thierry Eric | MCF 61 HDR | | GEII.IUT | | |
| Torres Rendas Maria-Joao | CR1 CNRS | | | | |
| Urvoy-Keller Guillaume | PR2 27 | | R&T.IUT | 2010/ | Head of Licence pro IUT R&T |
| Zarzoso Vicente | PR2 61 | PEDR 2007 | GEII.IUT | | |

## 5.2 Self evaluation

**Strengths** The “pôle SIS” benefits from a long tradition of intensive research in Signal Processing, Image Processing and Systems Theory. This leads the pôle to have strong and productive activities in high order signal processing and tensors, image processing, system identification and control as well as their applications in biomedical engineering, communications and drones.

In this framework, the major strengths of the pôle are as follows:
– The presence of a large number of senior (CNRS and INRIA) researchers enables SIS to rely on solid fundamental research topics (Tensor Data & Signal Processing, system identification and modeling, image coding, control theory and probabilistic techniques), assessed by the participation in a large number of Networks of Excellence, national and European projects, along with a good publication record.
– Moreover, SIS members are strongly committed to applying their research in various application areas (biomedical signal and image processing, drones, telecommunications. . . ), which is demonstrated by a large number of contracts with industry.
– Most of these activities take place in well established groups that have strong relations with local institutions (INRIA in particular) along with both national and international ones.
– The possible co-existence of leading established groups with smaller ones is a strength as it nurtures the growth and expansion of emerging topics whilst maintaining rich cross-team collaborations and reactivity.

**Weaknesses** The main weaknesses of SIS are:
– Its quite broad scope, that makes it difficult to have a strong cohesion between teams and members within the pôle.
– Its relatively low implication in the faculty of Sciences (due to the fact that signal processing in this faculty is taught by people that are in other labs, located in Nice rather that in Sophia-Antipolis).
– Related to that, the lack of a leading role for an educational institution (even if SIS is leading a master on Signal Processing and Image Processing at the Ecole Polytechnique Universitaire (EPU), the (associate and full) professors are distributed throughout the IUT, the faculty and the EPU).
– A cruel lack of permanent support engineers, which is a major problem for the implementation of experimental platforms.

**Opportunities** During the last four year period, a number of events have arisen within SIS, namely the recruitment of 9 new (associate and full) professors and researchers as well as the promotion of three senior associate professors. This has led to the emergence of new activities (one being a major evolution of a previous activity (drones) and the other a completely new activity (networks)). In view of this evolution the main opportunities are:
– The participation of SIS on national platform for drones, which should enhance I3S’s visibility.
– For the activity on network, the possibility to collaborate with the group working on signal processing for communication within the pôle, along with the COMRED pôle and teams at INRIA and Eurecom.
– The existence of the Ubinet Master (devoted to networking and targeted at an international audience, as courses are given in English).
– The participation of the university and INRIA towards the EIT-ICT Labs.
– The strong relations with INRIA, in various fields, which should lead to new activities (image processing for biology, which is described below, but also possibly signal processing for environment and vision for localization and mapping).
– The existence of a master on signal processing and image processing as well as a master on computational biology (where courses are given in English and where 4 members of SIS are teaching).

**Risks** The recruitment events described above, as well as some of the weaknesses lead to the following risks:

- a dispersion of topics (this risk has been for example addressed by the creation of the two new teams on drones and networks);
- the risk of exhausting members that have large contractual involvement;
- the risk of “loosing” members that are heavily involved in teaching activities;
- the difficulty in incorporating a large number of new junior permanent staff (to find them PhD students and help them in defining their research area);
- as for the other poles, the difficulty in finding good and motivated PhD students.

As one can see from this “opportunities and risks” analysis, the major challenges for SIS, following the recent recruitments, are, along with the continuation of previous projects, (1) to define new directions and (2) to ensure a proper career evolution for the junior members as well as (3) to foster and motivate research activities for members that are heavily involved in teaching activities.

## 5.3 Project and objectives

### 5.3.1 Tensor Data & Signal Processing

**Main contributors** *P. Comon, G. Favier, S. Icart, V. Zarzoso*

The aim of this research project is two-fold. On one hand, theoretical problems related to tensors will be addressed: tensor decompositions, uniqueness and identifiability properties of tensor models, numerical algorithms for parameter estimation. On the other hand, Telecommunications, Environment, Radar Imaging or EEG Imaging will serve as leading applications.

**Tensor decompositions.** Two families of tensor decompositions will be studied. The first one concerns decompositions into a sum of low-rank tensors, the most common being the Canonical Polyadic (CP) decomposition, also called Parafac decomposition, that corresponds to a sum of rank-1 tensors. Some conjectures are still partially unproved, including the fact that a tensor of rank strictly smaller than generic almost surely admits a unique CP decomposition [8], or the fact that the rank and the symmetric rank coincide [7].

The second one concerns Tucker type decompositions, the most popular being the high order singular value decomposition (HOSVD), very useful for data compression. Unlike the Parafac decomposition that is essentially unique under known conditions, the Tucker one is generally not unique unless some constraints are imposed on the core tensor, as in the case of the constrained Tucker model we proposed in [11] for MIMO nonlinear CDMA systems, or the constrained tensor model called CONFAC, in the context of MIMO antenna systems [10].

**Identifiability.** Uniqueness of tensor decompositions and parameter identifiability are strongly related. Models to identify can be purely multilinear (as in telecommunications, or fluorescent spectrometry at very low concentrations), or multilinear under constraints (*e.g.* CONFAC, or constrained Tucker). The design of such constrained tensor models along with the study of their uniqueness/identifiability properties will be the subject of future research.

**Development of numerical algorithms.** Tensor users in Engineering often do not use efficient algorithms. That’s why a tensor package is already under development upon the initiative of P. Comon and with the help of X. Luciani and J-P. Royer. It includes various standard optimization techniques, but also less standard (Enhanced Line Search, Hankel structure, positivity constrained. . . ). One or several matrix factors entering the CP tensor model can be structured, *e.g.* Hankel or block Hankel. Efficient non iterative algorithms can be devised in these circumstances, and do not suffer from the presence of multiple local extrema.

There does not exist general algorithms with proved convergence towards the global optimum, for computing the CP of general tensors. The development of algebraic solutions, extending those developed in [5] in the complex symmetric case, needs to be pursued. The simplest case is the calculation of the best rank-1 tensor approximation, and is –perhaps surprisingly– still under investigation.

**Applications to Telecommunications.** The first goal concerns the design of new transceivers with resource allocation, in the context of MIMO antenna systems, using constrained tensor models. The second one is to blindly and jointly estimating the channels, the transmitted symbols, and eventually the codes, using data tensor-based approaches. We recently proposed in [11] a new constrained Tucker model for MIMO CDMA systems using a nonlinear coding. Several perspectives of this work can be drawn, as for instance the development of adaptive algorithms that take the constrained structure of the input tensors into account, an optimization of the code matrices, and also more general multi-antenna/multicode transmission and multipath propagation scenarii. Another research topic concerns the design of blind receivers for nonlinear channels as it is the case with satellite or radio over fiber multiuser communication systems.

**Applications to nonlinear system modeling and identification.** We recently developed two such applications. The first one concerns a new family of nonlinear models, the so called Volterra-Parafac models, obtained in using a Parafac decomposition of high-order Volterra kernels viewed as tensors, which can result in a drastic parametric complexity reduction when the rank of the kernels is small with respect to their memory. An extended Kalman filter and LMS type algorithms were proposed to estimate the coefficients of such Volterra-Parafac models. Extensions of these results will be considered both from the tensor-based modeling (in particular for MIMO nonlinear communication channels) and algorithmic viewpoints.

The second one consists of applying a tensor analysis for determining the structure and estimating the parameters of block-structured nonlinear SISO systems, like Wiener, Hammerstein and Wiener-Hammerstein systems [21]. These results will be extended to more general block-structured nonlinear MIMO systems. Moreover, the associated Volterra kernels having constrained structures (Toeplitz, band-Toeplitz factors), specific algorithms taking such structures into account will be developed.

Note that this application is closely linked to the System identification and modeling activity described in Section 5.3.7.

**Applications to EEG Imaging.** We have already demonstrated in [4] that cerebral sources can be localized without solving the Maxwell equations. The idea is to exploit their nonstationarity in space and time. This leads to the decomposition of tensors, which can be supposed to be multilinear in a first approximation.

**Applications to Environment.** Several tensor decompositions may be studied in the context of environmental applications. The analysis of *water quality* by fluorescence spectrometry involves the identification of a tensor model, which is multilinear only at very low concentrations [37]. The *control of bioreactors* requires the measurement of the output biomass (concentration) as a function of time for various temperatures or various input streams. The tensor model is multilinear but components are coupled. The study of *microbial ecosystems*, for instance under the ground, can be perfomed by several techniques including electrophoresis in gel. Macro-molecules as ADN or ARN can be separated and classified this way. A decomposition of the three-variate function into a sum of products of univariate functions would be helpful.

**Applications to Radar Imaging.** The objective is to use a multilinear analysis for data compression and object recognition/classification in synthetic aperture radar (SAR) images. A high-order tensor can be formed from a SAR image database, each mode corresponding to a variation factor (bearing angle, viewpoint, polarisation. . . ). A multilinear projection is carried out to project the unknown object into multiple basis that characterize the learned classes from the training set. Multilinear projection algorithms will be the subject of future work.

### 5.3.2 Signal Processing and Networks

**Main contributors** *Luc Deneire, Jérôme Lebrun, Dino Lopez, Lucile Sassatelli, Guillaume Urvoy-Keller*

Signal Processing has been instrumental in the development of wireless networks, for example the introduction of MIMO (Multiple Input Multiple Output, i.e. multiple antennas at the transmitter and multiple antennas at the receiver) has significantly increased the capacity of wireless links and hence networks.

Unfortunately, the huge capacity gains on the link level do not scale at the network level, either for fundamental reasons that can be formalized by network information theory, or for technical reasons, in particular when high layer protocols are not specifically designed with the wireless channel in mind.

Taking these two aspects in mind, as well as the opportunity given by the recruitement of three (full and associate professors) in networking, I3S has decided to promote an activity which is at the frontier between "signal processing for communications" (more broadly Physical Layer related research) and networking, mainly in the frame of wireless networks.

The current activity plans are targetted at,

– **for the cross layer oriented research** : Transport and routing protocols for wireless mobile ad hoc networks (including sensor networks), transport protocols for large and dynamic bandwith/delay product networks and,
– **for the more signal processing oriented research** : Power efficient space-time coded modulation and cognitive radio.

**Transport and routing protocols for wireless mobile ad hoc networks.** This starting activity has been awarded an "ANR jeune chercheur" project.

The main target of this activity is the so-called MANET (Mobile Ad-hoc Networks), which is made of mobile users, mostly without the help of an infrastructure (no basestations). Due to node mobility and device heterogeneity, connectivity between nodes is intermittent, which leads to volatile networks. To cope with volatility, new internet architectures and protocols have to be developed. Networks that cope with this volatility are named Delay Tolerant (DT) networks. The main challenges of these DT-MANETs are the design of an architecture and protocols that work well in an environment characterized by uncertain networking conditions, high mobility and frequent network partition. Specifically, one has to design transport and routing protocols for DT-MANETs, but also determine the capacity of the DT-MANETs. The major novelty of the approach proposed, besides the inherent cross-layer nature of the problem is the use of network coding. Network coding is a (by now popular in the research community) technique that takes advantage of linear combination of data to lower the global resources needed to transfer data in a network. This technique has proven to be beneficial in specific transport layer design for wireless networks and we want to investigate further its benefits for DT-MANETs.

**Transport protocols for large and dynamic bandwith/delay product networks.** The complete independence of the End-to-End (E2E) protocols to the network infrastructure, allow their incremental deployment in heterogeneous IP networks, such as the Internet. The commonly used E2E protocol is TCP NewReno (referred to as, simply, TCP). However, networks with long delay and/or high bandwidth (known as large bandwidth-delay product -BDP- networks) are appearing. In such a large BDP network, TCP is unable to grab all the available resources. Moreover, wireless networks become much more dynamic than the wired links. To fully utilize the resources in large BDP networks, several approaches have been proposed. For instance, high speed versions of TCP, TCP versions with delay-based techniques to detect the under-utilization of the resources (*e.g.* TCP Vegas), and Explicit Rate Notification (ERN) protocols, where the routers inform the sender about the maximum achievable rate (*e.g.* XCP). However, high speed and delay-based TCP versions introduce inter and intra protocol unfairness. On the other hand, Explicit Rate Notification (ERN) protocols have demonstrated very high performances and fairness. Moreover, the ERN protocols are not compliant with current network protocols, limiting their use to experimental networks.

The main goal of this activity is hence to propose transport protocols that can cope with large BDP networks, that are interoperable with the other TCP versions and that can cope with the (by now classical) problems encountered in the wireless segments.

**Continuous phase space-time coded modulation.** To combine the power efficiency of Continuous Phase Modulation (CPM) with enhanced performance in fading environments, the use of CPM in combination with Space-Time Codes (STC) has recently been suggested [38]. In this activity, we will further investigate our recently developed CPM ST-coding schemes based on L2 -orthogonality. In [15, 14, 16], we already constructed a family of L2-orthogonal codes coined Parallel Code (PC). Now, by switching to multi-h CPM modulations [29], we plan to generalize further these designs to non-parallel codes (typ. crosswise mapping [13]). We will also study the use of convolutional codes (LDPC type) [25] in the design of CPM based MIMO systems so as to alleviate some difficulties in the design of non-parallel codes. We also detailed in [17] that by using L2 -orthogonality, the decoding complexity, usually exponentially proportional to the number of transmitting antennas, can be reduced to linear complexity. However, some practical considerations such as synchronization [6] remain to be thoroughly studied in order to provide robust implementations of our CPM based MIMO systems. A major achievement in our designs is that the systems based on this family of codes have full rate and achieve full diversity. Furthermore, unlike classical pointwise-orthogonality based STC, the proposed code designs display no restriction when extended to three and more transmit antennas [14]. However it is unclear how these properties may be used or extended in multi-user systems [2]. A promising approach relying on frequency-division multiplexing (FDM) for multi-user systems has recently been developed [1] for classical CPM. We plan to generalize this approach in our framework.

**Cognitive radio.** Current wireless networks use the radio spectrum in a very inefficient manner. Indeed, a frequency bandwidth is allocated in a fixed manner to the user, even when this user is not using the radio resource. This type of user is denoted as a “primary” user. When the primary user is not active, a “secondary” user could take advantage of the free spectrum: this is the idea behind *cognitive radio*. In this activity, the objective is to allow a primary user and a secondary user to transmit simultaneously. Indeed, if the interference caused by the secondary user is somehow known by the primary user, the latter can null out this interference and continue to transmit with the same throughput. To be able to perform this interference cancellation, the different users must share some information (in the extreme case, share all the transmitted messages). The goal of this activity is to explore the cooperation strategies (which information have to be shared) to enable the development of cognitive radio networks where both primary and secondary users transmit simultaneously.

### 5.3.3 Biomedical Signal Processing

**Main contributors** *O. Meste, H. Rix (émérite), V. Zarzoso*

I3S researchers working on biomedical signals aim to develop strong local collaborations around the processing, analysis and modeling of signals issued from Medicine and Biology. Inheriting from the former BIOMED group at I3S, ongoing research partnerships include the Cardiology Departments of Nice University Hospital (CHU) and Monaco Princess Grace Hospital (CHPG), as well as Nice University Sports Department (STAPS) together with the Institute of Sport Medicine of Monaco (IM2S). In the forthcoming years, the group’s activities will mainly focus on the analysis of heart diseases, with special emphasis on cardiac arrhythmias such as atrial fibrillation, and heart physiology coupled with respiration and blood pressure through exercise records. An important original goal of this project is to strengthen and consolidate an "information technology for health" (STIC-Santé) regional cluster of research into heart diseases. This local network will be founded on a recent national research contract (ANR) granted to I3S. These activities will not be restricted to local collaborations but will also open to international partners such as the Institute of Biocybernetics and Biomedical Engineering, Warsaw, Poland, through a 3 year international scientific program (PICS) granted by CNRS and PAS (2010-2012).

**Arial fibrillation (AF) analysis.** Despite being the most common cardiac arrhythmia encountered in clinical practice, the mechanisms behind the generation and self-perpetuation of AF are not yet fully understood. For these reasons, the disease is often referred to as "the last great frontier of cardiac electrophysiology". Further research at I3S aims at improving the understanding of this condition while having a direct clinical impact on the increasingly popular catheter ablation therapy. Current practice strongly relies on the expert's intuition and, as a result, inconsistent success rates have been reported by different centers offering the therapy. Our goal is to develop signal processing techniques yielding quantitative information to help the cardiologist perform a successful ablation while reducing its cost, duration and potential risks. A first part of this study will aim at an accurate cost-effective patient selection strategy by analyzing the surface electrocardiogram (ECG). As opposed to previous studies, the proposed research seeks a multidimensional (space-time-frequency-shape) characterization of the atrial ECG signal through the suitable combination of array signal processing techniques (*e.g.*, PCA, ICA and variants), time-frequency decompositions and wave-shape variability analysis. This first part will be partly funded by a 3-year "Young Researcher" ANR contract recently awarded to the team. A second part of the project will focus on the so-called complex fractionated atrial electrograms (CFAEs), a particular kind of endocardial signals thought to play a crucial role in the success of the ablation therapy yet still lacking a rigorous quantitative characterization.

**Cardiorespiratory system, exercise.** The cardiorespiratory system is complex in nature because of the nonlinear coupling observed within the heart rate variability. This complexity has been simplified by neglecting the blood pressure influence. A more general model including this factor will be proposed to confirm the findings obtained in previous works. Until now, this application aimed to provide a model of the heart rate variability for physiologic assessments. In the context of the proposed global project on heart disease characterization, ECG recordings during exercise provide new physiological conditions where the neural activity plays a prime role.

**Collaboration with the polish team (PICS).** The program entitled "Biomedical signals variability: analysis and interpretations for supporting non-invasive medical diagnosis" concerns especially cardiovascular disorders and brain perfusion deficit. The proposed project aims at improving non-invasive medical diagnosis by a detailed analysis and interpretation of the variability of optical and electrical bio-signals, in particular:

- Laser-Doppler micro perfusion signals recorded during arterial occlusions, post-occlusive hyperaemia and thermal stimulation. Laser Doppler spectra decomposition will be carried out.
- Perfusion and oxygenation signals of near infrared spectroscopy. The analysis will especially concern the distribution of time of flight of photons in tissue.
- EEG signals recorded simultaneously with the brain optical signals; in addition somatosensory Evoked Potentials (EP) will be recorded.
- Body surface potential maps (BSPM). A particular attention will be paid to the analysis and identification of heart repolarization and T-wave Alternans (TWA).

The objective of the first two points is to exhibit and evaluate the empirical or theoretical relations between the observations (distributions of time of flight of photons, distributions of red cell velocities in blood) and physical parameters like diffusion or absorption coefficients. The third point concerns detailed interpretation of brain neuro-vascular coupling, and will be compared to SPECT analysis. In addition, EP shape analysis will provide another means to assessing the oxygenation rate in the brain.

### 5.3.4 Analyzing and Processing Images for Biology

**Main contributors** *Laure Blanc-Féraud, Éric Debreuve, Xavier Descombes*

Recently, more and more imagery systems have emerged in all areas of life sciences. Among them, lot of innovative technologies produce images of biological systems at the cellular or sub-cellular levels, in 3D and 3D+t when imaging living cells. The potential is great for biologists with more and more imaging platforms being created in biological research centers, grouping image acquisition specialists (optic physicists) and biologists. Whereas optical manufacturers propose numerical processing utilities for image restoration and analysis with their optical systems (*e.g.* software packages as Imaris, Huygens, Metamorph), there is a need for specialized adapted image processing along with extended research programs in order to tackle this very high resolution imagery and to automatize the treatments.

This domain is rich and fruitful in new problems of image processing. We already have worked on some of these problems, in collaboration with bio-physicists and biologists. The three researchers have a complementary background and a solid experience in image processing including modeling by variational approaches and PDEs, stochastic approach, stochastic geometry, object and texture modeling, statistical analysis and indexation. We propose to create a new project-team dedicated to image processing for biology. This team is named APIBIO (Analyzing and Processing Images for BIOlogy) and will be a common group between I3S and INRIA. In the following, we point out some topics we will develop in the next 4 years.

#### A) Improving the quality of images

**Denoising.** Progress in denoising methods underwent a significant leap forward with nonlocal, patch-based methods, even compared with wavelet-based denoising and variational approaches calling upon sophisticated regularization. Based on distinct points of view, the methods UINTA (Unsupervised, Information-Theoretic, Adaptive Image Filtering) and NL-means (Non Local means) pioneered this field in which BM3D (3D transform-domain collaborative filtering) represents the latest, "still to be overcome" improvement, at least in terms of the classical performance measure PSNR (Peak Signal-to-Noise Ratio). Such techniques could be successfully tailored to biological images since these images often present a fair amount of self-similarity, especially in dynamic processes (*e.g.*, cell growth).

**Restoration.** All optical systems are inherently diffraction-limited and the image of a point source is a spot (the Point-Spread Function (PSF)) defining the resolution of images. When we know the degradations (PSF and noise statistics) the image can be restored by applying numerical treatment of deconvolution. We have long time experience in satellite image restoration and PSF estimation. However, the model of the degradations (3D PSF and noises) must be redefined for each new microscopic system, if possible. For example, models of PSF for fluorescent confocal miscroscopic system, are more complex than when imaging landscape by a satellite due to the depth observation (*e.g.* attenuation and distortion of wave in depth, effect of multiple refraction index). We will work closely to bio-physicists to model the new systems (for example HILO system developed at IBDC in Nice), or try to enhance the quality of images, by using coupling systems (for example Fluorescent Confocal microscope with a diffractive micro-tomography developed in UHA (University of haute Alsace)). Of course, progress are still to be made concerning inversion technics and regularization modeling in order to have best models for biological images and fast and automatic algorithms which could be easily used by end-users. This goal state non trivial problems of image processing.

**Completion of missing data.** In numerous applications, the image can be decomposed as objects of interest and a background. In such a case, the first step before analyzing the image is to extract the object or the collection of objects from the background. Due to the sensor noise, to occlusions or to additional non desired structures, the extraction process leads to an incomplete description of objects. Therefore, the geometry and/or the topology of the studied object may be affected. Completing the missing data is thus an important step before analyzing the objects under study, for example when one needs to infer the number of objects, their shape or the topology of a network.

#### B) Assisting biologists in analyzing images

**Structure detection.** Biological objects tend to have a predictable shape, probably more predictable than in other types of imagery where the appearance of 2-D projections of objects widely varies in terms of the point of view. This certainly makes the definition of geometrical constraints and their combination with data fidelity two topics of particular importance. They have been studied extensively in the scope of segmentation using active contours. In this context, geometrical constraints can be enforced mainly in three ways: (a) as a trade-off between data fidelity and constraints (by linear combination of the corresponding contour energies), (b) by projection of the contour onto the constraint space after each evolution step, and (c) by defining the contour parametrically in accordance with the constraints and solving the segmentation problem in the space of these parameters.

**Multiple object detection.** Numerous biological studies are based on the evaluation of a population. This population can consist of cells, neurons, axons, proteins... In such a situation, the first goal is to count the number of individuals in the population. Each individual can be, in most cases, represented by a simple geometrical shape (ellipse, tube, rectangle...). In this context, we propose to develop generic models based on the marked point process framework. These models allow embedding prior information on both the geometry and the repartition of random object configurations in the scene. The first applications we have in mind concern cells counting. This task is fastidious and time consuming. Moreover, evaluating the impact of a given disease or a given treatment requires to address a large number of images. Therefore, there is a need for developing softwares for automatically detecting and counting objects from biological images. Besides, one may need to discriminate between two populations, for example between sane and pathological cells. The marked point process framework can be extended to several populations of objects but classification can also be performed a posteriori by considering each detected object.

#### C) Describing the detected structures

**Indexing/retrieval, classification, and learning.** The main steps behind content-based indexing, retrieval, and classification are the feature extraction, the building of a synthetic image description from the extracted features, and the computation of the (dis)similarity measures between the query image and the images of the database, or the computation of the classification function for the query image. The methods can be distinguished in how they involve learning: no learning is involved, the (dis)similarity measure between two images is learned, or the classification rule is learned. If learning is involved, it is usually performed offline with good performances. However, introducing interactivity can offer a gain in accuracy otherwise very difficult to reach. Indeed, classification based on offline learning can achieve an excellent accuracy well inside the class clusters while possibly being frequently erroneous at the frontiers between classes.

**Statistical modeling.** Biological structures, such as cells, vessels or axons, exhibit a high variability. These supra-cellular structures may provide important information on the tissue properties to biologists, usually studying the cellular level. To model these structures, for analyzing their geometry or their topology, for discriminating between several classes, such as normal and pathological, this variability should be taken into account. We will investigate statistical model for shapes and textures. Graphs also play an important role for modeling vascular network or axons. Statistics on graph component such as number and position of branching points or length of edges, provide some relevant information on the topology of the graphs, taking into account the inter-specimen variability.

### 5.3.5 Multimedia image coding and processing

**Main contributors** *Marc Antonini, Michel Barlaud (émérite), Pierre Mathieu, Frédéric Payan*

The researchers working on this research activity aim to develop theoretical tools relative to image coding, processing and learning. They will draw their inspiration from the domains of image processing, information theory (statistical measures, rate-distortion theory and models, vector quantization...) and multiresolution analysis (wavelets) to develop applications such as bio-inspired image/video coding, multiresolution coding of static/dynamic surface meshes, content-based retrieval and learning.

**Bio-inspired image processing.** During the past two decades, research in still image compression originated several coding algorithms, especially the JPEG effort which lead to the international standard of the same name. One of the main properties of such a scheme is to allocate the major part of the bandwidth available to the low frequency sub-bands, enabling progressive decoding: low frequency sub-bands are transmitted (and obviously decoded) first, while higher frequency sub-bands are transmitted later in time. Interestingly, we retrieve a similar behavior in the human retina. Indeed, we know that the neural code of the retina conveys low frequency subbands of the stimulus first, then higher frequencies as time goes. In our works we consider the image stimulus as the data to encode, the retina as the image coder, and the optic nerve as the transmission channel toward the visual cortical areas. In addition, we know that this channel is noisy and has a restrained bandwidth. The neural code of the retina is not a simple intensity signal transform. Indeed, several neurophysiologic experiments have shown that the neural code corresponding to a given stimulus encompasses many characteristics that could encode the information that is the most relevant to decode the stimulus.

We can thus naturally raise the following question: how does the retina represent the visual stimuli and transmit it in order to deal with the evoked constraints? In that context, we recently started a pluridisciplinary research project in collaboration with the Mathematical and Computational Neuroscience project team of INRIA Sophia Antipolis (with P. Kornprobst - INRIA and B. Cessac - Lab J.A. Dieudonné). We want to focus on three main challenges:

– **Cracking the neural code** An important issue encountered in the study of spike-like codes is to decode them. Our goal is to infer, starting from a sufficiently realistic model, a decoding algorithm that could decipher actual neural recordings. This is also an issue of growing interest in the brain machine interface community.
– **Bio-inspired image coding** The main idea is to combine results in neurosciences with image processing techniques and to propose new efficient image and video coding algorithms that matches the mammalian visual system behavior.
– **3D perceptual models** Exploit the functional characterization of the retina and the extraction of cortical pertinent information to infer perceptual models for the tridimensional vision that can be exploited in 3D compression algorithms.

**Semi-regular remeshing.** Applying multiresolution analysis on surface meshes is not trivial, because of the *irregular* geometry sampling. Therefore remeshing methods have been developed for several years. Their common objective is to modify the topological and geometrical informations to get more structured meshes, of similar visual quality, and often based on subdivision connectivity. These meshes based on subdivision connectivity, frequently called *semi-regular* meshes, are well suited for wavelet filtering, and finally enables efficient progressive encoding of highly-detailed surfaces. Semi-regular meshes thus are particularly attractive for numerous applications. But several key problems remain. Our main challenges are:

– **Designing semi-regular remeshings for coloured/textured meshes** Current semi-regular remeshings take into account only the geometrical information as input data. So, additional attributes like colour vectors, textures, or normal are not preserved for the semi-regular ouput.
– **Designing semi-regular remeshings for clouds of points** Current semi-regular remeshings take only irregular meshes as input. Designing semi-regular meshes directly from clouds of points will *in fine* enable scanners to directly produce semi-regular outputs.

**Dynamic mesh coding.** Deforming surfaces are often represented by dense triangle meshes sharing the same connectivity. The shape deformations are simply obtained by spatially displacing the vertices across the time. This representation has a lot of advantages (fast visualization processing, simple data structure, storage), but only for specific surfaces, like surfaces undergoing few non-rigid deformations.

One of our objectives is to design dynamic meshes with time-varying connectivity from sequences of independent meshes. We intend to develop an original coarsening/remeshing algorithm directly driven by the encoding that will be done on the resulting dynamic meshes.

The key challenges are:

– **Designing efficient coding schemes** for arbitrary 3D meshes sequences, with an embedded remeshing algorithm, in order to depend as little as possible from the input sequence.
– **Data streaming** that enables on-the-fly compression/decompression of animations, to avoid the transmission of the whole data before reconstruction.

**3D perception and quality.** A challenge in 3D or stereoscopic rendering is to understand how are related the visual perception of the stimuli, the technological context of the data acquisition (3D scanner, hologram. . . ) and the visualization interfaces (PC monitor, home video systems, shutter or anaglyph glasses, auto-stereoscopic screens. . . ). In our project we plan to explore this research field benefiting from our works on neural coding and bio-inspired image processing.

**Learning and content-based image retrieval.** We can consider the following main perspectives for research in content-based image retrieval and categorization:

- **Active learning** as a tool for dealing with huge real-world databases (up to billion images).
- **Multiclass boosting** based classification using non linear separator.
- **Intrinsic multiclass image classification** with many (possibly) skewed categories, where classic binary one-versus-all classification approaches become unfeasible due to their computational cost.
- **Supervised learning** (batch or on-line learning) for improving performances of an image search system, by exploiting the ability of our boosting k-NN technique to identify a cluster of the most relevant images from a large collection.
- **Generalization of k-NN boosting** to boosting generic instance-based voting rules, that exploit annotated data in the feature space.
- **Evaluate generic risk functions** to be minimized in the boosting framework when learning prototypes for image classification and retrieval.

We plan also to extend these approaches to video classification in the context of bio-inspired processing.

### 5.3.6 Information, entropies end divergences

**Main contributors** *Luc Pronzato, João Rendas*

**Estimation of divergences.** We plan to continue the collaboration with Prof. Nikolai Leonenko from Cardiff University, UK, on the properties of entropy and divergence estimators based on nearest-neighbor distances. The approach we used in [23] is based on the computation of conditional moments of nearest-neighbor distances. However, the approach of Joe Yukich [39], based on the subadditivity of Euclidean functionals, seems more powerful, in particular when one wishes to estimate the Rényi-$\alpha$ entropy of a density $f$ having unbounded support and $\alpha < 1$. Besides revisiting the results in [23] with the alternative approach of Yukich, one objective is to apply his technique to the estimation of other divergences than those considered in [23], *e.g.*, Rényi-$\alpha$ divergences.

**Asymptotic normality.** The results in [23] concern the $L_2$-consistency of entropy and divergence estimators based on nearest-neighbor distances. A next important step would be to derive the asymptotic mean-squared error (MSE) of the estimators and prove their asymptotic normality. Knowing the expression on the asymptotic MSE would allow us to choose $k$ optimally (as a function of the size $n$ of the sample) when using $k$-th nearest-neighbor distances (note that the expression of the asymptotic bias is given in [23], but the asymptotic variance is much more difficult to obtain). Second, a central limit theorem would allow us to construct simple tests for the normality or Student-type distribution of a sample, using the property that the normal distribution has maximum Shannon entropy and the Student-$t$ distribution maximizes the Rényi-$\alpha$ entropy for a particular $\alpha$. Note that the nearest-neighbor distances (or $k$-th nearest-neighbor distances) in a given sample of $n$ i.i.d. variables being not independent, the derivation of a central limit theorem requires particular techniques.

**Other types of estimators.** The objectives presented in this paragraph could motivate a collaboration with the pôle MDSC on the algorithmic aspects of the constructions considered. Various entropy estimators for a p.d.f. $f$ from a sample of $n$ i.i.d. points distributed with $f$ can be obtained by solving graph optimization problems with nodes given by those $n$ points. The minimum spanning tree, the graph of $k$-th nearest neighbor distances or the optimal Traveling-Salesman-Problem (TSP) tour (the shortest Hamiltonian cycle) are examples of optimal graphs that can be used. Of course, the complexity of the underlying graph optimization problem may be a strong obstacle: for instance, the TSP problem being NP-complete, it seems preferable to use an entropy estimator based on the minimum spanning tree or nearest neighbor distances. However, different graph optimization problems might yield estimators with different accuracies. Therefore, a suboptimal graph for a complicated problem might yield a more accurate estimator than the optimal graph for a simpler problem. This raises challenging issues; indeed, the expression of the bias of the entropy estimator is only known for the graph of $k$-th nearest neighbors (which is not a problem when estimating differences between entropies but becomes an issue if the interest is in the entropy of a particular distribution); moreover, even in the easiest case of nearest neighbors, the MSE of the entropy estimator is still unknown, see above. This should thus be considered as a long term project. Another objective would be to consider entropy and divergence estimators based on other objects from computational geometry, such as Delaunay or Voronoi Tessellations (see, *e.g.*, [18, 26]).

### 5.3.7 System identification and modeling

**Main contributors** *Gérard Favier, Luc Pronzato, João Rendas*

**Nonlinear system modeling and identification.** Based on the techniques developped in research area 5.3.1, tensor tools are applied to a new family of nonlinear models, the so called Volterra-Parafac models and extended to the tensor-based modeling (in particular for MIMO nonlinear communication channels) and algorithmic viewpoints.

Tensor analysis is also applied for determining the structure and estimating the parameters of block-structured nonlinear SISO systems, like Wiener, Hammerstein and Wiener-Hammerstein systems [21]. These results will be extended to more general block-structured nonlinear MIMO systems. Moreover, the associated Volterra kernels having constrained structures (Toeplitz, band-Toeplitz factors), specific algorithms taking such structures into account will be developed.

**Experimental design and clinical trials.** A first objective will be to build on the results in [32, 30] showing that one-step-ahead sequential design is asymptotically optimal, for least-squares estimation in nonlinear regression or maximum-likelihood estimation in Bernoulli-type experiments (with possible application to clinical trials). Although of wide applicability, those results rely on the assumption that the design space $\mathfrak{X}$ is finite. This is not too restrictive in most practical situations, but a more natural assumption would be to assume that $\mathfrak{X}$ is a compact subspace of $\mathbb{R}^d$. The extension does not seem trivial, however (the results in [30] rely on a conditioning principle which can be used due to the presence of replicated observations when $\mathfrak{X}$ is finite). The paper [33] concerns the case where one designs a non-stationary experiment: the design objective corresponds to a compromise between an information criterion (for precise parameter estimation, based on the information matrix), to be maximized, and a penalty function, related to a cost to be minimized; the experiment is constructed sequentially and the weight $\lambda_n$ on the penalty term increases with the number $n$ of design points considered. The strong consistency of the estimator of the model parameters is still guaranteed when $\lambda_n$ does not increase too fast with $n$ [31], but the asymptotic normality is still an issue (an important one when one wishes to perform some statistical inference). The motivation to apply this method to the context of clinical trials comes from the fact that it permits to clarify the compromise to be made between the information gain from the trial (an issue of collective ethics) and the cost of the experiment (in terms of toxic or inefficient treatments given to the patients enroled in the trial, an issue of individual ethics). Promoting this approach among the statistical community involved in clinical trials is one of the objectives. Possible extensions concern the case where allocation of patients to treatments can be based on the observation of covariates. Then, by modeling the probability of success of each treatment as a function of covariates one could define allocation strategies that make a clear compromise between the gain in information (measured by the precision of the estimation of the model parameters) and the cost measured by the probability of giving a bad treatment to a patient. As before, one may modify the compromise in the course of the experiment, thereby trying to allocate patients more and more efficiently as more information is gathered.

**Experimental design, kriging and nonparametric modeling.** In absence of prior information, typical experiments for the observation of spatial fields (including computer experiments in industrial applications) are of the space-filling type: the idea is to try to spread the design points as uniformly as possible in the design space $\mathfrak{X}$. A usual approach there is to renormalize $\mathfrak{X}$ to the $d$-dimensional unit-cube and to use a Latine-Hybercube-design, or a design based on a low-discrepancy sequence when an incremental construction is required. Alternatively, one may construct a design that optimizes a geometrical covering measure: minimax optimal design aims at minimizing the maximum distance between a point from $\mathcal{X}$ and the set of design points (it thus corresponds to a sphere-covering problem over $\mathcal{X}$); maximin optimal design aims at maximizing the minimum distance between two design points (a variant of a sphere-packing problem over $\mathcal{X}$), see [19]. Minimax-optimal design is not much used, due in particular to the complexity of the evaluation of the maximum distance between a point from $\mathcal{X}$ and the set of design points (one short-term objective will be to investigate under which assumptions on $\mathcal{X}$ tools from computational-geometry can facilitate this evaluation); maximin-optimal design is often combined with Latine-Hypercube design in order to guarantee suitable projection properties of the design along each coordinate axis combined with good space-filling performance. Preliminary results, presented in [34], show that designs optimizing other covering measures are much easier to construct than maximin-optimal design and still have suitable space-filling properties. The objective here would be to construct covering measures combining geometrical properties (using spacings between design points) and statistical properties (using a measure of the uniformity of the distribution of points supposing that they are i.i.d.), also taking into account the projective properties along low dimensional subspaces. We intend in particular to investigate the properties of criteria based on entropy estimators that use nearest-neighbor distances or other constructions borrowed from computational geometry, see the objectives in Section 5.3.6. The optimization of such criteria would motivate a collaboration with the group working on constraint programming in the pôle MDSC. Distributed optimization, see the recent paper [9], is also an option that we might consider, see the next section for developments on this subject. Note that the collaboration with MDSC could be two-way: non parametric models (surrogates) could be substituted for unknown functions that intervene as objectives or constraints in a non-linear programming problem, the choice of a suitable model (the choice of a kernel in kriging for instance) could then be motivated by the use of constraint-programming techniques for the solution of the (approximated) problem.

Space filling-designs are not necessarily well adapted when constructing the interpolation/prediction of a random field by kriging. Indeed, the parameters entering the stochastic part of the model need to be estimated (usually by maximum likelihood) and good designs for prediction (space-filling) have usually poor performance concerning the estimation of the kernel parameters. This problem is central in the 2 year PHC project "Sequential Design for Random Fields", between I3S and the Department of Applied Statistics of the University of Linz, that started in 2010.

**Optimization and dynamical systems.** We shall continue our investigations of gradient-type algorithms with step-sizes generated by a dynamical system in several directions. First, it seems possible to estimate precisely the bounds of the spectrum of the quadratic operator, which forms a definite advantage over more usual Chebycheff-type iteration methods where these bounds are assumed to be known *a priori*; moreover, monotonicity of the convergence seems easy to obtain. Second, we want to investigate the non-asymptotic behavior of the algorithm in relation with the discrepancy of the sequence generating the step-sizes. Finally, we want to extend the approach to the resolution of linear systems of equations with non symmetric matrix, to non-quadratic (but convex) optimization and to optimization in the presence of constraints.

## 5.3.8 Autonomous navigation and mapping

**Main contributors** *Andrew Comport, Gilles Menez, João Rendas, Eric Thierry*

### A) Distributed Dynamic Sensing

Sensor networks and collective mobile robotics are two closely related fields where the ultimate goal is to be able to process a large amount of data simultaneously collected by distinct sensors in order to observe a given spatial field. Usually, the distinction between the two fields is determined by the different amounts of computing power, energy and communication capabilities that are assumed in each element of the set of participating nodes. In spite of these differences, many problems are shared between the two areas for which no formal acceptable solution is yet known. The goal of this activity is to formally study information acquisition and processing problems which arise in these new sensing-communication-computing large scale complex structures, and it stems out of the research activities being studied in the ANR C-FLAM that is ongoing at the time of writing this report. The specific problems briefly described below are either already under study or have been identified as topics to be addressed in the near future.

**Partial Observable Markov Decision Processes (POMDP).** Design of informative trajectories for a single observer whose task is to acquire a global map of an extended region is already a complex problem. Its distributed version, where a set of node collects must coordinate sampling trajectories such that the overall information is maximised, introduces a new fundamental difficulty, that is related to the uncertainty affecting the other actual nodes trajectories and sampled data. POMDP's (Partial Observable Markov Decision Processes) are a convenient formal framework to assess this problem, explicitly modeling the uncertainty about the system's state when control decisions must be taken. In the context of the ANR C-FLAM, and in collaboration with E. Moulines (LCTI, Telecom Paris), we will co-supervise a post-doc on the study of the application of Monte-Carlo (particle filtering) techniques to this problem.

**Rumor-robust distributed data fusion.** Although the robust fusion operator presented in [35] is formally defined with a large degree of generality, making no assumptions on the fused distributions, the results presented in that reference are preliminary, considering only the case of discrete random variables and pair-wise fusion. We identify three directions in which this joint work with Prof. J. Leitão from IST, Portugal, will be continued: *(i)* to answer important formal questions that remain open, such as the asymptotic properties of the fusion operator and its functional properties (associativity being an important one); *(ii)* consider the definition of majorization for the discrete multi-variate case, and further exploit the rich geometry of the problem to design efficient numerical implementations; *(iii)* consider the continuous case, where the notion of majorization relies on the concept of Lorenz domination.

The need to use rumor-robust fusion operators implies the acceptance of a conservative information composition that will necessarily discard some information that would be used to decrease uncertainty would all statistical dependencies between fused data items be known. This means that efficient multiple sensor acquisition techniques must try to distribute the data collection at each node such that the amount of acquired information, that will be discarded by the fusion operator, is minimized. When using the novel fusion operator proposed in [35], this corresponds to enforcing a policy of state-space partitioning together with a "refinement before fusion" approach: separate observers should improve discrimination inside distinct elements of the partition, before attempting to fuse their states of knowledge. We believe that this is true not only for the particular fusion operator that we proposed, but for any fusion algorithm that is robust to rumor, i.e., for any consistent distributed estimation algorithm. The demonstration of this conjecture for the majorization-based fusion operator will be presented in a paper that will be submitted soon, and its demonstration in the general case is a topic for future study.

**Copulas.** Copulas are functionals that describe statistical dependency, allowing the separation of the specification of mutual dependency from that of the distribution of the values of each individual random variable. In two of our ongoing studies the issue of mutual dependency is a crucial one: in the design of observation trajectories for spatially correlated fields, for which the correlation structure is a priori unknown, and in the definition of rumor-robust fusion algorithms for distributed estimation, where the dependency between the information exchanged by a set of nodes is not known. The goal of this research activity is to investigate the possibility of using copulas to parametrize the correlation structure of spatial fields – the major difficulty here is that copulas are well studied only for pairs of variables – and, in the context of the distributed fusion problem, to impose further constraints on the solution space of the fusion operator, with the goal of relaxing the conservativeness of the current method, which, although being less conservative than present alternative methods published in the literature, still discards eventually useful information. Note that in the discrete setting, the notion of majorization is closely related to the existence of a non-parametric copula relating the two random variables, suggesting that copulas may be the natural tool to derive more specific, yet robust, fusion operators.

**B) Visual localisation and mapping**

The aim of this research axis is to develop optimal sensing models for visual localisation and mapping of complex environments from multiple mobile cameras in real-time. The major goals are two-fold. On one hand, the theoretical problems related to modeling the dynamic motion of multiple visual sensors will be addressed: multi-view geometry, photometry, robust parameter estimation and identification, numerical non-linear optimisation. On the other hand, the project will aim at the leading application of robot navigation.

One driving goal will be to model the processes of 3D localisation and mapping (SLAM) of complex environments which will need to be represented optimally in terms of information compression including efficiency and robustness. In particular, this project will involve modeling 3D camera movement and/or complex scene motion such that it may be exploited in real-time. In particular, large-scale 3D environments that are dynamic and totally or partially unknown will be considered. One of the research challenges lies in formalising models that relate motion and structure to real-world observations whilst taking into account the dimension and variability of the state space. In autonomous applications it is also paramount to consider the robustness in the presence of real sensor measurements, uncertain models and their efficiency (hard real-time constraints) as essential elements of the problem.

To ensure high quality experimental validation we intend to exploit and further develop a multi-sensor platform acquired via the ANR project CityVIP and to associate it with robotic (experimental and commercial) platforms. We will also continue to transfer our results through the FUI project Adopic and to partners such as Thales Alenia-Space, Infotron, Cybernetix. . . . We shall continue our collaboration with INRIA colleagues from the ArobAS team, in particular through the ANR CityVIP. We also currently pursue multi-sensor approaches in a joint project CNPQ/INRIA/I3S with the CTI at Campinas (Brasil) which looks at integrating inertial measurements with vision.

### 5.3.9 Drones

**Main contributors** *Guillaume Allibert, Christian Barat, Guillaume Ducard, Tarek Hamel*

This research activity focuses on the development of the fundamental science and technology underlying the operation of dynamical aerial robotic vehicles. Due to its low cost, low energy use, and rich information content, vision is a unique sensor modality for control of robotic vehicles. We will develop control and image processing algorithms, based on rigorous systems theoretic foundations that provide practical and simple control for autonomous and semi-autonomous robotic vehicles in unstructured and cluttered environments.

**Vision-Based Control of Robotic Vehicles.** Autonomous and semi-autonomous aerial robotic vehicles are a key technology for a wide range of emerging applications in our society. Existing vehicles, apart from those used in military applications, operate only in environments where there is no risk for humans and limited risk of vehicle damage.

Such a safe operation is mostly achieved by limiting the physical characteristics of the vehicle or by choosing an environment that excludes human presence. However, in order to benefit from the full potential of robotic vehicles within the society, it is necessary to develop effective control and sensing systems that can fulfill the safety requirements without limiting the physical characteristics of the vehicle or environment.

Vision is the most robust, light-weight, low-cost and powerful exteroreceptive (sensing the environment surrounding the robot) sensor system that functions reliably in typical emerging applications, such as indoor or urban canyon environments. Vision based control will play a key role in enabling robotic vehicles in society to become reality. Our goal is to develop the fundamental science and technology that underpins the development of vision-based control of robotic vehicles. In particular, the aims are:

- To develop vision based motion primitives for a wide range of applications and vehicles.
- To develop a framework for effective vision-based obstacle avoidance in unstructured environments for dynamic robotic vehicles.

– To develop a framework for vision-based teleoperative control of semi-autonomous robotic vehicles.

**Control of underactuated systems.** The control of underactuated mechanical systems is an active research topic in Control and Robotics communities, in conjunction with the recent emergence of robotic applications, including the implementation of airships, submarines, VTOL (Vertical Take-Off and Landing) and aircrafts. Based on the acquired previous research conducted within the team, some assumptions have to be assessed when considering an application on a physical system. For the genericity of the approach, it is important to extend this study in two directions. The first one concerns the assumption according to which environmental forces only depend on the vehicle's velocity (and the independent time-variable). This assumption needs to be relaxed because it is not realisitic for a number of vehicles, like airplanes, for which drag and lift forces depend strongly on the angle of attack. The second direction concerns the assumption of non zero-crossing upon the so-called "apparent acceleration" -the resultant of external forces and desired accelerations. A route could consist in coupling the present approach with more involved, non-classical, control techniques aiming at the unconditional practical stability of the system. Besides these conceptual developments, conducting experiments on physical systems is indispensable to consolidate the results of this study with respect to claims of robustness and performance in particular.

**Observers on Lie groups.** The classical problem in computer vision and robotics consists in the computation of the homography relating images of a planar scene viewed from two different locations. Given two images of a planar scene there are several well known algorithms to numerically compute a (noisy) estimate of the underlying image homography from a set of point correspondences between the images. The error in each homography estimate depends on the algorithm used, with smaller error generally requiring significantly more computational effort, and is typically impossible to quantify. When a sequence of homographies is obtained from smooth motion of the camera it is advantageous to improve the quality of the estimates by applying an observer to exploit the temporal information in the sequence. One approach to this problem is to explicitly reconstruct the pose (the translation and the rotation in Cartesian space) of the camera associated with the estimated homographies and then apply an observer or filter to the underlying rigid-body state motion. It is also possible to consider the measured homography as an output and build a Kalman filter for the rigid-body motion and hence avoid the state reconstruction process. However, these approaches filter the rigid-body motion and not the homography itself and require at least the computation of the homography. Motivated by the homography estimation, two different directions will be considered.The first one, consists in the definition of an observer directly on the set of homographies to overcome limitations of the previous solutions and in order to generalise our recent tools in non-linear observer design for linear Lie groups. The second direction, consists on the development of an estimator of the homography matrix based on the homogenous space (without computing the homography). This direction could form the foundations of an emerging framework for observer design for invariant systems on Lie groups.

**Fault Detection Systems and Fault-tolerant Flight Controllers.** New generations of unmanned aerial vehicles (UAVs) will be designed to achieve their mission not only with increased efficiency, but also with more safety and security. Future UAVs will be operated with algorithms capable of monitoring the aircraft's health and of taking action if needed. Fault-tolerant control systems are capable of safe and reliable operation of a UAV and rely on the following key points:

– The flight control system must be robust against the aircraft model's uncertainties and external disturbances.
– An efficient fault detection and isolation (FDI) system should be capable of monitoring the health status of the aircraft.
– The guidance system should be reconfigurable depending on actuator fault occurrence or aircraft damage. It should generate an appropriate flight trajectory that avoids obstacles despite flight performance degradation.

# Bibliography


[1] P. R. A. Perotti and S. Benedetto. Adaptive coded continuous-phase modulations for frequency-division multiuser systems. *Advances in Electronics and Telecommunications*, 1(1):50–58, 2010.

[2] A. Barbieri, D. Fertonani, and G. Colavolpe. Spectrally-efficient continuous phase modulations. *IEEE Trans. Wireless. Comm.*, 8(3):1564–1572, 2009.

[3] F. Batard, K. Boudaoud, and M. Kamel. Web 2.0 Security: State of the Art. In *5ème Conférence sur la Sécurité des Architectures Réseaux et Systèmes d'Information (SAR-SSI 2010)*, page 16, Menton, France, May 2010. Menton, France.

[4] H. Becker, P. Comon, L. Albera, M. Haardt, and I. Merlet. Multiway space-time-wave-vector analysis for source localization and extraction. In *European Signal Processing Conference (EUSIPCO'2010)*, Aalborg, DK, 2010. 5 pages.

[5] J. Brachat, P. Comon, B. Mourrain, and E. Tsigaridas. Symmetric tensor decomposition. In *European Signal Processing Conference, (EUSIPCO'09)*, Glasgow, Scotland, 2009. 5 pages, hal-00435908.

[6] G. Colavolpe and R. Raheli. Reduced-complexity detection and phase synchronization of cpm signals. *IEEE Trans. Comm.*, 45(9):1070–1079, 1997.

[7] P. Comon, G. Golub, L.-H. Lim, and B. Mourrain. Symmetric tensors and symmetric tensor rank. *SIAM Journal on Matrix Analysis Appl.*, 30(3):1254–1279, 2008. hal-00327599.

[8] P. Comon, X. Luciani, and A. D. Almeida. Tensor decompositions, alternating least squares and other tales. *Jour. Chemometrics*, 23:393–405, 2009. hal-00410057.

[9] J. Cortés and F. Bullo. Nonsmooth coordination and geometric optimization via distributed dynamical systems. *SIAM Review*, 51(1):163–189, 2009.

[10] A. De Almeida, G. Favier, and J. Mota. A constrained factor decomposition with application to MIMO antenna systems. *IEEE Transactions on Signal Processing*, 56(6):2429–2442, 2008.

[11] G. Favier and T. Bouilloc. A constrained tensor based approach for MIMO NL-CDMA systems. In *European Signal Processing Conference, (EUSIPCO'10)*, Aalborg, Danemark, 2010. 5 pages.

[12] G. Goth. Ultralarge systems: Redefining software engineering? *IEEE Software*, 25(3):91–94, 2008.

[13] M. Hesse. *L2-orthogonal Space-Time Code Design for Continuous Phase Modulation*. PhD thesis, Université de Nice Sophia-Antipolis, 2010.

[14] M. Hesse, J. Lebrun, and L. Deneire. Full Rate L2-Orthogonal Space-Time CPM for Three Antennas. In *IEEE Global Telecommunications Conference, (GLOBECOM'08)*, pages 1–5, New Orleans, LA, USA, 2008. `http://hal.archives-ouvertes.fr/inria-00362141/en/`.

[15] M. Hesse, J. Lebrun, and L. Deneire. L2 Orthogonal Space Time Code for Continuous Phase Modulation. In *IEEE Workshop on Signal Processing Advances for Wireless Communications, (SPAWC'08)*, pages 1–5, Recife, Brazil, 2008. `http://hal.archives-ouvertes.fr/inria-00288334/en/`.

[16] M. Hesse, J. Lebrun, and L. Deneire. Optimized L2-Orthogonal STC CPM for 3 Antennas . In *Proc. IEEE International Symposium on Wireless Communication Systems, (ISWCS'08)*, pages 463–467, Reykjavik, Iceland, 2008. `http://hal.archives-ouvertes.fr/inria-00362167/en/`.

[17] M. Hesse, J. Lebrun, L. Lampe, and L. Deneire. Separable implementation of L2-orthogonal STC CPM with fast decoding . In *International Conference on Communications, (ICC'09)*, pages 1–5, Dresden, Germany, 2009. http://hal.archives-ouvertes.fr/inria-00364952/en/.

[18] R. Jiménez and J. Yukich. Asymptotics for statistical distances based on Voronoi tessellations. *Journal of Theoretical Probability*, 15(2):503–541, 2002.

[19] M. Johnson, L. Moore, and D. Ylvisaker. Minimax and maximin distance designs. *Journal of Statistical Planning and Inference*, 26:131–148, 1990.

[20] M. Kamel, K. Boudaoud, and M. Riveill. A low-energy consuming and component-based security management architecture for mobile devices. In *International Conference on Security and Management (in the context of WORLDCOMP 2010) (SAM 2010) AR=28%*, page 7. CSREA Press, July 2010.

[21] A. Kibangou and G. Favier. Tensor analysis-based model structure determination and parameter estimation for block-oriented nonlinear systems. *IEEE Journal of Selected Topics in Signal Processing, Special issue on Model Order Selection in Signal Processing Systems*, 4:514–525, 2010. http://hal.archives-ouvertes.fr/hal-00417815/en/.

[22] J. Kienzle, W. Al Abed, and J. Klein. Aspect-oriented multi-view modeling. In *AOSD '09: Proceedings of the 8th ACM international conference on Aspect-oriented software development*, pages 87–98, New York, NY, USA, 2009. ACM.

[23] N. Leonenko, L. Pronzato, and V. Savani. A class of Rényi information estimators for multidimensional densities. *Annals of Statistics*, 36(5):2153–2182, 2008. http://hal.archives-ouvertes.fr/hal-00331300/fr/.

[24] S. Lippi. Universal hard interaction for clockless computation: Dem glücklichen schlägt keine stunde! *Fundam. Inform.*, 91(2):357–394, 2009.

[25] R. Maw and D. Taylor. Space-time coded systems using continuous phase modulation. *IEEE Trans. Comm.*, 55(11):2047–2051, November 2007.

[26] E. Miller. A new class of entropy estimators for multidimendional densities. In *Proc. ICASSP'2003*, 2003.

[27] I. Mirbel and P. Crescenzo. Des besoins des utilisateurs à la recherche de services web : une approche sémantique guidée par les intentions. *RTSI Série ISI*, 15(4):24, July 2010.

[28] S. Mosser, M. Blay-Fornarino, and J. Montagnat. Orchestration Evolution Following Dataflow Concepts: Introducing Unanticipated Loops Inside a Legacy Workflow. In *International Conference on Internet and Web Applications and Services (ICIW) AR=28%, long paper*, pages 389–394, Venice, Italy, May 2009. IEEE Computer Society. http://rainbow.polytech.unice.fr/publis/mosser-blay-fornarino-etal:2009.pdf.

[29] E. Perrins and M. Rice. Optimal and reduced complexity receivers for m-ary multi-h cpm. In *2004 IEEE Wireless Communications and Networking Conference*, pages 1165–1170, Atlanta GA, USA, March 2004.

[30] L. Pronzato. Asymptotic properties of nonlinear estimates in stochastic models with finite design space. *Statistics & Probability Letters*, 79:2307–2313, 2009. DOI: 10.1016/j.spl.2009.07.025, http://hal.archives-ouvertes.fr/hal-00416008/fr/.

[31] L. Pronzato. Adaptive penalized optimal designs over a finite space. In A. Giovagnoli, A. Atkinson, and B. Torsney, editors, *mODa'9 – Advances in Model–Oriented Design and Analysis, Proceedings of the 9th Int. Workshop, Bertinoro (Italy)*, pages 165–172, Heidelberg, 2010. Physica Verlag.

[32] L. Pronzato. One-step ahead adaptive $D$-optimal design on a finite design space is asymptotically optimal. *Metrika*, 71(2):219–238, 2010. DOI: 10.1007/s00184-008-0227-y, http://hal.archives-ouvertes.fr/hal-00396975/fr/.

[33] L. Pronzato. Penalized optimal designs for dose-finding. *Journal of Statistical Planning and Inference*, 140:283–296, 2010. DOI: 10.1016/j.jspi.2009.07.012, http://hal.archives-ouvertes.fr/hal-00416014/fr/.

[34] L. Pronzato, M. Clergue, and S. Verel. Design of computer experiments : space-filling criteria, algorithms and adaptive strategies. 27th European Meeting of Statisticians, Université Paul Sabatier, Toulouse, France, 2009.

[35] M.-J. Rendas. Rumor-robust distributed data fusion. In *MFI, IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems*, pages 1–5, Salt Lake City, Utah, USA, 2010.

[36] J. Rojas Balderrama, J. Montagnat, and D. Lingrand. jGASW: A Service-Oriented Framework Supporting High Throughput Computing and Non-functional Concerns. In *8th IEEE International Conference on Web Services (ICWS'10)*, page 4, Miami, FL, USA, July 2010. IEEE Computer Society. ISBN: 978-0-7695-4128-0, `http://rainbow.polytech.unice.fr/publis/rojasbalderrama-montagnat-etal:2010.pdf`.

[37] J. P. Royer, Comon, N. Thirion, S. Mounier, R. Redon, H. Zhao, C. Potot, and G. Feraud. Water analysis with the help of tensor canonical decompositions. In *RUnsUd*, pages 407–410, Nice, 2010.

[38] G. Wang and X.-G. Xia. An orthogonal space-time coded CPM system with fast decoding for two transmit antennas. *IEEE Trans. Inf. Theory*, 50(3):486 – 493, March 2004.

[39] J. Yukich. *Probability Theory of Classical Euclidean Optimizaiton Problems*. Springer, Berlin, 1998.