MY RECENT RESEARCH INTERESTS

1 Modeling and Realization of Stochastic Systems

This has been one of my main research interests since about thirty years. *Stochastic Realization Theory* has emerged from this work as a fundamental contribution to Stochastic model building and Stochastic Systems Theory, which has developed over the years and is now been collected in a monograph co-authored with Anders Lindquist entitled *Linear Stochastic Systems: a Geometric Approach*. Stochastic Realization Theory is centered around the original idea of *Markovian Splitting Subspace* and *Markovian representation* of a random signal, which is a natural probabilistic analog of the notion of state and state-space model in deterministic dynamical systems and is rooted on the Bayesian notion of sufficient statistics. This new theoretical framework has provided a mathematical theory of model building which has provided the conceptual basis for later work on subspace identification and has led for the first time to the understanding of structural properties of stochastic systems like minimality, which are important in applications to filtering and recursive estimation algorithms of minimal dimension. For example a new minimal–complexity solution of a class of noncausal estimation problems has been found and a new role of the family of all solutions of the Algebraic Riccati Equation in the computation of the optimal noncausal estimator has been discovered.

The idea of stochastic state (splitting) has been applied to various types of signals, e.g. to finite-state processes. Stochastic realization in this context has the purpose of finding algorithms for modelling finite-state signals as functions of a finite state Markov Chain (what is now called a ”hidden Markov Chain”). This problem is being now recognized as a key problem in signal processing with many potential applications to source coding, speech recognition etc.. Work in this area has started in the 70’s and has continued until recently in collaboration with Jan van Schuppen.

Below we list the papers where the concept of splitting was shown to be the natural counterpart of the idea of ”state” in the stochastic setting and the basic ideas of stochastic realization theory were introduced.


2 Identification and Subspace identification

Early work in the field of identification was on identifiability and parametrization of multivariable models. Recent works has mostly been on subspace identification. There are basically two different approaches to the problem of fitting a model to observed data. The first, the optimization approach, is based on the principle of minimizing a suitable distance function between the data and the chosen model class. Well-known and widely accepted examples of distance functions are the likelihood function and the average squared prediction-error of the observed data. For multivariable models the optimization approach has several drawbacks. First there are rather subtle identifiability and parametrization issues which are traditionally solved by use of canonical forms. These however tend to lead to ill-conditioned estimation problems. Next, the likelihood (or prediction error) minimization can, except in trivial cases, only be done numerically by iterative algorithms in the parameter space, say in the space of minimal \((A, B, C, D)\) matrix quadruples. For this reason there is no guarantee of reaching a true minimum and often a time-consuming random search in the parameter space is necessary to validate the estimates.

The subspace identification approach is not based on optimization. It may be described as a two steps procedure by which one first constructs a state for the observed process, and then does regression on a state space model. The successive noise model identification step requires the solution of a Riccati equation. This is a system-theoretic paradigm essentially rooted on stochastic realization theory. It is well-known that subspace methods do not require the a priori choice of identifiable parametrizations and can be implemented by fast and reliable numerical schemes. A statistical assessment of these methods has been an open problem for some time. Work in collaboration with A. Chiuso has lead to substantial progress on the statistical analysis of subspace methods.


3. A. Lindquist and G. Picci, "Geometric Methods for State-Space Iden-


3 Factor Analysis and Errors-in-Variables Modeling

It is well-known that ARMAX models treat the observed variables in an asymmetric manner, since a distinction is made from the outset of which variables in the model are "inputs" and which are "outputs". In particular, input variables are assumed to be observed without error. As much argued by Kalman, these models may be inappropriate ("prejudiced") descriptions to impose to real data coming from economic time series or industrial processes involving feedback.

"Unprjudiced" models like Error–in Variables (EIV) or Factor–Analysis (FA) models, have been around for several years in the statistical literature but serious identifiability problems for these models have hampered their application. Solving the intrinsic "unidentifiability", or better the inherent non–uniqueness of these models has been an open problem for decades. The unidentifiability problem for a class of FA models (for the so–called "two–blocks" models), both static and dynamic, has been thoroughly studied in a paper appeared in the Journal of Econometrics in 1989. There it shown that the continuum of minimal FA models describing two given random signals can be parametrized explicitly by a certain projection matrix. The choice of a particular model (i.e. projection matrix) results in exact (i.e. with no modelling error) representation of a particular subset of the output variables while the complementary subset is instead represented with a maximal modelling error variance. A uniquely identifiable model can be selected by choosing how much representation error variance one is willing to tolerate on each out-
put vector. The identifiability of EIV models with white measurement errors (the so-called Frisch scheme) has been also addressed recently.


### 4 Stochastic model reduction by aggregation

The papers listed below document a tentative of understanding how well a stochastic reduced order model could represent a ”complicated ” deterministic system. This work elaborates theoretically on the observation that in many practical situations stochastic models work well as thy are effectively reduced–order descriptions of large deterministic systems in which ”parasites” and variables coupling with the environment are represented as additive ”noise” in the dynamical equations. A well–known problem in many areas of control, but especially in adaptive control, is how to cope with unmodelled dynamics. There seems to be some evidence that control schemes which use stochastic models and stochastic description of the environment are more robust to unmodelled dynamics.


### 4.1 Stochastic Control and applications

Below is a list of representative papers addressing various issues related to LQG, $H_\infty$ control and applications.


5 Vision-Based estimation and guidance

This last project is centered on Kalman filter-based motion and scene estimation from visual sensing. There is a close collaboration with the computer vision groups at UCLA (prof Soatto) and Caltech (prof Perona), and much joint work has resulted from the collaboration with these teams.


6 Applied projects and Grants

Applied work which has resulted from several contracts with industries and research agencies has led to the implementation of stochastic filtering and modern control algorithms to marine systems, electric drives, and more recently, to autonomous mobile robots based on computer vision. Principal industrial or applied scientific projects,


2. Project manager and team leader of the Italian team (IT-LADSEB) for the European Research Network of Excellence System Identification (ERNSI), funded by the Commission of the European Communities through the Human Capital and Mobility Program (HCM), formerly SCIENCE Project, started in 1992 and concluded in 1996.


5. Project manager and team leader of the Italian team (IT–LADSEB) for the European Research Network of Excellence *System Identification* (ERNSI), funded by the Commission of the European Communities through the Training and Mobility of Researchers Program (TMR), 1997-2003.

6. National coordinator and principal investigator of the University of Padova team, of the national research project *Identification and Control of Industrial Systems* funded by the Italian ministry of higher education (MURST), 1998-2000.

7. National coordinator and principal investigator of the University of Padova team, of the national research project *Identification and Adaptive Control of Industrial Systems* funded by the Italian ministry of higher education (MURST), 2000-2002.

8. National coordinator and principal investigator of the University of Padova team, of the national research project *New Algorithms for the Identification and Adaptive Control of Industrial Systems* funded by the Italian ministry of university research (MIUR), 2002-2004.

9. Consultant for various industrial groups, among which Tecnomare S.p.A. Venice, Italy; Ferrari S.p.A. Maranello, Italy; SATE S.r.L. Venice, Italy; Salvagnini S.p.A. Vicenza, Italy; and others.

