Summary of the Research Activity

The research activity fits into the context of the nonlinear control. It has been carried out striving to follow the most recent developments in the sector, and has concerned either methodological or applicative arguments.

Methodological arguments

- **Hybrid and discrete event systems**;
- **Digital control and regulation of discrete–time and sampled continuous–time nonlinear systems**;
- **Stabilization of nonlinear systems with input delays**;

Applicative arguments

- **Control of spacecraft structures**;
- **Control of synchronous and induction electric motors**;
- **Control of automobile powertrain**;
- **Active vehicle attitude control**;
- **Nonlinear control of nuclear reactors**.

This activity have been carried out in collaboration with colleagues in the frame of national/international collaborations, among which

- Salvatore Monaco, Stefano Battilotti, Alberto De Santis, *Dipartimento di Informatica e Sistemistica "Antonio Ruberti"*, Rome, Italy;
- Dorothée Normand–Cyrot, *Laboratoire des Signaux et Systèmes* del C.N.R.S., Paris, France;
- Peter Ramadge, Sanijeev Kulkarni, *Department of Electrical Engineering*, Princeton University, Princeton, USA;
- Bernardino Castillo, *Centro de Investigación y de Estudios Avanzados del I.P.N.*, Guadalajara, Mexico;
- Alberto Sangiovanni–Vincentelli, *Department of Electrical Engineering and Computer Science*, Berkeley University, Berkeley, USA;
- Maarouf Saad, *Département de Génie Électrique*, École de Technologie Supérieure, Université du Québec, Montreal, Québec, Canada;
- Jorge Rivera, *Departamento de Electrónica*, Centro Universitario de Ciencias Exactas e Ingenierías, Universidad de Guadalajara, Guadalajara, Jalisco, Mexico;
- Sergej Čelikovský, *Institute of Information Theory and Automation*, Academy of Sciences, Prague, Czech Republic;
- Alexander Dyda, *Department of Electrical Engineering*, Far Eastern State University, Vladivostok, Russia;

in addition to colleagues of my University (Maria Domenica Di Benedetto, Alessandro D'Innocenzo). A brief overview of this results is presented in the following (please refer to Form 7 for references).

Hybrid and discrete event systems systems. Main results:

1. Necessary conditions (also: some sufficient conditions) for the existence of a reduction of temporized hybrid systems (timed automata) to finite state automata [I4];
2. Synthesis of optimal controllers via bisimulation construction [I18];
3. Nonlinear state feedback regulation of electromagnetic valves for camless engines [I19];
4. Observability of hybrid systems, observability recovery from (minimal set) output information (from continuous signals), and decidability and complexity analysis of the verification problem for hidden Markov models [I23];
5. Fault diagnosis problem for nonlinear systems via a fuzzy sliding–mode observer approach [I24];

6. Abstraction procedure to translate a hybrid automaton into a timed automaton to verify observability and diagnosability properties, with application to electromagnetic valves for camless engines [I28];
7. Observability of continuous–time switched linear systems subject to unknown disturbances, unknown switching signals and unconstrained nonzero dwell time, with geometric characterization of the observability properties, and estimation of the state from the continuous measurements [I29].

These works have been carried out in collaboration with: Peter Ramadge, Sanijeev Kulkarni (Department of Electrical Engineering, Princeton); Maria Domenica Di Benedetto, Alessandro D'Innocenzo (Dipartimento di Ingegneria Elettrica e dell'Informazione, L'Aquila); Alberto Sangiovanni–Vincentelli (Department of Electrical Engineering and Computer Science, Berkeley); Bernardino Castillo (Centro de Investigación y de Estudios Avanzados del I.P.N., Guadalajara). Works: [I4], [I18], [I19], [I23], [I24], [I28], [I29], [B1], [C3], [C6], [C8], [C9], [C11], [C26], [C28], [C31], [C34], [C36], [C40], [C43], [C44], [C45], [C46], [C52], [C53], [C54], [C59], [C60], [C67], [C70], [Cr2], [Cr3], [R2], [R4], [R5], [R6], [R7], [R8], [R11], [R12], [T2].

Digital control and regulation of discrete–time and sampled continuous–time nonlinear systems. Main results:

1. Nonlinear discrete–time regulation for MIMO systems, existence conditions in terms of zero dynamics, and approximate solutions [I1];
2. Linear and nonlinear regulation of sampled nonlinear systems, with existence of the (exact or approximated) digital solutions under assumptions related to the existence of robust solutions to the continuous problem [I2];
3. Nonlinear digital multirate controller for asymptotic tracking of a reference attitude trajectory for rigid spacecraft [I7];
4. Robust regulation of a discretized nonlinear system ensuring a ripple–free behavior in the intersampling time [I10];
5. Introduction of the generalized immersion for the solution of the robust regulator problem [I17];
6. Nonlinear state feedback regulation of electromagnetic valves for camless engines [I19];
7. Hybrid control of induction motors via sampled closed representations [I21];
8. Digital sliding mode control scheme for discrete time nonlinear systems and application to for induction motors [I22].
9. Stabilization for the class of continuous time nonlinear systems which are discretized in closed form (strict feedforward form) via a fuzzy logic approach [I25];
10. Fuzzy nonlinear ripple free regulator solving the sample–data structurally stable regulation problem for the case of nonlinear or generalized immersion [I27].

These works have been carried out in collaboration with: Bernardino Castillo (Centro de Investigación y de Estudios Avanzados del I.P.N., Guadalajara); Salvatore Monaco (Dipartimento di Informatica e Sistemistica "Antonio Ruberti", Rome); Dorothée Normand–Cyrot (Laboratoire des Signaux et Systèmes, Paris); Sergej Čelikovský (Institute of Information Theory and Automation, Prague). Works: [I1], [I2], [I7], [I10], [I17], [I19], [I21], [I22], [I25], [I27], [I30], [B2], [C2], [C16], [C29], [C37], [C41], [C42], [C47], [C48], [C50], [C51], [C55], [C58], [C64], [C72], [C75], [C79], [Cr82], [R10].

Stabilization of nonlinear systems with input delays. Main results:

1. Discrete predictor–based control of nonlinear system in strict feedforward form with input time–delay via fuzzy logic approach [Ir1];
2. Stabilization of systems modeled via approximated representation (Euler, Runge–Kutta, Takagi–Sugeno, etc.) of the sampled system dynamics [C69].

These works have been carried out in collaboration with: Bernardino Castillo, Graciela Sandoval Castro (Centro de Investigación y de Estudios Avanzados del I.P.N., Guadalajara). Works: [Ir1], [C69], [C73], [C76].

Control of spacecraft structures. Main results:

1. Nonlinear adaptive control of flexible spacecraft [C1];
2. Active (piezoelectric actuators) vibration suppression with output controllers in flexible spacecraft attitude tracking [I5];
3. Adaptive robust tracking for flexible spacecraft in presence of environmental disturbances [I6];
4. Nonlinear digital multirate controller for asymptotic tracking of a reference attitude trajectory for rigid spacecraft [I7];
5. Attitude output feedback control for spacecraft with flexible appendages in presence of parametric uncertainties and/or environmental disturbances [I11];
6. Global state feedback and semiglobal output feedback of infinite dimensional large space structure with flexible elements [I12];
7. Attitude tracking via structurally stable regulation of rigid spacecraft with parameter uncertainties [C33];
8. Passive output dynamic control of spacecraft with flexible appendages [I14];
9. Active (piezoelectric) output dynamic controller for flexible spacecraft in presence of disturbances and parameter variations [I16];
10. Trajectory tracking for a quadrotor via fuzzy regulation [C78];

These works have been carried out in collaboration with: Salvatore Monaco, Alberto De Santis (Dipartimento di Informatica e Sistemistica "Antonio Ruberti", Roma); Bernardino Castillo (Centro de Investigación y de Estudios Avanzados del I.P.N., Guadalajara). Works: [I5], [I6], [I7], [I11], [I12], [I13], [I14], [I16], [I20], [B3], [C1], [C4], [C12], [C10], [C14], [C17], [C18], [C19], [C21], [C24], [C25], [C32], [C33], [C35], [C39], [C56], [C78], [R3].

Control of synchronous and induction electric motors. Main results:

1. Robust feedback control of a synchronous motor with model and parameter uncertainties, and load disturbances [I3];
2. Adaptive output feedback control of synchronous motors [I8];
3. Nonlinear H^∞ control of a permanent magnet synchronous motor subject to parameter variations [I9];
4. Hybrid control of induction motors via sampled closed representations [I21];
5. Digital sliding mode control scheme for discrete time nonlinear systems and application to for induction motors [I22];
6. Sensorless high order sliding mode control of induction motors [Ir2];
7. Structurally stable regulation for synchronous motors [C29];
8. Super–twisting sensorless control of permanent magnet synchronous motors [C68].

These works have been carried out in collaboration with: Bernardino Castillo (Centro de Investigación y de Estudios Avanzados del I.P.N., Guadalajara); Jorge Rivera (Departamento de Electrónica, Guadalajara). Works: [I3], [I8], [I9], [I21], [I22], [Ir2], [C5], [C7], [C13], [C15], [C20], [C22], [C23], [C27], [C29], [C30], [C37], [C38], [C41], [C49], [C64], [C68], [C72].

Control of automobile powertrain. Excellent benchmark for new theoretical results on hybrid systems, and as inspiration for further developments in the theory. Main results:

1. Estimation technique for injector characteristics based on a set of measurements, carried out using sensors present in classical cars [I15];
2. Nonlinear state feedback regulation of electromagnetic valves for camless engines [I19];
3. Abstraction procedure to translate a hybrid automaton into a timed automaton to verify observability and diagnosability properties, with application to electromagnetic valves for camless engines [I28];
4. Nonlinear output feedback regulation of electromagnetic valves for camless engines [C50].

These works have been carried out in collaboration with: Maria Domenica Di Benedetto (Department of Information Engineering, Computer Science and Mathematics, L'Aquila); Bernardino Castillo (Centro de Investigación y de Estudios Avanzados del I.P.N., Guadalajara). Works: [I15], [I19], [I28], [C47], [C48], [C50], [R9].

Active vehicle attitude control. Main results:

1. Adaptive active front steering with rear torque vectoring in an integrated controller to guarantee vehicle stability [I26];
2. Adaptive integrated vehicle control using active front steering and rear torque vectoring [C61];
3. Nonlinear adaptive tracking for ground vehicles [C62];
4. Smart management of actuator saturation in integrated vehicle control [C74].

These works have been carried out in collaboration with: Maria Domenica Di Benedetto (Department of Information Engineering, Computer Science and Mathematics, L'Aquila); Bernardino Castillo (Centro de Investigación y de Estudios Avanzados del I.P.N., Guadalajara). Works: [I26], [C51], [C57], [C61], [C62], [C71], [C74], [C63].

Nonlinear control of nuclear reactors. Main results:

1. Pressurizer pressure control in pressurized water reactors: performance study of the control systems in the presence of a turbine trip [C77];
2. Digital nonlinear control for pressurizers in a pressurized water reactor [Cr82].

These works have been carried out in collaboration with: Bernardino Castillo (Centro de Investigación y de Estudios Avanzados del I.P.N., Guadalajara). Works: [C77], [Cr80], [Cr81], [Cr82], [Cr83], [Cr1], [R13], [R14], [R15], [R16], [R17], [R1], [T1].