SCIENTIFIC CURRICULUM of REBECCA SALMONI

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1 Education

1.1 Academic Degrees

- Ph.D in Sciences et Technologies de l'Information des Télécommunications et des Système at Université de Paris 11, Orsay. Ph.D. defence 21/12/2007. Title of the thesis *Sur une sytnthèse optimale pour un système quantique à deux niveaux (on a time-optimal synthesis for a two-level quantum system)* Supervisors: Yacine Chitour (Paris XI), Ugo Boscain (CNRS, Dijon, France - SISSA, Trieste, Italy).

- Ph.D. in Computational Sciences and Informatics (Applied Mathematics) at Università di Napoli "Federico II". Ph.D. defence 03/02/2006. Title of the thesis *Su una sintesi ottima per un sistema quantistico a due livelli* . Supervisors: Yacine Chitour (Paris XI), Ugo Boscain (SISSA, Trieste, Italy).

- Laurea in Physics (4 years), Università di Napoli "Federico II", Degree thesis, November 2001. Title of the thesis *Descrizioni Hamiltoniane alternative per sistemi dinamici classici e quantistici* (Alternative hamiltonian descriptions for classical and quantum dynamical systems). Supervisor Giuseppe Marmo (Università di Napoli Federico II).

1.2 Fellowships and long term visits

- September 2006 - December 2006: Research Fellowship: *Modelli di sensori per la determinazione di parametri ambientali*, at Virgo laboratory of the Physics Departement of the Università di Napoli "Federico II"

- September 2004 - September 2005: Marie Curie Fellowship (Control Training Site) at CNRS of Paris (Supelec-Université de Paris 11, Orsay) collaborating with Prof. Y.Chitour.

- January 2004 - June 2004: Visiting Student at Sissa (International School for Advanced Studies), Trieste Italy taking classes of the PhD Program in Applied Mathematics (U. Boscain (SISSA): *Introduction to control theory*. A. Agrachev (SISSA): *Geometric control theory*) and collaborating with Dr.U. Boscain.

- July 2003 - July 2004 Co.Co.Co. at Virgo Laboratory (Universit di Napoli "Federico II")on the subject "Mathematical Modelling and Control of a Multipendular Mechanical Suspension for the attenuation of seismic noise in suspended optical cavities"

- November 2001 - October 2004: Graduate Student Fellowship at Università di Napoli "Federico II"

1.3 Schools and Conferences

- XXX *Scuola Estiva di Fisica Matematica (GNFM)*(Ravello, Villa Rufolo, 6-18 September 2005)
- XXIX *Scuola Estiva di Fisica Matematica (GNFM)*(Ravello, Villa Rufolo, 6-18 September 2004)
- 3rd *Sigrav School* at EGO- Pisa (Italy), May 2004
- *Problemi Matematici in Meccanica Quantistica* (on Mathematical Problems in Quantum Mechanics) - Modena (Italy), December 2003.
- Second European Junior Meeting on *Control Theory and Stabilization* -Torino (Italy), December 2003
- *Trimester on Dynamical and Control Systems* , (Sissa) Trieste (Italy), September-November 2003
- *Current Geometry 2003*, Napoli (Italy), June 2003
- Annual Conference *Problemi Attuali in Fisica Teorica* (on Current Problems in Theoretical Physics) - Vietri (Salerno, Italy), April 2003.
- Annual Conference *Problemi Attuali in Fisica Teorica* (on Current Problems in Theoretical Physics) - Vietri (Salerno, Italy), April 2002.
- 2nd International Conference *Understanding and Creating Music* Caserta, Italy- November 2002
- *Scuola Estiva di Fisica Matematica* -Ravello (Salerno, Italy), September 2002
- 1st *Diffiety School* - Forino (Avellino, Italy), July 1998.

1.4 Languages

- Italian, French, English

2 Invited Conferences and Talks

- Invitation to SIMUMAT for the Workshop "Mathematical Structures on Quantum Mechanics II" at UCM Madrid, Spain, March 2008, Communication: "A Time Optimal Synthesis for a two level Quantum System"
- "Advanced Winter School on the Mathematical foundations of control and quantum information theory", Castro Urdiales, Spain 11-15 February 2008, Communication: "A Limit Synthesis for a Quantum Spin System"

3 Scientific activity and professional skills

3.1 Research Areas

- Control Theory: Optimal Control, Quantum Control, Stability.
- Classical and Quantum Dynamical Systems.

My research interests are mainly classical and quantum mechanics and control.

In the last years I pursued my research activity at the CNRS in Paris (Supèlec), and SISSA in Trieste, under the supervision of Yacine Chitour and Ugo Boscain. My studies focused on the solutions for a Control System defined on a two dimensional sphere, the aim being to reach the South Pole starting from the North Pole and using rotations along two fixed axis (symmetric with respect to the north pole), in a minimum time. This Control System allows to modelize a two-level Quantum Systems (as well any kind of "unitary norm" problem), controlled by an external magnetic field (with bounded amplitude), with the aim of pursuing a transition from one state to another, in a minimum time. At the same time, the "Minimum-Time Problem" formulated on the two dimensional sphere is strongly connected to a similar problem for the Rigid Body, with the aim of reaching a given configuration starting from another in a minimum time. I also addressed the problem of how to stop a controlled harmonic oscillator in a minimum time, starting from different initial conditions, and with a limited set of controlled values. These two problems appear to be correlated.

A Control System is a Dynamical System whose evolution can be influenced by some external agents (the controls), and it's identified with a system of parameter-dependent ODEs. The differential geometric formulation turns out to be very convenient and natural within this context, allowing us to look at the whole issue in terms of families of vector fields parametrized by the controls.

To a control system it's possible to associate a certain cost (i.e. a functional defined on the paths), and determine which path minimizes this cost, given the boundary conditions. This type of problems are called Optimal-Control Problems, and can be seen as Variational Problems with non-holonomic constraints. An Optimum-Control Problem whose functional to be minimized is Time is called Minimum-Time Problem . The basic tool in the context of the

Optimum Control is the so called Pontryagin Maximum Principle (PMP). This theorem represents a generalization of the required conditions of the Calculus of Variations (Eulero-Lagrange equations, Weierstrass necessary condition) for problems with non-holonomic constraints.

The solutions to the quantum mechanical problem described above, are of a bang-bang type, i.e. characterized by the fact that the system switches from one control value to another. This problem has been first studied by Boscain-Chitour [2], who found a bound on the maximum number of switchings as function of the relative angle of the two considered rotations. There are still unresolved issues concerning the system's behaviour in a fixed neighborhood of the South Pole. It needs to be stressed that the PMP is a necessary but not sufficient condition for the minimization; as a consequence, the solutions found by applying the theorem are extremal, and the optimization must be assessed a posteriori. In the case of the problem on the sphere, my research focused on the assessment of optimality of the family of extremals when arriving in a neighborhood of the South Pole at the limit where the angle between the two rotations tends to zero. From the physical point of view, this represents a two level quantum system, interacting with low-intensity fields. This limit must be appropriately calculated, and the main result of my work is that in a fixed neighborhood of the South Pole, the optimal trajectories on the sphere tends, in a suitable sense to those of a controlled harmonic oscillator, with initial conditions on a fixed level of the energy.

In the framework of my Ph.D. studies my first research topic has been the Mathematical Modelling and the Control of Multipendular Suspensions for the lessening of seismic noise (Super Attenuators) used in the VIRGO experiment. The VIRGO experiment attempts to detect gravitational waves through the use of a Michelson interferometer with 3 Km-long arms. Each arm of the interferometer has a Fabry-Perot cavity of finesse 50 to increase the equivalent length of the arms, with the scope of obtaining the necessary sensitivity of the instrument. This instrument, in fact, is set to measure variations in length of the order $10^{-18}m$ (a length smaller than the ray of a proton!), which is the order of size needed for the movements produced by the passage of a gravitational wave. Such a great sensitivity makes it greatly important that one succeeds in isolating the instrument from any source of external noise. For this reason all the optics of VIRGO are mounted on special suspensions (Super Attenuators), capable of drastically reducing the amplitude of the oscillations due to the seismic noise of the frequency $\nu \geq 10Hz$. Such suspensions can be modeled, by first approximation, as chains of 7 pendulums (with all degrees of freedom) with elastic wires. Given the order of magnitude of the measurable displacements, it is valid to think that the instrument works at small oscillations and thus considers the linearized motion equations. In the stability regions of these equations, such suspensions act as low-pass filters for the seismic noise. On the other hand, at "resonance frequencies" the system is no longer stable and the oscillations due to the seismic noise are amplified. In order to stabilize the suspension in the resonance regions, there is a Control System with feed back.

In this area, my research (carried out under the supervision of Prof. L. Milano and under the consultation of Prof. A. Sarychev) consists of the study of possible resonances of this system subject to external stresses. It could be shown that, when the stress effects arising from the multipendular chain suspension point are taken into account, the dynamics is described by a system of ODE with time dependent coefficients which cannot be set in a normal (uncoupled) form, even in the small oscillation approximation. In this framework, parametric resonances (Hill's equation like) are expected to take place.

Although during my doctoral studies I have changed research areas from the Foundations of Quantum Mechanics to Control Theory, I continue to use the knowledge and tools of Differential Geometry and Quantum Mechanics that I acquired during my studies for my laurea thesis on Dynamical Systems.

My Laurea Thesis, carried out under the supervision of Prof. G. Marmo, can be summarized as such:

classically, a bi-hamiltonian description of a dynamical vector field, with "compatible" Poisson Brackets is linked to the complete integrability according to Liouville. The study of alternative descriptions for dynamics in Quantum Mechanics reveals that the canonical commutation relations are not univocally determined by dynamics, which appears to make sense in comparison to the analogous results that one obtains in Classical Mechanics. Indeed, from the quantum point of view, the existence of alternative Hamiltonian descriptions translates itself in the existence of various association rules among the observable and, consequentely, different Lie algebras, all of them consistent with the same dynamics. In order to do this, one makes use of Weyl's quantization procedure. This investigation gives different commutation relations for P and Q operators, and different possible realizations of the quantum system on the space L^2 of functions defined on Lagrangian submanifolds of different symplectic forms. Finally, through the Wigner Map, a Quantum Mechanics has been introduced on a symplectic space, such that classical dynamics (in Hamiltonian formalism) and quantum mechanics (in Heisenberg picture) are written on the same support, which makes a discussion of the classical limits of Quantum Mechanics possible from an algebraic point of view.

Bibliografy

[1] Pontryagin L.S., Boltianski V., Gamkrelidze R.,Mitchtenko E., The Mathematical Theory of Optimal Processes, John Wiley, New York, 1961

[2] Boscain U. and Chitour Y., Time Optimal Synthesis for Left-Invariant Control Systems on SO(3), SIAM J. Control and Opt. vol.44, no 1,2005

[3] Flaminio R., La sospensione degli specchi e il controllo di un interferometro per la rivelazione di onde gravitazionali, Ph.D Thesis in Physics, Universita' di Pisa, 1994

[4]Arnold V.I., Metodi matematici per la meccanica classica, Editori Riuniti 1979

[5]Dirac P.A.M., Principles of Quantum Mechanics, Oxford Science Publication

3.2 Publications

[1] Paolo Mason, Rebecca Salmoni, Ugo Boscain, Yacine Chitour, "Limit Time Optimal Syntheses for a control-affine system on S^2" SIAM Journal of Control and Optimization Vol.47 n.1 pp 111-143, January 2008 .