

# Curriculum Vitæ of the research and teaching activities

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# 1 Introductory notes

## 1.1 General data

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## 1.2 Actual position

Antonio Frisoli is Full Professor in Engineering Mechanics and Robotics (09/A2, ING/IND13 Applied Mechanics) at Scuola Superiore Sant'Anna and Head of the Human Robot Interaction (HRI) area at the TeCIP Institute (Institute for Communication, Information and Perception Technologies of Scuola Superiore Sant'Anna), where he is currently coordinating the activities of a group composed of about 20 people, of which 4 senior researchers, 6 PhD Students, 2 post-doc researchers, 3 research assistants and 1 technician and several undergraduate students.

The group of Human-Robot Interaction deals with developing theories, models and systems for new advanced human-machine interface systems, and in particular robotic systems that can physically cooperate (pHRI) with humans in a safe and intuitive manner and interact in Virtual Environments (haptic devices), within industrial and medical applications. The group has a consolidated experience in the areas of design of robots, with particular reference to exoskeletons and wearable robots, haptic devices and wearable haptics, theoretical kinematics and parallel manipulators, advanced control of electromechanical systems, robot assisted rehabilitation, FEM analysis, human-machine interfaces based on electro-biological signals (EEG, EMG), virtual reality immersive applications.

He has held and holds positions of scientific responsible for the Sant'Anna School of numerous international research projects. Currently he is scientific responsible for the Sant'Anna School of two European projects:

- Project Wearhap EU FP7-ICT-2011-9 "Wearable Haptic for Humans and Robots": the project is obiettvio developing innovative wearable interface for interacting with robots and virtual environments. Prof. Frisoli directs Wp4 for the development of new devices.
- EU Project 23 ICT Horizon 2020 Centaur "Robust Mobility and Dexterous Manipulation in Disaster Response by Fullbody Telepresence in Centaur-like Robot", prof. Frisoli is responsible for WP that deals with the development of telepresence station for remote control of a quadruped centaur robot.

He is responsible for Scuola Sant'Anna of the regional project Ronda, aimed at the construction of a robotic rehabilitation gym for post-stroke rehabilitation and the PRIN project Modulimb, funded by the Italian Ministry of Research. He has established since 2007 a joint laboratory with University Hospital of Pisa, Department of Neurorehabilitation, with a focus on upper limb rehabilitation by means of robotic and VR technologies. Prof. Frisoli actively participates in the promotion of new ideas and technology transfer of research results. He is a founding member of the spin-off Wearable Robotics, winner of the Marzotto Award 2013 as the best innovative start-ups (€250,000 prize). He also promotes industrial cooperation, as he was and is the coordinator of several projects with companies. Currently he manages a collaboration with the Fiat Research Center for evaluation of the performance of manual gearshift transmissions, coordinating a research project with Trenitalia for the development of robotic solutions for maintenance on condition of railway stocks.

Antonio Frisoli is associated member of IEEE (the Institute of Electric and Electronics Engineers) since 2000, where he has been the former IEEE Technical Committee on Haptics (2012-2014), that gathers more than 500 researchers in the area of haptics.

He is associate editor for IEEE Robotics & Automation Letters, Presence MIT Press, the general chair for the Human-Machine Interaction Summer School (HMISS 2017), the general chair of the conference Eurohaptics 2018 ([www.eurohaptics2018.org](http://www.eurohaptics2018.org)), a major international conference on haptics and touch enabled computer applications, and the primary European meeting for researchers in this field. He has been the former chair of the IEEE Technical Committee on Haptics, that gathers more than 500 researchers in the area of haptics, where now he acts as the Vice-Chair for Workshops and Tutorials.

He is authors of more than 150 scientific publications in peer reviewed conferences, scientific journals and books, and he has a Scholar h-index of 30 and Scopus h-index of 20.

### 1.3 Current assignments

#### Scientific responsible (PI) for Scuola Superiore Sant'Anna

- ModuLimb Project, "Probing the modular organization of the neuromuscular control of limb movements: an inter-disciplinary approach", funded by the National Ministry of Research as PRIN National Research Program. Prof. Frisoli is responsible for the realization of exoskeletons and the development of novel myoelectric control based on motor synergies.
- Principal Investigator of the project TeCIP Ronda FAS Health, funded by the Tuscany region (Institute budget  $\sim 300\text{K}\text{€}$ , three-year start date in January 2016) for the validation of robot technologies in neurorehabilitation
- Scientific responsible for the Sant'Anna School of the project Horizon 2020 Centaur (600K€, four-year start date in March 2015) EU Project 23 ICT Horizon 2020 Centaur "Robust Mobility and Dexterous Manipulation in Disaster Response by Fullbody Telepresence in Centaur-like Robot"). Prof. Frisoli is responsible for WP that deals with the development of telepresence station for remote control of a robot quadruped centaur.
- Principal Investigator for Scuola Superiore Sant'Anna of the FP7 project Wearhap (budget Institute  $\sim 900\text{K}\text{€}$ , four-year start date in March 2013) EU FP7-ICT-2011-9 "Wearable Haptic for Humans and Robots": the project aims at the development of innovative wearable interface for interacting with robots and virtual environments. Prof. Frisoli directs WP4 for the development of new devices.
- Scientific Manager of the project with Fiat Purchasing (Institute budget  $\tilde{1}50\text{K}\text{€}$ , four-year start date in March 2013) for the assessment of performance of manual gearshift transmissions
- Project Manager of project funded by Scuola Sant'Anna for the development of BCI systems for rehabilitation ( $\text{€}15,000$ )

#### Technical responsible in research projects

- Industrial project with Trenitalia on the "on-condition maintenance": robotics platform Responsible for the development of a robotic system (budget robotics  $\sim 400\text{K}\text{€}$ , three-year start date in September 2015): Antonio Frisoli is responsible for the system design robotics for the train underbody inspection and verifying the integrity of the pantograph

- Industrial project with Italian Railway Service (RFI), the topic Monitoring railway infrastructures through optical fibers sensors (budget Institute  $\sim 100\text{K}\text{€}$ , four-year start date in March 2013): Antonio Frisoli is responsible for the simulation using finite element models of the rails and ballast over the masonry bridge.

## 1.4 Professional career

- 2017: Full Professor in Associate professor in Engineering Mechanics and Robotics, scientific domain “Applied Mechanics” (09/A2 -ING-IND/13) Scuola Superiore Sant’Anna;3);
- 2012: National habilitation to full professor in Mechanical Engineering, scientific domain “Applied Mechanics” (ING-IND/13);
- August 2012: Associate professor in Engineering Mechanics and Robotics, scientific domain “Applied Mechanics” (09/A2, ING-IND/13) Scuola Superiore Sant’Anna;
- September 2010: winner of the national selection for one position of Associate Professor in the scientific domain of “Applied Mechanics” (ING-IND/13) at Scuola Superiore Sant’Anna;
- Period since August 2003- July 2009: Assistant Professor in Applied Mechanics (ING-IND/13) (6 years temporary position) at Scuola Superiore Sant’Anna;
- Period 1999-2003: Antonio Frisoli carried our scientific research and teaching activity at the PERCRO laboratory of Scuola Superiore Sant’Anna, within which is involved in numerous research project both at national and international level (EU projects), with collaborations established with industrial partners, universities, worldwide and European research institutes;
- Visiting research at Fermi national laboratory with the National Institute of Nuclear Physics in Batavia (Chicago), IL-USA, a Federal research in the U.S. high energy physics, research in the area of high energy physics - elementary particles. During this period he dealt with the design, testing and analysis of the mechanics of superconducting magnets with high field strengths, including LHC quadrupoles and / or new designs, designing equipment for the construction of superconducting magnets in an inert atmosphere.

## 1.5 Education and studies

- In 2002 Antonio Frisoli receives the PhD *summa cum laude* (diploma di perfezionamento) in Industrial and Computer Science Engineering, area of “Theoretical analysis and Experimental activities for the development of teleoperations systems in Virtual Environments”, from Scuola Superiore Sant’Anna, discussing a thesis entitled “titolo Design and Modeling of Haptic Interfaces: an integrated approach” with advisors prof. Massimo Bergamasco, Prof. Paolo Ancilotti, Prof. Paolo Dario, and invited members in the evaluation jury Prof. Vincent Hayward (McGill University), prof. Vincenzo Parenti-Castelli (University of Bologna).
- In 1998 Antonio Frisoli received the graduate degree (equivalent to Master of Science) *Summa cum Laude* in Mechanical Engineering from the Engineering Faculty of the Univesrity of Pisa with a thesis on “Design and Optimization of an haptic Interface with six degrees of freedom for high dexterity operations in Virtual Environments”, advisors Prof. Massimo Bergamasco, Prof. Marino Marini, Eng. Fabio Salsedo.

- In 1998 he received the diploma of graduate studies in Engineering from Scuola Superiore Sant'Anna, discussing a thesis on "Kinematic analysis and design of the haptic interface subsystem of the TREMOR project", advisor prof. Massimo Bergamasco
- In 1998 Antonio Frisoli obtained the national professional qualification as Engineer
- In 1994 Antonio Frisoli won the national selection by examination for 5 places at undergraduate level at the Scuola Superiore Sant'Anna (ranking 2nd over more than 400 participants) and he is admitted at courses in the Class of Experimental Science)
- In 1993 Antonio Frisoli receives the diploma from high school specialized in scientific studies (Scientific Lyceum A. Volta, Foggia Italy) with the maximum vote of 60/60.

## 2 Scientific and research activity

### 2.1 Research themes

His research interests deal with the design and control of spatial robots with high performance, the study and development of new advanced human-machine interfaces, and in particular robotic exoskeletons and wearable robots, haptic interfaces and wearable haptics, issues of theoretical kinematics and applied to the study of new mechanisms and parallel manipulators, design and development of novel robotic systems for the neuro-motor rehabilitation in virtual environments, robotic-aided rehabilitation, novel human robot interfaces based on electrobiological signals (EEG, EMG), e.g. BCI, investigation of sense of presence and multisensory interaction in virtual environments, biorobotics and cognitive robotics. In the following, a detailed description of main research themes is reported.

**Force-feedback exoskeletons** In the course of the last ten years Antonio Frisoli has significantly contributed to the development of different versions of arm and hand force feedback exoskeletons, characterized with incremental improvements of performance in terms of force fidelity, mechanical impedance, as well as in terms of weight and bulk. Antonio Frisoli has significantly contributed to the development of the force-feedback exoskeleton L-Exos and of its parts [J39], and to the development and definition of model-based and model-free controllers for application in Virtual Environments and teleoperation [C75]. The exoskeleton is characterized by cable transmission with tendons routed over pulleys, so that the moving masses are significantly reduced having motor located on the fixed frame. The system has been one of the first upper limb exoskeletons used in stroke rehabilitation [C89]. Different exoskeleton prototypes of the system were built and the systems have been significantly acknowledged in the scientific literature for the design and for its successful application in rehabilitation [J39, J32]. In a second configuration, developed on purpose for a museum application, an hand exoskeleton that can exert forces on the two fingers of the hand can be mounted as final interface on the end-effector. The combination of the hand and arm exoskeleton make a system with 10 DoF, with high performance in terms of dynamics, obtained through the coupling of a micro-system for the hand and a macro-system for the arm. The system was successfully employed in a itinerant exhibition in several well-recognized European museums, demonstrating high levels of reliability and robustness, in the context of the EU project Pure-Form, of which Antonio Frisoli was the responsible for technical and application development [J51].

Antonio Frisoli has completed the design and construction of an admittance-type exoskeleton for the arm targeting neuromotor rehabilitation, the Rehab-Exos [C80]. The core of the system was the development of an innovative actuated joint, composed of one brushless torque motor, integrated with a custom design 1-dof torques sensor, one Harmonic-Drive speed-reduced and two redundant position sensors, so that both irreversibility of motion can be guaranteed in case power is off, for increasing safety, while high back-drivability of motion can be achieved when the power and control is on, thanks to joint-located torques sensors, with at the same time high safety standards for the patient. Moreover the system is based on a modular actuation, so that the exoskeleton can be easily configured for left and right patients, with only a kinematic change [C39]. Within the BRAVO project, Antonio Frisoli has also coordinated in collaboration with University of Bologna the development of an integrated system that includes an hand active orthosis implemented by the hand for the performance of tasks of grasping [J17]. Recently, he has proposed the new of underactuated exoskeletons for stroke rehabilitation [J9], for which a novel framework for haptic rendering with underactuated device has been proposed [C6], receiving best student paper award at WHC2017. He has also contributed within the projects VERE and CENTAURO, to the construction of the ALEX exoskeleton [J16], a bimanual

tendon-driven exoskeletons that exploit novel solutions for the shoulder design and actuation.

**Rehabilitation robotics** In the field of rehabilitation robotics Antonio Frisoli has a joint laboratory with the Dept. of Neurorehabilitation, Hospital of Pisa, dott. Chisari where he conducted research in the field of upper limb rehabilitation [J12]. In particular Antonio Frisoli has proven the efficacy and the effects of robotic rehabilitation in stroke patients, conducted with upper limb exoskeletons in several studies [J32, C87] and in orthopedic rehabilitation as well [B5]. He has also shown in a research conducted in collaboration with UPC, Barcelona [J28], how haptic feedback can strengthen retention of regained motor abilities after therapy. Antonio Frisoli has also contributed to the design to passive system for upper limb rehabilitation [J13]. He has shown how EMG control can be used in stroke rehabilitation for control of exoskeletons [J17], studied how motor synergies are influenced by wearing an exoskeleton [J16]. In [J5] the validation of distal therapy, by robotic hand training, is preliminary reported in a small group fo stroke patients. Antonio Frisoli investigated aspects of motor learning, to devise strategy of “assistance as needed” where the robot provided only the required level of assistance, to increase the volitional effort from patient. Recently in ICORR 2017 conference, Antonio Frisoli and his group presented a work [C9, J6] on the on-line adapation of active assistance with Alex exoskeleton, based on on-line user estimation performance. A clinical study was also conducted to evaluate the efficacy of use virtuali reality rehabilitation in the developmental age [C1].

**Robot kinematics by means of screws theory** Theory of screws and analysis of kinematic law in the framework of differential geometry (Lie groups, Lie algebras) represent a powerful tool for the analytical and geometric point of view for the resolution of spatial kinematic problem, such as in the case of robot design. Antonio Frisoli has investigated and extended the tools of screws theory to study the acceleration properties of robots, deriving a new method for the analysis of parallel manipulators. He has made use of the developed techniques for different kind of applications, such as type-synthesis of new kinematics, analysis of parallel manipulators and gravity compensation laws.

*Type synthesis of purely translational parallel manipulators*

These activities has led in 2000 to the publication of one of the first seminal studies on this topics [C126], where it was introduced a general methodology for the type synthesis of translational parallel mechanisms with theory of screws. More in detail, Antonio Frisoli has investigated the synthesis of innovative parallel manipulators with reduced number of degrees of freedom. He was one of the first to propose the derivation with an analytical methodology of all admissible parallel kinematics that can lead to pure translation motion of the upper platform.

*Extension of screw theory methods to dynamic analysis of parallel manipulators* The developed methods were further extended to the movement and dynamic analysis of parallel manipulators, such as Gough-Stewart platforms, used in inertial motion simulators, MORIS (motorbike simulator) and INDICA (forklift simulator), developed at PERCRO laboratory in the associated research projects. The methodology of analysis based on screw theory has been then further extended to the Hamiltonian formulation in the dynamics of robotic systems, that can be directly used for the synthesis of control systems, exhibiting robustness to time delay in the signal transmission or computation eventually present in the system.

In collaboration with Prof. Rico [J50], Antonio Frisoli has also developed a generalized method based on the extension of the theory of the screws to higher order motion analysis, with the introduction of accelerators for the dynamic analysis of parallel systems. Their fundamental work on the subject has shown the application of the methodology for modeling the dynamics of a Stewart



platform and a parallel wrist with two degrees of freedom.

*Analysis of position accuracy of parallel manipulators under joint clearances*

Antonio Frisoli and colleagues developed and proposed a new method for the analytical characterization of position accuracy of parallel manipulators [J35]. In particular with reference to purely translating and purely rotational parallel manipulators an exact analytical methodology was derived to identify the poses corresponding to the worst case accuracy in terms respectively of rotations and translations of the upper platform. He has made use of the developed techniques for different kind of applications, such as type-synthesis of new kinematics, analysis of parallel manipulators and gravity compensation laws [J29].

**Design of parallel mechanisms with reduced number of degrees of freedom** Antonio Frisoli has conducted the study of innovative mechanisms with parallel kinematics presenting features of high kinematic isotropy and high static and dynamic performance.

During his research activity, several tools of analysis have been designed based on the theory of screws, that has allows him to evaluated in a direct manner the kineto-statics and dynamics performance of different mechanisms and to generate the analytical conditions for the synthesis of parallel manipulators with purely translational or rotational motion, and with reduced number of degrees of freedom.

In the following, he had further developed these concepts to design and implement innovative concepts of haptic interfaces, with high dynamic performance and high position accuracy, that can be used for bilateral remote teleoperation control architectures [J49]. The developed methods led to the ideation and construction of two haptic interfaces with parallel kinematics and pure translational motion, based on a new parallel kinematic architecture that was selected on the basis of its high performance in terms of stiffness and dynamic bandwidth. More recently an interface for fMRI studies has been designed and built based on a 3RUR kinematics [C69]. Antonio Frisoli has also been working on performance analysis of parallel mechanisms with purely translational motion, studying the conditions of isotropy and force transmission, and developing an innovative method for exact calculation of maximum accuracy under joint clearances in purely translational parallel manipulators [J35]. Antonio Frisoli has further investigated the performance analysis of parallel mechanism with purely rotational mechanisms, by studying the conditions for kinematic isotropy and force transmissions. These concepts have been then extended to the synthesis of parallel manipulators with spherical motion, leading to the introduction of a new kinematics that making use of crossed-linked parallelograms allowed to extend significantly the angular range of motion of the end effector, with a significant application in the synthesis of surgical tools for laparoscopic surgery [C97].

**New control techniques for exoskeletons** Antonio Frisoli has developed and proposed several innovative approaches in the control of upper limb exoskeletons, with a particular focus on rehabilitation issues [B9]. In particular his main contributions have been:

- Several schemes of model-free control based on sliding mode control: the controller exhibits high robustness to change in parameters and can guarantee finite time properties of convergence of error [C73, C70]
- Triggered gain position control: control gains are adjusted on the basis of the force exchanged in real time between the patient and the exoskeleton, developing a control paradigm "assistance as needed", in which the patient is more involved in the motion tasks [C90, C39]

- Impedance control of exoskeleton with model-based compensation of friction of tendon transmissions [C106]
- Joint torque control based on a state-space techniques with dynamics modelling [C39]
- EEG/EMG driven control of robots: this innovative approach uses techniques developed in recent years of motor imagery and Brain Computer Interfaces to detect the intention of moving or neural networks for mapping of surface EMG to force directions and movements of the upper limb [C23, J30].
- Intention driven control: in this framework a novel algorithm for bounded-jerk control of movement has been proposed and developed. The algorithm performs an on-line planning for reaching an object in the space, fulfilling biological constraints of human movement of minimum jerk, to provide active on-line assistance in rehabilitation paradigms that exploit gaze tracking [J26].

**New systems of haptic interfaces and advance man-machine interfaces for the interaction in virtual environments, wearable haptics** Antonio Frisoli has extensively worked on the design, modelling, implementation and control of new haptic interface systems. Recently he had developed new systems of haptic interfaces based not only on kinaesthetic stimulation, but that rely also or alternatively are based only on cutaneous stimulation applied at the level of the fingerpad [J8]. Antonio Frisoli proposed first a new method for the stimulation of the fingerpad, that is based on a small parallel manipulator, with one rotational and one translational stage, which can exert a controlled pressure on the fingerpad through a small plate, that can approach the finger with a given orientation, coincident with the one of the contact surface [J42]. Further designs were performed to devise more compact mechanisms making use of skin stretch stimulation of fingerpad. [J14] The miniaturization represents a crucial aspects for the realization of haptic interfaces that can be used in highly immersive virtual environments. Antonio Frisoli has dealt with the study and analysis of new actuators of piezoelectric type or based on electroactive polymers, [J34] that will allow to overcome the traditional limits of electrical actuation in terms of payload/power ratio. He had also performed research on multi-contact point simulation in haptic exploration of shape, by designing specific systems suitable for multi-point haptic feedback [J44]. In the past he had built a system for the haptic exploration of shapes with four contact points [B7, B10].

**Passivity and absolute stability during haptic interaction with virtual environments and time-delayed teleoperation** Antonio Frisoli has dealt with the study and performance of advanced man-machine interfaces, with particular attention to the study of passivity and absolute stability under conditions of teleoperation with time delay [J49, C113]. In teleoperation, stability can be severely compromised by delays and uncertainty on the explored environment. Antonio Frisoli developed the techniques of robust control and optimal control, to study how the effect of parameters, such as the inertia or stiffness presented by the remote environment, can affect absolute stability and system performance [C117]. An application of these algorithms has been the synthesis of optimal control systems for the human power augmentation. It is occupied also the development of algorithms that teleoperation using schemes of passivation of the active communication channel, through an encoding in terms of wave variables of the transmitted force-position information, enabling bilateral stable interaction between master and slave systems even in conditions of communication delays [C63].

**Modeling, simulation, design and control of robotics and mechatronics systems** Antonio Frisoli has dealt with the mechanical design, construction and control of several robotic systems: haptic interface for multiple points contact interaction [B10], motion and rowing simulators [J38], development of robotic active vision heads, biomedical systems for positioning of an ultrasound probe, for laparoscopy and for rehabilitation [C94], exoskeleton robotic systems for arm and hands, desktop haptic interfaces with different degrees of freedom, force sensors and many other electromechanical system with high mechatronic integration. Specific methodologies have been developed by Antonio Frisoli for the CAD simulation of kineto-static and dynamic performance of devices, the implementation of models for the simulation and design of control systems, the experimental identification of dynamic system parameters and the experimental validation of the control law on robotic systems [C117, C113].

**Robotic systems with elastic transmissions and multiple degrees of freedom** Antonio Frisoli has dealt in detail the analysis and design of cable-actuated systems, both with non-redundant and redundant implementations. In particular Antonio Frisoli has introduced a new system of transmission cables for the implementation of parallel manipulators, optimizing some geometric solutions to obtain the best conditions of isotropy and force transmission ratio, which has led to the realization of an innovative haptic interface with two degrees of freedom with high kinematic isotropy properties [C132, C29]. In addition he was responsible for the experimental characterization of the performance of cable-driven robots, particularly in the case of complex transmissions as those required by exoskeleton systems, deriving methods for the dynamic identification of natural modes and of the characteristic frequencies of the systems with lumped models [J43]. Antonio Frisoli has developed non-linear friction of the observers that can capture the complex nature of the friction generated by long cable transmissions and estimate the distribution of the torque on the joints in the case transmission joint coupling. The dynamic models of friction, thus developed, used in a feedforward control loop in the base, have been shown to greatly increase robot performance.

**Multimodal interaction in virtual environments and applications** Antonio Frisoli has been responsible for numerous projects in virtual reality applications of the technologies on display. He has worked the University Pompeu Fabra in Barcelona as part of a clinical protocol for testing the use of bimanual haptic interfaces for rehabilitation [J28]. He was involved in the development of a complete application for the simulation of a virtual museum, the Museum of Pure Form, within which you can touch the statues of digital systems using haptic interface. Antonio Frisoli has investigated presence and multimodal interaction in virtual environments. Within the European project Presencia, studies how the perception of the virtual environment is affected by the perception of one's body and the specific role of touch with simulated haptic interfaces on the sense of presence and immersion [J23, J45, J18] and later embodiment in the VERE project [J37].

**Advanced interfaces for training** He developed a prototype virtual reality simulator for simulating operations of medical assistance in case of cardiac arrest. The system was successfully demonstrated in the Italian national congress of the association IRC (Italian Resurrection Council). In collaboration with the Maggiore Hospital of Bologna developed Mini-Vrem, a virtual reality simulator for the simulation of resuscitation procedures [J40]. A second system based on 3D Kinect motion sensor has been developed coupled with a serious game, "Relive", capable of providing feedback in real time on the frequency and depth of performed chest compressions. The system was successfully

validated in an experimental study with 80 students from high schools that adhered to the experiment [J10]. Antonio Frisoli has also dealt with the development of a mechanical simulator of rowing within the European project SKILLS, for the simulation of in-door rowing. The system consisted of a kinematic structure that can reproduce the movements of both the sculling both of the rowing of the tip. The resistance of water is simulated through the use of passive dissipative air-fans, while equipping the system with "embedded" sensors for force and position allowed to estimate in real time the gesture made by the athlete [J38].

**Haptic rendering algorithms with force feedback** At the laboratory PERCRO, Antonio Frisoli promoted the development of a complete software library for rendering haptic, called H-Lib, able to calculate in real time the magnitude of the forces of interaction and contact between an operator connected by a ' haptic interface and objects in a virtual environment. This library was developed in particular for the computation of the geometric interaction forces exchanged during the exploration of digital models very complex, with a high number of polygons, as in the case of geometries acquired by means of laser scanning, e.g sculptures acquired in the digitalization campaign of the project Pure Form [C110].

Further he developed physical simulation models, such as deformation of elastic bodies, models of linear friction and rotation for 1 or 2 points of contact, multibody dynamics, as well as analytical algorithms that can calculate the value of the forces of interaction on the basis of the geometrical conditions of the contacts. In the field of haptic rendering, in collaboration with the Robotics Lab at the University of Stanford [C96, C108]. Antonio Frisoli has developed an original model for the simulation rotational friction during two fingers grasping of objects extending an approach derived from the robotic manipulation based on boundary curves, and conducted experimental activities conducted to validate the model Antonio Frisoli was responsible for the development of control systems for more realistic simulation in car simulators. In particular he developed models that allow the simulation of primary command of car, resulting in the definition of a new approach for the simulation of a manual car gearshift. It dealt with the simulation of deformable bodies based on linear models that approximate the behavior of nonlinear elastic bodies to large deformations [J48]. He is currently working on grasping of virtual objects with physical simulation of interaction in virtual environments using datagloves equipped with goniometric sensors. He developed a prototype of data glove sensorized equipped with vibratory pads, able to that can stimulate the fingertips only in the proximity of contact with a virtual object [J23].

**Mobile and cognitive robotics applications** Antonio Frisoli has been involved in developing systems of neuromorphic control for autonomous navigation of robots. He has developed an active vision head with 5 degrees of freedom, independent movement of the eyes and a size comparable to a human head [J41]. Using the active vision head developed at the laboratory were conducted PERCRO task of autonomous navigation of robots to achieve functional goals, avoiding obstacles on the path, simulating the activity of brain areas involved in the human navigation and perception of optic flow [C66]. The system has also enabled us to experimentally verify the performance of algorithms for navigation based on optical flow balance, inspired by models of animal behavior. Antonio Frisoli was involved in the study of control architectures for robot types that include neuromorphic support for memory and learning.

## 2.2 PI in Scientific projects

### 2.2.1 European projects

***EU ICT 23 Horizon 2020 Centauro “Robust Mobility and Dexterous Manipulation in Disaster Response by Fullbody Telepresence in a Centaur-like Robot” (2015-now)***

The CENTAURO project aims at development of a human-robot symbiotic system where a human operator is telepresent with its whole body in a Centaur-like robot, which is capable of robust locomotion and dexterous manipulation in the rough terrain and austere conditions characteristic of disasters.

The CENTAURO robot will consist of a four-legged basis and an anthropomorphic upper body and will be driven by lightweight, compliant actuators. It will be able to navigate in affected man-made environments, including the inside of buildings and stairs, which are cluttered with debris and partially collapsed.

The Centauro system will be capable of using unmodified human tools for solving complex bi-manual manipulation tasks, such as connecting a hose or opening a valve, in order to relieve the situation. The group of Antonio Frisoli is responsible as WP leader of the realization of the operator interface, consisting in a dual arm upper limb exoskeleton

***EU Wearhap FP7-ICT-2011-9 “Wearable Haptic for Humans and Robots” (2013-now)***

Project WEARHAP aims at laying the scientific and technological foundations for wearable haptics, a novel concept for the systematic exploration of haptics in advanced cognitive systems and robotics that will redefine the way humans will cooperate with robots. The challenge of this new paradigm stems from the need for wearability which is a key element for natural interaction. This paradigm shift will enable novel forms of human intention recognition through haptic signals and novel forms of communication and cooperation between humans and robots. Wearable haptics will enable robots to observe humans during natural interaction with their shared environment. Research challenges are ambitious and cross traditional boundaries between robotics, cognitive science and neuroscience. Antonio Frisoli is WP leader for devices development, and has managed the research activity focused on the development of different type of wearable haptic devices.

***EU IP IST-027731-PRESENCIA*** Antonio Frisoli has been the principal investigator for the Sant’Anna School of the project ”Presencia: Presence Research Encompassing Sensory Enhancement, Neuroscience, Cerebral-Computer Interfaces and Application” [www.presencia.org](http://www.presencia.org), lasting four years, funded in January 2006 for an amount of €350.000. The purpose of the research of Prof. Frisoli in the research project is to develop innovative systems for the kinematics of the fingertip haptic stimulation of new systems and haptic interfaces for multimodal interaction in a highly immersive virtual environments.

***EU StreP Project IST-027198 DECISION-IN-MOTION*** Antonio Frisoli was responsible for the Scuola Superiore Sant’Anna of the European project STREP DECISION-IN-MOTION ”Neural Decision-making in Motion” <http://www.decisionsinmotion.org>, funded for three years starting from January 2006 for an amount of €250.000 . The purpose of the project was the realization of a robotic autonomous platform, equipped with a robotic head with active vision capable of simulating the movements of both eyes of both the head, for the experimental study and implementation of new neuromorphic algorithms for autonomous navigation. The prototype developed at the laboratory PERCRO implemented a behavioral model based on neuromorphic algorithms that simulate the

visual areas V1, V2, MT, which allows him to perform tasks of achieving goals with simultaneous avoidance of obstacles, by modulating the trajectory followed as a function of the actual speed navigation. The project was successfully completed in February 2009. The results of the project have also had extensive media exposure, with a video project published online on New Scientist.

### 2.2.2 Bilateral projects

***VIGONI Bilateral Cooperation project between Italy and Germany*** Antonio Frisoli was the technical manager the project, where in collaboration with prof. Mark Greenlee, University of Regensburg he developed a haptic interface fMRI-compatible for neuroscientific studies. The project led to the construction and test of one single dof prototype and the realization of a 3-dof prototype [C69].

### 2.2.3 National projects

***ModuLimb Project, "Probing the modular organization of the neuromuscular control of limb movements: an inter-disciplinary approach" (2017-now)*** The project is funded by the National Ministry of Research as PRIN National Research Program. The project proposes two complementary approaches to probe directly the modular organization of neuromuscular control. On one side, it will investigate adaptation after simulated changes in the neuromuscular properties in healthy participants. A myoelectrically controlled exoskeleton will generate torques at upper or lower limb joints as if subjects controlled their own muscular apparatus but with novel geometrical and functional characteristics. It will then be possible to characterize the functional role of the modules and to test the prediction that, in a truly modular architecture, it is harder to adapt to perturbations that are incompatible with the modules than to compatible perturbations. On the other side, it will characterize the relationship between changes in the nervous system and changes in the modular organization of the muscle patterns. To reveal key neural substrates of the motor modules, we will perform a systematic comparison of the changes in the motor modules identified by muscle pattern decomposition in stroke, cerebellar, Parkinson's, and spastic paraparetic patients, during both upper and lower limb movements.

Prof. Frisoli is responsible for the realization of exoskeletons and the development of novel myoelectric control based on motor synergies.

***CNR Project for Young Researchers Ricercatori EnGrave (2002-2004)*** In 2002-2004 Antonio Frisoli was the PI of the research project CNR Young Researchers Engrave Engrave interactive 3D graphics, with the aim of creating a system for modeling artifacts in virtual environments. In particular, under this project it was designed a second version of the desktop haptic interface table, based on a prototype already made as a result of a previous research project, with parallel kinematics. Also in the course of the project numerical algorithms were developed to support interactive deformation of objects with haptic feedback in virtual environments.

### 2.2.4 Research project with industrial partners

***Contract with FCA on manual gearshift simulator (2017-now)*** The project aims at the development of a haptic simulator of force response of a manual automotive gearshift.

***Contract with Trenitalia srl on the "on-condition maintenance" (2015-now)*** Antonio Frisoli has been responsible for the development of robotics system for on condition maintenance

Antonio Frisoli is responsible for the development of a robotic system (budget robotics ~400K€, three-year start date in September 2015) for the train underbody inspection and verifying the integrity of the pantograph

***Contract with RFI srl (2016-now)*** This project is in the context of application of new sensing technologies based on optical fiber sensing for monitoring railway infrastructures, and in particular masonry bridge. Antonio Frisoli and his group have been responsible for the development of FEM models capable of simulating the effects of a structural failure at the level of railway track, where strain gauge optical sensors are posed. The FEM simulation are highly non linear and take into account the effect of ballasts. Experimental test have been conducted at RFI experimental facilities in Rome at RFI premises.

***Contract with Dida Network srl (2011)*** Antonio Frisoli is technical responsible of a project for the development of wearable technologies for the localization and tracking of blinds in out-door environments. The approach will make use of the integration of available GPS technologies with inertial measurements.

***Contract with Villa Serena (2010)*** Antonio Frisoli was the responsible for the realization of a passive device (Track Hold) for the rehabilitation of patients post-stroke for upper limb tracking and lift reduction during the execution of exercises in virtual environments . The device was developed for the Villa Serena Clinics of Pescara.

***Contract with (Whitehead Alenia Sistemi Subacquei) (2008-2009)*** The project, of which Antonio Frisoli was the coordinator of activities for the SSSA, between the SSSA and WASS Whitehead Alenia Underwater Systems, is aimed at the development of a testbed for numerical simulation and the study of the controllability of torpedoes and technical support to the WASS for the development of new algorithms for controlling and piloting of torpedoes.

***EchoDev (2005)*** The project stems out from a collaboration of the laboratory PERCRO with the CNR in Pisa, Bracco Inc. and the Department of Internal Medicine, University of Pisa. Antonio Frisoli was involved in the design and implementation of a robotic system for moving an ultrasound probe during monitoring of the brachial artery for cardiovascular risk assessment.

***Contract with PEC Italia S.r.l (2004-2005)*** Antonio Frisoli was technical manager of the project in conjunction with PEC Ltd and Agusta that led to the development of a robotic cell with two anthropomorphic robots operating on a testbed, for simulating the handling of the door of an helicopter. The testbed has been subjected to a fatigue cycle of 10,000 iterations, consisting in the simulation of opening and closing of the door of aircraft. Two robots COMAU NH-1 equipped with a gripper and a force sensor innovative parallel kinematic were used for experimentation.

### 2.3 Participation to research projects

Antonio Frisoli has participated either as owner, technical coordinator and research collaborator in numerous research projects at national and international level.

### 2.3.1 National projects

***BRAVO project “Brain computer interfaces for Robotic enhanced Action in Visuo-motOr tasks” (2010-2012)*** Antonio Frisoli has been the technical responsible under the BRAVO project funded by the IIT of the implementation of a robotic system for assistance in performing manual tasks guided by the command derived from gaze with eye tracking devices and the control of opening / closing of the hand through Brain Computer Interface. The project is also evaluating the clinical efficacy of motor imagery techniques by BCI for the rehabilitation of patients after stroke.

***Project on Exoskeleton funded by Monte Paschi Siena Foundation (2007-2009)*** Antonio Frisoli was the technical manager of the research project funded by the Fondazione Monte Paschi Siena, for two years from January 2007, for a funding of €250,000, managing the design and construction of new robotic systems for rehabilitation of neuromotor function in adult or pediatric patients. In this project, Antonio Frisoli supervised the design of an innovative exoskeleton system, specifically designed for safety and functional requirements in rehabilitation and developed a new actuated joint including Harmonic Drive gear type speed reduction and direct torque sensor. In collaboration with the Unit of Neurorehabilitation of University of Pisa, Santa Chiara Hospital, he worked on the development, design, construction and development of new robotic technologies for neuromotor rehabilitation of the upper limb in patients with post-stroke disabilities and their clinical validation. “Advanced applications in military technology robotic teleoperation” Ministry of Defense (2003-2005) The research project concerns the design and implementation of a teleoperation system called “body extenders”, to amplify the capabilities of a human operator to be used in tasks of handling loads, assembly room. Antonio Frisoli was involved in the preliminary design of the control system.

***PRIN project on new actuators (2009-2010)*** Antonio Frisoli participated to the design, implementation and construction of new actuator technologies based on piezoelectric and electroactive materials.

***PRIN AIDA Project (2007-2008)*** Antonio Frisoli as part of research unit SSSA, developed innovative haptic systems and applications for physical interaction with virtual objects in real time using gloves with sensors in virtual environments.

***MIUR Project RIME (2002-2004)*** Since 2002 until 2004 Antonio Frisoli worked on the project RIME (2001-2003) “Design and realization of haptic interface with 5 degrees of freedom for teleoperation in surgery” It was carried out the design and study static-kinematic performance of an haptic Interface with 5 degrees of freedom to be used for teleoperation in orthopedic surgery of the spinal cor. As part of the continuation of the same project it was implemented a master-slave teleoperation system for performing drilling operations in orthopedic surgery.

***MIUR Project METAFOR (2000-2002)*** Since 1999 until 2003 Antonio Frisoli collaborated to the project METAPHORS MURST (1999-2001) “Methods and tools applied to a family of robots for medical environment” (National Co-ordinator Prof. Aldo Rossi). In the project, having as its objective the study of the interaction robot-surgeon for the planning of implant surgery and neurology, Antonio Frisoli worked the development of the project of an optimal haptic interfaces with parallel kinematics and associated control algorithms, Young Researchers MURST Project (1999-2000). In



2002 Antonio Frisoli was the scientific responsible of a Young Scientists Scientific Research University Project (Art.65 cc. Sperim Sc.) "HI2 Highly Isotropic Haptic Interface", with the goal of designing an planar haptic interface with 2 degrees of freedom for interaction in virtual Environments. The project led to the realization and control of an Interface haptic innovative for the implementation principles, able to substantially increase the kinetic-static performance of the mechanism used.

**University SSSA projects** Antonio Frisoli was also appointed as the Sant'Anna School of the University the following research projects:

- 6004AF - parallel manipulators for assembly and teleoperation (2004-2005) project
- I6005AF - Study and preliminary evaluation of algorithms for power amplification (2005-2006)
- I6006AF - System for robotic applications in ultrasound medical examinations (2006-2007)
- I6007AF- Design of robots with fMRI compatibility (2007-2008)
- I6008AF - University neuromotor rehabilitation assisted by robots in Virtual Environments (2007-2008)

### 2.3.2 European projects

**Progetto EU-IP BEAMING, Being in Augmented Multi-Modal Naturally-Networked Gatherings** This project bring today's networking, computer vision, computer graphics, virtual reality, haptics, robotics and user interface technology together to produce a new kind of virtual transportation, where the person can be physically embodied interacting with life-sized people who may be thousands of kilometres away.

**EU IP Project VERE Virtual Embodiment and Robotic Re-embodiment** The Integrated Project aims at dissolving the boundary between the human body and surrogate representations in immersive virtual reality and physical reality. Dissolving the boundary means that people have the illusion that their surrogate representation is their own body, and act and have thoughts that correspond to this. The work in VERE may be thought of as applied presence research and applied cognitive neuroscience, and it would also significantly add to scientific knowledge in these areas.

The project studies the issues of embodiment in robotic systems and virtual environments. Antonio Frisoli has been responsible of the development of the of Embodiment Station, a platform that allows the user via haptic stimulation, kinesthetic, visual, etc to command in person a robotic or virtual alter-ego. As part of the project Antonio Frisoli has developed innovative algorithms for BCI, new prototypes of actuators for proprioceptive stimulation.

**EU IP SKILLS Project** Antonio Frisoli was responsible for the platform Demonstration on "Upper Limb Rehabilitation" in the European IP project SKILLS n (<http://www.skills-ip.eu/>), coordinated by the Scuola Superiore Sant'Anna prof. Bergamasco, funded for four years since October 2006. In this framework he conducted a controlled clinical trial evaluating the effects of a robotic treatment against physical therapy. He also contributed to the technical development of a simulator in-door rowing. The simulator reproduces the kinematics of in-door rowing a boat, allowing both the sculling is leading. The resistance of water was simulated using appropriately sized mechanical fans, and force sensors and position allow you to record the athlete's performance during the execution of the movement.

***NoE Enactive Network of Excellence (2003-2005)*** The Network of Excellence ENACTIVE was composed of 20 partners in Europe with expertise in robotics, ecological psychology, neuroscience, and HCI. Antonio Frisoli has directed the working group which dealt with the simulation in virtual environments of manual tasks and has been a permanent member of the NEB Network Executive Board. He also participated in numerous other workpackages, including the Research Directorate RD3.1 "Basic technologies for enactive interfaces", in which coordinated the activities of the laboratory PERCRO.

***Progetto IST-2000-29580 PURE-FORM (The Museum of Pure Form) (2001-2004)*** During 2002-2004 Antonio Frisoli was technical manager of the PURE project EU-IST Project FORM-2000-29580 (The Museum of Pure Form, [www.pureform.org](http://www.pureform.org)), coordinating and supervising the technical activities for the realization of an integrated virtual reality applications for museums, which led to the creation of a force-feedback exoskeleton with 10 degrees of freedom and the creation of the Museum of Pure Form, conceived as a system of virtual reality where the user can interact through the use of touch and sight with three-dimensional digital models of sculptures and works of art. A selection of sculptures belonging to different collections of European museums was made using a laser scanning system by creating a database of digital works of art, which formed the nucleus of a new store on the Internet shared among the partners and other museum European cultural institutions. Two haptic interface systems, including a exoskeleton innovative force feedback and a desktop interface to 2 points of contact, were the first to be validated in a CAVE immersive display system at the University College London (UCL - UK), and then in 3 exhibitions held in the National Museum of Fine Arts (Stockholm - Sweden), Centro Gallego de Arte Contemporanea (Santiago de Compostela-Spain), the Museum Opera del Duomo of Pisa (Italy).

The project in November 2004 received an honorable mention for the originality of the idea of Bussiness Plan and of the proposed idea of business model in the national selection for the prize PNI (National Award for Innovation). In June 2005, it was instead won a competition organized by the Greek Ministry of Culture in 2008 that led to the preparation of a multimedia room with a system of "Museum of Pure Form" in the Museum of Olympia. Intuition Network of Excellence (2005) Antonio Frisoli participated to the Network, as a member dell'Haptic Working Group. The Intuition Network of Excellence was the European network for research on virtual reality technologies. IST-2001-34231-CREATE Project The CREATE project aimed at the development of an environment based on Mixed Reality techniques that allows the construction and handling of a virtual temple with a high degree of interactivity. Antonio Frisoli was involved in the design and development of the haptic interface. EU IST-2000.26151-GRAB Project The main objective of the project was the design of haptic interfaces for blind people to access a Virtual Environment through the sense of touch and with audio support. Antonio Frisoli dealt with the kinematic analysis and mechanical design of the micromanipulator of the haptic interface system.

***1999-R.D.11030 VIRTUAL Project (2002)*** Collaboration on the project EU Project Virtual (Virtual reality systems for Perceived ergonomic quality testing of driving task and design). The main objective of the project was the development of an integrated platform, based on Virtual Reality technologies, including systems for testing and related experimental procedures to obtain a tool to improve the analysis and the ergonomic design of vehicles. Antonio Frisoli was involved in the development of a control system for replication of the primary controls of a car in Virtual Environments. He was involved in the the kinematic analysis and optimization of a parallel kinematics for the simulation of a car manual gearshift, interacting predominantly with the Fiat Research Centre

in Turin.

***ESPRIT N.20145 MORIS Project (2000)*** Collaboration on the project MORIS (Motorcycle Rider Simulator) The objective of the project MORIS (Motorcycle Rider Simulator) was the realization of an inertial system simulator of a 2-wheeled vehicle capable of providing the user with the same feelings of riding a motorbike in real conditions.

***TIDE N.4527 TREMOR Project (1999)*** Antonio Frisoli was involved in the CAD simulation of the kinematics of a motorcycle simulator. TIDE N.4527 TREMOR Project (1999)

In 1999 Collaboration to the EU project TREMOR (October 1997 - April 2000). The TREMOR project aimed at developing technological devices to support those affected by tremor in the upper limbs in order to restore and/or supplement their ability to handle daily activities. Antonio Frisoli was involved in the design and implementation of haptic interface with two degrees of freedom for the functional recovery of patients with writing tremor (multiple sclerosis, parkinsonian).

## 2.4 National and international collaborations

Antonio Frisoli has established ties continuous research collaborations and international exchanges with different national and international institutions, such as:

- Prof. David Rekenmeyer, University of Irvine, motor learning in hand rehabilitation
- Prof. Vito Bevilacqua, Polytechnic of Bari, Human-machine Interaction
- Prof. Etienne Burdet, Imperial College London, Motor learning in robot-assisted rehabilitation
- Prof. Dario Farina, Imperial College London, High-density EMG control of exoskeletons
- Prof. Lorenzo Masia, NTU, Soft exoskeletons
- Prof. Suni Agrawal , Columbia University, lower limb exoskeletons
- Prof. Sandra Hirche, TUM Munich, Haptic interfaces for robotic applications
- Prof. Sven Benkhe, University of Bonn, Teleoperation of humanoid robots
- Prof. Lacquaniti , Fondazione Santa Lucia, Motor control
- Prof. Andrea D'Avella, University of Messina, motor synergies
- Professor Ken Salisbury, Stanford University: Robotics Laboratory, haptic devices
- Prof. Vincent Hayward, McGill University, Montreal, Canada: Haptics Laboratory directed now at Universite Pierre et Marie Curie, Paris France, haptic devices
- Dr. Carsten Preusche, DLR Institute of Robotics and Mechatronics,: Telerobotics Laboratory, directed by Prof. Gerd Hirzinger, teleoperation
- Dr. William Provancher, Univeristy of Utah, Dept. of Mechanical Engineering, Mechatronics & Embedded Haptics Laboratory, fingertip haptics
- Prof. Mark Greenlee, University of Regensburg, Department of Psychology, fMRI haptic devices

- Prof. Heiko Neumannm, University of Ulm, Institute of Neural Information Processing Vision and Perception Lab Science, cognitive robotics
- Prof. Mel Slater, Facultat of Psychology. Universitat de Barcelona, Campus de Mundet, founder of Virtual Environments and Computer Graphics group in the Department of Computer Science, University College London, Presence and virtual embodiment
- Prof. Mavi Sanchez-Vives, Event Lab, Neuroscience and Experimental Technologies in Virtual Environments, Barcelona IDIBAPS, Presence and virtual embodiment
- Prof. Benoit Bardy, University of Montpellier I, Dept. of Sport and Movement Science, Sports training and motor learning
- Dr. Elga Cerchiari, Hospital Bologna, Department of Intensive Care, Director, CR technologies for CPR training
- Prof. Bruno Rossi, Department of Neurorehabilitation, University of Pisa, robot rehailitation
- Dr. Emilio Sanchez. CEIT, Applied Mechanics Department, Spain, Haptic simulation of primary commands

## **2.5 Technology transfer**

- Founding member of the Wearable Robotics innovative start-up, spin-off of Scuola Superiore Sant'anna, and recipient of the Marzotto award (starting grant of 250,000 €) as most innovative start-up in Italy in 2013. The company is commercializing the Alex bimanual exoskeleton for stroke rehabilitation.
- Invited as expert member in jury of UNIPOL technological incubator in 2014
- Authors of 6 patents, see section 5, reporting full list of patents
- Responsible of several industrial projects for innovation in specific application fields

## 2.6 Editorial activity

### Scientific journals

- Associate Editor Mit IEEE Robotics & Automation Letters (2015 -present)
- Associate Editor Presence MIT press (2009 -present)
- Guest Editor for IEEE Transactions on Haptics , Special Issue on ” Haptics in Rehabilitation and Neuroengineering” (2012)
- Associate Editor IEEE Transactions on Haptics , Special Issue on ” Haptics in Rehabilitation and Neuroengineering” (2007-2010)
- Member of International Scientific Committee of the International Journal on Interactive Design and Manufacturing, Springer (2007)

### Organization of conferences, summer schools and workshops *Conferences and summer schools*

- General Chair for Eurohaptics 2017 conference, to be held in Pisa on June 13-17, 2018 <http://eurohaptics2018.org/>
- General chair for 2<sup>nd</sup> edition of Human-Machine Interaction HMISS 2017 Summer School, to be held in Maratea (Italy), September 18-23 2017 <http://www.hmiss.it/>
- Member of International Scientific Committee of Human-Machine Interaction HMISS 2015 Summer School, September 14-18
- Chair of IEEE Technical Committee on Haptics, (2012-2014). Antonio Frisoli has worked actively in the foundation of the IEEE Technical Committee on Haptics which currently lists more than 400 members ([www.worldhaptics.org](http://www.worldhaptics.org))
- General Chair of the 2nd International Conference on Enactive Interfaces, ENACTIVE05 ([www.enactive2005.org](http://www.enactive2005.org)) which was held in Genoa on 17-18 November 2005

### *Workshops and tutorials*

- Workshop organizer at IEEE ICRA 2017- Singapore ”Advances and Challenges on the Development, Testing and Assessment of Assistive Robots: Experiences from Engineering and Human Science Research”, organizers J. Solis (Un Karlstad), Y. Takeda (Tokyo Insitute of Technology), E. Tanaka (Waseda University), A. Frisoli (Scuola Superiore Sant’Anna)
- Workshop organizer at IEEE Worldhaptics 2017 June 6-9, 2017, Furstenfeldbruck (Munich), Germany: ”Wearable haptic systems: design, applications, and perspectives” organized by Dr Claudio Pacchierotti, Dr Stephen Sinclair, Prof Massimiliano Solazzi, Prof Antonio Frisoli, Prof Vincent Hayward, Prof Domenico Prattichizzo
- Workshop organizer IEEE Worldhaptics 2015 ”Wearable Haptics” Organizers: Domenico Praticchizzo (University of Siena and IIT) Antonio Frisoli (Scuola Superiore Sant’Anna) Miguel Otaduy (Universidad Rey Juan Carlos)

- Worldhaptics 2015, Chicago: Workshop on "Wearable Haptics", organized by Prof. Antonio Frisoli (Scuola Superiore Sant'Anna), Prof. Miguel Otaduy, (Universidad Rey Juan Carlos – Madrid), Prof. Domenico Prattichizzo (University of Siena and Italian Institute of Technology)
- Workshop organizer Eurohaptics 2014 (Paris) "Haptics in Rehabilitation, Prosthetics and Neural Engineering : Robotic Aspects and Neuro-scientific Principles" Organizers: Matteo Bianchi (University of Pisa), Marcia O'Malley (Rice University), Antonio Frisoli (Scuola Superiore Sant'Anna), Lorenzo Masia (Technology University of Nanyang)
- Workshop organizer Eurohaptics 2014 (Paris) "Non-Invasive BCI and Haptics" Organizers: Mounia Ziat (University of Michigan), Antonio Frisoli (Scuola Sant'Anna), Jan Van Erp (Twente University)
- Workshop Tutorial organizer on "Workshop on wearable haptics, from neurophysiology foundations to new wearable haptic designs and exoskeletons" Haptic Symposium 2014
- Tutorial on exoskeletons, Wearhap project, Pisa 2015
- Workshop organizer Eurohaptics 2014 (Paris) "Non-Invasive BCI and Haptics" Mounia Ziat (Northern Michigan University), Antonio Frisoli (Scuola Superiore Sant'Anna), Jan Van Erp (Twente University)
- Tutorial organizer at IEEE Haptic Symposium 2014 "Brain Computer Interfaces & Haptics" Mounia Ziat, Northern Michigan University, USA Antonio Frisoli Human-Robot Interaction Area, PERCRO Lab, Scuola Superiore Sant'Anna, Italy Jan Van Erp, Perceptual and Cognitive Systems, TNO Christoph Guger, g.tec medical engineering GmbH
- General Chair of the 2nd International Conference on Enactive Interfaces, ENACTIVE05 ([www.enactive2005.org](http://www.enactive2005.org)) which was held in Genoa on 17-18 November 2005
- Tutorial on "Real-time Interaction and Inhabited Virtual Worlds" at Eurographics, September 5, 2006

### **Positions in organizing committees of international conferences**

**2017** Hands-on Demo Chairs, Asia Haptics 2018

**2017** Member of the election committee for TCH new chair

**2016** Awards chair for Work in Progress, Eurohaptics 2016

**2016** Sponsorship Chair IEEE Haptic Symposium 2016

**2015** Workshop and tutorial chair IEEE Worldhaptics 2015

**2015** Member of the International Scientific Committee of Human-Machine Interaction Summer School (2015)

**2014** Workshop and tutorial chair IEEE Haptic Symposium 2014

**2014** Program committee member for IEEE Haptic Symposim (2014-now)

**2014** Associate Editor of the Program Committee of Eurohaptics 2014 in the area of Engineering/Computer Science

**2012** Member of the Award Committee for IEEE Haptic Symposium 2012

### **Participation to Program Committees of International Conferences**

- Member of the program committee of IEEE Worldhaptics (2009-2011-2013-2015-2017)
- IEEE CEB (Conference Editorial Board) Associate Editor (2009-2014), IEEE ICRA-IROS
- Member of the program committee of IEEE Haptic Symposium (2011-now)
- Member of the program committee of of IEEE VR (2012,2014)
- Associate editor for IEEE ICRA International Conference of Robotics & Automation (2010-2013)
- Associate Editor for IEEE IROS International Conference on Intelligent Robots& Systems (2008, 2011-2013)
- Associate Editor for IEEE ROMAN International Conference on Human Robot Interaction (2011-2012-2013,2016, 2017)
- Associate Editor for IEEE Haptic Symposium 2011, 2013
- Associate Editor for IEEE VR 2012, 2014

### **Organization of special issues in international scientific journals**

- Guest editor of Special Issue on "Haptics in Rehabilitation and Neural Engineering" in IEEE Transactions on Haptics, editors Frisoli, Antonio and O'Malley, Marcia and Campolo, Domenico and Sienko, Kathleen, 2014 [E2]
- Guest editor of Special Issue on " Haptics in HRI: Cooperation and Communication" with Karon McLean in Journal of Human-Robot Interaction, 2015[E1]
- Guest editor with Professor. Antonio Camurri of the special issue on "Multisensory Interaction in Virtual Environments", published in the journal Virtual Reality, Springer, 2016 [E3]

## 2.7 Awards and invited talks

### Awards at conferences

- 2017** Best Student Paper Award at IEEE Worldhaptics 2017 held in Munich for the paper "Proxy-based haptic rendering for underactuated haptic devices" by Lobo, Daniel; Saraç, Mine; Verschoor, Mickeal and Solazzi, Massimiliano and Frisoli, Antonio and Otaduy, Miguel A [C6]
- 2016** Best Demonstration Award Finalist at Eurohaptics 2016 with hand-on demo Wearable Fingertip Devices for Rendering Cutaneous Force Feedback in Virtual Manipulation, Daniele Leonardis, Massimiliano Solazzi, Ilaria Bortone, Antonio Frisoli
- 2016** Best paper award at ICNVE 2016 : 18th International Conference on Noise and Vibration Engineering "A Detection Method of Faults in Railway Pantographs Based on Dynamic Phase Plots" G. Santamato, M. Solazzi, A. Frisoli [C22]
- 2016** Best student paper finalist at ICNR2016 "International Conference on Neurorehabilitation" with the paper ""Evaluation of a pose-shared synergy-based isometric model for hand force estimation: towards myocontrol" [C4]
- 2015** Best paper finalist at the conference IEEE ICORR 2015, Singapore Barsotti , M .; Leonardis , D .; Loconsole , C .; Solazzi , M .; Sotgiu , E .; Procopio , C .; Chisari , C .; Bergamasco , M .; Frisoli , A . , " A full upper limb robotic exoskeleton for reaching and grasping rehabilitation triggered by MI - BCI , " in Rehabilitation Robotics ( corr ) , 2015 IEEE International Conference on , vol . , No. , Pp.49-54 , 11 -14 Aug. 2015 [C23]
- 2014** Best paper finalist at the conference IEEE Haptic Symposium 2014: Loconsole C , Dettori , S .; Frisoli , A .; Avizzano , C.A .; Bergamasco , M . , An EMG - based approach for online predicted torque control in robotic -assisted rehabilitation , IEEE Haptic Symposium (2014 ) [C33]
- 2001** Best Student Paper Award Finalist at ICRA 2001 for the paper entitled "Simulation of a manual gearshift with a 2 DOF force-feedback joystick" by Antonio Frisoli, Carlo A Avizzano and Massimo Bergamasco [C123]

### Career awards

- 2014** IEEE RAS most active "Most active technical committee of the Year " for his role as chair of the IEEE Technical Committee on Haptics
- 2014** Second prize at "Startup Toscana 2014" with the industrial project "Wearable Robotics"
- 2012** Special mention to MiniVrem project at Digit@lia for talent organized by Accenture Foundation
- 2012** Winner with the project idea MiniVrem of Games For Health Europe 2012 (Federico Semeraro, Antonio Frisoli, Luca Marchetti)
- 2007** As "Vice-Chair for Information and Dissemination" of the IEEE Technical Committee on Haptics won the "Most Active Technical Committee of the IEEE Robotics and Automation Society Year for 2006" presented in Rome at ICRA 2007.



- 2004** Honorary mention as innovative idea in the competition "Start Cup Pisa" with the project Museum of Pure Form, for the development of processes and systems and three-dimensional virtual reality for the protection and enjoyment of cultural heritage (2004)
- 1998** Winner of a selection opened by the National Institute of Nuclear Physics in Pisa for qualified researchers to conduct a period of specialist training at the Fermi National Accelerator Laboratory in Batavia (Chicago), IL-USA (1998)
- 1995** Winner of the national selection (ranking 2<sup>nd</sup> over more than 400) with exams for five seats of undergraduate students at the Scuola Sant'Anna (SSSA) in Pisa

### Invited speeches and talks

- 2017** Invited session speech at XVII Italian Conference of Neurological Rehabilitation (Pisa, June 2017) on "Virtual reality technologies for rehabilitation"
- 2017** Workshop on "Tactile Coding and Neuroprostheses", Pontedera, invited talk on "Wearable haptics: virtual manipulation with cutaneous fingertip devices"
- 2017** Invited speaker at national workshop on "Rehabilitation and wearable robots for gait assistance", Pisa (2017)
- 2017** Invited talk at Smart Hospital 2.0, Firenzse June 23, 2017 , "Robotic exoskeletons for rehabilitation"
- 2017** Workshop on NeuroMuscular Diseases, invited talk on "E-Health, the development of assistive technologies for the impaired patient"
- 2017** Invited speaker at the workshop on "Augmenting Medicine" (Rome, March 2017) given in workshop organized by Italian National Council of Medicine
- 2016** Distinguished lecturer of IEEE Summer School in medical informatics (2016)
- 2015** Invited talk at workshop on "HAPTICS FOR NEUROSCIENCE AND NEUROIMAGING" within IEEE ICRA 2015, Seattle (Washington) with a talk entitled "fMRI haptic devices"
- 2015** Invited talk at the clinical workshop on "Back to the future. Ancient know-how and new frontiers of rehabilitation" patronized by Italian Society of Neurological Rehabilitation (SIRN) and Physical Rehabilitaiton (SIMFER), with a talk entitled "exoskeltons and robots: the human empowerment?", Verona November 2015
- 2015** Invited speaker at workshop on "Lesione midollare: quale ricerca e quali innovazioni?", Firenze, December 4, 2015
- 2015** Invited speaker at ErgoForum 2015 "Work Spaces Fueling Innovation", organzied by General Electric, Auditorium, Florence Learning Center, with a talk entitled "Exoskeletons"
- 2014** Invited speech at workshop on " Bimanual Haptics" held at Paris, Eurohaptics conference with a talk entitled "Bimanual haptic training for upper limb rehabilitation in stroke"

- 2015** Invited speech at Fondazione AIAS in the workshop on "ROBOTICA, REALTA' VIRTUALE E TELERIABILITAZIONE: NUOVE APPLICAZIONI IN RIABILITAZIONE" with a talk entitled "Robotic aided rehabilitation and clinical evaluation in post-ictus upper limb training", Congress Hall, Foundation Cassa di Risparmio Carrara, 4 giugno 2015,
- 2014** Invited speaker on "Virtual reality for training", at National Italian Resuscitation Congress, IRC 2014, Naples
- 2013** Invited speech at workshop "The neurorobotics: new opportunities in rehabilitation: application to robotics in rehabilitation, current and future perspectives", AIAS Marina di Massa 3/6/2013
- 2012** Andrea Bocelli Foundation workshop, invited speech on "Access to digital computing for the visually impaired" , July 2012
- 2012** ArsScientia Venice, invited speech on "X MOVE – Performing bodies: Spots, Biorobotics and Video art", Venice
- 2012** Participation by invitation to the workshop "Haptic Hardware Evaluation Practices," Haptics in 2012 in Vancouver organized by Evren Samur / Curt Salisbury with a presentation entitled "A comparative assessment of performance of active exoskeletons for haptic feedback: tendon driven vs. harmonic drives based designs "
- 2011** Lecturer at the Summer School 2011 held at the castle of Gargonza, July 25-30, 2011, on "Motor Learning and Rehabilitation Robotics"
- 2008** Invited talk on "In-door skill training in rowing practice with a VR based simulator", 10th european workshop on ecological psychology, Organized Jointly with the 2nd international congress of complex systems in sport, Madeira, 2008
- 2008** Workshop "PRESENCE and the Science of Virtual Reality "" , "Enhanced Perception through Haptic Technologies' 0.2-3 November 2008, Technion, Haifa
- 2008** "Robotic technologies for rehabilitation in VE" in The 3rd and XVR BCI Workshop, Antonio Frisoli (PERCRO, Italy), 14-15 May 2008, Pisa
- 2008** Invited as a expert at the Workshop on Strategic Exoskeleton-orientation at Otto Bock Health-Care GmbH, Febr 17, 2008
- 2008** Plenary Lecture on "Robotics in Rehabilitation" entitled "Robotics and Virtual Reality for Rehabilitation: Implementation and Results", XXXVI National Congress SIMFER 2008,
- 2008** Invited talk on "A limit-curves based soft finger god-object algorithm for two fingers manipulation of virtual objects" in Workshop of "Contact Models for Manipulation and Locomotion" in ICRA organized by Todd Murphey, Vijay Kumar in ICRA 2008,
- 2007** Invited talk on The Virtual Reality for the treatment of psychophysiological disorders induced by stress., SIPF XV CONGRESS COMPANY 'ITALIAN Psychophysiology, 30 November 2007, Pisa
- 2007** Robotic Technologies for Neuro-Rehabilitation in Virtual Environments, University of Siena, March 8, 2007

- 2007** Invited talk on "L-Exos: A Light Exoskeleton System for Functional Rehabilitation of the Arm" in Workshop on "Robotic Technologies for Rehabilitation" organized by Carlo Alberto Avizzano and Craig Carignan, ICRA 2007, April 14 2007
- 2007** "Foundations of Perceptual Robotics", in the graduate seminar on "Augmented Cognition / Cognitive Systems" University of Regensburg, June 28, 2007
- 2006** Keynote speaker session on "Haptic Systems in Interactive Design" at the conference Virtual Concept 2006 held in Biarritz, France.
- 2006** Key-note invited lecturer at the International Workshop VIA "Virtual Reality for Industrial Applications", held in Compiègne, November 2004, at the Technical University of Compiègne, 2006
- 2006** Lecture ARISER invited at the Summer School with a presentation on "Haptic technologies for interactive simulations in VR" (Santa Cesarea Terme, 2006).
- 2006** "Multimodal perception and engineering" Workshop November 21, 2006, UCL London
- 2006** Tutorial on "Real-time Interaction and Inhabited Virtual Worlds" at Eurographics, September 5, 2006
- 2004** "The human-robot sensorimotor coupling: an engineering perspective" in the Enactive Virtual Workshop, available <http://www.interdisciplines.org/enaction> edited by Roberto Casati, Sarah Bendaoud, July 23, 2004
- 2005** Antonio Frisoli, Gunnar Jansson, Massimo Bergamasco, Emanuele Ruffaldi, Pure-Form: Perception and exploration of digital shapes, International Conference on Applied Perception ICPA 13, 5-10 July 2005
- 2004** "Evaluation of multipoint contact interfaces in haptic perception of shapes" in "Multi-point Interaction with Real and Virtual Objects", Workshop on "multipoint interaction with real and virtual objects", in IEEE ICRA 2004, New Orleans
- 2004** The Museum of Pure Form in the workshop "Novel Technological interfaces for the perception of art and Fruition", January 22, 2004, CGAC, Santiago de Compostela
- 2003** Invited talk on "The percezione of virtual sculptures: The Museum of Pure Form" in the workshop on "High technology management in the Square of Miracles", Museum Opera del Duomo of Pisa, September 26, 2003
- 2003** "Haptic Interfaces for rehabilitation and assistance of disabled people", I-Learning and Strategic Scientific Meeting, 23-24 October 2003, Milan (Italy)

### **Role as scientific reviewer**

- Reviewer for LEaDing Fellows Programme Office, TU Delft
- Reviewer for European Union of project HAPPINESS "Haptic Printed Patterned Interfaces for Sensitive Surfaces", A new approaches for Human-Computer Interaction, H2020 project grant agreement N. 645145 (2017)

- Expert member of panel for Science Academy of Finland, Computer Science review panel (2017)
- Antonio Frisoli acted as evaluators of proposals in ICT CALL 5 at the European Commission, Directorate "General Information Society and Media" in the period from 16/10/2005 to 23/10/2005

## 2.8 Industrial collaborations and technology transfer

## 2.9 Patents and trademarks

1. Italian patent PI 1427176 "Dispositivo aptico per l'orientamento di un soggetto non vedente"
2. European Patent PCT/IB2017/051142, "Exoskeleton device for the hand", Frisoli Antonio, Solazzi Massimiliano, Gabardi Massimiliano
3. European Patent "Robotic equipment for on-condition maintenance of railway stock", Antonio Frisoli, Massimo Bergamasco, Massimiliano Solazzi, Massimo Bergamasco, Paolo Masini (patent application accepted), Italian patent application IT 201600098012
4. European patent EP1629949; Frisoli Antonio, Salsedo Fabio, Bergamasco Massimo, Simoncini Francesco, "Haptic Interface Device", 2006-03-01
5. World Patent WO2004058458 (US US7409882, Europa EP1581368, Australia AU2002368501) Salsedo Fabio, Dettori Andrea, Bergamasco Massimo, Franceschini Marco, Frisoli Antonio, Rocchi Fabrizio, "Exoskeleton Interface Apparatus", 2006-07-13
6. World Patent WO2006054163 (EU patent EP1828873, Italian patent ITPI20040084), Salsedo Fabio; Bergamasco Massimo; Frisoli Antonio; Cini Guido, "Portable Haptic Interface", 2007-09-05
7. Italian Patent ITPI20070020, Avizzano Carlo Alberto, Bergamasco Massimo, Frisoli Antonio, Ruffaldi Emanuele, Vanni Federico, "Simulatore Multimodale di Canottaggio", 2007-06-02, Sprint Rowing Simulator
8. Figurative trademark, N. 003105129 Pure Form, Antonio Frisoli, Massimo Bergamasco., 27/05/2004

## 2.10 Press release - main contributions

- La Nazione "Riabilitazione: la tecnologia è leggera e smart", Luglio 2016
- "A Pisa arriva il robot che si indossa", Il Tirreno, 2016
- "Nasce Centauro, il soccorritore per metà robot e per metà uomo" Il Secolo XIX, 2015
- Broadcast on national television Ulisse Rai 3: blind technologies Scuola Sant'Anna Ottobre 2015
- Repubblica, App per smartphone aiuta non vedenti a scattare foto e selfie, 20 Luglio 2015
- Corriere della sera, Selfie e foto anche per i non vedenti, 4 Agosto 2015

- Il Giornale, Lo studio: l'intelligenza artificiale ci metterà al riparo dalle crisi economiche, 16/7/2015
- Sole24 ore Alex, il robot che potenzia il braccio Aprile 2014
- Sole 24 ore In crescita i videogiochi per terapie e assistenza 1/9/2013
- Sole 24 ore Medicina e gaming alleate per insegnare la rianimazione 7/7/2013
- Sole 24 ore Sport e medicina, il robot plasma corpi performanti 9/9/2012
- Corriere della sera, Progetto in stile "Avatar" a Pisa, 30/11/2012
- Corriere delle comunicazioni, "Mini-vrem", 200mila € al game italiano "salva-vita", 2012
- Unomattina , "Realtà Virtuale scopre i sensi", Rai Uno, 30/11/2012
- Euronews futuris - La ricerca che avvicina il mondo virtuale a quello reale, 2012

### 3 Teaching activity

Antonio Frisoli has taught numerous courses both at undergraduate and post-graduate levels at different universities and faculties of engineering and medicine.

#### 3.1 Courses at Scuola Sant'Anna

Antonio Frisoli has given the following courses to undergraduate students of the Engineering Sector of the Class of Experimental Sciences:

**Robotics and Human-Machine Interfaces** (Embedded Computing Systems Engineering MSc Course, Faculty of Engineering) [Years 2012-now, Audience: **open to undergraduate and PhD Engineering students**], Description: *(6CFU) ING-IND/13 The course is given in the joint MSc by University of Pisa and Scuola Sant'Anna. It provides an introduction to kinematics, rigid body statics and dynamics, free-body diagrams and analysis of mechanical structure, introduction to robotics with homogenous transformation, direct and inverse kinematics, mobility analysis, root dynamics, control of robots in task space and joint space, application examples developed with Robotic Toolbox and ROS Gazebo.*

**Theory of non-linear elasticity** (Class of Engineering, PhD Course in Emerging Digital Technologies) [Years 2004-2005, 2013-now, Audience: **undergraduate and PhD Engineering students**], Description: *(3CFU) The course will cover an introduction to tensor algebra, kinematics of finite deformations, definition of deformation and stress measures in bodies with finite geometry and finite displacements, mechanical behavior of materials with introduction to tensor invariants, mechanical behavior of isotropic and anisotropic (composites) materials, mechanical behavior of incompressible materials, hyper-elastic models (neo-hook, Mooney-Rivlin, Gent), introduction to FEM and numerical examples in Ansys and Comsol Multiphysics (modeling of cylinder, balloon), elements of non-linear visco-elasticity and contact mechanics.*

**Principles of functional machine design with FEM applications** (Class of Engineering, PhD in Emerging Digital Technologies) [Years 2012-now, Audience: **undergraduate and PhD Engineering students**], Description: *(3CFU) The course is open to undergraduate and PphD students. The course provides an overview of functional machine design principles and introduction to FEM analysis, such as analysis of hyperstaticity in multi-loop mechanical system, transmission systems, design of force sensors and flexural hinges, lead screw actuators, analysis of dynamic modes, etc, all explained by means of FEM exercises in Ansys Workbench 14.5*

**Design and control of wearable robots** (PhD in Emerging Digital Technologies) [Years 2014-now, Audience: **PhD Engineering students**], Description: *(6CFU) The course is a projectual course explaining the mechanical design and control principles for implementing wearable devices, e.g. wearable haptics and exoskeleton systems*

**Mechanics of Robot – Part II (Modeling and control)** (Class of Engineering) [Years 2013-now, Audience: **undergraduate and PhD Engineering students**], Description: *(3CFU) Contents: Control of robot, stability and robustness, position, velocity, force and hybrid control, fundamentals of passivity. Behavior implementation: teleoperation, basic of haptic interaction, navigation.*

**Dynamical Systems II** (Class of engineering) [Years 2006-2007, Audience: **undergraduate students**], Description: *1 CFU, within integrated course of Prof. Bergamasco; the course provided a basic introduction to study of dynamic systems, stability in phase space, study of gyroscope model*

**Elements of CAD and FEA for the design of robotic manipulators** (Class of engineering) [Years 2005-2006, Audience: **undergraduate students**], Description: *2 CFU, within integrated course of Prof. Bergamasco; the course provided an introduction to CAD modeling with Pro-Engineering platform and integrated FEA simulation for analysis of mechanical structures*

In years 2001-2002 and 2002-2003 Antonio Frisoli was teaching assistant in the course of Prof. Massimo Bergamasco addressed to undergraduate students of "Computer Aided Design." He was lectures of the course in "Perception and design of experiments" for students of the ICT PhD students in Engineering (2010-2011) and in the International Master on Virtual Environments (2008/2009).

For academic year 2011/2012, he has been appointed as lecturer for parts of the teaching of "Mechanics of Robots - Part II" addressed to PhD students and parts of the course in "Advances in Robot and Interface Design" (4CFU) addressed to PhD students.

**Orientation meetings** Antonio Frisoli has participated actively in the creation and implementation of the first two editions of the School of Engineering for high Schools nationally selected Students, of San Miniato (2-5 February 2012, with a talk on "From robotics to virtual reality: technologies for advanced interaction man-machine ") and Pisa (2011). Antonio Frisoli has also actively participated in the organization of orientation meetings with the schools organized by the Institute TeCIP (2011, January 23, 2012).

### 3.2 Courses at University of Pisa

Antonio Frisoli has traditionally hold several courses in both Faculty of Engineering and Faculty of Medicine at University of Pisa:

**Bioengineering** (Bachelor in Physiotherapy, Bachelor in Therapy of Neuro and psychomotricity in the Development Age, faculty of Medicine ) [Years 2012-now, Audience: **Undergraduate students**], Description: *(3CFU) The course provides an introduction to robotic and virtual reality technologies for rehailitation, EMG and EEG analysis, biomechanics of human body*

**Fundamentals of mechanics and thermodynamics** ( Computer Science Engineering MSc Course, Faculty of Engineering) [Years 2008-2012, Audience: **Undergraduate engineering students**], Description: *(ING-IND/13, Applied Mechanics, 5 CFU) The course provided fundamental of mechanics for students in the computer engineering area*

**Mechanics of Robots** ( Mechanical Engineering MSc Course, Faculty of Engineering) [Years 2004-2007, Audience: **Undergraduate engineering students**], Description: *(ING-IND/13, Applied Mechanics, 6 CFU) The course provided an overview of Mechanics of Robots with kinematics, differential kinematics and statics, introduction to control, overview of Robotic Toolox*

**Robotics and Virtual Environments in Rehabilitation** (Bachelor in Physiotherapy, faculty of Medicine) [Years 2005-2011, Audience: **Undergraduate students**], Description: *The course was 1CFU module a module inside the course of "General methodology of Motor rehabilitation" . It provided an introduction to robotic and virtual reality technologies for rehailitation, EMG and EEG analysis, biomechanics of human body*

**Virtual reality and robotic technologies for rehabilitation** (Master in Sciences and Technologies of High Specialization in Rehabilitation, Faculty of Medicine ) [Years 2012-now, Audience: **Post-graduate students in Medicine, Motor Science, Bioengineering and Rehabilitation**], Description:(3 CFU) *The course provided an overview of recent advances in the robotic and virtual reality technologies for rehabilitation*

**Robotic Rehabilitation and virtual reality. Applications in rehabilitation medicine** (Specialization school of Rehabilitation Medicine, Faculty of Medicine ) [Years 2012-now, Audience: **Post-graduate students in Medicine**], Description:(3 CFU) *The course provided an overview of recent advances in the robotic and virtual reality technologies for rehabilitation*

Antonio Frisoli acted as a teaching assistant for the course of Mechanics of Robots, held by prof. Massimo Bergamasco for the degree course in Mechanical Engineering from the University of Pisa during the academic years 1999-2003.

### 3.3 Courses at University of Udine

Antonio Frisoli has traditionally hold hold a course in Faculty of Medicine at University of Udine:

**Property, Technology and biofunctionality prosthetics - Biomaterials** ( MSc in Medical Biotechnologies, Faculty of Medicine) [Years 2005-2012, Audience: **undergraduate students**], Description:(*BIO-10, 1 CFU*) *The course provided an introduction to biomaterials, with indication of biocompatibility, adhesion properties, analysis of production processes.*

### 3.4 International educational activities

**IEEE CEMRA Robotics and Automation educational program in haptics** Coordinator of the IEEE Robotics and Automation educational program in haptics, proposed by Antonio Frisoli as former chair of TC on Haptics, period years 2015-2016, The objectives of the educational program in haptics has been of spreading scientific knowledge in the area of haptics and providing younger researchers and PhD students the necessary instruments and knowledge to do proficient research in the field and promote scientific innovation in the area. Haptics covers a large inherently multidisciplinary field, including robotics, computer science, systems and control, experimental psychology, neuroscience and others.

Tutorials and workshops have been organized at 3 major conference events. Free participation was provided to students attendees both in IEEE Haptic Symposium 2014 Houston (US) and IEEE Worldhaptics 2015, Chicago (US) Major highlights A record number of workshop and tutorials have been reached for next IEEE WHC2015 (up to 11 in parallel workshops/Tutorials) Specific actions have been taken in order to promote the organization of tutorials on hot topics, i.e. surface haptics, haptic rendering of textures, BCI & haptics, etc

- Haptic Symposium 2014: Waive of registration fee was provided to 47 students thanks to the CEMRA project for a total amount of 2,250
- June 22-26 2015, Chicago (Illinois), IEEE Worldhaptics 2015: 9 workshop organized (of which 1 full day) 2 tutorials organized (of which 1 full day) 210 persons registered of which 109 students, with fee supported by the CEMRA program for students only
- on-line material in the form of videos lectures available at worldhaptics.org



**International Master in Virtual Environments** In the academic year 2010-2011 he was appointed as academic tutor for the organization and management of teaching activities within the International Master in Virtual Environments International for Industrial Applications at the Scuola Superiore Sant'Anna.

**International/national student exchange: supervision of students** Antonio Frisoli has been the supervisor of numerous exchange students from foreign and italian universities.

- UPMC, Polytech Paris, Louis Guyor , responsible for exchange of 1 student 3 months internship in robotics at SSSA, 2017
- University of Angers, responsible for exchange of 7 students (2 months internship) in the area of Engineering since 2015
- University Polytechnic of Bari, responsible for exchange of 8 students for 6 months intership since 2013

### 3.5 Other courses

- Lessons in the PhD course of Engineering, University of Siena, built-in "Virtual Reality Haptics in Design and Applications", year 2008
- Teaching of course "Design dell'Interfacce" by Pont-Tech srl under the project "Technical design and industrial design" for a number of hours equal to 12, year 2006
- Course "New interaction paradigms for cultural heritage" in the PhD program in Technology and Management of Cultural Heritage "for a total of 3 hours performed in the years 2005.2006
- Lessons in "MASTER IN COMMUNICATION AND PUBLIC POLICY" in the module "Introduction to multimedia languages", aa 2003/2004

### 3.6 Advisor/Jury member in PhD dissertations

Antonio Frisoli was also a member of PhD committees for the degree of Doctor of Philosophy of the following candidates.

**At SSSA** With underlined the candidate for which he acted as thesis supervisor (tutor) and/or scientific advisor

1. Ilaria Bortone (2017) "Socially-oriented technology Frameworkd for Rehabiitatioin of Children during Developmental Ages" (Tutor and advisor)
2. Mine Sarac Stroppa (2017) "Design, Implementation and control of an underactuated hand exoskeleton (Tutor and advisor)
3. Michele Barsotti (2016) "Human-machine interfaces used on electro-iological signals for rootic applications and neurorehabilitation" (Tutor and advisor)
4. Daniele Leonardis (2015) "Design and Evaluation of Novel Kinesthetic Haptic Interfaces for Embodiment in Virtual Environments" (Tutor and advisor)

5. Basilio Lenzo (2015) “Design and control of active orthoses for rehabilitation and assistance to the elderly”
6. Banitalebi Dehkordi Maryam (2013) “Design and Experimental Evaluation of Advanced Human-Robot and Human-Computer Interfaces for Assistive Applications”
7. Padilla Castaneda Miguel Angel (2012) “Virtual Embodiment through Human Upper Limbs Simulation: applications in Neuroscience and Rehabilitation”
8. Claudio Loconsole (2012) “Advances in human-machine interaction for Upper Limb Rehabilitation and Basic Life Support training” (Tutor and advisor)
9. Alessandro Filippeschi (2011) “Skill acquisition and transfer of rowing” (Tutor)
10. Umberto Olcese(2010) “Neuromorphic computational models for robotics” (Tutor)
11. Nicola Lucchesi (2009): “Design of novel robotic devices for human power augmentation”, (Tutor)
12. Silvia Pabon (2010): “A data glove with vibro-tactile stimulators for virtual interaction” (Tutor and advisor)
13. Siqiao Li (2010) “Design, Implementation and Application of Haptic Interaction Manipulators for Rehabilitation Tasks ” (Tutor and advisor)
14. Massimiliano Solazzi (2010): “Nuovi concetti di interfaccia aptica portabili”, Scuola Superiore Sant’Anna (Tutor)
15. Luis Ivan Villeda (2010) “Control of Upper Limb Exoskeletons for Rehabilitation” Scuola Superiore Sant’Anna (Tutor)
16. Luigi Borelli (2010) “Applicazioni di robotica in realtà virtuale per il trattamento delle disabilità motorie dell’arto superiore”, Scuola Superiore Sant’Anna (Tutor)
17. Federico Tarri(2009): “Theoretic/experimental analysis of actuation systems for portable robotic devices”, Scuola Superiore Sant’Anna (Tutor)
18. Walter Aprile (2008): “Cognitive aspects during haptic interaction”, Scuola Superiore Sant’Anna (Tutor)
19. Damaso Checacci (2006): “Parallel kinematics and mechanical response to force cues on locomotion interfaces”, Scuola Superiore Sant’Anna (Tutor)
20. Emanuele Ruffaldi (2006): “Multirate and Perceptual Techniques for Haptic Rendering in Virtual Environments”, Scuola Superiore Sant’Anna
21. Rossi Fabio (2006): “High Quality Modeling of 3D objects in Virtual Environments, Optimized Single Chart Parameterizations”, Scuola Superiore Sant’Anna
22. . Marcello Carrozzino (2006): “Efficient management and authoring of complex virtual environments”, Scuola Superiore Sant’Anna
23. Marco Fontana (2008): “Exoskeleton haptic interface for the human hand”, Scuola Superiore Sant’Anna

**At foreign institutions:**

1. Bernard Javot (2017) UPMC ,”Conception d’une nouvelle architecture de moteur oscillant à contact permanent”, THÈSE DE DOCTORAT DE L’UNIVERSITÉ PIERRE ET MARIE CURIE
2. Mohammed Esmaeili Malekabadi (2014), ”Compatiility of Wrist Exoskeletons with Human Biomechanical and Neural Constraints: Analysis and Design”, Nanyang Technological University
3. Andra Brogni (2011), Haptics Illusin in Virtual Environments”, Universitat Politecnica de Catalonia, Barcelona
4. Renaud Ott (2009), “Two-handed Haptic Feedback in Generic Virtual Environments”, Ecole Polytechnique Federal De Lausanne
5. Nivedita Gadhopy (2006) “The Sensorimotor Theories of Visual Consciousness” Institut Nicod, Paris, France,
6. Guillame Drieux, (2006) France “De la maquette numérique produit vers ses applications aval: propositions de modèles et procedes associés”, INPG Grenoble,

**Advisor in undergraduate dissertations** Antonio Frisoli also followed as a speaker in the preparation of numerous dissertations, for the Faculty of Engineering of Pisa and Scuola Superiore Sant’Anna.

In particular, Antonio Frisoli has been supervisor of the following theses:

- 8 theses for the degree in Automation Engineering, Polytechnic of Bari
- 3 theses for the degree in Embedded Computing Engineering, Faculty of Engineering University of Pisa
- 19 theses for the degree in Mechanical Engineering, Faculty of Engineering University of Pisa (three years, specialist, five VO)
- 1 thesis for the degree course in Biomedical Engineering, University of Pisa
- 1 thesis for the degree in Computer Engineering, University of Pisa
- 5 theses in the graduate program in Engineering, Faculty of Engineering University of Pisa
- 3 theses for a license with the SSSA
- 1 graduated licensing at the University Institute of Advanced Studies (IUSS) of Pavia
- 1 Degree Thesis in Media Engineering, Technical University of Ilmenau, Germany

## 4 Institutional activities

Antonio Frisoli, was appointed Head of Scientific Research of the Human Robot Interaction Laboratory at the Institute PERCRO TeCIP (Institute of Information Technology, Communication and Perception), Scuola Superiore Sant'Anna, where he directs the 'area of Human-Robot Interaction (HRI), composed by a group of about 20 people, including 4 senior researchers, 6 PhD students, 1 post-doc researcher, 3 graduate research assistants, 2 technicians and students in different thesis.

He is currently tutor of 9 undergraduate engineering students at Scuola Sant'Anna and has been up to now tutor of more than 20 undergraduate engineering students. Currently Antonio Frisoli is academic tutor of and 5 PhD students at the Sant'Anna School of Advanced International PhD "Innovative digital technologies", on the following topics: PhD Students:

1. Domenico Chiaradia, Control of exoskeletons
2. Domenico Buongiorno, EMG synergistic control of exoskeleton
3. Massimiliano Gabardi Wearable haptic devices
4. Giacomo Tattoli, robotic technology for inspection of train underbody
5. Dettori Stefano, automation techniques in energy production

He held the following positions in the past at the Sant'Anna School

- Representative of the Assistant Professors at the Faculty of Experimental Sciences and Applied
- Representative of the PhD students with the Class of Experimental and Applied Sciences
- Representative of the PhD students in the Library Commission of SSSA.

### 4.1 Participation to university boards

- Elected representative member of Governing Board (Giunta) of TeCIP institute, as representative of Perceptual Robotics area (2016-now)
- Member of the Local Ethical Committee at Scuola Suuperiore Sant'Anna
- Member of committee for admission to Scuola Superiore Sant'Anna (from 2007-2008 up to now). The committee has the task to prepare the oral and written tests on the basis of which the candidate will be evaluated and selected (national competition)
- Member of committee for admission to PhD program at Scuola Superiore Sant'Anna.
- Member of the Council of the PhD program of SSSA.
- Member of the PhD in Morphology and function of normal and pathological cells and tissues, in the Department of Human Morphology and Applied Biology, Faculty of Medicine, University of Pisa.
- Member of the Master of Science in Mechanical Engineering from the academic 2003-2004 to 2007-2008, Faculty of Engineering, University of Pisa

- Member of the Master of Science / Engineering Computer Science in the academic years from 2008-2009 to 2011-2012, Faculty of Engineering, University of Pisa
- Member of the Master of Science / Engineering Computer Science in the academic from 2008-2009 to 2011-2012, Faculty of Medicine, University of Udine
- Member of the Council of Bachelor Degree in Physiotherapy for the academic year 2008-2009 to 2011-2012, Faculty of Medicine, University of Pisa

## 5 List of publications

Antonio Frisoli has published more than 150 papers in international peer reviewed scientific journals and conferences. He has a Scholar h-index of 30, a Scopus h-index of 20.

Table 1: Bibliometric indicators

Description	Number of documents	Number of citations	H-Index
Scholar	246	3440	30
Scopus	156	1857	20
ISI	132	909	15 <sup>1</sup>

### Journal Articles

- [J1] Domenico Buongiorno, Edoardo Sotgiu, Daniele Leonardis, Simone Marcheschi, Massimiliano Solazzi, and Antonio Frisoli. “WRES: a novel 3DoF WRist ExoSkeleton with tendon-driven differential transmission for neuro-rehabilitation and teleoperation”. In: *IEEE Robotics and Automation Letters* (2018).
- [J2] Massimiliano Gabardi, Massimiliano Solazzi, Daniele Leonardis, and Antonio Frisoli. “Design and Evaluation of a Novel 5 DoF Underactuated Thumb-Exoskeleton”. In: *IEEE Robotics and Automation Letters* (2018).
- [J3] D. Leonardis, C. Loconsole, and A. Frisoli. “A survey on innovative refreshable braille display technologies”. In: *Advances in Intelligent Systems and Computing* 587 (2018), pp. 488–498. DOI: 10.1007/978-3-319-60597-5\_46.
- [J4] Mine Sarac, Massimiliano Solazzi, Miguel A Otaduy, and Antonio Frisoli. “Rendering Strategies for Underactuated Hand Exoskeletons”. In: *IEEE Robotics and Automation Letters* (2018).
- [J5] M. Barsotti, D. Leonardis, N. Vanello, M. Bergamasco, and A. Frisoli. “Effects of Continuous kinaesthetic feedback based on tendon vibration on Motor Imagery BCI performance”. In: *IEEE Transactions on Neural Systems and Rehabilitation Engineering* PP.99 (2017), pp. 1–1. ISSN: 1534-4320. DOI: 10.1109/TNSRE.2017.2739244.
- [J6] Stroppa F., C. Loconsole, and A. Frisoli. “Convex Polygon Fitting in Robot-Based Neuro Rehabilitation”. In: *Soft Computing, accepted with minor revision* (2017).
- [J7] D. Leonardis, M. Solazzi, I. Bortone, and A. Frisoli. “A 3-RSR Haptic Wearable Device for Rendering Fingertip Contact Forces”. In: *IEEE Transactions on Haptics* 10.3 (2017), pp. 305–316. DOI: 10.1109/TOH.2016.2640291.
- [J8] Claudio Pacchierotti, Stephen Sinclair, Massimiliano Solazzi, Antonio Frisoli, Vincent Hayward, and Domenico Prattichizzo. “Wearable haptic systems for the fingertip and the hand: taxonomy, review, and perspectives”. In: *IEEE Transactions on Haptics* (2017).
- [J9] M. Sarac, M. Solazzi, E. Sotgiu, M. Bergamasco, and A. Frisoli. “Design and kinematic optimization of a novel underactuated robotic hand exoskeleton”. In: *Meccanica* 52.3 (2017), pp. 749–761. DOI: 10.1007/s11012-016-0530-z.

- [J10] F. Semeraro, A. Frisoli, C. Loconsole, N. Mastronicola, F. Stroppa, G. Ristagno, A. Scapigliati, L. Marchetti, and E. Cerchiari. “Kids (learn how to) save lives in the school with the serious game Relive”. In: *Resuscitation* 116 (2017), pp. 27–32. DOI: 10.1016/j.resuscitation.2017.04.038.
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Ai sensi delle norme in materia di dichiarazioni sostitutive di cui all'art. 46 e ss. del D.P.R. 445/2000 si dichiara che tutto quanto dichiarato corrisponde a verità.

Pisa March, 1 2018

A handwritten signature in black ink, appearing to read "Antonio Fucini". The signature is written in a cursive, flowing style.