Master Thesis in Mechatronics
October 2015
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ENERGY HARVESTING
Design of a wide-band vibration energy harvester for autonomously powered sensors

refer to Prof. Braghin and Ing. Tomasini

Traditional kinetic energy harvester have a reasonable energy conversion efficiency only at resonance. Thus, two main approaches are followed in case of wide-band input frequency: either design a substructure, on which to mount the harvester having several eigenmodes in the frequency range of interest, or design a substructure having a nonlinear (hardening/softening, multistable, …) behaviour so that the curved resonance peak covers a wide range of frequencies.
Design of a bi-stable energy harvester for autonomously powered sensors

refer to Prof. Braghin and Ing. Belloni

The concept of energy harvesting is based on the tuning of the dynamic response of the harvesting structure with the kinetic energy available on its surroundings. This energy could be potential harvested by converting this kinetic energy in electrical energy. The energy conversion of kinetic energy is most effective exploiting the phenomenon of resonance, in which the harvesting structure would exhibit large oscillations.

The aim of this thesis is to design an energy harvesting device, based on bi-stable laminates and piezoelectric transduces, capable of converting energy from a broadband of input motions. This aim is achieved by designing the stiffness of the composite structure, structural part and the piezoelectric transducing layer, and the mass distribution.
Periodic substructure for the localization of energy for vibration energy harvesting

refer to Prof. Braghin and Ing. Tomasini

Periodic structures allow to re-direct the incoming vibration along desired paths. Thus, through a properly designed substructure, the kinetic energy can be directed where the harvester is.
Sensorial nodes powered by wind energy harvester for railway applications

refer to Ing. Tomasini

- **Idea**
  Galloping-based piezo-aeroelastic systems exploit vibrations induced by an aerodynamic instability, as the galloping instability, to deform a piezoelectric beam and recover energy thanks to the piezoelectric effect.

- **Application**
  The goal of the project is to supply energy to wireless sensorial nodes to be used on railways vehicles to measure quantities relied to the railway safety.

- **Thesis**
  The goal of the thesis is to design, realize and test a new optimized galloping-based energy harvester.

**Wind tunnel tests** on the energy harvester prototype(s) and **field tests on railway vehicles** are planned.
Wind energy harvesting

refer to Ing. Tomasini

- **Idea**
  Centimetre-scale wind turbines are being developed during the last years for harvesting energy from wind to supply sensors for diagnostic purposes.

- **Application**
  The target of the sensor is to measure accelerations in correspondence of axle boxes of trains to detect possible deteriorations of the running conditions.

- **Thesis**
  Aim of this thesis is the design and the optimisation of a nano wind turbine. Wind tunnel tests and in line tests with prototypes on railway vehicles will be performed.
SMART STRUCTURES – SENSORS
Quadrature error of 3D MEMS gyroscopes refer to Prof. Braghin and Ing. Milani

Production tolerances of MEMS inertial sensors, and in particular MEMS gyroscopes, are responsible for the coupling between imposed motion along drive direction and the motion along sense direction. This coupling is called quadrature error. The aim of this work is to develop a topological optimization algorithm in order to obtain a design less affected by the quadrature error.
Nonlinear behaviour of 3D MEMS gyroscopes

refer to Prof. Braghin and Ing. Milani

Experimental evidence shows that MEMS gyroscopes may exhibit a nonlinear behaviour that is characterized, at given working temperatures, by high amplitude limit cycles. This phenomenon may be due to the coupling of pretensions in the material and nonlinear effects of the driving forces. The aim of this research is to understand the true causes of these limit cycles and to find out design solutions to overcome the problem.
Measurement of the dynamic behavior of 3D MEMS gyroscopes

refer to Prof. Braghin and Ing. Milani

Performance assessment design and statistical inference through automatic testing is the aim of this thesis. A robust approach is searched for in order to be applied to the production line to be able to select only those gyros that are mechanically sane before passing them over to the further production stages.
Mechatronic MEMS Force Sensor

refer to Prof. Braghin and Ing. Abbasi

Load cells are force sensors, which are used in weighing equipment. Most conventional load cells are made from steel or aluminum. When a load is applied, the metal part of the load cell deforms. This is measured by resistive strain gauges.

To minimize hysteresis and creep, expensive materials and fabrication techniques have to be used. Using silicon no hysteresis and creep do occur. Moreover, standard micromachining techniques can be used and accurate micromachined strain gauges can easily be integrated in the design.

The aim of this research is to design and optimize a multiaxial load/pressure sensor based on silicon and piezoresistive sensing elements.
Preventive maintenance has been utilized in many large industrial plants since it provides cost-effective solutions to long-term operation of expensive equipment. However, existing systems cannot gain wide acceptance since the cost associated with the deployment of a preventive maintenance system outweighs the gains. WSNs have been shown to provide cost-effective yet accurate maintenance capabilities.

The general goal of this activity is that of providing design criteria for the network architecture and topology of the sensor network serving the specific needs of the application scenarios of power plants.
SMART STRUCTURES – ACTUATORS
The thesis deals with the development of a stand-alone actuator to be used in vibration suppression application. The device embeds an electronic board with a micro to get measurements from sensors and to control vibrations according to different control algorithm. Actuators can work together exchanging information through Bluetooth and wireless modules.

Refer to Ing. Cinquemani and Ing. Cazzulani.
Design of a twisting multi-stable morphing actuator

refer to Prof. Braghin and Ing. Belloni

Multi-stable structures offer great potential as adaptable load-carrying components for achieving large deflections as actuation is only required to induce changes between statically stable configurations. Recently, a new class of twisting multi-stable structures offering great design flexibility have been introduced. The transition between the stable states is achieved through a jump phenomenon known as snap-through. To trigger this action, an actuation input is required to deflect the structure past a critical displacement position.

Thesis @ Purdue
Compliant mechanisms offer the simplest solution for obtaining huge transmission ratios. For this reason they are widely used in a number of applications that range from MEMS devices to watches and to stockbridges. The aim of this thesis is to develop a simulation code to design compliant mechanisms that satisfy given transmission ratios, dimensions, internal stresses, etc.
SMART STRUCTURES – LOGICS
Control of 1D and 2D structures based on distributed sensing (OBR) and discrete actuation

refer to Prof. Braghin, Ing. Cinquemani and Ing. Cazzulani

The use of optical fibres as distributed sensors and piezo patches as discrete actuators open new possibilities for vibration suppression of slender 1D or 2D mechanical structures. However, being the actuators non co-located, also new challenges in terms of stability and performances have to be faced. In the present thesis, a framework for designing these types of smart structures is searched for. The thesis deals with the study of control logics for vibration reduction in large flexible structures. In detail, the aim of the work is the development of control algorithms which exploit the availability of arrays of sensors to improve control performances. The experimental tests will be performed on carbon fiber structures equipped with arrays of Fiber Bragg Grating sensors.
Switched changes of structural parameters, e.g. due to changes in the impedance of piezo shunts, may lead to significant vibration reduction. These changes do require very small energy amounts but may excite higher frequency vibration modes. The aim of this research is to analyze, from an energy point of view, the logics as well as to set-up a simple test bench to test these logics.
Vibration suppression is crucial to ensure adequate operation over a wide range of conditions of lightly damped structures, and currently is an important research field within the field of Control and Smart Structures. In particular, for structures which may undergo dynamic instability, such as flutter, leading to undesirable levels of vibrations, suppression mechanisms need to be implemented. Compliant morphing structures incorporating multi-stable elements are a relevant example where vibration suppression is crucial both to maintain the stability of each stable configuration as well as to avoid dynamic instabilities triggering large amplitude vibrations.

Thesis @ Purdue

refer to Prof. Braghin and Ing. Belloni
The study of active vibration control and fatigue damaging have been always considered as separate topics in literature. In many cases, a reduction of vibrations implies a reduction of structure stresses and, as a consequence, an improvement in terms of structure lifetime. Anyway this is not generally true. Think, for example, to high-performance controls, which typically apply high forces on the structure. These forces can cause high local stress and high fatigue damaging on their application points. The aim of this thesis is the development of active control logics able to minimize the fatigue damage of a structure and, as a consequence, to maximize its lifetime. The work will be divided into a theoretical/numerical analysis (to formulate the control logic itself) and an experimental campaign on a 2D structure (to test the proposed logic on a real application).
The aim of this thesis is to study the effect of sensor/actuator damaging on control performance, considering different kinds of control logics. Secondly, it will be possible to study different formulations of the control algorithm in order to take the actuator/sensor possible damage into account even during the placement of sensors and actuators on the structure and in the definition of the control gains. These new formulations should be able to guarantee the stability of the controlled system even in case of actuator or sensor fault. The study will be performed both numerically and experimentally.
Statistical diagnostic and prognostic techniques for passive and active systems

refer to Prof. Braghin

More and more structures and systems are fitted with sensors to assess their dynamic behavior and eventually predict their residual life. The aim of this thesis is to carry out a review of existing statistical techniques to carry out diagnostics and prognostics on smart structures.
APPLICATIONS
Human-robot cooperation is increasingly needed in common industrial tasks, such as cooperative assembly, cooperative parts handling, learning procedures.

The aim of the proposed thesis is to design an impedance controller based on the sliding mode control theory, in order to improve human–robot interaction. In fact, properly defining the impedance control parameters, the operator perception of the manipulator can be adapted based on the target task needs.

A cooperative assembly task will be taken into account as a target application. The controller will be able to define the controlled robot behaviour based on the assembly procedure (e.g., having a stiff behaviour for high-precision assembly and soft behaviour for fast operations execution).
Robust Interaction Control Scheme for Lightweight Manipulators

refer to Prof. Braghin and Ing. Roveda

Light-weight manipulators are increasingly used in interaction tasks, due to their intrinsic properties (e.g., low mass and high controlled compliance). Commonly, such manipulators interact with compliant environment, approaching it with a target low velocity.

The aim of the thesis is to design a robust interaction control schema, including:
- a robust observer of the target environment stiffness (to be compensated by the controller);
- a robust velocity controller (with respect to the environment stiffness) to properly define the optimal approaching velocity;
- a robust force-tracking controller (with respect to the environment stiffness) to control the interaction force, also in the free motion – to – contact transition.
Robotized disassembly tasks are particularly challenging due to the intrinsic characteristics of the industrial manipulator (i.e., high inertia and stiffness).

Therefore, disassembling a component, robot end-effector starts oscillating with high amplitudes. Such behaviour is unsafe for both operators and other manipulators in the same working area.

The aim of the thesis is to model the disassembly phenomena (e.g., disassembly a component from a foundry mold) and design a model-based controller to limit/avoid any robot end-effector oscillation during the task execution.
Servo-electric gripper design for food Industry

Design of a servo-electric gripper (2-3 fingers) to perform pick-n-place tasks. The gripper has adaptive stiffness control to hold in smooth way different object.

Main activities:
- State of the art
- Choice and kinematic analysis of the mechanism
- Dynamic analysis
- Control logic design
- End-effector prototyping

refer to Prof. Braghin and Ing. Pallucca

Thesis @ Productivo
Development of new platform for industrial robot programming code.


The robot industry

Babel tower

Refer to Prof. Braghin and Ing. Pallucca

Thesis @ Productivo
Design of a robot for protective coating of high voltage electric lines

refer to Prof. Pennacchi and Ing. Chatterton

Low friction coatings for high voltage lines avoid ice formations that could lead to the collapse of the line.

The thesis will be carried out in cooperation with Terna. Coatings taken into account are PTFE as well as biodegradable polymers and will have to be applied to both new cables and existing lines. Thus, a mobile robot is considered the most probable solution. For powering the robot, inductive energy from the line could be exploited.
The aim of this thesis is to develop an active 3D mast vibration absorber that is capable of adjusting both the phase and the amplitude of the balancing force. The targets are the detailed design of the aMVA as well as the design of a test bench for analyzing its performances.
Performance analysis of distributed control logics for active helicopter struts

refer to Prof. Braghin and Ing. Cazzulani

The aim of this thesis, based on a previous work, is to develop a test bench for testing piezo based active struts as well as centralized and distributed control logics for minimizing the transmitted vibrations to the fuselage.
Switched damper for helicopter horizontal stabilizer

refer to Prof. Braghin and Ing. Cazzulani

To damp out vibrations of the horizontal stabilizers (tailplanes) of helicopters, a switched damper based on piezoelectric actuators is studied.

The advantage of this solution is that no external power should be required thus developing a standalone system that can easily be fit into existing stabilizers.
This thesis deals with **simulation** of VAWTs (Vertical Axis Wind Turbine). A full scale model of the turbine, designed at PoliMi, which is under testing in the Wind Tunnel, will be taken as reference. Aim of the research is development of an **aeroelastic numerical model** based on existing simple aerodynamic tools, e.g. lifting line or panel method, to be coupled with a **multibody simulator** (MBDyn – C++) and the numerical implementation of advanced **control strategies** of the IPC (Individual Pitch Control) for maximizing the system efficiency.
Objectives of this work is the development of the **hydrodynamic model and control design** of the system reported in the figures. This experimental rig consists of a simulator of the dynamics of floating wind turbines, by means of **Hardware-In-The-Loop** environment that allows to integrate in real time the hydro-platform interaction (numerically), which strictly depends on the wind turbine’s dynamics and the wind loads (measured); the outputs of the real-time environment are the displacements given by the actuators to the wind turbine scale model. **The tests are carried out within the wind tunnel boundary layer section.**
Current practice in wind turbines operation is that every turbine has its own controller that optimizes its own performance in terms of energy capture and loading. This way of operating wind farms means that each wind turbine operates based only on the available information on its own measurements. This gets the wind farm to operate in a non-optimum way, since wind turbines are not operating as players of a major system.

The thesis focus will be the study of innovative solutions based on wind farm open and closed loop advanced control algorithms which will enable to treat the entire wind farm as a unique integrated optimization problem. This will be possible thanks to the development of appropriate dynamic tools for wind farm simulation, at a reasonable computing effort.
A control logic for vibration reduction in cutting process with milling

Traditional milling machines can suffer from problems related to vibrations, which affect the quality of their products. Particularly critical are vibrations, induced by dynamic coupling, that may generate instability phenomena. In this thesis work we analyze methods for the identification of models of the "machine-process" system and control algorithms for vibration reduction. The research will be carried out numerically and experimentally, on a test bench created ad hoc, representative of a new generation of smart cutting machines.

refer to Ing. Ripamonti
Wearable upper limb exoskeletons have experienced a significant evolution in the past years thanks to their use in several applications that range from rehabilitation medicine, virtual reality simulation and teleoperation.

In the present thesis, the student is asked to optimize the mechanical design of an existing exoskeleton developed in cooperation with TUWien and enhance its control in order to automatically carry out specific tasks based on gaze and voice inputs and implement force control to compensate for its own weight.
Flywheel energy storage technology has several advantages with respect to chemical batteries:
- very high capacity
- short charge times
- almost infinite lifetime
- fully recyclable
That’s why flywheels are studied for several different applications that range from grid energy storage to transportation applications.

The thesis aims at further investigating flywheel energy storage for road and rail transport.
Study of an acoustic device based on array sensor

This thesis aims to study a device, based on a microphone array, for the monitoring, localization and characterization of possible threats on the water surface. The work will be developed in collaboration with the Italian Navy. The device will be designed to be installed on board modern ships or naval bases, which are considered sensitive targets.

refer to Ing. Ripamonti
Nowadays the design of 2D phononic crystals and locally resonant metamaterials is more a trial-and-error procedure. The goal is to define a specific design strategy, with a particular focus on noise rejection. The introduction of nonlinear elements could help to boost system’s performances.
Micro & Nano phononic crystals for MEMS applications and heat control

Due to their nature, phononic crystals are effective for high frequency applications. The idea is to study micro- and nano-devices for the control of vibrations, ultrasounds and heat.

Cloaking

MEMS

Thermo-crystals
The idea of boosting performances of periodic structures through the use of semi-active elements has been extensively discussed in the literature. This thesis, starting from some preliminary results obtained with classic control logics, aims at applying modern control logics to such active elements. Stochastic control and mode localization will be analysed.
It is not trivial to design phononic crystals for low frequency applications. Locally resonant metamaterial can help to achieve this goal. The thesis will focus on low applications with a particular focus on vibration isolation.

Refer to Prof. Braghin and Ing. Belloni

(b) Longitudinal excitation

(c) Transverse excitation
Active vibration control of the probe for superconducting magnets

refer to Prof. Braghin and Prof. Castelli Dezza

To measure amplitude and direction of the magnetic field within a superconducting magnet a test wire is inserted and a pulsating current is imposed. If the wire is exactly at the center of the magnetic field, no motion of the wire occur. Instead, if the wire is eccentric, it starts to vibrate. However, at increasing amplitude of oscillation (of the order of few microns) nonlinear effects occur that make it difficult to correctly estimate the amplitude and direction of the magnetic field. An active system for positioning and controlling the vibration of the powered "test wire" within the electromagnet is searched for.

Thesis @ CERN
Design of an active probe for assessing the magnetic field of superconducting magnets

refer to Prof. Braghin and Prof. Castelli Dezza

Presently, the assessment of the magnetic field within a superconducting magnet is carried out manually using a Hall probe. The aim of this thesis is to setup a device that automatically measures the magnetic field within the electromagnet at both ambient and cryogenic temperatures.

Thesis @ CERN
Expert system for fast and accurate setup of industrial CT machines

For the last few years industrial Computed Tomography (CT) has been regarded as a promising technology, which can evolve towards an integrated quality control of complex workpieces combining dimensional metrology and material defect analysis.

Goal of this thesis is to design an expert system that can automatically determine optimal CT scan parameters and support users in the CT set-up process. This system uses a similarity approach to determine optimal imaging parameters.

Thesis @ RWTH Aachen