M.Sc. in Bionics Engineering – UNIPI, SSSA and IMT, since 2015

• International program
• Limited enrollment (max 20 students per year – from 2019: max 30 students per year)
• 2 majors: biorobotics and neural engineering

Growing number of applications (109 in 2018)

http://www.bionicsengineering.it/
M.Sc. in Bionics Engineering
Classes of 15/16-16/17-17/18 & 18/19

March 2019
Mission of the M.Sc. in Bionics Engineering

Educating the Engineer of the 21st Century

able to face new challenges and to foster opportunities for Society and Industry

Biorobotics and Neural engineering are a fantastic “gym” to train new INNOVATORS
Going beyond traditional engineering education

Problem (curiosity and application driven)

Scientific knowledge (Discovery)

Invention

Prototypes, experiments

Design

Factory, organization, management

Product

Specifications

Market

Research

Industry
The birth of Bionics

Bionics as an inter-science discipline officially dates back to 1958 when Major J. E. Steele coined the term making reference to a research program at the Wright-Patterson Air Force Base in Dayton, OH, USA.

**Meetings**

The various underlying the behavior of artificial and real organisms were brought into closer focus at a national symposium held 13-15 September 1956 on the occasion of the sponsorship of the Wright Air Development Division of the United States Air Force, was attended by approximately 500 persons. Several invited papers reported new developments concerning methodologies of information handling used by living systems and artificial models of each system. The papers impressed the participants that they indeed discovered that major results could be made in a shorter time. This report is based entirely on my notes, I apologize for any errors of fact or interpretation, and for not mentioning many talks because of lack of space.

At the start, J. E. Steele of the Air Force Base introduced the term bionics. Steele pointed out three aspects of such programs which are needed for the incorporation into artificial systems: (i) the awareness necessity of certain computer organization—for examples, the ability of certain fish to detect a change in the electric field in the water around them; (ii) the ability of certain species to store food for extended periods of time; and (iii) the ability to store information at molecular levels, even for periods of generations, as is the chromosomes. An example of the numerical use of a living system is a prototype of an artificial system is the application to an optical storage device. The system is based on the simple principle that the brain's visual systems that provide information on velocity.

J. E. Steele delineated (i) that in long or in such fundamental understanding of the laws of organization could be accomplished by using living systems; (ii) the thought processes in animals and existing organisms; and (iii) the living systems themselves and their behavioral benefits to the design of such organisms. Steele illustrated the need for a research program in these fields and gave examples of existing machines in which the two types of design are used. (Cited in the text when we introduced a few examples of organinterpreted by C. H. Gray, New York, 55–60 (1960).

The birth of Bionics

The primary goal of bionics is “to extend man’s physical and intellectual capabilities by prosthetic devices in the most general sense, and to replace man by automata and intelligent machines”

These objectives were pursued by using models from the animal kingdom...

Research efforts were mainly driven by military applications

Current applications of bionic technologies

- Festo’s Newest Robot Is a Hopping Bionic Kangaroo
- Shark skin-inspired swimsuits
- POWERSKIN CARBON-ULTRA
- Shark skin-inspired swimsuits
- Scientific American: Artificial Muscles
- IEEE spectrum
Bionics intended as technologies intimately interacting with the body

The Revolution Will Be Prosthetized

We Will End Disability by Becoming Cyborgs

Diabetes Has a New Enemy: Robo-Pancreas
# M.Sc. in Bionics Engineering

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<td>Biomechanics of human motion (Vito Monaco)- 6 ECTS</td>
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<td>Soft and smart materials (Matteo Cianchetti) – 6 ECTS</td>
<td>Instrumentation and measurements for bionic systems (Angelo Maria Sabatini) – 6 ECTS</td>
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<td>Biological data mining (Francesco Marcelloni) – 6 ECTS</td>
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<td>Principles of bionics engineering (Paolo Dario) – 6 ECTS</td>
<td>Economic assessment of medical technologies and robotics for healthcare (Giuseppe Turchetti) – 6 ECTS</td>
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<td>Neuromorphic engineering (Calogero Maria Oddo) – 6 ECTS</td>
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<td>Mechanics of elastic solids and biorobotic structures (Antonio De Simone) – 6 ECTS</td>
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In black: mandatory courses
In orange: elective courses (students need to complete at least 12 ECTS by choosing elective courses)

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# M.Sc. in Bionics Engineering

## 2nd year – Curriculum: Biorobotics

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<tr>
<th>1st semester</th>
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<td>Artificial limbs (Christian Cipriani) – 6 ECTS</td>
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<td>Robot companions for assisted living (Stefano Mazzoleni) – 6 ECTS</td>
<td>Micro/nano robotics and biomaterials (Leonardo Ricotti) – 6 ECTS</td>
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<td>Human and animal models in biorobotics (Cecilia Laschi) – 6 ECTS</td>
<td>Cloud robotics (Filippo Cavallo) – 6 ECTS</td>
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<td>Robotics for minimally invasive therapy (Arianna Menciassi) – 6 ECTS</td>
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## 2nd year – Curriculum: Neural Engineering

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<thead>
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<tbody>
<tr>
<td>Advanced image processing (Nicola Vanello) – 6 ECTS</td>
<td>Integrative cerebral function (Angelo Gemignani) – 6 ECTS</td>
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<tr>
<td>Neural tissue engineering (Giovanni Vozzi) – 6 ECTS</td>
<td>Neural interfaces and bioelectronic medicine (Silvestro Micera) – 6 ECTS</td>
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<td>Bionic senses (Danilo De Rossi) – 6 ECTS</td>
<td>Affective computing (Enzo Pasquale Scilingo) – 6 ECTS</td>
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<tr>
<td>Design of interactive robots and machines (Daniele Mazzei) - 6 ECTS</td>
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**Final duties:** Lab training (3 ECTS) and Thesis (15 ECTS)

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M.Sc. in Bionics Engineering

1st Year

(1st semester)

http://www.bionicsengineering.it/
Statistical signal processing

Focus

- Statistical signal processing methods for deterministic and random parameter estimation, data analysis, random signal recovery and filtering, model identification, power spectral density estimation.

Main Contents

- Orthonormal base signal expansion, Principal Component Analysis (PCA), Sample estimators, Method of moments estimators, Maximum likelihood estimators, Linear and Non Linear Least Squares Least, Bayes estimation, Minimum Mean Square Error (MMSE) and Maximum A Posteriori (MAP) estimation, Linear MMSE (LMMSE) estimation, ARMA modeling, Wiener filter for signal filtering, prediction and interpolation, parametric and non Parametric power spectral density estimation.

Learning Outcomes

- Background knowledge necessary to solve typical problems by using methods of statistical signal processing

http://www.bionicsengineering.it/
Soft and smart materials

Focus

• Use of soft materials for developing innovative sensors and actuators

Main Contents

• Novel actuation technologies
• Introduction to Finite Element Models (FEM)
• FEM implemented in ANSYS software for non-linear analysis for design purposes

Learning Outcomes

• Use of soft/compliant material for the design of intelligent mechatronic systems

http://www.bionicsengineering.it/
Biological data mining

Focus

• Main techniques used in Data Mining

Contenuti principali

• Data Preprocessing
• Frequent pattern mining
• Classification
• Clustering
• Outlier Detection
• Laboratories on the application of the methods presented during the course

Learning Outcomes

• To provide a solid knowledge of the main techniques used in data mining. This knowledge will allow identifying the most suitable approach for solving each type of data mining problem.

http://www.bionicsengineering.it/
Behavioral and cognitive neuroscience

Focus

• Neuroimaging has revolutionized neuroscience, allowing us to investigate the neural correlates of behavior and mental functions

Main contents

• basics of brain anatomy and physiology
• neuroimaging methodologies: principles, applications, methods of analysis
• neurobiological correlates of cognition and behavior
• functional neuroanatomy of perception, consciousness and sleep, language, emotions and behavior motor control and representation of action, development of brain-computer interfaces

Objective

The course introduces the theoretical and methodological aspects of cognitive and social neuroscience, introducing to the fundamentals of brain anatomy and physiology, and to neuroimaging techniques

http://www.bionicsengineering.it/
Biomechanics of human motion

Focus

- Biomechanics of human movements and physiological principles underlying motor control.

Main Topics

- 3D kinematics and kinetics;
- physiology of muscle contraction
- modeling of muscle-tendon actuators;
- numerical methods to solve dynamic models adopted in biomechanics;
- EMG signals
- instruments in a motion lab

Learning Outcomes

- Methodological approach for the study of human motion during dynamic motor tasks mediated by muscle-tendon actuators

http://www.bionicsengineering.it/
Instrumentation and measurements for bionic systems

Focus

• Methods and techniques for the measurement of physical and electrical variables in bionic systems

Main Contents

• Application and design of measurement systems
• Measurement systems behavior through mathematical modeling
• Probability & statistics for analysis of experimental data

Learning Outcomes

• How to deal with measurement problem solving (data acquisition, analysis and interpretation)

http://www.bionicsengineering.it/
Neural and fuzzy computation

Focus

- Basic concepts and models of Computational Intelligence
- Application of the associated techniques to real-world problems in several application domains

Main Contents

- Artificial neural networks
- Deep learning
- Fuzzy logic
- Fuzzy systems
- Genetic algorithms

Learning Outcomes

- Design and develop intelligent systems with human-like capabilities in terms of reasoning, learning and adaptation

http://www.bionicsengineering.it/
Computational neuroscience

Focus
• Introduction to fundamentals of the CNS considering both the bio-inspired neural modelling and computational point of view

Main Contents
• Neuroscience modeling
• Spiking and reservoir computing neural networks
• Advanced computational learning models
• Dynamical/Recurrent neural networks

Learning Outcomes
• Capability of analysis and development of advanced CNS/Machine Learning models

http://www.bionicsengineering.it/
M.Sc. in Bionics Engineering

1st Year

(Additional courses that can be selected by students) – 1st semester

http://www.bionicsengineering.it/
Principles of bionics engineering

Focus

• Make students able to face frontier engineering problems, by combining science and hi-tech approaches (proper of bionics design)

Main Contents

• Introduction to the course, historical hints and definitions
• Bionic structural design and main material classes and fabrication technologies
• Bionic locomotion principles and robotic zoo
• Swarm intelligence and collective behaviors
• Morphological computation
• Bionic sensors and actuators
• Bionic energy management: comparison between animals and robots
• Examples of current bionics systems and applications
• Ethical, economic and legal considerations related to bionics

Learning Outcomes

• Providing basic knowledge and principles on design, fabrication, and control processes of bionics systems
• Highlighting current bionics systems and their applications
• Stimulating students directly to develop innovative bionic concepts by exploiting the knowledge acquired during the course

http://www.bionicsengineering.it/
Neuromorphic engineering

**Focus**

- Computational and physical models that emulate neuron dynamics

**Main Contents**

- Technological solutions for embedded spiking systems
- Signal processing techniques for spiking signals (artificial or physiological)
- Methods for simulating neuron dynamics (e.g. Izhikevich model)
- Use and design of neuromorphic systems

**Learning Outcomes**

- Neurorobotic systems and neurophysiological data for restoring sensori-motor functions

http://www.bionicsengineering.it/
Mechanics of elastic solids and biorobotic structures

Focus

- Non linear mechanics of one-dimensional active and elastic systems in the regime of large deformations: from robotic arms to elephant trunks

Main Topics

- Infinitesimal and finite rotations
- Kinematics and equilibrium of deformable rods
- Material properties and constitutive models
- Principle of virtual powers and the Finite Element Method
- Applications: wires and tendons, Euler’s elastica and Galileo’s beam, bending with large deformations, buckling and post-critical behavior of elastic systems

Learning Outcomes

- Methodological approach for the study of shape control problems in biological and robotic systems

http://www.bionicsengineering.it/
M.Sc. in Bionics Engineering

1st Year
(Additional courses that can be selected by students) – 2nd semester

http://www.bionicsengineering.it/
Economic assessment of medical technologies and robotics for healthcare

Focus

• To analyze the economic and business dimensions of the medical technologies and of the robotics for healthcare sectors

Main contents

• Specificities of the healthcare sector and economic dimension of medical technologies and robotics for healthcare
• Economic assessment techniques of robotics for healthcare and its sustainability
• Business and marketing models of robotics for healthcare

Learning Outcomes

• To understand the specificities and mechanisms of the healthcare sector and to define the strategies to favor the acquisition and transfer to the clinical practice of medical technologies and robotics for healthcare.

http://www.bionicsengineering.it/
M.Sc. in Bionics Engineering

2nd Year
Curriculum: BIOROBOTICS
(1st semester)

http://www.bionicsengineering.it/
Artificial limbs

Focus

• Restoration of the upper limb sensorimotor function through prostheses

Main Contents

• Anatomy and neurophysiology of the upper limb
• Upper limb prosthetic components
• Human-machine interfaces for prosthetics
• Pattern recognition control
• Embedded controls

Learning Outcomes

• Technologies and methods to design and assess upper limb prosthetic components and systems

http://www.bionicsengineering.it/
Robot companions for assisted living

**Focus**

- Robotics for rehabilitation and assistance and technologies for functional assessment

**Main contents**

- Introduction to rehabilitation and assistive robotics
- State of the art of robotic systems for rehabilitation and assistance
- Human-robot interaction: kinematics, dynamics and control techniques

**Learning Outcomes**

- Design of robots for rehabilitation and assistance
- Human-centered control strategies for safe and reliable human-robot interaction

http://www.bionicsengineering.it/
Human and animal models in biorobotics

Focus

• Bioinspired robotics and biorobotic platforms for neuroscience and biology

Main contents

• Humanoid Robotics, Neurocontrollers
• Bioinspired perception, Robot vision
• Embodied Intelligence and Soft Robotics, Underactuated mechanisms

Learning Outcomes

• How to design and control robots using bio-inspired principles

http://www.bionicsengineering.it/
Robotics for minimally invasive therapy

Focus

• Robot, intelligent tools, integrated mechatronic systems to improve accuracy and repeatability in surgical interventions

Main Contents

• Why do we need surgical robots?
• Surgical operation: autonomous robots, tele-operated robots, hand held, shared control. Endoluminal robotic approaches.
• Guidelines for designing easy to use robots, featured by a limited invasiveness

Learning Outcomes

• Knowledge and tools to build/use robots in surgical/diagnostic/therapeutic fields

http://www.bionicsengineering.it/
M.Sc. in Bionics Engineering

2nd Year

Curriculum: BIOROBOTICS

(2nd semester)

http://www.bionicsengineering.it/
Robotic exoskeletons

Focus

- Design challenges and state-of-the-art solutions of wearable robots

Main Contents

- Introduction to wearable robotics
- State of the art of upper- and lower-limb robotic exoskeletons
- Multi-layered control architectures running on real-time targets with FPGA processors
- Labview RT and FPGA modules

Learning Outcomes

- Design of wearable powered robots for movement assistance, rehabilitation, augmentation and/or functional replacement.

http://www.bionicsengineering.it/
Micro/nano robotics and biomaterials

Focus

- Regenerative medicine and micro/nano-medicine

Main Contents

- Microfabrication technologies
- Molecular biology, stem cells and regenerative medicine
- Biomaterials promoting tissue regeneration
- Micro/nano robots for advanced therapies
- Physical triggers to promote drug delivery

Learning Outcomes

- Technologies and approaches to regenerate human tissues
- Techniques to use micro/nano-technologies for targeted therapies

http://www.bionicsengineering.it/
Cloud robotics

Focus

- Basic knowledge and methodologies for designing and implementing service robotic solutions based on the integration of mobile robotic platforms, sensor networks and Cloud computing.

Main Contents

- State of the art of social robotics and human robot interaction
- Architecture and functioning of Internet of Things devices based on STM32 microcontroller
- Software and hardware architecture for programming robotic platforms with ROS and Gazebo
- Design and implementation of perception-reasoning paradigms for human robot interaction

Learning Outcomes

- Design and development of cloud social robots for assistance, geriatric assessment and support in assisted living applications

http://www.bionicsengineering.it/
M.Sc. in Bionics Engineering

2nd Year

Curriculum: NEURAL ENGINEERING

(1st semester)

http://www.bionicsengineering.it/
Advanced image processing

Focus

• Models and Methods for brain function analysis

Learning Outcomes

• How different methods for brain function studies are applied
• Link between experimental design and data analysis approaches

Main Contents

• Functional Magnetic Resonance Imaging (fMRI)
• Brain connectivity from fMRI and Electroencephalography (EEG)
• Source imaging from EEG and MRI

http://www.bionicsengineering.it/
Neural tissue engineering

Focus

- Technological processes and materials to build neural grafts and promote their interaction with physiological neural tissue

Learning Outcomes

- Acquire the strategies to develop grafts and scaffolds that can be implanted to promote nerve regeneration and to repair neural damage

Main Contents

- Bioactive materials and their characterisation
- 2D and 3D Fabrication
- Neuro-Chemical functionalisation

http://www.bionicsengineering.it/
Bionic senses

Focus

• Pre-neural and neural components of human and animal senses.
• Bionics senses design

Main Contents

• Introduction to natural senses
• Properties of biological receptors
• Physics of pre-neural media
• Sensations and perceptions
• The human senses
• Modeling and design of bionic senses

Learning Outcomes

• Engineering artificial sensing and perceptual systems through biological principles to implement neural-prostheses to restore lost functions, for human augmentation and bio-inspired perceptional machines

Evolving pre-retinal & retinal hardware
Design of interactive robots and machines

Focus

• Complex system used for interaction with humans

Main Contents

• Human-centred Design
• Smart objects and systems
• Internet of things

Learning Outcomes

• Design of systems able to interface with humans
• Learning base concepts of “human-centered design”

http://www.bionicsengineering.it/
M.Sc. in Bionics Engineering

2nd Year

Curriculum: NEURAL ENGINEERING

(2nd semester)

http://www.bionicsengineering.it/
Integrative cerebral function

Focus

• Cognitive and emotional brain functions as the by-product of the activity of anatomo-functional distributed and integrated brain networks.

Main Contents

• Node and rich-clubs in the human connectome
• Sleep, mentation and dreaming
• Biological bases of consciousness
• Theory of mind and mirror neuron system
• Empathy in the emotional context
• Stress in the context of body and mind integration

Learning Outcomes

• Methodological aproach for the study of complex brain functions and their biological bases

http://www.bionicsengineering.it/
Neural interfaces and bioelectronic medicine

Focus

• Implantable neuroprostheses

Main Contents

• Brain-to-machine interfaces
• Artificial limbs with neural control
• Sensory and motor neuroprostheses
• Neuromodulation of the autonomic nervous system

Learning Outcomes

• Provide students with methodologies for the development and validation of implantable systems for neuromodulation

http://www.bionicsengineering.it/
Affective computing

Focus

• Advanced techniques for monitoring and process physiological signals for studying emotions

Main Contents

• Physiology of emotional response
• Computational modeling of emotions
• Origin, processing and monitoring of ECG, breathing pattern, EDA and voice
• Nonlinear methods and models for biomedical signal processing
• Eye tracking, body movement analysis and facial emotion recognition

Learning Outcomes

• Acquire basic knowledge to monitor and process physiological signal corresponding to different emotional states

http://www.bionicsengineering.it/
M.Sc. in Bionics Engineering

2nd Year

Final duties

http://www.bionicsengineering.it/
Lab training (3 CFU)

This activity will consist of 75 h of Lab training that the student will perform in dedicated facilities and laboratories, with the aim to increase his/her experience in laboratory practice.
Thesis (15 CFU)

The final examination involves the preparation of a report on a research activity, and in its presentation and discussion.