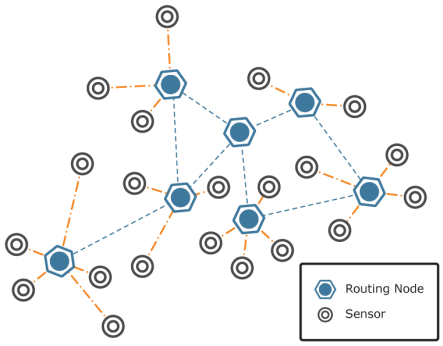
University of Padova,
Dept. of Information Engineering

2013 Summer School of Information Engineering,

Sensors and sensors networks



Bressanone (BZ), Italy
July 1 – 5, 2013

the co-Directors
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2013 Summer School of Information Engineering,

Bressanone (Brixen, BZ), Italy - July 1 – 5, 2013

Sensors and sensors networks

Sunday 30/6 (Hotel Gruener Baum)

17:00 – 19:00 SSIE Opening, Welcome, Introduction to the school and Program description (Gaudenzio Meneghesso, Silvano Pupolin, Co-Directors).

Monday 1/7 (Casa della Gioventù)

8:30 – 11:00 **Volker Cimalla** *Fraunhofer Institute of Applied Solid-State Physics (IAF) Freiburg / Germany* "Gallium Nitride based sensors"

11:00 – 13:30 **Flammini Alessandra**, *Università degli Studi di Brescia* "Sensor networks for industrial applications"

15:00 – 17:00 PhD students Presentations

Tuesday 2/7: (Casa della Gioventù)

8:30 – 11:00 **Andrea Cusano**; *Università del Sannio*; "Fiber Optic Sensors for Industrial Applications: Perspectives, Challenges and New Trends"

11:00 – 13:30 **Thilo Sauter**, *IISS Institute for Integrated Sensor Systems*, "Integration, security, and synchronization aspects"

15:00 – 17:00 PhD students Presentations

Wednesday 3/7: (Casa della Gioventù)

8:30 – 11:00 **Paolo Zaffoni**, *ALSTOM Ferroviaria SpA*, "Sensors in the railway environment"

11:00 – 13:30 **Kalle Johannson**, *KTH Royal Institute of Technology, School of Electrical Engineering* "Networked control and autonomy"

15:00 – 17:00 PhD students working Groups

Thursday 4/7: (Casa della Gioventù)

8:30 – 11:00 **Christian Scheideler**, *Institut für Informatik, Universität Paderborn*, "Self-assembling sensor networks"

11:00 – 13:30 **Andrea Facchinetti, Giovanni Sparacino** *Department of Information Engineering, University of Padova,* "Making a Glucose Sensor Smarter for Managing Diabetes: Where We Are and Where to Go**"**

15:00 – 17:00 PhD students working Groups

Friday 5/7: (Hotel Gruener Baum)

8:30 – 11:00 **Deniz Gunduz** *Electrical and Electronic Engineering Imperial College, London,* "Energy harvesting wireless sensor networks"

11:00 – 13:30 **Workshop**: "Wireless sensor and actuator networks", WSAN - *Department of Information Engineering, University of Padova,*

Luca Corradini, "Overview of Power Processing Techniques for Harvesting-Based Wireless Sensor Nodes"

Giada Giorgi, "Design and characterization of sensor nodes under real constraints"

Leonardo Badia "Modeling and Optimizing the Operation Policies of Energy Harvesting Devices under Realistic Assumptions"

Ruggero Carli "The impact of battery degradation on Harvesting-based Wireless Sensor Devices"

15:00 – 17:00 PhD students working Groups

Saturday 6/7: (Hotel Gruener Baum)

9:00 – 11:00 **SSIE 2013 Final test**

11:30 – 12:00 SSIE Closing, (Gaudenzio Meneghesso, Silvano Pupolin, Co-Directors)

ABSTRACTS

Volker Cimalla
Fraunhofer Institute of Applied Solid-State Physics (IAF) Freiburg, Germany
Gallium Nitride based sensors
Abstract: The tutorial will cover the latest research in III-V nitride-based sensors for gas, chemical, biological, and medical applications. Wurtzite AlGaN, InGaN and AlInN exhibit a macroscopic non-linear pyroelectric polarization, which dramatically affects the optical and electrical properties of multilayered Al(In)GaN/GaN hetero-, nanostructures and devices. Gradients in polarization cause huge built-in electrostatic fields and bound interface charges at surfaces and heterointerfaces. The corresponding free carrier concentration profiles are very sensitive to any manipulation of surface charge. This physical effect can be used to develop novel sensors for ion fluxes, gases and polar liquids. AlGaN/GaN-heterostructures with polarization induced two dimensional electron gases (2DEG) are used to detect gases, ion fluxes or biomolecules and to determine volume and pH-value of water based nano- and picoliter droplets. Direct monitoring of bioreactions by recording of the ion channel activity of cells was demonstrated as well as the application in selective DNA sensors by appropriate surface functionalization. The tutorial features a balance between original theoretical and experimental research in basic physics, device physics, novel materials and device structures, process, and systems. It will begin with a general overview of the basic physics of the devices and the device designs, followed by the current state of the art, new trends, and unique advantages and limitations of this technology.

Andrea Cusano;
Optoelectronic Div. - Engineering Dept. - University of Sannio, Benevento, ITALY;
Fiber Optic Sensors for Industrial Applications: Perspectives, Challenges and New Trends
Abstract: Over the past two decades, fiber-optic technology has revolutionized the telecommunications industry, enabling high-capacity, long-distance communications and networking at staggeringly low costs. Fiber sensing—the use of fiber optics for industrial sensing applications—is another exciting growth area for this versatile technology. Some ideas indeed have made the leap from the laboratory into the highly competitive market of sensor technology. This transition has taken the better part of 20 years and reached the point where fiber sensors enjoy increased acceptance as well as a widespread use for structural sensing and monitoring applications in civil engineering, aerospace, marine, oil & gas, composites, smart structures, bio-medical devices, electric power industry and many others. Optical fiber sensor operation and instrumentation have become well understood and developed. And a variety of commercial discrete sensors based on Fabry-Perot (FP) cavities and fiber Bragg gratings (FBGs), as well as distributed sensors based on Raman and Brillouin scattering methods, are readily available along with pertinent interrogation instruments. Among all of these, FBG based sensors—more than any other particular sensor type—have become widely known, researched and popular within and out the photonics community and seen a rise in their utilization and commercial growth. This lecture reviews the major milestones of their technological evolution during the thirty years from the discovery of Kenneth Hill in 1978. Further, the lecture includes an overview of the major developments carried out at University of Sannio aimed to demonstrate the effectiveness of the technology to provide suitable solutions for strategic industrial sectors. The lecture analyses some "Case Studies" demonstrating how the synergy between research and industrial worlds would open new successful market options.

Thilo Sauter,
IISS Institute for Integrated Sensor Systems, Austrian Academy of Sciences
Integration, security, and synchronization aspects

Abstract: Sensor networks, be they wired or wireless, are often part of a larger network infrastructure. In order to allow for effective transmission of information, such networks must be properly integrated. We discuss integration problems, suitable architectures, and in particular hybrid network concepts supporting seamless real-time capabilities. We also address security issues which are especially demanding in sensor networks due to the potentially large number of nodes, the high degree of distribution, and the inherent resource constraints. Finally, we will discuss synchronization aspects in distributed sensor systems, their basic operation principles, ways to improve synchronization accuracy, and applications or services that can be built upon precise synchronization, such as localization of wireless nodes.

Paolo Zaffoni,
ALSTOM Ferroviaria SpA,
Sensors in the railway environment
Abstract: Alstom Centralized Diagnostic System (SDC) is built upon a network of intelligent diagnostic sensors (specifically designed to interface railway signalling equipment) and communication devices which main purpose is to centralize collected trackside information. The main scope of SDC is to interface SCC systems (Italian Integrated Control Center), supplying them, and in particular the Diagnostic and Maintenance Sub-System, with all the information needed for diagnostic of signalling equipment, acquired both from station and from Automatic Block (BA) trackside shelters. A specific interface protocol is provided for this purpose

Christian Scheideler,
Institut für Informatik, Universität Paderborn,
Self-assembling sensor networks
Abstract: Self-assembling nano-structures have already been investigated for a number of years in various classical disciplines like physics, chemistry, and biology, but research has mostly focused on rather simple particles without intelligence like DNA molecules. In recent years, also self-assembling structures based on intelligent particles have been investigated, particularly in the context of modular robotics. Self-assembling nano-stuctures have a number of very interesting applications, especially in medical treatment and environmental monitoring. An important problem in these contexts is the so-called smart paint problem: Given a certain object O and particle structure S that is connected to O, design a simple distributed protocol for the particles that allows them to transform their structure in order to cover O as good as possible without losing connectivity at any point in time. In my talk I will discuss particle models and ways of solving the smart paint problem and show how this can help to solve certain monitoring problems.

Andrea Facchinetti, Giovanni Sparacino
Department of Information Engineering, University of Padova
Glucose Sensor Smarter for Managing Diabetes: Where We Are and Where to Go.
Abstract. Tight monitoring of glucose concentration in the blood is essential in the management of diabetes, a pathology which affects 350 millions of people in the world. Since the early 2000's, portable and minimally-invasive continuous glucose monitoring (CGM) sensors have been proposed in the market to measure glucose concentration in real time with a 1-5 min sampling period and for up to 7 consecutive days. These CGM sensors are potentially usable in applications of great clinical impact, as on-line prediction of forthcoming dangerous hypo/hyperglycemic events and artificial pancreas algorithms for closed-loop glucose control, but some accuracy and precision problems of the state-of-art devices are still open. In this lecture we present some on-line signal processing algorithms that we have developed in the recent past to render glucose sensors "smarter". In addition, we describe progresses and perspectives of our recently established collaboration with Dexcom Inc., one

of the world's leading glucose sensors manufacturers, aimed at porting some of our algorithms within a commercial CGM device.

Deniz Gunduz
Electrical and Electronic Engineering Imperial College
Energy harvesting wireless sensor networks
Abstract: Lifetime of wireless sensor networks depends critically on the energy available at individual sensor nodes. However, constraints on the cost and physical size of low-complexity sensor nodes severely limit the battery capacity. Moreover, battery replacement can be impractical or impossible due to inaccessibility of remote sensor nodes, or their vast numbers. Harvesting the available ambient energy is a promising technology for sensor networks providing theoretically perpetual operation. However, in most cases harvested energy is limited in quantity and sporadic in availability, necessitating novel communication schemes to best exploit this intermittent energy. In this lecture we will study the design of intelligent communication schemes for energy harvesting sensor nodes. Focusing on a point-to-point time-varying channel, we will consider stochastic arrival of both energy and data over time, and take into consideration practical system parameters such as battery leakage and energy consumed in the processing circuitry. We will identify the optimal transmission schemes in the "offline optimization" framework, which assumes non-causal knowledge of all future events in the system; as well as in the "online optimization" framework, assuming only a statistical knowledge about the underlying random processes. Finally, we will provide a "learning-theoretic" approach, suitable for practical scenarios in which the statistical properties of the underlying random processes are either not known at the deployment, or vary over time. If time permits, we will also consider challenges in designing communication protocols for networks of energy harvesting nodes.

Workshop: "**WSAN: Wireless sensor and actuator networks**"
Speaker: Luca Corradini, *Department of Information Engineering, University of Padova*
Title: Overview of Power Processing Techniques for Harvesting-Based Wireless Sensor Nodes
Abstract: The broad range of potential applications of Wireless Sensor Networks (WSN's) is drawing attention from many and interdisciplinary research fields, encompassing telecommunications, control theory and low-power electronics. Crucial to the practical utilization of large-scale WSN's is the sensors capability to operate over extended periods of time in an essentially zero-maintenance fashion. Such *energy autonomy* is a key requirement for large-scale WSN's, in which tens to hundreds of sensor nodes are scattered over the environment. Scenarios include industrial monitoring, building automation and surveillance systems, and even more challenging outdoor applications such as landslide detection networks, in which sensor nodes may no longer be accessible once deployed. For the above reasons, conventional sensor nodes powered by non-rechargeable batteries are evolving into *harvesting-based sensor nodes* capable of absorbing ambient energy and locally storing it into an on-board rechargeable cell. Because of the very nature of harvesting-based nodes, smart power processing and battery management solutions are mandatory for effective utilization of the available energy and prolonged sensor lifetime. The talk first provides a preliminary overview of available energy sources and power processing techniques for harvesting-based wireless sensor nodes. The presentation then outlines recent and ongoing activities of the Power Electronics Group in the energy harvesting field.

Speaker: Giada Giorgi, *Department of Information Engineering, University of Padova*
Title: Design and characterization of sensor nodes under real constraints.
Abstract: The growing interest on Wireless Sensor and Actuator Networks (WSAN) in these last years is mainly due to the benefits that such kind of distributed measurement and control systems present. WSANs represents a winner technology in situations where a wired communication infrastructure results to be excessively demanding in terms of accessibility, feasibility and maintainability costs or it results even impossible to realize. Furthermore, in

this context network nodes must be necessarily fed up by autonomous energy sources, such as batteries or energy harvesting modules and, on the other hand, they must be designed in order to consume few energy resources. Finally, WSANs, as well as any distributed measurement system, must also rely on a common timescale that needs to be shared among its constituent elements. In this talk we will illustrate the comprehensive structure of a sensor node by describing the main functionalities and characteristics of its constituent elements such as the measurement block, the power management unit, the communication interface, the clock module and the elaboration unit. The attention will be focused in particular on the clock module and synchronization systems, which represent a crucial issue in measurement applications.

Speaker: Leonardo Badia, *Department of Information Engineering, University of Padova*
Title: Modeling and Optimizing the Operation Policies of Energy Harvesting Devices under Realistic Assumptions
Abstract: Battery-powered devices are subject to limitations in their energy storage. Such a constraint is often simply represented as if the devices had an ``energy bucket'' which can be emptied but not replenished. Energy harvesting capabilities change this rationale by allowing the energy storage part to become more similar to a buffer, which could be studied within a queueing system context. A communication device, e.g., a wireless sensor node, is therefore characterized by an energy queue, which must be coordinated with the data queue it has to transmit. Yet, several assumptions should be included in the representation of the energy queue in order to have a meaningful approach. For example, not only the discharge process of the battery is correlated, as it happens in batches due to transmission of packets from the data queue, but also the arrival instants of energy in the battery cannot be independent. Moreover, a precise evaluation of the exact level of charge in the battery is difficult, as it is both time- and also energy-consuming. This talk will discuss the challenges in properly modeling such a system, showing how oversimplified models can lead to system underutilization and/or inefficiency. Conversely, we will also show how, under proper conditions, even a small amount of information on the battery charge status can be extremely helpful in achieving an almost-optimal performance.

Speaker: Ruggero Carli, *Department of Information Engineering, University of Padova*
Title: The impact of battery degradation on Harvesting-based Wireless Sensor Devices
Abstract: Energy Harvesting Wireless Sensor Devices are increasingly being deployed in today's sensor networks, due to their demonstrated advantages in terms of prolonged lifetime and autonomous operation. However, there are irreversible degradation mechanisms which strongly affect the battery lifetime, calling for intelligent management policies to minimize the impact of these phenomena while guaranteeing a minimum Quality of Service (QoS). In particular these degradation mechanims cause the storage capability of a battery to diminish over time, depending on how the battery is used. Degradation phenomena due to deep discharge are significantly strong for Lithium-Ion (Li-Ion) batteries, which represent the reference case of rechargeable batteries in consumer electronics. Importantly, the deeper the discharge of the battery, the faster the degradation. In this talk we focus on a mathematical characterization of harvesting-based battery-powered sensor devices, stressing the impact of the battery discharge policy on the irreversible degradation of the storage capacity. Firstly, we propose a general stochastic framework, based on Markov chains and suitable for policy optimization, which captures the degradation status of the battery. Secondly, we formulate a policy optimization problem as the maximization of the battery lifetime, subject to a minimum guaranteed QoS in each battery degradation status. We show that this problem can be solved efficiently by a sequential linear programming optimization algorithm over the degradation states of the battery. Interestingly, a numerical evaluation gives evidence of the fact that a lifetime-aware management policy significantly improves the lifetime of the sensor node with respect to a "greedy" operation policy, while guaranteeing the minimum required QoS.