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TUTORIAL WORKSHOP 4:

Title: Smart MEMS and Sensor Systems 1: Cogent sensing and intelligent applications.

Presenters: Dr Elena Gaura and Dr Robert Newman

This tutorial is the first presented by the authors of ***Smart MEMS and Sensor Systems (2006, Imperial College Press)***. The aim of the tutorial is to present the directions of research, development and technological evolution for Electro Mechanical Microsystems, and in particular microsensors. The development of MEMS devices has generally followed a bottom up methodology, reaching now a stage where the capabilities of the devices could be used much more effectively in systems designed from the top down to include them. A holistic view of the requirements of MEMS based systems and the capabilities of the microdevices must be taken if such systems are to deliver the promise that was expected. This tutorial provides the integrative perspective required for workers in all areas of the field, to enable them to appreciate the system level design issues leading to breakthrough sensing applications.

Synopsis: Microsensors are particularly buoyant sector in the industry of man-made complex machines. Traditionally, the main sensor requirements (linearly transferred from the macro sensors industry to the micromachining technologies) were in terms of metrological performance, i.e. the (most often) electrical signal produced by the sensor needed to match relatively accurately the measurand. Such basic sensor functionality is no longer sufficient. The nature of industry demand, and therefore the research goals of the sensing community are presently shifting, away from aiming to design perfect mono-function transducers towards the utilization MEMS based sensors as system components. A new set of requirements for sensing systems and more generally for measurement systems is therefore being generated. Such requirements ultimately imply that components are enhanced with increasingly autonomous functional capabilities. It is here, in the area of data processing and extraction of information, that the author proposes to situate the core of the tutorial, expanding both ways: towards the sensing devices themselves and the MEMS technology which enables their production and towards the application end of the enhanced sensing systems.
The presentation clarifies the strands of development in sensing, some of which are linked with the industry demand for “replacement products” (process/instrumentation sensors designed for high accuracy or cheap/minimum size& weight/minimal electronics sensors for liberal use in appliances and automotive industry for example), whilst other strands are under development either to enable new applications or to support the dreams of future machines (for example large networks of sensors exhibiting collective behaviour and ultimately cogent sensing to enable cogent actuation and eternal vehicles). The evolution process is discussed from a system requirements perspective and supported by an analysis of the components which make a sensor/sensor system, from the simplest such sensor performing straight forward metrology through the self-testing sensor to the fully fledged cogent sensor which can autonomously make informed decisions on the data and perform complex information transformations. The hardware and software requirements of the sensors along this line will be discussed and example implementations will be shown.

The newer pool of potential “big” sensors applications need more than MEMS device technology perfection - the inherent, natural MEMS properties of size and potentially low cost encouraged the liberal usage of these devices in applications (smart skin with thousands of devices embedded, deployable sensor webs, etc) which in turn lead to the need to rely on/add efficient and clever processing of data generated by the sensing device, before such data reaches the outer world. Technology perfection might not, therefore, be, in the new light, the primary aim in developing successful MEMS sensors and particularly sensor systems. Since signal processing is needed anyway by the sensing application, most imperfections could also be, potentially, compensated for in the software/hardware associated/integrated with the sensor, as long as the integration of sensor and processing is resolved.
Attendees will gain the perspective and context of the field in order to make design decisions which optimally utilize current and forthcoming developments in these technologies.

Audience: the tutorial would be of interest to all scientists whose research is related to the following:

- Control engineers aiming to deploy intelligent sensors (individual sensors or networked sensors) for plant and process control.
- MEMS and nanodevices technologists/designers/developers as they need to have an awareness of the design constrains of the systems which will use their devices. Such concerns are likely to influence the specification and detail design of the microdevices and the processes used to fabricate and package them.
- Application developers considering use of networks of intelligent MEMS devices who will need to understand and be able to handle the complexities of design of such systems.
- Circuit designers whose work is in the areas of electronic interfacing of MEMS, calibration, electronic design for performance enhancement, robustness and reliability. The tutorial will be of interest from the viewpoint of system partitioning and hardware design of intelligent nodes, node design for dedicate collaborative problem solving.
- Specialists working at system level in sensor networks. This tutorial will allow them to understand how their specialism relates to the application and device level specialisms.

Content:

The tutorial will consist of three sessions, each of 60 minutes. Sessions will consist of a mixture of presentation and open discussion.

Tutorial content:

1. Oversold dreams and practical potentials
- what was promised by MEMS and what was actually delivered – current sensor markets
- new dream applications (Smart Dust, GEMS, the ageless machines)
- MEMS attributes, technological requirements and integration challenges
    - transducers: mechanical components and electronic interfaces
    - signal conditioning and integration
2. Advanced Microsystems - where the top down meets the bottom up
- enhanced sensor functionality – compensation, calibration, self-test, power management
- smart sensors
- intelligent sensors
- cogent sensors – achieving autonomy
3. Top down system functions in sensor systems
- the data to information translation – what, where and how
- self contained and information delivering systems

TUTORIAL WORKSHOP 5:

Title: Smart MEMS and Sensor Systems 2: Practical aspects of wireless sensor network desingn.

Presenters: Dr Robert Newman and Dr Elena Gaura

This tutorial is the second presented by the authors of Smart MEMS and Sensor Systems (2006, Imperial College Press). This tutorial concentrates on the problems posed in the design of large scale wireless sensor networks. The literature in the field is rich, containing solutions to many problems. Only some of these problems will be faced in practice by implementers of WSN, and not all of the theoretical solutions work. Practical experience of WSN design is required to separate out the real problems and real solutions. The perspective here is strictly practical, and top-down, so as to provide helpful guidance for those embarking on WSN design.

Audience: the tutorial would be of interest to all scientists whose research is related to the following:

- Control engineers aiming to deploy intelligent sensors (individual sensors or networked sensors) for plant and process control.
- MEMS and nanodevices technologists/designers/developers as they need to have an awareness of the design constrains of the systems which will use their devices. Such concerns are likely to influence the specification and detail design of the microdevices and the processes used to fabricate and package them.
- Application developers considering use of networks of intelligent MEMS devices who will need to understand and be able to handle the complexities of design of such systems.
- Circuit designers whose work is in the areas of electronic interfacing of MEMS, calibration, electronic design for performance enhancement, robustness and reliability. The tutorial will be of interest from the viewpoint of system partitioning and hardware design of intelligent nodes, node design for dedicate collaborative problem solving.
- Specialists working at system level in sensor networks. This tutorial will allow them to understand how their specialism relates to the application and device level specialisms.

Synopsis :There are many current proposals for hugely ambitious information gathering systems based on very large networks of autonomous intelligent sensors. These sensors are, individually, of the type that we call ‘cogent’, endowed with the capability of transforming raw data into information. Typically, the proposals envisage thousands or millions of such sensors, collaborating together to make an overall system with highly advanced functionality (although, often, the precise nature of this functionality is not explored). Some prototype sensor networks exist, or are being developed, but at a small scale of perhaps a few hundred sensors, as an upper limit. Many of the theoretical studies that appear in the literature are based on requirements derived from these huge ‘dream applications’, and very few have been proven in practice. Typically, the practical state of the art in practical sensor system design is small, centralised systems, composed of a few tens of nodes, at most. These

systems have demonstrated the usefulness of WSN as a research and monitoring tool, and point the way to the next generation of systems, which will employ hundreds of collaborating nodes in flat, peer-to-peer architectures. The design requirements of systems on this scale is very different from those of the small systems, but are not in all cases well served by the research into huge, dream systems. In order to design these systems, a practical, top-down view is necessary, which will guide the development new science that is needed. The new science is based on experiment and carefully scoped theory, concentrating on real solutions to those problems which need solving in practice to enable hundreds-of-node systems. The tutorial presents an account of these developments in the most important areas of investigation, which are: node hardware design; wireless protocols; operating system support; middleware (system management and information extraction) and design and implementation techniques. In each case, the discussion starts with the established state of the art, epitomised by the MICA/Telos/TinyOS platform, and highlights the development which will be necessary for the next generation of systems.

Content:

The tutorial will consist of three sessions, each consisting of 60 minutes. Sessions will consist of a mixture of presentation and open discussion.

1. A review of potential applications of large networks of sensors will be presented. A critical view will be taken on proposed such applications particularly with respect to the practicality and cost of the system development process. Also discussed will be the skills and expectations of the design communities with respect to such systems and the nature of the interdisciplinary teams working to develop these systems and the ways of promoting communication and clarifying the interfaces within the team.
2. Systems requirements to enable top down system design. Design tools and development environments. Simulation, emulation and prototyping. Query mechanisms and agent systems. The scale of applications systems. Survey of some exemplar applications and the algorithms required to support them.
3. Models of system organisation (centralised vs. flat). System level services: network discovery, localisation, surface construction, synchronisation, fault management. Operating systems support. Specialised vs. general purpose OS. Node hardware. Hardware requirements – the myth and reality. ‘Big motes’ vs ‘little motes’. Economics and resource use. Computational, interface and RF systems hardware.

Dr. Elena Gaura, Reader in Pervasive Computing, Coventry University, Director of Cogent Computing Applied Research Centre. MSc (Hons) Electronics Engineering (1991), Technical University of Cluj, Romania and PhD (2000) in Microsensors, Coventry University. Prior to joining Coventry University, she was with Brunel University, Uxbridge and Rutherford Appleton Laboratory. Has extensive research experience in the design of integrated microsensors and development of intelligent MEMS based systems. Currently she is exploring, at theoretical and experimental level, real life deployment issues in wireless sensor networks, particularly to do with hardware integration, scalability and robustness of field measurements. She has some 90 refereed publications and has organized several symposia on Smart Sensors and Systems at the world largest nanotechnology conference, Nanotech (NSTI). She is a member of several national advisory bodies in the Microsystems field and a member of the EPSRC College of Peers since 2002.

Dr. Robert Newman, currently Head of the Department of Creative Computing at Coventry University. He holds a BSc in Physics from the University of Birmingham (1976) and a PhD in Computer Science from Coventry University (1998). His research career has covered computer aided creativity and, more lately, pervasive computing and sensing systems. He has been a principal researcher in four major EU research programs, and project manager of two of them, working with major

industrial collaborators including Ford, Rolls-Royce PLC, Volkswagen, BMW, BAE Systems and EADS. He has been PI for one EPSRC research project, the research quality of which was assessed as ‘tending to internationally leading’. He has also had an extensive industrial career This has included technical directorships of two companies, with responsibility for design and development of innovative digital electronic products, two of which have received product design awards. He is also a member of the UK DTI Foresight Vehicle Steering Committee for Design and Manufacturing Processes (DMAP) and the Steering Committee of the Wireless sensing Special Interest Group, advisory panel to the DTI.