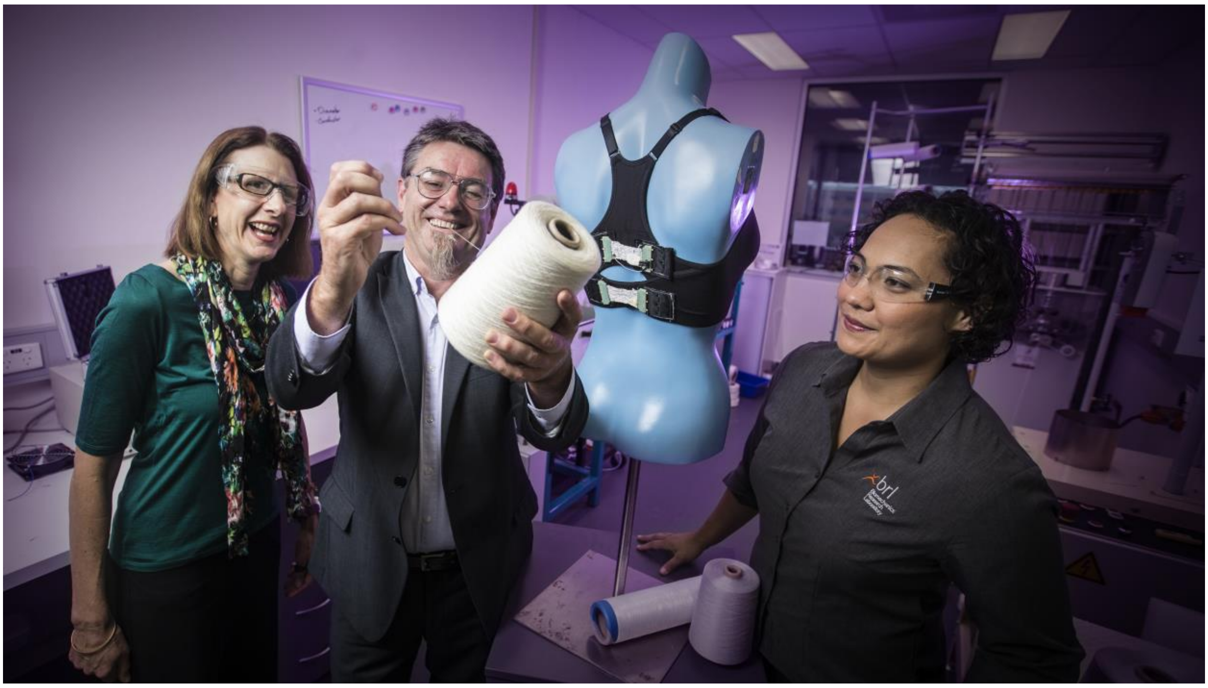

Wearable and Implantable Sensors Workshop

Friday 19 August 2016

LKM Theatre, Innovation Campus, North Wollongong

Program and abstract booklet

ANFF

ARC Centre of Excellence for Electromaterials Science

UNIVERSITY OF WOLLONGONG AUSTRALIA

PROGRAM: Wearable and Implantable Sensors Workshop

Date: Friday 19 August 2016

Venue: Leon Kane-Maguire Theatre, AIIM Facility, Innovation Campus, North Wollongong

10:00am	**Registration**
10:15am	Prof. Joseph Wang (University of California San Diego, USA) Stretchable and Self-Healed Electrochemical Sensors and Biofuel Cells based on Novel Materials for Wearable Applications
10:45am	Parisa Sowti Khiabani (University of New South Wales, Australia) A Paper-Based Sensor for Monitor Sun Exposure
11:15am	Prof. Wenlong Cheng (Monash University, Australia) Nano-enabled Skin-like Wearable Biomedical Sensors
11:45am	***Morning Tea***
12:15pm	Dr Joanne Macdonald (University of the Sunshine Coast, Australia) Text Displays for DNA Biosensors that don't require Batteries or Wires
12:45pm	Prof. Roland De Marco (University of the Sunshine Coast, Australia) Synchrotron Radiation Soft X-ray Spectroscopy Studies of Electrochemical Sensors: Implications for Wearable and Implantable Polymeric Sensors
1:15pm	***Lunch***
2:00pm	Prof. Gursel Alici (University of Wollongong, Australia) Soft Strain Sensors
2:30pm	Dr Rouhollah (Ali) Jalili (University of Wollongong, Australia) Wearable and Implantable 3D Structures Based on 2D Materials
2:45pm	Dr Caiyun Wang (University of Wollongong, Australia) Organic Conductors for Wearable Energy Storage
3:00pm	Dr Javad Foroughi (University of Wollongong, Australia) Smart Fiber to Smart Garment
3:15pm	***Break***
3:30pm	Public Information Session – Wearable Sensing Technologies What we have and where we are going! 10 minute presentations followed by Panel Q&A Facilitator: Natalie Foxon - Gordon Wallace - Joseph Wang - Katina Michael
4:15pm	***Refreshments***

Joseph Wang

Joseph Wang is a Distinguished Professor and Chair of Nanoengineering at University of California San Diego (UCSD) and the Director of the Center for Wearable Sensors (CWS) of the Jacobs School of Engineering. Before joining UCSD in 2008 he held Regents Professor and Manasse Chair positions at NMSU and served as the Director of the Center for Bioelectronics and Biosensors (at the ASU Biodesign Institute). Wang is also a Honorary Professor from 6 different universities and the recipient of two National **American Society Awards** for **Electrochemistry** and **Instrumentation**. He was the recipient of the 1994 **Heyrovsky Memorial Medal** (of the Czech Republic), the 2012 **Breyer Medal** (Royal Australian Chemistry Institute), and the 2013 **Spiers Memorial Medal** (Royal Society of Chemistry), for his major contributions to electrochemistry. He is also a **RSC Fellow** and **AIMBE Fellow**. Wang serves as the founding Chief Editor of the Wiley journal *Electroanalysis* and on the editorial board of 15 other journals. The research interests of Dr. Wang include the development of advanced nanomotors and nanoactuators, nanobioelectronics and electrochemical biosensors, wearable sensor systems, and advanced materials for biofuel cells. He has been the mentor of 25 Ph.D. candidates and 150 research associates. He has authored over 980 research papers, 11 books, 20 patents, and 35 chapters (**H Index 111**). He was ranked as the most cited electrochemist in the world in 1995, the 'Most Cited Researcher in Engineering' during 1995- 2005. Website: http://nanoengineering.ucsd.edu/~joewang/

Stretchable and Self-Healed Electrochemical Sensors and Biofuel Cells based on Novel Materials for Wearable Applications

Joseph Wang

Dept Nanoengieering, UCSD, San Diego, CA 92093, USA

Email: josephwang@ucsd.edu

Printed flexible electrochemical sensors and biofuel cells have received considerable attention in the fields of wearable devices and mobile health. A challenge unique to such wearable electrochemical devices is mechanical resiliency. Mechanical damage-induced device failure is a common occurrence that can limit the operational lifespan of wearable sensors and biofuel cells. Recognizing these issues and challenges, this presentation will describe specially-engineered stretchable inks, based on conducting polymers, carbon-nanotubes and elastomeric binders that can be utilized to realize soft, highly stretchable electrochemical devices [1]. These devices can endure strains as high as 500% with minimal impact on electrochemical properties. To address the critical issue of device failure, we will describe the first example of a self-healing all-printed electrochemical device [2]. The self-healing inks have been carefully formulated to achieve suitable printability, favorable electrochemical behavior, along with a rapid self-healing capacity. The autonomous healing ability is incorporated within the inks by adding healing-agent loaded microcapsules. When the device is damaged, the capsules, along the crack, rupture and release the healing agent, rapidly restoring the electrical conductivity and the electrochemical response. These devices can be easily mated with the human skin for continuous non-invasive monitoring of vital chemicals, such as, electrolytes (sodium, potassium), and metabolites (lactate, alcohol). The remarkable stretchable and self-healing abilities of these devices enable them to endure extreme deformations commonly experienced by the human skin and yet perform without much impact of their sensing ability. Our work thus holds great promise in the wearable healthcare domain wherein defiance towards extreme mechanical deformations is crucial.

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2. "Self-healing Inks for Autonomous Repair of Printable Electrochemical Devices", Bandodkar, A. J. et al. *Adv. Electron. Mater.* 2015, DOI: 10.1002/aelm.201500289.

Acknowledgments

This work was supported by the NIH (Award R21EB019698).

Parisa Sowti Khiabani

Parisa Sowti Khiabani is a Ph.D student within the School of Chemistry at UNSW, Sydney, as well as a member of the Australian Centre for NanoMedicine (ACN). Currently, she is working under the supervision of Scientia Prof. Justin Gooding on the development of wearable UV sensors. So far she has patented a paper-based sensor for monitoring sun exposure and at the moment she is working on a reversible graphene-based UV sensor. Parisa got her BSc in Materials Engineering-Ceramics at University of Tabriz in 2008 and her MSc in 2011 at Materials and Energy Research Center of Iran. During her Masters, she developed metal oxide semiconductor-based gas sensors fabricated by AC electrophoresis deposition and investigated the effects of deposition pattern as well as morphology of the nanoparticles on their sensing properties.

A Paper-Based Sensor for Monitor Sun Exposure

Parisa Sowti Khiabani[1,2], Alexander H. Soeriyadi[1,2],Peter J. Recce[3], J. Justin Gooding*[1,2,4]

[1] School of Chemistry,
[2] Australian Centre for NanoMedicine,
[3] School of Physics,
[4] *ARC Centre of Excellence in Convergent Bio-Nano Science and Technology,*
The University of New South Wales
Sydney 2052 Australia

Email: p.sowtikhiabani@unsw.edu.au
Email: Justin.Gooding@unsw.edu.au

Because of high dosage of UV of sun in Australia, it is so easy to get sun burnt. This can cause skin cancer in long term [1]. On the other hand, it is difficult to judge the appropriate amount of time that is safe under UV sun exposure, as it depends on so many parameters such as the intensity of solar UVR and skin type of the person who is being exposed to solar UV [2]. Therefore, there is a need for some sun exposure sensor which is simple, easy to use and inexpensive. Another important aspect is that it should not be only cheap but also composed of entirely benign materials. This is what we seek to achieve with the technology described herein using entirely materials that are already approved for human use.

For this purpose, the decolouration of common food dyes by TiO_2 when exposed to UV radiation [3-6] is applied to fabricate an easy to fabricate, simple to use, disposable sun exposure sensor that can be tuned to different skin types. In this regard, suspension containing a FDA approved food dye (e.g. brilliant blue FCF), TiO_2 and polyvinylpyrrolidone (PVP) as a binder was printed on paper using ink-jet printing. As a result of decomposition of this food dye by TiO_2 in presence of UV, the film will lose the inherent colour of the dyes. The decolouration can be easily observed by the naked eye. Quantitative analysis of decolouration change was performed using UV-Vis reflectance spectra of films fabricated using ink jet printing. Finally, decolouration of the films was calibrated to match UV exposure time of different skin types, by using different UV neutral density filter with the ability of transmit between 1.5 to 70% of UV radiation from the sources to the photoactive film. The decolouration time could be adjusted most effectively by coating the device using filters although fabrication parameters such as the actual dye, the ratio of dye to TiO_2 or the film thickness also gave some control over the decolouration time.

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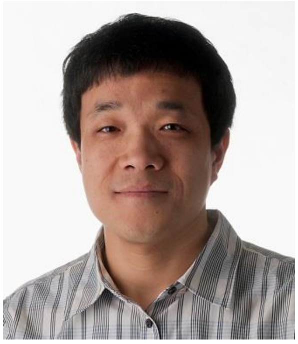
Wenlong Cheng



Wenlong Cheng is a full professor in the Department of Chemical Engineering at Monash University, Australia. He earned his PhD from Chinese Academy of Sciences in 2005 and his BS from Jilin University, China in 1999. He held positions in the Max Planck Institute of Microstructure Physics and the Department of Biological and Environmental Engineering of Cornell University before joining the Monash University in 2010. His research interest lies at the Nano-Bio Interface, particularly addressing plasmonic nanomaterials, DNA nanotechnology, nanoparticle anticancer theranostics and electronic skins. He has published >70 papers including 3 in Nature Nanotech, 1 in Nature Mater and 1 in Nature Comm.

Nano-enabled Skin-like Wearable Biomedical Sensors

Wenlong Cheng[1,2]

[1] Department of Chemical Engineering, Monash University, Clayton VIC 3800, Australia
[2]Melbourne Centre for Nanofabrication, Clayton VIC 3168, Australia

Email: wenlong.cheng@monash.edu

Next generation of electronic devices will be not only flexible but also stretchable, enabling applications impossible to achieve with existing rigid circuit board technologies. This needs new materials and new design principles. In this talk, I will discuss our recent progress in fabrication of electronic skin materials using gold nanowires [1-3], ionic liquid [4] and bio-inspired design [5]. These materials can be used to fabricate high-performance wearable biomedical sensors enabling real-time monitoring artery wrist pulses, body motions and sporting activities in real-time and in-situ. Our sensors can communicate via smartphone, indicating the potential of remote health management anytime anywhere.

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Joanne Macdonald

Dr Macdonald is the co-developer of a DNA computer that plays a game of tic-tac-toe interactively against a human opponent. She also developed an antidote to cocaine, now in Phase III clinical trials for the treatment of cocaine overdose. Dr Macdonald is jointly appointed as Senior lecturer in Molecular Engineering at the University of the Sunshine Coast, Queensland (Australia) and an Assistant Professor in Clinical Medical Sciences at Colombia University in New York City (USA). With a PhD in virology from the University of Queensland (Brisbane, Australia), her current research portfolio includes the development of novel biosensors for the detection of viruses such as Hendra and Ebola, funded by a Queensland Government Smart Futures Fellowship. She recently received funding from the Bill and Melinda Gates foundation to apply her technology for the detection of mosquito transmitted diseases Dengue, Malaria, Chikungunya and Wolbachia.

Text Displays for DNA Biosensors that don't require Batteries or Wires

Joanne Macdonald

Inflammation and Healing Research Cluster & Genecology Research Centre,
University of the Sunshine Coast, Qld. Australia

Email: jmacdon1@usc.edu.au

We have developed novel biosensing devices operated by DNA-based computing elements that display results in human-readable text, but do not require batteries or wires because molecules themselves power the device. The text displays can operate in solution phase using a fluorescent output, or be embedded onto a lateral flow device with colorimetric output. The adaptation of molecules into computational components enables unprecedented control over molecular operations and provides a novel interface to autonomously interpret molecular signals without requiring advanced laboratory instruments and sophisticated operations. These devices demonstrate the power of molecular engineering for the advancement of new technology frontiers.

Roland De Marco

Professor Roland De Marco received his PhD in Chemistry/Physics from La Trobe University in 1992. He was awarded the 2008 RACI Lloyd Smythe Medal for excellence in research in Analytical Chemistry. Roland De Marco is also an internationally recognized leader in the field of electrochemical sensors. His major strength is in the field of electrochemical surface and interface analysis, and he has a strong track record of using state-of-the-art electrochemical and surface analytical techniques in the micro-and nano-characterization of electrochemical devices. He has been recognized for his national and international leadership in neutron and synchrotron science through his current appointments on the Australian Institute of Nuclear Science and Engineering (AINSE) Materials, Structures and Dynamics Specialist Committee as well as the Chair of the Program Advisory Committee of the Soft X-ray beamline at The Australian Synchrotron. He presently serves as the Deputy Vice-Chancellor (Research and Innovation) at the University of the Sunshine Coast.

Synchrotron Radiation Soft X-ray Spectroscopy Studies of Electrochemical Sensors: Implications for Wearable and Implantable Polymeric Sensors

Roland De Marco

Faculty of Science, Health, Engineering and Education, University of the Sunshine Coast, 90 Sippy Downs Drive, Sippy Downs, Queensland, Australia 4556

Email: rdemarc1@usc.edu.au

Surface analysis by synchrotron radiation-X-ray photoelectron spectroscopy (SR-XPS) and near edge X-ray absorption fine structure (NEXAFS) provides a high power for structure elucidation that is invaluable in a probing of the mechanistic chemistry of electrochemical devices. With the electroanalysis of difficult bioanalytes in complex media like sweat and blood using wearable and implantable sensors, this interfacial chemistry, especially the fouling of sensor surfaces by sample matrix components, is critical to the reliability and robustness of sensor devices. In this presentations, two clear demonstrations of the advantages of SR-XPS and NEXAFS in electrochemical sensing will be presented [1-2]. Recent SR-XPS, NEXAFS and valence band (VB) spectroscopy data on poly(3-octyl thiophene) [POT]/poly(vinyl chloride) [PVC], redox molecule doped PVC membrane and multiwalled carbon nanotube (MWCNT)/PVC chemical sensors will be presented [3-4], showing that key mechanistic information about technologically important electrochemical systems may be elucidated using these cutting edge methodologies.

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Gursel Alici

Gursel Alici received the Ph.D. degree in robotics from the Department of Engineering Science, Oxford University, Oxford, U.K., in 1994. He is currently a Senior Professor at the University of Wollongong, Wollongong, Australia, where he is the Head of the School of Mechanical, Materials, Mechatronic (and Biomedical Engineering) since 20111. His research interests are soft robotics, system dynamics and control, robotic drug delivery systems, novel actuation concepts for biomechatronic applications, robotic mechanisms and manipulation systems, soft and smart actuators and sensors, and medical robotics. He has generated more than 300 refereed publications, and delivered numerous invited seminars and keynote talks on his areas of research. Dr. Alici was a Technical Editor of the IEEE/ASME Transactions on Mechatronics during 2008–2012. He is a Technical Editor of the IEEE Access, the first IEEE open access journal with interdisciplinary scope. He is a Member of the Mechatronics National Panel formed by the Institution of Engineers, Australia. He has served on the international program committee of numerous IEEE/ASME International Conferences on Robotics and Mechatronics. He was the General Chair of the 2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics held in Wollongong, Australia. He is the leader of Soft Robotics for Prosthetic Devices theme of the ARC Center of Excellence for Electromaterials Science. He received the Outstanding Contributions to Teaching and Learning Award in 2010 and the 2013 Vice-Chancellor's Interdisciplinary Research Excellence Award from the University of Wollongong. He has held visiting professorship positions at Swiss Federal Institute of Technology, Lausanne (EPFL), City University of Hong Kong, and University of Science and Technology of China (USTC).

Soft Strain Sensors

Gursel Alici[1,2]

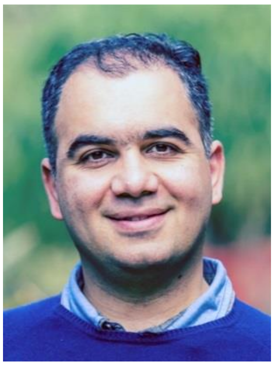
[1]School of Mechanical, Materials and Mechatronic Engineering,
[2]ARC Center of Excellence for Electromaterials Science
University of Wollongong, 2522 NSW, Australia

Email: gursel@uow.edu.au

Since its emergence, the field of soft robotics continues to draw a significant interest from researchers. As part of this new area, significant efforts have been dedicated to designing and fabricating flexible and stretchable electronic components toward realising soft and human friendly devices for use in various soft robotics applications. One group of such devices are elastomer based sensors, which, in contrast to their rigid counterparts, can accommodate large but reversible deformations without losing functionality or applying additional mechanical constraints on the main system into which they are incorporated. Soft sensors, the resistive or capacitive properties of which change as the strain or curvature applied to them are varied, have been of particular interest. The change in these electrical properties basically occurs due to the change in the device geometry in response to the applied mechanical stimulus. Our ultimate aim is to use these strain sensors to measure joint and tip positions of the fingers of a soft and underactuated prosthetic hand (i.e. ACES prosthetic hand) without using externally placed sensors for feedback information of the actual positions. To that end, two strategies can be executed; mounting a single larger sensor on the entire finger, which is usually the preferred method in existing studies with flex (also known as bend sensors) or stretchable sensors, and placing one smaller sensor on each joint and extrapolating the tip position as well as individual joint positions from the acquired data.

In this talk, after briefly describing the ultimate aim of the ACES theme of "Soft Robotics for Prosthetic Devices", we will present our recent progress on soft strain sensors, including their fabrication and response characterization, made of silicone rubber substrates engraved with microchannels, which are filled with conductive liquids.

Rouhollah Jalili



Dr Rouhollah Jalili is an engineer and a material chemist holding a graphene development fellowship from the Australian Research Council Centre of Excellence for Electromaterials Science. He obtained his BSc and MSc in Engineering from the Isfahan University of Technology, Iran. Thereafter, he received his PhD degree from the Intelligent Polymer Research Institute at the University of Wollongong in 2013. His research breakthrough was the demonstration of the key role of graphene oxide liquid crystals in the fabrication of multifunctional graphene-based architecture using industrially scalable techniques such as wet-spinning, electrospinning, printing (ink-jet and extrusion) and coatings. He has also developed solvophobic soft self-assembly of graphene oxide sheets in a wide range of organic solvents, which provides a platform for tailor-making self-assembled and self-oriented graphene-based composites with large-area molecular ordering. His current research focus includes the development and fabrication of graphene and other two dimensional materials for application in flexible electronic and bionic devices.

Wearable and Implantable 3D Structures Based on 2D Materials

Rouhollah Jalili

ARC Centre for Electromaterials Science, Intelligent Polymer Research Institute,
AIIM Facility, Innovation Campus, University of Wollongong,
Wollongong, NSW 2522, Australia

Email: rjalili@uow.edu.au

The prospect of developing multifunctional flexible three-dimensional (3D) architectures based on integrative chemistry for wearable, implantable, lightweight, foldable, yet robust, electronic components that can turn the many promises of 2D materials-based devices including graphene into reality is an exciting direction that has yet to be explored. However, this will only be achieved if scalable, processable forms of them are developed along with ways to fabricate these forms into material structures and devices. Here, the chemistry suitable for the development of aqueous and organic solvent 2D materials dispersions is presented. Also, the fundamental insights and challenges that can provide the basis for the development of fabrication protocols for these two-dimensional soft materials, in a diverse array of processing techniques for making devices for production of wearable and implantable electrodes is demonstrated.

Caiyun Wang

Dr. Caiyun Wang is currently a senior research fellow in Intelligent Polymer Research Institute and ARC Centre of Excellence for Electromaterials Science at University of Wollongong. Her current research interests focus on the fabrication of flexible/stretchable electrodes and their applications in flexible/wearable batteries or implantable bioelectric batteries. The highlights of the work include publications in *Advanced Materials, Advanced Energy Materials, Advanced Functional Materials and Chemistry of Materials* etc. She has published 1 book chapter and 55 research papers, which attracts over 1,318 citations with an h-index of 19 to date. She is an Editorial Board Member of *Scientific Reports*.

Organic Conductors for Wearable Energy Storage

Caiyun Wang, Kewei Shu, Chen Zhao, Yu Ge, Gordon G. Wallace

Intelligent Polymer Research Institute, ARC Centre of Excellence for Electromaterials Science, University of Wollongong, Wollongong, New South Wales 2522, Australia

Email: caiyun@uow.edu.au

Lightweight and wearable energy storage devices are urgently demanded to drive the flexible and wearable electronic devices such as sensors for biomedical and healthcare applications. Organic conductors (i.e. conducting polymers, carbon-based materials) are an ideal candidate for use in wearable energy storage devices. They can offer the advantages of high charge storage, high conductivity, easy processability and environmental benign.

Their properties can be tuned at the molecular level. They can be fabricated into different forms for use. They can be used as electrodes alone. Also they can easily form composites between different types of organic conductors via different structural model. The synergistic effect between the components leads to the enhanced electrochemical properties.

Javad Foroughi

Javad Foroughi received the B.S. and MS degree in textile engineering from Isfahan University of Technology, Isfahan, Iran, in 1997 and the PhD degree in material engineering from University of Wollongong, Australia in 2009. He is currently working as ARC senior research fellow at Intelligent Polymer Research Institute, University of Wollongong, Australia. His research interests include Nanomaterials, Electromechanical actuators ("artificial muscles") using inherently conducting polymers and / or carbon Nanotube, bionics and novel fibres spinning and the use of these in the development of smart materials for biomedical applications and electronic-textile.

Smart Fiber to Smart Garment

Javad Foroughi

University of Wollongong, Australia

Email: foroughi@uow.edu.au

Today's 'wearable technologies' mostly consist of electronic devices like wrist bands for fitness and health monitoring. However, the fastest growth sector in the coming years is predicted to be *smart garments* where the electronics are incorporated into the fabrics. A conductive highly stretchable 3D CNT knitted fabric has been produced. The mechanical and electrical properties of the knitted CNT/spandex fabric are very stable over 10000 cycles of strain and/or bending. In addition the electrical resistivity of the knitted CNT/spandex structure is strain dependent providing a stable wearable sensor to monitor human movement. The effect of knitting parameters on strain gauge performance and electromechanical actuation has been explored. 3D CNT knitted fabricated structure as a flexible highly stretchable conductive material has a great potential to be used as strain gauge and/or actuator in smart textiles.

Gordon G. Wallace

FAA, FTSE, FIOP, FRACI

Professor Gordon Wallace is involved in the design and discovery of new materials for use in Energy and Health. In the Health area this involves using new materials to develop biocommunications from the molecular to skeletal domains in order to improve human performance via medical Bionics. In the Energy area this involves use of new materials to transform and to store energy, including novel wearable and implantable energy systems for the use in Medical Bionics. He is committed to the translation of fundamental discoveries into practical applications. He is a passionate communicator, dedicated to explaining scientific advances to all in the community from the lay person to the specialist. Gordon was recently appointed to the Prime Ministers Knowledge Nation 100. Gordon is a Fellow of the Australian Academy of Science, Australian Academy of Technological Sciences and Engineering (ATSE), Institute of Physics, and Royal Australian Chemical Institute (RACI). He has published more than 800 refereed publications; a monograph (3rd Edition published in 2009) on Conductive Electroactive Polymers: Intelligent Polymer Systems and co-authored a monograph on Organic Bionics (published 2012). He has recently co-authored an eBook on 3D BioPrinting He led the presentation of a MOOC on 3D Bioprinting on the FutureLearn platform. Gordon has supervised almost 100 PhD students to completion and has mentored more than 50 research fellows. Gordon completed his undergraduate (1979) and PhD (1983) degrees at Deakin University and was awarded a DSc from Deakin University in 2000. He was appointed as a Professor at the University of Wollongong in 1990. He was awarded an ARC Professorial Fellowship in 2002; an ARC Federation Fellowship in 2006 and ARC Laureate Fellowship in 2011.

Move, Grind, Sweat! We are “watching” every moment

Gordon G. Wallace

ARC Centre of Excellence for Electromaterials Science, Intelligent Polymer Research Institute, AIIM Facility, Innovation Campus, University of Wollongong, Wollongong, NSW 2522, Australia

Email: gwallace@uow.edu.au

Advances in materials science, additive fabrication and information technology have converged to allow us to prototype wearable devices containing highly functional materials. This has had a dramatic impact on our ability to create wearable sensing and actuating technologies.

Here we will illustrate advances and remaining challenges through a number of examples including, the knee sleeve [1] and the SWEATCH [2]. The knee sleeve is a wearable device that monitors knee flexion in real time providing either direct feedback for training and rehabilitation purposes and/or data logging for training, rehabilitation or clinical diagnostics. The SWEATCH is a wearable sweat monitor that allows for real time analyses of electrolyte composition and concentration. It is initially targeted for use in sports training although there are potential applications in medical diagnostics.

Another example is the bionic bra wherein the goal is the integration of sensing technologies with artificial muscles. The sensors alert the wearable muscle technology to adverse anatomical movement and they subsequently provide restrictions.

While 3D printing has enabled advances in prototype development in each of these areas challenges around manufacturing and seamless interaction remain.

We still have some way to go.

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Katina Michael

Katina Michael is a professor in the School of Computing and Information Technology in the Faculty of Engineering and Information Sciences at the University of Wollongong. Katina has been the editor-in-chief of *IEEE Technology & Society Magazine* since 2012, a Senior Editor of *IEEE Consumer Electronics Magazine*, and more recently an associate editor of *Ethics and Practices of Biomedical Engineering*. Katina also has served as a board member of the Australian Privacy Foundation since 2008, and has been a volunteer for the Consumer Federation of Australia since 2010. Her main research area is in the social implications of emerging technologies with a specific interest in implantables technologies for medical and non-medical applications in relation to socioethics and culture, privacy and security, risk and trust, law and regulation.

Repurposing Medical Implants from Therapeutics to Augmentation: the money is where the market is

Katina Michael

Faculty of Engineering and Information Sciences, University of Wollongong, Wollongong, NSW 2522, Australia

Email: katina@uow.edu.au

For over 55 years we have witnessed the development of heart pacemakers [1]. Incremental innovations have meant that this product technology has advanced as the industry surrounding it has created better componentry and connectivity. Once we considered the application of implantables for those who only desperately required it for life sustaining purposes, often as a last resort. Today, however, the emphasis is shifting from a restorative need to replace a human function that has been lost or degraded, to one that is preventative and takes on a guise of human augmentation. In all we are witnessing the rise of persuasive computing- that which not only acts as a tool or media, but also as a mechanism to change attitudes and behaviours of social actors through direct interaction or through a mediating role. For example, companies like Medtronics wish to implant sensors in everyone [2]. Their belief is to take the medical technology to the whole market, relying on a medical platform for non-medical control, care and convenience applications. The question is not whether we can achieve this technically, but whether answers to questions about ethics, culture and society can keep pace with rapid scientific advancements [3].

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