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Introduction

Welcome to the Institute of Design, Robotics and Optimisation (iDRO). We perform research and provide services to analyse and design complex systems that involve technology, people and services.

The three primary areas of our activity are:

**Bio-Mechatronic & Robotics**
Theoretical and experimental research towards mechatronic and robotic systems that assist people to achieve their goals, a particular focus of which is healthcare technologies.

**Design Sciences**
Design Sciences are the theoretical frameworks that underpin processes of designing. They include design theory and methodology, traditional engineering sciences and an emerging body of design science that draws on the social, biological and physical sciences to underpin human-centred designing, meeting people's physical, emotional and social needs.

**Energy Efficient Automotive and Aerospace Structures**
Theoretical and experimental research into lightweight materials, structures and optimisation techniques. The outcomes of this research is applied to automotive and aerospace structures to create a next generation of energy efficient vehicles; reducing vehicle mass whilst maintaining performance and adhering to safety requirements.

We deliver our research through partnerships with industry, multi-disciplinary collaborations, and end user engagement. The institute consists of 18 internationally regarded academic staff and in total over 50 researchers and technical staff, with expertise in design systems, solid mechanics, dynamics and control, optimisation and aerospace and structural engineering.

iDRO researchers have access to excellent facilities and equipment within three laboratory areas: Control & Dynamics, Design, Strengths of Materials. We have access to dedicated equipment including:

- Experimental facilities for characterising the dynamic behaviour of materials and systems including small-scale and full-size brake dynamometers
- The University’s Charterhouse Rehabilitation Technologies laboratory (supported through School of Mechanical Engineering and Medicine) including motion tracking system to support development of novel restorative rehabilitation technologies;
- Purpose-built Design Systems Laboratory including soft metrology facilities and design observation suite for audio-visual recordings to study ways in which people interact with technology and new products.

This brochure presents our current research activity. We would be delighted to discuss any technical issues that fit within our expertise. We are very experienced at obtaining external funding to work in partnership with industry and would be delighted to embark on new collaborations with academics.

Please contact individual institute members if we can be of help, or alternatively if you are unable to find what you are looking for, please contact me.

Dr Rob Richardson, Director of the Institute of Design, Robotics and Optimisation.

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www.engineering.leeds.ac.uk/idro
Bio-Mechatronics and Robotics

In 2013 the University of Leeds was awarded major funding from the Engineering and Physical Research Council (EPSRC) to form a £4.3M National Facility for Innovative Robotics Systems directed by members of iDRO. We are researching into Bio-Mechatronic and Robotic solutions in new and challenging scenarios. We have developed surgical devices to radically enhance surgical possibilities while minimising patient trauma, created medical rehabilitation devices that are under trial in Hospitals across the UK, developed robotic systems to explore the ancient pyramids of Giza, are researching into a new understanding of how humans grasp and manipulate objects, and have developed new concepts for lower limb prosthetics. We use an applied multi-disciplinary approach that pushes the boundaries of robotic technology and impacts upon wider society through specific application.
We are developing robotic systems with the capability of exploring natural and artificial environments that cannot be safely or easily accessed by humans.

**Overview**

There are many scenarios where exploration robotics have the potential to have significant impact:

- Improved manufacture of complex engineering systems (Aircraft, nuclear power stations, ships) through inspection and monitoring of inaccessible locations.
- Improved surgical outcomes through developing technologies to monitor and measure patients internally during surgery.
- To discover new knowledge of archaeological sites, whilst preventing damage.
- Saving lives through quick identification of victims trapped within buildings following a natural disaster.

Some locations are difficult to access due to their physical location or size, while others maybe hazardous to human health due to heat, air pressure, toxic chemicals, nuclear radiation or human action such as in war zones.

Exploration robots are often small requiring miniature mechanisms, actuators, sensors and electronics. They need the capability of operating at a distance from direct human intervention for long periods of time in the presence of incomplete sensor information and delays in communication.

Current research projects cover a broad range of applications, below are some example projects:

**The Djedi robotic archaeological expedition**

Over the last 5 years we have developed state of the art robotic systems to explore the Great Pyramid of Giza, Egypt (figure 1). Our robots have the capability of climbing 70m within a confined space of 20cm by 20cm and deploying snake cameras and drills.

On our most recent mission we successfully navigated the southern airshafts, deployed a snake camera and discovered writing that has been hidden for thousands of years. (Dr Richardson, R.C.Richardson@leeds.ac.uk)

**Biomimetically inspired search and rescue robotics**

Despite significant advances in technology and science, natural disasters remain a very real threat to human populations around the world. Tsunamis, tornadoes, floods and earthquakes occur all too frequently, and can lead to loss of life on an epic scale. Ironically, the technological advancement of our society can, in some cases, amplify the severity of consequences many-fold. With the density of population found in today’s cities, in which people live and work in huge, multi-storey buildings, urban disasters can be the most devastating. In the aftermath of a disaster, the task of finding survivors is of utmost importance. One particularly challenging scenario is a “pancake collapse”, in which a multi-storey building (typically reinforced concrete), collapses downwards. While most of the building contents are immediately crushed beyond recognition, people sometimes survive in small voids that form between the layers.

The challenging task of finding survivors among the rubble of collapsed or damaged buildings is one where mobile robots could make an extremely valuable contribution. The problem, of course, is that this sort of environment is extremely challenging from a locomotion point of view. Traditional wheeled or tracked robots have little chance of successfully navigating through the complex and irregular spaces between debris so alternative strategies must be identified. To this end, it can be quite helpful to look to the natural world for inspiration. Indeed there are all sorts of animals that would be quite at home in this sort of environment. Bio-inspired robotics for search and rescue in collapsed buildings is an active area of research within iDRO.

An EPSRC funded project developed a robotic system, biologically inspired by the European Mole, to provide search and rescue robots with unique capabilities. The developed system has the capability to burrow through loose debris to gain access deep within damaged buildings to search for survivors.

The other search and rescue robot under development in iDRO falls under the umbrella of serpentine (snake-like) robots, although the animal it draws its inspiration from is actually a worm called C. elegans (that also crawls with sinusoidal undulations). Although significant progress has been made in the development of robots with serpentine properties, one of the main outstanding challenges relates to the adaptation of the locomotion waveform to external constraints (obstacles). Our WormBot uses a novel, computationally efficient distributed control system based on the C. elegans neural network to generate robust undulations. More importantly, the robot exhibits a remarkable ability to adapt its waveform to accommodate external constraints. What is particularly interesting is that this adaptation occurs without any explicit mapping or planning. Instead, obstacles in the environment are overcome based purely on proprioceptive feedback representing the current body shape. The robot does not even need to know the obstacles are there! (Dr Jordan Boyle, J.H.Boyle@leeds.ac.uk)
UK MoD Grand Challenge
We participated in the UK’s grand challenge to develop autonomous vehicles to survey an area for improvised explosive devices and snipers. We developed (in collaboration with the University of Manchester, BAE systems and MBNA) autonomous air and ground vehicles (figure 2). The novel patented design of the air vehicle was a configuration from 6 propellers in a Hex-rotor configuration. We developed a ground vehicle based around a six motor drive system to enable independent body orientation and locomotion. (Dr Richardson, R.C.Richardson@leeds.ac.uk)

Perch and stare for unmanned air vehicles
We have developed control algorithms to enable unmanned air vehicles to perform perch and stare manoeuvres (figure 3). The perch and stare approach involves a UAV performing a point landing on a building or wall to observe for an extended period of time and then re-launch. (Dr Richardson, R.C.Richardson@leeds.ac.uk)

Selected Publications:

Industrial Collaborators
- Dassault Systemes, BAE systems, MBDA, Soutek UK,
- Staff involved: Dr Rob Richardson, Dr Abbas Dehghani, Dr Jordan Boyle

Figure 2: The 'weed' robot deployed in the UK MOD grand challenge

Figure 3: A render of a UAV with a leg for perchning
Rehabilitation Technologies and Prosthetics

“Advanced Technologies should primarily be directed towards those who need them most, so as to eliminate any discrimination in the society and provide an opportunity for inclusion of all.”

Our research in this area involves inspiration from biological systems to design and develop smart systems and devices for medical applications and to assist and support living. The research covers distributed smart sensors, actuators, machine intelligence and control, design and control, including kinematics and dynamics.

The human body combines intelligence with sophisticated sensors and actuators. Thus, being a fascinating example of natural biomechatronics, this makes it the most logical source of inspiration and study when designing and developing similar intelligent systems. Living creatures, in general, with unique characteristics provide great sources for learning and inspiration.

Overview
The focus of research has been on the following areas:
• Locomotion (Human locomotion, locomotion aspect of robotic systems)
• Intelligent control (Artificial Neural Network, Fuzzy Logic, Adaptive Control)
• Smart Artificial limbs and other medical devices
• Activity monitoring systems
• Robotic Rehabilitation devices
• The study of Prehension and inclusive design.

Current Novel Research Projects
Smart bioLeg - A key feature of human locomotion is its adaptability and robustness to changing situations. For the cases of standing, walking, turning, ascending and descending steps/ramps, and sitting, the lower limb segments and body centre of mass require a sophisticated intelligent sensory-motor-control system to ensure adaptability. In close collaboration with our industrial partner research has been carried out in three key areas for the design and development of advanced lower limb prosthetic devices, including:
• Improving lower limb prosthetic devices through a modelling and simulating approach
• A mechatronic system for the optimum alignment of lower limb prosthesis
• A novel biomechatronic above knee prosthetic device based on dynamic coupling effect between the body of the amputee and the prosthetics.

A large EPSRC funded project is currently being carried out in collaboration with our industrial partner to design and develop the next generation of artificial lower limb: A Smart Biomimetic, Self Tuning, Fully Adaptable Lower Limb Prosthetics with Energy Recovery (Smart BioLeg). (Dr Abbas Dehghani, A.A.Dehghani-Sanj@leeds.ac.uk)

Smart bioHand - One of the import areas in upper limb prosthetic systems is the control of the device in relation to user intent. This is achieved through the use of myoelectric signal, also called a motor action potential, which is an electrical impulse that produces contraction of muscle fibres in the body. In order to be able to control the prosthetic device the signal should be analysed and user intent extracted through pattern recognition. Research has been carried out in this area with focus on designing and developing an intelligent prosthetic hand using hybrid actuation and myoelectric control. (Dr Abbas Dehghani, A.A.Dehghani-Sanj@leeds.ac.uk)

Smart bandage and activity monitoring – Pressure gradient in compression bandages play an important role in the treatment of venous leg ulcer. Research has also been carried out on the pressure mapping of medical compression bandages used for venous leg ulcer treatment (also relevant to prosthetic stump pressure mapping) with the aim towards smart bandages. Work has also been conducted on the activity monitoring in relation to leg ulceration. (Dr Abbas Dehghani, A.A.Dehghani-Sanj@leeds.ac.uk)

Research is currently being carried out in this area to design and develop smart bandages for A&E applications. This work is funded by Technology Strategy Board (TSB) and our industrial partner.

Prehension and Inclusive Design
We are researching into prehension (the act of grasping and manipulating objects) and how this influences the ability of individuals to participate in society. Prehension is one of the most valuable capabilities a human being can possess, and is intrinsic to many activities required to maintain independence and quality of life. Whether an object can be gripped and manipulated as intended depends on both the object’s physical properties, and the capabilities of the person using it. Where an individual’s capabilities do not fit with those assumed by those who design the environment and products we need in daily life, the consequence is design exclusion, in which individuals are effectively “designed out” of performing a given activity.

Our approach explores three routes for addressing this: therapeutic interventions, intended to aid skills acquisition and improve individual capabilities; the design of assistive technology to supplement an individual’s capabilities, and inclusive design – rethinking the way we design all products to minimise design exclusion. To this end, we undertake three core activities:
• Studying the mechanics of prehension to identify how object properties (such as size, shape and surface) and individuals’ capabilities (such as hand size, grip strength, co-ordination) affect the ability to manipulate objects in the ways required by activities of daily living.
• Developing therapeutic and assistive technologies to improve individuals’ prehension, with a particular emphasis on play-based therapy for children;
• Developing decision support tools to aid inclusive design; by helping designers to predict the capability demands their concepts place on individuals, we aim to raise awareness of where they are causing design exclusion, and what they can do to reduce this. This also has useful applications for the ergonomic assessment of products in general.

This means working closely with psychologists, physiotherapists, clinicians and sociologists to develop workable technologies, and ensure that the systems developed are driven by the needs of end users rather than by technological considerations. (Dr Ray Holt, R.J.Holt@leeds.ac.uk)
Intelligent Pneumatic Arm Movement (iPAM)
One of our main focuses is on the development of devices to help restore motor function in those who suffer brain injury. Here, a project that has received particular interest is the development of an intelligent robotic system to deliver physiotherapy (figure 4). Developed in collaboration with the Academic Department of Rehabilitation Medicine, iPAM, is a dual robotic system that is designed to deliver programmes of physical therapy to adults who have suffered stroke, and is currently undergoing clinical trials. (Prof Martin Levesley, M.C.Levesley@leeds.ac.uk)

Active Gaming Device for Children with Cerebral Palsy
Cerebral palsy (CP) is the commonest cause of severe physical disability in childhood affecting 1 in 400 children. Difficulties with arm movement are common in children with CP. A low cost computer home based rehabilitation exercise system (HB-RES) based on joystick/video games has been developed for use with young children with CP. This allows the children to practice arm movements in an enjoyable game setting where the resulting exercise has potential for therapeutic benefit. A second grant has been awarded to develop the work further. (Prof Martin Levesley, M.C.Levesley@leeds.ac.uk)

Selected Publications:

Industrial Collaborators:
• Chas A Blatchford, the largest UK manufacturer of lower limb prosthetics
• RSL Steeper, the leading upper limb prosthetics manufacturer in the UK
• BAE systems
• National Instruments

Staff Involved:
Dr Peter Culmer, Dr Abbas Dehghani, Dr Ray Holt, Prof Martin Levesley, Dr Rob Richardson, Dr Andrew Jackson.
“Bringing cutting-edge engineering to the cutting-edge of surgery”

Background

- **Modern Surgery:** Surgery and technological innovation go hand in hand. Recently the introduction of minimally invasive techniques and instrumentation has brought a revolution in surgical practice; reducing patient trauma, improving cosmesis and speeding recovery.
- **Clinical Challenges:** Despite these advances, many challenges remain. Modern healthcare systems face increasing pressures to improve efficiency and clinical outcomes, while surgeons must train and perform more complex MIS operations with limited instrumentation.

Our Research

“Developing and applying engineering expertise with clinical input to bring real improvements in surgery.”

**Engineering Advances: Our Core Skills**

Our research in Surgical Technologies is based on developing and translating engineering expertise to address clinical needs. At Leeds, our strengths cover basic and applied areas:

- **Bio-tribology** (novel and bio-inspired materials and surfaces)
- **Mechatronics** (mobile robotic devices and locomotion systems)
- **Control systems** (control of surgical systems, human-robot interaction and haptics)
- **Sensor systems** (electro-chemical and tactile sensing / modelling)
- **Materials** (ferrous nanoparticles, tissue mechanics modelling).

**Clinical Themes: Applying the Skills to Surgical Challenges**

**Improved Instrumentation**

We are working actively with surgeons and the surgical device industry to develop improved systems for MIS.

- **Optimising surgical graspers:** Continued research is working to characterise and optimise the performance of surgical graspers used routinely in MIS to manipulate tissue. This includes quantifying their ability to grip tissue (needing precise measurement of tissue mechanics), and combined this with clinical measures (to assess resultant tissue damage). This research will enable improved instrumentation to minimise tissue damage and improve grip function.

- **Novel Sensing Systems:** We are pioneering work in electro-chemical sensing for tissue assessment, in work funded by Cancer Research UK. The ultimate goal is to provide new sensing modalities which can discriminate between diseased (cancerous) and healthy tissues, both intra-operatively and post-operatively, to aid the surgeon in obtaining the best clinical outcome for the patient. (Dr Pete Culmer, p.r.culmer@leeds.ac.uk).

**Enabling New Approaches**

Innovative engineering offers exciting opportunities for entirely new surgical approaches, previously considered ‘science fiction’, which could completely change the face of future surgery.

- **Intra-abdominal Robot:** Research supported by the UK NIHR ‘New and Emerging Applications of Technology’ Programme, developed a meso-scale intra-abdominal robot for exploratory use in MIS. The robotic system employs bioadhesive polymers and miniature piezo-electric actuators for locomotion on the surface of the peritoneum. The project was highly successful and received wide publicity across the media.

- **CODIR:** We’re collaborating on a large EU funded project with the Institute for Medical Science and Technology, University of Dundee to develop a robotic system for next-generation low-trauma colonoscopy. The work is highly multidisciplinary and our team of PhD researchers have backgrounds in both engineering and surgery. Our work centres on understanding the highly challenging and variable environment of the colon and developing novel robotic solutions for locomotion in this space (figure 5).

- **Ferrofluids for Tissue Manipulation:** This research uses ferrofluids to magnetise tissues as a means of aiding intra-abdominal tissue retraction (figure 6). These fluids have the attraction of being easy to apply in the operative setting, being biocompatible and readily absorbed into the systemic circulation with a good safety profile, and offer a means of atraumatic, reversible retraction (Dr Pete Culmer, p.r.culmer@leeds.ac.uk).
Award-winning Student Projects
We link our Surgical Technologies research to teaching – giving undergraduate students challenging, exciting and relevant projects to tackle. A project in 2011 produced a haptic system for palpation of a virtual liver in MIS, with the aim of helping to identify tumours in healthy tissue. It went on to win awards (UK National Instruments Student Design Award) and media attention (e.g. BBC TV News, BBC Radio 4). This was followed in 2013 by a project which produced a prototype mobile robot for gastro-intestinal surgery – coming runner-up in the Global Student Design Award run by National Instruments.

A Multidisciplinary Centre for Surgical Technologies
Our research in Surgical Technologies is underpinned by close collaborations between researchers in the School of Mechanical Engineering, Surgical Sciences and the Institute of Psychological Sciences. This is complemented with close links to the NHS Leeds Teaching Hospitals Trust – helping us combine clinical knowledge with our research expertise and state-of-the-art facilities.

The School of Mechanical engineering has world-class laboratory facilities in tribology, surface and materials engineering. The new EPSRC funded robotics manufacturing facility provides world-class equipment for prototyping new surgical instrumentation and robotics.

Clinical facilities in the Academic Unit of Surgery include labs for tissue analysis and histology, laparoscopic training facilities and access to state-of-the-art da Vinci surgical robot systems.

The National Institute for Health Research Colorectal Therapies ‘Healthcare Technology Co-operative’ (NIHR Colorectal Therapies HTC) is based at Leeds Teaching Hospitals NHS Trust. The Surgical Technologies group are members of this initiative, together with partners from the NHS, academia, industry, funders, and patients and public – aiming to generate new ideas and interventions that target areas of unmet clinical need.

Leeds Oncological Engineering Conference
Surgery remains the only curative intervention available with many forms of cancer. To address the challenges of improving surgical technologies in this field we have brought together engineers, clinicians, scientists and industry representatives to develop the concept of “Oncological Engineering”. Initial research around this concept demonstrated that there is significant potential for advances in cancer surgery to mirror those already developed in radiotherapy and pharmacology.

The Leeds Oncological Engineering Conferences (2011, 2012, 2013) have attracted leading figures in academia and industry from around the world, facilitating multidisciplinary collaboration and catalysing future research in this area.
Design Sciences

Design Sciences are the theoretical frameworks that underpin the process of designing. They include design theory and methodology, traditional engineering sciences and an emerging body of design science that draws on the social, biological and physical sciences to underpin human-centred designing, meeting people’s physical, emotional and social needs.
Affective engineering involves measuring people’s affective responses to products, identifying the features of the product to which people are responding, and then using the information to improve the design of the product. By affective response, we mean the way they feel about the product. This involves two activities. First, accurate measurements of people’s affective engagement with products need to be measured and, second, the physical properties of the product and the mechanics of the interaction need to be characterised.

**Overview**
First activity at Leeds in 2001 started from comments by industrial collaborators in the manufacturing arena that although efficient and high quality manufacture was certainly necessary, ensuring that manufactured products would be what people wanted to buy (in preference to competitors’ products with the same functionality and usability) was becoming the bottleneck in new product introduction processes. Traditionally this was the area of industrial design, but perhaps a more systematic, engineering, approach would lead to an increased number of successful products. An engineering approach to subjective human-product interaction studies had been pioneered in Japan, starting from the 1970s. It is known there as kansei engineering.

Affective engineering is a Western interpretation of Kansei engineering which has been pioneered by Nagamachi at Hiroshima University since the 1970s. At Leeds, we have been applying the principles of affective engineering to the tactile properties of product packaging, personal care and domestic cleaning products, and to touch-sensitive display screens.

The focus of our research includes the following areas:

**Combination of visual and tactile cues** Our research will determine how different tactile cues are combined by the toucher, and how being able to see something affects tactile perception. We are investigating how stickiness and roughness affect the perception of softness, and how being able to see what is being touched with a laparoscopic tool affects someone’s perception of its softness. We are applying our findings to tactile displays for laparoscopic surgery and to applications in the digital economy. Modelling of the human finger has enabled us to better understand the mechanisms of human touch (figure 8) (Dr Brian Henson, B.Henson@leeds.ac.uk).

**Quantitative methods for measuring affective response** We have developed new techniques for analysing the results of studies in the consumer evaluation of products. The approach, which uses the Rasch probabilistic model rather than statistics, and which is similar to item response theory, allows the construction of psychometric instruments that produce linear scales, need only small samples for reliability, and allow the outcomes of different experiments to be accurately compared. (Dr Brian Henson, B.Henson@leeds.ac.uk).

**Electrostatic Tactile Stimulation** The mechanics of electrostatic tactile stimulation are being studied which may eventually enable surface topographies to be simulated on the flat touch screens of telephone and tablets. (Dr Brian Henson, B.Henson@leeds.ac.uk).

**Prototyping of surface textures** This work has developed a process with which to design and manufacture bespoke surface textures which evoke particular affective responses. (Dr Brian Henson, B.Henson@leeds.ac.uk).

**Selected Publications**

**Industrial Collaborators**
Nokia, Mars, Cadbury, Boots, P&G, Logitech, SSL International, Fundermax.

**Staff Involved:**
Dr Brian Henson
Enterprise Engineering

What kinds of supply systems are needed to maintain the quality of the myriad parts in a jet engine?

What kinds of enterprise and product service systems are needed to deliver sustainable products and services?

The ideas behind the emerging discipline of Enterprise Engineering provide a framework that builds upon the view that an enterprise, of which supply chains and product development systems are just two kinds, can be regarded as an organic entity with its own life-cycle and both socio and technical elements.

There exists an enterprise realization process with three key steps: Define, Develop and Deploy. Three aspects of an enterprise need to be realized during an enterprise realization process: Purpose, Agency and Products & Services. These can be brought together to form the framework presented in Figure 9.

![Figure 9: Enterprise engineering framework](reproduced from McKay, A., Kundu, S., de Pennington, A. “Supply networks: an approach to designing an extended enterprise”. 6th International Conference on Product Lifecycle Management, Bath, UK, 6-8 July 2009.)

Enterprise networks sit in the agency row. However they are developed to serve some purpose (in the Purpose row) and deliver products & services (in the Artefact row). Enterprise operating systems link these different facets across the stages of the enterprise realization process; they are socio-technical systems. The ability of an enterprise to deliver value to stakeholders.

Our goal is to provide tools that offer human practitioners improved support for the design and development of enterprise operating systems in two broad application areas: product-service systems (Figure 10), and sustainable industrial systems (Figure 10). It is anticipated that the availability of such simulations will offer real benefits in providing systematic support for business development processes. For example, the ability to simulate a production enterprise operating system would enable the implications of alternative make/buy decisions to be explored. (Prof Alison McKay, A.McKay@leeds.ac.uk).

**Key Research Projects**

- S4T - Service Support Solutions; Strategy and Transition. EPSRC/BAE SYSTEMS, 2008-2009
- Leverhulme Visiting Professorship. Prof Mark Henderson, Arizona State University, 2007
- EPSRC/ESRC Grand Challenge project: Knowledge and Information Management Through Life. EPSRC/ESRC. 2006-2009
- RAEng VP in Engineering Design for Sustainable Development 2003-2008
- Distributed Aircraft Maintenance Environment (DAME). eScience, 2002-2005
- Virtual Packaging Design Office (VPDO) EPSRC/Teaching Company Scheme with Unilever, Alpla & Raffo Design 2000-2002

<table>
<thead>
<tr>
<th>Define</th>
<th>Develop</th>
<th>Deploy</th>
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</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Mission definition/strategy</td>
<td>Action programmes</td>
</tr>
<tr>
<td>Agency</td>
<td>Enterprise architectures</td>
<td>Enterprise operating system</td>
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<tr>
<td>Artifact</td>
<td>Product &amp; service architectures</td>
<td>Products &amp; services</td>
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### Key Publications


### Staff involved:

Prof Alison McKay, em Prof Alan de Pennington, Dr Saikat Kundu (Visiting Researcher, Manchester Metropolitan University), colleagues in Leeds Socio-Technical Centre (lubswww.leeds.ac.uk/cstsd/)

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**Figure 10: Enterprise engineering framework applications**

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<thead>
<tr>
<th>Define</th>
<th>Develop</th>
<th>Deploy</th>
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<tbody>
<tr>
<td>Purpose</td>
<td>Deliver contractual requirements &amp; stakeholder strategies</td>
<td>Enterprise operating system</td>
</tr>
<tr>
<td>Agency</td>
<td>What are the best network &amp; process architectures?</td>
<td></td>
</tr>
<tr>
<td>Product &amp; Service</td>
<td>What are the best products and services?</td>
<td>How might candidate services behave in different situations?</td>
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</tbody>
</table>

(a) Product service systems

<table>
<thead>
<tr>
<th>Define</th>
<th>Develop</th>
<th>Deploy</th>
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</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Enable sustainable lifestyles</td>
<td>Enterprise operating system</td>
</tr>
<tr>
<td>Agency</td>
<td>What are the best through-life network architectures?</td>
<td></td>
</tr>
<tr>
<td>Product &amp; Service</td>
<td>What are the best products and services?</td>
<td>How might solutions behave in different situations?</td>
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(b) Sustainable development
Our research focuses on two key areas: innovative medical devices and design for wellbeing.

Innovative Medical Devices
How we can design systems that deliver products to market, improve human well-being and increase industrial competitiveness.

We work with problem owners (such as medical practitioners) to identify and define design challenges and create innovative design responses driven from the problem and user need rather than technological perspectives. Our research in this area is built around the design challenges themselves and focuses on inputs to new product development processes.

Design for Wellbeing
How can societal needs, such as those of an ageing population and affordable healthcare systems, be met through technology-driven design solutions.

Participation in leisure activities and other activities of Daily Living is recognised as a key factor in maintaining physical and mental wellbeing and independence through older age. Issues related to personal mobility and other capabilities (eg, the Cambridge Inclusive Design capabilities) often result in reduced access and confidence which becomes a barrier to participation in independent leisure activities for many older adults and so fuels a vicious cycle of decline to physical inactivity and dependence. The goal of this research is to increase choices available to older adults for participation in independent activities of daily living by building detailed understandings of user needs using whole systems design thinking, processes and interventions to accommodate their lifelong mobility needs.

We are an inter-disciplinary research group interested in Wellbeing. Our research specialisms span Cultural Studies, Branding and Marketing, Design Thinking, Mechanical Engineering, Psychology, Transport Studies, Electronic and Electrical Engineering and Ageing & Exercise Studies. We plan conducting a pilot study of perceptions and behaviours related to leisure activities in city centres with a specific focus on uncovering barriers to mobility and participation. The activity we plan undertaking falls under the programme Lifelong Health and wellbeing. Participation in leisure activities is recognised as a key factor in maintaining physical and mental wellbeing and independence through older age. Perceived and real barriers to personal mobility result in reduced confidence, which affects participation in independent leisure activities for many older adults fuelling a vicious cycle of decline in physical inactivity and dependence. The outcomes from the study will generate economic, social, and health gains for an ageing population, local councils, policy makers, designers, and commercial establishments. (Prof Alison McKay, A.McKay@leeds.ac.uk).

Key Research Projects
We are currently carrying out a pilot studies to record and observe actual behaviour and to elicit the views of older adults in two case study domains: 1) Retail & Leisure and 2) Exploring the City.

The primary data we collect will be analysed from an inter-disciplinary perspective to generate whole systems thinking around ageing, leisure activities, mobility and wellbeing for the two case study domains.

iDRO’s contribution to this area builds on the following projects.
• SEEDS: An organic approach to virtual participatory design. A Design in the Digital World project (EPSRC) 2009-2011
• RAEng VP in Engineering Design for Sustainable Development 2003-2008

Key Publications

Staff Involved:
Prof Alison McKay, Dr Abbas Dehghani, Dr Raymond Holt, Lisa-Dionne Morris, colleagues in the Leeds Design for Wellbeing group (Dr Kishore Bucha (School of Design), Sue Hayton (LHRI), Peter Gardner (Institute of Psychological Sciences), Dr Yvonne Barnard (Transport Studies), Dr Andrew Kemp (School of Electronic and Electrical Eng), David Raffo (Independent Design Consultant) and visiting Professor Alan de Pennington).

Opportunities for Future Research
We welcome enquiries from problem owners.
How might computer-based tools enhance creativity and innovation in early design processes?

Creativity and innovation are key factors in the nation’s competitiveness and wealth creation. Innovation management processes are used to ensure organisations respond effectively to internal and external opportunities. However, the focus of these processes tends to be at an organisational level and they are not well integrated into technical aspects of the product development processes that deliver products to market. This research investigates ways in which the emerging discipline of (shape and spatial) design computation can enhance technical creativity and innovation in early product development processes. If successful, the research could lead to a new generation of computer aided design synthesis systems that support early design ideation processes leading to improved responsiveness to customer needs, reduced time to market and reduced through life costs.

Our research in this area is contributing to the emerging discipline of design computation. This is based on shape and spatial grammar formalisms (Stiny, 2008). It provides an alternative scientific foundation on which a new generation of computer aided design synthesis tools might be built. In contrast to traditional CAD systems that support the definition of a design once its shape is known, design computation provides the possibility for designers to work with ambiguous shapes in ways more aligned with creative design activities described by Schon and Wiggins (Schön and Wiggins, 1992). Schon and Wiggins demand systems that support ambiguity and emergence. (Prof Alison McKay, A.McKay@leeds.ac.uk).

We characterise our research in this area using the schematic shown in Figure 11.

Figure 11

Key Research Projects

Designing with Vision. (Leverhulme) 2009-2011
AHRC/EPSRC Designing for the 21st Century project: Design synthesis and shape computation. 2007-2008

Opportunities for Future Research

We are keen to recruit students with educational backgrounds in at least one of the following, or allied, disciplines: shape-based design, computer science, mathematics. Students wishing to work in this area will ideally have practical design experience and a willingness to work across disciplines and with experimental software prototypes.

Ideally students in this area will have some computer programming expertise or an interest in developing such skills. Possible projects fall into all areas covered in the schematic in Figure 11:

- Designer designing shapes: work on shape grammar theory (Stiny, 2008) and paper-based applications to specific design styles and brands and improved understanding of human creativity and innovation.
- Design system computing shapes: work on the computer implementation of grammar-based systems.
- Interaction between human designers and computational design synthesis systems: exploring questions around how emerging computational design synthesis systems might be integrated into new product development processes.

Key Publications


Staff Involved:

Prof Alison McKay, em Prof Alan de Pennington, Dr Hau Hing Chau, Dan Trowsdale.
Our research into Energy efficient Aerospace and Automotive Structures is a response to the need for society to use less energy and other resources. Current activities include design issues in energy efficient vehicles and products for limited resources. A key aspect of this research lies in optimising the design of automotive and aerospace vehicles through the application of advanced materials and optimisation algorithms that result in lighter weight vehicles which, in turn, consume less energy during the operational phases of the lifecycles.
This area employs advanced numerical and experimental characterisation techniques to investigate lightweight materials and structures with the aim of improving both the energy efficiency and safety of ground and air vehicles. Previous projects include the processing and properties of highly oriented thermoplastics such as silane-crosslinked polyethylene and wood fibre-polypropylene composites, designed to reduce both weight and cost. Other projects include the design and analysis of carbon-fibre reinforced honeycomb sandwich panels and the optimisation of stacking sequence for aircraft composite structures (figure 12).

Another major area of interest is the investigation of brakes and drivetrain components that are lightweight, energy efficient and designed to minimise the environment impact of vehicles in terms of noise, vibration and damage to the carriageway. Lightweight brake rotors are a topic of on-going investigation since they can significantly reduce the upsprung mass of the vehicle. In this context, aluminium metal matrix composites, carbon fibre ceramic composites and coated rotors have all been considered both experimentally and analytically at Leeds.

Current projects are investigating carbon-carbon composite clutches and light alloy brake rotors with a temperature resistant rubbing surface. Analysis of brake squeal and judder is another area of expertise, especially modelling techniques to take account of thermal deformations on the properties of a disc brake to squeal which is a considerable environmental nuisance (figure 13). Experimental facilities include both small and large-scale brake dynamometers, a clutch test rig, state-of-art materials characterisation facilities, a large drop test rig, and advanced computer codes (ABAQUS, RADIOSS, LS-DYNA). Industrial collaborators have included Federal Mogul, Toyota, TMD Friction, Simpact Engineering, Micropol, QinetiQ, Altair Engineering and Bridon International. (Prof Barton, D.C.Barton@leeds.ac.uk, Dr Brooks, P.C.Brooks@leeds.ac.uk).

Recent Publications

Staff Involved:
Professor D C Barton, Dr P C Brooks
Overview
Optimisation is a methodology which allows any performance measure of a process or a product to be maximised or minimised, allowing any resources required to be efficiently used with minimal impact on the environment.

Multidisciplinary optimisation is a methodology which uses the interdisciplinary interactions of the applications of a structure, component, system, process or design in order to improve its overall performance (figure 14).

If performance evaluation of the object/process requires significant computing time, it is necessary to develop and use metamodels. They allow the complex behaviour of the system to be represented with simpler, computationally inexpensive and relatively noise free models obtained, for example, by Genetic Programming, Moving Least Squares Method or based on the interaction of low- and high-fidelity simulation models. Different optimisation techniques including evolutionary algorithms and gradient-based methods can then be used to find the optimum on these metamodels. Such models are also applicable for stochastic analysis and optimisation, where for example a large Monte Carlo simulation can be performed to assess reliability and robustness of a system or a process.

Multidisciplinary optimisation research spans several Schools of the Faculty of Engineering. Development of the metamodel-based infrastructure for multidisciplinary applications is one of the major activities in the group.

Another major activity is the development of a large-scale optimisation technique (100s of design variables) based on the mid-range approximation method (MAM). To deal with the curse of dimensionality, approximations in MAM are based on intrinsically linear functions as well as simple rational functions and moving least squares approximations with a linear base function. The final approximation is arrived at using an adaptive selection and regression-based model assembly. This approach was successfully used on a number of live design projects at Rolls-Royce where a single simulation took tens of hours, with a performance orders of magnitude faster compared to other optimisation techniques. This technique can handle other major issues arising in industrial applications such as numerical noise and occasional simulation failures.

This expertise is complemented by experience in topology optimisation, which has been applied to a number of areas such as the aerospace and civil engineering industry. (Dr Osvaldo M Querin, O.M.Querin@leeds.ac.uk)

Selected Research Projects
Below are some of our research projects. We also engage in collaborations with industry providing specific expertise in multidisciplinary, structural and fluid dynamic optimization.

1. TSB and Rolls-Royce, SILOET-2, Development of stochastic optimization methodology for turbomachinery applications, £256,000 (2013-2016).
3. ALaSCA Advanced lattice structures for composite airframes, EU Programme Transport (including Aeronautics), Partner 194,400 (2010-2013).
6. DTI CFMS (Centre for Fluid Mechanics Simulation) Core Programme TP/L3001H. Co-sponsored by Rolls-Royce plc and Airbus UK Ltd. Development of large-scale optimization techniques for aerothermal design systems. £250,000 (2007-2010).

Selected Publications

Staff Involved
Dr Osvaldo M. Querin
iDRO researchers have access to excellent facilities and equipment within three laboratory areas: Control & Dynamics, Design, Strengths of Materials. We have access to dedicated equipment:

A control and dynamics laboratory for development of advanced robotic systems incorporating manufacturing facilities including rapid prototyping and computer aided manufacturing.

- Experimental facilities for characterising material behaviour include static and dynamic universal test machines and a high speed thermal imaging system alongside full and reduced scale brake dynamometers (figures 15, 16, 17, 18).
- The University’s Charterhouse Rehabilitation Technologies laboratory (supported through School of Mechanical Engineering and Medicine) including motion tracking system to support development of novel restorative rehabilitation technologies;
- Purpose-built Design Systems Laboratory including soft metrology facilities and design observation suite for audio-visual recordings to study ways in which people interact with technology and new products (figure 19).

Figure 15: Strength of Materials laboratory

Figure 16: Dynamics and control lab

Figure 17: Material testing machine

Figure 18: 3D printing

Figure 19: Observation suite
Dr Jordan Boyle
Dr Jordan Boyle, a Lecturer in the School of Mechanical Engineering, has a multi-disciplinary background and a long-standing interest in biological sensorimotor systems (particularly locomotion). He received his BSc (Hons) and MSc degrees in Electrical Engineering from the University of Cape Town (Africa’s highest ranked university) before coming to Leeds to do a PhD in the School of Computing.

His PhD research involved using computational modelling and data analysis, in collaboration with experimental biologists, to successfully decipher the neuro-mechanical mechanisms underlying locomotion of the nematode worm *C. elegans*. His work revealed an unusual distributed control system that exploits the interplay between the nervous system, body and environment to generate robust and adaptive locomotion with minimal computational cost. Following completion of his PhD, Jordan secured a one-year EPSRC fellowship to develop a bio-inspired WormBot based on the *C. elegans* control strategy that is remarkably proficient at adapting its locomotion to environmental constraints – something that remains a major challenge for crawling robots.

His work focuses on bio-inspired locomotion, with a particular interest in invertebrates like worms and insects and the way these relatively simple animals exploit the interplay between their nervous system and embodiment.

Dr Peter Brooks
Dr Peter Brooks is a Senior Lecturer in the School of Mechanical Engineering. His current research interests embrace the areas of automotive braking systems, sports engineering, dynamics and durability engineering. Projects in each area invariably contain a blend of advanced numerical simulation (finite element analysis or multibody dynamics) and experimental characterisation of the system behaviour.

Current projects are associated with brake squeal, optimisation of automotive chassis components and skeleton bob chassis dynamics. These projects are supported by Toyota, Ferodo, Leyland Technical Centre, nCode International, UKSport and Ice Sport Technology.

Prof David Barton
Prof. David Barton is Head of School in Mechanical Engineering. His current research interests are focused in the areas of automotive braking systems, high strain-rate crashworthiness studies and polymer engineering. Each area involves advanced numerical simulation (usually finite element analysis) coupled with experimental characterisation and modelling of complex material behaviour. Some current project are concerned with disc brake squeal, high rate processing and properties of polymers, modelling of bone biomechanics and impact crashworthiness of composite materials. Previous sponsors include MERL, EPSRC, Micropol, DuPont and Bridon International.

Dr Pete Culmer
Dr Pete Culmer is a Senior Translational Research Fellow (STRF) in Surgical Technologies, based in the School of Mechanical Engineering, University of Leeds, UK. He obtained a first class Mechatronics MEng degree from the University of Leeds, and then undertook a PhD to develop novel control techniques for a dual-robot arm rehabilitation system. This work has been used in a range of studies to deliver assisted arm exercises to improve arm function in people with stroke and received industry recognition (2008 NHS Medipex Innovation Awards, Best in Class and Editor’s Choice at the 2009 National Instruments Awards and Best Innovation from NHS Scotland in the 2009 Scottish Health Innovations Ltd awards).

He built on this work during post-doctoral research positions, establishing a firm interest in medical and rehabilitation engineering and expertise in working on highly multidisciplinary projects. He continues to work with colleagues in the Institute of Psychological Sciences on collaborative projects including CKAT, a tool which makes objective computerised measurements of hand movements to improve the assessment of human motor control. This is currently being used to assess a large cohort of children as part of the NHS Born in Bradford Study.

Pete was awarded his current position, funded by the Biomedical Health Research Centre (BHRC), in 2010 and works with a growing team of researchers including engineers, surgeons and psychologists, conducting research into new surgical technologies. Within this field, his areas of research interest are sensing, analysis and feedback of information for improved operative performance and training. He currently supervises several PhD students and post-doctoral researchers and is working closely with colleagues in the Surgical Technologies Research Group. This group is led by Prof. Anne Neville (Engineering) and Prof. David Jayne (Surgery) for a truly multidisciplinary research focus.
**Dr Abbas Dehghani**
Dr Abbas Dehghani is a senior lecturer in the School of Mechanical Engineering. He has multi-disciplinary engineering qualifications including electronics and digital systems engineering. His research focuses around biomechatronics and biorobotics and he has experience in the latest design, sensing, actuation and intelligent control technologies for artificial limbs. Dr Dehghani has worked on and managed projects funded by EPSRC, DTI, KTP and directly by industry (BAE systems) and has (as leader of the Mechatronics Research Group), had oversight of a team of 8 RSs and 25 PhD students. He is a member of steering committee of IMechE Mechatronics Forum. He has also been external examiner for a number of UK universities.

**Dr Brian Henson**
Dr. Brian Henson is a Senior Lecturer in Design and Manufacture, having first joined Leeds as a research engineer in 1992. He became a lecturer in 1996 and gained his PhD in 1999. In soft measurement his research involves the contact mechanics of touch, quantitative methods of evaluating self-report data for affective engineering, and synthesis and manufacture of tactile textures. He was the principal investigator at Leeds of the FP-6 NEST project, SynTex, “Measuring feelings and expectations associated with texture” (NEST043157), and was a co-investigator on the UK-funded project AFTEX, “Surface textures for affective communication” (EPSRC EP/D060079/1). He has supervised over a dozen industrial projects in affective engineering for companies such as Mars, Boots and Procter and Gamble. In 2005, he held a six-month Royal Academy of Engineering Industrial Secondment to Mars Ltd., where he transferred his knowledge of soft measurement, and gained experience of industrial new product development processes. Dr. Henson’s other interests in product development manifest themselves principally through Knowledge Transfer Partnerships with local companies.

**Dr Ray Holt**
Dr Ray Holt is a Lecturer in the School of Mechanical Engineering. His research focuses on integrating the perspectives of stakeholders from across the product lifecycle into design decisions. Decision making is an integral part of the design process, and failure to take account of all the important stakeholders and stages in a product’s life when designing can lead to unforeseen problems and costly corrections. He is particularly interested in how we can incorporate user perspectives in the design of medical and assistive devices, especially with users, such as children or stroke patients, who present difficulties for conventional user-involvement approaches. This means evaluating existing and developing new methodologies for user involvement with these groups, and also applying these methods to integrate user perspectives in projects aimed at developing medical or assistive technologies.

**Dr. Andrew Jackson**
Dr. Andrew Jackson is a Teaching and Research Fellow in the School of Mechanical Engineering. He gained his PhD at the University of Leeds in 2003 in the field of vehicle dynamics and control. The work, sponsored by QinetiQ, focused on the simulation and control of a six-wheel-drive hybrid electric off-road vehicle.

As a research fellow, his focus shifted from vehicle dynamics to robotics, working as part of a multi-disciplinary team including engineers, clinicians, physiotherapists and people with stroke to develop the iPAM robotic exercise system. He is currently overseeing a randomised control trial of the system within two National Health Service trusts where it is being used by physiotherapists to treat acute stroke patients. His current research interests remain within rehabilitation robotics, primarily focused on the upper-limb. He is also a Certified LabVIEW Developer.

**Prof Martin Levesley**
Prof Martin Levesley is Director of Student Education at the School of Mechanical Engineering. His background in dynamics and control, was gained at the Department of Mechanical Engineering at Southampton University were he obtained my PhD and undertook postdoctoral research in the field of aero engine vibration control, in collaboration with Rolls Royce. After moving to Leeds in 1997, his research interests broadened to include various automotive and medical engineering applications. He currently leads all engineering aspects of a number of multidisciplinary research projects aimed at developing intelligent systems to deliver automated restorative physical therapy.

**Prof Alison McKay**
Alison McKay is a Chartered Engineer and a Fellow of the Institution of Mechanical Engineers. She joined the School of Mechanical Engineering at the University of Leeds in 1984 as a research engineer, gaining her PhD in 1996; since 2001 she has led the launch of the University’s multidisciplinary undergraduate programme in Product Design. She is a founding member of the Leeds Socio-Technical Centre.

Her research centres on socio-technical aspects of product-service systems and the networks of organisations that both develop and deliver products to market, and support them through life to disposal or reuse. The focus of her personal research lies in the establishment of systematic and, where possible, well-founded underpinnings for such systems, in particular, for the definition of product data. This has led to research on extended enterprise network structures and their alignment with the delivery of business strategy, issues in sustainable product design, and the establishment of computer aided design systems to support early design activity (when new shapes are being defined) and so enhance designers’ creativity.
Ms Lisa-Dionne Morris

Ms Lisa-Dionne Morris is a Senior Teaching Fellow for the MDES Product Design programme. She has a design career spanning 15 years with experience in both the automotive and product design sector. She graduated from the Royal College of Art with a MA in Industrial Design and has worked as an Industrial Designer for companies such as IBM Corporation and Aston Martin. She has numerous designs which have been both nationally and internationally recognized and has dedicated much of her work to developing improved operational user interfaces for older consumers.

Since graduating from the Royal College of Art Lisa-Dionne has been involved in all aspects of engineering and design education. Her experience includes working in several Higher Education Institutes and as an advisor to industry. Lisa-Dionne's varied background has allowed her to exercise and refine her learning and teaching skills as an accomplished product designer with expertise in the four main aspects of Human Factor: Ergonomics, Anthropometrics, Physiology and Psychology. She has a proven track record of delivering successful products and learning and teaching applications from the initial flash of creativity to the detail necessary for effective implementation.

Prof Anne Neville

Anne Neville is Professor of Tribology and Surface Engineering, in the School of Mechanical Engineering, University of Leeds. She was elected as a Fellow of the Royal Academy of Engineering in 2010, and also awarded a 10-year research chair in emerging technologies by the Royal Academy of Engineering in 2009 – the first of its kind to be awarded by the Academy.

Her main research interests include corrosion and tribo-corrosion, lubrication and wear, and mineral scaling. Her research is funded by EPSRC, ERC, FP7 EU, NHS, RAEng and Industry. Anne Neville has received many international awards including, Elected Fellow of the Royal Academy of Engineering, 2010; Institution of Mechanical Engineering, Donald Julius Groen Prize for achievements in Tribology, 2011; Royal Society Wolfson Research Merit Award 2013.

She is Editor-in-Chief for Tribology: Materials, Surfaces and Interfaces, published by Maney and IoM3 and serves on the Editorial Board of 4 other major peer-reviewed journals. She has over 220 original publications in major peer review journals.

Dr Osvaldo M. Querin

Dr Osvaldo M. Querin is Associate Professor in the School of Mechanical Engineering, Senior Member of the American Institute of Aeronautics and Astronautics, Fellow of the Royal Aeronautical Society (FRaes) and secretary of the Association for Structural and Multidisciplinary Optimization in UK (ASMO-UK). His research interests lie in structural topology optimization, having been instrumental in the development of the Bi-directional ESO (BESO), Sequential Element Rejection and Addition (SERA) and Isolines/Isosurfaces Topology Design (ITD) methods of topology optimization. He has published 6 edited books, 3 book chapters, 46 journal and 82 conference publications.

Dr Robert Richardson

Dr Robert Richardson is the Director of Institute of Design, Robotics and Optimization and a Senior Lecturer at the School of Mechanical Engineering, University of Leeds, UK. He currently holds a prestigious research contract to explore The Great Pyramid of Giza, Egypt using robotic technology and has discovered writing in the Great Pyramid that was hidden for thousands of years [1]. The New Scientist magazine placed his discoveries in the top 10 scientific discoveries of 2011. In the 2008 he was successful in developing air and ground robotic systems that reached the final of the UK MOD Grand Challenge.

His current research interests include exploration robotics, surgical robotics, prosthetics, mobile robotics and search and rescue robotics. He has led and been involved in numerous research projects including funding from EPSRC, UK MOD, NHS Neat, UK Home Office and industrial partners. He is a Fellow of the IMechE.

Mr Dan Trowsdale

Mr Dan Trowsdale is a Senior Teaching Fellow in the School of Mechanical Engineering at the University of Leeds. With a proven track record in product design, innovation and manufacturing, Dan brings a creative approach, commercial expertise and manufacturing know how, to research projects. His experience in design management has involved responsibilities for component design, tooling and production processes for manufacture both in Europe and China with product sales throughout Europe and the USA. His experience includes the publishing, management and commercial exploitation of intellectual property in the form of patents, design registrations and trademarks, and is named as inventor on several patents. Dan has also worked as design advisor to UK industry through business support networks such as Business Link and the Design Council.

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