UNIVERSITY OF BIRMINGHAM

ROBOTS FOR **SELF-REPAIRING CITIES**

Self-Repairing Cities Annual Event / 20 June 2018

Hornton Grange, University of Birmingham

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Welcome to the Robots for Self-Repairing Cities event, which aims to bring together researchers, industry and city makers to discuss the current challenges in maintaining city infrastructure systems and how state-of-the-art robotic technologies can be used to address those challenges.

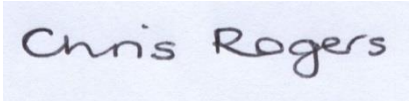
We believe this meeting is of relevance to anyone who wishes to understand how robots can be used to improve infrastructure resilience now or in the near future, and the multiple benefits of this approach.

This is the second annual event organised by the Self-Repairing Cities project and, as you would expect, we will showcase some of the work we have been doing on the project over the past 30 months. In addition, we are delighted to be joined by a great line up of speakers, who will be giving insights into broader developments across this area. Just as importantly, we want to hear what your priorities are for research in this area are: please do give us your thoughts throughout the day, but particularly in the discussion session planned at 3.30pm.

To find out more about the Self-Repairing Cities project, please take time to peruse the project brochures available during the day, see the posters and demonstrations during the breaks and speak to the various project members. We recognise that achieving our Grand Challenge of zero streetworks by 2050 will only be possible by working with all relevant stakeholders and so we are interested in exploring collaborations and continuing conversations that keep us focused on outcomes that will be both cutting edge and relevant.

For those on Twitter, please follow us on @SelfRepairCity and join the conversation today using the hashtag #RobotsforSRC.

We look forward to a day full of interesting and fruitful discussions.



Professor Chris Rogers,
Director, UKCRIC National Buried Infrastructure Facility
School of Engineering
University of Birmingham

UNIVERSITY OF LEEDS UCL UNIVERSITY OF BIRMINGHAM UNIVERSITY OF Southampton EPSRC Engineering and Physical Sciences Research Council

Schedule

Time (hrs)	Item
09:30	*Registration, refreshments and exhibition*
10:00	Introduction by Chris Rogers, University of Birmingham
10:10	**Keynote talk**: “Advances and developments in self-responding construction materials”. Kevin Paine, University of Bath
10:40	**Project talk**: “Road repair by 3D printing – terminating potholes”. Mark Miodownik and Richard Jackson, UCL.
10:55	Discussion
11:10	*Refreshments and exhibition*
11:30	**Keynote talk**: “Where water meets city infrastructure and the use of marine robotics for inspection”. Dan Hook, ASV Global
12:00	**Industry talk**: “Robotic Roadworks”. Graeme Cleeton, ULC Robotics
12:15	**Project talk**: “Drone Revolution”. Rob Richardson, University of Leeds, and Stephen Prior, University of Southampton
12:30	Discussion
12:45	*Lunch and exhibition*
13:45	**Keynote talk**: “Rejuvenating the urban utility underworld – the challenge of getting “Street-Wise” in 21st Century cities”. Tony Rachwal, UK Water Partnership
14:15	**Industry talk**: “Digital Balfour Beatty” Stuart Jauncey and Steve Crossland, Balfour Beatty
14:30	**Project talk**: “Infrastructure condition assessment and an autonomous decision framework”. Chris Rogers, University of Birmingham
14:45	**Project talks**: “The impact of automation on urban ecosystems”. Mark Goddard, University of Leeds. “Can people in self-healing cities be self-employing?” Gary Dymski, University of Leeds
15:00	*Refreshments and exhibition*
15:30	**Discussion session on the priorities for research**
16:25	**Conclusion**
16:30	*Close*

Talk Abstracts

Advances and developments in self-responding construction materials

Kevin Paine, University of Bath

Material degradation of our civil engineering structures is generally inevitable and consequently structures need regular maintenance. However, research within the EPSRC funded Materials for Life (M4L) project (2013-2016) has developed a suite of biomimetic self-healing construction materials that have the ability to adapt and respond to damage without external intervention; as demonstrated in the first UK full-scale field trials on self-healing concrete. Following on from M4L, the EPSRC funded programme grant Resilient Materials for Life, a collaboration between Cardiff, Bath, Bradford and Cambridge Universities, is facilitating the creation of 'smart' materials that can further self-sense, self-diagnose and self-repair (self-respond) when subject to a wider range of damage scenarios. This presentation will overview the findings of M4L and outline our ambitions in RM4L as this research expands to a higher level of complexity, breadth and practical application.

Speaker biography: Dr Kevin Paine is a Reader in Civil Engineering within the BRE Centre for Innovative Construction Materials at the University of Bath and a Director on the EPSRC Programme Grant "Resilient Materials for Life" (RM4L). His research focuses on smart and innovative concrete technologies. Prior to working at Bath, he was a Lecturer at the Concrete Technology Unit, University of Dundee. He has a PhD in civil engineering from the University of Nottingham.

Road repair by 3D printing – terminating potholes

Mark Miodownik and Richard Jackson, UCL

In order to reduce road infrastructure repair and maintenance costs, autonomous repair drones and ground robots must be able to responsively address varied defect geometries and material demands, to which 3D printing is a uniquely placed solution. We document the development of an asphalt 3D printer which provides novel material properties such as increased toughness and ductility when compared to poured and cast asphalt, and can have many different materials added during repairs. This system is mounted on a drone and the results of field testing are reported.

Speaker biographies:

Mark Miodownik is Director of Institute of Making at UCL where he teaches and runs a research group. For more than ten years he has championed materials research that links the arts and humanities to medicine, engineering and materials science. His current research interests are animate materials, innovative manufacturing, and sensoaesthetic materials. Prof Miodownik regularly presents BBC TV programmes on engineering which have reached millions of viewers. He was awarded a MBE in 2018 for services to Science, Engineering and Broadcasting

Richard Jackson is a Research Associate at the Institute of Making and Mechanical Engineering at UCL. He received his MSc (2002) in Physics from Durham University and PhD (2006) in Biomedical Nanotechnology from Newcastle University. After a Postdoctoral position at Newcastle engineering intracortical microelectrodes for brain-machine interfaces, he worked for a spinout company from Imperial College London and the National Physical Laboratory developing next generation proteomic and genomic microfluidic devices. Starting at UCL in 2013 his research now focuses on leading various efforts to design, fabricate and test various novel micro- and nano-structured composite smart active materials, primarily involving additive manufacturing methods and techniques. He has developed the composite asphalt 3D printing head for autonomous mounting in the Self Repairing Cities Project.

Where water meets city infrastructure and the use of marine robotics for inspection.

Dan Hook, ASV Global

The inspection of river banks, bridges, dock walls, sewer systems, piers, jetties and anywhere that water meets with rigid infrastructure is difficult and potentially dangerous. For these reasons it is often one of the less frequently inspected interfaces. Marine robotics offers capabilities to change this and identify potential failures long before they happen. Present technologies are mainly focussed on inspection but in this talk ASV will also comment on ideas for future intervention.

Speaker biography: Dan Hook CEng, MRINA is a qualified Naval Architect and Chartered Engineer with over 15 years' experience in the unmanned marine industry. Dan joined Seaspeed Marine Consulting as a Naval Architect in 2002 before moving onto the position of Technical Director in 2007. During his time at Seaspeed, Dan specialised in unmanned platform and high speed craft design and consultancy.

Prior to his recent new role as Senior Director (UK) – Business Development, Dan held the position of Managing Director at ASV Global, a company at the forefront of developments in unmanned marine systems for the Military, Offshore Energy, and Science and Survey Industries. Dan has built a vibrant team of naval architects, engineers and robotics experts, seeing the company grow from 3 people to over 100 in just seven years. During this time the team have delivered over 90 Unmanned Systems to commercial and defence customers in the UK and all over the world.

As well as his role at ASV Global, Dan maintains an active role in industry. He is currently the Chairman of the Maritime Autonomous Systems (MAS) Council run by the Society of Maritime Industries, and is a member of the Solent Marine and Maritime Steering Group.

Robotic roadworks

Graeme Cleeton, ULC Robotics

Speaker biography: Graeme Cleeton is the Vice President of UK Operations at ULC Robotics. In this role, he manages ULC's field operations involving CISBOT, CIRRIS XI™ and CIRRIS XR™ and works to develop new markets and drive business growth across the UK. Prior to joining ULC Robotics in 2016, Graeme held executive positions with Northern Gas Networks and Balfour Beatty Utility Solutions. With more than 30 years of experience in the UK utility industry, Graeme has an outstanding track record of developing, implementing and delivering first-class strategy and planning for efficiently driving growth and improving company profitability.

Drone revolution

Rob Richardson, University of Leeds, and Stephen Prior, University of Southampton

Autonomous air vehicles (Remotely Piloted Aircraft Systems, RPAS) are becoming integrated into the mainstream, from the armed forces using them as reconnaissance and weapons platforms, to large internet companies proposing their use as a global delivery system.

New challenges in RPAS include, efficient propulsion systems, Non- line of sight (NLOS) communication, aerial docking (Swarms), operations where GPS is denied, blocked or spoofed, and UAVs to deploy autonomous vehicles.

Speaker biographies:

Dr Stephen D Prior is Reader in Unmanned Air Vehicles within Engineering and the Environment at the University of Southampton. He is a Chartered Mechanical Engineer, Corporate Member of the IMechE and Fellow of the Higher Education Academy. His research interests are in the areas of Mechatronics, Autonomous Unmanned Systems, Robotics and Design Engineering. He was Project

Lead for the MoD Grand Challenge i-Spy team in 2008 and was the Team Leader for Team HALO, winner of the DARPA UAVForge Competition 2012. He has been an editor for the International Journal of Micro Air Vehicles since 2010.

Professor Robert Richardson is a Professor of Robotics, in the School of Mechanical Engineering, University of Leeds. As PI and Director of the EPSRC National Facility for Innovative Robotic systems, he leads a major EPSRC investment to physically create robust robotic devices. He is co-Director and robotics lead for the EPSRC Grand Challenge to develop autonomous infrastructure inspection robots; and the robotics lead for the EPSRC UKCRIC Centre for Infrastructure Materials Performance Leeds investigating robots for inspection of difficult to access infrastructure and facilities to stress test robotic devices. Within the School of Mechanical Engineering at Leeds, he is the director of the Multi-disciplinary Institute of Design, Robotics and Optimisation at the University of Leeds (20 academics and 50 members). He is a Fellow of the IMechE.

Rejuvenating the urban utility underworld – the challenge of getting "Street-Wise" in 21st Century cities.

Tony Rachwal, UK Water Partnership

The UK has over 1 million kilometres of pipe and cable networks, mostly buried under urban streets and pavements. They provide most of our essential water, drainage and energy services. These invisible assets are ageing and customer acceptances of failure is diminishing, as is the patience of urban drivers when confronted by network driven street-works for repair and renewal. What are the opportunities and barriers for developing "Street-Wise" technologies to quietly and efficiently rejuvenate our buried urban utility underworld? This presentation illustrates the journey from a 1996 "Street-Wise" workshop to a 2025 vision where "Body Scanners in the Street", Smart Pigs and in-pipe robots might lead to healthier buried networks and less urban street disruption.

Speaker biography: Tony is an independent water innovation consultant. He is a chemist and process technologist with over 40 years' experience in the UK and international water industry sector. For most of his career, he worked for the water utility, Thames Water and for a period, the international multi-utility, RWE Thames Water, retiring as European R&D Director in 2006.

Tony is currently a Director of the UK Water Partnership, leading the research and innovation action group. He is also Industrial Business Fellow (Water) at the University of Surrey. He has published over 50 scientific papers on water sector technology development. Tony has represented the UK on the American Waterworks Research Foundation and the EU Water Supply and Sanitation Technology Platform.

Finding 21st Century solutions for rejuvenating the underworld of urban, utility pipe networks is a current technology area Tony has been championing.

Digital Balfour Beatty

Stuart Jauncey and Steve Crossland, Balfour Beatty

Speaker biographies:

Stuart Jauncey is the Business Manager at Balfour Beatty Living Places currently delivering the Highways Services Partnership and City Watch CCTV contracts for Southampton City Council. Trained as an Electrical Engineer, Stuart has worked in contracting delivering industrial and commercial projects including cable manufacturing, cinema, hospital wing, petrol filling stations. A move into the Public Sector Stuart spent 13 years in Asset Management including responsibilities for Energy & Carbon Management, Procurement, Estates Management and Capital Prioritisation. Before joining Balfour Beatty Stuart delivered a large portfolio of renewable investment projects and

modular housing and regeneration consultancy. Stuart is passionate about H&S, energy, regeneration and is excited about innovation.

Steve Crossland is a broadly experienced Chartered Civil Engineer with design management experience on sewers, water main and trunk main rehabilitation within a design and construct partnering environment with several water company clients. He has developed his career in basic infrastructure design and supervision over 25 years, with increasing responsibility through various roles in local government, consultant, water companies and contractors: Steve currently holds the role of Head of Engineering - Water with Balfour Beatty - Gas & Water.

Steve is a Steering Group Member representing Balfour Beatty on the Utility Strike Avoidance Group (USAG) since 2012 and on the Working Group that provides the Annual Utility Strike Report. He was a co-author with the University of Birmingham on the ICE published paper 'Causes, Impacts and costs of strikes on buried utility assets' (Sept 2015).

Infrastructure condition assessment and an autonomous decision framework.

Chris Rogers, University of Birmingham

There is an increasing pressure on the cities and utility companies to maintain their ageing infrastructure systems while dealing with the challenges of contextual change (growing urban populations, changes in demand patterns and climate, ever-limited resources) and increasing performance expectations. Truly effective maintenance requires a proactive approach to detect any defect at its early stages and also to identify and eliminate its trigger(s). By so doing, the dual benefits of (greatly) extended asset life and reduced maintenance expenditure could be achieved, leading to huge savings at the network level. Recent developments in robotics offer potential solutions to this infrastructure management problem. Our hypothesis is that utilising robotics and autonomous condition assessment systems will deliver several benefits: enhancing the efficacy of infrastructure maintenance systems by minimising human errors where visual inspection is employed; providing the opportunity to deploy geophysical technologies (e.g. GPR and ultrasound) where human access is impossible (e.g. inside pipes) or undesirable (e.g. at height in the streetscape, in close proximity to vehicles on busy roads) and systematically over long periods (e.g. throughout overnight closures); and eliminating or removing destructive methods associated with infrastructure condition assessment. However, each of the existing geophysical technologies has some limitations associated with their working conditions or practices, thus requiring research to make this ambition achievable. While bringing streetworks expertise to bear on these challenges, researchers at University of Birmingham are in parallel developing a decision support system for these emerging robotic and autonomous systems. This will enable autonomous decision-making by suggesting the most appropriate geophysical and/or alternative method(s) for identifying defects (e.g. cracks in asphalt) and establish their triggers (e.g. failed drainage, a leaking pipe, physical overloading, embrittled asphalt).

Speaker biography: Professor Chris Rogers, with a previous background in Civil Engineering practice and geotechnical engineering research, has been working on two primary, necessarily interrelated, themes of infrastructure engineering and urban sustainability, resilience and liveability for the past 20 years. Building on prior research into trenchless technology, buried pipes, soil stabilisation and road foundations, since 2004 he has led the multi-university EPSRC Mapping the Underworld (MTU) research initiative. MTU started by addressing the complex challenge of locating and mapping pipelines and cables buried beneath the streets, and thereafter expanded into the use of shallow-surface geophysics to assess the condition of road structures, buried pipelines and cables, and the ground that supports them both (Assessing the Underworld). In iBUILD he worked with engineers and economists to explore alternative business models emerging from considerations of infrastructure interdependencies, while his future cities research has focussed on underground space use and the future of utility service provision. He led the multi-disciplinary

Urban Futures consortium (part of EPSRC's Sustainable Urban Environments programme) and the Liveable Cities Programme Grant, both exploring the performance of future cities in relation to citizen and planetary wellbeing. Having served as a member of the Lead Expert Group of the UK Government Foresight Future of Cities project, he chairs the ICE's Research, Development & Innovation Panel, leads the creation of the National Buried Infrastructure Facility a Birmingham and is Director of Research Integration for the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC).

The impact of automation on urban ecosystems

Mark Goddard, University of Leeds

Urban green spaces and the wildlife inhabiting cities are important for providing a wide variety of ecosystem services to people. When envisioning a future city maintained by autonomous robots we must understand the ecological impact they themselves might cause – both positive and negative. We are using a number of tools to address this knowledge gap, including a 'horizon scanning' exercise, a systematic literature review, and ecological surveys across gradients of light, noise and air pollution in order to model the possible changes in biodiversity which might be associated with reduced pollution – one purported benefit of robots operating in cities.

Speaker biography: Mark's research focuses on biodiversity conservation and the provision of ecosystem services in human-modified landscapes, in particular urban environments. He is currently working as a Research Fellow in Urban Ecology on the Self-Repairing Cities project, researching the impact of automating cities with robots on urban biodiversity and ecosystem structure and function. Mark is also collaborating on a number of international urban biodiversity initiatives, including UrBioNet, a global network to support urban biodiversity research, monitoring and practice.

Can people in self-healing cities be self-employing?

Gary Dymski, University of Leeds

What are the social and economic consequences of introducing robotics and AI into urban infrastructure maintenance? There is the specific impact on workers who are currently employed to do urban-infrastructure maintenance and repair tasks, and there are broader societal concerns about how the robotics/AI revolution will affect work, inequality, and social welfare. We review the preliminary shift-share data on specific employment impacts, and also consider the broader challenges posed by the robotics/AI transition. A successful transition will require rethinking of education, work, distribution, and value. Societies cannot ask individuals to navigate this transition on their own: navigating artificial intelligence expanded emotional intelligence. This will result in the strengthened macro-meso-micro linkages needed to render continual technical advance consistent with economic and social sustainability.

Speaker biography: Professor Gary Dymski has done research on topics including racial and gender discrimination and redlining in credit markets, ethnic banking, banking strategies and mergers, financial exclusion, financial governance, and financial crises and community economic development. Gary is also co-leader of the Leeds University interdisciplinary Cities research theme; in addition to the self-healing cities project, he is a co-investigator the ESRC-funded Productivity Insights Network project, and a research-hub co-leader in the ESRC-funded Rebuilding Macroeconomics initiative.

The future of infrastructure robotics – looking to the horizon

With the Self-Repairing Cities hitting its mid-term point, we want to ask industry, city makers and our fellow academics help us develop a shared vision for a future using robotics and autonomous systems to help deliver resilient city infrastructure.

The interactive session will look to draw out the areas for biggest impact, priorities, technical challenges and opportunities, and to develop a route map to 2050 highlighting the roles of the different participants in achieving this vision.