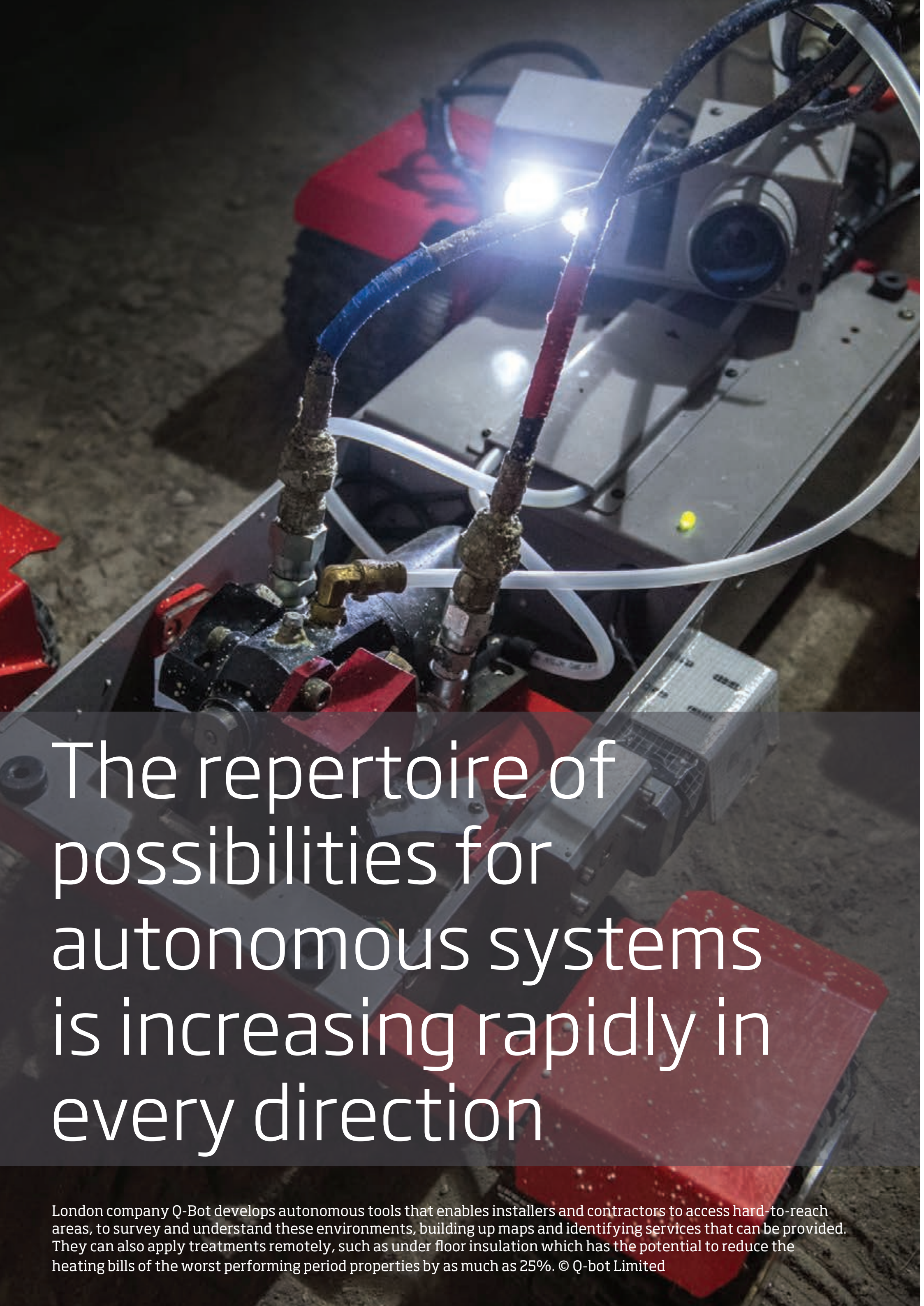
Innovation in autonomous systems

Summary of an event held on Monday 22 June 2015 at the Royal Academy of Engineering.

ROYAL ACADEMY OF ENGINEERING



The repertoire of possibilities for autonomous systems is increasing rapidly in every direction

London company Q-Bot develops autonomous tools that enables installers and contractors to access hard-to-reach areas, to survey and understand these environments, building up maps and identifying services that can be provided. They can also apply treatments remotely, such as under floor insulation which has the potential to reduce the heating bills of the worst performing period properties by as much as 25%. © Q-bot Limited

Innovation in **autonomous systems**

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at the Royal Academy of Engineering

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www.raeng.org.uk/autonomoussystems

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1. Foreword

Over the past four years, the Royal Academy of Engineering has organised a series of half-day events that have explored and highlighted innovation in engineering sectors that are seen as having potential for growth and for global reach.

On 22 June 2015, leading engineers, academics and business people gathered at the Academy to discuss *Innovation in autonomous systems* and the trends and issues of a branch of engineering that touches many different sectors. The event heard presentations from researchers, manufacturers and users, with an emphasis on the short to medium term. Discussion focused on next steps to help further develop applications and grow markets for autonomous systems.

This report is not a verbatim record of the event; rather, it seeks to highlight some of the issues raised and to contribute to further discussion.

Autonomous systems also include types of anthropomorphic automatons that interact with humans. Forming a staple of science fiction they are now starting to become reality

2. Autonomous systems

Autonomous systems are machines and systems that are capable of performing a series of operations where the sequence is determined by the outcome of the previous operation or by reference to external circumstances that are monitored and measured within the system itself.

Unlike more traditional machines that have a single purpose or whose range of activities is determined from the outset, the autonomous system tailors its behaviour and operations in accordance with the circumstances that it finds: it is 'smart' or 'intelligent'. It 'discovers' what is going on in its sphere of operation, and adapts its course of action in accordance with what it finds.

The conventional view of autonomous systems has equated them with robots. This view encompasses the industrial robot, which is often a manipulator linked to sequential machining operations and incorporates sophisticated sensing and feedback to ensure that the correct sequence of operations is carried out to the required accuracy. Autonomous systems also include types of anthropomorphic automatons that interact with humans. Forming a staple of science fiction they are now starting to become reality.

These different kinds of robot are, however, only part of the broader concept of autonomous systems. Automation combines sensors and control systems to enable complex sequences of operations to be performed in many different types of system. Currently, these range from, for example, autopilot systems within aircraft through to the complicated series of activities undertaken by domestic washing machines. These can all be viewed as varieties of autonomous system.

Degrees of autonomy vary and are often very constrained. But now several engineering-based technologies are coming together to extend the range and the opportunity for autonomous

systems. The development of wireless sensors and universal connectivity enables a continuous flow of data to be sent; onboard processors can handle the data and activate appropriate responses; new kinds of software architecture allow more complex decision-making to be applied automatically within systems. The repertoire of possibilities for autonomous systems is increasing rapidly in every direction.

There are, however, still constraints and concerns. Autonomous systems work well within defined and controlled situations and there is huge potential for further development in these areas. Many of the applications where the reliability and controllability of machine-based systems could be very beneficial still need to interface with human beings. The technology for autonomous vehicles, for example, is not a great leap forward from the systems in today's cars; the problem is not the autonomous vehicle, but all the other vehicles on the road controlled by humans, and the pedestrians and the cyclists.

There are similar uncertainties about extending autonomous systems into other occupations, for example, health and social care. The concept of automating some of the assistive functions that could enable older people to retain their independence for longer is highly attractive. But this is a new level of system complexity and requires trust in the technology, often from people whose appetite for innovation is limited. Advances in recent years in computing, internet operation and security suggest that these reservations can be overcome. An important factor will be communication with the public about the emerging technology and its wider social implications.

The concept of automating some of the assistive functions that could enable older people to retain their independence for longer is highly attractive

The Mercedes S 500 autonomous car uses sensors already fitted on the production S-Class to 'see' obstacles and interpret roadside information and a sophisticated route pilot to navigate the way. In September 2013 the pilot car took on traffic lights, roundabouts, pedestrians, cyclists and trams, as it navigated its way from Mannheim to Pforzheim, in western Germany

The technology for autonomous vehicles, for example, is not a great leap forward from the systems in today's cars; the problem is not the autonomous vehicle, but all the other vehicles on the road controlled by humans, and the pedestrians and the cyclists

> Autonomous systems are a highly competitive market and have attracted the recent attention of some of the biggest and fastest-growing companies in the world

3. The UK position

Some perceive that autonomous systems only equate to robotics and automation, but the technology includes so much more. By broadening the definition of the sector, the UK can enhance the uptake and development of such systems in many industries and communities. The broader definition of autonomous systems plays to many UK strengths in terms of research and development in sectors such as software development, sensors, control algorithms and systems development.

Autonomous systems are a highly competitive market and have attracted the recent attention of some of the biggest and fastest-growing companies in the world. Professor David Lane FREng, Director of the Edinburgh Centre for Robotics, who chaired the event, spoke of a "feeding frenzy" among companies such as Google, Amazon and Uber to recruit talented engineering students worldwide for their planned operations in this area.

There have been recent initiatives to help give international advantage to the UK in the development of autonomous systems, and the UK government made a manifesto commitment before the 2015 election for investment in robotics expertise.

There are other UK advantages aside from political support. In the area of applying autonomous systems in healthcare, for example, the UK's National Health Service could act as a single coherent customer, and can offer opportunities to trial new systems.

The UK's position on autonomous vehicles is also an advantage. By not signing the Vienna Convention – which, for most countries, limits the degree to which public roads can be used for trials of new kinds of vehicle and new control systems – the UK is in a good position to host real-world trials of next-generation cars.

The C-Enduro is one of 50 systems developed by ASV. The autonomous marine vehicle with a self-righting hull can operate for up to three months at a time using a combination of solar, wind and diesel energy. It can be used by oceanographers for a variety of sea-going research missions and for security and defence purposes including chemical detection and anti-submarine warfare © ASV

There are other businesses looking to develop autonomous systems to help stimulate growth. From the defence and security industries, where autonomous systems offer the possibility of taking on jobs that are too dangerous or unpleasant for humans to do, through to the highly competitive retail sector, which looks to extend the efficiencies of automation and autonomous systems throughout the supply chain, the UK has potential to be a significant world player in the application of new ideas into new markets.

Keith Williams, Group Vice President for Intelligent Systems at the innovation consulting group Altran, said that autonomous systems were at a "technical tipping point" where technologies that were previously independent such as data analytics, connectivity, robotics and sensors were now interacting. In addition to the market 'push' of the involvement of the big names, there was also market 'pull' in terms of potential productivity gains that were of particular relevance to UK industry. "If we apply best-in-class robotics, we could increase productivity by 22–23%," he said. "This is a great opportunity for the UK, but it needs to be addressed now and urgently."

Williams said that the leadership offered by the big groups getting involved could be turned to advantage by individual countries which took a proactive role in fostering the deployment of systems. "We have to use the regulatory system for competitive advantage, with the government taking a role as an active risk-taker and innovative links through to venture capital that could include using national institutions such as the NHS," he said. "The world is moving, the opportunity is big, and we have to act now."

Advantages of autonomous systems are their ability to go into places and situations where humans cannot

4. What can autonomous systems do?

The virtues of robots and other conventional autonomous systems are that they extend and expand upon human capabilities. Industrial robot systems improve on human performance in terms of strength and speed, and more generally their prime assets in industrial use are accuracy and endurance.

Advantages of autonomous systems are their ability to go into places and situations where humans cannot. This includes dangerous places, such inspecting inside nuclear reactors to check for faults, and inaccessible places, such as inside aero-engines.

Within current markets, there is a lot of scope for innovation. Examples presented at the event included the use of unmanned aerial and marine systems, taking advantage of advances in control systems, sensors and onboard processing.

Dr Oliver Payton from the University of Bristol is part of a team that is developing small-scale drone aircraft that can be used to map radiation leaks and other environmental phenomena from the air. The nuclear incident at Fukushima in Japan after the 2011 earthquake and tsunami was the starting point for the work, he said. Manned surveillance of the radiation from the plant using helicopters was deemed too dangerous until days after the event. The development of small-scale unmanned aerial vehicles (UAVs) offered not only safety benefits, but also advantages in terms of speed of deployment, lower cost and configurability.

Dr Payton's project demonstrates how autonomous systems can quickly benefit from innovation in many other sectors. In terms of instrumentation and sensors, the team uses gamma ray spectrometers developed in the nuclear industry, together with liDAR systems – the equivalent of radar that uses light – and open-source UAV autopilot systems, to create a system capable of producing isotopic maps of square-km sized areas.

> These airborne and seaborne autonomous systems are successors to traditional robotics, in that they are devices that are programmed by humans, but are able to work remotely with no direct human contact

"Ideas can be deployed quickly", said Dr Payton, who noted the use of off-the-shelf components and do-it-yourself staples such as duct tape in prototype systems. The aim, he said, was to reduce costs "to the point of becoming a disposable unit" compared to the current manned solution, while maintaining performance and reliability.

As well as in the air, at sea the safety considerations, speed of deployment and innovation in sensors are factors behind the growth of Autonomous Surface Vehicles (ASV). The company's managing director, Dan Hook, told the event that gathering data from the world's oceans was always seen as expensive and potentially dangerous. ASV has identified a wide range of markets from mine detection and clearance through to evaluation of sea conditions for offshore energy structures where autonomous vessels could operate reliably and safely. A significant contract for the company has seen the devices deployed as high-speed remote targets for the Royal Navy.

The benefits of autonomous devices in this industry, he said, are to do with the modularity of systems and their potential for redeployment and reuse. These help save money: "in terms of scientific research, you are simply going to get more data for a much lower cost," Hook said. There are still technology issues to be overcome in the areas of autonomy, situational awareness and real-time sensor processing and most systems currently operate on a line of sight communication link. ASV is working on an over-the-horizon capability, and this will bring "real cost savings" for operators, Mr Hook said.

These airborne and seaborne autonomous systems are successors to traditional robotics, in that they are devices that are programmed by humans, but are able to work remotely with no direct human contact. The relationship between humans and autonomous systems is changing, with numerous innovations now designed to engage and interact with people.

The Sheffield Robotics brings together researchers in engineering, science and design, at the two Sheffield Universities, to develop robotic systems that interact with the natural world, including contact with humans. Centre Director, Professor Tony Prescott, told the event that some of their research is driven by what he sees as a moral obligation to use robotics to help tackle the demographic problem of the ageing population.

Developed countries are experiencing a trend in increasing lifespans and falling birth rates. In the UK, the number of elderly people is rising dramatically at a time when the ability of the state to provide social care is beset by economic difficulties as well as staff shortages. Quality of life for older people is achieved best by enabling them to remain independent in their own homes for as long as possible. Loss of independence is often the result of fairly small-scale changes: psychological factors such as confidence, a marginal reduction in mobility, or forgetfulness.

MIRO is a biomimetic robot created by the University of Sheffield that copies the behaviour of animals. It can learn from its interactions and can become loyal to its owner and respond to their voice

Work on assistive technology at Sheffield Robotics is wide ranging. It includes biomimetic studies that have developed a pet-like robot companion, and the development of an intelligent table designed for people with limited mobility that comes to the user and configures itself to their sitting or lying position.

The popular idea that autonomous systems in the home will include humanoid-style robotic 'butlers' may not come to pass, Professor Prescott said: "They're expensive to build and maintain, and are not the ideal design for many of the challenges we face in the home. We are more likely to see an "ecology" of simpler robotic systems that interface with a central computing hub that regulates the future smart home."

There is a need, he said, to rethink our definitions of robotic technologies to include interactive devices that offer functionality alongside some discreet sensing and monitoring, a few gentle reminders for the forgetful and a degree of unobtrusive companionship. Professor Prescott terms this kind of autonomous system as a 'social bridge'. Its key to success will be how comfortable the market, mainly older people who are less receptive to innovation, feels about it.

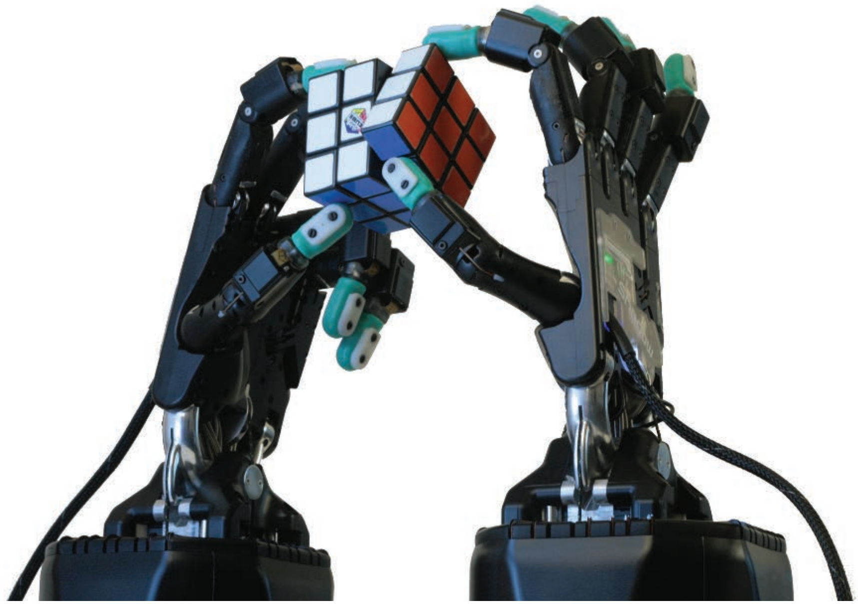
> We 'instinctively' know, if asked to fill a series of differently-sized teacups that we will need to pour different amounts. But a robot has to be told: pour to a certain level from the top, or pour the same amount, which will mean some are overflowing and some only half-full

5. Extending the capabilities of autonomous systems

The aim for some autonomous systems research, outlined at the event, is to broaden the range of tasks that are entrusted to robots and other automated devices. This would bring machine reliability into new real-world situations, such as domestic use with human interaction. This means there are new demands for the autonomous system: the ability to respond to unexpected turns of events or responses, and to make adjustments in behaviour accordingly.

If one of the future aims is to use autonomous systems in social care, then the systems need to be able to handle human unpredictability. Currently, autonomous vehicles have to operate in a real world in which not every road user is as rational and safety-conscious as the autonomous system.

"The key challenge is knowledge," said Professor Michael Beetz, Head of the Institute for Artificial Intelligence at the University of Bremen in Germany. There are key aspects to everyday tasks that we as humans very rarely verbalise: we 'instinctively' know, for instance, if asked to fill a series of differently-sized teacups that we will need to pour different amounts. But a robot has to be told: pour to a certain level from the top, or pour the same amount, which will mean some are overflowing and some only half-full. "Things we do everyday but never communicate make it hard," Professor Beetz said. "A simple instruction like 'pour stuff from a pot' depends on what is in the pot, and then the robot has to reason how to grab the pot, whether it's got a lid or not, when to stop. These things have to be programmed explicitly."



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The Bremen team, that he leads, is working on a universal open language that will 'parameterise' plans and instructions and create a knowledge base that describes real actions. But even with this kind of knowledge, there is a need for the robot to know when to apply what it knows. As humans, we do this by using 'episodic memories', which apply context to actions and enable us to extract the appropriate response and action from our reservoirs of knowledge.

Professor Beetz and his team are working on giving autonomous systems this kind of experience so they learn what works and what doesn't. Making instruction manuals and web-based materials 'readable' by machines, and creating a single core knowledge bank in a universal language, enables a system to share what it has learned with other systems.

At King's College London, Professor Maria Fox is working on other aspects of intelligence that need to be understood if autonomous systems are to handle real-world situations. Her work is aimed at building awareness of time constraints into autonomy: teaching them to act in a timely fashion, to anticipate the next action and the consequences of both past actions and the actions they are about to take; to plan ahead.

An example of an autonomous system that would require this kind of time-based intelligence is a management system for a bank of batteries, where the system has to be able to anticipate charge and discharge cycles, monitor individual battery performance and the collective output, and be ready for unexpected events.

Professor Fox is developing automated planning algorithms. The planning system searches among actions that can be applied, and infers what happens if available courses of action are pursued and what system constraints each course will generate. In the search-infer-relax paradigm that Professor Fox uses, the planner uses a 'relaxed' model of how actions interact, in order to obtain estimates of the difficulty of a problem. These estimates are used to guide search, along with inference which prunes out parts of the search space that are inconsistent with the model. This kind of forward planning is, she said, critical to future autonomous system 'smartness': "The timing of actions is critical; just as critical as knowledge," she said.

The requirement to build more human-like reasoning and intelligence into autonomous systems to make them fitter for the complexities of the real world has implications for the way that humans interact with the systems. At Warwick University, Dr Jack Cohen, supported by the Royal Academy of Engineering Enterprise Hub, has developed a headset that brings together augmented and virtual reality with 3D, allowing computer use to be visualised and captured in new ways.

Dr Cohen's work is at an early stage, but the implication is that there could soon be different ways to use computers other than through keyboard and mouse or touchscreen interfaces. He is developing a more immersive experience using head-mounted displays and head orientation tracking technology. The user will interact with the computer and software through a three-dimensional computer-generated environment. Uses will go beyond the computer game industry to professions in design, architecture and teaching.

> The implication is that there could soon be different ways to use computers other than through keyboard and mouse or touchscreen interfaces. The user will interact through a three-dimensional computer-generated environment

Photo: Woman using virtual reality headset

> For many sectors, autonomy would make a fundamental change to current business models

6. The markets for autonomous systems

The 'push' for autonomous systems is coming from the involvement of the huge corporations and from the linking together of technology developments in connectivity, sensors and handling of big data. Market 'pull' is coming from a very wide range of applications where autonomy promises to do things that could not be done before, or to do existing operations more efficiently or safely. The event assembled a diverse panel of business, funders and research experts to point to just a few of the implications of innovation in this sector. The overriding view from all was that it was impossible to overstate the impact that the technology of autonomous systems are going to have.

Paul Clarke, Director of Technology for the online retail group Ocado, said that autonomous systems were at the heart of his group's future plans, and that there were technical challenges that it was seeking to overcome. Robotic picking of groceries for delivery was a complex task, he said: Ocado carries over 40,500 different types of item, many of them with irregular shapes, some of them delicate and often with a short shelf life. Robotic delivery, at least between warehouses, but perhaps in the longer term out to customers, is attractive too, and as a company with a lot of fixed assets in terms of buildings and mobile assets in vehicles, automating the maintenance is also on the wishlist.

Clarke's aim, he said, was "to use robotics to add value" to the business. The intersection of the internet of things with autonomous systems, through smart devices inside smart homes, is an attraction, and there are potential new business areas to go into that could include health.

Automated warehouse storage and retrieval system

Dr Sabine Hauert is Lecturer in Robotics at the Bristol Robotics Laboratory, and president of Robohub.org, an information-sharing website about developments in autonomous systems. One of the areas that she has been investigating is the potential for robot swarms, where micro- and nano-bots can act individually or collectively, to be used in areas such as targeted treatment for cancerous cells. Robotics, she said, had the potential to change working and domestic lives, the exploration of the planet and beyond, and manufacturing and service industries. But there are also societal challenges in terms of acceptance that could be tackled through better communication with the public.

Dr Chris Haley, Head of New Technology and Start-up Research at Nesta, saw the likelihood that for many sectors, autonomy would make a fundamental change to current business models. In the automotive sector, for example, switching the emphasis in driving from a human being to the vehicle is likely to affect the vehicle ownership model: people may buy 'mobility' as a concept rather than a vehicle as such. Risk, and the whole insurance sector that deals in it, changes fundamentally when autonomous systems are in play. And the way we live now in cities is geared to movement that is principally dictated by cars. In all of this, Dr Haley added, there would be some people who gained from the changes and some who lost out, so this was a matter for the development of education and skills policy and for wider governmental involvement.

Dr Nikos Pronios, Lead Technologist for Information and Computing Technologies at Innovate UK, is part of the mechanism that ensures the UK government is fully informed on technologies such as autonomous systems and is also responsible for channelling public investment into research in this area. Autonomous systems, he said, will have a long evolutionary path towards their complete 'autonomy', and in the short-term should be seen as supporting human decision-makers to make more intelligent decisions. The wide adoption of autonomous systems without a human in the loop during their operation, face various challenges that are technical, societal, regulatory and environmental.

Autonomous systems have the potential to affect every part of life, business, industry and education, and the implications are huge across the board. As the event chairman Professor Lane concluded, there is "everything to play for".

Autonomous systems have the potential to affect every part of life, business, industry and education, and the implications are huge across the board

7. Further information and reading

Royal Academy of Engineering – Autonomous systems: social, legal and ethical issues
www.raeng.org.uk/publications/reports/autonomous-systems-report

Nesta – Our Work Here is Done: Visions of a Robot Economy
www.nesta.org.uk/publications/our-work-here-done-visions-robot-economy

Nesta – Creativity vs Robots: The Creative Economy and the Future of Employment
www.nesta.org.uk/publications/creativity-vs-robots

8. Acknowledgements

The Royal Academy of Engineering would like to thank the following speakers for their contribution to *Innovation in autonomous systems*:

Chair

Professor David Lane FREng
Director, Edinburgh Centre for Robotics

Speakers

Professor Michael Beetz
Professor for Computer Science, Faculty for Informatics, University of Bremen; Head of the Institute for Artificial Intelligence

Paul Clarke
Director of Technology, Ocado

Dr Jack Cohen
RAEng Enterprise Fellow, University of Warwick

Professor Maria Fox
Professor of Computer Science, King's College London

Dr Chris Haley
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Dr Sabine Hauert
President and Co-Founder, Robohub

Dan Hook
Managing Director, Autonomous Surface Vehicles

Dr Oliver Payton
Research Associate, University of Bristol

Professor Tony Prescott
Director, Sheffield Centre for Robotics

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