UK-RAS White papers

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UK-RAS NETWORK
ROBOTICS & AUTONOMOUS SYSTEMS

Manufacturing Robotics
The Next Robotic Industrial Revolution

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UK-RAS NETWORK
ROBOTICS & AUTONOMOUS SYSTEMS

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FOREWORD

THE NEXT ROBOTIC INDUSTRIAL REVOLUTION

Welcome to the UK-RAS White Paper Series on Robotics and Autonomous Systems (RAS). This is one of the core activities of UK-RAS Network, funded by the Engineering and Physical Sciences Research Council (EPSRC). By bringing together academic centres of excellence, industry, government, funding bodies and charities, the Network provides academic leadership, expands collaboration with industry while integrating and coordinating activities at EPSRC funded RAS capital facilities, Centres for Doctoral Training and partner universities.

Since the start of the first industrial revolution, Britain has been synonymous with manufacturing. As we enter the era of the fourth industrial revolution, innovation in RAS will underpin technological change bringing opportunities for UK manufacturing to be more productive across all sectors. Already, RAS is starting to change the way in which large-scale manufacturing industries do business, bringing improved competitiveness, flexibility and higher living standards. As these technologies move beyond their traditional settings by becoming safer, smarter and cheaper, future research and development will afford the next generation of “smart factories” the ability for human and machines to work closer together in new ways, helping UK manufacturing to be more local and high-value.

This whitepaper discusses the role of RAS in making UK manufacturing more productive and highlights the future trends, opportunities and challenges for UK manufacturing to keep up with technological change. The UK-RAS white papers are intended to serve as a basis for discussing the future technological roadmaps, engaging the wider community and stakeholders, as well as policy makers in assessing the potential social, economic and ethical/legal impact of RAS. It is our plan to provide annual updates for these white papers so your feedback is essential - whether it be pointing out inadvertent omissions of specific areas of development that need to covered, or major future trends that deserve further debate and in-depth analysis.

Please direct all your feedback to white-paper@ukras.org. We look forward to hearing from you!

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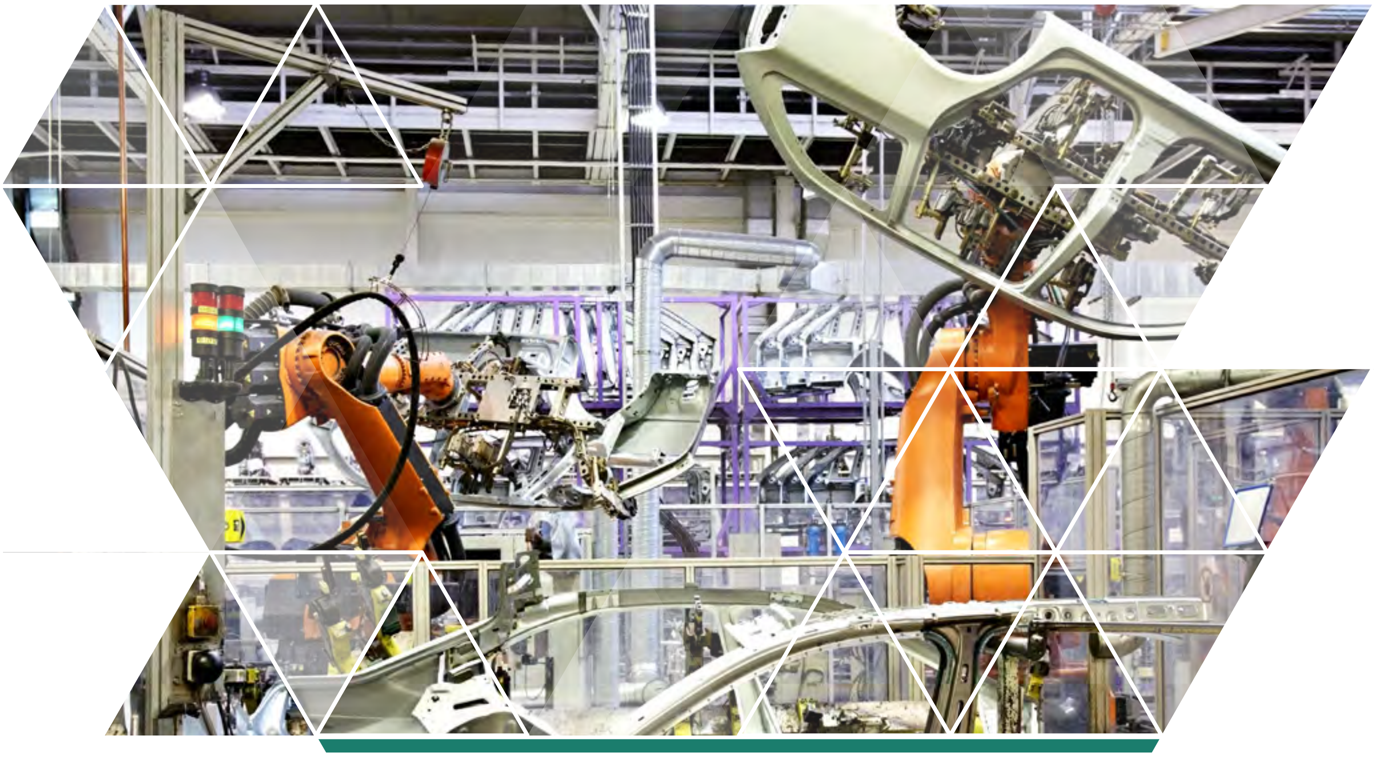
On behalf of the UK-RAS Network, established to provide academic leadership, expand collaboration with industry while integrating and coordinating activities at EPSRC funded RAS capital facilities, Centres for Doctoral Training and partner universities.

CONTENTS



> From industries such as aerospace and automotive to food and drink, electronics, biotechnology, agriculture and the creative industries, future success will be defined by the ability for UK firms to rapidly adapt their physical and intellectual infrastructures to make manufacturing faster, more sustainable and responsive to both global markets and local customer needs.

1. THE NEXT ROBOTIC INDUSTRIAL REVOLUTION

Ushering in a "Golden Age" in productivity, the first industrial revolution began in Britain with the mechanisation of the textile industry. Driven by new technologies, such as the steam engine, for the first time cotton mills emerged as places where manufacturers could use machines to automate tasks previously done by hand. From this point onwards, progress in the design of motorised machines, coupled with new methods for metal production, became a key pillar for economic development; paving the way for greater trade and transport between cities through the building of large infrastructure projects including rail networks, bridges, tunnels, aqueducts and ports. Higher standards of living were also achieved as new methods for automation were used in primary sectors of the economy, such as agriculture and mining, helping to lower costs of labour intensive foodstuffs and the collection of raw materials.

In the 20th century, the second industrial revolution kick-started new levels of growth with the age of mass production. Inspired by the meat-packing plants in Chicago and Cincinnati, new technologies such as the moving assembly line at Ford, and the use of electricity, enabled successful economies to exploit higher levels of automation to establish more efficient production processes. Advances in machinery improved the precision in product manufacture, which helped generate a new wave of scientific discoveries that fundamentally changed how people lived (such as the telephone, the light bulb and the internal combustion engine). Altogether, these innovations improved the connectivity for economies to grow in scale, reduce costs and allow supply chains to become ever more profitable. Key drivers for success also came from the standardisation of manufacturing processes that improved the quality of consumer products. Further, the development of legal frameworks encouraged a growing ecosystem of innovators with the freedom to take advantage of financial rewards without being exposed to early competition.

Throughout history, technological innovation in automation has underpinned every industrial revolution. Continuing this trend, progress in scientific disciplines such as mechatronics, computing and communication technologies has given birth to the field of modern robotics and autonomous systems (RAS); giving rise to new capabilities that will enable economies to be more productive and resilient.

The first industrial revolution (1760 - 1840):

Illustration of a mechanised loom powered by steam (key growth industries include textiles, iron and steel, coal leading to capital infrastructure investments)

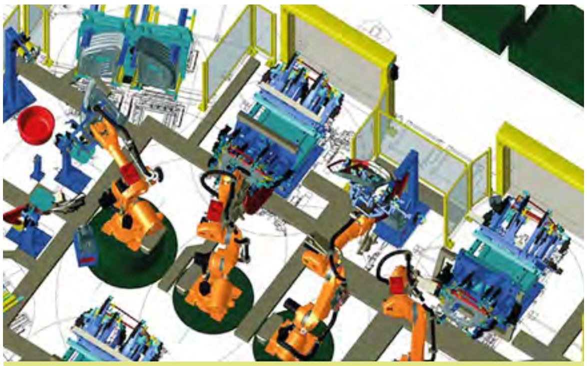
Second industrial revolution (1870 – 1914)

Assembly line at the Ford Motor Company (mass production techniques led to the expansion of electricity, petroleum and steel industrial sectors)

Already robotic systems play an important role in a range of economic activities from the automotive, aerospace and electronics industries to food, recycling, logistics, and biotechnology sectors. Combined with the growth in digital innovation, the increasing capabilities for both automation and connectivity is providing a new platform for closer relationships between designers, managers, workers, consumers and physical industrial assets that will fundamentally change the dynamics of the value chain to be more responsive to customer needs. With the convergence of associated technologies such as artificial intelligence, big data, embedded systems and human-machine interaction, progress in RAS will not only target highly repetitive low-skilled jobs but also highly routine medium-skilled professions. As the fourth industrial revolution is upon us, UK manufacturing needs to be positioned to exploit future opportunities in RAS. With Govt. support, successful UK firms will be able to develop new business models that open up value chains in new ways for a more productive economy.

Successful firms that exploit a RAS-led fourth industrial revolution will:

- Be more productive, resource efficient and responsive to customers
- Support mass customisation of products focusing on high value manufacturing
- Have easy access to robotic technologies with increasing levels of autonomy
- Exploit digital frameworks to provide closer relationships between manufacturers, products, value chains, business models and consumers.
- Have access to a local and highly skilled multi-disciplinary workforce
- Support flexible and robust legal systems to trade and protect intellectual property to other economies and competitors respectively
- Utilise new RAS security and safety frameworks for new integrated modes of working



Third industrial revolution (1980 – 2015)

Digital manufacturing -
RobCAD is a popular software used in digital manufacturing. Models of automated machinery and production lines can be created and simulated in real time (emergence of computing, simulation and communication technologies support new methods for digital manufacturing)

Fourth industrial revolution (2016-2020)

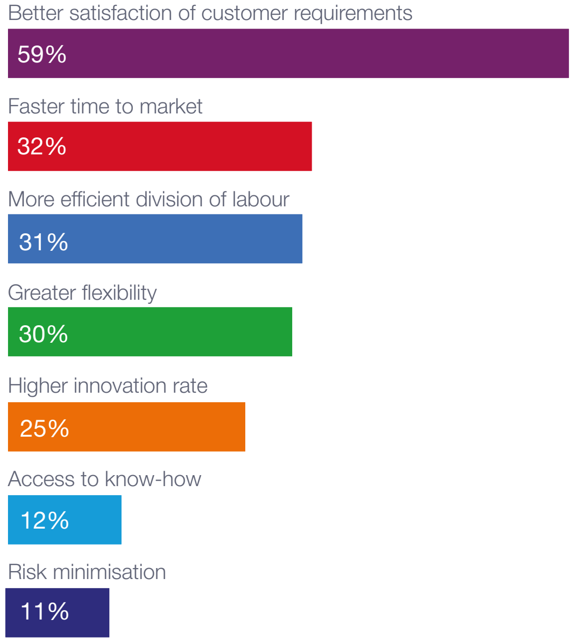
Illustration of a Factory of the Future (convergence of robotic and ICT technologies to create cyber-physical manufacturing systems that have the potential to be more productive, resource efficient and responsive to customer needs)

2. RAS TO BRING TOGETHER A SET OF CONVERGING TECHNOLOGIES FOR INTELLIGENT AUTOMATION

A number of remarkable technologies are converging: unprecedented computing power, dexterous robots, novel materials, software that can learn and a range of web-based services. Soon the factory of the past, limited to producing only identical products, will be transformed. As researchers develop more intelligent and flexible robot capabilities, these technologies will help manufacturers lower the cost of reconfiguring their production processes for smaller batch sizes of a wider variety. In doing so, they will be able to tailor each product to their customer's needs and move up the value chain, whilst being less reliant on a low skilled workforce. Through these changes, the Factory of the Future will focus on high value, mass customisation.

As robotic technologies become smarter, faster and cheaper, they will be called upon to do more. Moving beyond traditional, repetitive, or even dangerous tasks such as welding and materials handling, increasingly robots will take on more human capabilities. Progress in maturing information and communications technologies (ICT) such as artificial intelligence, machine learning, vision and haptic sensing, are starting to give robots traits that mimic our own ability to interact, manipulate, train and recognise objects needed to autonomously customise products. Already, we are witnessing robots such as the ReThink Robotics Baxter robot and Amazon Robotics Kiva warehouse system taking on more jobs that require higher levels of dexterity including picking and packaging, testing or inspecting products and assembling complex electric components. Demonstrating the maturity of these solutions, data collected by the The Robot Report show that companies such as Foxconn (supplier to Apple and Samsung) recently invested $118M in robots to improve their factory capabilities. Further, by designing robots with greater precision, we can begin to manufacture in new domains beyond what is physically possible, such as working at the scale of a cell to create new types of drugs or at the size of an aircraft, beyond human physical capabilities.

Driver for closer co-operation (selection of the top 2 reasons by percentage)



Source: PriceWaterHouseCoopers, Strategy& - Industry 4.0, Opportunities an allenges of the industrial internet

Manufacturing co-bot

ReThink Robotics Baxter Robot

A new generation of "collaborative" robots will also enhance the impact of intelligent automation by maximising the abilities of both humans and machines. As robots become safer and allow close working with humans, the potential applications widen beyond the traditional industries of aerospace and automotive to food and drink, agriculture, biotechnology and the creative industries which are already adding robotic co-workers to their ranks. Based upon preliminary results from an EPSRC sponsored survey by University of Sheffield, University College London and University of Warwick on human and robot interaction, factories of the future will be developed to be adaptive and smart manufacturing systems. They will use intelligent robots and machines that cooperate both among themselves and workers in a safe, autonomous and reliable manner to support capabilities that otherwise would not be possible.

Through closer integration of RAS, ICT, embedded systems and big data technologies, factories of the future will achieve the following objectives:

- Mass customisation through flexible and reconfigurable machinery and robots
- Embedded cognitive functions for supporting the use of machinery and robot systems in changing shop floor environments
- Symbiotic safe and productive human-robot interaction, professional service robots and multimodal human-machine-robot collaboration in manufacturing
- Smart robotics - scaling up for flexible production and manufacturing

Automated warehouse

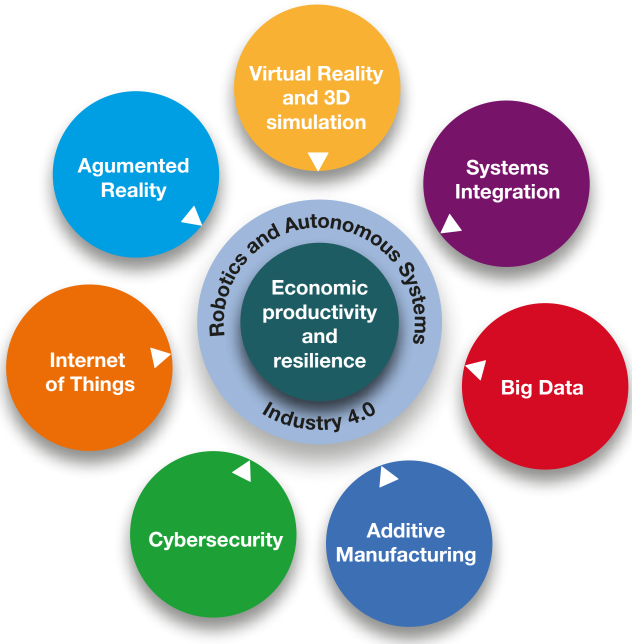
Amazon Robotics Kiva system (Automation, Control and Intelligent Systems, 2016)

Optimised SMT lines for electronics industry

Kuka LBR Iiwa collaborative robot

3. PROGRESS IN RAS TO ENHANCE THE DIGITAL REVOLUTION

Building upon progress made in ICT and embedded systems technologies, industrial leaders are starting to enhance their product portfolio with digital functionalities to introduce data-based driven services, real-time analysis and security functions. To help support these initiatives, governments at the forefront of the fourth industrial revolution are developing policy frameworks to ensure their economies take advantage of these technological innovations and increase productivity. Originating from the German Govt., Industry 4.0 is a framework that promotes the computerisation of manufacturing. By defining the term "smart factory", Industry 4.0 brings together paradigms such as the internet-of-things and cyber-physical systems. In doing so, it harnesses the potential of connected devices that can communicate with each other, making decisions that are more responsive. Examples include completing tasks intelligently with minimal human input and materials being transported across the factory floor using autonomous mobile robots performing deliveries in real-time. It is expected that the revolution in RAS combined with Industry 4.0 will enable manufacturers to coordinate resources more efficiently and automate processes at a greater scale to increase productivity.



It is clear that digitising the factory and supply chain, in addition to the introduction of Intelligent Automation, is set to be the biggest change to UK manufacturing in a generation. Based upon results from a conference at the Manufacturing Technology Centre, it was reported that whilst most UK manufacturers are familiar with the term, many don't understand what Industry 4.0 actually means nor fully appreciate its potential impact to their business. In response, key differentiators for the UK include its record in innovation and world leading expertise in its research base. These aspects need to be exploited in order to compete with the rest of Europe, especially Germany.

Fundamentally, continued investment in RAS research, education and skills will have a critical role in delivering Industry 4.0. It will provide opportunities to test and demonstrate new production methods to major challenges such as security, safety and trust with robotic co-workers, consequences of intelligent automation on the workforce, and adapting to changes in human resources. To overcome these barriers, continued support for activities, such as collaboration between academia and the High-Value Manufacturing Catapult Centres, will help to exploit the world

"

If UK manufacturers were to invest as much in Industry 4.0 as their German counterparts, they could boost their revenues by £20B".

Steve Brambley, deputy director of Gambica, argues that it is essential for the UK not to be left behind by the fourth industrial revolution.

Source: Industry 4.0- the opportunity for UK manufacturing, The Manufacturer class multi-disciplinary skills that exist in the UK and train the next generation of industry leaders. Further, working within the Govt.'s Productivity and Innovation Plan, supporting these relationships is essential for maximising value, and bridging the gap between areas where the UK has a distinct competitive advantage.

Key benefits for UK firms that implement RAS and Industry 4.0 frameworks:

- On demand, mass customisation of products and services
- Distributed local and global production base, with manufacturing performed closer to the customer and having the ability to support greater diversity of products
- 'Digitised' manufacturing value chains, with digital connections between customers, manufacturers and suppliers increasing the speed and efficiency of manufacturing, and enhancing opportunities for international collaboration
- Digital fabrication tools providing greater freedom of design and optimisation.
- More flexible manufacturing systems delivering better throughput, quality and cost performance
- Enable utilisation of a highly skilled multi-disciplinary workforce for faster innovation

Siemens virtual reality CAVE system

Collaborative automation, Cranfield University

Eye tracking controlled robot manufacturing, Cranfield University

4. CONTINUED INNOVATION IN RAS FOR UK MANUFACTURING MATTERS

Manufacturing is a fundamental activity of the UK economy. Accounting for more than half of all UK exports, it contributed £148Bn to UK Gross Value (GVA) in 2013. As UK manufacturing moves toward more high-tech and high-value activities, strengths in key sectors such as aerospace and automotive are broadening to the life sciences, biotechnology, agriculture, food and drink and the creative industries. To date, food and drink manufacturing provides the largest number of UK jobs. Investments in the next generation of manufacturing capabilities related to the areas of embedded electronics, graphene, biomaterials and other advanced materials, are also starting to grow.

To underpin greater levels of productivity, across all sectors, it is essential that UK manufacturing is at the heart of a dynamic future economy. As stated in BIS economic reports (NO. 10A), innovation and training in manufacturing leads to upward growth throughout the whole economy; increasing demand for raw materials, energy, and services like research, design and finance. In 2012, it accounted for £12.8Bn in UK business R&D and provided employment for 2.6M people. Further, UK manufacturing jobs are becoming highly skilled with more employees having a degree, thus leading to increased wages and living standards.

For UK manufacturing to compete against growing global competition, current expertise in RAS and related ICT technologies needs to be exploited. By embracing RAS in combination with technologies such as embedded systems, internet-of-things, machine learning, big data and artificial intelligence central to the Digital Revolution and the Government's Innovation Plan, will be a key differentiator for closer collaboration between manufacturing supply chain management and customers through integrated systems. As advances in technological innovation provide new manufacturing capabilities for mass customisation, consumer demand for these types of products will also increase. Further, flexible processes such as additive manufacturing, advanced joining, and reconfigurable robotics will reduce the importance of economies of scale in some types of manufacturing and support greater localisation of the supply chain. Altogether, it is expected that successful firms will favour suppliers that are local and adaptable to these changes.

UK Manufacturing contributions in 2015:

10%
of GVA

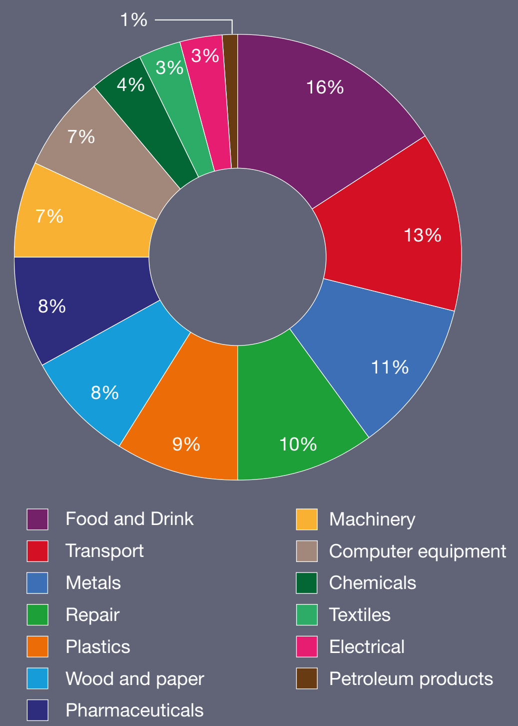
69%
of R&D (£12.7Bn)

15%
of business investment (£27.3Bn)

Average earnings
(mean annual gross pay - £30,009)

Source: OECD

Sub-sector contribution to UK manufacturing output, 2014:



Source: The Manufacturer, Annual Manufacturing Report 2016

5. ROADMAPS FOR THE FUTURE

Findings from the Foresight "Manufacturing the Future Report" indicated that manufacturers are increasingly using a wider value chain to generate new and additional revenue from pre- and post-production activities. For example, surveyed in 2011, 39% of UK manufacturers with 100 or more employees derive value from associated services related to their products. As manufacturers expand their activities to capture value throughout the lifecycle of their products, an integrated view of manufacturing is needed that places greater importance on using new sources of knowledge to establish closer relationships with customers.

Taken from commentary at Siemens Congleton, in a globalised manufacturing market place, UK manufacturing has adapted to continuously increasing world-wide cost competitiveness, especially from lower-cost geographies. This adaption has been primarily driven through the application of cost-reduction methodologies such as classical lean manufacturing, which seeks to reduce non-value manufacturing activities, and therefore, positively impact the business EBIT. However, we find ourselves in a commodity driven marketplace, regardless of business area, where customer expectation on cost, availability and flexibility is the norm. This modern-day consumer appetite, a key fundamental driver of Industry 4.0, puts RAS at the heart of the manufacturing environment.

This new environment, however, is not simple nor predictable, but complex and dynamic; it is not based on simplistic, repeatable and ergonomically challenging traditional tasks but based on the very tactile skills, intuition and tacit knowledge that typify human behaviour. It is the ability to replicate human factors in terms of efficient learning/teaching, responding to direct environmental change, highly capable manipulation skills, work-place perception and safe "colleague" collaboration that will fundamentally allow RAS to continue to drive future productivity in a way that lean manufacturing has served so well.

It is expected that future successful firms will create new sources of revenue by:

- Selling services in combination with products
- Using products to generate information about consumers and their usage
- Capturing value by selling technological knowledge
- Shifting to a circular way of doing business and recycling end of life products
- Making use of changes in ownership by providing more robust products for collaborative consumption
- Forming strategic alliances with manufacturers and academic institutions across sub-sectors, resulting in collaborative communities which may become more significant than networks dominated by lead firms
- Using operational capabilities combined with greater entrepreneurial insight to respond rapidly to technological developments
- Using new digital metrics to access the scale and location of sectoral changes with greater speed
- Maximising the added value of human skills within automated processes

Manufacturing productivity growth in 2014:

3.4%

compared to 0.2% in the whole economy

Source: Manufacturing: statistics and policy, Briefing paper 01942, 2015

Exports and trade in 2014:

£224.3Bn

Exports

£305.6Bn

Imports

Source: Manufacturing: statistics and policy, Briefing paper 01942, 2015

6. RAS CHALLENGES FACING UK MANUFACTURING

Increasingly, challenges from globalisation combined with competition against highly automated and low-wage economies are affecting the success of UK firms. It is clear UK manufacturing needs to change, shifting focus towards high-tech and high-value markets. However, without support for further training and education in RAS and related ICT technologies, UK firms will not have the skills to react to changes in the global market compared to other competing economies. The worst case for inaction is erosion of UK industrial capabilities leading to a hollowing-out of local supply chains across sectors.

Tackling outdated views of automation being barriers to adoption

Despite strong interest in using RAS technologies, there is still perceived resistance holding back widespread adoption. Inevitability, much of the resistance is tied to cost, access to skills and a lack of understanding of how to produce attractive returns on investments; both up-front and ongoing through maintenance and programming of new tasks. Further, according to a survey of UK manufacturers for ABB Robotics, a false belief prevails that current robotic automation solutions are not suitable for low volume or bespoke production processes. It also concluded a lack of awareness of state-of-the-art research in robotic automation, especially in systems that demonstrate advanced levels of flexibility and agility.

Jobs versus robots in manufacturing

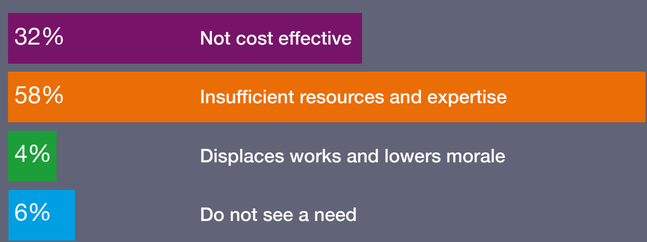
As technological advances lead to ever greater robotic capabilities, companies will grapple with the dilemma of humans and machines competing against each other. Manufacturers could face a series of human resource challenges as they introduce robots to more varied manufacturing tasks with greater need for human-machine collaboration. Based upon industry surveys, over one third of manufacturers said that the biggest impact of robots on the workforce in the next three years is the new job opportunities that will arise to engineer advanced robots and robotic operating systems. In total, one in four felt that the biggest impact would be more demand for new talent to manage the robotic workplace. Equally important is that 27% of manufactures said the biggest impact would be replacement of workers. As robots become more pervasive on factory floors, employers and employees will need to manage not only the benefits but also the human resource challenges.

The conventional thinking is that companies are buying robots to replace people. In contrast, many companies are using robots so they can expand and improve product quality and increase production. For example, in the case of Tesla Inc., investment in automation has led to the hiring of more skilled engineers and sales staff to support growth. Supported by the International Federation of Robotics, they estimate in the longer-term new kinds of service sector and technology jobs will be created, such as creating 'apps' for robots and developing various forms of knowledge services for them to use. In particular, these are areas where the UK can excel. As companies continue to embrace robotics and become more data driven, their success will largely hinge on shaping and building a workforce that can best exploit such technological advancements. To do that, manufacturers are feeling a growing need to draw from a wider pool of talent.

Key findings to overcome future challenges facing UK manufacturing:

- Greater investment in multi-disciplinary STEM subjects and education
- Continued support for initiatives such as High Value Manufacturing Catapults, RAS apprentice schemes, and academic engagement to overcome old perceptions of robotic automation
- Support closer collaboration between academics, training institutes, catapults and SMEs to set up demonstrator projects that overcome business barriers and real-world application integration
- Exploit the "UK Engineer" as a key asset for future growth

Over the next 3 years what would limit future investment in robotic technologies:



Source: PwC and Zpryme survey and analysis, "2014 Disruptive Manufacturing Innovations Survey"

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>
> The unfortunate flipside of the success of robotic automation in the automotive industry is that it has led to a popular belief that robots are only suitable for mass-production processes,” says Mike Wilson, general industry sales and marketing manager for ABB Robotics in the UK. “This couldn’t be further from the truth. Developments in robotic technology have made robots more flexible than ever, enabling them to be switched quickly between completely different products and processes
>
> Source: ABB robotics and automation survey

7. GROWING INTERNATIONAL UPTAKE IN INDUSTRIAL ROBOTICS AND PATENTS

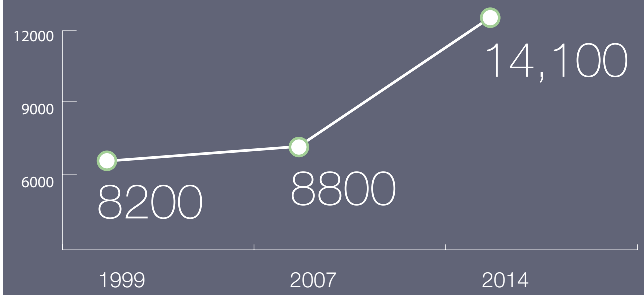
Since 2007, there has been a sharp growth in orders for industrial robots. According to the Robotics Industries Association, orders in North America surpassed 20,000 units from 2011-2013 with a rapid increase in the first half of 2014. Altogether, only five markets represent 70% of the total volume: China, Japan, the US, the Republic of Korea and Germany. In the UK, sales of industrial robots hit 2,100 units in 2014 after considerable investment in the automotive industry between 2011 and 2012. In total, the International Federation of Robotics estimates the global industrial robot market to reach $41Bn by 2020.

Investor interest has also risen sharply since 2010. According to the PwC/NVCA Money Tree Report based on data from Thomson Reuters, capital investments by US venture capital firms rose to approximately $172M (in 10 investment rounds) in 2013, tripling 2011 levels. Supporting continued growth, it is estimated by the UK Intellectual Property Office that 120,000 robotics patents have been published in the last 10 years, tripling in rate from 2004 to 2013. Investment activity also included companies outside of traditional manufacturing. Recent examples include, Google's acquisition of at least eight robotic companies since 2013, including Redwood Robotics, Industrial Perception and Schaft Inc. In 2012, Amazon also demonstrated its commitment to using robotic systems for warehouse automation through buying Kiva systems for $775M. The online retailer plans to roll out 10,000 Kiva robots into a network of warehouses, a move that could realise cost savings of up to $900M according to an analysis by robohug.org.

Based upon industry market reports, key drivers for investment growth include:

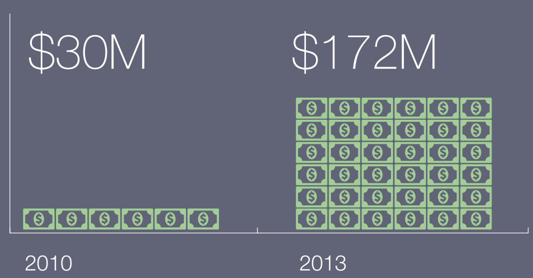
- Continued integration of Industry 4.0 - linking the real-life factory with virtual reality and data driven services
- Breakthrough of human-robot collaboration technologies that maximises the capabilities of both humans and machines in the production line
- Simplification of robotic platforms and flexible interfaces suitable for SMEs to programme for different application needs
- Continued global competition and investments in RAS and ICT technologies
- Energy-efficiency and using new materials, e.g. carbon-composites, require continued retooling of production
- Growing consumer markets require expansion of production capacities
- Demand for flexible automation to extend value throughout the product lifecycle
- Continuous quality improvement requires sophisticated high tech robot systems
- Increases in robotic capability and dexterity to take over dangerous, tedious and dirty jobs that are not feasible or safe for humans

Orders of industrial robots in North America spike in 2014:



Source: International Federation of Robotics 2013

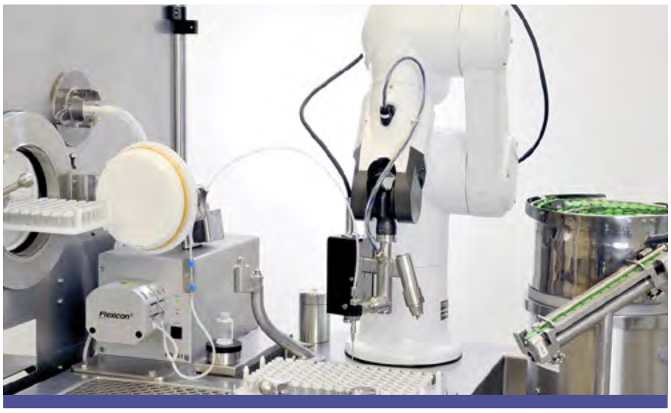
US venture capital investment in robotics technology start-ups:



Source: PwC/NVCA MoneyTree Report based on data from Thomson Reuters

8. RAS MAKING INROADS ACROSS DIFFERENT MANUFACTURING SECTORS

For decades, advanced industrial robotics have been mainly deployed by the automotive industry. In 2005, 69% of all industrial robot orders in North America were made by automotive OEMs to automotive components companies, according to data from the Robotic Industries Association. By 2014, that figure had reduced to 56%, offset by increasing shares by other industries including the food and beverage, consumer goods, life sciences, pharmaceutical, biomedical and metals industries. “We have received orders from tier-one and tier-two suppliers to the automotive industry, but we are attracting interest from other industries such as the plastics, medical devices, food and beverage and high-tech industries,” said Jim Lawton, CMO of Boston-based Rethink Robotics (maker of the Baxter collaborative robot) in an interview with PriceWaterHouseCoopers.
Still, there is much room for growth in the non-automotive sectors. The ‘robot density’ (robots per 10,000 employees) in the automotive industry in the US in 2013 is more than 10 times higher than that in general industry (1,091 vs. 76), according to IFR.



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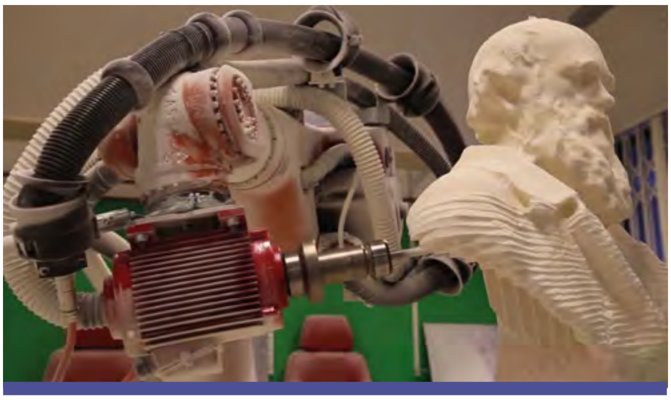
Food and Drink manufacturing, Fanuc

Agriculture, Bonriob



Creative Industries, University College London

9. REVIEW OF INTERNATIONAL FUNDING INITIATIVES

Countries are also supporting modernisation of the manufacturing industry through funding programmes and research initiatives. To provide a review, we summarise and breakdown activities into the following international territories:

The United States:

- Advanced Manufacturing Partnership (AMP)- a private-sector body that brings together representatives of the research, business and political communities to chart a "course for investing and furthering the development of the emerging technologies" and support reshoring of manufacturing jobs
- In the 2013 budget, the funding earmarked for advanced manufacturing increased by 19% to $2.2Bn. The National Institute of Standards and Technology (NIST), which is the body responsible for standardisation, has been allocated $100M of funding to provide technical support to the domestic manufacturing industry through the provision of research facilities and know-how
- NIST is also responsible for the Advanced Manufacturing Portal, which was set up at the AMP's recommendation and is intended to facilitate networking between government, university and private initiatives in the field
- Jobs and Innovation Accelerator Challenge initiative is investing $20M in a further 10 Public-Private Partnerships in the field of advanced manufacturing

The EU:

- euRobotics (comprising the European Commission and 180 companies and research groups) created a robotics research program called SPARC, to kindle a regional robotics hub, with investments of €700M from the EC and €2.1Bn from euRobotics. The program is expected to create 240,000 jobs and lift Europe's market in robotics by about €4B per year
- €2.4Bn has been invested in the ARTEMIS technology platform to promote R&D projects in eight sub-programmes that include both "Manufacturing and Production Automation"
- €1.2Bn have been awarded to the Public-Private Partnership initiative "Factories of the Future" which launches annual calls for proposals for projects in the area of smart, ICT-driven manufacturing

China:

- The 12th Five-Year Plan (2011-2015) aims to reduce dependency on foreign technology and pursue global technology leadership in seven "strategic industries" including High-End Equipment Manufacturing and a New-Generation Information Technology
- €1.2Tn fund to stimulate supply and demand through subsidies, tax breaks and other financial incentives. They also intend to increase R&D investment as a proportion of GDP from 1.5 to 2% by 2015
- In the machine tools sector, priorities include themes such as intelligent manufacturing equipment, intelligent control systems, high-class numerically controlled machines and industrial control and automation
- The School of Software at Dalian University of Technology established a research group as long ago as 2009 with a remit that includes the investigation of CPS applications in automation engineering

10.EXISTING UK MANUFACTURING INVESTMENTS IN THE RESEARCH BASE

Manufacturing the Future is a key research theme sponsored by the EPSRC with a portfolio size approximately worth £350M. It aims to help solve some of the most serious challenges facing the UK and in the future, particular in high-value and specialist manufacturing sectors underpinned by the research base. To do so, investments have been made to establish the following centres:

- Centre for Intelligent Automation, £5.8m (Loughborough University and Cranfield University)
- Centre for Innovative Manufacturing in Advanced Metrology, £4m (University of Huddersfield)
- Centre for Innovative Manufacturing in Ultra Precision, £5.2m (Cranfield University and University of Cambridge)
- Centre for Innovative Manufacturing for Industrial Sustainability, £4.5m (Cranfield University, University of Cambridge, Loughborough University and University of York)
- Centre for Innovative Manufacturing in Industrial Sustainability, £5.2M (University of Cambridge, Cranfield University, Loughborough University and Imperial College London)
- Centre for Innovative Manufacturing in Regenerative Medicine, £5.8M (Keele University, Loughborough University and University of Nottingham)
- Centre for Innovative Manufacturing in Laser-based Production Processes, £5.5M (University of Cambridge, Cranfield University, Heriot-Watt University, University of Liverpool and University of Manchester)
- Centre for Innovative Manufacturing in Medical Devices, £5.6M (University of Bradford, University of Leeds, University of Newcastle, University of Nottingham and University of Sheffield)
- Centre for Innovative Manufacturing in Through Life Engineering Services, £4.8m (Cranfield University and University of Durham)
- Centre for Innovative Manufacturing in Large-area Electronics, £5.5M (University of Cambridge, Imperial College London, University of Manchester, and Swansea University)
- Centre for Innovative Manufacturing in Composites, £4.9m (University of Nottingham, University of Bristol, Cranfield University and University of Manchester)
- Centre for Innovative Manufacturing in Additive Manufacturing. £4.9m (University of Nottingham, University of Leeds and Loughborough University)
- Centre for Innovative Manufacturing in Continuous Manufacturing and Crystallisation, £4.9m (University of Strathclyde, University of Bath, University of Glasgow, Heriot-Watt University, Loughborough University, University of Edinburgh and University of Cambridge)
- Centre for Innovative Manufacturing in Emergent Macromolecular Therapies, £4.9m (University College London, Imperial College London and the London School of Pharmacy)

To support ground breaking research in manufacturing, the EPSRC have run funding calls under the follow themes:

Autonomous Manufacturing:

- Robotic disassembly technology as a key enabler of autonomous remanufacturing, £1.9m (University of Birmingham)
- Aerial Additive Building Manufacturing: Distributed Unmanned Aerial Systems for in-situ manufacturing for the built environment, £2.3m (Imperial College London, University of Bath and University College London)
- Autonomous Inspection in Manufacturing and Remanufacturing, £1.9m (University of Strathclyde and University of Sheffield)

EPSRC manufacturing theme portfolio size approx.

£350m

Source: EPSRC

Manufacturing the Future:

- MTC Engineering Doctorate Centre, £1.2M (Manufacturing Technology Centre and University of Nottingham)
- Centre for Doctoral Training in Embedded Intelligence, £3.5M (Loughborough University)
- Light Controlled Factory, £2.5M (University of Bath, University College London and Loughborough University)
- High Value Manufacturing Catapult Fellowship Centre, £0.99M (University of Sheffield)
- Personalised Stent Graft Manufacturing for Endovascular Intervention, £1.2M (Imperial College London)
- Novel optical instrumentation for robotic manufacturing, £0.65M (Cranfield University)
- Enabling Technologies for Actuated Continuum Surfaces Undergoing Large Deformations, £0.1M (University of Nottingham)
- Flexible and Reconfigurable Laser Processing Tool, £0.1M (Loughborough University)
- Flexible Robotic Assembly Modules for the Built Environment, £0.06M (University of Reading)

To support community engagement in RAS and manufacturing the EPSRC have established the following networks:

- UK-RAS Network
- Industrial Systems in the Digital Age

Example EPSRC research projects

Autonomous Inspection in Manufacturing and Remanufacturing, £1.9M

Aerial Additive Building Manufacturing: Distributed Unmanned Aerial Systems, £2.3M

Tele-operation for Multiple Scales: Enabling Exploration, Manipulation, and Assembly Tasks in new worlds beyond human capabilities, £3M

11.WORKING WITH THE HIGH-VALUE MANUFACTURING CATAPULTS TO TRANSLATE RAS FOR INDUSTRY NEEDS

Catapult Centres are designed to enable companies to access equipment, expertise and information needed to develop and commercialise ideas and innovations. The High Value Manufacturing Catapult (HVMC) is based at the seven research centres listed below. Each centre has a specific focus on an area of manufacturing:

- Advanced Forming Research Centre (AFRC)
- Advanced Manufacturing Research Centre (AMRC)
- Centre for Process Innovation (CPI)
- Manufacturing Technology Centre (MTC)
- National Composite Centre (NCC)
- Nuclear Advanced Manufacturing Research Centre (NAMRC)
- Warwick Manufacturing Group (WMG)

These centres are available to businesses which can demonstrate that they have a product or idea, and require the expertise or equipment that the Centres can provide. Working with the HVMC enables companies to gain access to world-class expertise and the latest industrial scale equipment, allowing them to scale up their innovation, while deferring their own investment decisions until it has been established that can be exploited on a commercial scale. The HVMC has received over £200M of Government investment since 2011. The overarching aim of the Catapult is to double manufacturing's contribution to GDP.

Across the HVMC research is underway into the development and application of RAS technologies in manufacturing. Such work includes the development of collaborative workspaces (i.e. going beyond collaborative robots to include the manufacturing process in the safety/risk assessment), flexible automation and manufacturing systems and lowering the cost of implementation of such systems. This is combined with research into other major disruptive manufacturing technologies such as additive manufacturing and Industry 4.0. Throughout this work, the aim of the HVMC Catapult is to develop innovations made in academia into exploitable solutions for industry.

HVMC highlights

£15	£1.6 Bn	1,259	£183M	1,577
net benefits to the UK economy for every £1 of public core funding received	Economic impact	HVM projects	value of contracts	employees

Source: UK Manufacturing Review 2015-2016

CONCLUSIONS

Over the next 5 to 10 years, innovation in RAS will underpin technological change bringing opportunities for UK manufacturing to be more productive across all sectors. Already, RAS is starting to change the way in which large scale manufacturing industries do business, bringing improved competitiveness, flexibility and higher living standards. As these technologies move beyond their traditional settings by becoming safer, smarter and cheaper, future research and development will afford the next generation of "Smart Factories" the ability for humans and machines to work closer together in new ways helping UK manufacturing to be more local and high-value. With growing competition from other economies, it is becoming essential that UK manufacturing has access to the RAS tools and skills needed to adapt to future changes. Tackling issues such as regulatory standards, outdated perceptions of RAS and IP protection will play a crucial role in the successful translation of RAS technologies. By working together to leverage existing investments in RAS, connected ICT technologies, and infrastructure, we believe the UK has the potential, to not only become more productive, but generate whole new sectors by leading the fourth industrial revolution.

Key findings include:

- New technologies in RAS are leading the way for change in UK manufacturing
- The fourth industrial revolution will focus on high-tech and high-value applications, in particular processes for mass customisation
- Continued RAS innovation will bring together a range of information and communications technologies (ICT) to develop more flexible and agile automation systems
- Future successful firms will use new technologies to create a much wider and digital value chain
- Increasing competition from the US, China, Germany and Japan as they invest in new forms of technologies to support frameworks such as Industry 4.0
- Investing in RAS will enhance Industry 4.0 and help reshore UK manufacturing
- Breakthroughs in human-robotic interaction technologies will enable manufacturers to maximise the capabilities of both their machine and human workforce
- Outdated perceptions of robotic automation technologies, and their effect on jobs, continue to be barriers to adoption amongst SMEs and industry
- Research base has strengths and capabilities in RAS that can be exploited by SMEs and industry
- Supporting training for new RAS skills will help UK manufacturers adapt to future challenges
- Continued academic collaboration with the High Value Manufacturing Catapults is essential in demonstrating the benefits of new RAS technologies coming from the research base and overcoming perceived barriers to adoption by SMEs.

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As the UK strives to overcome challenges when competing, not just with low-wage economics but also highly automated economies, training the next generation of RAS leaders will be a key differentiator in driving up productivity, jobs and future prosperity across the UK’s manufacturing base.

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