Autonomous Manufacturing Workshop Report

4th September 2014

Dr Karen Brakspear
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1.0 Introduction

1.1 Background

High-value manufacturing industries play a key role in enhancing the economic competitiveness of the UK. In 2012, manufacturing accounted for 10% of national economic output and more than half of all UK exports. The future of manufacturing will demand more flexible and adaptive processes with greater productivity, reliability and ensured quality in order to remain competitive. As such, UK manufacturing is driven by technological change and intellectual ingenuity regardless of the industrial sector.

Autonomous systems, which have the ability to learn, adapt and take decisions, have already been labelled as revolutionary technologies of the future in many sectors (8 Great Technologies\(^1\)) and the potential for this technology to make a significant impact in manufacturing has been highlighted by a number of relevant reports including the Foresight report on the Future of Manufacturing\(^2\), the TSB Landscape for the future of High Value Manufacturing in the UK\(^3\), and more recently the publication of the national Robotics and Autonomous Systems (RAS) Strategy document\(^4\). Increasing application of autonomous systems in manufacturing presents the opportunity to boost productivity, flexibility and reliability, add value in a competitive arena and enable innovative new production processes.

Industrial robotics has already had a huge impact in manufacturing; increasing productivity and repeatability, reducing waste and taking over tasks that are arduous, impossible or dangerous for humans. The challenge now is to design a smarter system which incorporates autonomous systems to adapt production processes appropriately for enhanced capability, efficiency, flexibility, sustainability or quality. Addressing this challenge will require combined knowledge and research across a breadth of research areas which may include, but are not limited to, production engineering, computing, control, instrumentation, human interface and mechatronics.

The EPSRC Manufacturing the Future theme is committed to supporting a funding activity in this area. Autonomous systems, underpinned by developments through stimulation of the UK research base, have the potential to make a significant impact in the UK manufacturing sector.

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1. 8 Great Technologies
3. A Landscape for the future of High Value Manufacturing in the UK, Feb 2012. TSB HVM Landscape
Publication of the RAS Strategy and increasing political interest in the area prompted the organisation of this Workshop to ensure that an EPSRC led activity in autonomous manufacturing would generate a diverse portfolio of research that is industrially relevant and focused on advanced manufacturing solutions. Furthermore, to identify beneficial opportunities to align this portfolio of research with existing research and networking activities in other sectors, and those supported by other funding mechanisms e.g. Innovate UK.

The workshop was held on Thursday 4th September 2014 and was a productive event, enabling different academic disciplines and industrialists to engage around an area of common interest and explore potential avenues of future research.

The results of the workshop, comprising this report and the notes taken during the day will be used to assist the EPSRC to understand autonomous manufacturing, the underlying research challenges and the direction EPSRC support should take to address these challenges.

1.2 Aims and Objectives

EPSRC’s Manufacturing the Future theme works to create, capture and accelerate the benefits of ground-breaking research for future UK manufacturing. Autonomous manufacturing aligns strongly with two of the four priority research challenges for the theme; Innovative Production Processes and Manufacturing Informatics. There is a compelling case for innovative research in this area to enable advanced future manufacturing solutions, however the multidisciplinary nature of the teams required and the diversity of sectorial needs in the area requires more a thorough exploration of the research challenges and the appropriate scheme for delivery.

The following objectives were therefore identified for the event:

- Identify and build consensus around how to shape a Manufacturing the Future funding activity in Autonomous Manufacturing and how this could align with the RAS Strategy.
  - Build consensus around the individual research challenges in Autonomous Manufacturing.
  - Explore what ‘success’ could look like.
  - Consider the appropriate scope of the funding activity to ensure that the right people apply with a diverse range of ideas.
The intention of this workshop was to feed into an EPSRC funding activity in the area of Autonomous Manufacturing. The outputs of the workshop will be used to shape the funding activity with regards to scope and format.

1.3 Attendance

Due to time constraints we were unable to invite expressions of interest to attend the workshop through an open call; instead attendees were invited based on their knowledge and experience, with the intention of achieving a balance of academic disciplines and industrial sector representation.

There were 34 delegates in attendance at the event from academia and industry, featuring a range of disciplines (including robotics, human factors, manufacturing engineering and computer science), sectors (aerospace, automotive and biotechnology) and with representation from the RAS Special Interest Group (SIG), HVM Catapult and the Knowledge Transfer Network (KTN) (for delegate list, see Annex 1).

2.0 RAS Strategy and Special Interest Group (SIG) outputs

The RAS SIG was established in January 2013 in a partnership between Innovate UK and the KTN. The SIG, comprising steering group membership of leading industrialists and academics, aims to stimulate collaboration and innovation in RAS capabilities, leading to increased productivity and growth.

Richard Walker, from Shadow Robot Company and member of the RAS SIG steering group, provided an overview of the RAS Strategy document that was launched in July 2014. This document outlines a UK strategy for stimulating growth in robotics and autonomous systems. The strategy was developed for the Government’s Department for Business, Innovation and Skills by the RAS SIG, in consultation with EPSRC and the UK robotics industry.

The Strategy highlights the manufacturing sector as a major market opportunity for RAS, with the potential to encourage production re-shoring to the UK, agile and responsive production, as well as job creation.

During the development of the RAS Strategy, a series of community activities took place including deep dives into the opportunities and drivers for RAS in important sectors, one of which was manufacturing. David Bisset from iTechnic
Ltd provided a summary of the outcomes from this deep dive, and announced that a formal report was due to be published.

The deep dive demonstrated that RAS offers multiple opportunities in manufacturing, with potential to be widely deployed throughout the supply chain from producer to consumer, engaged in various tasks and enabling advanced production technologies and methods. A comprehensive set of value creation opportunities were consequently identified which could enhance UK competitiveness, increase capability, improve working conditions and create jobs. These include:

- Hybrid Factories
- Bespoke Manufacturing
- Reconfigurable Systems
- Integrated Design
- Smart Manipulation
- Contract Assembly

The Strategy and the deep dive outcomes provided a useful contextual summary of the innovation opportunities presented by autonomous manufacturing. However these activities were largely led by Innovate UK and as such, the fundamental underlying research challenges and needs critical for the success of autonomous manufacturing have not been thoroughly explored. The intention of the Workshop was to address this knowledge gap.

### 3.0 Workshop Outputs

The workshop consisted of three broad sessions over the course of one day (for full agenda, see Annex 2). These sessions built from discussions around terminology and definitions of autonomy, to autonomous manufacturing research challenges and the ‘must haves’ for an activity in this area.

The EPSRC definition of the manufacturing Grand Challenge in robotics and autonomous systems was provided as ‘to further knowledge, understanding and innovation of the research challenges underlying the implementation of autonomous systems in UK manufacturing’.

The following discussion provides a review of the outcomes of the workshop and an indication of key areas of interest which were developed during the course of the day.
3.1 What is Autonomous Manufacturing?

Activity

This was not an activity designed to produce a strict and accepted definition of the term ‘autonomy’, since this is likely to differ between disciplines. Instead the terminology used was explored and its interpretation by different people discussed. The aim of the session was to ensure that future EPSRC activity in the area of ‘autonomous manufacturing’ appeals to the relevant communities and is appropriate to the aims of the grand challenge.

In order to understand the terminology and definitions associated with ‘autonomy’ and ‘autonomous manufacturing’, the initial session to the workshop allowed these to be explored in diverse groups (with respect to discipline, sector and industrial/academic background). This was achieved through two activities; first a pre-workshop exercise in which participants were asked to submit three words or short phases about what they thought autonomy meant (in the context of its application in manufacturing). These words/phrases were combined into a word cloud as a focus for group discussion (Figure 1). Secondly, participants discussed in groups the levels of autonomy that exist and mapped these against examples of future potential applications of Autonomous Manufacturing.

Output

Other forms of ‘autonomy’ exist (e.g. energetic autonomy), however it was largely agreed by participants that in a manufacturing context, autonomy referred to the ability of a system to be self-aware, self-reliant and self-directed. Autonomous manufacturing systems should have advanced cognitive capabilities to enable the reasoning, planning and decision making required to achieve strategic self-directed goals and adapt to different variables. It was also stressed by a number of participants that autonomous systems and robotics are not necessarily the same thing, and that the research challenges for each are likely to be distinct.

There was significant discussion around the levels of autonomy required for manufacturing applications. The consensus was that this was application specific, dependent on the type of task, its importance, and the reach of its effect (e.g. intra- or cross-process influence). It was felt unlikely that fully autonomous systems (i.e. without human control) would provide the optimal manufacturing solutions of the future. Instead, the case was made for human-system collaborative working that is designed into the system at the outset and the
balance of which is optimised to the particular process. It was felt by the group that the level of autonomy suitable to a manufacturing application should be optimised to ensure the maximum benefit to productivity, capability, precision, consistency and quality.

Figure 1. Word cloud created from participant’s definition of Autonomy in a manufacturing context

3.2 Developing Research Themes

Activity

This activity aimed to identify and explore the individual research challenges that underlie the implementation of autonomous systems in UK manufacturing.

Participants were initially asked to brainstorm these research challenges individually before group comparison and discussion. It was expected that research challenges could, and should, be identified that do not fully fall within EPSRC’s remit, but that a sub-focus of which could be addressed by EPSRC funded researchers. Clustering of research challenges and prioritisation of
clustered themes led to 4 priority research areas which were explored in more detail in other activities.

Output

This clustering activity produced a series of sixteen themes (listed below and the raw output detailed in Annex 3) and participants were then given the opportunity to prioritise these through voting (number of votes are in brackets after the theme title). The top four priority research themes were then determined with agreement from the group as a whole. These four priority themes chosen for further development within the workshop are denoted by a star (*).

<table>
<thead>
<tr>
<th>Table 1. Research Challenge Themes</th>
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<tbody>
<tr>
<td>Human-Robot Interaction (10)*</td>
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<tr>
<td>Adaptation, learning and complexity (system) (9)*</td>
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<tr>
<td>System behaviour and modelling (6)*</td>
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<td>Sensing, Sensors, Sensor integration (5)*</td>
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<td>Adaptive tooling (4)</td>
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<tr>
<td>Integration, design and legacy systems (3)</td>
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<tr>
<td>System level programming tool (2)</td>
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<td>Adaptive processes (2)</td>
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<td>Awareness and interpretation (2)</td>
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<tr>
<td>Decision making and optimisation (2)</td>
</tr>
<tr>
<td>Human in the loop – skills and instruction (people) (2)</td>
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<tr>
<td>Business/socio-economic case (2)</td>
</tr>
<tr>
<td>Intuitive programming (1)</td>
</tr>
<tr>
<td>Verification, deployment and validation (including safety) (0)</td>
</tr>
<tr>
<td>Data analytics (0)</td>
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<tr>
<td>Cognitive factors (0)</td>
</tr>
</tbody>
</table>
3.3 Potential EPSRC activity

Activity

The remainder of the workshop entailed activities targeted at exploring the shape of future EPSRC activity in this area, including how addressing these research challenges could align with the recommendations outlined in the RAS Strategy, who and what would be essential for success, and where EPSRC support should be prioritised.

Delegates were split into mixed groups and asked to develop an EPSRC activity in ‘Autonomous Manufacturing’ using the following points as stimulus:

- What is needed for the success of the priority research challenges identified, and what already exists that can be exploited, in the context of skills, clusters and assets.
- What responsible innovation issues need to be considered?
- Who needs to be involved and how can this be ensured?
- What would success look like for an EPSRC activity in Autonomous Manufacturing?

Output

Alignment to the RAS Strategy

The RAS Strategy identified a number of strands important in the delivery of future developments in robotics and autonomous systems for the benefit of the UK. During the Workshop we explored three of these strands; RAS Assets, Clusters and Skills, in the context of addressing the priority research challenges shown in Table 1.

One asset that was most consistently identified as being essential to the successful tackling of these priority research challenges was a test-bed ‘factory’ that could be used to link development and demonstration. Such a test facility, either virtual or physical, could provide the critical resource for testing the safety and efficacy of an autonomous system, or demonstrating it to end-users. Such test factories do exist in various forms and stages of development; however challenges remain around accessibility and their fit for purpose for a diverse range of applications.

Clusters in autonomous manufacturing were seen clearly to include academia (from multiple disciplines), industry and the HVM Catapult, with flow of information, ideas and research challenges occurring within and between all groups. Effective clusters were known to exist in other sectors (e.g. automotive, defence, games industry) that could be utilised to share learning and best practice.

Relevant EPSRC Centres for Doctoral Training (CDTs) were also identified as clusters providing appropriately skilled individuals for the future research and industrial application of autonomous systems in manufacturing, and it was highlighted that younger students should be influenced to choose this path and feed the people pipeline. The skills that are needed for research into future autonomous manufacturing are highly multidisciplinary. As such, individuals are needed who are highly skilled in these separate areas and who are also capable of working effectively in multidisciplinary teams.

Responsible Innovation

Responsible Innovation is a process that seeks to promote creativity and opportunities for science and innovation that are socially desirable and
undertaken in the public interest. It includes, but goes beyond, considerations of risk and regulation, important though these are. Participants were asked to explore the potential issues around responsible innovation in autonomous manufacturing. To demonstrate the thought processes behind this sort of approach during the development of advanced technologies, the activities of an EPSRC funded project aimed at exploring a Framework for Responsible Innovation in ICT (FRIIICT) were presented.

Participants identified potential issues with respect to economic, social and ethical accountability. These included the impact of enhanced UK competitiveness on the economy, the effect on humans in the workplace environment (safety, skills, jobs) and the collection and use of data.

Participants recognised the value of researchers exploring these issues at an early stage in the research process and stressed the importance of engaging with all stakeholders to ensure a sense of ownership is developed. Human-sensitive innovation was felt to be particularly emphasised given the potential impact on human skills and jobs.

**Who needs to be involved?**

It was clearly agreed that successfully addressing the research challenges underlying Autonomous Manufacturing would require a multidisciplinary team which engages with appropriate individuals across the manufacturing supply chain i.e. both system suppliers and manufacturer end users, as well as applied researchers at higher TRL (i.e. HVM Catapult). The academic disciplines identified as being important were both technical and social, including, but not limited to, engineers, computer scientists, designers and social scientists.

Industry involvement was seen as being essential given the need to fully understand the research challenges, the application and the design requirements for a system that could potentially collaborate with human workers. Furthermore, industrial translation and adoption of research in this area is dependent on the potential return on investment, as well as adherence to legislation and regulations. Such conversations therefore need to occur early in development of a project.

Other groups of people, bodies and organisations that were identified as potentially providing secondary beneficial involvement included regulators and standards bodies, expert communicators, economic and legal consultants, and representatives from other sectors (e.g. marine, transport) to share best practice.
**Key to success**

Participants were asked to summarise the ‘must-haves’ for an EPSRC activity in Autonomous Manufacturing, and to visualise what success might look like. The outputs of this activity were a useful and coherent summary of the crucial aspects discussed over the course of the day, as well as the opportunity to include key messages which might otherwise have been missed.

Participants emphasised that the core focus of any activity should be on researching and developing next generation manufacturing solutions that enhance productivity, efficiency, quality or reliability (where clear advances in autonomy of these technologies or processes can be demonstrated). Furthermore, that full autonomy need not necessarily be the aim and that this should be tailored appropriately to the application(s).

The planned impact pathway of research in Autonomous Manufacturing was felt to represent a significant area for assessment and evaluation. As such, key to the success of any research project in this area is the request for appropriate resources to engage with relevant stakeholders, disseminate best practice to industry and promote technology transfer.

Shared learning across sectors was also highlighted as something that should be encouraged in order to achieve the most impact in manufacturing. This included sectors relevant to the technology development, such as the games industry, as well as those other sectors that stand to significantly benefit from advances in robotics and autonomous systems e.g. marine, transport.

Various points outlined earlier in this report were also reiterated in this activity, however primarily these related to the need for multi-disciplinary teams and opportunities to test/demonstrate technology and systems under development in a virtual or physical test-bed.

### 3.4 Final outputs

The outputs of the workshop have identified four research challenge strands where there is scope for EPSRC funding to make a significant impact. These four strands are based on the priority challenges identified in the workshop, but broadened to include important and related areas of research. Three strategies for the successful delivery of these research challenges were identified and these are also detailed below.
Research Challenges:

Advanced collaborative working

Autonomous systems have the capacity to replace, augment or complement human activity. They have the potential to work collaboratively with humans or machines and significantly advance both physical and intelligent capabilities. The level of autonomy that is most suitable and beneficial will be application specific, however it is likely that in many cases a certain level of human/RAS collaboration will be required in a production environment. Such collaboration will require trust and understanding of the system, as well as means of ensuring safety. The research challenges associated with advanced collaborative working include capturing operator actions, communication methodologies, architectures for hybrid decision-making, models for human behaviour prediction and understanding, as well as new human factors knowledge and methods.

Learning and decision making

Autonomous systems can gain information about their environment, adapt and independently make decisions based on reasoning. As such, these systems need to be self-aware, able to self-program, learn, react and report in an appropriate manner, achieving through-life learning and adaptive process improvements. Examples include capturing of human skill or modelling complex manufacturing processes, systems and products, and responding to variability in the process. Such learning will enable flexible, adaptive and/or reconfigurable processes (including production processes, material processing and material manipulation in manufacturing). The development of these smart cognitive architectures presents a number of research challenges including how to respond to variability and uncertainty in a production environment, how to reason with partial or inconsistent information, and how to describe and use data about human skill.

System design and behaviour

There will be inherent challenges in designing a system for autonomy, collaborative working with humans (and other autonomous systems), safety and integration into the current factory environment (including legacy systems). A systems approach to design should be employed, that enables human monitoring of the system and predictability of behaviour and the decisions made. As such, simulation and predictive modelling to enable a deeper robust understanding of system behaviour and autonomous actions will be key.
Advanced sensing and sensor integration

A factory environment is likely to generate diverse and complex scenes to be sensed and interpreted by autonomous systems. Managing multiple and variable sensor inputs in an accurate, reliable and robust manner, leading to data analysis and interpretation appropriate to the integrity of the data will be a challenge. Development of novel next-generation sensors capable of detecting difficult to measure variables, or plug-and-play sensors for flexible use, will also contribute to a step-change in autonomous systems for manufacturing.

Delivery:

Assets: Test environments that are fit for purpose, or enhancing access to such environments.

The need for a production facility which mimics the real environment for testing, developing and demonstrating will be crucial for all the research strands identified. Such a facility could be physical, or eventually an advanced virtual reality which allows different situations and production processes to be simulated. Appropriate facilities are likely to be in existence but may benefit from developments for broader use or opportunities to enhance access.

Clusters: Networks or consortia building activities

There was strong indication that success in autonomous manufacturing would only be achieved through collaborative research, both across multiple disciplines, with industry and with other public investments in the manufacturing landscape (e.g. the HVM Catapult). Such partnerships need encouraging and enabling to bring together the ‘best of the best’ and ensure the UK becomes globally competitive in this area. Networks or consortia offer the opportunity to better define the technology and knowledge gaps through road mapping activities, perhaps in a sector or process specific manner, to learn best practice from other sectors and also to demonstrate the value of autonomous manufacturing to industry. Clusters can also take a UK leadership role, building links with international researchers and multinational companies in order to ensure that UK research can be globally competitive.

Grand Challenges: Research funding

Addressing the fundamental research challenges underpinning the successful development and implementation of autonomous systems for the benefit of UK manufacturing is likely to require large, long-term flexible funding and a cross-disciplinary team. The aim of such funding would be to stimulate novel science and engineering research with the grand challenge ambition of advanced manufacturing solutions that enhance capability, efficiency, flexibility,
sustainability or quality. The expected outcomes would be a diverse set of research programmes that span manufacturing applications, processes, and value sectors, that exploit novel and adventurous research for the advancement of autonomous systems in the factory environment.

3.5 Conclusion

Autonomous systems present multiple value creation opportunities for the UK manufacturing sector, not least the ability to augment existing capabilities and enhance production flexibility, potentially leading to agile and responsive production processes that are globally competitive. There are a wide range of engineering, computing, human interface and design research challenges to be addressed to realise this potential. Concurrently is the need to develop the assets and the networks to facilitate this research, enabling it to be of the highest quality and industrially relevant to a range of sectors.

EPSRC will take forward the discussion held as a result of this workshop into the programme planning and future strategy. The outcomes from the workshop along with additional advice and feedback will be used to influence the future of EPSRC support in the theme of Autonomous Manufacturing.

For specific questions or feedback related to Autonomous Manufacturing, please contact:

Karen Brakspear (EPSRC, 01793 444106)
### 4.0 Annexes

#### Annex 1: Workshop Attendees

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
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<tbody>
<tr>
<td>Alan Norbury</td>
<td>Siemens</td>
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<tr>
<td>Andrew West</td>
<td>Loughborough University</td>
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<tr>
<td>Arthur Richards</td>
<td>Bristol University</td>
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<tr>
<td>Carwyn Ward</td>
<td>Bristol University</td>
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<tr>
<td>David Bisset</td>
<td>iTechinic Ltd</td>
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<tr>
<td>David Manby</td>
<td>Aylesbury Automation</td>
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<tr>
<td>Derek Long</td>
<td>Kings College London</td>
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<tr>
<td>Diane Howard</td>
<td>EPSRC</td>
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<tr>
<td>Dominic Bushnell</td>
<td>TAP Biosystems</td>
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<tr>
<td>Geoff Pegman</td>
<td>RU Robots</td>
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<tr>
<td>George Panoutsos</td>
<td>The University of Sheffield</td>
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<tr>
<td>Hannah Pearson</td>
<td>EPSRC</td>
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<tr>
<td>Jacques Penders</td>
<td>Sheffield Hallam University</td>
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<tr>
<td>Jeremy Wyatt</td>
<td>The University of Birmingham</td>
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<tr>
<td>John Gray</td>
<td>The University of Manchester</td>
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<tr>
<td>Karen Brakspear</td>
<td>EPSRC</td>
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<tr>
<td>Ken Young</td>
<td>The MTC</td>
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<tr>
<td>Mark Claydon-Smith</td>
<td>EPSRC</td>
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<td>Mark Summers</td>
<td>Airbus</td>
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<td>Mike Jackson</td>
<td>Loughborough University</td>
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<td>Niels Lohse</td>
<td>Loughborough University</td>
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<tr>
<td>Paul Peterson</td>
<td>Jaguar LandRover</td>
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<td>Peter Kinnell</td>
<td>Loughborough University</td>
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<td>Philip Moore</td>
<td>Falmouth University</td>
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<tr>
<td>Phil Webb</td>
<td>Cranfield University</td>
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<tr>
<td>Richard Pitman</td>
<td>High Value Manufacturing KTN</td>
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<tr>
<td>Rich Walker</td>
<td>Shadow Robot Company</td>
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<tr>
<td>Sarah Sharples</td>
<td>The University of Nottingham</td>
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<tr>
<td>Samia Nefti-Meziani</td>
<td>The University of Salford</td>
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<tr>
<td>Smita Jenna</td>
<td>Loughborough University</td>
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<tr>
<td>Subramanian Ramamoorthy</td>
<td>The University of Edinburgh</td>
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<tr>
<td>Susan Soulsby</td>
<td>EPSRC</td>
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<td>Svetan Ratchev</td>
<td>University of Nottingham</td>
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Annex 2: Workshop Agenda

Thursday 4th September
Brunel Murdoch Room, Sir Denis Rooke Building, Loughborough University

10:00-11:00 Welcome (Karen Brakspear)
   Autonomous Manufacturing and EPSRC’s Manufacturing the Future Theme (presentation from Mark Claydon-Smith, EPSRC)
   Robotics and Autonomous Systems (RAS) Strategy (presentation from Richard Walker, Shadow Robot Company Ltd)
   Outcomes of the RAS Special Interest Group (SIG) deep dive in Manufacturing and Logistics (presentation from David Bisset, iTechnic Ltd).
   Objectives (Karen Brakspear)

11:00-11:15 Introductions

11:15-11:55 What is Autonomy? (facilitated session)

11:55–12:20 Manufacturing in the RAS Strategy, part 1 (facilitated session)

12:20-12:30 Centre for Innovative Manufacturing in Intelligent Automation (presentation from Prof Mike Jackson, Loughborough University)

12:30-1:15 Lunch

1:15-2:25 Manufacturing in the RAS Strategy, part 2 (facilitated session)

2:25-4:50 Scope of Autonomous Manufacturing: Ideas and People (facilitated session)
   Responsible Innovation (facilitated session)
   Funding ‘must haves’ (facilitated session)

3:15-3:35 Refreshment break

4:45-5:00 Wrap up and close (Mark Claydon-Smith)

5:00-5:30 Optional tour of the Intelligent Automation laboratories
Annex 3: Research Challenges raw output

Human-'Robot' Interaction - Future Challenges (10)

- Make R behaviour predictable for humans
- Human robot interaction co-adaptation to process requirements, human and robot both adapt and communicate their adapted to each other
- People and robots 'together'
- Integration of safety into autonomy to provide guarantees of safe operation
- Defining the level of human interaction for auto-manufacturing systems
- Handling surprise in human interaction. Often we try and design it out but if the machine can't surprise me, it'll just do what I'd do anyway, so why bother with the machine
- Define/recognise human intentions (in H-behaviour)
- Safe human-robot/auton sys interaction in assembly
- Safe collaborative working
- Acceptance and trust and understand?) in autonomous systems
- Human-machine symbiosis - regulation - when to switch over
- Cognitive collaboration (speech, gesturing, ...)

Adaptation, Learning and Complexity (System) (9)

- More generic (complexity)
- Alternative Title? Adaptive, Learning and Re-Configurable Systems
- Allocation of function
- Intelligence
  - self aware
  - adaptive
  - reactive
  - reporting - data
  - environmentally aware
- Learning models of human (operator) behaviour in complex tasks
- Self-organisation and emergence
- Self-programmable machines
- Capturing human skill
- Self-learning systems
- Flexible or adaptive grasping
- (Virtual) Learning (self) in first time - right environment
- Safe robotic systems with high accuracy
- Self-optimising manufacturing cells
- Skill capture from people and systems
- What tools/techniques are required to deploy successfully autonomous systems?
- Deciding what aspects of manufacturing (automation) should be autonomous - support tools and skills

System behaviour and modelling (6)
• Advancement of simulation and modelling
• Understanding system behaviour
• Analysing interactive system behaviour - to establish safety, stability, robustness (mathematics, theory...)
• Models of computation for "encoding" complex, adaptive tasks in autonomous systems
• Co-bot power (safety) limit
• Through life learning of product back into manufacturing process
• We need to be able to simulate/predict what will happen more easily and more accurately
• How to characterise and then check conformity to boundaries of autonomous activity
• Virtual to real integration challenge
• Skill learning systems. Self adaptive. Detailed audit trail of autonomous decisions and data supported reasons for decisions
• We need to be able to visualise and understand a debug mode for autonomy

Sensing, sensors and sensor integration (5)

• Reliable sensing technology
• Provably safe/consistent sensing of complex scenes
• Advanced sensing and manipulation
• Fusion of inputs from multiple/diverse sensors
• (within product) Sensing/perception improved interpretation
• Learning to feel quality (fit, graunch, ...)
• Standards for sensor integration

Adaptive Tooling (4)

• Modular, self-reconfig machine tools
  - mech design
  - standardised control platform
  - self (re) programming
• Dextrous force sensitive manipulation (unstructured manipulation)
• Process Tools
  - reconfigurable
  - multi tasking
  - multi sector

Integration, design and legacy systems (3)

• Key role of 'design' in creating 'autonomous systems' co-existing with humans
• Large scale deployments of human-robot interaction applications in the spirit of Grand Challenges
• Scalability
• Integration sensors manufacturing systems - legacy systems integration
• Modular self/reconfigurable cells for flexible manufacture/assembly
• How to design a hybrid person-autonomy system from the outset
• Understand technology development required to allow human integration, safety, communication etc
• Design for adaptability - how do you design a system to suit purposes you’ve never considered?
• Recognising system failures in development - particularly across multiple spheres of autonomy (including human)

Adaptive Process (2)

• Long term adaptation to flow system variables within a multiscale (time) process
• Autonomous continuous process development
• Best fit processes that cope with variability
• Optimise your neighbour
• Adaption of part handling and processing to optimise throughput and reduce errors
• The supplier sent slightly the wrong part - now what?

System level programming tool (2)

• Black Box adaptive control
• Independent decision making capabilities
• Open Architectures for automation/autonomy → distributed autonomy → scalable systems
• Common "language" for all robot control - abstraction layer

Awareness and interpretation (2)

• Communication of decision flow in an autonomous in human intelligible form to analyse post operation decision failures
• Interpretation of the unknown/unforeseen
• Awareness (self and environment)
• Spotting shift change - robots understanding human behaviour and characteristics
• Understanding that the task went wrong

Decision making and optimisation (2)

• Building robust contingency plans without over complicating operations
• Decision making and cognitive skills
• Complex process optimisation (planning is challenge)
• How do you explain decisions ie why a particular output has been arrived at?
• Handling complexity of decisions. However they’re made, how do we trust and supervise decision making that is purposefully more difficult than I (human) can deal with?
• Rapidly learning to see new things
• Haptic interaction
• Perception and manipulation involving eg tools in human-machine co-work

**Human in the loop - skills and induction/(people) (2)**

• Create critical mass of skills in autonomous systems
• Skill acquisition
• Human re-skilling and knowledge gathering
• Skills transfer from human to robot without programming

**Business case/socio-economic (2)**

• Job creation?
• The £1,000 industrial manipulator
• Reduce cost of robotics
• Autonomous manufacturing systems for SMEs (supply chain), cheap, easy to use

**Other (2)**

• Where’s the best use of spare time around the process
• Movable robots: take the robot to the work not take the work to the robot
• Mobility of manufacturing resources

**Intuitive programming (1)**

• We need to understand what intuitive means for robot programming
• Fast, strong and safe movement
• Simplify teaching of robots
• Task based instruction (non-programmed interfaces)

**Verification deployment and validation (safety) (0)**

• Manufacturing test environment for autonomous systems (real factory)
• Guidance of design and legislation restricts agility and acceptance
• Verification and validation
• Autonomous systems will be complex and vulnerable. Cannot be deployed without sound, high skill base
• Deployment: Novel vehicles/cells
  ▪ Multi-sectorial
  ▪ Integrated services
• Trust and safety
• Determination of boundaries of domain of adaptation [stability/safety] of autonomous systems - validation
• Policy and regulation around health and safety in manufacturing environments
• A new and inclusive and adventurous approach to safety in autonomous systems
• Validation is a big challenge - to get confidence
• Smooth autonomy level change/negotiation
• Understand acceptable risk
• Standards for higher level structures
• More of a TRL 4-9 issue?

Working together (0) – include in human-robot collab?

• (How) can human factors, computer scientists, automation (media+) communicate effectively
• Physical collaboration

Cognitive factors (0)

• Designing systems to enable effective human monitoring of autonomous systems and control and understanding - supervision of autonomy
• Gesture and expression in production line interaction
• Autonomy designed to work with and around humans
• Identification of tasks suitable for automation and those better served by skilled humans

Data analytics (0)

• Use data more effectively stimulate learning
• Integrity of data in manufacturing systems
• Data/information integration → horizontal → vertical