FOREWORD

Innovation in Space is vital in order to meet the UK Government target of tripling the size of the Space Sector by 2030. The FAIR-SPACE Hub led by University of Surrey is a perfect example of innovative ideas being developed both within and outside the sector. The Hub has brought together experts from academia, industry and government to “think-outside-the-box” to create ideas using space robotics development to benefit all sectors of the UK economy. My congratulations to the Hub and its staff and collaborators for making such a fine start to the programme.

Professor Richard Holdaway CBE FREng
Chair of FAIR-SPACE Independent Steering Committee, UKRI-STFC

The FAIR-SPACE Hub is part of the Industrial Strategy Challenge Fund Robotics and Artificial Intelligence for Extreme Environments Challenge which is aimed at increasing the productivity of the nuclear energy, space, deep mining and offshore energy sectors. FAIR-SPACE is a use-inspired research hub which is specifically focussing on solving some of the challenges of the space sector through the use of robotics and artificial intelligence technologies. This requires multidisciplinary approaches and bringing business and academia together to work in partnership to develop solutions and accelerate the commercialisation of these technologies.

Dr Lucy Martin
Head of Robotics, UKRI-EPSRC

It is vital that the UK benefits from the excellent work undertaken in the Research Base and translates that into productivity gains and wealth creation in the economy. As a part of the Industrial Strategy Challenge Fund, Government has invested £93M in Robotics and Artificial Intelligence for Extreme Environments. A substantial part of this investment is funding 4 use-inspired research hubs, enabling academia to directly engage with industrial developers and end-users, providing leading edge expertise and knowledge. I am delighted to see the FAIR-SPACE hub connecting with industry, working together with the space community internationally to accelerate UK based products and services to market.

Andrew Tyrer
Challenge Director – Robotics, Industrial Strategy Research Fund
MESSAGE FROM THE HUB DIRECTOR

Professor Yang Gao FIET FRAeS

FAIR-SPACE Hub integrates world-class academic and industrial capabilities behind a series of use-inspired research challenges, addressing UK national priorities in orbital manipulators, autonomous planetary vehicles, and robotic support for manned exploration.

Since FAIR-SPACE was set up in November 2017, we have been delivering the Hub’s vision on three fronts:

Research Excellence: Our research focuses on harnessing best-in-class solutions for an end-to-end ecosystem involving space robotic and autonomous systems, and operating within an analytical framework bounded by strong performance and safety guarantees. Co-developed with industrial end users, the core research is delivering innovations that help increase the competitiveness of the existing UK space industry, and help lower barriers to entry for new UK enterprises by reducing cost, shortening lead times, boosting efficiency, and extending operational lifespans.

Industry & End-User Engagement: Our research outputs are being demonstrated through use cases defined by industry to address high-priority applications in the space sector. The use-case demonstrators will help prepare UK stakeholders to take leadership in opportunities over the horizon, such as spacecraft servicing and assembly at the International Space Station (ISS), Mars/Phobos sample return, and Jupiter’s icy moon Europa exploration. The Hub also exploits synergies with the non-space sectors for knowledge and technology transfer through the Hub’s impact plan.

Capability & Community Building: Our engagement activities involve a wide range of audience from academia, industry, governmental and educational bodies, to the general public. For example, we have been actively engaging with other robotics hubs, with the space community by offering open access to space robotics software frameworks and hardware platforms, and with the younger generation and the public through the School Robotics Week, and International Space University programmes.

EXECUTIVE SUMMARY

Advances in robotics and autonomous systems are changing the way space is explored in ever more fundamental ways. Both human and scientific exploration missions are impacted by these developments. Where human exploration is concerned, robots act as proxy explorers: deploying infrastructure for human arrival, assisting human crews during in-space operations, and managing assets left behind. As humans extend their reach into space, they will increasingly rely on robots enabled by artificial intelligence to handle many support functions and repetitive tasks, allowing crews to apply themselves to problems that call for human cognition and judgment. Where scientific exploration is concerned, robotic spacecraft will continue to go out into Earth orbit and the far reaches of deep space, venturing to remote and hostile worlds, and returning valuable samples and data for scientific analysis.

The FAIR-SPACE Hub goes beyond the-state-of-the-art in robotic sensing and perception, mobility and manipulation, on-board and on-ground autonomous capabilities, and human–robot interaction, to enable space robots to perform more complex tasks on long-duration missions with minimal dependence on ground crew. This will result in more intelligent and dexterous robots that can be more self-sufficient, being able to detect and respond to anomalies on board autonomously and requiring far less teleoperation.

In this way the FAIR-SPACE Hub is set to become a national centre of excellence in space intelligent systems and robotics that will help realise the target of creating a £40bn UK Space Industry by 2030.

Through the development of novel technologies for robotic platforms used in orbit or on planet surfaces, the research programme merges the best available off-the-shelf hardware and software solutions with trailblazing innovations and new standards and frameworks, aiming at the development of a constellation of space robotics prototypes and tools.

Crucially, this Hub seeks to accelerate the prototyping of autonomous systems in a scalable way, where the innovations and methodologies developed can be rapidly spun out for wide adoption in the space sector worldwide and therefore we anticipate that the work in the Hub will have significant national and international relevance across a broad range of sectors including nuclear, marine and maritime, digital manufacturing and healthcare.

This report summarises the main achievements of the Hub during its first year of operation and highlights the excellent research already being undertaken as well as the broader engagement activities of the Hub which demonstrate the Hub’s ambition to support the growth of the UK Space Sector and ensure that cutting edge research can be used, challenged, valued and deployed into other sectors.

Research Excellence

- Sensing/Perception
- Mobility/Mechanisms
- AI/Autonomy
- Human-Robot Interaction
- System Engineering

Industry & End-User Engagement

- Industry-Defined Use Cases
- Space Mission Opportunities
- Technology/Knowledge Transfer

UK Capability & Community Building

- Space Robotics Community Growth
- Extreme Robotics Hub Integration
- Open Platform Development
- Educational & Public Outreach

The Hub seeks to become a national centre of excellence in space intelligent systems and robotics that will help realise the target of creating a £40bn UK Space Industry by 2030. Through the development of novel technologies for robotic platforms used in orbit or on planet surfaces, the research programme merges the best available off-the-shelf hardware and software solutions with trailblazing innovations and new standards and frameworks, aiming at the development of a constellation of space robotics prototypes and tools.
Throughout the Hub’s first year, it has engaged with over 30 businesses, visited over 25 schools/universities and inspired over 1200 students, published the UK-RAS space white paper and over 10 original research articles, and developed over 10 software prototypes and hardware testbeds.

This report summarises the main achievements of the Hub during its first year of operation and highlights the excellent research already being undertaken as well as the broader engagement activities of the Hub. Through the 5 research themes, 3 use-case scenarios and 2 testbeds, the Hub is already achieving significant impact, both academic and industrial.

This report, therefore, not only highlights the successes of the research teams, but also demonstrates the Hub’s ambition to support the growth of the UK Space Sector and to ensure that cutting edge research can be used, challenged, valued and shared by other sectors.

Throughout the Hub’s first year it has engaged with over 30 businesses, visited over 25 schools/universities and inspired over 1200 students, published the UK-RAS space white paper and over 10 original research articles and developed software prototypes and hardware testbeds for orbital/surface scenarios, which will be leading facilities for use by both academia and industry.

With about 30 collaborative partners and 40 academics, professionals and researchers from all over the world, the Hub is a national centre of excellence generating significant interest from all over the world.

The Hub has already generated £1.07m of new research income during the first year, adding to original UKRI/UKSA funding of £7.96m for the initial 3.5-year programme. Hence, the Hub is set to recruit 4 new PhD students and 4 new Postdoctoral researchers in 2019 alone and will seek to leverage over £2.5m of industrial support by 2021.
**HUB MEMBERS**

**SENIOR ACADEMIC TEAM**

**Professor Yang Gao FIET FRAeS**
is the Professor of Space Autonomous Systems at the Surrey Space Centre of the University of Surrey and the Head of STAR Lab. She is an internationally renowned space roboticist, specializing in sensing, perception, navigation, control, autonomy and biomimetic mechanisms, demonstrated through real-world space mission development (e.g., ESA’s ExoMars, Proba3 and LUCE-ice mapper, UK’s MoonLITE/Moonraker, and China’s Chang’E3). She is the Hub Director and the Research Theme Lead on sensors, perception and autonomy (Themes 1 & 3).

**Professor Sethu Vijayakumar FRSE**
is Director of the Edinburgh Centre for Robotics and holds a Personal Chair in Robotics at Edinburgh University. He has world-leading expertise in robotics, data driven motion planning, motor control, and optimization in autonomous systems, and his latest project involves a collaboration with NASA-Johnson Space Centre on the Valkyrie humanoid robot being prepared for unmanned robotic pre-deployment missions to Mars. He is the Hub’s Research Theme Lead on mobility and locomotion research (Theme 2).

**Professor Guang-Zhong Yang CBE FREng FIEEE FIET**
is Director and co-founder of the Hamlyn Centre at Imperial College London and leads the EPSRC UK-RAS Network, which provides academic leadership in RAS, expanding collaboration with industry. He is internationally recognized as a leading roboticist pioneering key human-robot technologies including perceptual docking and inverse realism, and has created a wide range of robotic hardware platforms such as the i-Snake® and Micro IGES systems. He is the Hub’s Research Theme Lead on the human robot interaction (Theme 4).

**Professor Michael Fisher FBCS FIET**
is the Director of a multi-disciplinary Centre for Autonomous Systems Technology at the University of Liverpool, and is an internationally leading researcher in formal verification of autonomous systems, particularly safety, reliability and ethics. He leads the UK Network on the V&V of Autonomous Systems, and has led space RAS research on both formation-flying satellites and astronaut-robot teamwork with NASA-Ames. He is the Hub’s Research Theme Lead on system engineering research (Theme 5).

**Professor Samia Nefti-Meziani**
is the Director of Centre for Autonomous Systems & Advanced Robotics, and Chair of Robotics at Salford. She has 25 years of experience in the development of concepts, mechanisms and algorithms in the areas of embodied intelligence, soft computing and robotics and pioneered the first application of soft robotics systems in manufacturing. She contributes to the Hub’s Research Themes on locomotion, mechanisms and system modelling (Theme 5).

**Professor Carsten Maple FBCS**
is Director of the GCHQ/EPSRC Centre of Excellence in Cyber Security Research and Professor of Cyber Systems Engineering at Warwick. His expertise in developing secure, resilient and trustworthy systems is recognised internationally, being a High Level Advisor to the European Commission, and PI/Co-I of international robotics network projects like CAPRI and PETRAS. He contributes to the Hub’s Research Themes on trusted robotic systems (Theme 1 & 5).

**Dr Saber Fallah**
is a Senior Lecturer in Vehicle and Mechatronic Systems at Surrey and the Director of Connected Autonomous Vehicles (CAV) lab, specializing in advanced control, estimation and optimization for autonomous vehicles (Themes 2 & 3).

**Dr Robert Merrifield**
is the Deputy Director of the Hamlyn Centre at Imperial College London, and the Coordinator of the EPSRC-funded UK-RAS Network, the EPSRC RAS Capital Equipment Grant (£6.6M) and the UK Robotics Week’s Robot Challenges (Themes 1 & 5).

**Dr Louise Dennis**
is a Lecturer at Liverpool and specializes in verifiable autonomous systems with an emphasis on agent-based reasoning, planning and machine ethics. She also has extensive experience with public engagement on robotics (Themes 3 & 5).

**Dr Steve Davis**
is a Lecturer in Manufacturing, Automation and Robotics at Salford. He developed the world’s smallestvariable stiffness, high DOF dexterous hand and a low-cost dexterous gripper capable of blind grasping (Theme 2).

**Dr Emma Wright**
is a Lecturer in Vehicle and Mechatronic Systems at Surrey and the Director of Connected Autonomous Vehicles (CAV) lab, specializing in advanced control, estimation and optimization for autonomous vehicles (Themes 2 & 3).

**Dr Christopher Lee**
is the Hub Programme Manager, University of Surrey.

**Dr Richard Gillham Darlley**
is the Hub Technical Manager, University of Surrey.

**Dr Zhimin Li**
is a Lecturer in Robotics and Control at Edinburgh, and leads the Advanced Robotics Group and a PI of Edinburgh’s Valkyrie Lab, focusing on robust control, optimization and machine learning for dynamic robot motion and behavior (Theme 2).

**Dr Clare Dixon**
is a Reader in the Department of Computer Science at Liverpool and led the Department’s Robotics and Autonomous Systems Research Group from 2015-2017. She has over 25 years experience in the area of formal verification and automated reasoning (Themes 4 & 5).

**Professor Tim Watson**
is the Director of the WMG Cyber Security Centre at Warwick. He has over 25 years of academic and industry experience currently working on protection of infrastructure against cyber-attack applicable to space RAS (Themes 1 & 5).

**Jane Adkins**
is the Deputy Director of the Hamlyn Lab, focusing on robust control, estimation and optimization for autonomous vehicles (Theme 2).

**Dr Alexei Lisitsa**
is a Lecturer in the Department of Computer Science at Liverpool. His research concerns automated reasoning, methods for automated verification, and computer security (Themes 3 & 5).

**Dr Claire Dixon**
is an expert in the Department of Computer Science at Liverpool. Her research expertise is in formal verification and automated reasoning (Themes 4 & 5).

**Dr Robert Merrifield**
is the Deputy Director of the Hamlyn Centre at Imperial College London, and the Coordinator of the EPSRC-funded UK-RAS Network, the EPSRC RAS Capital Equipment Grant (£6.6M) and the UK Robotics Week’s Robot Challenges (Themes 1 & 5).
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<tr>
<td>Nikos Mavrákis, Postdoc</td>
<td>Dr Rafael C. Cardoso, Postdoc</td>
<td>Dr Quentin Rouxel, Postdoc</td>
<td>Dr Hu Yuan, Postdoc</td>
<td>Dr Saber Mahboubi, Postdoc</td>
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<tr>
<td>Marco Visca, PhD student</td>
<td>Dr Marie Farrells, Postdoc</td>
<td>Control and motion re-targeting on humanoid robot Valkyrie for tele-operation and manipulation tasks.</td>
<td>Privacy, security and trust issues in space robotics and autonomous systems.</td>
<td>Mechatronics, Soft robotics, computer vision, Artificial intelligence.</td>
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<td>Dr Muhammad Zeeshan Babar, Postdoc</td>
<td>Dr Pedro Próenca, Postdoc</td>
<td>Dr Vladimír Iyán, Postdoc</td>
<td>Andrew Baker, Robotics technician</td>
<td>Dr Fani Deligianni, Postdoc</td>
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<td>Robust GNC for orbital manipulation.</td>
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**USE-INSPIRED RESEARCH & DEVELOPMENT**

### Crosscutting Research Themes/Topics

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<th>Research Themes</th>
<th>Academia &amp; Industry Partners</th>
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<td>Theme 1: Sensing &amp; Perception</td>
<td>T1.1 3D Sensing &amp; Perception: Imperial, Warwick, NEPTEC, ThalesAS, CAS-COMP, Catapults</td>
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<tr>
<td>Theme 2: Mobility &amp; Mechanisms</td>
<td>T2.1 Extreme Terrain Mobility: SSTL, Salford, Surrey, Airbus, RACE, KUKA, IT, CASC-SAAT, NASA-JSC</td>
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<tr>
<td>Theme 4: Human-Robot Interaction</td>
<td>T4.1 Remote Interaction: Imperial, Edinburgh, Liverpool, Airbus, SSTL, RACE, InTouch, CAS-CSU</td>
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<tr>
<td>Theme 5: System Engineering</td>
<td>T5.1 Design for Verifiability: Warwick, Edinburgh, Salford, SSTL, ThalesAS, BAE, STFC-Harbre</td>
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### Use Cases

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<tr>
<th>Relevant Space Missions</th>
<th>Non-Space Applications</th>
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<td>In-orbit servicing of satellites, Refuelling, Assembly and manufacturing of large structures like telescopes.</td>
<td>Nuclear waste management</td>
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<tr>
<td>Mars/Phobos sample return, outer solar system exploration such as Jupiter/Europa.</td>
<td>Nuclear decommission characterization, Deep mine, mapping &amp; inspection, etc.</td>
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<tr>
<td>ISS extravehicular and intervehicular activities, Human settlement and habitation on Moon and Mars, etc.</td>
<td>Operator-Robot Interaction scenarios in nuclear, underwater and deep mine.</td>
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### Crosscutting Research Themes/Topics

- **Theme Lead: Surrey**
- **Theme Lead: Edinburgh**
- **Theme Lead: Liverpool**
- **Theme Lead: Imperial**
- **Theme Lead: SSTL**

### Relevant Space Missions

- Nuclear waste management
- Underwater pipe/asset manipulation
- Nuclear decommission characterization
- Deep mine, mapping & inspection, etc.
- Operator-Robot Interaction scenarios in nuclear, underwater and deep mine.

### OUR R&D PROGRAMME OFFERS:

- Five cross-cutting research themes underpinning major industry-led challenges.
- Each research theme addresses a set of scientific topics and objectives through collaborative projects between academia & industry.
- Outputs from selected themes are coherently combined within industry-defined use cases to demonstrate new knowledge and technologies.

In the intermediate term, the R&D will help achieve the following, which address challenges imposed by space environments and missions:

- Low-computation, high-accuracy 3D mapping & perception
- Energy-optimized locomotion mechanisms & control
- Resource-aware computation, & data assimilation for parameter tuning (such as in GNC algorithms)
- Hardware/Software reconfiguration & self-verification in real time

In the long term, the R&D will achieve long-lived, robust mobility & autonomy for next-generation space robots.

*Courtesy of NASA*
INDUSTRY-DEFINED USE CASES

At the heart of the Hub is the desire to co-create with the user organisations who form part of this consortium, and to this end, the Hub has developed industry-led use cases that represent high potential applications and address industry and market needs.

This allows us:
- To merge the best available off-the-shelf hardware/software solutions with trailblazing innovations, new standards and frameworks, leading to a constellation of space RAI prototypes and tools.
- To accelerate the prototyping of autonomous systems in a scalable way, where the innovations and methodologies developed can be rapidly adopted by the space industry.

Matt Perren
Chair of FAIR-SPACE International/Industrial Advisory Board, Airbus Defense & Space.

Savvas Neophytou
Deepbridge Capital

The orbital use-cases are set to demonstrate high accuracy, precision placement of high degree-of-freedom (DOF) manipulator/end-effector to capture and manipulate cooperative and non-cooperative objects in orbit.

The final showcase demonstrates research outputs from Theme 2 (manipulation & capturing mechanisms), Theme 3 (proximity GNC software) and Theme 5 (system V&V & security).

The planetary use-cases are set to demonstrate long-duration surface & subsurface exploration in unstructured, planetary surface environments.

The final showcase demonstrates outputs from Theme 2 (surface rover & subsurface drill mechanisms), Theme 3 (decision-making software) and Theme 5 (system V&V & security).

The human-robot use-cases are set to demonstrate human-robot cooperation and collaboration for performing inspection tasks, applicable to both orbital and planetary space environments.

The final showcase combines research outputs from Theme 4 (wearable/AR technology in spacesuit) and Theme 5 (HRI V&V & security).

This relationship relies on the open sharing of innovative concepts, a good understanding of industry needs and excellence in research project execution. I am confident that this working mode will deliver again with our other partners within the FAIR-SPACE Hub.

As early-stage technology investors, we have been aware of the University’s strengths in the fields of robotics and AI - the substantial body of work of FAIR-SPACE speak for themselves. Scalable and globalisable products underpinned by strong IP are important yardsticks for investment and we expect FAIR-SPACE to provide those in abundance.

Saivvas Neophytou
Deepbridge Capital
The potential of 3D sensing in space robotics is largely untapped and is yet to be fully realised. Stereo-vision based depth perception using optical cameras is the de facto standard, and in comparison, space-rated LiDAR is more power hungry and bulky although it brings advantages such as range and sensing robustness needed by future missions.

Recognition of human-made objects (e.g. sample caches and tools, other spacecraft), natural hazards/landmarks, and dynamic events such as weather phenomena (e.g. Martian dust devils) are important for complex tasks such as in-space robotic servicing.

safer space navigation, cache acquisition for sample returns, and opportunistic scientific observation of events. These tasks will require the use of higher-level representations, going beyond point clouds and boundary representations, to include solid objects and shapes. These are also likely to play a central role in future implementations of fast mapping.

Space sensing and perception are crucial for providing rapid, autonomous navigation and manipulation for future orbital and planetary missions, and are therefore directly linked to Guidance, Navigation and Control (GNC). Simultaneous Mapping and Localization (SIM) being the state-of-the-art, fast mapping method which has not been widely adopted in space applications.

The method possesses myriad parameters that need tuning to allow effective use in a given scenario. These include thresholds that control feature-matching, RANSAC parameters, and criteria to decide when to introduce new map elements or trigger a search for loop closure matches.

**OUR RESEARCH HELPS ACCELERATE DEVELOPMENT OF COMPACT 3D PERCEPTION TECHNOLOGY FOR SPACE THAT COMBINES OPTICAL AND LIDAR SENSING IN A COST-EFFECTIVE WAY.**

Yang Gao
Lead of Research Theme 1, University of Surrey

**RESEARCH THEME 1**

**USE-INSPIRED RESEARCH CHALLENGES ADDRESSED BY FAIR-SPACE:**

The potential of 3D sensing in space robotics is largely untapped and is yet to be fully realised. Stereo-vision based depth perception using optical cameras is the de facto standard, and in comparison, space-rated LiDAR is more power hungry and bulky although it brings advantages such as range and sensing robustness needed by future missions.

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**INITIAL RESEARCH PROJECTS**

- **Sparse 3D sensing and map fusion:** Develop RGB-D based sparse sampling and 3D map construction fusing with optical camera data under sparsity constraints.
- **Fusion of event-based cameras and depth sensing:** Hardware and software development to allow fusion of event-based/ range sensors and detection of Region of Interest.
- **Resilient SLAM for space:** Develop low computational, robust simultaneous mapping and navigation algorithms for space conditions.
MOBILITY & MECHANISMS

USE-INSPIRED RESEARCH CHALLENGES ADDRESSED BY FAIR-SPACE:

Future space missions require manned and unmanned planetary vehicles to access and traverse extreme terrain topographies (such as steep and deep craters, gullies, canyons, lava tubes, and soft, friable terrains) in faster traverse speed, longer range and greater coverage. The current monomorphic surface vehicle designs (such as Mars rovers) are limited. There are growing demands for increased/enhanced dexterity for robotic manipulation in space including sample manipulation, assembly of large structures, moving heavy tools, or preparing a site prior to crew arrival. Current drawbacks in relevant technologies relate to limitations in material and mechatronic properties of space-rated manipulator components, control of high DOF, real-time computation and reaction to external forces, power requirements, and lack of multi-modal control systems.

Technologies in grappling, capture & sampling mechanisms are needed to increase handling capabilities of space debris and in-orbit assets, and sample acquisition and handling capabilities for sample returns and in-situ resource utilization. The space sector currently lacks several mechanism solutions, such as lightweight, deep-drilling under low gravity, sampling at depth without losing or contaminating the samples, and grappling and capture of non-cooperative targets (without capture aids, in a wide range of masses or dynamic spin/free drift).

INITIAL RESEARCH PROJECTS

• Rough terrain multi-contact locomotion: develop all-terrain mobility on rugged surfaces using actuator-optimized mechanism with coordinated manipulation for path clearance.

• Robust manipulation and grappling: develop novel dexterous robotic arm/hand and its optimal control to coordinate whole system’s redundancy for energy-efficient manipulation tasks.

• Subsurface sample acquisition: develop bio-inspired robust mechanisms for drilling/sample acquisition suitable for metamorphic deployment from the surface vehicles.

OUR RESEARCH WILL ALLOW INTELLIGENT GRASPING AND MANIPULATION OF OBJECTS IN SPACE AND ON OTHER PLANETS WITHOUT THE NEED FOR DIRECT HUMAN CONTROL OR ADVANCED PLANNING.

Samia Nefti-Meziane
Project Lead within Research Theme 2, University of Salford

INNOVATIONS DEVELOPED BY FAIR-SPACE:

Energy-efficient mobility & locomotion mechanisms, to handle variations and uncertainties of planetary surface and sub-surface properties (incl. topology, appearance, regolith characteristics, etc).

• Providing low-actuation design for dynamic surface mobility (incl. bio-inspired roving, crawling, etc.) to overcome rugged terrain.

• Providing lightweight gripper design for handling of non-cooperative targets and arbitrary objects.

• Providing light-weight, low-power design for subsurface mobility (incl. bio-inspired drilling and sampling) to penetrate into planetary regolith in low gravity.

• Offering planetary regolith simulants preparation and characterization techniques.

MOBILE CHASSIS FOR DYNAMIC LOCOMOTION / COURTESY OF SURREY

Gripper for non-cooperative target / Courtesy of Salford

MOBILE CHASSIS FOR DYNAMIC LOCOMOTION / COURTESY OF SURREY

LIGHTWEIGHT, LOW POWER “WASP DRILL” COURTESY OF SURREY

FAIR-SPACE ANNUAL REVIEW 2018
INITIAL RESEARCH PROJECTS

- **Resource-aware reconfigurable GNC:**
  Design high-fidelity GNC system that can adjust its computational load depending on the sensing and computational resources available and can tolerate faults.

- **Multi-objective task planning:**
  Develop dynamic coordination of both global and local tasks, subject to the external operating environment, resources, and mission time.

OUR RESEARCH WILL ENABLE US TO SEAMLESSLY TRANSITION BETWEEN TELEOPERATION AND FULLY AUTONOMOUS OPERATIONS BY IMPLEMENTING ROBUST SHARED AUTONOMY FOR SPACE ROBOTS, AGNOSTIC OF THE FORM FACTOR OR DEGREES OF FREEDOM.

Sethu Vijayakumar
Project Lead within Research Theme 3, University of Edinburgh
Astronaut-robot interaction requires mitigating effects of latency on remote control, facilitating astronauts’ situational awareness, and minimizing bandwidth requirements and performance variation due to human differences.

Typical proximal interaction between human and robot deals with uncertainly in recognizing user activity, gaze, gestures, speech or other indicators of implicit operator intent; behavioural models capable of predicting future operator actions, and communicating large volumes of complex system-state information to users in a short period of time. In space, it also involves robot interfaces to spacesuits in vacuum and dusty environments, and effective control of robots by astronauts via the suit. Many factors influence astronauts’ attention, peri-personal perception and cognitive performance in weightless or micro-gravity environments, exacerbated by isolation and confinement. Effective multi-modal interaction of astronauts with robots can help reduce the necessary training and ultimately enhance human control and decision making in hazardous environments.

The fundamental issue is how to achieve effective human utilization of multiple sensory modes based on Virtual/Augmented Reality (VR/AR) for enhanced performance.

The research theme focused on integrating novel wearable robotic technology and advanced bio-sensing to enhance astronauts’ capabilities in space.

**Use-inspired research challenges addressed by Fair-Space:**

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**Initial research projects:**

- **Wearable astronaut-robot proximal interaction technology:** Create a human-robot interface technology that can be used to control space robots during physically demanding scenarios such as during a spacewalk or whilst performing intra-vehicular maintenance at ISS.

- **Combined Augmented Reality/Virtual Reality for space environments:** Create a combined AR/VR methodology that enables astronauts to efficiently interact with robots, and respective system prototypes. AR will be applied to enhance the information content available through the human vision system, robot-mounted cameras, and VR scenes.

**Innovations developed by Fair-Space:**

- Wearable technologies in the spacesuit for enhanced, real-time human-robot interaction.
- Providing astronaut space helmet with integrated AR, eye-tracking and electroencephalogram (EEG) technology for intention detection.
- Providing astronaut inner spacesuit with advanced biosensing technology for monitoring and detecting stress.
- Providing soft exoskeleton technology for tele-operation of humanoid robotic manipulation, or for astronaut exosuit to enhance manned operation.
**SYSTEM ENGINEERING**

**USE-INSPIRED RESEARCH CHALLENGES ADDRESSED BY FAIR-SPACE:**

To allow for comprehensive V&V, space RAS need to be designed in a modular, transparent fashion to be potentially flexible, repairable and reusable. In the long term, this provides a key route to a range of verification techniques, powerful metrics, self-analysis and fault diagnostics, and forms a step towards future, sector-wide, architectural standards.

Existing RAS V&V covers a range of techniques: formal verification, simulation-based and physical testing. Future missions will demand high levels of assurance concerning space autonomy, component resilience, efficiency and responsibility, to enable multirobot and long-lived space RAS with critical resource constraints.

Moving to heterogeneous teams of vehicles, astronauts, operators, and assets, also requires the development of sophisticated approaches based on the V&V of multi-robot systems and the V&V of human-robot teamwork. While standards for security and safety are widely cited, none of the recognised standards covering cyber-security for space systems are largely under-developed. Long-term applications of space RAS require research effort to: properly define safety and security requirements; develop and incorporate new threat modelling approaches; develop protocols for resilience; choose countermeasures to minimize the likelihood and impact of attacks. The analysis of safety will address not just damage to assets, but to the environment and, crucially, damage to humans, which will build on V&V work for human-robot interaction.

**INNOVATIONS DEVELOPED BY FAIR-SPACE:**

- Generic, reusable, repairable system software architecture for verifiability and formal specification, to move towards appropriate and verifiable design patterns:
  - Enabling flexible, transparent, and compositional software architecture (e.g. to define GNC and perception software).
  - Providing formal and precise descriptions of both individual component behaviour (e.g. motion planning) and semantic component interfaces.
  - Formalising use-case requirements, environmental constraints, and the expectations for long-duration deployment of the overall system and components.
  - In the long term, providing a key route to a range of verification techniques, powerful metrics, self-analysis and fault diagnostics, and forms a step towards future, sector-wide, architectural standards.

- **INITIAL RESEARCH PROJECTS**
  - **Modularity and Verifiability:** Map out library of key components and architectural designs for space RAS that are amenable to a range of V&V, prioritising the three use-cases.
  - **Threat Landscape for Space RAS:** Undertake an analysis of the cyber-security landscape for space RAS and design protocols for future standardization.
  - **Dimensions for Verification:** Research into formalisation and logical properties for key space verification dimensions (communications, spatial, time, energy, etc), and their combination into a scalable, flexible and applicable range of verification tools.

**INITIAL RESEARCH PROJECTS**

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ON-EARTH TESTBEDS

FAIR-SPACE develops a range of integrated hardware & software testbeds, offering realistic simulation of space factors in order to facilitate testing and validation of our research outputs on Earth.

FOR ORBITAL SCENARIO, OUR TESTBED OFFERS:

- 6 degree-of-freedom orbital dynamics and motion of cooperative or non-cooperative target objects in free space.
- 6 DOF manipulation and ≥6DOF grasping mechanisms in a complete range of control modes from tele-operation to full autonomy.
- Environmental parameters (such as lighting) affecting sensing & perception in orbit.
- Disturbances and uncertainties caused by orbital dynamics, occlusion and sensor noise, affecting precision and accuracy of the manipulation and capturing systems.
- System V&V against ground truth and benchmarks.

FOR PLANETARY SCENARIO, OUR TESTBED OFFERS:

- Planetary surface and subsurface properties (topology, regolith characteristics, strength, etc) affecting locomotion & mobility performance of rovers and drills.
- Environmental parameters (e.g., lighting, dust) affecting sensing & perception.
- Multi-DOF surface & subsurface mobility mechanisms in a full range of control, data acquisition and analysis, and adjustable gravity effects.
- Disturbances and uncertainties affecting precision and accuracy of the surface & subsurface mobility systems.
- System V&V against ground truth and benchmarks.
The ideal future for orbital robotics is to remove the debris that we’ve created in space and to build, assemble and manufacture satellites in orbit. Partnering with FAIR-SPACE who addresses industrial challenges in orbital robotics is really key for us as a commercial business, so we can look forward to moving more quickly than we would have done by ourselves.

Sir Martin Sweeting
Executive Chair, SSTL
FAIR-SPACE TECHNOLOGIES FOR PLANETARY SCENARIO

ONBOARD AUTONOMY:
- Trusted decision-making framework ranging from remote operation, shared to full autonomy
- Multi-objective optimization
- Dynamic coordination between global & local tasks

ASTRONAUT SPACESUIT:
- Space helmet with integrated AR, eye-tracking and EEG technology
- Inner spacesuit with advanced biosensing
- Soft robotics for force augmentation

SURFACE MOBILITY:
- Bio-inspired locomotion for rugged terrain
- Optimizing number of actuators
- Enabling compact vehicle design

SUBSURFACE MOBILITY:
- Light weight & low power
- Energy-efficiency in low gravity

FAIR-SPACE’s R&D is clearly closely aligned with European Space Agency’s vision on planetary robotics for future mission concepts such as Mars Sample Return, Sample Fetch Rover, Deep Space Gateway and several Lunar exploration ideas like Moon Village. Hence we find very important and useful to be an industry partner with FAIR-SPACE.

James Coates
Director, NEPTEC UK

Our work on AR/VR for aerospace, defence and marine, helps to reduce the risk of operating in dangerous conditions and helps to optimise operations such as task planning and human-robot interaction. Therefore we look to FAIR-SPACE as a new business opportunity for the company but also to develop new partnerships to take our products forward.

Trevor Linn
CEO, Turbulent Designs

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Trevor Linn
CEO, Turbulent Designs
INDUSTRIAL ENGAGEMENT HIGHLIGHTS

FAIR-SPACE and its close engagement with industry, has tremendous potential to develop a robust and useful evidence base that will inform not only the space sector but also support the development of other autonomous systems such as unmanned aerial vehicles, unmanned maritime systems and even driverless cars. More than that, the technologies being developed in AI robotics are crucial to creation of new business and growth, particularly for UK tech startups and SMEs.

VENTUREFEST

To date FAIR-SPACE has forged links with the Satellite Applications Catapult and its regional South Coast Centre of Excellence in Satellite Applications to ensure that it is working with local SMEs in the supply chain. The Hub exhibited in conjunction with the Centre at the Venturefest South event in Winchester. The Hub had a robotic display in the “Moon Village” and showcased a variety of technologies.

This event had Mark Boggett CEO of Seraphim Capital as keynote whilst Colin Baldrey, Head of Regional Growth at the UK Space Agency also presented. The event was attended by over 500 innovators, entrepreneurs and investors who braved the snow to come and find out about space and innovation.

US AEROSPACE INDUSTRY HUB

Hub Director, Professor Yang Gao was invited by Foreign Commonwealth Office and Department of International Trade to visit US Aerospace Industry Hub in Los Angeles. Yang visited over 10 US companies during the trip and NASA-JPL. Southern California’s aerospace sector is known for Mars landings, the Space Shuttle, the B-2 Stealth Bomber development of GPS systems and entrepreneurs from Howard Hughes to Elon Musk, and is also home to the Space and Missile Systems Center at Los Angeles Air Force Base which designs, develops and purchases more than $5 billion worth of space and missile systems annually.

Given Los Angeles is a hub of space research and aerospace industry, FAIR-SPACE’s visit to the Los Angeles space cluster was a great opportunity to spur further collaboration between the UK and US. In particular the partnership between FAIR-SPACE and NASA’s Jet Propulsion Lab, including new joint mission concepts and further work with the Solar System Exploration Research Virtual Institute. Our inaugural reception also sums up the theme Brits in Space.

Nicholas Hooper
Head of Science & Innovation
British Consulate-General Los Angeles
Foreign & Commonwealth Office

GREAT FESTIVAL OF INNOVATION

The UK Government’s GREAT Festival of Innovation 2018 has taken place in Hong Kong. The aim was to celebrate the UK’s unique technological abilities, and create fantastic new opportunities for British businesses to sell their products and expertise to the world.

The way we live, work, learn and play in the world is changing exponentially. Innovation has made our countries borderless, cities smarter, work automated, education virtual, and put play into our pockets.

Professor Yang Gao was the UK representative space roboticist invited to participate in the panel discussions in relation to Space Innovation and Global Warming. Her inputs also helped to promote the UK’s research excellence in space engineering and robotics research.

Nicholas Hooper
Head of Science & Innovation
British Consulate-General Los Angeles
Foreign & Commonwealth Office

SPACE WHITE PAPER

The UK has extensive expertise, facilities and technologies that are major enablers to a wide range of manned and unmanned space systems. FAIR-SPACE has led the development and publication of the UK-RAS White Paper on Space Robotics & Autonomous Systems.

Comprehensive engagement took place with a variety of businesses to ensure that industry needs, and particularly commercial space endeavors were well understood and captured in the White Paper.

In this way the White Paper is the basis for discussing future technological roadmaps and highlights the commonalities between space and terrestrial RAS whilst at the same time acknowledging the distinctive design and environmental constraints.

Professor Yang Gao of the Hub was an invited speaker at the Eyes on 2028 event in London organised by Airbus. The event was primarily participated by senior management staff of space industry for expert talks, panel discussions and seminars exploring themes such as March of the Machines, the World at our Command and Fake News Wars.

EYES ON 2028

Professor Yang Gao, of the Hub was invited as key note speaker for the Eyes on 2028 event in London. Organised by Airbus, this event was primarily participated by senior management staff of space industry for expert talks, panel discussions and seminars exploring themes such as March of the Machines, the World at our Command and Fake News Wars.

AEROSPACE VALLEY FRANCE

Professor Samia Nefti-Meziani of the Hub was invited to present to the Aerospace Valley which is a French cluster of aerospace engineering companies and research centres.

This French cluster is home to over 500 affiliated companies (including Airbus, Air France Industries and Dassault Aviation) and is responsible for over 120,000 jobs in the aviation and spaceflight industries. In addition, some 8,500 researchers are active within the affiliated companies and institutions.

Professor Nefti-Meziani highlighted just how research and technologies being developed in the Space sector, including those being developed by the FAIR-SPACE Hub can also be applied to the aerospace sector.
**INTERNATIONAL ROBOTICS SHOWCASE**

FAIR-SPACE attended the International Robotics Showcase, a highlight event that marked the start of UK Robotics Week 2018.

The showcase was part of the International Business Festival held in Liverpool which was the biggest business event of the year with over 55 major events; 5000s of industry professionals and 200 world-class speakers.

Professor Yang Gao also gave a guest talk on the FAIR-SPACE Hub which focussed on better understanding the world in the development and commercialisation of AI technologies.

**WESTMINSTER INSIGHT TALK**

Prof Samia Nefli-Meziani of the Hub was a speaker at the Westminster Insight - Leading the World in Artificial Intelligence and Machine Learning - Investment, Innovation and Going for Growth.

The event sought to analyse how the UK can exploit the benefits of AI and machine learning for society and the wider economy, and the challenges and opportunities for skills, employment, governance and accountability.

With millions of pounds of investment into AI announced, attendees also had the opportunity to consider priorities for funding and investment for AI research, skills and start-up’s in order to ensure the UK can lead the world in the development and commercialisation of AI technologies.

**NUCLEAR INDUSTRY OPEN DAY**

FAIR-SPACE has been working with the UK Atomic Energy Authority’s centre for Remote Applications in Challenging Environments (RACE). RACE focuses heavily on collaborative R&D in order to deliver innovative products and services in a variety of sectors including nuclear, petrochemical, space exploration, construction and mining.

Professor Carsten Maple of the Hub also attended the RACE open day which focussed on better understanding industry needs in the nuclear sector as we move towards more sophisticated Robotics and AI solutions.

RACE is seeking to work closely with FAIR-SPACE given common interests in robotics and AI for extreme environments. Our first success, winning funding from the InnovateUK Call for the UK Space Debris Mitigation, Active Debris Removal and Space Servicing Vehicles.

NUC provides an excellent platform for FAIR-SPACE to explore the challenges that the burgeoning space robotics market faces with regards to aspects such as regulation, licensing and liability. Indeed it was felt that the UK has great strengths in terms of regulatory and legal aspects of space innovation which will provide a positive environment in which in-space robotics could flourish.

**UKSA SPACE ROBOTICS WORKSHOP**

FAIR-SPACE was invited to display our work on robotic drill inspired by the wood wasp, as part of Parliamentary Week. Several companies funded through the InnovateUK Call were also present.

The event organised by the Health & Safety Executive sought to showcase robotics that are making the workplace safer for humans by removing them from extreme environments. Sarah Newton MP and Minister for Disabilities, Health and Work gave a speech.

UKSA SPACE ROBOTICS WORKSHOP

Dr Chris Lee, Hub Technical Manager, attended a meeting on the future of in-space robotics led by the Knowledge Transfer Network (KTN) on behalf of the UK Space Agency. Discussions took place between industry and academia to explore the challenges that the burgeoning space robotics market faces with regards to aspects such as regulation, licensing and liability.

Indeed it was felt that the UK has great strengths in terms of regulatory and legal aspects of space innovation which will provide a positive environment in which in-space robotics could flourish.

**UK PARLIAMENT WEEK**

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**MARINE AUTONOMY & TECHNOLOGY SHOWCASE**

FAIR-SPACE has engaged with cross-sectoral knowledge and technology transfer. The showcase organised by the National Oceanography Centre is an example of other sectors for extreme environments. The ability to explore the most extreme oceanic environments including the ocean depths without the need for human operation, allows scientists to explore the oceans in ways that were previously not possible.

As robotics technology becomes more advanced and economically viable there will be a shift towards activities being supplemented by teams of robots used cooperatively under minimal human supervision. It is here where the synergies between marine autonomy and space robotics can be found.

**INDUSTRIAL ENGAGEMENT HIGHLIGHTS**

**EUROfusion** is a great start.

Our first success, winning funding from the InnovateUK Call for the UK Space Debris Mitigation, Active Debris Removal and Space Servicing Vehicles.

**RACE** focuses heavily on collaborative R&D in order to deliver innovative products and services in a variety of sectors including nuclear, petrochemical, space exploration, construction and mining.

**Nuclear Industry**

FAIR-SPACE has been working with the UK Atomic Energy Authority’s centre for Remote Applications in Challenging Environments (RACE).

**Westminster Insight**

Prof Samia Nefli-Meziani of the Hub was a speaker at the Westminster Insight - Leading the World in Artificial Intelligence and Machine Learning - Investment, Innovation and Going for Growth.

**ESA Industry Day**

The FAIR-SPACE team attended the European Space Agency’s Clean Space Industrial Day which gave an insight to the technological advancement achieved to date in the fields of eco-design for space, technologies for Space Debris Mitigation, Active Debris Removal and Space Servicing Vehicles.

**UKSA Space Robotics Workshop**

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**KTN’s Space Team Work with UK Business to Ensure They are Connected with Funding, Expertise and Innovators from Other Sectors. We are very pleased to work closely with the FAIR-Space Hub who plays a significant role in bringing together businesses, academics as well as potential funders for UK Space Robotics & AI.**

Andy Bennett
Knowledge Transfer Manager, KTN-Space
In its first year, FAIR-SPACE engagement activities have not been restricted to UK shores. The team has participated in over 70 events of which a quarter were international.

**INTERNATIONAL RECOGNITION**
- Yang Gao appointed to Advisory Board of EU H2020 project on AI robotics for deep mining research.
- Yang Gao invited as keynote speaker of 12th NASA/ESA Conference on AHS.
- Michael Fisher appointed to British Standard Institute’s AI standards committee and robot safety and ethics committee, as well as International Standard Committee P7009.
- Louise Dennis appointed to International Standard Committee P7009.
- Samia Nefti-Meziani appointed to National Robotics Network board.

**CROSS HUB COLLABORATION**
- FAIRSPACE & RAIN Hubs jointly hosted technical session at Nature sponsored Light Conference, China, July 2018.
- FAIR-SPACE & ORCA Hubs actively promoted each other during UK Robotics Week 2018 from our respective stands.
- FAIR-SPACE, ORCA & RAIN Hubs jointly conducted Responsible Research Initiative or ORBIT training, Liverpool, September 2018.
- FAIR-SPACE, ORCA & RAIN joint postdoc meeting, Liverpool, September 2018.
- FAIRSPACE & RAIN Hubs aimed at developing research collaboration on common research interests, including robotic vision and verifiable Autonomous Systems Architectures (which has the potential to impact across all Hubs and across all sectors).

**HIGH-PROFILE LECTURE**
“Experience: A space odyssey” is the Royal Institute Lecture in June 2018 that marked 50 years since the release of “2001: A Space Odyssey”. FAIR-SPACE Hub Director Professor Yang Gao delivered an invited talk at this event and joined the expert panel discussing how AI can help us survive in space, whether we should advocate for research into cryonics and what it takes for humans to be isolated for such long periods of time.

**SCIENCE FESTIVAL EXPERT PANEL**
Dr Louise Dennis of the Hub participated in a panel interview on the future of robotics run by the BBC at Manchester Science Festival in front of a live audience. This Tomorrow’s World Live programme explores the future of our lives alongside robots. The expert panel discussed “What roles will robots play and how will they change us?”.
EDUCATIONAL & PUBLIC OUTREACH

FAIR-SPACE has engaged across the education sector from primary through to postgraduate level in addition to the general public, professionals, industry and policy makers. This includes engagement with the media through interviews and articles as well as work with local charities and through national initiatives such as the Women in Engineering Day.

The engagement with our youngest members of society is of note this year with over 50 activities consisting of events, school visits, workshops and other activities.

SCHOOL CAREER DAY

FAIR-SPACE Hub Director received a written invitation by a year-6 pupil (who is a space robotics enthusiast) to attend a careers afternoon at the All Saints CE Primary School in Horsham, West Sussex in June 2018. The Hub Programme Manager and a PhD student attended and engaged with nearly 100 school children who visited the Hub’s stand taking part in discussions on AI & Robotics and for Space and routes into STEM related careers.

SCHOOL SPACE ROBOT CHALLENGE

FAIR-SPACE was a co-sponsor of the School Robot Challenge during the UK Robotics Week in June 2018. The Hub also exhibited at the Cheltenham Science Festival to promote the school challenge and engaged with over 200 school children (age 4 - 14).

UNIVERSITY SPACE ROBOT CHALLENGE

FAIR-SPACE co-sponsored the UKSEDS IUK Students for the Exploration and Development of Spacel Lunar Rover Competition, whose final contest and award ceremony took place on 1st July 2018 held at RAL Space. The activity objective was to get undergraduate students to build planetary rovers that can collect simulated lunar regolith with the rovers undergoing vibration tests to simulate space launch. Over 50 students from 8 UK universities attended the final.

SCHOOL “LEGO ROVERS WORKSHOP”

Throughout the year, FAIR-SPACE’s Liverpool partner has visited 18 schools (900 pupils) engaging with mainly primary school age but also senior schools/general public delivering lego rover workshops to encourage involvement in STEM subjects from a young age.

“WOMEN IN ENGINEERING” EVENT

FAIR-SPACE has supported and exhibited at the “Be Inspired” event organized by Fluor Ltd on Weds 27th June. The event was part of Women in Engineering Day, with the primary objective being to promote STEM subjects and careers in engineering to secondary school students.

EDUCATIONAL & PUBLIC OUTREACH
WORK WITH US

There are several ways that you can work with the FAIR-SPACE team and we would like to hear from you if you are a technology provider, an end user of robotics and AI, a policy maker interested in the broader issues surrounding space robotics, someone working in the scientific community or a member of the general public.

As the Hub grows we will be engaging with more collaborators, and building new partnerships. We will also be seeking to directly work with interested parties through the following mechanisms:

**FAIR-SPACE INNOVATION FUND:**
We will be launching an “Innovation Fund” in order to enable the inclusion of industry and academic partners who can bring additional value to the programme. Partners from robotics sectors and those that could utilise robotics and AI technology in other sectors such as nuclear, marine, mining or health are particularly welcome.

**FAIR-SPACE PARTNERSHIP PROGRAMME:**
Through our Partnership team we will be offering opportunities to work closely with the Hub in order to shape future research activity and ensure it is not only industry focused but meeting the needs of wider society.

**FAIR-SPACE EVENTS:**
These will be taking place across the UK and will include a forthcoming showcase event at the FAIR-SPACE hub site at the University of Surrey where you will be able to meet the team and visit our on-ground test beds.

We will also be launching our regular e-bulletin to ensure that you can keep up to date with all our news and follow our progress as we begin to commence tests and prepare our research for commercialisation.

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**TO REALISE SOCIAL AND ECONOMIC BENEFITS, FAIR-SPACE WILL CONTINUE TO NURTURE OUR STRONG PARTNERSHIP BETWEEN BUSINESS AND ACADEMIA TO ENSURE WE CREATE TRUE INNOVATION AND OF COURSE, TO ENSURE THE UK CAN LEAD THE WORLD IN THE DEVELOPMENT AND COMMERCIALISATION OF AI AND ROBOTIC TECHNOLOGIES.**

Ann Swift
FAIR-SPACE Partnership Manager, University of Surrey

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