CRADLE

CENTRE FOR ROBOTIC AUTONOMY IN DEMANDING AND LONG-LASTING ENVIRONMENTS

ANNUAL **REPORT**

YEAR ONE
2023-2024

Proud to be part of

MANCHESTER 1824
The University of Manchester

amentum

THE FIRST
12 MONTHS

The launch of the CRADLE Prosperity Partnership marked a significant milestone in advancing robotics for demanding and long-lasting environments.

In just 12 months, the centre has become a vital hub where academia and industry collaborate to address complex challenges across various sectors. We have successfully deployed several robotic platforms in real-world applications, highlighting the practical value of our unique research and innovation methodology. This progress demonstrates the potential of CRADLE's work to make a lasting impact. As we reflect on these achievements, we are excited about the future and remain committed to shaping the next phase of robotics and autonomous systems in the UK and globally.

CONTENTS

ABOUT THE PARTNERSHIP	4
AMENTUM	4
THE UNIVERSITY OF MANCHESTER	5
CRADLE'S MISSION	6
WORK PACKAGES	8
WORK PACKAGE 1: **COMPONENTS**	10
WORK PACKAGE 2: **ARCHITECTURES**	12
WORK PACKAGE 3: **INTERACTIONS**	14
WORK PACKAGE 4: **ASSURANCE**	16
WORK PACKAGE 5: **DEMONSTRATORS**	18
INDUSTRY ENGAGEMENT ACTIVITIES: CRADLE IdEAs	20
CRADLE IdEA: **HIGHWAYS**	22
CRADLE IdEA: **RAISE PROJECT**	24
CRADLE IdEA: **ASSURANCE IN AUTONOMY WORKSHOP**	26
PROJECT SUPPORT TEAM	27
OUTREACH	28
THE FUTURE	30
GET IN TOUCH	31

ABOUT THE PARTNERSHIP

AMENTUM

Amentum, the industry partner in CRADLE, is a global, advanced engineering and innovative technology solutions company, with over 50 years' experience of deploying robotic and autonomous systems in hazardous and challenging environments to solve complex challenges. Acting as a systems integrator, but also with the ability to design, build, test and deploy bespoke robotic systems, we remove humans from harm in sectors including nuclear, space, defence, and critical infrastructure. Employing more than 53,000 people across 80 countries, with 6,000 of these in the UK, our people apply undaunted curiosity, relentless ambition, and boundless imagination to challenge convention and drive progress.

"In the first 12 months, I've been so impressed with how CRADLE has accelerated our work in the field of robotics and autonomy. The teams from both Amentum and The University of Manchester have worked really hard to develop an aligned approach between Industry and Academia and has led to strides in technology innovation, great engagements with clients and their challenges, and the development of our talented people. I'm excited to see what the next year brings and hope to share that progress widely."

Duncan Steel
Industry Director

"As CRADLE passed its first anniversary, I took a moment to look back at our progress. Together, we have achieved a great deal in a relatively short amount of time. I'm proud of the progress that the team has made – much of which can be seen in this report. In particular, the Industry Engagement Activities (IdEAs), in their various maturities, have continued at pace and the relationships we are building through those will, I am sure, lead us to unexpected and interesting places; and we have plenty more planned for 2025."

Professor James Kell
Industry Co-Director

amentum

THE UNIVERSITY OF MANCHESTER

The University of Manchester is one of the UK's largest single-site universities, renowned for its academic excellence and vibrant student community. The University is a powerhouse of research and discovery; 26 Nobel laureates are among its former staff and students; and it was ranked fifth for research power – the quality and scale of research and impact – in the UK government's Research Excellence Framework (REF) 2021. The Faculty of Science and Engineering houses the Centre for Robotics and Artificial Intelligence, which brings together over 100 researchers from engineering, computing, and social sciences. A key focus of the Centre is developing advanced robotic systems for extreme environments. Looking ahead, the University aims to diversify its robotics research into different sectors to address a wider range of societal challenges.

MANCHESTER 1824
The University of Manchester

"The CRADLE partnership has advanced significantly over its first year. Not only have most of the academic posts commenced, and commenced generating new research, but the separate Amentum and Manchester teams have joined together to achieve a common vision and joint way of working on problems. From an academic view it has been refreshing to see how committed our Amentum colleagues are to developing low Technology Readiness Level (TRL), and longer horizon research. While keen to take advantage of opportunities to apply existing research to develop industrial solutions, it is central to CRADLE that we continue to look ahead towards the next problem, the next technology, and the next opportunity. As we begin year two, we look forward to exciting new research developments and routes to impact global industries."

Professor Michael Fisher
Academic Director

"CRADLE brings together academic excellence and industrial experience, leading to a unique environment where opportunities across the Technology Readiness Level (TRL) spectrum can be explored in a connected and informed way. The benefits of CRADLE have been greater than the sum of the individual parts, and a host of opportunities have been created across new sectors, which has only been possible by having both Amentum and The University of Manchester engaging with end-users together, as a whole. The synergies between the two partners and the enthusiasm with which the teams are working together make this one of the most exciting projects I've been involved in, and there is the potential to have a genuine impact on the robotics landscape over the coming years."

Dr Simon Watson
Academic Co-Director

CRADLE'S **MISSION**

The CRADLE Prosperity Partnership brings together the industrial experience that Amentum has in applied robotics and autonomous Systems with the research expertise at The University of Manchester in this field, to create a collaborative research centre that is internationally leading and sustainable in the long term.

Our vision for CRADLE is that it will deliver novel and transformational technology for demanding, dirty and dangerous environments, removing humans from harm, allowing its benefits to be realised across wide sectors of UK markets and beyond.

In accordance with the ambitions of the Engineering and Physical Sciences Research Council (EPSRC), CRADLE demonstrates how business and academia can come together to co-create and co-deliver research and innovation that addresses industry-driven challenges and delivers economic and societal impact.

"CRADLE offers industry the opportunity to position itself at the forefront of technological advances in robotics and autonomous systems, applying fundamental research undertaken by world-leading academics to help solve the most complex challenges in demanding and heavily regulated sectors. It supports the delivery of accelerated impact, by commercialising research and innovation and ensuring that it meets the real and most challenging needs of industry. Further, it drives the development of skills and talent, ensuring a pipeline of world-class people in the robotics field thereby driving further growth across industry in the UK and beyond."

Kayleigh Jackson
Industry Project Manager (Delivery and Exploitation)

"At CRADLE, we provide an exceptional platform for academic researchers to take their work from theory to practice, deploying robots and testing their solutions in real-world environments. This hands-on experience strengthens our global reputation for pioneering research and innovation in robotics and artificial intelligence. CRADLE fosters international collaboration by attracting both UK and global talent to tackle complex challenges. By bridging academic research with real-world applications, we are not only advancing the field but also positioning The University of Manchester, Amentum, and our partners at the forefront of technological progress worldwide."

Dr Paul Dominick Baniqued
Academic and Technical Project Manager

CRADLE INDUSTRIES

CRADLE aims to develop novel, transformational technologies to address complex challenges in demanding, dirty, and dangerous environments across a range of heavily regulated industries. A key focus is on identifying common challenges across sectors, enabling the transfer of knowledge and technology to enhance efficiency and innovation.

CRADLE's work spans multiple sectors, including:

- SPACE
- NUCLEAR LIFECYCLE
- URBAN INFRASTRUCTURE
- TRANSPORTATION
- UTILITIES
- OFFSHORE
- PORTS AND MARITIME
- DISASTER RESPONSE
- REGULATION
- ENERGY GENERATION
- HEALTHCARE
- CONSTRUCTION
- CYBER SECURITY

WORK PACKAGES

The research programme is structured around five interconnected Work Packages (WPs) to ensure a collaborative and integrated approach to solving complex challenges using robotics and autonomous systems.

Each WP comprises both an academic and industry lead, ensuring that research efforts are not only grounded in scientific rigor but also aligned with real-world industry needs. This structure fosters active collaboration across disciplines, promoting cross-pollination of ideas and solutions. The need for engagement between WPs ensures that advancements in one area benefit others, leading to more cohesive and robust technological innovations.

These WP are essential for the development of robotics and autonomous systems in the industries targeted by CRADLE. These sectors are heavily regulated and often involve high-risk environments, requiring advanced robotic systems that can operate safely and effectively.

The unique value of CRADLE's WP structure lies in its collaborative framework, which drives innovation by connecting academic research with industry expertise. This ensures that the technologies developed are not only cutting-edge but also practical and scalable. By having a structured, cross-functional approach, CRADLE is better equipped to produce impactful outcomes, making it a leading force in advancing robotics and autonomous systems for challenging and regulated environments globally.

1 COMPONENTS

- Modelling and Control of Complex Robotics Systems
- Risk-Aware Motion Planning and Control
- Robust Sensor Fusion
- Human-Understandable Confidence Metrics

2 ARCHITECTURES

- Architectural Transparency
- System Aware Architectures
- Mechanisms for Robot Collectives

3 INTERACTIONS

- Robots to Humans
- Humans to Robots
- From One to Many

4 ASSURANCE

- Evidence Generation
- Informing Future Standards
- Design for Assurance

5 DEMONSTRATORS

- Requirements and Benchmarking Analysis
- Design Tool Chains
- Simulated Environments
- Cyber-Physical Mission Environments

Image: CRADLE Robotics and AI / The University of Manchester / STFC Boulby Underground Laboratory

WORK PACKAGE 1
COMPONENTS

Improving the reliability of subsystems to ensure mission success in resilient robot autonomy.

MEMBERS

Bruno Adorno
Academic Lead

Keir Groves
Academic Co-Lead

Marti Morta Garriga
Industry Lead

Mohamed Atia
Postdoctoral
Research Associate

Seyonne Leslie-Dalley
PhD Student

SUMMARY

WP1 aims to develop reliable robotic system components that are tolerant to faults, self-aware, can provide confidence metrics about their performance, and are transparent to the wider robotic system. Developing these new components will enable safe decision-making and action by higher-level layers of autonomous robotic systems.

MODELLING AND CONTROL OF COMPLEX ROBOTICS SYSTEMS

New environments and tasks require more complex robot morphologies and systems, such as mobile manipulators and underwater multi-robot systems. The aim is to research holistic frameworks comprising modelling, control and estimation theory, and planning that can exploit the benefits of redundant robotic systems to allow robots to function even if failures happen, that are agnostic to the systems' morphologies, and with formal guarantees to prove their reliability.

RISK-AWARE MOTION PLANNING AND CONTROL

Robots moving in an environment involves risks due to the workspace, degradation or failure of the robot's actuators. The aim is to study risk-aware, chance-constrained motion planning and control techniques that dynamically integrate those risks, informed and estimated by other system components to develop safer robot motions. Developed techniques should be computationally efficient and provide formal guarantees, ensuring the theoretical properties required by higher-level layers across the robot architecture.

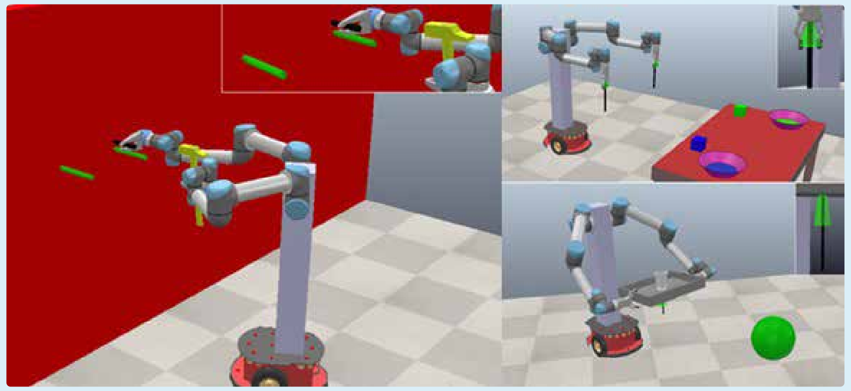
ROBUST SENSOR FUSION

Sensors are used to estimate the environment's state and the robot's condition. Sensor information must be reliable for the robot to decide actions and inform operators and other systems. Fusing sensor data makes the system resilient to mis-readings, degradation or sensor failure and provides more precise estimates than each sensor alone.
The aim is to research fusion and state estimation algorithms that account for failures explicitly and leverage sensor redundancy or heterogeneous sensor modalities to provide more robust and precise estimations.

HUMAN-UNDERSTANDABLE CONFIDENCE METRICS

Uncertainty is intrinsic to robotic systems. Moreover, sensors are noisy, actuators have mechanical imperfections, and the models used for planning and control are simplifications of reality. Confidence metrics provide means to communicate how sensor data or actions taken are so other systems or humans can make decisions and understand under which circumstances those measurements were taken.
This research focuses on providing transparency and human-understandable information about the system's state.

Three examples of bimanual tasks requiring different degrees of two-arm coordination: a) hammering a nail, b) independent placement of two objects into separate dishes, and c) transporting a large tray. Tasks are described and controlled using the same mathematical description, with differences only in the geometrical parameters, with formal guarantees of obstacle avoidance and closed-loop stability.



RESEARCH SPOTLIGHTS

Mohamed Atia

Mohamed's research aims to develop a modelling framework for underwater vehicle-manipulator systems, accounting for complex non-linear hydrodynamics effects. Computational fluid dynamics simulations have been done to analyse these non-linear behaviours, helping develop accurate analytical models. Those analytical models under development are computationally efficient and can be computed online, which is crucial for model-based control frameworks.

This technology is widely applicable to inspection, maintenance and monitoring of vessels and underwater structures related to maritime infrastructure or nuclear decommissioning.

Seyonne Leslie-Dalley

Seyonne's research focuses on developing a control framework for the cooperative manipulation of two independent underwater vehicle-manipulator systems. The framework will enable the intuitive description of a general bimanual manipulation task while also considering not only the system's intrinsic constraints and environmental constraints but also constraints specific to that manipulation task.
With direct applications in underwater industries such as the inspection and maintenance of offshore structures, nuclear pond decommissioning, and marine exploration, the framework's versatility extends beyond these environments offering potential use in any industry where cooperative manipulation could be used.

WORK PACKAGE 2
ARCHITECTURES

Designing flexible and transparent software architectures to enable autonomous robots to be deployed reliably and verifiably in demanding and long-lasting scenarios.

MEMBERS

Michael Fisher
Academic Lead

John Brotherhood
Industry Lead

Louise Dennis
Academic Researcher

Marie Farrell
Academic Researcher

Raynaldio Limarga
Postdoctoral
Research Associate

Sen Zheng
Postdoctoral
Research Associate

SUMMARY

A software architecture is a collection of software elements, together with the relationships between them. In robotic systems these elements are often associated with modular components that, together, describe and implement the overall behaviour of the system. WP2 will explore modular, transparent, resilient, and verifiable architectures applicable across sectors, targeting both individual and interacting systems, and providing both strong behavioural guarantees and guidelines for their use.

ARCHITECTURAL TRANSPARENCY

Not only are architectures important in highlighting structural and design decisions, but the way we build these architectures has a fundamental impact on the effectiveness of our systems. Building them in the right way can promote transparency (hence: explainability; verification; assurance), flexibility (to cope with unforeseen issues), and resilience (reliability and recovery). Building them carelessly can make all these aspects difficult (and sometimes impossible). We aim to provide guidance on, and patterns for, best practice.

SYSTEM AWARE ARCHITECTURES

A key aspect of developing robots for demanding and long-lasting environments will be their resilience, especially their ability to cope with unexpected situations. It is here that autonomous decisions will need to be made. This will require software reconfigurability and an awareness, in the robot itself, about what architectural changes are possible and how those changes will affect the capabilities of the robot. Ensuring effective and appropriate architectural mechanisms to achieve this 'self-awareness' is an important target.

MECHANISMS FOR ROBOT COLLECTIVES

Architectural aspects are important, not only for individual robots, but for both multi-robot and human-robotic interacting systems. In collaboration with WP3 we aim to explore these aspects, providing reliable and transparent approaches to architectures for both robot swarms and human-robot teams.

RESEARCH SPOTLIGHTS

Raynaldio Limarga

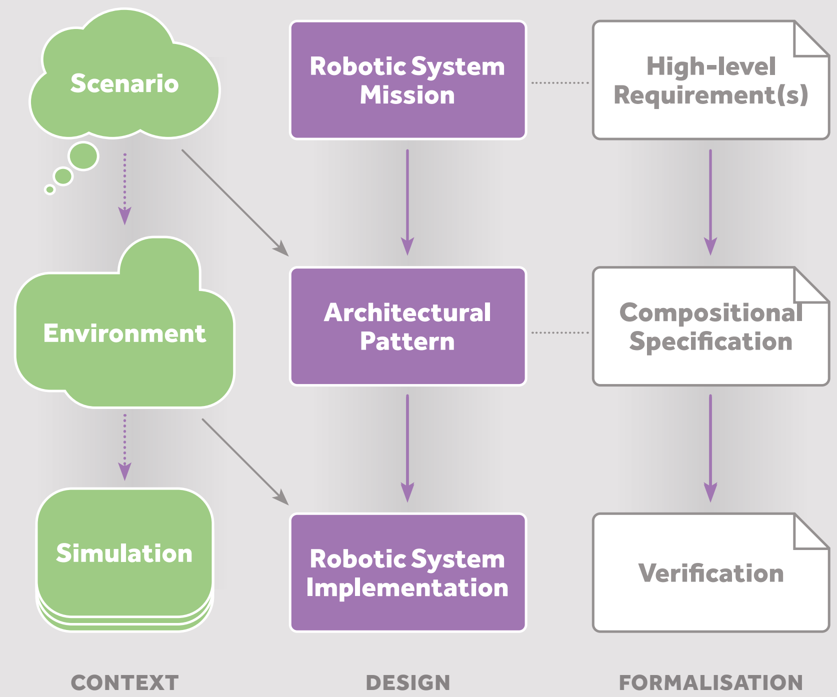
Ray's work will involve examining and developing the architectures needed for resilient and trustworthy autonomous systems while also ensuring that the core autonomous decision-making is both identifiable and verifiable. This involves empowering the systems to navigate and respond effectively to unforeseen or unpredictable scenarios. The team will build resilience into every design layer while maintaining transparency and accountability, ensuring every decision is traceable and justifiable. Only by this can we establish strong trust in the overall decision-making processes. Trust in autonomous systems is paramount to ensure engineers, users, and regulators feel confident in deploying robotics in complex and dynamic environments.

Sen Zheng

Sen's research will focus on the analysis of various types of robot collectives, including human-robot teams, robot teams, and robot swarms. Unlike single robots, collectives offer greater fault tolerance, enabling them to operate efficiently and withstand faults even during performance degradation, making them highly promising for industrial applications, such as environmental protection, disaster response, nuclear, and space missions. This work, between WP2 and WP3 aims to develop mathematically rigorous methodologies and practical tools to ensure the reliability and transparency of robot collectives, instilling greater confidence in stakeholders throughout the development and deployment of these systems.

CASE STUDY

Given a specific mission for our prospective autonomous robotic system, together with a scenario where the robot carries out this mission, we can provide a pattern (possibly several) leading to the transparent and reliable design of such a robot. The selected pattern, with the specific environment in which the robot will be deployed, leads to a full implementation of the architecture which might then be assessed firstly in a simulated environment then in a real deployment. At each stage we must be transparent about the required and implemented behaviours, for example via formalisation.



WORK PACKAGE 3
INTERACTIONS

Enhancing collaboration by addressing challenges in human and robot interactions for trustworthy and effective teamwork.

MEMBERS


Angelo Cangelosi
Academic Lead


Kathryn Mearns
Industry Lead


Clare Dixon
Academic Researcher


Emily Collins
Academic Researcher


Federico Tavella
Postdoctoral Research Associate


Joseph Bolarinwa
Postdoctoral Research Associate


Sen Zheng
Postdoctoral Research Associate


Xinyun Chi
PhD Student


Matthew Rolph
PhD Student

SUMMARY

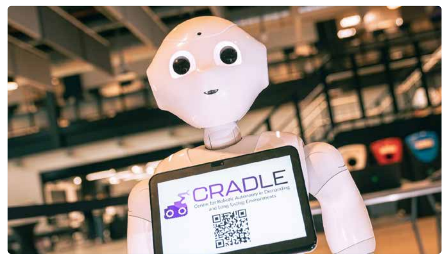
Human-robot interactions addresses joint work and collaboration between people and autonomous systems including the move from classical dyadic interactions between a human user and a robot, to scenarios with heterogenous teams of multiple people and robots.

ROBOTS TO HUMANS

Key challenges of the interaction between robots and humans involve describing what the robot is doing, why it is doing it (e.g., goals) and what the plan is for the future. This requires an explanation of transparent behaviour linking it to WP2. New research into people's theory of mind (ToM) of autonomous systems can potentially develop an understanding of the robot's behaviour and goals. This provides mechanisms for understanding interactions with users (WP5) and regulators (WP4).

HUMANS TO ROBOTS

The user requires information to understand how the robot uses input from its sensors and interactions with humans to decide what to do. This information is the step from 'concept to action' ensuring that users can

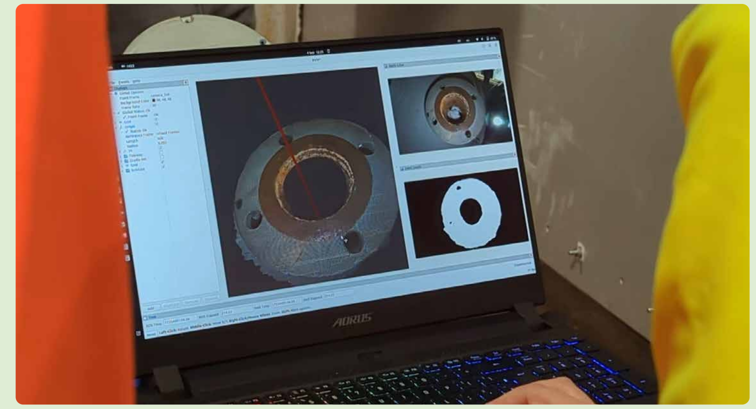


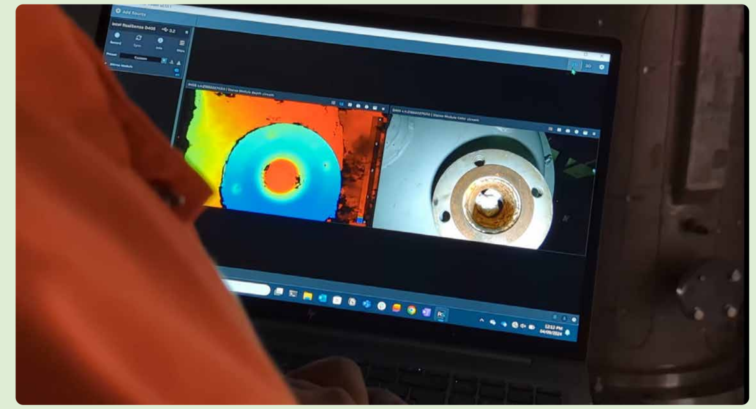
convey what the robot must do. This involves exploring and developing a library of instructions from dialogue to 'programming by example'. This will provide mechanisms for actors to affect the performance of robots and will be important for WP5.

FROM ONE TO MANY

As well as robots interacting with people they are being designed to work in small groups (robot teams) or larger numbers of robots (swarms). It is important to make sure both robot-robot teams and swarms and human-robot teams can achieve the task where possible, can recover from failure and interact in a safe manner etc. In WP3 we will, in collaboration with WP2, apply formal verification, a mathematical analysis of systems to assess this alongside non-formal verification techniques.

Human Factors are important to consider in the development of interfaces for robots, as they ensure that the design allows users to operate robots effectively, provides confidence that the interface minimises human error, and ensures the safety of both human operators and robots. The Amentum Human Factors team was involved throughout the development of the Robotic Automation of Innovative Spark Erosion (RAISE) project, particularly in the design of the user interface. Human Factors recommendations applied in the RAISE project included improving the quality of feedback received by the operator from the robot, such as a clear visual indication of when the robot was stationary versus in motion, clearer labelling, and the correct use of colour and layout, making it easier to adjust the angles of the robot arm on the interface.
Amber Drinkwater
Human Factors Consultant at Amentum





RESEARCH SPOTLIGHTS

Federico Tavella

Federico is working on foundational models to enhance human-robot interaction and collaboration. These models, when integrated into physical robots, will significantly improve their abilities by providing them with knowledge and enabling them to understand and respond to various types of information. This approach will allow us to move beyond traditional programming methods and utilise natural language to instruct robots on tasks and facilitate their learning. Through the integration of these models, we can create robots that are more capable, adaptable, and intuitive in their interactions with humans.

Xinyun Chi

Xinyun is working on learning-based robot manipulation, which focus on robot learning from human demonstration with adaptive control, aiming to improve the human-robot interaction by providing more natural and personalised robot assistance based on current user status. By integrating imitation learning-based robot manipulation and adaptive control using real-time human feedback input, this pipeline aims for implementation across diverse industrial scenarios, enabling robots and humans to collaborate with seamless interaction, which will further lead to improved human robot interaction with enhanced human satisfaction and trust.

Matthew Rolph

Matthew is working on disambiguation of human instructions using large language models, with aims to enable robots to better comprehend natural language and improve human-robot interactions in ambiguous instruction scenarios. Integrating this into a range of industrial settings, the goal is to enhance collaborative efforts and reduce friction in human-robot collaboration when responding to natural language queries.

WORK PACKAGE 4
ASSURANCE

Generating better evidence and arguments for ethical, safe, and secure design and implementation of robotics and autonomous systems.

MEMBERS


Louise Dennis
Academic Lead


Frederic Wheeler
Industry Co-Lead


Harry Newton
Industry Co-Lead


John Mackey
Industry Co-Lead


Michael Fisher
Academic Researcher


Dhaminda Abeywickrama
Research Fellow

SUMMARY

This work package focuses on the assurance challenges that come with autonomous robotic systems. What kind of guarantees do we need? We want guarantees of safety, but also security and potentially ethics. How do we design our systems so we can evidence those guarantees? And how can we curate and present that evidence?

EVIDENCE GENERATION

The evidence required by a regulator or other body, typically involves not just the system itself (the robot and its software) but evidence about the way that system was developed, how hazards were identified and mitigations devised. Therefore, we are looking both at techniques for verifying the behaviour of robotic autonomous systems, but also how those techniques fit into toolchains for generating and organising evidence throughout the development and deployment lifecycles.

INFORMING FUTURE STANDARDS

Much of the evidence needed will involve demonstrating adherence to standards. However, there is a lack of widely accepted standards for the development of AI and robotic autonomous systems. We plan to perform basic research into what it means for a robot to be safe, secure and ethical and how this can be established through the development process so that this can inform future standards.

DESIGN FOR ASSURANCE

Together with WP2 we will investigate methodologies for designing robotic autonomous systems in ways that will enable us to evidence their safety. This will include developing component-based architectures for these systems, linked with techniques for validating individual components and patterns of assurance that can be related to design patterns.

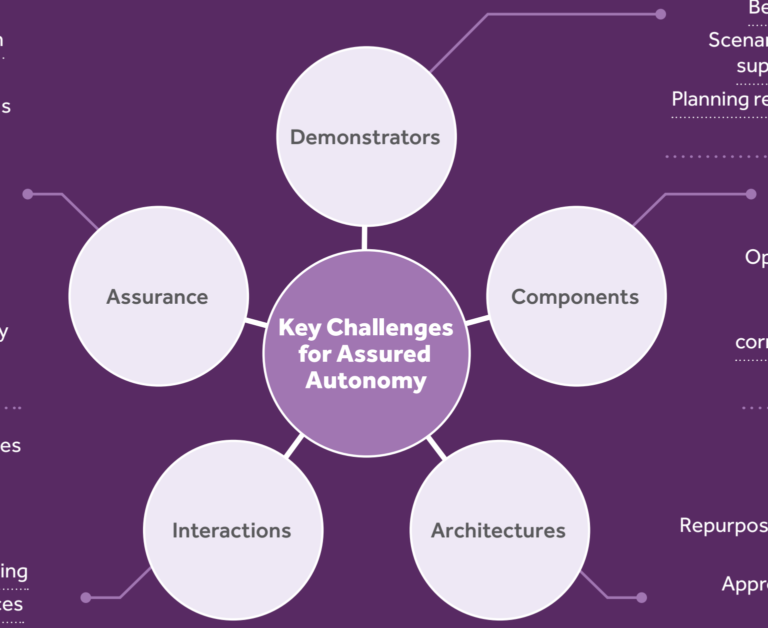
RESEARCH SPOTLIGHT

Dhaminda Abeywickrama

Dhaminda's current research is focused on developing a 'reference assurance case' for a ground-based autonomous inspection robot (see page 17). A reference assurance case is a structured framework that serves as a standardised template (e.g., patterns) and as an example for developing assurance cases across various industries. It provides a baseline of accepted practices, arguments, and evidence, which can be adapted to specific projects or systems. The reference case will also incorporate physical/functional architecture, hazard analysis, requirements, safety architecture, and arguments, with an initial application in a case study on verge inspections for the highways sector. In the first year, Dhaminda has published three research papers, which acknowledge CRADLE, on topics including risk analysis for autonomous robotic swarms, standards for soft robotics, and a corroborative approach to the verification and validation of robotic swarms.

Early safety case design
Traditional approaches to validation
Ensuring testing & V&V
Diversity of AI-enabled autonomous systems in MASS & ROC
Safety, security & robustness
Balance of risk: benefits vs risks
Fairness & ethics
Accountability & governance
Contestability & redress
Legal implications: assigning liability in case of failure

Human factors: adapting human roles with automation
Identifying level of automation
Supervision, human factors
Human interaction in decision-making
Designing human-machine interfaces
Managing human factors
Assumptions & limitations



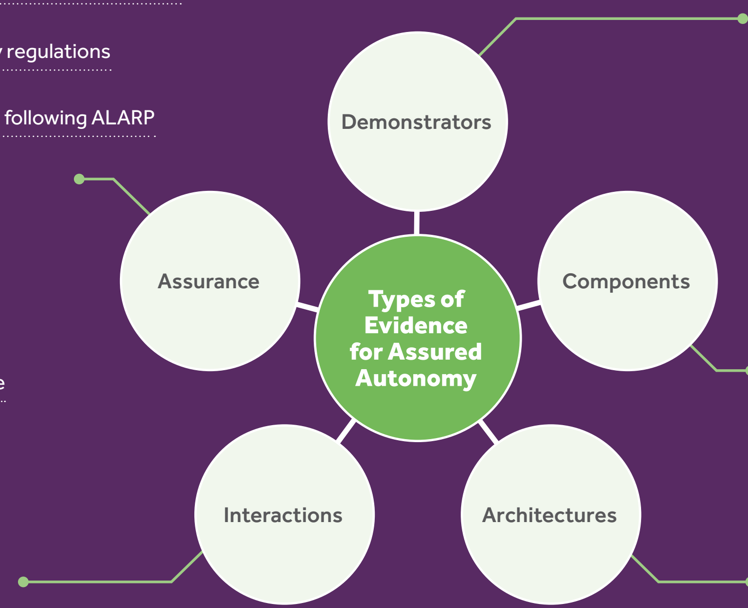
Benchmarks & standards
Scenario/synthetic testing to supplement physical tests
Planning recovery & maintenance

COTS component assurance
Operational environment variability
Completeness & correctness of ODM/ODD

System integration
Change implications
Repurposing robots for different tasks
Appropriate transparency & explainability
Explainability of autonomous component part

Use of designated standards
International AI regulatory & standards alignment
Certification compliance
Industry standards and safety regulations
Early-stage safety case
Optioneering documentation following ALARP
Proportionality of evidence
Systemic hazard analysis
Risk & quality management
Cybersecurity measures
Data & information sharing
Data & governance
Technical documentation
Well-documented safety case
AI safety validation
Testing and V&V

Behaviour competency
Hierarchy of control
Foreseeable misuse
Appropriate human oversight
Transparency for stakeholders
Stakeholder collaboration



Simulation & pilot testing
Testing: digital/synthetic & 'real-world'
Testing in controlled/restricted environments
Maintenance & recovery plans

Operation modes & fault management

Systems engineering & validation approach

KEY: **AI** – Artificial Intelligence | **ALARP** – As Low As Reasonably Practicable | **COTS** – Commercial Off-The-Shelf
MASS – Maritime Autonomous Surface Ships | **ODM/ODD** – Operational Domain Model/Operational Design Domain
ROC – Remotely Operated Craft | **V&V** – Verification and Validation.

WORK PACKAGE 5
DEMONSTRATORS

Showcasing next-generation solutions in a range of cyber-physical environments leading to the deployment of robotic platforms in the real world.

MEMBERS


Simon Watson
Academic Lead


Matthew Goundry
Industry Lead


Christopher Bishop
Postdoctoral Research Associate


Michael Oates
Robotics Specialist


Lewis Wheelhouse
PhD Student


Alexander Morley
PhD Student


Joshua Bettles
PhD Student


Toluwani Soboyejo
PhD Student

SUMMARY

WP5 aims to advance robotics systems to alleviate humans from dangerous and repetitive tasks. Its two main goals are to showcase novel CRADLE robotic technologies and to develop methods for matching robots to various tasks. To achieve this, WP5 is creating RoboAlchemy, a groundbreaking software designed to address these challenges effectively.

REQUIREMENTS AND BENCHMARKING ANALYSIS

Requirements analysis is essential for defining and formalising the exact needs for a robot to complete a task. To evaluate how well a robot meets these requirements, a new ontology is being developed which will enable a comprehensive evaluation of the robot functionalities compared to the mission requirements. This will be facilitating informed decision-making for robot operators and designers.

DESIGN TOOL CHAINS

The design toolchain, RoboAlchemy, will integrate task and environment requirements to identify the most suitable robot functionalities and components. By analysing these factors comprehensively, RoboAlchemy will ensure that every system element is considered. This approach will enable the identification of optimal configurations, streamlining the design process and enhancing the efficiency of robotic systems. Through its thorough matching and recommendation functionalities, RoboAlchemy will support the creation of highly effective and tailored robotic solutions.

SIMULATED ENVIRONMENTS

A key element of RoboAlchemy will be the ability to plug into simulation and visualisation tools. As the first stage of verification, RoboAlchemy will simulate its proposed robot undertaking the given tasks in tools such as Omniverse. This will allow users to visualise and assess the robot's performance in a controlled, virtual environment before real-world implementation. The simulation will help identify potential issues, optimise task execution, and ensure the robot's capabilities align with task requirements, enhancing the overall reliability and effectiveness of the solution.

CYBER-PHYSICAL MISSION ENVIRONMENTS

Cyber-Physical Mission Environments integrate physical robots with virtual simulations to enhance mission planning and execution. By combining real-world robotic capabilities with advanced digital environments, these systems allow for comprehensive testing and optimisation. In RoboAlchemy, this approach will enable precise modelling of tasks and scenarios, ensuring that robots are thoroughly evaluated before deployment. This fusion of physical and virtual elements ensures that robots can perform reliably and effectively in complex, real-world conditions.

RESEARCH SPOTLIGHTS

Lewis Wheelhouse

Lewis is developing a robotic platform for pipe network inspection, focusing on adaptive gripping and new locomotion techniques to navigate complex, congested, multi-pipe environments. This research has direct applications in the oil, gas, and nuclear industries, where it enhances inspection efficiency and safety.

Joshua Bettles

Joshua is developing a Cobot Radiological Survey Assistant, focusing on coverage path planning techniques to maximise scan coverage over 3D non-convex geometries, such as humans while avoiding collisions with the surface. This work has direct applications for characterising radioactive contamination on objects at barriers between controlled areas within the nuclear industry.

The CRADLE cell *(shown above and left)*, located in the Amentum's laboratories in Birchwood Park, Warrington, is a mock-up of a nuclear fuel reprocessing cell for robotic decommissioning demonstrations. It features adjustable lighting, CCTV, network connectivity, industrial furniture, and a central 1-ton vessel, along with various pipes and beams. The cell is enclosed, with an adjacent elevated control room and observation window. Besides testing and demonstrations, it will support long-term experiments in a safe, realistic environment and be mirrored by a digital twin to explore integrated virtual and physical testing.

INDUSTRY ENGAGEMENT ACTIVITIES

CRADLE IdEAs

The Prosperity Partnership model requires that research should be led by industry need, with work being co-delivered and co-created between the industry and academic partners. In order to fully understand industry need, we have developed a programme of Industry Engagement Activities, or IdEAs, which is formed of three stages.

All WP Leads or empowered delegates → Industry challenge holders

CRADLE Technical Lead(s) and PM → down-selected CRADLE team* → Challenge holder contact

CRADLE Technical Lead(s) and PM → down-selected CRADLE team → Challenge holder contact

STAGE ONE: CHALLENGE IDENTIFICATION

The CRADLE team facilitates an industry day where invited challenge holders share details of issues, ideas and challenges. This can take many forms, for example a workshop at CRADLE facilities or at a conference, with a single client, cross-sector representation or entire industry stakeholders. The aim is for the CRADLE team to gain a detailed understanding of industry challenges and their impact.

STAGE TWO: CONCEPT DEVELOPMENT

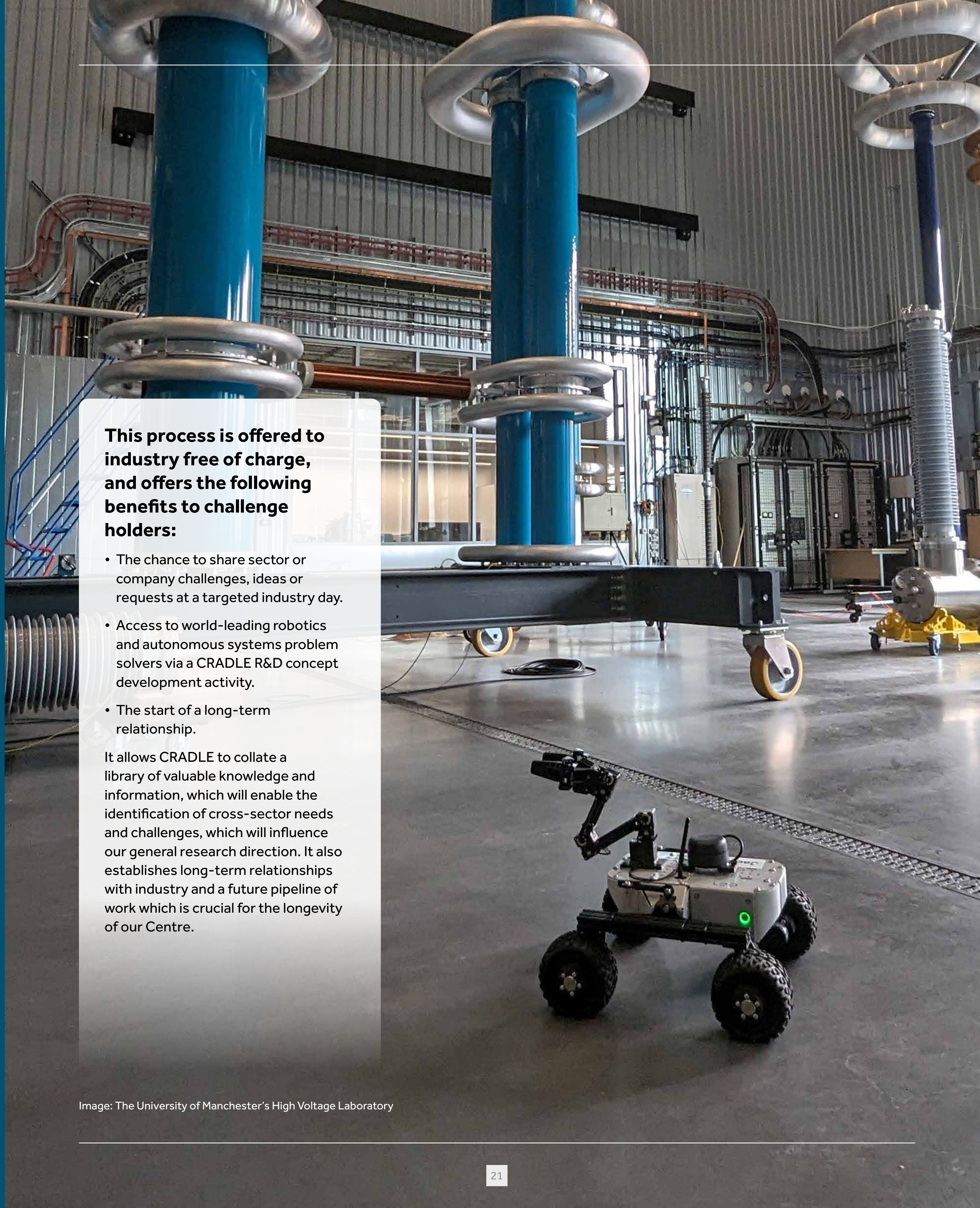
The CRADLE team analyses the outputs of stage one, identifying cross-sector commonalities, concept solutions and realistic timescales to achieve them.

STAGE THREE: NEXT STEPS

Based on the concept solution developed in stage two, the CRADLE team and challenge holders reconvene to agree next steps. This may include a demonstration of the concept, proposals for future work including technology development and/ or research, the identification of funding routes, a decision to go no further, or something else.

Long-term relationship established →

*Team selected based on an informed decision as to WP relevance founded on the information gathered at Step 1.



This process is offered to industry free of charge, and offers the following benefits to challenge holders:

- The chance to share sector or company challenges, ideas or requests at a targeted industry day.
- Access to world-leading robotics and autonomous systems problem solvers via a CRADLE R&D concept development activity.
- The start of a long-term relationship.

It allows CRADLE to collate a library of valuable knowledge and information, which will enable the identification of cross-sector needs and challenges, which will influence our general research direction. It also establishes long-term relationships with industry and a future pipeline of work which is crucial for the longevity of our Centre.

Image: The University of Manchester's High Voltage Laboratory

CRADLE IdEA
HIGHWAYS

national highways

CRADLE's first Industry Engagement Activity was organised for National Highways, a government-owned company responsible for operating, maintaining, and improving England's major roads. Prior engagement with our colleagues in Jacobs raised initial discussions on how highway inspection could be carried out more safely by using robotics and remote operations to reduce the amount of time people spend on the road in hazardous conditions.

In September 2023, the CRADLE team ran a challenge identification session which was attended by National Highways challenge holders. The team spent the morning discussing the breadth of challenges facing National Highways, then used the afternoon to prioritise these challenges according to urgency and impact. As a result of the workshop, the CRADLE team presented several technology implementations to demonstrate robotics capabilities for the sector.

Initial Visit to M61 Motorway

With the guidance of a National Highways inspection engineer, the CRADLE team initially visited a verge in a section of the M61 motorway that had landslips and other hazards. The purpose of the visit was to determine and demonstrate the suitability of robotic sensors (LiDAR, RGBD depth sensor, stereo cameras, etc.) for these inspections.

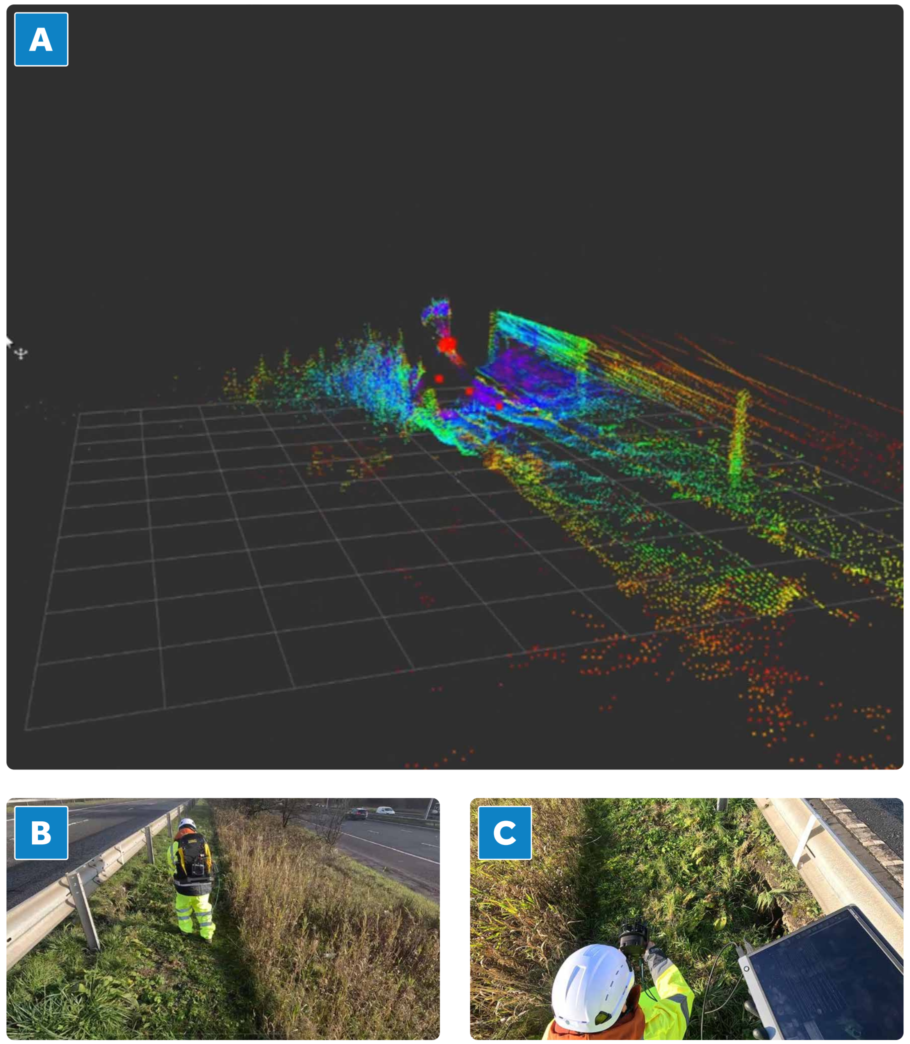


Figure 1: Initial visit to a section of the M61 motorway as part of the National Highways industry engagement. (A) Point cloud data generated from a LiDAR and stereo-camera sensor kit. (B-C) Photos taken at the verge of the motorway. (C) Vegetation and subsidence as prominent features to be noted and reported by the inspection engineer.

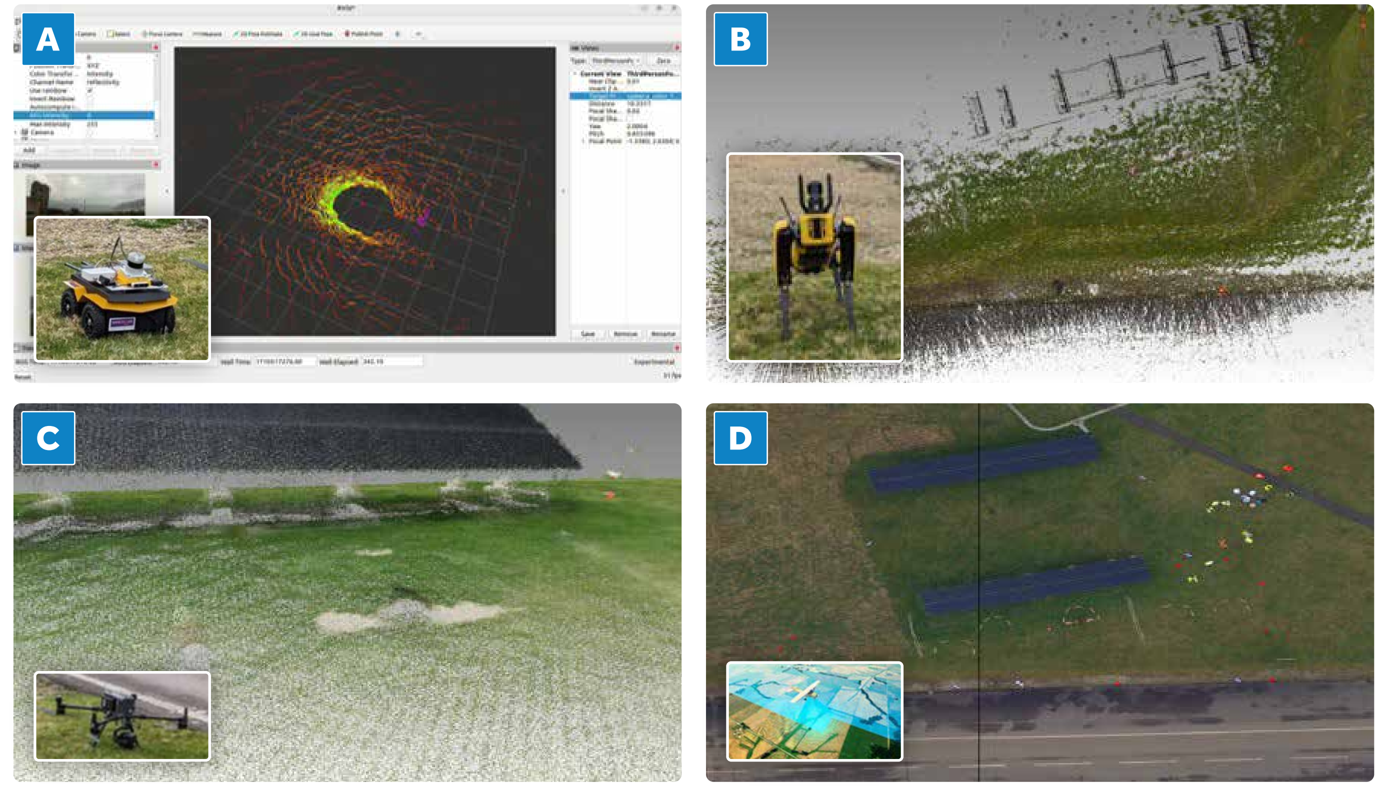


Figure 2: CRADLE's deployment activity at the National Highways Development Centre. (A) ClearPath UGV with a LiDAR sensor, depth camera, and GNSS receiver. (B) Boston Dynamics Spot with a Leica 360 LiDAR sensor. (C) Matrice 300 UAV with LiDAR sensors, GNSS receiver, and onboard cameras. (D) GeoPod sensor payload on an aircraft.

Technical Sprint and Deployment at the National Highways Development Centre

Two of the key challenges identified related to the frequent human inspection of motorway edges and how to inspect the interior of structures such as motorway gantries. In February 2024, the CRADLE team held a two-week technical sprint aimed at demonstrating the current art of the possible and potential future capabilities achievable with further sector collaboration via new research opportunities (e.g., sponsored work, and PhD projects). This industry engagement concluded with a deployment at the National Highways Development Centre test motorway at the Fire Service College near the Cotswolds in March 2024.

The deployment involved several robotic platforms that gathered footage and geospatial data of simulated features characterised during the initial visit:

1. Unmanned ground vehicle (UGV) with sensors (i.e., a ClearPath Jackal with a GNSS receiver, Ouster LiDAR, and RealSense camera)
2. Boston Dynamics Spot quadruped with a Leica 360 LiDAR
3. Unmanned aerial vehicle (UAV) with LiDAR, GNSS receiver, and cameras
4. GeoPod sensor payload on aircraft

The figures above show the platforms deployed on-site and their corresponding data.

CRADLE IdEA
RAISE PROJECT

The RAISE project: "Robotic Automation of Innovative Spark Erosion" was born from the CRADLE IdEAs process. This was done as a collaboration with Nottingham-based startup Scintam Engineering who have developed unique portable EDM (electrical discharge machining) equipment – designed for the fast removal of seized fasteners such as bolts or rivets, that may otherwise result in long delays at overhaul. This is a new technology with high value potential to a number of industries, in particular as part of a roboticised solution to allow for remote operation and automation in demanding and long-lasting environments.

CRADLE led a three-month technical sprint culminating in a live technology demonstration to industry professionals, hosted at the Amentum laboratories in Birchwood. The showcased technology comprises a base X2 tracked robot platform for navigation, with a UR10 manipulator arm to allow for dextrous control of the EDM probe, which is integrated as a payload. The CRADLE team integrated onboard cameras and sensors and developed a controls architecture which enabled full remote operation, environment mapping and automated detection of target bolt features for removal. After this initial phase of development, the system is capable of remotely removing fasteners in a mock-up nuclear cell environment, demonstrating potential future value for the nuclear decommissioning industry amongst other potential applications.

This is a landmark achievement for CRADLE after its' inception last year, to be tackling innovative industry challenges, and to have done so by forming a collaborative team consisting of colleagues from Amentum, The University of Manchester, and Scintam Engineering as a partner SME. After the success of this initial technology demonstration, CRADLE aims to continue development of this platform and work towards a fully integrated and deployment-ready solution, and to advance automation elements as far as would be suitable for a particular use case.

"At Scintam, we have always wanted to promote our technology to the nuclear and other demanding environment sectors, but this is difficult as an SME. CRADLE has shown us what a diverse team of engineering and business minds, from industry and academia, can achieve in a short development period. Each consortium member played to their own strengths – with Scintam providing the FastEDR portable EDM equipment – and the experts at CRADLE providing the know-how for integrating our system with the robotics, computer vision, and remote operation platforms. This is something that would have taken us 12 months+ to achieve in-house, but with CRADLE we were able to demonstrate the system to key industry players within 6-months from inception of the project. We are excited to see the follow-on from the showcase day and we hope to work with the CRADLE team to commercialise the platform."
Sam Catchpole-Smith
(CEO, Scintam Engineering)

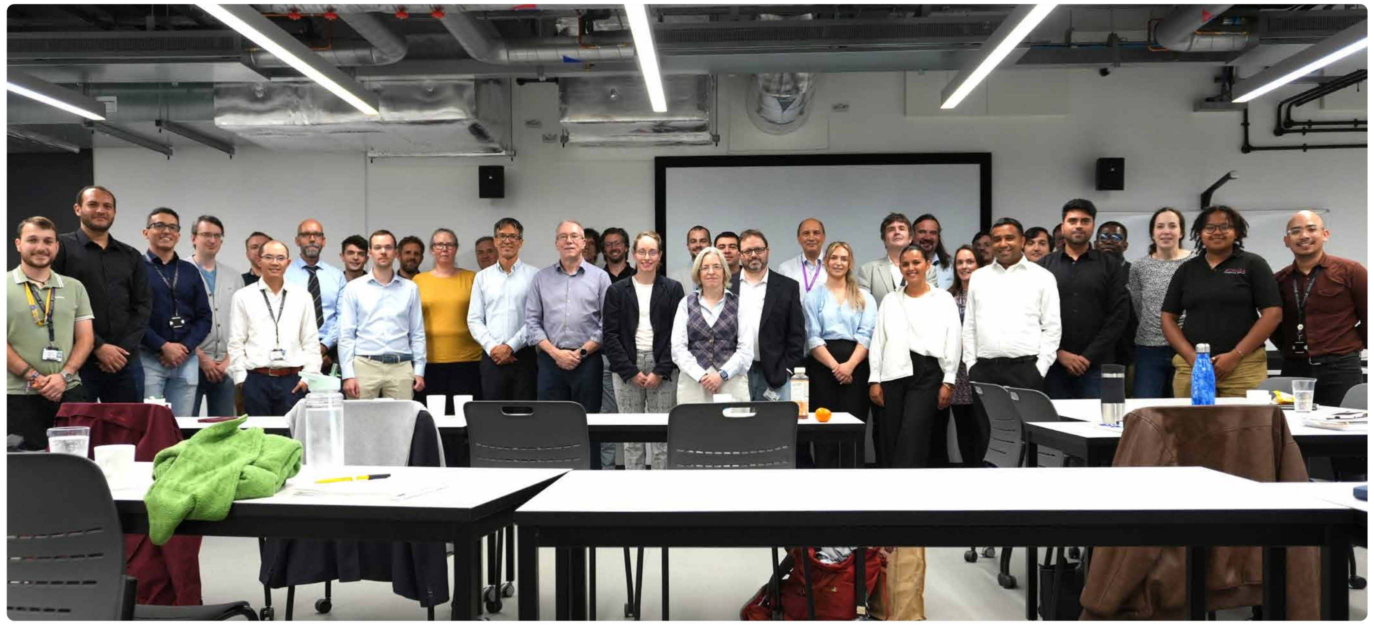
"The RAISE IdEA provides a good platform and environment to develop our research themes. The project integrated complex systems and developed algorithms running on a modular architecture with most components able to be reused and improved. It allowed us to learn to work together between technical teams and work packages which provided guidance and best practices, resulting in a successful demonstration and many ideas for the future."
Marti Morta-Garriga
Industry Lead, CRADLE Components WP1

CRADLE IdEA **ASSURANCE IN AUTONOMY WORKSHOP**

CRADLE welcomed a diverse group of regulators and assurance bodies operating in demanding, long-lasting environments to a workshop on 'Autonomy and Safety Assurance in the Early Development of Safe Robotics and Autonomous Systems'.

Invited speakers and participants from the Health and Safety Executive (HSE), Office for Nuclear Regulation (ONR), Rail Safety and Standards Board (RSSB), Maritime and Coastguard Agency (MCA), Environment Agency (EA), and Civil Aviation Authority (CAA) discussed key challenges, and the types of evidence expected for Assured Autonomy, covering a range of use cases for autonomous inspection, including ground, nuclear, underwater, and aerial applications. The day was a great success, hopefully, the first of a series of future engagements, with the outputs contributing to CRADLE's development of a reference assurance case for an autonomous inspection robot.

Convening such a diverse group of regulators to discuss a topic as novel as autonomy is a significant challenge – a great example to demonstrate the power and value of bringing academia and industry together via the CRADLE programme.



PROJECT SUPPORT **TEAM**

Stella Flint
Project Administrator
The University of Manchester

Jade Simpson
Project Manager
Amentum

Danish Khan
Robotics Technical Specialist
The University of Manchester

Kwai Wa-Tse
Robotics Software Technical Specialist
The University of Manchester

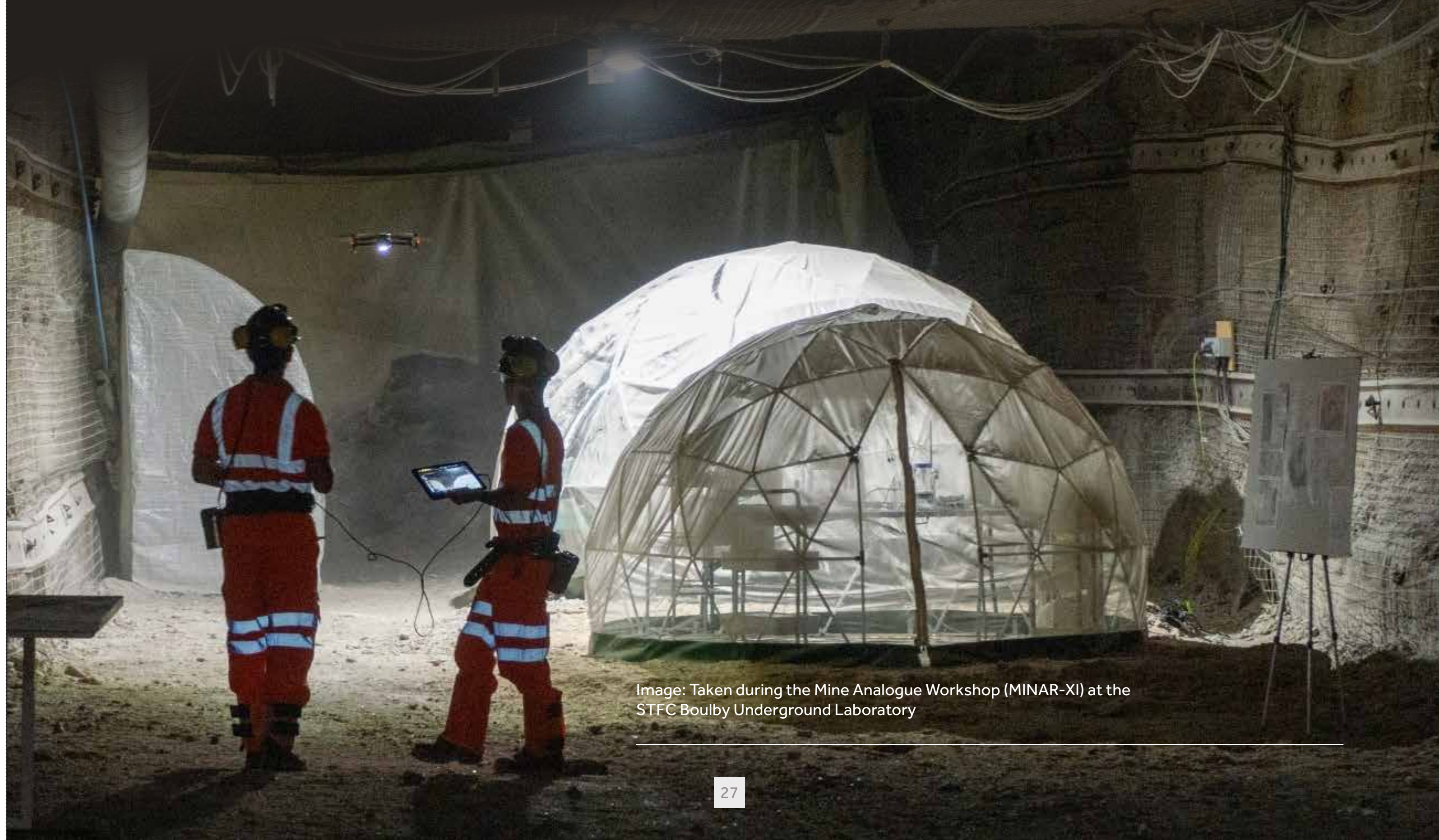
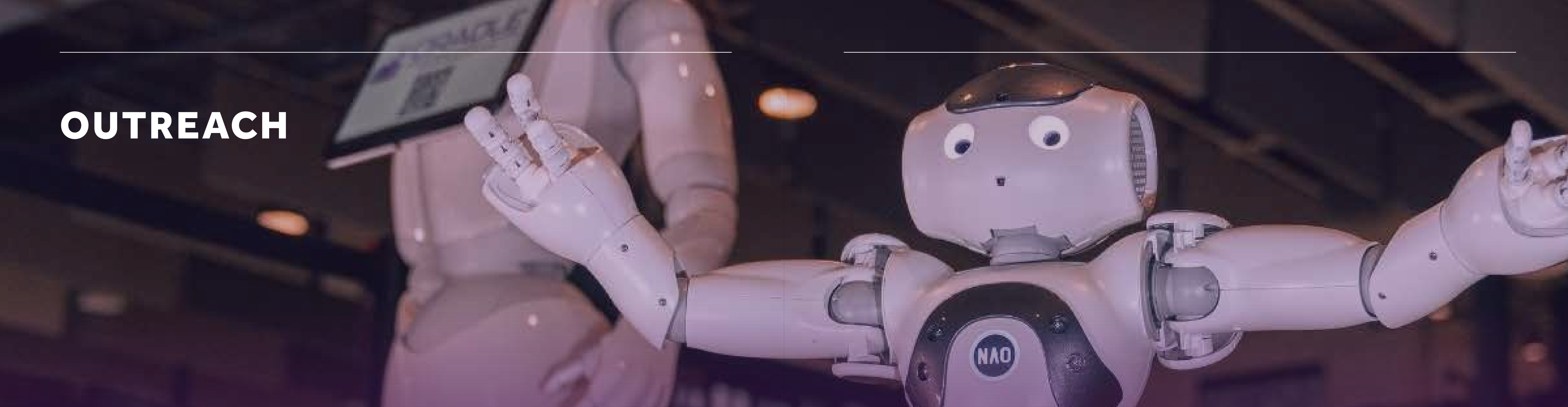


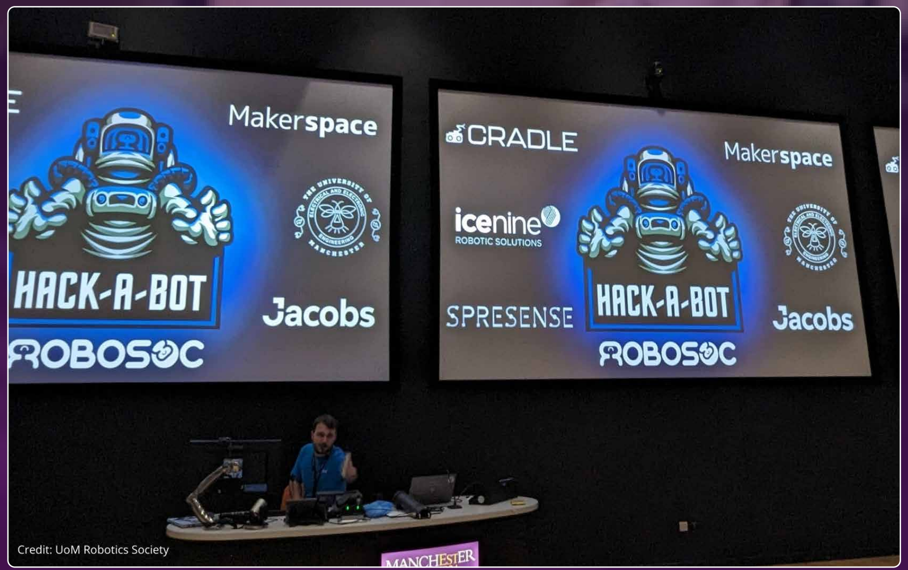
Image: Taken during the Mine Analogue Workshop (MINAR-XI) at the STFC Boulby Underground Laboratory



OUTREACH

CRADLE values interaction with the public in all stages of the research process through a variety of events including all members of our team, working with non-academic partners to ensure we reach further into the community.

The centre commits to public engagement to inspire the public by showcasing our contribution and its benefits to life in the UK. These activities aim to attract people of all ages; especially young talent, to the range and desirability of STEM, whether that be a career choice or engaging in clubs and societies at school.



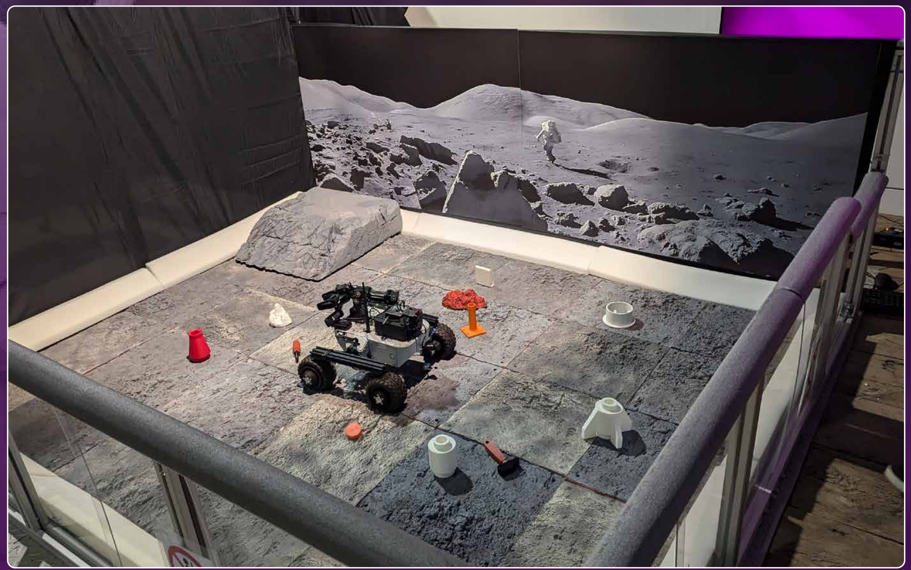
Credit: UoM Robotics Society

HACK-A-BOT

Hack-A-Bot 2024, the third annual robotics hackathon by The University of Manchester's Robotics Society, brought together over 200 students from various disciplines for 24 hours of innovation. Sponsored by CRADLE, the event featured hands-on robotics kits, expert talks, and career insights. 16 teams competed in the ROVER challenge, building remotely operated vehicles to tackle tasks like inspection and exploration. The sponsorship opened doors for more students to dive into robotics, sparking interest in future careers and research, and inspiring the next generation of roboticists.

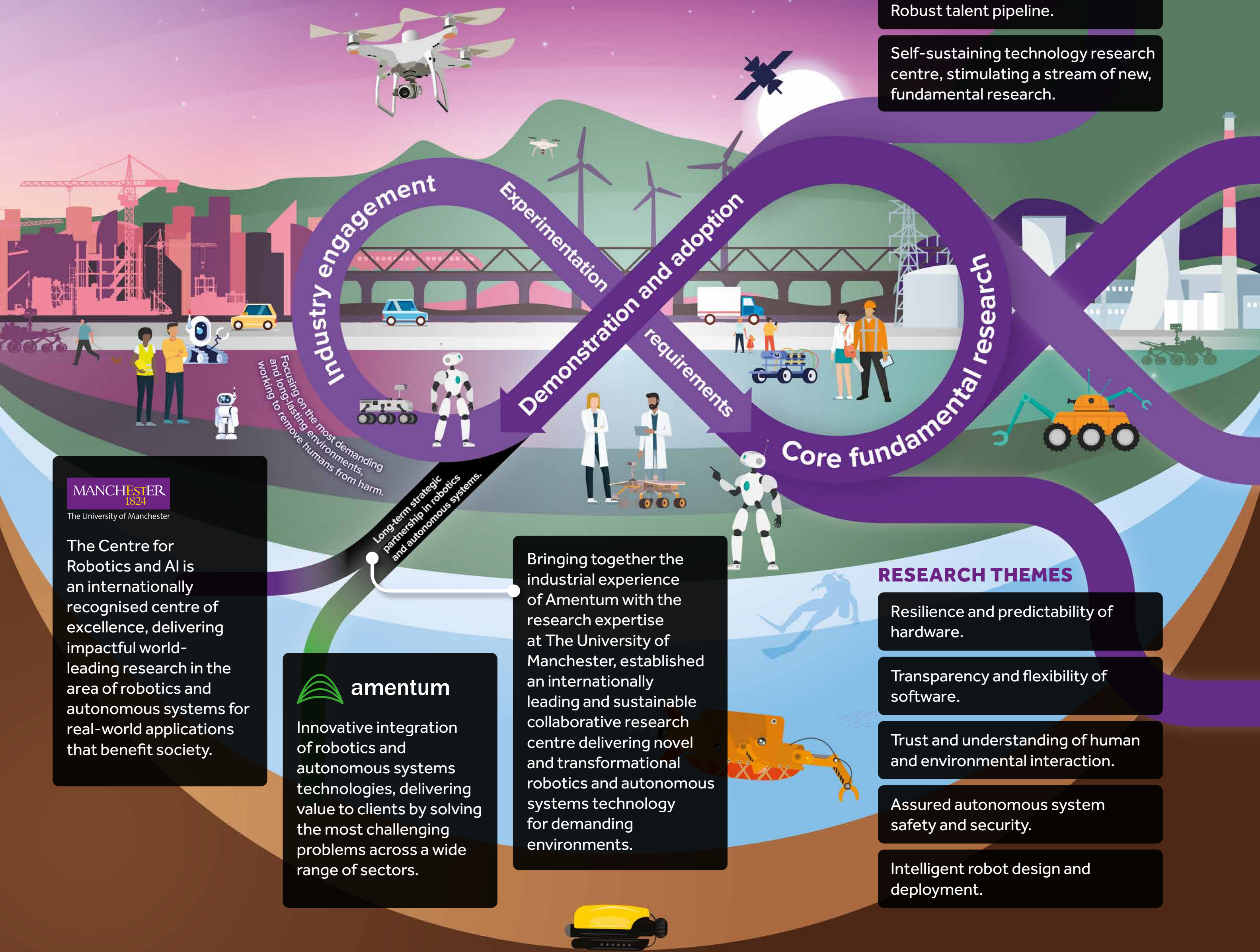
MANCHESTER SCIENCE FESTIVAL: EXTREME SPACE ROBOTICS

CRADLE collaborated with The University of Manchester's Space Systems Engineering Research Group to showcase an immersive experience on extreme space robotics at the Manchester Science Festival 2024. Visitors explored the challenges of operating robots on the moon through three interactive zones: an augmented reality (AR) zone for landing a lunar rover, a virtual reality (VR) zone for navigating lunar caves, and an extended reality (XR) zone for operating a physical robot to build habitats or collect samples. The event engaged people of all ages, highlighting the complexities of space exploration and inspiring curiosity about robotics and future space missions.



THE FUTURE

Delivering economic, social, and cultural prosperity to the UK and beyond, empowering industry with advanced robotics and autonomous systems.



DELIVERING

- Deployment of novel autonomous robotic solutions, securing additional funding, and accelerating commercialisation and spin-outs.
- Enhanced international research and development profile.
- Impact and influence on standards and policy.
- Community building and outreach.
- Robust talent pipeline.
- Self-sustaining technology research centre, stimulating a stream of new, fundamental research.

MANCHESTER 1824
The University of Manchester

The Centre for Robotics and AI is an internationally recognised centre of excellence, delivering impactful world-leading research in the area of robotics and autonomous systems for real-world applications that benefit society.

amentum

Innovative integration of robotics and autonomous systems technologies, delivering value to clients by solving the most challenging problems across a wide range of sectors.

Bringing together the industrial experience of Amentum with the research expertise at The University of Manchester, established an internationally leading and sustainable collaborative research centre delivering novel and transformational robotics and autonomous systems technology for demanding environments.

RESEARCH THEMES

- Resilience and predictability of hardware.
- Transparency and flexibility of software.
- Trust and understanding of human and environmental interaction.
- Assured autonomous system safety and security.
- Intelligent robot design and deployment.

GET IN TOUCH

CRADLE is looking for your problems and key challenges to drive our industry engagement activities and research direction. If you are interested in how CRADLE could help you, how we could work together, or simply want to know more, please contact info@cradlerobotics.co.uk.

CRADLE

CRADLE

Proud to be part of

MANCHESTER 1824 The University of Manchester

amentum

Centre for Robotic Autonomy In Demanding and Long-lasting Environments

1B.005 Engineering Building B
The University of Manchester
Booth Street East
Manchester
M13 9PL
United Kingdom

www.cradlerobotics.co.uk

DW.3932.11.24