STOP KILLER ROBOTS IN UK UNIVERSITIES

AN INVESTIGATION INTO THE ROLE OF UK UNIVERSITIES IN THE DEVELOPMENT OF AUTONOMOUS WEAPONS SYSTEMS

ABOUT US

The UK Campaign to Stop Killer Robots is a network of UK-based organisations working
for the development of new law on autonomy in weapons systems. We are a member of
the global Stop Killer Robots campaign, which has over 180 member organisations in
66 countries. The UK Campaign to Stop Killer Robots includes a broad range of NGOs,
academics, students and tech workers all of whom share a concern about growing autonomy
in weapon systems. Its Steering Committee comprises Amnesty International UK, Article 36,
Drone Wars, United Nations Association–UK (UNA-UK) and Women's International League
for Peace and Freedom UK. The UK Campaign to Stop Killer Robots is hosted by UNA-UK
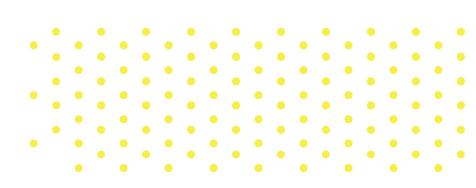(registered charity no.1146016) – for more details see una.org.uk

Some of the people behind the Campaign to Stop Killer Robots
Credit: Stop Killer Robots/Clare Conboy

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ACCOMPANYING RESOURCES

A detailed mapping exercise of research being carried out at the following 13 academic institutions where links to the MoD and private arms companies were identified: Alan Turing Institute, Cranfield University, Imperial College London, University College London (UCL), University of Birmingham, University of Bristol, University of Cambridge, University of Edinburgh, University of Manchester, University of Oxford, University of Southampton, University of Strathclyde and University of Warwick.

AWS-relevant spinout companies created by academics within some of our 13 selected universities. These companies have retained close ties to their respective universities through their staff and research partnerships, many of which have been identified in Annex I.
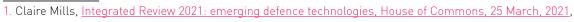
EXECUTIVE SUMMARY

Government investments into technology relevant to the creation of autonomous weapons systems (AWS) are booming.[1] AWS could reshape how wars are fought, but the ethical, legal and practical challenges posed by the technology make it highly controversial. The UN Secretary-General has declared machines with the power and discretion to take lives without human involvement "politically unacceptable, morally repugnant and should be prohibited by international law"[2].

This report presents the findings of a UK Campaign to Stop Killer Robots investigation into the role of UK university research in aiding the development of AWS. While the authors acknowledge that a vast range of technology could contribute indirectly to AWS, the study uncovers a much more direct relationship between research being undertaken, its funding sources, and the risk that its outputs may be incorporated into AWS.

The study examined 13 institutions that have received significant funding from the UK's Ministry of Defence and that have links with the developers of AWS-relevant technology – typically UK-based military or arms manufacturers – and found 65 research programmes whose outputs are at risk of either being incorporated into AWS or facilitating their development, even if indirectly.

More broadly, the investigation found a disturbingly close relationship between the defence sector and UK universities, inadequacies and contradictions in universities' ethics frameworks, a lack of safeguards for the end-user and dual-use risks associated with AWS-relevant technology and a concerning absence of transparency, accountability or ethical consideration around research with potential military applications.

There is a complacent and permissive research environment within those publicly-funded institutions researching sensitive technology for military applications. This gives rise to a credible risk that the proceeds of UK publicly funded research could be incorporated into AWS.

1. Claire Mills, Integrated Review 2021: emerging defence technologies, House of Commons, 25 March, 2021,

2. UN Secretary-General Antonio Guterres, UN press release, 2019

INTRODUCTION

Over the last decade, concerns about the development of autonomous weapons systems (AWS), or 'killer robots', have seized the attention of the international community. Since 2014, this issue has been discussed at the United Nations under the auspices of the Convention on Certain Conventional Weapons (CCW), which aims to ban or restrict the use of weapons which are considered excessively injurious or whose effects are indiscriminate.

The extent to which weapons currently exist that can be described as 'autonomous' is a subject of some debate. What is clear is that rapid technological developments are enabling militaries to increasingly incorporate autonomy into weapons systems.[3] Many of these systems involve unmanned aircrafts and have been deployed, or are being developed, in at least 12 countries, including China, France, Israel, South Korea, Russia, the United Kingdom, and the United States.[4]

Although there is no agreed international definition of "autonomous weapons systems", the scope of weapons systems of concern should be understood as those that select (i.e. search for or detect, identify, track) and engage (i.e. use force against, neutralise, damage or destroy) targets with potentially lethal force, based on matching sensor inputs to a target profile, without human intervention following their activation or launch.[5] Whilst many existing weapons systems operate using such a process, technological advances – especially in the development of artificial intelligence (AI) and machine learning – mean that we are on the brink of a new generation of weapons systems that pose even greater challenges to meaningful human control, including those that do not allow for such control and have sometimes been dubbed 'fully autonomous'.

The loss of human control and judgement in the use of force and weapons raises serious concerns from humanitarian, legal and ethical perspectives, bringing further risks of harm to those affected by armed conflict and increasing the dangers of conflict escalation. At the heart of these concerns is a fundamental ethical challenge for humanity as decisions about life and death are delegated to sensors, software and machine processes.[6]

In 2012, the Campaign to Stop Killer Robots – now a coalition of over 180 NGOs working across more than 60 countries – was created to call for an international treaty that a) prohibits autonomous weapons that cannot be meaningfully controlled and those that target humans, and b) regulates other autonomous weapons to ensure meaningful human control over the use of force.

Ever since, the UN Secretary General, the International Committee of the Red Cross (ICRC), Nobel Prize Winners, thousands of scientists, roboticists and tech workers, along with nearly 70 states, have advocated for a new, legally binding framework on autonomy in weapons systems.[7] However, international progress towards such a goal has been stalled by a small number of military powers who regard the creation of new international law as premature, including Russia, Israel, the US and the United Kingdom.

On the one hand, the UK government maintains that 'it does not possess fully autonomous weapons systems and has no intention of developing them', claiming that 'when deploying autonomous weapons systems, it will always ensure meaningful and context-appropriate human involvement across the system lifecycle from development to deployment, ensuring human

3. Mary Wareham, Stopping Killer Robots, Human Rights Watch, 2020.

4. Ray Acheson, A WILPF Guide to Killer Robots, Reaching Critical Will, 2020.
Peter Burt, Off the Leash, Drone Wars UK, 2018.
Vincent Boulanin and Maaike Verbruggen, Mapping the Development of Autonomy in Weapon Systems, SIPRI, 2017.

5. ICRC position on autonomous weapons systems. ICRC, 2021, [Accessed 18 May 2022], This is also the scope of systems that the Stop Killer Robots campaign and others refer to as autonomous weapons systems.

6. Ibid.

7. Global: A Critical Opportunity To Ban Killer Robots - While We Still Can. Amnesty International, 2021.

responsibility for outcomes.'[8] However, the Ministry of Defence (MoD) continues to prioritise and pursue research work in all three of the key disciplines underpinning autonomous weapon technology: computer science; robotics; and sensors. The MoD is also actively undertaking research into technology that supports the development of armed autonomous drones. Although none of the MoD's current projects are intended to develop a lethal autonomous weapon systems, these projects represent developments in technology which could be combined with other systems to form the building blocks of such weapons systems.[9]

British universities play a key role in the government's and MoD's pursuit of autonomous systems, with academics and research departments having numerous and well-established research projects with the Defence Science and Technology Laboratory (DSTL), including in robotics and AI technology with potential military applications. Furthermore, individual universities often receive substantial funding for research projects from private arms companies.[10]

This study aims to identify the nature and scope of research work on autonomous systems and AI which is taking place in a select set of UK universities and assess the risk that such work could contribute to the development of autonomous weapons systems. On the one hand, it aims to ensure that researchers are fully aware of both the intended and unintended potential end-use of their technology and understand the possible implications of their work, enabling open discussion about any related concerns. On the other, the report seeks to encourage universities to establish clear policies to guide such research and guarantee that the university will not contribute to AWS development or production.

Immoral Code London Premiere- 19.05.2022
Credit: William Morris for Campaign to Stop Killer Robots & Amnesty International

8. Question for Ministry of Defence, 2022 [accessed May 2022].

9. Peter Burt, XLUUVs, Swarms, and STARTLE: New developments in the UK's military autonomous systems, Drone Wars, 2020.

10. Leyla Manthorpe Rizatepe, Are UK universities being drawn into developing autonomous weapons. Responsible Science Journal, no 3, 2021.
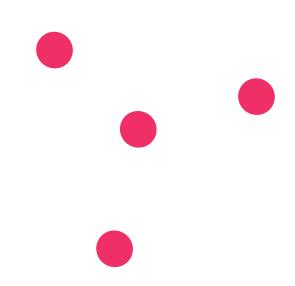
APPROACH AND METHODOLOGY

The links between universities and the MoD's autonomy agenda led to the launch in September 2020 of the University Stream of the UK Campaign to Stop Killer Robots, which supports student groups advocating for greater transparency with regards to universities' funding sources and dual-use research projects. The overall aim is to ensure that academic institutions establish a clear policy detailing procedures to certify that their research and innovation will not contribute to the development or production of autonomous weapons systems, including by implementing tangible safeguards such as ethical guidelines and committees, risk assessment protocols, and contract clauses to protect against reverse engineering and unintended harmful uses.

While the UK Campaign to Stop Killer Robots' university initiative is open to any UK student groups concerned about research that could contribute to the development of autonomous weapons, this study has focused on 13 academic institutions with expertise in the technical fields underpinning the development of autonomous systems, and where links to the MoD and private arms companies were identified as a result of a mapping research exercise of publicly available information.

THESE INSTITUTIONS WERE:

- The Alan Turing Institute
- Cranfield University
- Imperial College London
- University College London
- University of Birmingham
- University of Bristol
- University of Cambridge
- University of Edinburgh
- University of Manchester
- University of Oxford
- University of Southampton
- University of Strathclyde
- University of Warwick

Research was undertaken over the period July 2021-March 2022 by a network of student fellows who conducted internet-based investigation into university research programmes, supplemented by interviews with researchers, university representatives, and student bodies. Research programmes with potential for application in military autonomous or AI systems were rated according to whether they have a higher, medium, or lower risk of utility in the development of autonomous weapons systems or classified as "insufficient information", where there was not enough publicly available information to allow the project to be assigned to one of the three categories.

DEFINITIONS AND TERMINOLOGY USED IN THIS REPORT

Autonomous weapons systems (AWS) are the range of weapons systems that detect and apply force to a target based on sensor inputs. The specific object that is struck by an autonomous weapons system, and the time and place of this, are determined by sensor processing: following activation, there is a period of time where such systems can apply force to a target without direct human approval. For the Stop Killer Robots campaign and others such as the ICRC, a new international treaty to regulate autonomy in weapons systems should apply to this range of systems.[11] The campaign calls for a treaty that, firstly, prohibits autonomous weapons that cannot be meaningfully controlled and those that target humans, and, secondly, regulates other autonomous weapons to ensure meaningful human control over the use of force.

Autonomous weapons systems may use advanced computational processing techniques or **artificial intelligence (AI)** as part of this process of applying force – but not necessarily. Autonomous weapons systems are not limited to '**AI weapons**'. The range of **military applications of artificial intelligence** is also wider than the specific development of autonomy in weapons systems. Furthermore, the development of **autonomous functions** is being pursued in a range of areas of military technology beyond the application of force, such as in navigation systems. The UK Campaign to Stop Killer Robots' concern is with the erosion of human control and increasing autonomy in weapons systems that detect targets and apply force following human activation: many areas of research and development, particularly in AI and autonomy, are linked to and could feed into this.

States have been discussing **lethal autonomous weapons systems (LAWS)** under the framework of the UN Convention on Certain Conventional Weapons (CCW) since 2014. In this report, we have chosen to use the term AWS rather than LAWS as we consider the overall autonomous functions described above to constitute the key characteristics of the systems of concern, rather than 'lethality'. The range of systems described as AWS by the Stop Killer Robots campaign does not exclude any definition of LAWS that has been proposed at the CCW. References to 'lethal autonomous weapons systems' are made in this report where referring to the CCW, or to the Future of Life Institute pledge[12] on Lethal Autonomous Weapons, which is endorsed by universities, academics, technology companies and researchers and promoted by the Stop Killer Robots Campaign.

AWS-relevant research, projects and technologies in this report are those researching or developing technologies, functions or frameworks that we assess could contribute to the development or use of autonomous weapons systems. These include projects that could contribute different building blocks or components that make up such systems. Acknowledging that much research can have a range of applications or be **dual-use** (have both civilian and military applications), we are not inferring that all these projects are currently and directly contributing to autonomous weapons systems, but rather, that they may have the potential to do so whether intentionally or unintentionally. This is why action by universities, and, crucially, new international law is urgently needed to contain such risks.

Projects identified through this study and listed in Annex I have been assigned a red-amber-green-grey rating, which assesses the risk that findings from the project may in the future contribute as a 'building block' to the development of autonomous weapons systems. The ratings are as follows:

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11. See Stop Killer Robots, Our policy position, 2022.

12. Lethal Autonomous Weapons Pledge, Future of Life Institute, [Accessed 26-06-2022], .

Level of Risk	Risk assessment criteria
Higher	The purpose of the research project is to contribute to i) the development of weaponry or ii) targeting capabilities as part of the ISTAR [intelligence, surveillance, target acquisition, and reconnaissance] function, or iii) militarily applicable tactics such as swarming. The project has the potential to increase the degree of automation in weapons systems. The project is funded through an agency of the Ministry of Defence or by a contractor with a track record of developing military autonomous technology. Example: A project to improve sensor performance funded by a multinational defence contractor.
Medium	Research with dual-use potential into robotics, computer sciences, sensor technology or a similar field of research which underpins the development of autonomous technologies or might contribute to legitimising the future use of autonomous weapons systems in warfare. There is potential that the research findings may contribute to the future development of autonomous weapons systems in the absence of any control measures to prevent this. Example: A project to develop software for use in the development of self-driving vehicles.
Lower	No immediately apparent military or dual-use applications in the development of autonomous technologies. Example: A project to develop a regulatory framework for the future application of autonomous technologies.
Insufficient information	Insufficient information is available in the public domain to allow the project to be assigned to one of the above categories. Example: A project for which only a one sentence description is available in the public domain, with no further supporting information or web-link to a full project description.

These ratings have been assigned by the authors on the basis of information publicly available about each project, which is often limited. Transparency around the scope of university research projects is sometimes an issue, and so the UK Campaign to Stop Killer Robots is open to reviewing the rating for a particular project if provided with further information about its research in anticipation that this will help contribute to greater transparency and understanding.

Given the nature of emerging technologies such as artificial intelligence, their potential for use over a wide range of applications, and the potential human rights implications associated with their use, we would emphasise that all projects researching new applications of technology have a residual risk of contributing to the development of future weapons systems.

In addition to the projects listed in Annex I, which is not an exhaustive list, our study identified a number of projects undertaking basic research into new areas of science and technology (S&T), such as quantum computing, photonics, materials science, and gravimetry, which could plausibly contribute to the development of autonomous weapons systems. Due to the immature status of such technologies and uncertainties over their future application, such projects have not been included in Annex I.[13]

It should be noted that, given the time limitations on the investigation, this report does not provide an exhaustive account of all AWS-relevant research within our 13 selected institutions. Based on this initial assessment we believe there are significantly more ongoing AWS- relevant activities. By offering a broad overview of the extent of current research with potential applications for AWS, we intend this study to draw attention to the urgent need for policy and legal instruments to regulate and impose limits on the development and use of autonomous weapons systems – and similar high-risk technologies.

The findings, presented in this report, provide an evidence-based outline of the role UK universities play in the development of military autonomous technology and AI, detailing extensive ongoing research, close relationships with military bodies, and student recruitment activities which together reveal a research sector that is dangerously permissive and, as a result, is endorsing the advancement of AWS capabilities, even if unintentionally. The next section summarises the key findings of our investigation.

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13. These include, for instance, the UK National Quantum Technology Hub in Sensing and Timing (NQTHST) and the Centre for Doctoral Training in Materials for Demanding Environments (M4DE) REACH. For further information please access: here and here

KEY FINDINGS

OUR INVESTIGATION IDENTIFIED RESEARCH WITHIN EACH OF OUR SELECTED INSTITUTIONS WHICH WAS ABLE TO CONTRIBUTE TO THE DEVELOPMENT OF AUTONOMOUS WEAPONS CAPABILITIES IN THE ABSENCE OF SAFEGUARDING POLICIES.

Our investigation identified at least 65 recent and ongoing projects within the realms of sensor technology, AI, robotics, mathematical modelling and human-machine pairing. Of these we judged 17 to pose a higher risk of use in the development of autonomous weaponry. Developers of AWS-relevant technology are consistently present within our target institutions as major strategic partners, or more specific project funders, whilst it is not uncommon for university research staff members to also occupy positions within defence companies.

IN SOME OF THE INSTITUTIONS INVESTIGATED, THE DEVELOPMENT OF TECHNOLOGY THAT COULD ADVANCE THE DEVELOPMENT OF AWS IS CARRIED OUT VIA SPINOUT TECHNOLOGY COMPANIES CREATED BY UNIVERSITY ACADEMICS, WHICH DIRECTLY DEVELOP AWS-RELEVANT TECHNOLOGIES IN PARTNERSHIP WITH DEFENCE BODIES.

Our investigation identified at least six spinout companies engaged in research which may advance, even if unintentionally, the development of AWS. Spinouts retain close ties to their respective universities through their staff, and through project partnerships and concomitant student engagement activities.

STUDENTS WITHIN SOME OF OUR TARGET INSTITUTIONS ARE ENLISTED IN ACTIVITIES AND INITIATIVES LINKED TO MANUFACTURERS OF AWS-RELEVANT TECHNOLOGIES, INCLUDING:

At least six defence-partnered Centres for Doctoral Training (CDTs) that are developing AWS-relevant technologies across autonomous robotics, mathematical modelling, sensing and photonics; Defence-partnered student project work developing AWS-relevant technological capabilities; Postgraduate curricula developed in AWS-relevant disciplines with defence company advisors and associated recruitment channels to AWS developers (whilst often lacking ethics modules); University-endorsed student recruitment to developers of autonomous military technology via wider recruitment networks.

THERE IS A SIGNIFICANT LACK OF TRANSPARENCY AROUND AWS-RELATED RESEARCH WITHIN OUR TARGET INSTITUTIONS. OUR INVESTIGATION ENCOUNTERED THIS LACK OF TRANSPARENCY IN THREE PRINCIPAL FORMS:

- In the lack of information made publicly available by institutions regarding funding received through defence partnerships;

- In lack of information surrounding ethical decision-making arrangements on research funding at the universities' highest ethical boards;

- In the manner in which the universities engaged with information requests in the scope of our investigation and campaigning activities. No freedom of information (FOI) request issued by our investigation was answered in full, and the responses received indicate a general unwillingness to effectively address the need for safeguarding policies.

THE STANCES OF THE SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) RESEARCH STAFF WHO ENGAGED WITH OUR INVESTIGATION TOWARD AWS ARE NUANCED, AND DO NOT REFLECT THE INACTION OUR INVESTIGATION ENCOUNTERED FROM THE UNIVERSITIES ON AN INSTITUTIONAL LEVEL.

Interviews with individual staff corroborated the need for institutional policies to safeguard universities' research from being incorporated into AWS. Without safeguarding policies, staff are often made to choose between their ethics (where they may support the regulation of or a prohibition on AWS) and the continuation of their work when deliberating over funding from AWS-related bodies.

UNIVERSITIES CONSISTENTLY LACK ROBUST, UNIVERSITY-WIDE ETHICS POLICIES ADDRESSING THE SPECIFIC APPLICATIONS OF RESEARCH.

Across all target institutions, our investigation found no reference to AWS or military research in research ethics policy, at neither the university nor department level. This allows for significant variation in the ethical stance of any one university's research and teaching, with higher-profile activities being more likely to uphold higher ethical standards with respect to AWS than less public activities. This suggests that concerns over funding often prevail over ethical research considerations.

STUDY WAR NO MORE:
AN OVERVIEW OF THE BRITISH MILITARY-UNIVERSITY NEXUS

The relations between arms-producing companies, the military – including the MoD – and UK higher education institutions are many and go a long way back in time. The UK Government's 2020 announcement of a substantial increase in military spending, and the subsequent Integrated Review,[14] dedicated significant attention to the government's aspiration for increased investments in S&T and research and development (R&D). As a result, the post-Brexit vision for a Global Britain promises that the UK will become a "science superpower," raising the R&D budget by 100%.[15] This shift puts UK universities at considerable risk of further entrenchment in defence-based partnerships and research projects.

This study takes as a starting point that the role of universities in society is to empower individuals, undertake research for the greater benefit of humanity and to tackle society's problems, and promote values, ethics, and civic engagement. According to this viewpoint universities should not be unduly influenced by, or beholden to, corporate interests or government. Over-representation of military interests in the university sector is problematic because it distorts focus away from humanitarian aims and facilitates the use of force in addressing global conflicts.

In brief, what do we mean by the military-university nexus? Militarisation denotes the processes whereby military influences, interests and priorities move into civilian spheres of life.[16] British universities encompass all the higher education institutions found across the UK, including the various settings defining the university space, for example: taught and research-based degrees; research centres, faculties, departments and hubs; R&D programs where university staff often collaborate with external partners (public, private and third sector); and career services. The nature of the involvement of the military and arms manufacturing companies with these settings includes everything from sponsorship of students' programmes, student placements and graduate schemes, teaching relationships tied to specific university departments, direct (overt) and/or indirect (covert) research, investment and consultancy relationships[17] and pension scheme investments.[18]

Notably, the number of UK universities that do not have any ties to military industry whatsoever is exceedingly low.[19] Those with the largest military funding include the University of Cambridge, Cranfield University, Imperial College London (UCL), the University of Oxford and the University of Sheffield.[20] Seven of the military contractors sponsoring research at the University of Oxford have been called out by organisations such as Amnesty International for demonstrating an "alarming

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14. Announced first with the 2021 Integrated Review and reinforced in the latest 10-year Defence Equipment Plan, the UK Government has embarked on the highest military spending journey since the end of the Cold War. Granted this spending increase was declared before the Russian invasion of Ukraine in February 2022 and the drastic upsurge in military expenditure now sweeping Europe as a result, the UK's already bloated defence budget is likely to continue to grow.
See: HM Government, "Global Britain in a competitive age: The Integrated Review of Security, Defence, Development and Foreign Policy," Her Majesty's Government, March 2021, Ministry of Defence, HM Government, "The Defence Equipment Plan 2021-2031" Her Majesty's Government, 2022.

15. Stuart Parkinson, "Military involvement in UK universities", Scientists for Global Responsibility, presentation, 24 January 2021, Stuart Parkinson, "Militarising Research: The dark side of Global Britain's science agenda", Responsible Science Journal, No. 4 2022, pp. 30-33.

16. Rachel Woodward, K. Neil Jenkings and Alison J. Williams, Militarisation, universities and the university armed service units, Political Geography Volume 60, pp. 203-212, 2017, .

17. Where funding often comes from the state via the MOD, but can also include direct investments between universities and arms companies (in either direction).

18. Anna Stavrianakis, "In arms' way: arms company and military involvement in education in the UK", ACME: An International E-Journal for Critical Geographies, 8 (3) 2009, pp. 505-520, Parkinson, "Military Involvement."

19. Stuart Parkinson, "Military-university collaborations in the UK – an update", Scientists for Global Responsibility, 2015, .

20. Ibid.

indifference to the human cost of their business."[21] Still, investments and the University's denial of their unethical nature continue. Between 2017-2019 Oxford received £6 million from Rolls Royce while the company was simultaneously paying millions of pounds in penalties due to bribery charges,[22] and recent FOI requests reveal how the University accepted at least £726,706 in the same period from the Atomic Weapons Establishment, the body in charge of designing and producing the UK's nuclear warheads.[23] Between 2015 and 2018, various defence contractors provided nearly £40 million in grants to 15 universities with top ranking engineering departments.[24] Imperial College London alone received more than £9 million in arms company funding from 2013 to 2017.[25]

Integrating the military industry within public institutions offers an effective way for arms producers to improve their public image amid growing awareness of the indiscriminate harm[26] and human rights violations resulting from UK arms exports.[27] At the same time, the rising presence of military actors and interests in universities make these sites increasingly militarised spaces, further endangering the notion of higher education as "a public good and an autonomous sphere for the development of a critical and productive citizenry."[28]

There are plenty of cases that help expose arms companies' active use of university relations to reinforce the public narrative that the military industry takes responsibility for the complex reality of its goods and saves more lives than it takes – simply put, that it is a force for good. One example is BAE Systems[29] £30,000 contribution to a research project at the University of Portsmouth missioned to "understanding the moral components of conflict."[30] Adding to this, BAE[31] sponsors the Centre for Ethics and Law at UCL, featuring BAE Chief Counsel for Compliance and Regulation on the advisory board.[32] All the while, along with several other European arms manufacturers, BAE awaits a decision by the International Criminal Court's Office of the Prosecutor to investigate their complicity in the alleged war crimes perpetrated in Yemen.[33]

Though arms industry funding only makes up a small percentage of a university's overall income, it has a significant impact on the departments and research teams associated with its target disciplines, such as engineering, computing and physics.[34] Heavily favoured R&D areas are new and emerging technologies including machine learning, autonomous systems and robotics, drones, and

21. Ben Jacob, "Funding under fire", The Isis, 15 November 2019.

22. Ibid.

23. Ben Jacob, "Oxford University's ties to nuclear weapons industry revealed", Cherwell, 13 November 2019.

24. Elliot Murphy, "British universities are being increasingly captured by arms corporations", Declassified UK, 17 September 2020.

25. Ibid. For earlier numbers see: Tim Street and Martha Beale, "Study War No More", Campaign Against Arms Trade, October 2007.

26. Indiscriminate attacks are those:
(a) which are not directed at a specific military objective; (b) which employ a method or means of combat which cannot be directed at a specific military objective; or (c) which employ a method or means of combat the effects of which cannot be limited as required by international humanitarian law; and consequently, in each such case, are of a nature to strike military objectives and civilians or civilian objects without distinction.

27. Elliot Murphy, Arms in Academia: The Political Economy of the Modern UK Defence Industry, Routledge India, 2020.

28. Giroux, 2001, p. 2, cited in Stavrianakis, "In arms' way", p. 506.

29. The UK's largest arms corporation, which sold more than £15 billion worth of arms and services to Saudi Arabia between 2015 and 2020, the first five years of the brutal air campaign against Yemen. See: Dan Sabbagh, "BAE Systems sold £15bn worth of arms to Saudis during Yemen assault", The Guardian, 14 April 2020.

30. Elliot Murphy, "British universities are being increasingly captured by arms corporations", Declassified UK, 17 September 2020.

31. Apart from their endeavours into the ethics of warfare, BAE also provides PhD studentships in engineering and hosts several strategic university partnership programs, which are, for instance, related to drones (Cranfield University); immersive systems (University of Birmingham); and artificial intelligence (University of Southampton). See: Murphy, "British universities."

32. Ibid.

33. ECCHR, "Made in Europe, Bombed in Yemen", European Center for Constitutional and Human Rights, February 2020, .

34. Stuart Parkinson, "Military involvement in UK universities", Scientists for Global Responsibility, presentation, 24 January 2021.

space, cyber and directed energy weapons.[35]

The three-pronged military-research-funding nexus between academia, industry and government has many faces. While some constitute open synergies, such as the Joint Security and Resilience Centre and Academic RiSC[36] or the University Defence Research Collaboration,[37] there remains a significant lack of transparency with regards to exactly what money goes where, what research is being undertaken or what weapons systems could be developed as a result of military – and industry – funded academic research.

DUAL-USE TECHNOLOGIES

While autonomous weapons systems can take a number of forms, their composite technologies most often fall within the research domains of sensor technology, robotics, artificial intelligence, control theory and robotics communications. Technologies developed within these broad research domains are inherently dual-use: innovations developed for civilian applications can also be applied directly or modified for use in military applications. For instance, a sensor could be developed for use within manufacturing or land-surveying, but it could also be used to enhance the situational awareness of an armed drone. This presents a significant challenge for understanding which research programmes may contribute to the development of AWS, as without full transparency around the intended applications of a research project and controls on the use of certain technologies, we cannot confirm the end uses to which research findings may be put.

Our investigation consistently encountered a lack of transparency around the intended applications of research projects: most projects describe their outputs' applications in broad terms with no direct mention of weaponry. For instance, the project "Flexible autonomy for swarm robotics," affiliated with the Alan Turing Institute and the University of Southampton, describes its intended application as "disaster response."[38] This project is developing AI algorithms and interfaces for autonomous robot swarms, technologies highly relevant to military applications and AWS, despite not being identified as such in the project specification. The project's partnership with the French defence company Thales also raises reasonable concerns that its research output might potentially be applied to AWS development[39], and as such, it has been identified as a higher risk project by this study.

35. Stuart Parkinson, "Militarising Research: The dark side of Global Britain's science agenda", Responsible Science Journal, No. 4 2022, pp. 30-33.

36. Click here; here

37. An £8 million joint venture between the MOD and the Defence Science and Technology Laboratory "aimed at using academic research to boost military capabilities." See: Peter Burt, "Off the leash: the development of autonomous military drones in the UK", Drone Wars UK, November 2018, p. 43, .

38. Flexible autonomy for swarm robotics, The Alan Turing Institute, [accessed June 2022].

39. Thales are known to have developed autonomous swarming technologies. A 2021 report by Pax for Peace found Thales' position on AWS to be "unclear". See: Frank Slijper, Slippery Slope The arms industry and increasingly autonomous weapons, Pax for Peace, 2021.

ETHICS AND POLICY

Our research identified that universities' approach to ethics can often be contradictory. By way of example, the University of Bristol Robotics Laboratory undertakes a project on "Robot Ethics,"[40] which considers the ethical and societal implications of AI and robotics developments. On the other hand, this same department conducts research that could facilitate the development of component technologies that could be integrated into AWS. In a similar manner, AWS-relevant projects within STEM departments of the University of Southampton appears to adopt a different ethical approach to AWS to the Department of Politics and International Relations "DRONETHICS" project[41], which researches the ethical and legal implications of drone violence and the use of drones in military, security and policing environments.

University teaching also reflected disparate ethical stances. For instance, Imperial College London's Department of Computer Science's "Ethics, Privacy, AI in Society" course offers students the "tools needed to reason and make decisions about the ethical, social and legal aspects of Artificial Intelligence", including critical approaches to "the technology of autonomous systems."[42] The same department offers defence partnered doctoral training developing unmanned aerial vehicle (UAV) technology.[43]

We found a similar unevenness in ethical stance in universities where, notably, high-profile activities more often reflect ethical values than less visible research activities. Notably, following successful campaigning efforts from students and pressure groups, in 2016 the University of Southampton's endowment fund divested from the arms trade. However, our investigation finds evidence of sustained, lower profile, links with defence bodies through research partnerships and activities at Southampton.[44] Similarly, the University of Birmingham's high-profile "Policy Commission" convenes policy experts to deliberate on a changing annual theme; in 2014, the theme was "The Security Impact of Drones", and its conclusions advocated for the strict regulation of AWS. Despite this, the University of Birmingham sustains close ties with AWS-related technology developer BAE Systems, as one of its five Strategic University Partners.[45] Our investigation identifies multiple defence-partnered research projects conducting AWS-relevant research within the University. This ethical disparity between universities' more prominent activities on the one hand, and ones that are less public on the other, suggests that concerns over reputation (and ultimately funding) often prevail over ethical research considerations.

Furthermore, the coexistence of activities informed by opposing ethical values is symptomatic of an overwhelming lack of robust, university-wide ethics policies. Across all 13 selected institutions, our investigation found no reference to autonomous weapons systems or military research in research ethics policies. University research ethics policies are consistently general in their scope, open to interpretation, and without reference to specific applications of research.

For instance, the highest ethical decision making body at the University of Cambridge is the Committee on Benefactions and External Legal Affairs (CBELA). CBELA makes decisions on research "likely to give rise to significant public interest, whether such benefactions are

40. Robot Ethics, Bristol Robotics Lab, [accessed August 2022],

41. Emergent Ethics of Drone Violence: Towards a Comprehensive Governance Framework, University of Southampton, [accessed August 2022].

42. Ethics, Privacy, AI in Society, Imperial College London Department of Computing, [Accessed June 2022].

43. EPSRC Centre for Doctoral Training in High Performance Embedded and Distributed Systems, EPSRC, [accessed August 2022].

44. Examples include:
Research project: Autonomous learning agents for decentralised data and information networks, University of Southampton, and Research centres and partnerships , University of Southampton.

45. BAE System's Strategic University Partners are the Universities of Birmingham, Manchester, Strathclyde, Cranfield, and Southampton - "Collaborating with academia to develop new technologies", BAE Systems, April 2017, .

acceptable on ethical or reputational grounds."[46] Although this policy may imply that "ethical" and "reputational" considerations have equal weighting, this cannot be confirmed due to lack of transparency around CBELA's decision making, which follows the University's ethical guidelines.[47] These guidelines are broad and reference charity law, prohibiting benefactions (donations) that have arisen "in whole or in part from activity that violated international conventions that bear on human rights", which include the right to life, remedy and dignity. However, the conduct of AWS-relevant research in Cambridge raises questions about the university's ability to ensure that its funding sources and the potential outcome of its research fully respect and reinforce International Human Rights Law principles.

Similarly general in scope is the University of Birmingham's 'Code of Ethics', which applies to its research practices, teaching and financial activities. Within the code, "academic freedom" and "original, significant and rigorous research" are highlighted as core values. However, these are vaguely defined and make no reference to weaponry or military applications.[48]

The University of Southampton and Cranfield University classify public research ethics frameworks as their principle ethical terms of reference. Southampton states all its research is subject to the Engineering and Physical Sciences Research Council's (EPSRC) framework for responsible innovation[49], which, while having various provisions to promote ethical and legal research practice, does not explicitly reference autonomous weapons systems. Southampton also stated that it does not intend to develop more specific policies on weapons, but it does "review any proposals for activities in this general area of work."[50]

In response to an FOI request dated 30th July 2021, Cranfield University abstained from disclosing details related to funding for projects concerning autonomous systems, stating that it would exceed the allotted time and financial allowance provided for by the Freedom of Information Act 2000. Nonetheless, Cranfield declared that it follows "all government legal and ethical requirements including submitting research to the Ministry of Defence Research Ethics Committee as and where appropriate."[51]

Reference to autonomous weapons systems was notably absent from the Alan Turing Institute's most relevant ethical policy document, "Understanding artificial intelligence ethics and safety", a 97-page guide for responsible AI in the public sector. While the guide does advocate for fairness, accountability, sustainability and transparency in AI development, it contains no references to military applications of AI.[52]

More promisingly, the University of Edinburgh expressed its intention to implement a University-wide autonomous weapons systems ethics policy in response to pressure from its Student Council to sign the Future of Life pledge calling for strong international norms, regulations and laws against lethal autonomous weapons.[53] Its College of Science and Engineering stated that most of its research is "application agnostic, or explicitly associated with benign applications," but acknowledged the potential for its research to be applied malignly, stating "the difficulty [...] is that much of the technology is dual-use". This emphasises the need for holistic regulation of AWS

46. "Advisory Committee on Benefactions and External and Legal Affairs: Name change and revised terms of reference", Cambridge University Reporter, 18 June 2018, pg. 728,.

47. "Ethical guidelines on the acceptance of benefactions: Notice", Cambridge University Reporter, October 2001.

48. "The University of Birmingham Code of Ethics", University of Birmingham, 24th April 2018.

49. G00492 Freedom of Information Request response, 11 August 2021.

50. Ibid.

51. FOI: Autonomous systems research, Aug 17, 2021.

52. Leslie, D., "Understanding artificial intelligence ethics and safety: A guide for the responsible design and implementation of AI systems in the public sector", The Alan Turing Institute, 2019.

53. "Lethal Autonomous Weapons Pledge", Future of Life Institute, [Accessed 26-06-2022].

development at institutional, national and international levels, as genuinely benign research may be misapplied when adopted outside of the remit of university policy.

The urgency for legal safeguards is exemplified by developments within UCL. Despite it being the only institution covered in this report to have signed the Future of Life pledge, UCL has carried out at least two research projects, in partnership with defence bodies and the UK government, that could have future implications for autonomous weapons systems development, even if these are not intended.

Immoral Code London Premiere- 19.05.2022
Credit: William Morris for Campaign to Stop Killer Robots & Amnesty International

TRANSPARENCY

Our research encountered transparency-related challenges across all 13 investigated institutions. These issues manifested themselves in three principal ways.

Firstly, there is a scarcity of information made publicly available by institutions regarding funding sources and details of ongoing research and partnerships with defence companies. The severity of this varies between institutions: for instance, the University of Cambridge publishes details of the large research grants it receives in its annual University Reporter,[54] while the University of Oxford does not. Both the universities of Birmingham and Edinburgh have searchable project databases, but while Birmingham's discloses the key partner of a research project, Edinburgh's uses broad classifications for funders such as "Research Collaboration with external organisation."[55]

Levels of transparency also varied between departments and laboratories within the 13 target institutions, with some publishing titles, dates and descriptions of projects, while others only describe their research in relation to broad research themes such as "Autonomous Systems." Especially opaque is the University of Bristol's Digital Systems Lab, associated with the 'CNN-based Real-Time Object Detection on UAV Images' project and about which our investigation could find no information beyond its affiliation with the laboratory. Even in circumstances where more detailed funding information was published by the universities, this was rarely done through easily accessible central university channels, but instead through supplementary project materials such as presentation slides or brochures, accessible via targeted search engine searching.

The majority of projects listed in Annex I of this report have received funding from government bodies such as the Engineering and Physical Science Research Council and other bodies which are part of UK Research and Innovation. These two bodies publish more detailed information in their associated databases on a project's funding partners, purpose and applications. However, far less detail is published around projects funded by the Ministry of Defence through programmes such as the Defence and Security Accelerator (DASA). For instance, the only information our investigation could find surrounding the University of Southampton's "Human-UAV teaming in dynamic and uncertain environments", and "Human Machine Teaming for Intelligence Analysis" projects, relates to the funding awarded to them through DASA in 2017-2018.[56] Neither the Ministry of Defence, nor the University of Southampton, offer any further project details.

The second form in which a lack of transparency emerged in our investigation concerned ethical decision-making at the universities' highest ethical boards, such as the Committee on Benefactions and External Legal Affairs (CBELA) at the University of Cambridge, the University Executive Board or Council at the University of Birmingham, and the Committee to Review Donations and Research Funding at the University of Oxford.[57] We were unable to find publicly available information on the research deliberated over by these decision making bodies, and the way in which particular policy criteria, such as reputational and ethical impacts, are applied in the decision making process.

54. "Special numbers for the academic year 2020-21", Cambridge University Reporter, retrieved 26-06-2022.

55. Click here

56. Defence and Security Accelerator funded contracts: 1 April 2017 to 31 March 2018, GOV.UK.

57. Part of Council Regulations 15 of 2002: Regulations for Committees Reporting Directly to Council or one of its Main Committees, University of Oxford, [Accessed 26-06-2022].

The third form in which a lack of transparency emerged was the manner in which our 13 selected institutions engaged with enquiries from our student research fellows: namely the sparse and inadequate responses we received to our Freedom of Information requests[58] and campaign letters. From over 15 FOI requests submitted by our fellows, four institutions did not respond at all within three months, and the remainder have been in-part, or fully denied, in some cases in a manner that we believe is not compliant with Freedom of Information legislation. For instance, Imperial College London would only provide support in phrasing our request (as they are required to under section 16 of the Act) on the condition our investigator gave the purpose of the request.

In the few circumstances in which universities replied to FOI requests, the information was vague or incomplete, adding little to our understanding of AWS-related research in these institutions. For instance, the University of Manchester disclosed that its Department of Electrical and Electronic Engineering had received £106,681 of research funding from the defence company MBDA UK between 2020 and 2021. In light of the area of expertise of such a Department and the interests of the funder, it is possible that a portion of the disclosed funding could be used to develop AWS-relevant technologies, but this cannot be confirmed without the project specifics that were denied in our request.

It should be noted that some of the institutions that did respond to our campaign's requests denied any involvement in research relevant to AWS. For instance, in response to a Freedom of Information request received on 20th July 2021, the University of Southampton stated it has "consistently, and without exception, refused to undertake work on the design or development of weapons or weapons systems, including autonomous weapons systems", and that it has "never received funding to work on lethal autonomous weapons systems." [59]

The University of Cambridge protested "in the strongest terms" the suggestion that its research may be contributing to the development of autonomous weapons systems, highlighting that university departments that hold ties with military bodies also have non-defence partners. The university also emphasised the non-defensive applications of its research, for instance the application of its swarm robotics research to "humanitarian missions."[60] [61]

The University of Strathclyde stated that both its Department of Electronic and Electrical Engineering, and its Department of Design, Manufacturing and Engineering Management "confirm that there is no work undertaken which entails the direct or indirect manufacture of autonomous weapons or related components." The University of Manchester responded with "To the best of our knowledge, the University of Manchester's research programmes do not involve direct or indirect manufacture of autonomous weapons or related components – e.g. for military purposes."[62]

Although none of the research conducted at Cambridge, Southampton, Manchester and Strathclyde is primarily intended for developing autonomous weapons systems, the lack of safeguards to ensure that the research will not be applied in this way by partners or future buyers of the technology is concerning. While their denials implicitly express an opposition to AWS, none of these four institutions have established adequate policies or controls to prevent research findings from being used in ways which may be problematic, or publicly committed to not participate in nor support the development, manufacture, trade, or use of autonomous weapons systems.

58. Examples of Freedom of Information requests submitted by our Campaign include:How does UCL adhere to the Future of Life Pledge, February 2022, Defence funding for Computer Science Department at UCL, August 2021, and FOI response from the Alan Turing Institute, 5 August 2021.

59. G00492 Freedom of Information Request response, 11 August 2021.

60. Lorna Kimmins, 'Stop Cambridge Killer Robots' campaign launched following lethal autonomous weapons investigation, Varsity, October 29 2021.

61. Georgia Goble & Lorna Kimmins, Pro-Vice-Chancellors condemn 'Killer Robots' accusations as 'misrepresentation', Varsity, November 5 2021.

62. 021-559 Freedom of Information request response, 14 October 2021.

STUDENT ENGAGEMENT AND RECRUITMENT

Our investigation found that universities' relationships with defence bodies often involve concomitant student engagement and recruitment activities.

In Cranfield University, students are being actively recruited to Project Tempest, a proposed fighter aircraft concept developed in partnership with Rolls Royce, Leonardo and MBDA and with the support of the UK Ministry of Defence. In addition, in 2019, BAE Systems sponsored a multi-university competition at Cranfield Airport, where students were challenged to develop defence strategies to counter 'swarm attacks' by UAVs.[63] In the University of Cambridge, undergraduate Computer Science students are involved in project work for the Prorok Lab, which is developing autonomous robots in partnership with the US Army's Distributed and Collaborative Intelligent Systems and Technology (DCIST) Collaborative Research Alliance (CRA) and the US Army Combat Capabilities Development Command, known as DEVCOM. This raises particular concerns as the ethics teaching within Cambridge's Computer Science MSc-BSc core curriculum does not consider the military applications of computer science research.[64]

Centres for Doctoral Training (CDT) are sites of especially close interaction between students and industry. CDTs are research collaborations between universities and industry partners, training PhD student cohorts in skills for future careers in academia or industry. A CDT programme is typically a four-year studentship, involving cohort-wide modules alongside more traditional research-based training, where programmes are designed and conducted in close collaboration with industry. Our investigation identified at least six defence-partnered CDTs, training students in research domains relevant to autonomous weapons systems and funding student projects aligned to the research interests of the defence industry. These include Bristol's 'Future Autonomous and Robotic Systems (FARSCOPE)' CDT, partnered with BAE Systems, DSTL, and Blue Bear Systems Research; and Edinburgh's 'Robotics and Autonomous Systems' CDT, partnered with Leonardo and Thales.Defence bodies are also closely involved with postgraduate courses in autonomous weapons systems-relevant disciplines, either through close student recruitment ties, or in an advisory capacity.

IN CRANFIELD UNIVERSITY:

- An 'Autonomous Vehicle Dynamics and Control' MSc, the Industrial Advisory Board of which includes Boeing, Thales, BAE Systems, QinetiQ, QuadSAT and HEROTECH8, among others.[65]

- An MSc in 'Military Aerospace and Airworthiness', which specifically focuses on the military context of engineering for aerospace and airborne vehicles, includes modules on guided weapons (including radar and infra-red technology, control and guidance systems), electro-optics and infrared systems (including surveillance and tracking systems), and radar.[66] The main service customers are the Royal Air Force (RAF), Royal Navy and the British Army, as well as industry contacts including DSTL, MBDA and Thales, who make up the Industry Advisory Panel for this course.

- A 'Military Vehicle Technology' MSc features modules such as 'Uninhabited Military Vehicle Systems' and has no compulsory ethics module. Its Industrial Advisory Panel includes experienced engineers from the Ministry of Defence, as well as UK based and international defence companies.

63. The future of Combat Air, BAE Systems, accessed May 2021, www.baesystems.com/en/the-future-of-combat-air.

64. Teaching materials seen in an interview with an undergraduate student.

65. Autonomous Vehicle Dynamics and Control MSc, Cranfield University, [accessed May 2022], https://www.cranfield.ac.uk/courses/taught/autonomous-vehicle-dynamics-and-control.

66. Military Aerospace and Airworthiness MSc, Cranfield University, [accessed May 2022], https://www.cranfield.ac.uk/courses/taught/military-aerospace-and-airworthiness.
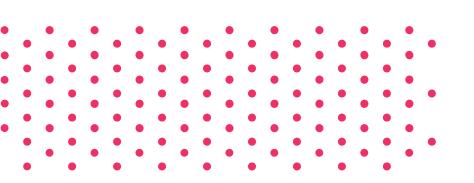
IN THE UNIVERSITY OF MANCHESTER:

- MSc programmes through the Department of Mechanical, Aerospace and Civil Engineering are advertised as holding recruitment ties with defence institutions through "strong industrial links with Airbus, Rolls-Royce, EADS, DSTL, MBDA and the European Space Agency's European Space Research and Technology Centre (ESTEC)", and as being the "preferred academic partner for BAE Systems in experimental aerodynamics and dynamic load."[67]

- An MSc programme in 'Advanced control and systems engineering' and an MPhil in 'Electrical and Electronic Engineering' in partnership with companies such as BAE Systems.

IN THE UNIVERSITY OF STRATHCLYDE:

- MSc programmes in 'Autonomous Robotic Intelligent Systems,'[68] 'Marine Engineering with Specialisation in Autonomous Marine Vehicles,'[69] and 'Mechatronics & Automation,'[70] with ties to companies such as Xilinx, Leonardo and Rolls Royce through recruitment and course projects.

Our investigation also identified stand-alone recruitment channels to developers of technology relevant to autonomous weapons systems. For instance, the University of Cambridge's Department of Computer Science hosts a 'Supporters' Club': a group of companies who pay a membership fee to gain access to student recruitment through an annual careers fair and dinner; opportunities to host talks and advertise to students; and via student 'group project' proposals. Among its 83 current members[71] are Rebellion Defence and Xilinx, which have hosted talks and advertised internships using Supporters' Club channels.[72]

67. Department of Mechanical, Aerospace and Civil Engineering, University of Manchester, [accessed May 2022].

68. MSc Autonomous Robotic Intelligent Systems, University of Strathclyde, [accessed May 2022].

69. MSc Marine Engineering with Specialisation in Autonomous Marine Vehicles, University of Strathclyde, [accessed May 2022].

70. MSc Mechatronics & Automation Degree, University of Strathclyde, [accessed May 2022].

71. Supporters Club Members, Cambridge Department of Computer Science and Technology, [accessed May 2022].

72. Emails advertising event with Rebellion Defence: Internships with Xilinx seen in interview with a current undergraduate Computer Science student.

VIEWS OF RESEARCHERS

The need for institutional policies to safeguard universities' research against being incorporated into autonomous weapons systems is corroborated by our interviews with researchers in AWS-relevant fields, which found that:

- There may be a lack of knowledge within the academic community with regards to military autonomous technologies, their capabilities and the current stage of their development, and their development trajectory with respect to meaningful human control. One academic from the University of Warwick was sceptical that AWS would operate without meaningful human control, telling us: "I am not an expert on these systems, but I am wondering if humans are actually involved in verification of targets and final decision making?"

- Researchers at UCL working within AWS-relevant fields felt they did not have a good understanding of autonomous weapons systems and the surrounding issues, and directed our investigation elsewhere. This may imply some degree of feeling among academics that AWS ethics are only relevant to those conducting direct military research, highlighting the importance of messaging around dual-use technology and the dangers of inadequate safeguarding policies.

- While a number of researchers did not respond to our investigation, some were open to discussing autonomous weapons systems. An academic from the University of Cambridge developing autonomous robotics was heartened by the prospect of campaigning efforts around AWS at Cambridge, and said they felt there was a need for open discussion. They also said that, while they were not actively supportive of autonomous weapons systems, they would consider partnering with AWS-related bodies if it meant their research would continue to be funded. This points to the need for university-level policies and regulation around AWS-relevant research, so that researchers are not made to choose between their ethics and the continuation of their work.

- Within the majority of the institutions under investigation are academics who have signed the Future of Life Pledge, and our investigation found a number of projects which advocate for responsible innovation and ethical AI, indicating that there might be a window of opportunity to engage researchers in efforts to establish measures to prevent university research from contributing to the development of autonomous weapons systems.

CONCLUSIONS AND RECOMMENDATIONS

Our investigation demonstrated that universities play a key role in the UK government's pursuit of autonomous weapons systems and advanced military technologies. Academics and research departments have numerous and well-established research projects with the Ministry of Defence and receive substantial funding for research projects from private arms companies, including those developing robotics and AI technology with potential military applications. Furthermore, students within some of our sample institutions are enlisted in activities and initiatives linked to manufacturers of AWS-relevant technologies, including through defence-partnered research programmes, internships and recruitment opportunities.

Despite this strong military-university nexus, our investigators encountered a significant lack of transparency around research projects with potential relevance to autonomous weapons systems within the institutions we studied, with information regarding funding received through defence partnerships being particularly difficult to obtain in the public domain or even through Freedom of Information requests.

Our report also demonstrated that universities consistently lack **robust, university-wide ethics policies** and safeguarding mechanisms to control the specific applications of their research and thus prevent dual-use technology developed in their premises from being incorporated by third parties into component technologies that are liable for adoption into an autonomous weapons system or other malicious uses. We also identified that researchers are often unaware of the risks of dual-use technologies and their potential links to AWS, illustrating that the absence of adequate safeguarding policies place a disproportionate burden on individual academics to assess the moral and practical implications of their work. There appears to be a general lack of awareness and sensitivity around the dual-use risks of AI and autonomous technologies, and a requirement for more robust ethical frameworks and national leadership to address this issue. This appears to be an understudied area which we consider would benefit from a further investigative study to test our conclusions and suggest appropriate control measures.

Stop Killer Robots/Marta Kosmyna

CAMPAIGN TO STOP KILLER ROBOTS

StopKillerRobots.org

ALL UNIVERSITIES HAVE A RESPONSIBILITY TO MINIMISE THE RISKS THAT THEIR RESEARCH PROGRAMMES COULD HELP ADVANCE AUTONOMOUS WEAPONS SYSTEMS-RELATED CAPABILITIES.

THE UK CAMPAIGN TO STOP KILLER ROBOTS ENCOURAGES ALL UK UNIVERSITIES TO:

- Sign the Future of Life Pledge calling for strong international norms, regulations and laws against lethal autonomous weapons;
Make a stand-alone pledge to establish mechanisms to minimise the risks that university dual-use research could be applied for unintended malicious uses or incorporated in harmful weapons systems, such as autonomous weapons systems. Promote the pledge and raise awareness of it amongst university students, researchers, staff, and industrial partners;

- Incorporate a specific policy to assess the risks of dual-use research using AI and autonomous technology into a university-wide ethical framework (and within the framework of relevant faculties) to help guide ethical decision-making on research funding and activities.

- Regularly and transparently report on any ongoing research programmes for which particular vigilance is required to ensure that university-developed technology is not applied in harmful a manner, such as in violation of International Human Rights Law and International Humanitarian Law;

- Increase the transparency of universities' funding sources and research projects, particularly those in controversial areas such as partnerships with defence bodies, for instance by creating a public, user-friendly and regularly updated database.

- Provide expertise to – and engage with – relevant stakeholders to facilitate the development of national and international legislation to restrict and regulate the development and use of autonomous weapons systems. Expertise would be particularly valuable with regards to developing legal provisions to prevent dual-use technology built for peaceful purposes being incorporated into devices with harmful applications. The UK Campaign to Stop Killer Robots advocates for an international legal treaty that firstly, prohibits the development and use of autonomous weapons that cannot be meaningfully controlled and those that target humans, and, secondly, regulates other autonomous weapons to ensure meaningful human control over the use of force.

STOP KILLER ROBOTS IN UK UNIVERSITIES – ANNEX

An investigation into the role of UK universities in the development of autonomous weapons systems

CONTENTS

ANNEX I: RESEARCH PROJECTS

Annex I outlines examples of recent and ongoing research projects within our 13 selected institutions which we have identified in the field of science and technologies that are relevant to the potential development of autonomous weapons systems. This compilation is not intended to be exhaustive. Instead, it aims to provide an overall overview of research initiatives within UK universities that could contribute to the development of component technology that could in turn be incorporated into an autonomous weapons system in the absence of legal safeguards to prevent this from happening.

Projects listed in Annex I have been assigned a **RED** - **AMBER** - **GREEN** - **GREY** rating, which assesses the risk that findings from the project may in the future contribute as a 'building block' to the development of autonomous weapons systems. Please refer to page 9 for further information in relation to the risk categories adopted.

ALAN TURING INSTITUTE

The Alan Turing Institute was established in 2015 as a national institute for data science and artificial intelligence. The Institute was originally a joint venture between the University of Edinburgh, the University of Cambridge, University College London, the University of Warwick and the University of Oxford. In 2018 this partnership was expanded to incorporate the University of Leeds, Queens Mary University of London, the University of Manchester, the University of Southampton, Newcastle University, the University of Birmingham, the University of Bristol and the University of Exeter. Its main funding body is the UK Government Agency Engineering and Physical Sciences Research Council (EPSRC). Defence and security are among the core research areas of the Institute, which holds strategic partnerships with the Government Communications Headquarters (GCHQ), DSTL and Strategic Command, some of which are aimed at "developing data science methodologies and techniques, and in the direct application of data science."[1]

FLEXIBLE AUTONOMY FOR SWARM ROBOTICS - RED

Start Date	Unknown
End Date	Unknown
Known Partners	Thales
Funding	Unknown
Affiliation	Unknown
Description	This project is developing AI algorithms and interfaces that "ensure that human operators aren't overloaded and that they understand the automated actions taken by the swarms."[2] The project is structured around "a set of use-cases", where the only use-cases specified are those provided by Thales, relating to drones. The project website frames these use-cases in terms of disaster response. It is anticipated that the research "should enable deployments of up to 100 robots with minimal human oversight.''[3]

MODEL CRITICISM IN MULTI-AGENT SYSTEMS – PHD PROJECT - AMBER

Start Date	September 2019
End Date	February 2024
Known Partners	UKRI[4]
Funding	Unknown
Affiliation	Autonomous Agents Research Group, within the Edinburgh Centre for Robotics
Description	This studentship is developing new algorithms which are able to assess the adequacy of models of other agents. These algorithms are designed for the statistical hypothesis testing of probabilistic agent models, and will "enable autonomous agents to detect model inadequacy, and to take appropriate action (such as revising models or asking for clarification)."[5] This aims to allow autonomous agents to decide whether its models of other agents are inadequate and therefore prevent bad decisions from being made as a result of inadequacies in the models used to predict the actions of other agents.

1. Please see: "University Defence Research Collaboration (UDRC)", https://udrc.eng.ed.ac.uk/

2. Flexible autonomy for swarm robotics, The Alan Turing Institute, [accessed May 2022], https://www.turing.ac.uk/research/research-projects/flexible-autonomy-swarm-robotics.

3. "AI-driven robot swarms evaluated to create larger and more efficient fleets", The Alan Turing Institute, 30 September 2020, https://www.southampton.ac.uk/the-alan-turing-institute/news/2020/09/ai-driven-robot-swarms.page.

4. https://gtr.ukri.org/projects?ref=studentship-2270360

5. Model criticism in multi-agent systems Enabling autonomous agents to reason about the adequacy of models used to predict the actions of other agents, The Alan Turing Institute , [accessed June 2022] https://www.turing.ac.uk/research/research-projects/model-criticism-multi-agent-systems.

CRANFIELD UNIVERSITY

Cranfield University is a postgraduate university specialising in technology, engineering, defence and security. It describes itself as a "trusted and influential partner to the UK Ministry of Defence for over 30 years," having worked on "classified projects for government and industry."[6]

As one of BAE Systems' Strategic University Partners, Cranfield University has been involved in several research projects as well as collaborating with the company to develop a Master's degree in Applied Artificial Intelligence.[7] This course forms part of the UK Government Office for AI Initiative, which focuses on widespread uses of AI technologies and "ethical, safe and trustworthy development of responsible AI". The MSc does include a compulsory module in ethical, regulatory and social aspects of AI, though further details with regards to this module were not found in the public domain. The PhD projects "'Integrated Sense and Avoid Algorithm for the Operation of Multiple UAS", and "Swarming Algorithms used to achieve Goal-based Missions" were ongoing at Cranfield University at the time this research was conducted.

UNIVERSITY OF CRANFIELD FACILITIES AND INITIATIVES DEVELOPING AND TESTING RESEARCH IN AREAS OF TECHNOLOGY RELEVANT TO AWS

Aircraft and unmanned air vehicles testing	Students and staff at Cranfield University have access to the University's own airport, which allows them to test and fly aircraft.[8] In 2019, Air Chief Marshal Stephen Hillier (then Chief of the Air Staff) announced a £50,000 investment in Cranfield's National Flying Laboratory.[9] This allows flight trials of experimental equipment, including unmanned air vehicles.
Digital Aviation Research and Technology Centre	In 2017, the construction of a £65 million Digital Aviation Research and Technology Centre (DARTeC) was announced to address research including data communication, the use of drones in civilian settings, and the use of self-sensing and self-aware technologies in aircraft.[10] DARTeC was funded by several defence bodies including Boeing UK, Thales, Aveillant, Saab and Raytheon UK.
The Aerospace Integration Research Centre	The Aerospace Integration Research Centre (AIRC) encompasses a number of facilities, including the Intelligent Automation Laboratory, researching human robot collaboration, and the Aerospace Autonomy Laboratory, researching technologies for autonomous flight vehicles, as well as sensors, communications and network systems for aerospace.[11] The centre cost an initial £35 million, funded by Airbus, Rolls Royce and Cranfield University following an award by the Higher Education Funding Council for England (HEFCE).[12]

6. https://www.cranfield.ac.uk/

7. Applied Artificial Intelligence MSc, Cranfield University, [accessed May 2022], https://www.cranfield.ac.uk/courses/taught/applied-artificial-intelligence.

8. Cranfield's global research airport, Cranfield University, [accessed May 2022], www.cranfield.ac.uk/business/access-our-world-class-facilities/cranfields-global-research-airport.

9. National Flying Laboratory Centre, Cranfield University, [accessed May 2022], www.cranfield.ac.uk/centres/national-flying-laboratory-centre.

10. Digital Aviation Research and Technology Centre, Cranfield University, [accessed May 2022], www.cranfield.ac.uk/centres/digital-aviation-research-and-technology-centre.

11. Aerospace autonomy laboratory, Cranfield University, [accessed May 2022], https://www.cranfield.ac.uk/facilities/aerospace-autonomy-lab.

12. Centre for the future of aerospace opens at Cranfield, [accessed May 2022], https://www.cranfield.ac.uk/press/news-2017/centre-for-the-future-of-aerospace-opens-at-cranfield

The Multi User Environment for Autonomous Vehicle Innovation	The Multi User Environment for Autonomous Vehicle Innovation (MUEAVI) facility was constructed to aid testing and experimentation for ground and airborne autonomous technologies, and cost an initial £19 million.[13] The majority of current projects appear to involve self-driving and semi-autonomous cars, urban and off-road vehicles.
Drone Innovation Hub	In 2021, Cranfield announced the launch of the Drone Innovation Hub facility in collaboration with Ebeni Ltd and Neuron Innovations, supporting "innovators in the UK Drone and Future Air Mobility (FAM) ecosystems."[14]

The following recent and ongoing research projects are identified as AWS-relevant.

EUROSWARM - RED

Start Date	2016
End Date	2017
Known Partners	European Defence Agency; Centre of Autonomous & Cyberphysical Systems; The French Aerospace Lab ONERA; Office National d'Etudes et de Recherches Aérospatiales; Swedish Defence Research Agency; University of Patras, Applied Mechanics Lab
Funding	European Defence Agency - €434,000
Affiliation	Centre for Autonomous and Cyber-physical Systems
Description	This project investigated "key techniques to enable swarm UAVs to self-decide optimal task allocation and resource management; to use cooperative guidance as well as creating a robust sensor network enabling the UAVs to operate independently."[15]

ADAPTABLE UAVS[16] - RED

Start Date	Unknown
End Date	Unknown
Known Partners	BAE Systems
Funding	Unknown
Affiliation	Unknown
Description	This project developed hybrids between fixed and rotary-wing aircraft, allowing "UAVs to better adapt to evolving future battlefield situations' and 'work together in a swarm.'[17] BAE Systems engineers involved in the project described adaptable UAVs as 'one of a number of concepts being explored through close collaboration between industry and students in academia' to develop 'novel solutions' for applications in 'the battlefield of the future.'

13. Multi User Environment for Autonomous Vehicle Innovation (MUEAVI), Cranfield University, Retrieved May 2022 from https://www.cranfield.ac.uk/facilities/mueavi.

14. Drone Innovation Hub, Cranfield University, [accessed May 2022], https://www.cranfield.ac.uk/themes/aerospace/drone-innovation-hub.

15. EuroSWARM: Developing technology for UAV swarms in defence applications Cranfield University, [accessed May 2022], www.cranfield.ac.uk/research-projects/euroswarm-developing-technology-for-uav.

16. Lisa Daigle, Engineers, students in UK team to design adaptable UAVs, Military Embedded Systems, 2 October 2017, www.militaryembedded.com/unmanned/isr/engineers-students-in-u-k-team-to-design-adaptable-uavs.

17. Engineers unveil futuristic unmanned aircraft concept that uses both fixed and rotary wing flight, BAE Systems, 29 Sep 2017 www.baesystems.com/en/article/engineers-unveil-futuristic-unmanned-aircraft-concept-that-uses-both-fixed-and-rotary-wing-flight.

FUTURE COMBAT VEHICLE FLEET - RED

Start Date	2019
End Date	2022
Known Partners	QinetiQ; DSTL; Williams Advanced Engineering; Horstman Defence Systems; HORIBA MIRA; Catalyst Corporation
Funding	DSTL - £3.2million[18]
Affiliation	Centre for Defence and Engineering
Description	This project (2019-2022) "explores innovative solutions for ground vehicle mobility" that includes unmanned vehicles, as well as incorporating radar sensor systems. "In particular, the project will investigate advanced running gear solutions for wheeled manned and autonomous vehicles to close the gap between the mobility of wheeled and tracked vehicles. The running gear will integrate with QinetiQ's world-leading, in-wheel electric hub drive technology and the two combined will deliver significant benefits in armoured vehicle design. The solutions will enable platforms with significant increases in operational and tactical mobility along with survivability and fuel efficiency benefits."[19] In addition, the project will explore "benefits for vehicle design, terrain scanning and sensing, use of optical and light detection and ranging (LiDAR) with other sensor systems - such as RADAR - with an integrated control system."[20]

18. Dstl award £3.2m contract to shape UK's future combat vehicle fleet, Defence Science and Technology Laboratory, September 2019,
https://www.gov.uk/government/news/dstl-award-32m-contract-to-shape-uks-future-combat-vehicle-fleet.

19.   Ibid.

20.   Ibid.

IMPERIAL COLLEGE LONDON

EPSRC CENTRE FOR DOCTORAL TRAINING IN HIGH PERFORMANCE EMBEDDED AND DISTRIBUTED SYSTEMS - AMBER

Start Date	01-04-2014
End Date	30-09-2022
Known Partners	BAE Systems; Arm Holdings
Funding	EPSRC Grant EP/L016796/1 - £4,099,016[21]
Affiliation	Department of Computing, Department of Electrical and Electronic Engineering
Description	The focus of this Centre for Doctoral Training is "High Performance Embedded Distributed Systems (HiPEDS)", which can range "from implantable smart sensors to secure cloud service providers." The Centre will train students in developing "solutions for focused problems, but also to embed such solutions into complex systems with many diverse aspects, such as power minimisation, performance optimisation, digital and analogue circuitry, security, dependability, analysis and verification."[22]

The CDT is reportedly concerned with "three key application areas: healthcare systems, smart cities, and the information society", however the following projects developing UAVs are also funded by the grant:

• "Learning to Fly by MySelf: A Self-Supervised CNN-based Approach for Autonomous Navigation."[23]

• "Towards an Efficient Accelerator for DNN-based Remote Sensing Image Segmentation on FPGAs," which develops an optimised deep neural network model for real-time remote sensing imaging segmentation. |

CNN-BASED REAL-TIME OBJECT DETECTION ON UAV IMAGES - GREY

Start Date	Unknown
End Date	Unknown
Known Partners	Unknown
Funding	Unknown
Affiliation	Intelligent Digital Systems Lab (iDSL)
Description	This project explores the trade-offs involved in the development of real-time object detectors based on deep convolutional neural networks (CNNs) that can enable UAVs to perform vehicle detection under a resource constrained environment such as in a UAV. [24]

21. EPSRC Centre for Doctoral Training in High Performance Embedded and Distributed Systems, EPSRC, https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/L016796/1

22. EPSRC Centre for Doctoral Training in High Performance Embedded and Distributed Systems, EPSRC, https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/L016796/1

23. Alexandros Kouris and Christos-Savvas Bouganis, Learning to Fly by MySelf: A Self-Supervised CNN-based Approach for Autonomous Navigation, International Conference on Intelligent Robots and Systems, 2018 http://cas.ee.ic.ac.uk/people/alk15/files/IROS_2018_drone_nav.pdf.

24. Robotics and Unmanned Aerial Vehicles (UAVs), Imperial College London, [accessed May 2022], from https://www.imperial.ac.uk/intelligent-digital-systems/research/robots-and-uavs.

UAV EGO-MOTION ESTIMATION- AMBER

Start Date	Unknown
End Date	Unknown
Known Partners	Technology Strategy Board UK; Barnard Microsystems
Funding	Technology Strategy Board UK
Affiliation	Department of Electrical and Electronic Engineering
Description	This project focuses on the development of a system that estimates the ego-motion of an unmanned plane using a single camera.[25] In one output publication, the authors describe this capability as essential to allow UAVs to "become as autonomous as possible."[26]

PYFR: TOWARDS INDUSTRY AND EXASCALE- RED

Start Date	23-09-2018
End Date	22-03-2022
Known Partners	BAE Systems; MBDA; MTU Aero Engines AG; nVIDIA; Zenotech Ltd; Kitware Inc; NASA Glenn Research Center; NASA Langley Research Center; Pointwise; Oak Ridge National Lab
Funding	EPSRC Grant EP/R030340/1 - £1,080,908[27]
Affiliation	Department of Aeronautics
Description	This project is an extension of the Fellowship: 'Developing Software for High-Order Simulation of Transient Compressible Flow Phenomena: Application to Design of Unmanned Aerial Vehicles' – EP/K027379/1 (which ended on 22 September 2018).[28] The Fellowship developed PyFR, a software leveraging the capabilities of "massively-parallel" computing platforms in order to simulate unsteady airflow over complex UAV configurations. This extension to this Fellowship is for the purpose of extending the application of PyFR to turbine blades, missiles, buildings and submarines. The program is a large collaboration between industry and multiple academic partners including Stanford University and Massachusetts Institute of Technology.

25. Robotics and Unmanned Aerial Vehicles (UAVs), Imperial College London, [accessed May 2022], from https://www.imperial.ac.uk/intelligent-digital-systems/research/robots-and-uavs.

26. Maria E. Angelopoulou and Christos-Savvas Bouganis, Vision-Based Egomotion Estimation on FPGA for Unmanned Aerial Vehicle Navigation. IEEE Transactions on Circuits and Systems for Video Technology, 24(6), 2014 pp.1070-1083, https://cas.ee.ic.ac.uk/people/ccb98/papers/AngelopoulouTSCV13.pdf.

27. Robotics and Unmanned Aerial Vehicles (UAVs), Imperial College London, [accessed May 2022], https://www.imperial.ac.uk/intelligent-digital-systems/research/robots-and-uavs.

28. Developing Software for High-Order Simulation of Transient Compressible Flow Phenomena: Application to Design of Unmanned Aerial Vehicles, EPSRC, https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/K027379/1

UNIVERSITY COLLEGE LONDON (UCL)

Over the time of this research project, our investigation was unable to identify research programmes within UCL that may represent higher, medium or lower risk for the development of autonomous weapons systems. However, UCL carries out a number of more general research projects that may have military applications in the future, such as those shown below.

ELECTROMAGNETIC IMAGING FOR AVIATION SECURITY

Start Date	Unclear, likely 2019[29]
End Date	Unknown
Known Partners	DSTL; UK Department for Transport
Funding	Defence and Security Accelerator Scheme - £332,520[30]
Affiliation	Laser Cooling Group, Department of Physics and Astronomy
Description	This project is developing sensors using magnetic induction tomography, an electromagnetic imaging technique which allows the sensor to "operate on an automated basis and with great penetration through metallic barriers."[31]
	This research will reportedly be applied to transport security.

EPSRC CENTRE FOR DOCTORAL TRAINING IN CONNECTED ELECTRONIC AND PHOTONIC SYSTEMS (CEPS)

Start Date	01-10-2019
End Date	31-03-2028
Known Partners	Over 30 partners, including Airbus; BAE Systems; DSTL; Leonardo MW; Teraview; Thales; PervasID
Funding	EPSRC Grant EP/S022139/1 - £5,419,248
Affiliation	Department of Electronic & Electrical Engineering
Description	This is a joint venture between UCL and the University of Cambridge, established to train students in photonics science, to meet commercial demand spanning applications in "information, sensing, communications, manufacturing and personal healthcare systems."[32]

29. UK Connected and Autonomous Vehicle Research and Development Projects 2017, Centre for Connected and Autonomous Vehicles,
https://www.connectedautomateddriving.eu/wp-content/uploads/2017/10/2017_United-Kingdom_Connected-and-Automated-Vehicle-Research-and-Development-Projects.pdf.

30. "Electromagnetic imaging for aviation security, Defence and Security Accelerator", 17 January 2019,
https://www.gov.uk/government/news/electromagnetic-imaging-for-aviation-security.

31. Ibid.

32. https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S022139/1

UNIVERSITY OF BIRMINGHAM

The following projects are affiliated with the University of Birmingham's Microwave Integrated Systems Laboratory (MISL), within the School of Engineering. The laboratory is "the biggest academic research team in the UK working in radar and remote sensing,"[33] with thirty staff including ten to fifteen PhD students. Its website cites grants and contracts from companies such as BAE Systems.

STREAM: SUB-THZ RADAR SENSING OF THE ENVIRONMENT FOR FUTURE AUTONOMOUS MARINE PLATFORMS - AMBER

Start Date	01-01-2020
End Date	30-06-2023
Known Partners	ASV Global (UK); BAE Systems; Jaguar Land Rover Limited; Raymarine Limited; Sea Mammal Research Unit; University of Southampton
Funding	EPSRC Grant EP/S033238/1 - £854,175[34]
Affiliation	The Microwave Integrated Systems Laboratory (MISL), School of Engineering
Description	The purpose of this project is to serve the growing markets for autonomous ships, and for small-to-medium, more agile boats. This project is developing a novel sub-THz radar as the "key sensor modality" for safe path planning and adaptation to dynamic environments. The project is a collaboration between MISL at the University of Birmingham, and the Sea Mammal Research Unit at the University of St Andrews. It uses facilities and equipment provided by the Millimetre Wave Group at St Andrews.

CORTEX: COGNITIVE REAL TIME SENSING SYSTEM FOR AUTONOMOUS VEHICLES - AMBER

Start Date	01-03-2019
End Date	30-03-2022
Known Partners	Jaguar Land Rover; Myrtle Machine Learning
Funding	Innovate UK - £2,003,735[35]
Affiliation	MISL, School of Engineering
Description	This project is developing "key enabling technologies and sensing techniques for autonomous driving in all on-road and all-weather driving conditions."[36] This will be achieved through data fusion from a combination of high-resolution radars and vision-based systems.

33. Microwave Integrated Systems Laboratory, University of Birmingham, https://www.birmingham.ac.uk/research/activity/eese/communications-sensing/misl/index.aspx.

34. https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S033238/1

35. Cognitive real time sensing system for autonomous vehicles - CORTEX, UK Research and Innovation, [accessed May 2022] https://gtr.ukri.org/projects?ref=104268.

36. Ibid.

BISTATIC UHF SYNTHETIC APERTURE RADAR PHENOMENOLOGY – PHD PROJECT - RED

Start Date	01-09-2020
End Date	31-07-2024
Known Partners	DSTL[37]
Funding	DSTL
Affiliation	MISL, School of Engineering
Description	This PhD project will "investigate the phenomenology observed in bistatic, ultra-high frequency (UHF), Synthetic Aperture Radar (SAR) imagery, in order to characterise the capability provided by such systems". This project is specifically concerned with airborne applications of this imagery technique for "a variety of defence, security and remote sensing applications."

ASSIVE SAR IMAGING USING BROADBAND INTERNET SATELLITE TRANSMISSIONS – PHD PROJECT - GREY

Start Date	01-09-2020
End Date	31-07-2024
Known Partners	DSTL[38]
Funding	DSTL
Affiliation	The Microwave Integrated Systems Laboratory (MISL), School of Engineering
Description	No further information on this project could be found.

LOW-COST, HIGH-RESOLUTION, DRONE-BORNE SAR IMAGING – PHD PROJECT - AMBER

Start Date	Unknown
End Date	Unclear, associated paper published in 2021
Known Partners	Turkish Ministry for National Education
Funding	Turkish Ministry for National Education
Affiliation	MISL, School of Engineering
Description	The associated paper for this studentship "develops and examines methods for the production of real-world, very-high resolution imagery using a high-frequency drone-borne synthetic aperture radar operating at short ranges."[39]

The University of Birmingham also carries out projects in the area of Radar Sensing and Drones. Recent publication outputs in this research domain include: 'SNR dependent drone classification using convolutional neural network', 2021- funded by EPSRC UK National Quantum Technology Hub in Sensing and Timing (NQTHST) grant; 'Cognitive approaches to detection of small targets', 2021 – funded by BAE Systems; 'Memory-augmented cognitive radar for obstacle avoidance using nearest steering vector search', 2020; 'Cognitive Radar System for Obstacle Avoidance Using In-Motion Memory-Aided Mapping', 2020 – both funded by the China Scholarship Council, National Key R&D Program of China; 'Memory-enhanced cognitive radar for autonomous navigation', 2020 – funded by the EPSRC; 'Advanced cognitive networked radar surveillance', 2021 – funded by DSTL and Aveillant. Ongoing and recent projects within this research domain include:

37. Bistatic UHF Synthetic Aperture Radar Phenomenology at University of Birmingham, FindAPhD.com, [accessed May 2022], https://www.findaphd.com/phds/project/bistatic-uhf-synthetic-aperture-radar-phenomenology/?p121663.

38. Research PhD Passive SAR Imaging using Broadband Internet Satellite Transmissions, University of Birmingham, [accessed October 2021], https://research.birmingham.ac.uk/en/projects/research-phd-%C3%A2-passive-sar-imaging-using-broadband-internet-satel.

39. Ali Bekar, Michail Antoniou, Chris Baker, Low-cost, high-resolution, drone-borne SAR imaging, IEEE Transactions on Geoscience and Remote Sensing, 9 Jun 2021, https://research.birmingham.ac.uk/en/publications/low-cost-high-resolution-drone-borne-sar-imaging.

MEFA: MAPPING AND ENABLING FUTURE AIRSPACE - AMBER

Start Date	01-04-2020
End Date	31-03-2023
Known Partners	EPSRC; BAE Systems; Thales Ltd
Funding	EPSRC Grant EP/T011068/1 - £879,278[40]
Affiliation	NQTHST, School of Engineering and Physical Sciences, MISL, School of Engineering and Physical Sciences
Description	This is an interdisciplinary project developing algorithms to distinguish between unmanned air vehicles and birds, using a "staring" form of radar sensor created specifically to track drones.
	This project held live trials at Cranfield Airport with GPS-tagged birds of prey provided by the International Centre for Birds of Prey.[41]

COGNITIVE RADAR WITH MACHINE LEARNING FOR ENHANCED DETECTION AND TRACKING – PHD PROJECT - RED

Start Date	01-02-2021
End Date	31-01-2025
Known Partners	EPSRC; BAE Systems
Funding	EPSRC's I-CASE Scheme; BAE Systems[42]
Affiliation	NQTHST, MISL, School of Engineering and Physical Sciences
Description	This studentship is developing "the next generation of signal processing algorithms that will push the limits of radar situational awareness in challenging operating environments."[43] Specifically, the programme aims to:
	Investigate the application of machine learning algorithms in cognitive radar architectures to create a dynamic perception of the operating environment
	Investigate adaption of radar waveforms and signal processing based on the dynamic environmental perception in order to optimise detection and tracking
	Develop the appropriate simulation environment to confirm theoretical understanding and assess the resulting performance
	Design and conduct a proof-of-concept experimental campaign to verify theoretical findings in a controlled environment
	Successful candidates are expected to conduct their research at MISL at the University of Birmingham, as well as spend time at BAE Systems.[44]

40. MEFA: Mapping and Enabling Future Airspace, EPSRC, https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/T011068/1

41. Live trials at airports explore bird movement in urban environments, UK Quantum Technology Hub, 6 July 2021, https://www.quantumsensors.org/news/2021/07/06/live-trials-at-airport-explore-bird-movement-in-urban-environments.

42. Machine Learning in Cognitive Radar for enhanced detection and tracking at University of Birmingham, FindAPhD. com, [accessed May 2022], https://www.findaphd.com/phds/project/machine-learning-in-cognitive-radar-for-enhanced-detection-and-tracking/?p121508.

43. Ibid.

44. Ibid.

ROBUST HIGH-PERFORMANCE RADAR RECOGNITION OF DRONES - GREY

Start Date	30-10-2020
End Date	29-06-2021
Known Partners	DSTL;[45] Aveillant
Funding	Defence and Security Accelerator - "Countering Drones Phase 2" Ref. ACC6017551 - £349,984[46]
Affiliation	NQTHST, MISL, School of Engineering and Physical Sciences
Description	No further information on this project could be found.

COGNITIVE ARRAY RADAR ARCHITECTURES FOR IMPROVED DETECTION AND TRACKING[47] - GREY

Start Date	01-02-2018
End Date	31-01-2022
Known Partners	BAE Systems
Funding	BAE Systems
Affiliation	NQTHST, MISL, School of Engineering and Physical Sciences
Description	No further information on this project could be found.

ROBUST DETECTION OF SMALL AIRBORNE TARGETS FOR SECURE SOCIETY - PHD PROJECT - AMBER

Start Date	20-09-2021
End Date	01-01-2025
Known Partners	Department for Transport; Rutherford Appleton Laboratory; Aveillant[48]
Funding	Department for Transport, Future of Aviation Security Solutions (FASS) programme
Affiliation	NQTHST, School of Engineering and Physical Sciences
Description	This studentship is "building the necessary mathematical and computational framework for intelligently detecting, tracking and discriminating small drone-like targets against others."[49]

45. Research output, University of Birmingham, https://research.birmingham.ac.uk/en/searchAll/index/?search=Robust+high-performance+radar+recognition+of+drones&pageSize=25&showAdvanced=false&allConcepts=true&inferConcepts=true&searchBy=PartOfNameOrTitle

46. Defence and Security Accelerator funded contracts: 1 April 2020 to 31 March 2021, Gov.uk, Updated 22 October 2021, https://www.gov.uk/government/publications/accelerator-funded-contracts/defence-and-security-accelerator-funded-contracts-1-april-2020-to-31-march-2021.

47. Cognitive array radar architectures for improved detection and tracking, University of Birmingham, https://research.birmingham.ac.uk/en/projects/cognitive-array-radar-architectures-for-improved-detection-and-tr

48. Robust Detection of Small Airborne Targets for Secure Society at University of Birmingham, FindAPhD.com, https://www.findaphd.com/phds/project/robust-detection-of-small-airborne-targets-for-secure-society/?p121509.

49. Ibid.

ULTRA-LOW PHASE NOISE OSCILLATOR FOR RF SENSING - PHD PROJECT[50] - GREY

Start Date	01-09-2020
End Date	31-08-2024
Known Partners	DSTL
Funding	DSTL[51]
Affiliation	NQTHST, School of Engineering and Physical Sciences
Description	No further information on this studentship could be found.

The following projects are affiliated with the Intelligent Robotics Laboratory (IRLab), or the Robotics and Computer Vision Laboratory, based in the School of Computer Science at the University of Birmingham. IRLab investigates 'computer vision, knowledge representation and reasoning, cognitive systems, interactive learning, formal verification, and dexterous manipulation.'

SCALABLE INFERENCE OF AFFORDANCE ACTIVITY, AND INTENT FROM SPATIO-TEMPORAL INPUT - RED

Start Date	01-01-2021
End Date	30-05-2021
Known Partners	US Office of Naval Research[52]
Funding	US Office of Naval Research
Affiliation	IRLab, School of Computer Science
Description	This project is developing AI architectures which will enable "scalable inference about other agents' activities, intentions, and affordances."

BURG: BENCHMARKS FOR UNDERSTANDING GRASPING - GREEN

Start Date	01-11-2019
End Date	31-10-2022
Known Partners	EPSRC
Funding	EPSRC Grant EP/S032487/1 - £357,129[53]
Affiliation	IRLab, School of Computer Science
Description	This project is investigating robotic object manipulation by developing task-orientated grasping capabilities. It is also developing "BURG" a "castle of setups, tools and metrics for community building around an objective benchmark protocol."[54]

50. Ultra-low phase noise oscillator for RF sensing PhD, University of Birmingham, https://research.birmingham.ac.uk/en/projects/ultra-low-phase-noise-oscillator-for-rf-sensing-phd

51. Research output, University of Birmingham, https://research.birmingham.ac.uk/en/searchAll/index/?search=Ultra-low+phase+noise+oscillator+for+RF+sensing&pageSize=25&showAdvanced=false&allConcepts=true&inferConcepts=true&searchBy=PartOfNameOrTitle

52. Projects - Robotics and Computer Vision, University of Birmingham, [accessed May 2022], https://www.birmingham.ac.uk/research/activity/computer-science/artificial-intelligence/intelligent-robotics-lab/projects.aspx.

53. BURG: Benchmarks for UndeRstanding Grasping, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S032487/1

54. Projects - Robotics and Computer Vision, University of Birmingham, [accessed May 2022], https://www.birmingham.ac.uk/research/activity/computer-science/artificial-intelligence/intelligent-robotics-lab/projects.aspx.

EXPLAINABLE REASONING AND LEARNING FOR AD-HOC MULTI AGENT TEAMWORK- RED

Start Date	01-06-2020
End Date	31-05-2023
Known Partners	US Office of Naval Research
Funding	US Office of Naval Research[55]
Affiliation	IRLab, School of Computer Science
Description	This project is developing "algorithms and architectures for long-duration autonomy in a team of heterogeneous agents operating without prior coordination in complex, adversarial environments."

PERCEPTION-GUIDED ROBUST AND REPRODUCIBLE ROBOTIC GRASPING AND MANIPULATION – GREEN

Start Date	01-04-2019
End Date	30-09-2022
Known Partners	EPSRC
Funding	EPSRC Grant EP/S032428/1 - £347,725[56]
Affiliation	The National Centre for Nuclear Robotics (NCNR), School of Mechanical Engineering
Description	The aim of this project is to develop and test "perception and manipulation strategies that will allow a robot to grasp and manipulate objects from a complex scene."

The following projects detail the central funding and subsidiary projects within NCNR. Research for the NCNR is located at the University of Birmingham within the Extreme Robotics Lab, "Europe's leading academic lab focused on advanced robotics and AI in nuclear environments."[57] Amongst its ongoing research grants, the Lab's website lists an £130,000 grant from the UK Ministry of Defence, which is being used for the development of "human-AI collaboration for control of remote robot vehicles."[58]

THE NATIONAL CENTRE FOR NUCLEAR ROBOTICS (NCNR) - AMBER

Start Date	02-10-2017
End Date	01-04-2022
Known Partners	Over 30, including National Nuclear Laboratory; JET Propulsion Laboratory; National Physical Laboratory; Forth Engineering Ltd; Ionix Advanced Technologies Ltd; Synthotech; Shield; BAE Systems; AWE; Eidos Education; Imitec Ltd; Haption; Jacobs UK Limited; Shadow Robot Company Ltd; UltraSoC
Funding	EPSRC Grant EP/R02572X/1 - £12,256,862[59]
Affiliation	School of Mechanical Engineering

55. Ibid.

56. https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S032428/1

57. National Centre for Nuclear Robotics, NCNR, [accessed September 2022], https://www.ncnr.org.uk/

58. Our projects - Robotics, University of Birmingham, [accessed May 2022], https://www.birmingham.ac.uk/research/activity/metallurgy-materials/robotics/our-projects.aspx.

59. National Centre for Nuclear Robotics, NCNR, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/R02572X/1

Description	The NCNR is a consortium of researchers from eight universities (Birmingham, Essex, Bristol, Edinburgh, UWE, Queen Mary, Lincoln and Lancaster) and over thirty industry partners. The Centre is developing robotics which can operate in nuclear environments. With this challenge is the opportunity to investigate "advanced telepresence", "real-time 3D modelling and [robotic] semantic understanding of objects and scenes", and "active [robot] vision in dynamic scenes and vision-guided navigation and manipulation", involving "novel sensors", "advanced algorithms for robot perception", and "new kinds of robots to deploy sensors into hard-to-reach locations."[60]

ADVANCED CONTROL OF ROBOTIC MANIPULATORS FOR CUTTING AND RESIZING – PHD PROJECT - GREY

Start Date	19-12-2018
End Date	18-12-2022
Known Partners	National Nuclear Laboratory[61]
Funding	National Nuclear Laboratory
Affiliation	NCNR, School of Mechanical Engineering
Description	No further information on this project could be found.

ROBUST REMOTE SENSING FOR MULTI-MODAL CHARACTERISATION IN NUCLEAR AND OTHER EXTREME ENVIRONMENTS - AMBER

Start Date	01-05-2017
End Date	01-11-2021
Known Partners	JET Propulsion Laboratory; National Nuclear Laboratory
Funding	EPSRC Grant EP/P017487/1 - £1,398,053[62]
Affiliation	NCNR, School of Mechanical Engineering
Description	This multidisciplinary project is a collaboration between researchers at the University of Birmingham and the University of Essex, which aims to address the problem of characterising extreme environments (for instance the geometry and layout of a nuclear environment being decommissioned), using remote sensing, AI and robotics.

60. Engineering and Physical Sciences Research Council (EPSRC), UK Research and Innovation, [accessed September 2022], epsrc.ukri.org

61. Direct Research Portfolio 2019/20 Q2 Lot A - University Interactions, Updated October 2019, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/857834/Direct_Research_Portfolio_2019_to_2020_Q2.pdf.

62. Robust remote sensing for multi-modal characterisation in nuclear and other extreme environments, EPSRC, [accessed September 2002], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/P017487/1

The following projects are affiliated with the Human Interface Technologies (HIT) Team, based within the Department of Electronic, Electrical and Systems Engineering. The HIT team develops virtual reality and telepresence/telerobotic technologies for applications in aerospace, defence and healthcare. Its past projects include the Future Mission Systems 2035 mixed reality research for BAE Systems, which used motion capture and tracking to develop a 3D mission display 'command table.' The command table can be used to display enhanced mission information, the location of mission actors and UAVs, floating 'menu' screens, and "simulated aerial 3D 'keyhole'/laser sensor scans of suspect terrorist assets."[63] This particular project was conducted through multiple phases around 2014.[64]

USING HUMAN-SYSTEMS INTERACTION TECHNIQUES TO INFLUENCE PERCEIVED TRUST IN MULTISENSOR SYSTEMS – PHD PROJECT - AMBER

Start Date	01-09-2018
End Date	31-07-2022
Known Partners	EPSRC; BAE Systems[65]
Funding	EPSRC[66]
Affiliation	HIT, Department of Electronic, Electrical and Systems Engineering
Description	This studentship is investigating "techniques used to present data, information and intelligence from multiple onboard and remote sensor systems (e.g. as part of unmanned platforms), and how these factors can influence the trust an operator places in those data, and any other sources of information or intelligence."[67]

INDUSTRIAL POST-DOCTORATE IN AUGMENTED REALITY (AR)/VIRTUAL REALITY (VR) AND MIXED REALITY- GREY

Start Date	01-06-2018
End Date	31-05-2021
Known Partners	BAE Systems
Funding	BAE Systems[68]
Affiliation	HIT, Department of Electronic, Electrical and Systems Engineering
Description	No further information about this post-doctorate could be found.

63. BAE Systems: Future Mission Systems 2035, University of Birmingham, aAccessed May 2002] https://www.birmingham.ac.uk/research/activity/eese/communications-sensing/hit-team/defence/bae-systems-future-mission-systems-2035.aspx.

64. Human Interface Technologies Team, University of Birmingham School of Electronic Electrical & Systems Engineering, https://www.birmingham.ac.uk/Documents/college-eps/eece/research/bob-stone/hit-team-brochure.pdf.

65. Projects, University of Birmingham, [accessed September 2022], https://research.birmingham.ac.uk/en/searchAll/index/?search=Using+Human-Sytems+Interaction+Techniques+to+influence+Perceived+Trust+in+Multisensor+Systems&pageSize=25&showAdvanced=false&allConcepts=true&inferConcepts=true&searchBy=PartOfNameOrTitle

66. Human-Systems Interaction Techniques to Increase Trust In Multi-sensor Systems, UKRI, [accessed September 2022],https://gtr.ukri.org/projects?ref=studentship-2110704#/tabOverview

67. Ibid.

68. Research output, University of Birmingham, [accessed September 2022], https://research.birmingham.ac.uk/en/searchAll/index/?search=Industrial+post-doctorate+in+AR%2FVR+and+Mixed+Reality&pageSize=25&showAdvanced=false&allConcepts=true&inferConcepts=true&searchBy=PartOfNameOrTitle

UNIVERSITY OF BRISTOL

(T-B PHASE): THALES-BRISTOL PARTNERSHIP IN HYBRID AUTONOMOUS SYSTEMS ENGINEERING - AMBER

Start Date	01-10-2017
End Date	31-03-2023
Known Partners	Thales
Funding	EPSRC Grant EP/R004757/1 - £2,050,757[69]
Affiliation	Department of Computer Science
Description	This multidisciplinary project brings together expertise in robotics, AI, and systems engineering, in a five-year partnership between the University of Bristol and Thales Group. The project is investigating solutions for "fundamental autonomous system design problems in the context of three real-world Thales use cases: Hybrid Low-Level Flight, Hybrid Rail Systems, and Hybrid Search & Rescue."
	By embedding Robustness, Resilience and Regulation as part of the development life-cycle, T-B PHASE aims to "provide those who commission and develop hybrid autonomous systems with tools that enable early-stage evaluation and demonstration in the development lifecycle." In addition, the project seeks to "accelerate the adoption of new hybrid autonomous systems by reducing the costs of development, the risks of deployment, and the length of the development life-cycle."[70]

EPSRC CENTRE FOR DOCTORAL TRAINING IN FUTURE AUTONOMOUS AND ROBOTIC SYSTEMS – FARSCOPE (GRANT 1) AND FARSCOPE-TU: TOWARDS UBIQUITY (GRANT 2) - AMBER

Start Date	Grant 1: 01-04-2014 Grant 2: 01-10-2019
End Date	Grant 1: 30-09-2022 Grant 2: 31-03-2028
Known Partners	BAE Systems; DSTL; Blue Bear Systems Research; SciSys; Rolls-Royce
Funding	EPSRC Grant EP/L015293/1 (Grant 1) - £4,930,858
	EPSRC Grant EP/S021795/1 (Grant 2) - £4,846,104
Affiliation	Department of Engineering Mathematics
Description	In partnership with the University of West England, this Centre is training "over 50 students in the essential Robotics and Autonomous Systems (RAS) technical underpinning skills, the ability to integrate RAS knowledge and technologies to address real-world problems, and the understanding of wider implications and applications of RAS and the ability to innovate within, and beyond, this sector."[71]
	FARSCOPE makes use of the Bristol Robotics Laboratory (BRL), one of the largest robotics laboratories in Europe.

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69. Thales-Bristol Partnership in Hybrid Autonomous Systems Engineering (T-B PHASE), EPSRC, [Accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/R004757/1

70. Faculty of Engineering, University of Bristol, [Accessed September 2022], https://www.bristol.ac.uk/engineering/research/t-bphase/about-us/

71. EPSRC Centre for Doctoral Training in Future Autonomous and Robotic Systems - FARSCOPE, EPSRC, [Accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/L015293/1

UKRI TRUSTWORTHY AUTONOMOUS SYSTEMS NODE IN FUNCTIONALITY - RED

Start Date	01-11-2020
End Date	30-04-2024
Known Partners	DSTL; Thales
Funding	EPSRC Grant EP/V026518/1 - £3,315,004[72]
Affiliation	Department of Aerospace Engineering
Description	This project is one of seven nodes in the Trustworthy Autonomous Systems programme. Bristol's "Functionality" node is investigating trust in autonomous systems of "evolving functionality", i.e. a system which may change its function or the way it performs a task without human intervention.

The project focuses on how functional evolutions can be monitored, tested, and regulated for safety. It focuses on three evolving technologies: swarm systems, soft robotics, and unmanned air vehicles. These systems will be studied in real time to explore both how they are developed and how features can be built into the design process to increase trustworthiness (termed Design-for-Trustworthiness). |

72. UKRI Trustworthy Autonomous Systems Node in Functionality, EPSRC, [Accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/V026518/1

UNIVERSITY OF CAMBRIDGE

The University of Cambridge holds an extensive portfolio of military connections spanning research funding, collegiate investments, spin-out companies and student recruitment. Student activists from the Demilitarise Cambridge campaign estimate that, between 2014 and 2019, the University received over £36 million in funds for research grants from the arms industry or government defence bodies. This funding increased from an estimated annual total of £6.5million in the 2014-15 financial year, to £8.4million in 2018-19 (more recent accounts are not yet published). Demilitarise Cambridge has described the University's intimate and lucrative ties to the military as the 'Cambridge military-academic complex', citing relationships with major arms companies such as BAE Systems, Roke Manor Research and Rolls Royce.[73]

The "Resilient Path Coordination in Connected Vehicle Systems" project is affiliated with the Prorok Lab, based in the Department of Computer Science. The lab's mission is "to develop the techniques that endow autonomous agents with the intelligence that enables them to cooperate towards common goals." The lab's past research outputs have been funded by the likes of TerraSwarm and United Technologies (now Raytheon, research titled "Formations for Resilient Robot Teams"), and recently DEVCOM (the US Army's corporate research laboratory) and DCIST. The Prorok lab lists 17 current researchers among its staff, including PhD and MPhil students, and one undergraduate student.[74]

RESILIENT PATH COORDINATION IN CONNECTED VEHICLE SYSTEMS - AMBER

Start Date	01-04-2019
End Date	30-09-2021
Known Partners	EPSRC; ERC; DEVCOM; UKRI; DCIST; Arm Ltd; Nokia Bell Labs; Amazon Science[75]
Funding	EPSRC Grant EP/S015493/1 - £236,186[76]
Affiliation	Department of Computer Science

73. Please see: R Bradbury, N Chye, J Hunter, "Colleges hold over £6.5m in arms companies", Varsity, November 2018, https://www.varsity.co.uk/news/16519;
Demilitarise screening Google Sheet, Compiled by the Cambridge Student Union Ethical Affairs Campaign, using data published in the annual University Reporter, https://docs.google.com/spreadsheets/d/18jXxcAzoev7H3IFuLUbH-CNgrwLYWxTtbM7h4t1u18o/ ;
"Feature: Inside the Cambridge military-academic complex", MENA Solidarity Network, October 2018, https://menasolidaritynetwork.com/2018/10/01/feature-inside-the-cambridge-military-academic-complex/.

74. Please see: Learning to Communicate in Multi-Agent Systems; https://www.proroklab.org/?publications; the US Army Research Laboratory's Distributed and Collaborative Intelligent Systems and Technology Collaborative Research Alliance, including multiple US universities such as MIT and UPenn, and the University of Cambridge – developing autonomous swarms: https://www.dcist.org/

75. Partners indicated by the logos which appear at the end of this project presentation delivered by Professor Prorok – https://www.youtube.com/watch?v=J9Olp6YqQhw

76. Resilient Path Coordination in Connected Vehicle Systems, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S015493/1

Description	This project aimed to develop a multi-agent AI driving method for "systems that are potentially non-cooperative and unreliable," leveraging "decentralised planning to guarantee collision-free paths at all times and in all circumstances."[77]
	The same funders are listed in a presentation on the project titled 'The Emergence of Adversarial Communication in Multi-Agent Reinforcement Learning', delivered in January 2021.
	Further related output publications under review or in preprint include:
	• 'The Holy Grail of Multi-Robot Planning: Learning to Generate Online-Scalable Solutions from Offline-Optimal Experts': a collaboration between Cambridge researchers and Ethan Stump of DEVCOM, funded by DEVCOM, ERC and EPSRC.
	• 'Graph Convolutional Memory for Deep Reinforcement Learning', funded by ERC and Toshiba Europe Ltd
	• 'Decentralised Control with Graph Neural Networks', funded by DEVCOM and EPSRC
	• Gaussian Process Based Message Filtering for Robust Multi-Agent Cooperation in the Presence of Adversarial Communication,' funded by DEVCOM, and researchers supported by EPSRC and Amazon Research Award.

UNIVERSITY OF EDINBURGH

SIGNAL PROCESSING IN THE INFORMATION AGE - RED

Start Date	01-07-2018
End Date	31-03-2024
Known Partners	Leonardo MW Ltd; ADS Group Limited; Atlas Elektronik UK; QinetiQ; Thales Ltd; BAE Systems; SeeByte Ltd; MathWorks; Kaon Ltd; Cubica; Roke Manor Research
Funding	EPSRC Grant EP/S000631/1 - £4,092,207[78]
Affiliation	School of Engineering
Description	This project is Phase 3 of a long running University Defence Research Collaboration (UDRC), which brings together researchers from five universities who are specialised in signal processing, data science and machine learning, to investigate "fundamental mathematical signal and data processing techniques that will underpin future technologies required in the future operating environment."[79] The project is a collaboration between Edinburgh, Heriot-Watt University, University of Strathclyde and Queen's University Belfast. It is classified by the EPSRC as serving the "Aerospace, Defence and Marine" industrial sector. Phases 1 and 2 had been conducted in collaboration with the Ministry of Defence's Centre for Defence Enterprise, and the US Office of Naval Research.

UKRI TRUSTWORTHY AUTONOMOUS SYSTEMS NODE IN GOVERNANCE AND REGULATION - AMBER

Start Date	01-11-2020
End Date	20-04-2024
Known Partners	BAE Systems; Altran UK; DSTL; Civil Aviation Authority; D-RisQ Ltd; Ethical Intelligence; NASA Ames Research Centre; OPTOS Plc; Vector Four; Scottish Informatics and Computer Science Alliance (SICSA); National Physical Laboratory; Legal & General; Craft Prospect; Digital Health and Care Institute; Microsoft; nVIDIA; Aesthetic Integration
Funding	EPSRC Grant EP/V026607/1 - £2,671,812
Affiliation	School of Informatics
Description	This is a multidisciplinary research consortium "building: experience of regulatory structure and practice, notions of cause, responsibility and liability, and tools to create evidence of trustworthiness into modern development practice."[80] Researchers from Edinburgh, Heriot-Watt, Glasgow, King's College London, Nottingham and Sussex, across computer science and AI, law, ethics and humanities and design are creating a "novel software engineering and governance methodology" for emerging autonomous technologies.

78. Signal Processing in the Information Age, EPSRC, [Accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S000631/1

79. Ibid.

80. UKRI Trustworthy Autonomous Systems Node in Governance and Regulation, EPSRC, [Accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/V026607/1

UKRI TRUSTWORTHY AUTONOMOUS SYSTEMS NODE IN TRUST[81] - GREY

Start Date	01-11-2020
End Date	30-04-2024
Known Partners	Age UK; BAE Systems; Consequential Robotics Ltd; DSTL; Dyson Ltd and Dyson Technology Ltd; Honda; Lloyd's Register Foundation; Offshore Renewable Energy Catapult; Schlumberger; SeeByte Ltd; Shadow Robot Company Ltd; SoftBank Robotics; Thales Ltd; The Data Lab; Total E&P UK PLC
Funding	EPSRC Grant EP/V026682/1 - £3,056,751
Affiliation	Department of Computer Science, Department of Mathematics
Description	This is one of seven research nodes within the Trustworthy Autonomous Systems research initiative (see University of Southampton's TAS hub, below). This research will be grounded in Psychology and Cognitive Sciences, and aims to develop fundamental understanding which will inform the design of all autonomous systems going forward.

EPSRC CENTRE FOR DOCTORAL TRAINING IN ROBOTICS AND AUTONOMOUS SYSTEMS - AMBER

Start Date	01-04-2014
End Date	30-09-2022
Known Partners	BAE Systems; Honda; Hydrason Solutions Ltd; Industrial Systems and Control Ltd; Kinova; KUKA Robotics UK Limited; Leonardo MW Ltd; Mactaggart Scott & Co Ltd; National Institute of Informatics; OC Robotics; Renishaw; Schlumberger; SciSys Ltd; SeeByte Ltd Shadow Robot Company Ltd; SICSA; Subsea 7 Limited; Thales Ltd; Touch Bionics; Transport Research Laboratory (TRL) Ltd; YDreams
Funding	EPSRC Grant EP/L016834/1 - £5,784,697[82]
Affiliation	Edinburgh Centre for Robotics
Description	This CDT is based on the Edinburgh Centre for Robotics in partnership with Heriot-Watt University, and is a four year PhD programme training the next cohort of researchers in the research domains underpinning autonomous systems: "including robot learning, field robotics, anthropomorphic & bio-inspired designs, human robot interaction, embedded control and sensing systems, multi-agent decision making and planning, and multimodal interaction."[83]

81. UKRI Trustworthy Autonomous Systems Node in Trust, EPSRC, [Accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/V026682/1

82. EPSRC Centre for Doctoral Training in Robotics and Autonomous Systems (RAS) in Edinburgh, EPSRC, [accessed September 2022],https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/L016834/1

83. Ibid.

UNIVERSITY OF MANCHESTER

The University of Manchester's Aerospace Research Institute, affiliated to the Faculty of Science and Engineering, delivers significant research on AI and robotics within its "Autonomous Systems Research Theme," which investigates remote task-performance in hazardous environments, and remote sensing. BAE Systems, MBDA Systems and Rolls Royce are amongst the Institute's partners.[84] The following project is affiliated with the Autonomous Systems Research Theme:

AMORR@MANCHESTER: AUTONOMOUS MOBILE RELIABLE ROBOTS- AMBER

Start Date	Unknown
End Date	Unknown - AMORR was successfully demonstrated by 2016
Known Partners	MBDA Systems; Sellafield Ltd; International Atomic Energy Agency[85]
Funding	Specific funding unknown
Affiliation	Autonomous Systems Research Theme, Aerospace Research Institute
Description	The AMORR project has developed a "reliable autonomous solution", comprising algorithms with fault tolerant and predictive maintenance capabilities. AMORR can "can be used with several types of robotic platforms, such as ground, aerial, and water robots."[86]

The University of Manchester is home to the "Robotics for Extreme Environments" group, which is formed of researchers from the Department of Mechanical, Aerospace and Civil Engineering,[87] the Department of Electrical and Electronic Engineering, and the Department of Computer Science. The group develops autonomous intelligent systems for use in extreme environments. Its main purpose is to investigate solutions for challenges in nuclear decommissioning, offshore wind farm inspection and mining, by bringing together experts from areas that include control systems engineering, advanced sensing, machine learning, swarm robotics and tele-operation. The following projects are affiliated with the group:

MIMREE: MULTI-PLATFORM INSPECTION MAINTENANCE AND REPAIR IN EXTREME ENVIRONMENTS - AMBER

Start Date	Unknown
End Date	Latest news update on website dated 2020[88]
Known Partners	Thales; Offshore Renewable Energy Catapult; Wootzano Ltd[89]
	Royal Holloway University of London; University of Bristol; Royal College of Art
Funding	Unknown
Affiliation	Robotics for Extreme Environments (Department of Mechanical, Aerospace and Civil Engineering; Department of Electrical and Electronic Engineering; and Department of Computer Science).

84. Autonomous Systems Research Theme, University of Manchester Aerospace Research Institute, [accessed June 2022,] http://www.aero.manchester.ac.uk/our-research/autonomous-systems/.

85. Ibid.

86. Ibid.

87. The Department of Mechanical, Aerospace and Civil Engineering conducts research on Aerospace Engineering, as a result of which it holds "strong links with Rolls-Royce and BAE Systems and further links with unmanned aerial vehicle research (UAVs, drones), biomimetics, microsystems, flow diagnostics and space technologies." See: Aerospace engineering, University of Manchester Department of Mechanical, Aerospace and Civil Engineering, accessed June 2022, https://www.mace.manchester.ac.uk/research/themes/aerospace-engineering/.

88. Latest news from MIMRee Project, MIMRee, [accessed September 2022], https://www.mimreesystem.co.uk/news

89. MIMRee Project Partners, [accessed September 2022], https://www.mimreesystem.co.uk/consortium

Description	This project aims to create a "fully autonomous intelligent robotic platform to plan and execute inspection and repair missions without the need for an offshore human presence." The project comprised multiple systems, including an "autonomous surface vessel" and an unmanned aerial system.
	The primary intended application of this research is the inspection and maintenance of offshore wind farms.

HOME-OFFSHORE: HOLISTIC OPERATION AND MAINTENANCE FOR ENERGY FROM OFFSHORE WIND FARMS - GREEN

Start Date	11-04-2017
End Date	10-11-2020
Known Partners	British Approvals Service for Cables (BASEC); BPP-TECH; CENSIS; DNV GL (UK); European Marine Energy Centre; Fugro (UK); Hi Speed Sustainable Manufacturing Inst; Hydrason Solutions Ltd; Nova Innovation Ltd; Offshore Renewable Energy Catapult; Scottish Power; Siemens; University of Edinburgh
Funding	EPSRC Grant EP/P009743/1 - £3,048,221
Affiliation	Robotics for Extreme Environments (Department of Mechanical Aerospace and Civil Engineering; Department of Electrical and Electronic Engineering; and Department of Computer Science)
Description	The project aimed to develop remote inspection capabilities for the asset management of offshore wind farms. The initiative envisaged developing drones, where "advanced robotic monitoring and advanced sensing techniques will be integrated into diagnostic and prognostic schemes which will allow improved information to be streamed into multi-physics operational models for offshore wind farms."[90]

ROBOTICS AND ARTIFICIAL INTELLIGENCE FOR NUCLEAR (RAIN)[91] - GREY

Start Date	02-10-2017
End Date	30-09-2022
Known Partners	ABB Power Grids UK Limited; AWE; Beihang University; BP; Chinese Academy of Science; Createc Ltd; Department for International Trade; EDF Energy Plc (UK); Festo Ltd; Forth Engineering Ltd; Fusion For Energy ; Gassco; Imitec Ltd; Innotec Ltd; Italian Institute of Technology
	ITER – International Fusion Energy Org; James Fisher Nuclear Limited; Japan Atomic Energy Agency; Longenecker and Associates; Moog Controls Ltd; National Nuclear Laboratory; Nuclear AMRC; Nuclear Decommissioning Authority; Nuvia Limited; OC Robotics; Oxford Investment Opportunity Network; Rolls-Royce Plc; Shadow Robot Company Ltd; Sprint Robotics; Tharsus; The Manufacturing Technology Centre Ltd; **Uniper** Technologies Ltd.; University of Florida; University of Texas at Austin; Valtegra; Virtual Engineering Centre (VEC)
Funding	EPSRC Grant EP/R026084/1- £12,807,912[92]
Affiliation	Robotics for Extreme Environments (Department of Mechanical, Aerospace and Civil Engineering; Department of Electrical and Electronic Engineering; and Department of Computer Science).

90. HOME-Offshore: Holistic Operation and Maintenance for Energy from Offshore Wind Farms, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/P009743/1

91. Robotics and Artificial Intelligence for Nuclear (RAIN), UKRI, https://gtr.ukri.org/projects?ref=EP%2FR026084%2F1#/tabOverview

92. Robotics and Artificial Intelligence for Nuclear (RAIN), UKRI, [Accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/R026084/1

Description	This is a large collaborative research venture spanning multiple universities, investigating fundamental robotics science for primarily nuclear applications, while also holding a "keen focus on applications and exploitation in a much wider range of challenging environments."

The University of Manchester's Department of Electrical and Electronic Engineering conducts research projects in the area of 'Autonomous Systems'. These focus on aerial, underwater, and ground unmanned vehicles and are conducted in partnership with companies and institutions such as BAE Systems, Rolls-Royce, North West Aerospace Alliance and Roke Manor Research.[93] A higher risk research project conducted by is listed below.

AN INTEGRATED VISION AND CONTROL ARCHITECTURE FOR AGILE ROBOTIC EXPLORATION- RED

Start Date	01-09-2015
End Date	31-01-2021
Known Partners	BAE Systems; Blue Bear Systems Research Ltd; DSTL; TRW Automotive
Funding	EPSRC Grant EP/M019284/1 - £858,324
Affiliation	School of Electrical and Electronic Engineering
Description	This project aims to develop "the design and application of novel image plane sensor-processor systems, the associated high level vision algorithms, and their integration within a control-aware architecture for autonomous robotic systems, in particular Micro Aerial Vehicles (MAVs)."[94] Such "agile micro air-vehicles, and more generally, advanced vision-based navigation systems for autonomous robots will find both civilian and military applications in reconnaissance and search and rescue operations."

MACHINE LEARNING AND EXPLAINABLE AI – PHD PROJECT - AMBER

Start Date	Unknown
End Date	Unknown
Known Partners	EPSRC; BAE Systems[95]
Funding	EPSRC iCASE (Industrial Case) studentship funding
Affiliation	School of Electrical and Electronic Engineering
Description	This studentship "aims at the development of novel, explainable AI and machine learning models for human-machine interaction."

93. Autonomous systems – University of Manchester Department of Electrical and Electronic Engineering, Accessed June 2022, https://www.eee.manchester.ac.uk/research/expertise/autonomous-systems/.

94. An Integrated Vision and Control Architecture for Agile Robotic Exploration, EPSRC, [Accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/M019284/1

95. Machine Learning and Explainable AI (EPSRC iCASE studentship) at The University of Manchester, FindAPhD.com, [Accessed June 2022], https://www.findaphd.com/phds/project/machine-learning-and-explainable-ai-epsrc-icase-studentship/?p129393.

ORIGIN LOCATION AND ORIENTATION OF IMAGERY AIMS – PHD PROJECT - RED

Start Date	September 2017
End Date	March 2022
Known Partners	BAE Systems
Funding	EPSRC[96]
Affiliation	Department of Computer Science
Description	The purpose of this studentship was to improve the ability for UAVs to accurately navigate using low quality GPS data.

96. Origin Location and Orientation of Imagery Aims, UKRI, [Accessed September 2022],
https://gtr.ukri.org/projects?ref=studentship-1961868#/tabOverview

UNIVERSITY OF OXFORD

FROM SENSING TO COLLABORATION: ENGINEERING, EXPLORING AND EXPLOITING THE BUILDING BLOCKS OF EMBODIED INTELLIGENCE[97] - AMBER

Start Date	01-02-2021
End Date	31-01-2026
Known Partners	Accenture Labs; BP International; Bossa Nova Robotics; Honda Research Institute (Europe); L3Harris (ASV); Navtech Radar; Ocado Group; Oxbotica; Oxfordshire County Council; UKAEA RACE; Saga Robotics; Scan Computers; The Shadow Robot Company; Australian Research Council Centre of Excellence for Robotic Vision; QUT; Autonomous Systems Lab and Institute of Robotics and Intelligent Systems at ETH, Zurich[98]
Funding	EPSRC Grant EP/V000748/1 - £5,994,620
Affiliation	Department of Engineering Science
Description	This project is a collaboration between researchers at Oxford and UCL, aiming "to deliver autonomous systems which amplify human capacity and potential."[99] With the impetus that robots "need to be able to sense, interpret, act, navigate, coordinate and collaborate with an unprecedented acuity."[100] The project spans multiple disciplines and applications. Recent publications from the Oxford Robotics Institute under this grant[101] include: • 'Depth-SIMS: Semi-Parametric Image and Depth Synthesis'. • Fast-MbyM: Leveraging Translational Invariance of the Fourier Transform for Efficient and Accurate Radar Odometry.' • 'Risk-Averse Bayes-Adaptive Reinforcement Learning'. • 'Risk-Aware Motion Planning in Partially Known Environments'.

97. https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/V000748/1

98. "From Sensing to Collaboration – An EPSRC Programme Grant", University of Oxford Department of Engineering Science, 07 Dec 2020, https://eng.ox.ac.uk/news/from-sensing-to-collaboration/.

99. https://epsrc.ukri.org/research/ourportfolio/vop/grantlist/THEME/Engineering/ORGANISATION/1000547/9999/

100. "Prof Berthouze has a new EPSRC program grant starting on 1st February 2021!", UCL Interaction Centre, https://uclic.ucl.ac.uk/news-events-seminars/prof-berthouze-has-a-new-epsrc-program-grant-starting-on-1st-february-2021.

101. "Papers", Oxford Robotics Institute, [accessed June 2022], https://ori.ox.ac.uk/publications/papers/.

UNDERSTANDING SCENES AND EVENTS THROUGH JOINT PARSING, COGNITIVE REASONING AND LIFELONG LEARNING[102]– RED

Start Date	01-10-2015
End Date	28-02-2022
Known Partners	EPSRC; US Office of Naval Research
Funding	EPSRC Grant EP/N019474/1 - £1,114,547
	US Office of Naval Research, grant ONR MURI N00014-16-1-2007[103]
	US DoD $4.5M (3 year base period) + $3.0M (2 year option period) = $7.5M (total)
	UK MoD $3.0M (3 year base period) + $2.0M (2 year option period) = $5.0M (total)[104]
Affiliation	Department of Engineering Science
Description	This Multidisciplinary University Research Initiative (MURI) aimed to develop computer 'visual common sense' through psychology and cognitive experiments, knowledge representation, lifelong learning and computer-vision tasks.[105] It was jointly funded by the EPSRC and the US Office of Naval Research, and comprised researchers from Oxford, Glasgow, Birmingham and Reading in the UK, as well as Stanford University, Carnegie Mellon University, University of Illinois, Massachusetts Institute of Technology, and Yale in the US.[106]
	The Oxford Department of Engineering is responsible for Oxford's portion of the MURI's EPSRC funding.[107] [108] Recent publications include[109]:
	• 'Calibrating Deep Neural Networks using Focal Loss', 2020.
	• 'Continual Learning in Low-rank Orthogonal Subspaces', 2020.
	• 'Instance Segmentation of LiDAR Point Clouds', 2020.

102. Understanding scenes and events through joint parsing, cognitive reasoning and lifelong learning, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/N019474/1

103. Understanding Scenes and Events through Joint Parsing, Cognitive Reasoning and Lifelong Learning, MURI, [accessed September 2022], https://vcla.stat.ucla.edu/MURI_Visual_CommonSense/.

104. Understanding Scenes and Events through Joint Parsing, Cognitive Reasoning and Lifelong Learning, Center for Vision, Cognition, Learning, and Autonomy, University of California Los Angeles, https://vcla.stat.ucla.edu/MURI_Visual_CommonSense/.

105. "About · MURI." robots.ox.ac.uk, 2015, [accessed July 2022], https://www.robots.ox.ac.uk/~nsid/muri/about/.

106. "PROFESSOR PHILIPPE SCHYNS", University of Glasgow, [Accessed July 2022], https://www.gla.ac.uk/research/beacons/futurelife/professorphilippeschyns/.

107. Semantic Information Pursuit for Multimodal Data Analysis, EPSRC, [Accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/N019474/1

108. "Publications", Torr Vision Group, [accessed July 2022], https://www.robots.ox.ac.uk/~tvg/oldsite/publications.php.

109. Ibid.

SEMANTIC INFORMATION PURSUIT FOR MULTIMODAL DATA ANALYSIS[110]– RED

Start Date	01-01-2018
End Date	31-12-2022
Known Partners	Unknown
Funding	EPSRC Grant EP/R013616/1 - £1,230,961
Affiliation	Department of Statistics
Description	This MURI research uses advanced statistical methods and non-convex optimisation to develop algorithms that can represent data from a scene in the most informative way, from which intelligent decision making can be based. The initiative is composed of researchers from Oxford, the University of Surrey, and UCL in the UK, as well as the the University of California, Los Angeles (UCLA), University of Southern California (USC), University of California, Berkeley, John Hopkins University, University of Maryland College Park, and Stanford University in the USA. The EPSRC classifies its MURI grant to Oxford as under the 'Aerospace, Defence and Marine' industrial sector.[111] A 2018 paper titled 'Hamiltonian Descent Methods' was partly funded by the grant.[112] The paper also received funding from the UK Ministry of Defence, the U.S. Army Research Laboratory and the U.S. Army Research Office.

EPSRC CENTRE FOR DOCTORAL TRAINING IN AUTONOMOUS INTELLIGENT MACHINES AND SYSTEMS (AIMS)[113] - AMBER

Start Date	Original funding: 01-04-2014 Renewed funding: 01-10-2019
End Date	Original funding: 30-09-2022 Renewed funding: 31-03-2028
Known Partners	Original: Ascending Technologies GmbH; Schlumberger; InfoSys Technologies Ltd; BAE Systems; QinetiQ; Google; Xerox; YouGov; Honeywell; BP; Microsoft; ABB Power Grids UK Limited; Renewed: Five AI Limited; EDF Energy Plc (UK); Toshiba; Satellite Applications Catapult; QinetiQ; Schlumberger; MathWorks; Rhodes House; Rail Safety & Standards Board; Continental Automotive GmbH; AECOM Limited (UK); NASA Frontier Development Lab; Ordnance Survey; Oxbotica Ltd; Huawei Group; nVIDIA; Samsung; Toyota; DeepMind;
Funding	Original funding: EPSRC Grant EP/L015897/1 - £4,597,032 Renewed funding: EPSRC Grant EP/S024050/1 - £5,266,183
Affiliation	Department of Engineering Science; Department of Computer Science

110. Semantic Information Pursuit for Multimodal Data Analysis, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/R018693/1

111. Visualising our Portfolio, UKRI, [accessed September 2022], https://epsrc.ukri.org/research/ourportfolio/vop/grant-list/THEME/Information%20and%20Communication%20Technologies/ORGANISATION/1000547/9999/

112. Chris J. Maddison, Daniel Paulin, Yee Whye Teh, Brendan O'Donoghue, and Arnaud Doucet, "Hamiltonian Descent Methods", Department of Statistics, University of Oxford, DeepMind, 14 September 2018, https://arxiv.org/pdf/1809.05042.pdf.

113. Original grant: EPSRC Centre for Doctoral Training in Autonomous Intelligent Machines and Systems (AIMS), EPS-RC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/L015897/1; Renewed grant: EPSRC Centre for Doctoral Training in Autonomous Intelligent Machines and Systems, EPSRC, [September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S024050/1

Description	AIMS is a cross-sector venture "focused on student training in algorithms, devices, and data feeds inherent to autonomous, intelligent machines & systems."[114] The project's key skill areas of concern are: • Machine Learning, as a unifying core; • Robotics & Vision; • Cyber-Physical Systems (e.g. sensor networks); and • Control & Verification[115] • The Centre has received two EPSRC grants, the first in 2014, and a renewal in 2019. It is currently partnered with defence bodies QinetiQ and Oxbotica, and has partnered with Honeywell and BAE Systems in the past.

ACE-OPS: FROM AUTONOMY TO COGNITIVE ASSISTANCE IN EMERGENCY OPERATIONS[116] – AMBER

Start Date	01-12-2019
End Date	30-11-2022
Known Partners	National Fire Chiefs Council; Oracle Corporation; DSTL; FLIR Systems AB; University of Virginia; BB7 Fire Limited; Queensland University of Technology.
Funding	EPSRC Grant EP/S030832/1 - £1,215,068
Affiliation	Department of Engineering Science; Department of Computer Science
Description	ACE-OPS is a joint research venture between the University of Oxford, the University of Virginia and Queensland University. The project is synergising sensor technologies, cognitive assistance tools, and mobile autonomy capabilities to create an "end to end response system" for emergency response teams. The project's use cases are "emergency teams" such as firefighters, and its work is "introducing various levels of autonomy enabling aerial vehicles to simultaneously perform tasks of mapping, communication and localisation."

114. Visualising our portfolio, UKRI, [accessed September 2022], https://epsrc.ukri.org/research/ourportfolio/vop/grantlist/THEME/Training/ORGANISATION/1000547/9999/

115. https://aims.robots.ox.ac.uk/

116. ACE-OPS: From Autonomy to Cognitive assistance in Emergency OPerations, EPSR, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S030832/1

VISUAL AI: AN OPEN WORLD INTERPRETABLE VISUAL TRANSFORMER[117] - AMBER

Start Date	01-12-2020
End Date	30-11-2025
Known Partners	Plexalis Ltd; Intelligent Ultrasound; Toshiba; BBC; Continental Teves AG & Co. oHG; Nielson; Samsung.
Funding	EPSRC Grant EP/T028572/1 - £5,912,097
Affiliation	Department of Engineering Science
Description	The "Visual AI" project is proceeding in partnership with the University of Edinburgh and the University of Bristol. The project is developing computer vision and scene understanding through "the next generation of audio-visual algorithms." These will use visual, audio and text modalities to understand scenes "with the flexibility and interpretability of a human visual system."[118] [119]

RESPONSIBLE AI FOR LONG-TERM TRUSTWORTHY AUTONOMOUS SYSTEMS (RAILS): INTEGRATING RESPONSIBLE AI AND SOCIO-LEGAL GOVERNANCE[120] - AMBER

Start Date	01-01-2022
End Date	30-06-2024
Known Partners	Autonomous Drivers Alliance; Addleshaw Goddard LLP; Imperium Drive; Society for Computers and Law; Amazon Web Services (Not UK); Oxbotica Ltd
Funding	EPSRC Grant EP/W011344/1 - £1,723,460
Affiliation	Oxford Responsible Technology Institute; Department of Engineering Science
Description	RAILS is a collaboration between researchers from the universities of Oxford, Leeds, York and UCL. The project is investigating autonomous systems operating in changing environments, namely 'open-ended dynamic environments' and 'systems that change over time.'[121] The project will consider the challenges presented by changing environments, and the impact of these changes on autonomous systems, taking into account a range of autonomous system applications including unmanned aerial vehicles.[122]

117. Visual AI: An Open World Interpretable Visual Transformer, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/T028572/1

118. Ibid.

119. "Publications, Visual AI Project", Robots.ox.ac.uk, [accessed July 2022], https://www.robots.ox.ac.uk/~vgg/projects/visualai/publication.html.

120. Responsible AI for Long-term Trustworthy Autonomous Systems (RAILS): Integrating Responsible AI and Socio-legal Governance, UKRI, [accessed September 2022], https://gtr.ukri.org/projects?ref=EP%2FW011344%2F1

121. Long-term Trustworthy Autonomous Systems: project funded by the Trustworthy Autonomous Systems Hub, University of Oxford Department of Computer Science, 3rd December 2021, http://www.cs.ox.ac.uk/news/2000-full.html.

122. Visualising our Portfolio, UKRI, [accessed September 2022], https://epsrc.ukri.org/research/ourportfolio/vop/grant-list/THEME/Non%20Theme%20Specific/ORGANISATION/1000547/9999/

UNIVERSITY OF SOUTHAMPTON

The University of Southampton is well-equipped for research into autonomous systems, particularly through its Autonomous Systems Laboratory, which features an Autonomous Systems Testbed facility. This facility provides a test arena for autonomous systems capabilities, such as advanced decision making, navigation and control. The site was used in 2011 to develop 'Sysbrain,' a cognitive software agent control system with "human-like reasoning."[123]

Southampton also hosts five University Technology Centres (UTCs) in partnership with Microsoft, Airbus, RNLI, Lloyd's Register and Rolls-Royce. Notably, Rolls-Royce UTC for Computational Engineering researches aerospace engineering solutions, while Microsoft Institute for High Performance Computing develops technological solutions to "problems in the aerospace, automotive, bioengineering, marine and telecommunications sectors."[124]

On the other hand, Southampton is home to the "Emergent Ethics of Drone Violence: Towards a Comprehensive Governance Framework (DRONETHICS)," a project that address the ethical and legal implications of drone violence and the use of drones in military, security and policing environments. Several leading academics in the field of AI and ethics are involved in DRONETHICS.

CASCADE: COMPLEX AUTONOMOUS AIRCRAFT SYSTEMS CONFIGURATION, ANALYSIS AND DESIGN EXPLORATORY- RED

Start Date	01-02-2018
End Date	31-01-2023
Known Partners	University of Manchester; University of Bristol; Cranfield University; Imperial College London; Babcock International Group Plc (UK); BAE Systems; Behavioural Robotics Ltd; Blue Bear Systems Research Ltd; Civil Aviation Authority; DSTL; Department for Transport; QinetiQ; Satellite Applications Catapult; Stirling Dynamics Ltd; Thales Ltd; Catapult
Funding	EPSRC Grant EP/R009953/1 - £4,448,296[125] According to a project presentation given in 2019, the project's total budget is £6.99m[126]
Affiliation	University of Southampton; University of Manchester; University of Bristol; Cranfield University; Imperial College London

123. See: Southampton scientists develop control system to allow spacecraft to think for themselves, University of Southampton, https://www.southampton.ac.uk/engineering/news/2011/03/11_control_system_to_allow_spacecraft_to_think_for_themselves.page

124. See: University of Southampton Research centres and partnerships, University of Southampton, https://www.southampton.ac.uk/engineering/business_partnership/services/research_centres_and_partnerships.page

125. CASCADE (Complex Autonomous aircraft Systems Configuration, Analysis and Design Exploratory), EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/R009953/1

126. Mario Ferraro, Overview of the research activity of the CASCADE project, November 2019, EPSRC, https://cp.catapult.org.uk/wp-content/uploads/2021/01/CASCADE-Overview-of-the-research-activity-of-the-CASCADE-project-compressed-1.pdf.

Description	This project is a collaboration between industry and five UK universities with the main goal of accelerating the exploitation of aerial robotics across a wide range of science and industry applications.
	The project is focussed on the operation of advanced aerial robotics systems including UAV swarms in multi-target surveillance systems and small unmanned aircraft systems (SUAS).
	The project also intends to "shape the technological and regulatory standards" in order to build an ecosystem where "safe and commercially and scientifically vibrant industry" can grow.[127] To this end, the Simulation Environment for the Evaluation of Drone Policies and Operational Deployment (SEEDPOD), an initiative within CASCADE, will "objectively analyse rules, policies and concepts of operations for drone usage in urban and other regions."[128] The project will use this analysis to provide a "detailed, realistic and wide-ranging simulation" that can aid the measurement of the risks and impact of a "significant expansion of drones and other aerial robots in the future."[129]

HUMAN-UAV TEAMING IN DYNAMIC AND UNCERTAIN ENVIRONMENTS - AMBER

Start Date	Unclear, around 2017 /2018
End Date	Unknown
Known Partners	DSTL
Funding	Defence and Security Accelerator competition "Fast-track: revolutionise the human information relationship for Defence" - ACC102123 - £73,073.58[130]
Affiliation	Faculty of Engineering and Physical Sciences
Description	While no further information in relation to this project could be found in the public domain, a paper abstract titled the same name suggests that this project may have helped create an algorithm for human-agent coordination, which may be applied to "ground and unmanned aerial vehicles."[131]

HUMAN MACHINE TEAMING FOR INTELLIGENCE ANALYSIS - AMBER

Start Date	2017
End Date	2017
Known Partners	DSTL
Funding	Defence and Security Accelerator competition "Standard-track: revolutionise the human information relationship for Defence" - ACC102157 - £99,819.14[132]
Affiliation	Agents, Interaction and Complexity research group, IT Innovation Centre, Faculty of Engineering and Physical Sciences

127. CASCADE, [accessed June 2022], https://cascadeuav.com/.

128. "CASCADE is looking for an experienced software engineer to build an advanced unmanned traffic simulation environment", CASCADE UAV, 24th May 2019, https://cascadeuav.com/2019/05/24/cascade-is-looking-for-an-experi-enced-software-engineer-to-build-an-advanced-unmanned-traffic-simulation-environment/.

129. Mario Ferraro, Overview of the research activity of the CASCADE project, Nov 2019, EPSRC, https://cp.catapult.org.uk/wp-content/uploads/2021/01/CASCADE-Overview-of-the-research-activity-of-the-CASCADE-project-compressed-1.pdf.

130. Defence and Security Accelerator funded contracts: 1 April 2017 to 31 March 2018, updated 22 October 2021, GOV UK, [accessed 28-06-2022] https://www.gov.uk/government/publications/accelerator-funded-contracts/accelerator-funded-contracts-1-april-2017-to-31-march-2018.

131. Human-UAV teaming In dynamic and uncertain environments, University of Southampton Institutional Repository, 2018, https://eprints.soton.ac.uk/425699/.

132. Defence and Security Accelerator funded contracts: 1 April 2017 to 31 March 2018, Gov UK, Updated 2021, https://www.gov.uk/government/publications/accelerator-funded-contracts/accelerator-funded-contracts-1-april-2017-to-31-march-2018

Description	No further details with regards to the project's specific objectives were identified in the public domain.

UKRI TRUSTWORTHY AUTONOMOUS SYSTEMS (TAS) HUB - AMBER

Start Date	01-09-2021
End Date	31-07-2024
Known Partners	University of Nottingham; King's College London
	Over 60 partners including BAE Systems; the Ministry of Defence, Northrop Gruman (UK); Qinetiq; Boeing; and Thales.
Funding	EPSRC Grant EP/V00784X/1 - £11,940,671
Affiliation	Department of Electronics and Computer Science
Description	This Hub is a collaboration between the University of Southampton, the University of Nottingham and King's College London, and serves as the central coordinator between seven TAS research nodes in other institutions. The TAS hub "will establish a collaborative platform for the UK to deliver world-leading best practices for the design, regulation and operation of 'socially beneficial' autonomous systems which are both trustworthy in principle, and trusted in practice."[133] To achieve this, it will bring together research from across the seven TAS nodes, to "deliver the fundamental scientific principles that underpin TAS."

DISTRIBUTED SENSING, CONTROL AND DECISION MAKING IN MULTIAGENT AUTONOMOUS SYSTEMS - AMBER

Start Date	01-06-2012
End Date	30-04-2017
Known Partners	Unknown
Funding	Two EPSRC Grants: EP/J011894/1[134] - £1,335,148 and EP/J011894/2[135] - £1,262,837
Affiliation	Academics from the Department of Electronics and Computer Science, the Department of Aeronautics and Astronautics and Department of Engineering and Physical Sciences.
Description	This project is led by the University of Sheffield, in collaboration with several academics from the University of Southampton. "This project intends to develop a new methodology for autonomous cooperating multi-agent systems that is to boost the technological capabilities of our partner companies and the robotics industry in general."[136]

133. Trustworthy Autonomous Systems Hub (TAS), University of Nottingham, [accessed 28-06-2022], https://www.nottingham.ac.uk/research/beacons-of-excellence/smart-products/projects/trustworthy-autonomous-systems-hub-tas/.

134. Distributed Sensing, Control and Decision Making in Multiagent Autonomous Systems, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/J011894/1

135. Distributed Sensing, Control and Decision Making in Multiagent Autonomous Systems, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/J011894/2

136. Distributed Sensing, Control and Decision Making in Multiagent Autonomous Systems, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/J011894/1

UNIVERSITY OF STRATHCLYDE

MADE SMARTER UK – RESEARCH CENTRE FOR SMART, COLLABORATIVE AND INDUSTRIAL ROBOTICS - AMBER

Start Date	30-09-2021
End Date	29-03-2025
Known Partners	Over 15 partners including Made Smarter; UKRI; Rolls-Royce; and The Alan Turing Institute
Funding	UKRI and Made Smarter funding under EPSRC Grant EP/V062158/1 - £4,821,585[137]
Affiliation	Department of Design, Manufacturing and Engineering Management
Description	As a partner of the "Made Smarter Innovation Research Centre for Smart, Collaborative Industrial Robotics", the University of Strathclyde received funding for its research into robotics and human-agent collaboration, aiming to "advance smart manufacturing by eliminating barriers and accelerating widespread use of smart collaborative robotics technology, to unlock the full potential of the UK industry in productivity, quality, and adaptability."[138]

This project prioritises the following research domains:

- Collaboration: Robotic systems need better models of how people naturally interact with others to start truly collaborating with them and fully leverage their respective strength;

- Autonomy: Robots need to extend their sensory perception and autonomous cognition capabilities to effectively carry out increasingly complex tasks, deal with variations, and disruptive changes;

- Responsiveness: The process of designing, verifying, validating, deploying, and operating automation needs to become more accessible for a wider range of people and organisations;

- Acceptance: The societal, cultural, and economic impact of automation needs to be better explored to inform future policy, regulations, and education requirements."[139] |

The University of Strathclyde's Department of Design, Manufacturing and Engineering Management is also home to the "Robotics and Autonomous Systems" research group, which develops automated systems and intelligent robotics with improved efficiency and awareness. This group hosts the Space Mechatronic Systems Technology (SMeSTech) laboratory developing Multiple Autonomous Robots (MARs), including UAVs, drones and climbing mobile robots. The following recent and ongoing projects are affiliated with SMeSTech:

137. Made Smarter Innovation - Materials Made Smarter Research Centre, EPSRC, [accessed September 2022], https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/V061798/1

138. New research centre to transform the relationship between people and technology in UK manufacturing, University of Strathclyde, 30 November 2021, https://www.strath.ac.uk/whystrathclyde/news/2021/newresearchcentretotrans-formrelationshipbetweenpeopleandtechnologyinukmanufacturing/.

139. Ibid.

NOVEL PATH PLANNING ALGORITHMS AND SMART NAVIGATION STRATEGIES OF MULTIPLE AUTONOMOUS ROBOTS FOR THE VISUAL INSPECTION OF ASSET INTEGRITY IN CONFINED SPACE - AMBER

Start Date	01-10-2019
End Date	31-03-2023
Known Partners	UK Net Zero Technology Centre
Funding	Associated paper[140]: UK Net Zero Technology Centre; University of Strathclyde Research Excellence Award Stewardship
Affiliation	SMeSTech Laboratory, hosted by the Robotics and Autonomous Research Group within the Department of Design, Manufacturing and Engineering Management.
Description	This project investigates "novel path planning algorithms and smart navigation strategies for developing a feasible solution to the autonomous visual inspection and assessment of internal and external surface conditions in confined spaces."[141] Its publicised use case is the inspection of key assets in harsh environments, for instance, in the oil and gas industry.

DEEP LEARNING-BASED SMART AUTONOMOUS SYSTEMS FOR THE VISUAL INSPECTION OF ASSET INTEGRITY IN HARSH ENVIRONMENT – PHD PROJECT - GREEN

Start Date	01-09-2018
End Date	30-09-2021
Known Partners	Unclear
Funding	Partly funded by the University of Strathclyde and China Scholarship Council's studentships.
Affiliation	SMeSTech Laboratory, hosted by the Robotics and Autonomous Research Group within the Department of Design, Manufacturing and Engineering Management.
Description	This project investigated novel robotic and autonomous systems as applied to the visual inspection of internal and external surface conditions.[142]

140. Yang, Beiya; Yang, Erfu; Yu, Leijian; Loeliger, Andrew. High-precision UWB based localisation for UAV in extremely confined environments. In: IEEE Sensors Journal. 2022; Vol. 22, No. 1. pp. 1020-1029, https://pureportal.strath.ac.uk/en/publications/high-precision-uwb-based-localisation-for-uav-in-extremely-confin.

141. "Novel Path Planning Algorithms and Smart Navigation Strategies of Multiple Autonomous Robots for the Visual Inspection of Asset Integrity in Confined Space", [accessed 28-06-22] https://pureportal.strath.ac.uk/en/projects/novel-path-planning-algorithms-and-smart-navigation-strategies-of.

142. Deep Learning-Based Smart Autonomous Systems for the Visual Inspection of Asset Integrity in Harsh Environment, [accessed 28-06-22], https://pureportal.strath.ac.uk/en/projects/deep-learning-based-smart-autonomous-systems-for-the-visual-inspe.

AN INVESTIGATION INTO NOVEL STRATEGIES FOR ADAPTIVE, INTELLIGENT AND ROBUST CONTROL OF AUTONOMOUS ROBOTS THROUGH THE STUDY OF DYNAMIC INTERACTIONS BETWEEN ROBOTS AND THEIR HARSH ENVIRONMENTS – PHD PROJECT - AMBER

Start Date	09-2016
End Date	03-2020
Known Partners	EPSRC
Funding	EPSRC[143]
Affiliation	SMeSTech Laboratory, hosted by the Robotics and Autonomous Research Group within the Department of Design, Manufacturing and Engineering Management.
Description	This project aimed to develop "novel strategies for adaptive, intelligent and robust control of autonomous robots through the study of dynamic interactions between robots and their harsh environments."[144] This project used robotic vision systems and sensor devices for intelligent task planning and object manipulation.

LOCUST: LOW-COST INTELLIGENT UAV SWARMING TECHNOLOGY FOR VISUAL INSPECTION OF OIL AND GAS VESSELS - AMBER

Start Date	01-06-2019
End Date	31-12-2021
Known Partners	Oil & Gas Technology Centre (OGTC)
Funding	Total funding - £263,184.58, of which, £199,984.58 was provided by the OGTC[145]
Affiliation	SMeSTech Laboratory, hosted by the Robotics and Autonomous Research Group within the Department of Design, Manufacturing and Engineering Management.
Description	This project sought to develop an "autonomous visual inspection system" which "provides an initial assessment of internal and external surface conditions through the use of a UAV swarm equipped with on-board cameras."[146] Its publicised use case is the inspection of key assets in harsh environments, for instance, in the oil and gas industry.

Strathclyde's Department of Electronic and Electrical Engineering is formed of several institutes that carry out research that are relevant to robotics and autonomous systems. These include the Institute for Sensors, Signals & Communications, which is also home to the Centre for Signal & Image Processing (CeSIP) and the Centre for Ultrasonic Engineering.

While CeSIP conducts research into new algorithms, architectures and applications, often in collaboration with industrial partners such as QinetiQ and BAE Systems, the Centre for Ultrasonic Engineering produces robotic solutions, such as mobile robotics and UAVs for in-process and asset inspection. In collaboration with the Advanced Forming Research Centre (AFRC) and Spirit Aerosystems, the centre secured £1.5M funding through the VIEWS programme (Validation and Integration of Manufacturing Enablers for Future Wing Structures) to commission a new robotic inspection cell at the AFRC. [147] [148]

143. An investigation into novel strategies for adaptive, intelligent and robust control of autonomous robots through the study of dynamic interactions bet, University of Strathclyde, https://gtr.ukri.org/projects?ref=studentship-1803462.

144. Ibid.

145. Low-Cost Intelligent UAV Swarming Technology for Visual Inspection of Oil and Gas Vessels, University of Strathclyde, https://pureportal.strath.ac.uk/en/projects/low-cost-intelligent-uav-swarming-technology-for-visual-inspectio.

146. Ibid.

147. Advanced Forming Research Centre Highlights Newsletter, AFRC, [accessed 28-08-22], https://mjcengineering.com/wp-content/uploads/2016/10/AFRC-Highlights.pdf

148. VIEWS: to develop future-wing technology, Axilliu, [accessed 28-08-22], https://www.axillium.com/portfolio-posts/views-ati-30m/

The University of Strathclyde is also part of the University Defence Research Collaboration in Signal Processing, led by companies and institutions such the UK MoD DSTL, Thales, Leonardo, the University of Edinburgh. With primarily military aims, the initiative develops smart sensor systems, AI for tracking and surveillance, advanced radar processing and deep learning for defence solutions.[149] [150]

A project that represents a low level of risk to the development of autonomous systems conducted by the Department of Electronic and Electrical Engineering is listed below

AIMAREM: AUTONOMOUS INSPECTION IN MANUFACTURING & REMANUFACTURING - GREEN

Start Date	01-05-2016
End Date	31-12-2020
Known Partners	Association for Robotics in Architecture; Autocraft Drivetrain Solutions Ltd; KUKA Robotics UK Limited; Los Alamos National Laboratory; Production Technology Centre; Spirit Aerosystems
Funding	EPSRC Grant EP/N018427/1 - £1,988,392[151]
Affiliation	Department of Electronic and Electrical Engineering
Description	This project is developing an end-to-end manufacturing inspection process, using a "unique combination of data collection, processing and visualisation tools combined with efficient robot path planning and obstacle avoidance."

The Department of Computer and Information Sciences is home to the initiative "Robust Reasoning for Intelligent Agents" project, which investigates the intersection of machine learning and task planning with the goal of developing long-life autonomous systems that are robust and trusted. "Our vision is to develop novel approaches to intelligent control that are capable of reacting robustly and safely in dynamic and challenging environments, explaining their behaviour, and working within mixed teams of humans and machines."[152] The following CDT is attached to this research theme:

CENTRE FOR DOCTORAL TRAINING IN EXPLAINABLE AI AND INDUSTRIAL DECISION SUPPORT (EXPLAIN) - AMBER

Start Date	Established in October 2020
End Date	Unknown
Known Partners	ESA/ESOC; AGS Airports; ANRA technologies; RedOne technologies
Funding	Unknown
Affiliation	Department of Computer and Information Sciences
Description	This CDT is investigating human-agent collaboration, optimising the use of human expertise through artificial intelligence. Among current projects are investigations into "the links between robust optimisation and flexible plan execution" and "designing new architecture for goal reasoning on-board persistently autonomous robot teams."[153]

149. Signal Processing in the Information Age – University Defence Research Collaboration Phase 3, ERPE, [accessed 28-06-22], https://www.erpe.ac.uk/news/signal-processing-information-age-university-defence-research-collaboration-phase-3.

150. University Defence Research Collaboration (UDRC), University of Edinburgh, [accessed 28-06-22], https://www.eng.ed.ac.uk/research/activity/university-defence-research-collaboration-udrc#:~:text=UDRC%20Aims,promote%20communications%2C%20guidance%20and%20training.

151. Autonomous Inspection in Manufacturing & Remanufacturing (AIMaReM), EPSRC, https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/N018427/1

152. "Our Research", AI@Strathclyde, [accessed June 2022], https://www.strath.ac.uk/research/aistrathclyde/ourresearch/.

153. "Robust Reasoning for Intelligent Agents", AI@Strathclyde, [accessed June 2022], https://www.strath.ac.uk/research/aistrathclyde/ourresearch/robustreasoningforintelligentagents/.

UNIVERSITY OF WARWICK

Our investigation into the University of Warwick identified the following projects developing AWS-relevant technologies. Both are affiliated with the Warwick Manufacturing Group, a multidisciplinary department of the university spanning engineering, management, manufacturing and technology research.

R-DIPS: REAL-TIME DETECTION OF CONCEALMENT OF INTENT FOR PASSENGER SCREENING (PHASES 1 AND 2) - RED

Start Date	Phase 1: 30-09-2019 Phase 2: 01-04-2020
End Date	Phase 1: 29-03-2020 Phase 2: 28-02-2021
Known Partners	DSTL
Funding	Phase 1: Defence and Security Accelerator Scheme - £144,999.94[154]
	Phase 2: Unknown
Affiliation	Computer Science Department, Warwick Manufacturing Group
Description	This project "aims at developing a machine learning and computer vision solution to track, in real-time, multiple individuals across a set of non-overlapping surveillance cameras to detect those with suspicious behaviours and movements within an airport. The project will improve the screening process of passengers to detect those attempting to mask nefarious intent."[155]

SWARM: SELF-ORGANISING WIDE AREA AUTONOMOUS VEHICLE REAL TIME MARSHALLING - AMBER

Start Date	2018
End Date	2020
Known Partners	Aurigo (RDM Group); Milton Keynes Council
Funding	Innovate UK (Centre for Connected and Autonomous Vehicles, of the Department for Transport and the Department for Business, Energy and Industrial Strategy) - £1,986,677,[156] grant ref. 103287[157]
Affiliation	Warwick Manufacturing Group
Description	This project developed a "novel application of SWARM technologies to provide efficient and safe fleet control of Autonomous Pods." The project delivered a fleet of "Marshal" Pods, which used sensors and AI enabling them to "organise the routing behaviour of 'Regular' Pods via SWARM technologies."[158]

154. GOV.UK. "Defence and Security Accelerator funded contracts: 1 April 2019 to 31 March 2020." [accessed June 2022], https://www.gov.uk/government/publications/accelerator-funded-contracts/defence-and-security-accelerator-funded-contracts-1-april-2019-to-31-march-2020.

155. "DASA award to Dr Victor Sanchez to improve security at airports." Warwick Department of Computer Science, Fri 01 May 2020, https://warwick.ac.uk/fac/sci/dcs/news/?newsItem=8a17841a71bb9e770171cfe24d4e5237.

156. "UK Connected & Autonomous Vehicle Research & Development Projects 2018", pg. 42, Centre for Connected and Autonomous Vehicles, September 2018, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/737778/ccav-research-and-development-projects.pdf.

157. Dong R., Woodman R., Jennings P.A., Brewerton S., Birrell S.A., Higgins M.D., "A simulation study of platooning AV fleet service in shared urban environments with uncertainties", Transportation Engineering, 4 , art. no. 100062 (2021), https://pureportal.coventry.ac.uk/en/publications/a-simulation-study-of-platooning-av-fleet-service-in-shared-urban/fingerprints/.

158. SWARM, CAV UK, https://my.sharpcloud.com/html/#/story/49ed62b0-2443-42a3-bcd4-72092aab0729/element/b6d-cbae6-f8f0-4437-8b8c-db993859302f

ANNEX II: SPINOUT COMPANIES

Annex II lists AWS-relevant spinout companies created by academics within some of our 12 selected universities. These companies have retained close ties to their respective universities through their staff and research partnerships, many of which have been identified in Annex I. It should be noted that this list is far from exhaustive and instead aims to provide a few examples of initiatives that, although not primarily carried out by academic institutions, involve academics, researchers and university staff and might be relevant to AWS technology.

UNIVERSITY OF MANCHESTER

Ice9	Ice9, a spinout of the University of Manchester's "Robotics for Extreme Environments Group (REEG)." The company was founded by REEG researchers to commercialise products and platforms for extreme environments. Ice9 develops mobile robots "used for repetitive tasks to reduce or eradicate human errors."[159]

UNIVERSITY OF OXFORD

Living Optics	Living Optics is a "3D laser spectrometer and single shot hyperspectral imaging"[160] company, founded in 2020 [161] as a spinout of the University of Oxford's Physics Department. Living Optics is developing advanced computer vision through its "very unconventional" camera, able to capture "information inaccessible to the human eye" in order to make machines "more accurate, more autonomous, more useful, and safer."[162]
	In 2020, Living Optics received funding from the UK MoD as part of the Defence and Security Accelerator programme's 'Advanced Vision 2020 and Beyond' competition. The competition awarded 13 contracts worth £2.3 million to research ventures developing electro-optic and infrared sensors, with potential use cases including target identification, and threat detection in difficult environments.[163] No further information in relation to Living Optic's research connected to this funding received from the MoD could be found in the public domain.

159. Solving awkward problems with bespoke solutions, Icenine, https://ice9robotics.co.uk/about

160. Companies formed, Oxford University Innovation, [accessed June 2022], https://innovation.ox.ac.uk/portfolio/companies-formed/page/3/.

161. Living Optics, Oxford Investment Consultants, [accessed June 2022], https://www.oxfordinvestmentconsultants.com/portfolio/living-optics-oxford-investment-consultants/

162. Our Story, Living Optics, [Accessed June 2022], https://www.livingoptics.com/our-story.

163. DASA awards £2.3m to develop novel sensor technology, WIREDGOV, [accessed June 2022], https://www.wired-gov.net/wg/news.nsf/articles/DASA+awards+2.3m+to+develop+novel+sensor+technology+05052020131500?open.

Animal Dynamics	Animal Dynamics "develops autonomous vehicles that are inspired by nature."[164] The company was founded in 2015 by entrepreneur Alex Caccia and a professor within Oxford's Department of Zoology. Animal Dynamics has developed a manta ray-inspired underwater drone for the Royal Marines,[165] a dragonfly-inspired reconnaissance drone,[166] and a flagship parasailing UAV 'Stork', which received funding from the UK MoD under its 2017 'Autonomous last mile resupply' competition.[167] Between March 2017 and March 2020, Animal Dynamics received 7 separate grants from the Defence and Security Accelerator programme[168] totalling £1,432,351. These projects are named: • Paramotor payload delivery • Stork150 powered paraglider ALMR system • Low Energy Autonomous Navigation And Marine Propulsion • UAV Swarm as a C-UAV system • Shearwater AWUAS • GPS denied submerged open ocean navigation: fusion of sensors, data and movement behaviour for magnetic positioning • RayDrive: permitting autonomy in challenging benthic, littoral environments In 2020, the company participated in the Army Warfighting Experiment (AWE),[169] an annual event in which the British Army tests and provides feedback on new defence technologies from industry. Animal Dynamics has also collaborated with Oxford's "EPSRC Centre for Doctoral Training in Industrially Focused Mathematical Modelling."[170]
Mind Foundry	Mind Foundry is an AI solutions company founded in 2016 by Professors from Oxford's Machine Learning Research Group, within the university's Department of Engineering Science. While the only use cases mentioned on Mind Foundry's website are "government and public sector" and "insurance," a job opening advertised in 2021 for a "Head of Defence & Security, Applied Machine Learning" suggests the company may be conducting research with potential defence applications. In the job description "signal processing, geospatial modelling, image processing, natural language processing, high fidelity simulations of physical systems" were listed as the research domains of concern for this position.[171]

164. Animal Dynamics Limited: Culture, LinkedIn, [accessed June 2022], https://www.linkedin.com/company/animal-dynamics-limited/life.

165. Larisa Brown, Royal Marines will use an underwater drone disguised as a manta ray to snoop for Britain, The Sunday Times, July 2021, https://www.thetimes.co.uk/article/royal-marines-will-use-an-underwater-drone-disguised-as-a-manta-ray-to-snoop-for-britain-xpwqbnnwv.

166. Michael Dempsey, The stealthy little drones that fly like insects, April 2020, https://www.bbc.co.uk/news/business-51840027?fbclid=IwAR2znTlwTwE4-loelwW1feS5FW5aPXZ6K8tyIaMZ8yeY-VNQzo2JVs6ltk0.

167. Defence and Security Accelerator funded contracts: 1 April 2018 to 31 March 2019 Defence and Security Accelerator, Updated 22 October 2021, https://www.gov.uk/government/publications/accelerator-funded-contracts/accelerator-funded-contracts-1-april-2018-to-31-march-2019.

168. Defence and Security Accelerator funded contracts, Defence Science and Technology Laboratory, 16 February 2017, https://www.gov.uk/government/publications/accelerator-funded-contracts

169. https://www.animal-dynamics.com/press.

170. EPSRC Centre for Doctoral Training in Industrially Focused Mathematical Modelling, EPSRC/InFoMM, https://www.maths.ox.ac.uk/system/files/attachments/Bond-Animal%20Dynamics-Lay-Report_Final.pdf

171. https://www.mindfoundry.ai/careers-apply?gh_jid=4873360003 [accessed 11th March 2022]

Oxbotica	Oxbotica, "a global leader in autonomous vehicle software", was founded in 2014 by staff from Oxford's Mobile Robotics Group. Oxbotica's leading product is Selenium, a complete vehicle autonomy solution able to transform vehicles into autonomous vehicles using machine learning, and without the need for GPS. When coupled with Oxbotica's Caesium, an "in-cloud fleet and data management platform", Selenium vehicles are able to behave as a fleet. While Oxbotica's website does not mention technologies with potential defence applications, senior staff members have given interviews in which they confirm or allude to the company's work within defence.[172] In 2016, Oxbotica secured funding from the UK's Centre for Defence Enterprise (CDE) to assess the effectiveness of a newly developed vision based localisation system, as compared with laser and GPS localisation systems. The vision-based system was found to perform far better, validating Oxbotica's development of this technology for use in autonomous vehicles operating in off-road, unstructured environments.[173] In 2018, Oxbotica secured funding for the project "Autonomous GPS-free Off-Road Vehicle Navigation Using Low Cost Stereo Vision," through Innovate UK's "Automotive Exceptional Projects 2018", in collaboration with the defence company Qinetiq. The project received a total of £1,517,035 to develop large off road vehicles integrated with Oxbotica's Selenium autonomous system, and a fleet-level control system including "a goal-based mission planning system."[174] The company has partnered with the following initiatives involving the University of Oxford: • "From Sensing to Collaboration: Engineering, Exploring and Exploiting the Building Blocks of Embodied Intelligence"[175] • "EPSRC Centre for Doctoral Training in Autonomous Intelligent Machines and Systems (AIMS)"[176] • "Responsible AI for Long-term Trustworthy Autonomous Systems (RAILS): Integrating Responsible AI and Socio-legal Governance."[177]

172. Professor Newman: Mark Piesing, Going for a test drive in the smart car revolution, July 2022, https://inews.co.uk/news/uk/oxbotica-self-driving-car-driving-geni-pod-14736. Dr Graeme Smith: CEO Interview – Dr Graeme Smith, Oxbotica, Business & Innovation Magazine, January 2019, https://www.businessinnovationmag.co.uk/look-no-hands/.

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174. Results of Competition: Automotive Exceptional Projects 2018, Innovate UK, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831191/Competition_Results_-_Automotive_Exceptional_Projects_2018.pdf.

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176. EPSRC Centre for Doctoral Training in Autonomous Intelligent Machines and Systems, EPSRC, https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S024050/1

177. Responsible AI for Long-term Trustworthy Autonomous Systems (RAILS): Integrating Responsible AI and Socio-legal Governance, EPSRC, https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/W011344/1

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Industrial Systems and Control	Industrial Systems and Control (ISC) is a spinout of Strathclyde's Department of Electronic and Electrical Engineering, established in 1987. The company provides "tools, technologies and consultancy capabilities" to its industrial partners and has been engaged on "many defence related projects, both for surface ships and submarines, as well as working in control for avionics systems and land vehicles. ISC latest developments are related to control for Unmanned Vehicles."[178]
	ISC's partners include BAE Systems, Rolls-Royce and Qinetiq and the EPSRC Centre for Doctoral Training in Robotics and Autonomous Systems, led by the Heriot-Watt University.[179]

178. ISC - Industries - Defence

179. EPSRC Centre for Doctoral Training in Robotics and Autonomous Systems (RAS) in Edinburgh, EPSRC, https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/L016834/1

ANNEX III: LIST OF ACRONYMS

AFRC	Advanced Forming Research Centre
AI	Artificial Intelligence
AIRC	Aerospace Integration Research Centre
AIMS	Autonomous Intelligent Machines and Systems
AR	Augmented Reality
AWS	Autonomous Weapons Systems
BAE	BAE Systems
BURG	Benchmarks for UndeRstanding Grasping
CRA	Collaborative Research Alliance
CBELA	Committee on Benefactions and External Legal Affairs
CCW	Convention on Certain Conventional Weapons
CDE	Centre for Defence Enterprise
CDTs	Centres for Doctoral Training
CEPS	Connected Electronic and Photonic Systems
CeSIP	Centre for Signal & Image Processing
DARTeC	Digital Aviation Research and Technology Centre
DASA	Defence and Security Accelerator
DCIST	Distributed and Collaborative Intelligent Systems and Technology
DSTL	Defence Science and Technology Laboratory
DEVCOM	Combat Capabilities Development Command
EPSRC	Engineering and Physical Sciences Research Council
ESTEC	European Space Research and Technology Centre
FAM	Future Air Mobility
FASS	Future of Aviation Security Solutions
FARSCOPE	Future Autonomous and Robotic Systems
FOI	Freedom of Information
GCHQ	Government Communications Headquarter
HEFCE	Higher Education Funding Council for England
HiPEDS	High Performance Embedded Distributed Systems
HIT	Human Interface Technologies
ICRC	International Committee of the Red Cross
iDSL	Intelligent Digital Systems Lab
IHL	International Humanitarian Law
IRLab	Intelligent Robotics Laboratory
ISC	Industrial Systems and Control
ISTAR	Intelligence, Surveillance, Target Acquisition, and Reconnaissance
LAWS	Lethal Autonomous Weapons Systems
LIDAR	Light Detection and Ranging
M4DE	Materials for Demanding Environments
MARs	Multiple Autonomous Robots
MAVs	Micro Aerial Vehicles

MISL	Microwave Integrated Systems Laboratory
MoD	Ministry of Defence
MUEAVI	Multi User Environment for Autonomous Vehicle Innovation
MURI	Multidisciplinary University Research Initiative
NCNR	National Centre for Nuclear Robotics
NQTHST	National Quantum Technology Hub in Sensing and Timing
NGOs	Non-Governmental Organisations
OGTC	Oil & Gas Technology Centre
R&D	Research and Development
RAF	Royal Air Force
RAILS	Responsible AI for Long-term Trustworthy Autonomous Systems
SAR	Synthetic Aperture Radar
SICSA	Scottish Informatics and Computer Science Alliance
SMeSTech	Space Mechatronic Systems Technology
S&T	Science and Technology
STEM	Science, Technology, Engineering, and Mathematics
SUAS	Small Unmanned Aircraft Systems
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UCL	University College London
UDRC	University Defence Research Collaboration
UKRI	UK Research and Innovation
UHF	Ultra-high Frequency
UTC	University Technology Centre
VR	Virtual Reality