UKRI Trustworthy Autonomous Systems Hub

FUNCTIONALITY

INTELLIGENT ROBOTS AND SELF-GOVERNING SWARMS: THE FUTURE OF FUNCTIONALITY IN AUTONOMOUS SYSTEMS

Developing technology that we can trust and rely on is key to its future acceptance and expansion within our society. Over recent decades we have been developing increasingly complex systems to carry out specified tasks and operate in a pre-determined way; their functionality, largely controlled by us.

However, as our knowledge of technology advances, so does the capability of the technology itself. Autonomous systems (AS) are emerging with the tantalising potential to develop and adapt functionality for themselves, without human input. These are exciting advances – but not without their challenges. How will this autonomy impact on how they operate in complex situations in the real world? How can we realistically predict what they are going to do and ensure they always make the right decisions? And how does this self-learning impact on our trust?

These mission-critical questions are at the heart of the Functionality Node of the UKRI Trustworthy Autonomous Systems (TAS) Programme – a £33m multi-disciplinary research programme funded as part of the Strategic Priorities Fund comprising six Nodes – separate research projects examining individual aspects of trust in autonomous systems.

A number of key challenges are being examined: how does giving autonomous systems the ability to evolve their functionality influence how we specify, design, verify, regulate and build trust in these systems? How can we monitor and check how they are operating in unpredictable environments? Who is to blame if something goes wrong? There are complex considerations around expectation, responsibility and ethics.

Dr Shane Windsor from the University of Bristol sums up the ultimate goal: “In our work, we are interested in systems with functionality that evolves through time from emergent behaviours, that are safe, reliable, resilient, ethical and trustworthy”.

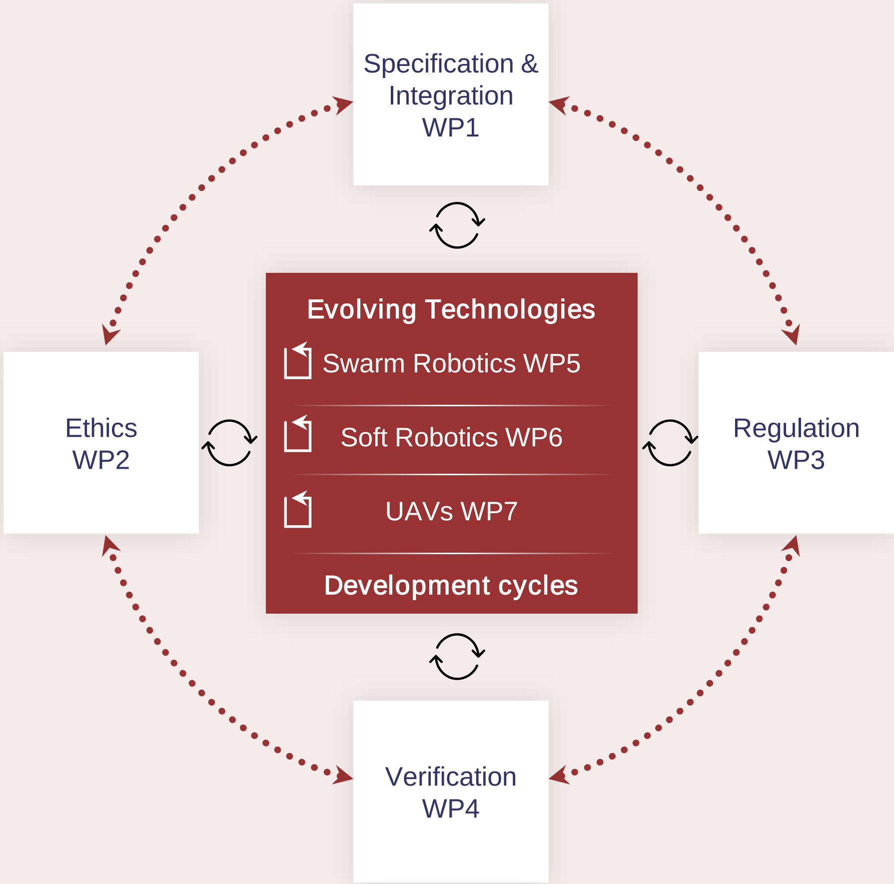
DESIGN FOR LIFE

The starting point for addressing some of these challenges is at the development stage.

Researchers are examining if changes need to be made in the design of autonomous systems to assist with evolving functionality once they are in operation. Professor Kerstin Eder from the University of Bristol emphasises the importance of this:

“There are challenging research questions around specifying for evolution and adaptation, as autonomous systems adapt over time. We need to identify design principles and operational techniques that enable trustworthy evolving functionality.”

A Design-for-Trustworthiness framework for adaptive autonomous systems is being developed which will help create guidelines, methodologies and technologies for evolving functionality. There are four focused research themes - specification, verification, ethics and regulation – and three adaptive technology development use cases: swarm robotics, soft robotics and unmanned aerial vehicles.



Overview of the TAS Functionality Node structure, 4 design-for-trustworthiness process research themes (WP1-4) around 3 developing technology use cases (WP5-7) (from Windsor et al., 2022).

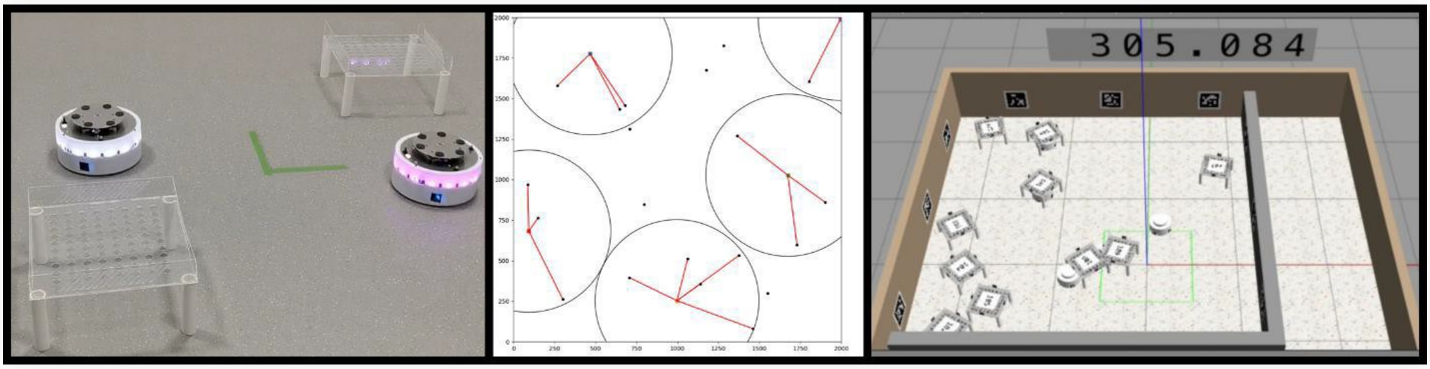
THE SWARM EFFECT

One of the key areas of research in furthering our understanding of adaptive functionality is observing how robots work together, as well as individually.

It is still early days for swarm technology - groups of robots operating together to achieve an objective - but there is significant interest in its potential. It is hoped that robotic swarms, with increasing levels of autonomy, will be able to adapt to their environment, enabling them to be widely used in many critical situations; emergency rescue, healthcare and logistics, for example.

The signs so far are positive, but translating this potential from theory into real life scenarios is far from easy. How do we ensure that what works in a test environment works in practice? Swarm functionalities, such as information-gathering, decision-making and sychronisation, need to be measurable, reliable, ethical, resilient and safe. What happens if one autonomous element is swapped or upgraded – does this impact the safety and functionality of the entire swarm?

TAS research teams are developing the cyber-physical infrastructure for swarms, including low and high-fidelity simulators and physical test beds. The TAS Functionality Node is studying swarm solutions for storage and retrieval in unstructured environments like cloakrooms. Low-fidelity simulators allow high-level ideas and concepts to be tested and explored quickly with standard computers. Slower, high-fidelity simulators provide the next step in gathering accurate results and highlighting potential issues. Swarm robot hardware, such as the DOTS platform, enables real-world testing and assessment of user and public trust in these systems.



The TAS Functionality-Toshiba DOTS cloakroom attendant robot (left), the low fidelity 2D simulator (middle) and the high-fidelity 3D simulator (from Windsor et al., 2022).

SWARM RESEARCH - THINKING ‘OUT OF THE BOX’

There is a growing appetite for ‘out-of-the-box’ swarm robotics - systems that can be used by operators with limited expertise and training. Work is underway into whether swarms could be deployed without complex set-up or infrastructure. Real-life simulation (or as close to it as possible) is key to exploring this ‘out-of-the-box’ potential.

A test facility for autonomous systems has been set up in Bristol where the TAS Functionality Node is based. The Bristol Robotics Lab is an open-access testbed for swarm robotic experimentation. Featuring a swarm of up to twenty robots that can be observed by publicly accessible webcams, the aim of the Lab is to model and ‘play’ with swarm AS scenarios in a more ‘out-of-the-box’ way.

It is hoped that the findings can help address challenges around perceptions of trust and responsibility, which could lead to exciting positive impacts on our lives. Dr Sabine Hauert from the TAS Functionality Node at the University of Bristol says there is enormous potential:

“For me, the most exciting areas of application are those that interact with the real world and human beings. Particularly, the idea of robots for intra-logistics could be useful for the third-party sector, local communities and the local sector circular economy. Could ‘out-of-the-box’ swarms be used on small scales for bakeries, foodbanks, small shops and care homes?”

Swarm arena for testing functionality of the DOTS at the Bristol Robotics Laboratory

[1] https://www.youtube.com/watch?v=Vwg7e-W7KZw

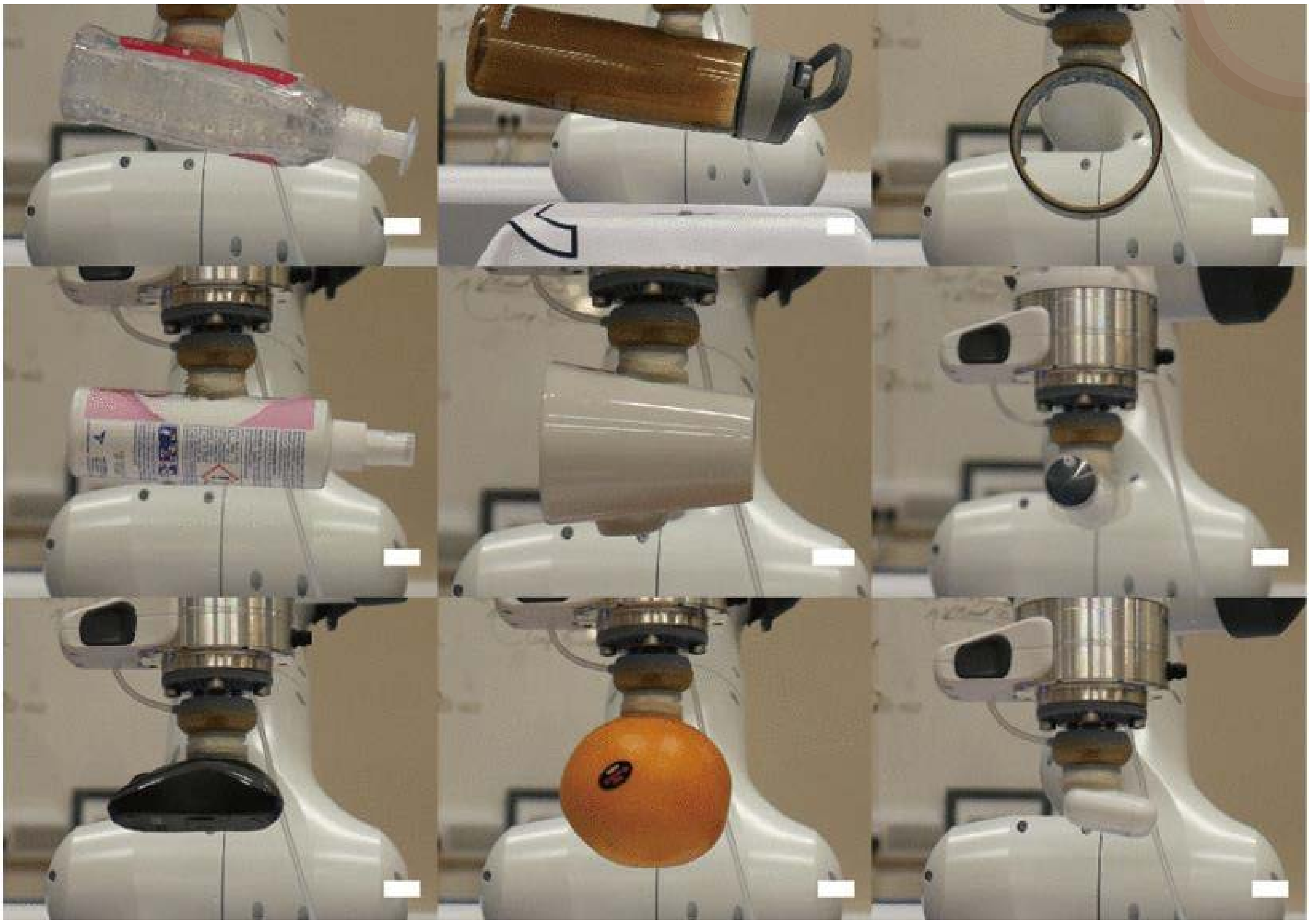
TAS research is also looking at better communication with swarms. The TAS Functionality Node has developed a web app enabling individuals to interact with a virtual swarm, modifying behaviours through performance and control metrics, and assessing real time trade-offs without the need for programming knowledge.

However, as Dr Sabine Hauert emphasises, test environments can only go so far and more real-world data is needed for future advancements:

"The thing we are missing is more Living Labs. Places in the community that we can go to test some of these systems in a more meaningful way in controlled real-world settings. This would open up applications in construction, environmental monitoring and healthcare."

SOFT ROBOTICS

Another key area of research around adaptive functionality is soft robotics. These are robots made from non-traditional materials that are – as the name suggests – soft and flexible. With these robots, the materials' properties do some of the work, rather than the need for each element to be controlled using motors and mechanics.



An adaptive, contact triggered, soft suction cup on a 7 degree of freedom, Franka Emika, robotic arm picking up objects of different shapes, curvatures, and textures (from Yue et al., 2022)

TAS researchers are currently working on making the functionality of soft robotics more predictable by using modular components. Guaranteeing the performance of a single module can generate more predictable outcomes when it interacts with other modules.

In a similar way to swarms, advances in this area would open up a wealth of applications for wider society. TAS researchers are, for example, studying multifunctional grippers for manufacturing that would limit downtime and aid productivity; robots for picking and packing; and in the medical field, soft robotic surgical assist tools.

DRONES

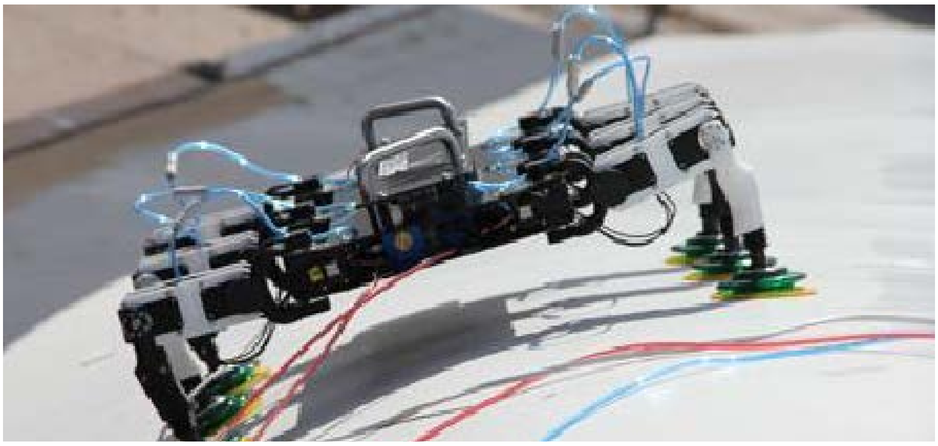
Progress is also being made in adaptive functionality within the field of unmanned aerial vehicles (UAVs) – more commonly knowns as drones.

Researchers are looking into the use of machine learning for flight control of UAVs. Here, a drone would adapt as it flies along, learning from experience of different conditions and environments, such as rural or complex urban environments, via sensory feedback. As with soft robotics, UAV research is bio-inspired, aiming for the manoeuvrability and adaptability that we see in animals and birds. This opens up significant potential in infrastructure monitoring, surveillance, emergency response, logistics and even personal transport and aviation.

Thales are exploring the use of UAVs in offshore wind farm inspection, maritime search and rescue and ground vehicle resupply. The aim is to further expand potential uses of self-learning autonomous systems. Dr Matt Ball, Chief Scientist from Thales UK, says it is compelling research:

“We are working in partnership with academia to learn the general principles and results that we can apply. For example, in a project combining different autonomous systems on an offshore windfarm, we are using an uncrewed surface vehicle to get out to the windfarm, and then a UAV deploying a crawler robot for inspection and repair of the blade.”

[2] From: https://s.wsj.net/public/resources/images/TE-AB752_SOFTRO_M_20180307180915.jpg



Images from multi-platform robotic inspection system windfarm trials as part of the Offshore Renewable Energy (ORE) Catapult MIMRee project involving both Thales and University of Bristol.

Another specific scenario is enabling quadcopters to carry parcels in urban areas using reinforcement learning. The machine learning is initially being tested in a simulation environment and will then be expanded into a scaled test urban environment.

Studies are also underway into ground and airspace risk modelling and the future of crowded shared airspace.

FUTURE IMPACTS OF ADAPTIVE FUNCTIONALITY

Two key questions remain at the heart of evolving technology: how will autonomy make a difference - and what will we, as society, accept?

Ambitions surrounding autonomous systems and artificial intelligence span every part of our lives – macro to micro. From emergency rescues to clinical care; swarms of UAVs in disaster recovery scenarios to wearable robotics controlling cellular level swarms for wound healing.

Dr Shane Windsor says the goal is to create systems that can adapt to different locations and environments, and ultimately make our lives easier:

“I would love to see robots in the everyday world. Adaptation is a key enabler. You can design a static solution with current techniques, but it will only work for a limited set of situations. But an adaptive AS that can cope with high levels of difference and suit the environment they are working in, that is where I would like to see things going.”

The focus now is on taking the technological advances that we are seeing in a test environment and transitioning them into the real world – and knowing how far and how fast to go with this, as Dr Shane Windsor explains:

“There are a lot of things we can do currently and are technically on the horizon, but there will be a difference between what we can do and what we do - for example due to security and regulation - as well as questions about whether these are the right things to be doing.”

The promise is that evolving autonomous systems will add value to our lives. They can take us out of extreme situations, prevent us from risking our lives in dangerous environments, help us with our daily logistics, advance our medical abilities and assist with our care needs.

But this promise depends on trust.

Public perceptions are complex and there has always been a degree of caution about what ‘intelligent’ technology may mean for our way of life. In order to trust, we need our evolving autonomous systems to be reliable, human-centric and ethical. Ongoing research into adaptive functionality is key to this. We need to be totally on board for the ride, actively pushing for this potentially life-changing technology and not just passively accepting it as our future.

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