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Annual Impacts and Benefits Narrative

Thales-Bristol Partnership in Hybrid Autonomous Systems Engineering (T-B PHASE)

Business lead: Thales University lead: University of Bristol Grant reference: EP/R004757/1

Summary

T-B PHASE is a £5M EPSRC prosperity partnership between Thales and the University of Bristol that aims to deliver design principles and processes for hybrid (human-machine) autonomous systems engineering. The research programme is addressing the Hybrid Autonomous Systems Engineering 'R3 Challenge'; Robustness, Resilience, and Regulation; and will engage with live use cases from within Thales including (but not limited to) digital rail, search and rescue, and ultra-light traffic management.

Introduction and background

Hybrid autonomous systems are those where groups of people are in direct, ongoing interaction with groups of autonomous robots or autonomous software, e.g. a mixture of autonomous and human-operated trains and trams providing efficient, integrated public transport. Emerging technologies in robotics, AI and ICT mean that hybrid autonomous systems of this kind will become increasingly common in a much wider set of situations. Smooth, reliable, safe interaction amongst machines and people will be key to success.

As we enter this new design space, a crucial challenge for the engineers of hybrid autonomous systems across all potential settings is ensuring that the system behaviour is Robust and Resilient and that it meets Regulatory demands: the R3 Challenge.

T-B PHASE aims to:

- Innovate new design principles and processes that integrate over the full system life cycle from early stages through to disposal to ensure that the tangible products of the work are delivered to specification and cope with evolving task parameters;
- Build new analysis and design tools that enable a complex system's interactions to be mapped, understood and bounded at design concept stage;
- Develop new whole-life-course monitoring approaches capable of identifying early warning signals for anomalous system behaviour, tipping points, and cascading failure in hybrid autonomous systems, enabling proactive informed intervention and management;
- Train/develop people with the skills required for leadership in systems engineering.

The partnership approach between academia and industry enables us to implement a programme of impact and integration activities that respond to the real needs of stakeholders within the business and beyond. The approach enables academic researchers to engage with live Thales use cases ensuring the research is relevant to the current and anticipated future needs of industry.

The University of Bristol and Thales have a long-standing track record of research collaboration, marked in 2016 by the signing of a strategic agreement which established a framework to govern collaborative research between the two parties. By engaging in the T-B PHASE programme, Bristol and Thales committed to share expertise and jointly pursue fundamental research questions in the context of highly practical design problems in order to significantly advance the capability to operate confidently in one of the most important emerging areas for modern engineering.

Project achievements: outputs, outcomes and impact

Selected project highlights:

Theme 1: Self-Monitoring in Context (Pitonakova, University of Bristol)

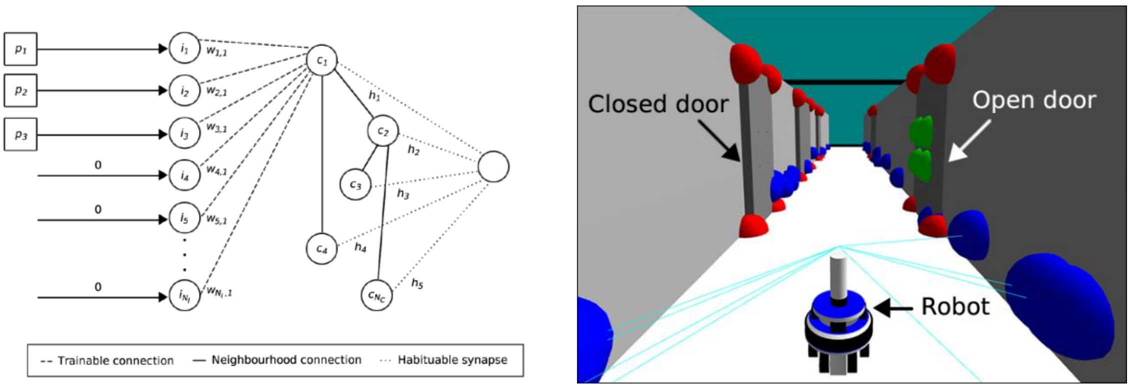
An autonomous robot's ability to detect novelty in its own performance or in its environment could make it more robust and safer. This is particularly important given that such a robot may operate in an open environment that changes over time and may itself change due to learning, adaptation, degradation, failure or malicious attack. This study considered using Grow When Required Neural Networks (GWRNNs) as a way of learning to detect novelty in a robot's environment.

First, we have shown that there are two important parameters affecting GWRNN performance and learning speed -- the number of neuron input connections (which determines how many features a network can consider at a given point in time), and the neuron activation threshold (which controls the network's growth). We have demonstrated that using a new plastic variant of the GWRNN, where the value of the first parameter varies from one clustering neuron to another based on the size of input vectors that they represent, leads to more robust performance. In general, we conclude that it is desirable to create adaptation mechanisms that automatically adjust a novelty detector's parameters but that are parameter-free themselves.

Secondly, we have demonstrated that a novelty detector may perform fundamentally differently in the one-shot and in the continuous variants of the novelty detection task. In the latter, a series of successive distinct novelties take place sequentially and a novelty detector needs to be able to distinguish between different novelties that may have similar features but that occur in different places or at different times. This may be especially important in robotic applications such as surveillance and intruder detection.

Thirdly, we have also shown that performance of a novelty detector may vary significantly when it comes to recognising different types of novel events. For instance, the ability to notice the appearance of previously unseen objects is fundamentally different from the challenge of noticing the disappearance of familiar objects.

Finally, we have demonstrated that adding localisation information to the sensory input vector of a novelty detector often improves its ability to distinguish between different objects and to detect the absence of previously learned objects. It should be noted, however, that the impact of location data noise on learning speed and on the likelihood of reporting false positives needs to be studied in detail.

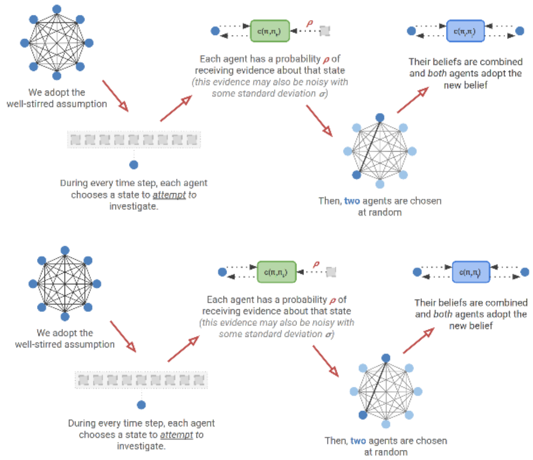


Caption: A schematic diagram of the Grow When Required Neural Network (GWRNN) architecture (left) and a representation of the simulated corridor environment in which the robot novelty detection tasks were undertaken.

Theme 2: Consensus Formation for Collaborative Autonomy (Crosscombe, University of Bristol) and Theme 3: Dynamical Hierarchical Task Decomposition and Planning for Heterogeneous Systems (Kent, University of Bristol)

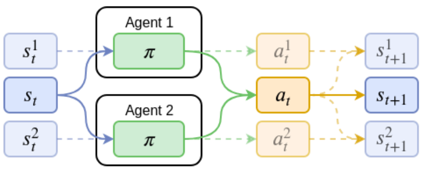
There are many real-world problems that can be effectively solved using multiple agents, such as search and rescue, surveillance, monitoring and mapping. This can result in a need for coordination, cooperation, and ultimately communication, that may or may not be possible in many situations. Different problems may also dictate to what extent we require the ability to distribute and/or decentralise our decision making.

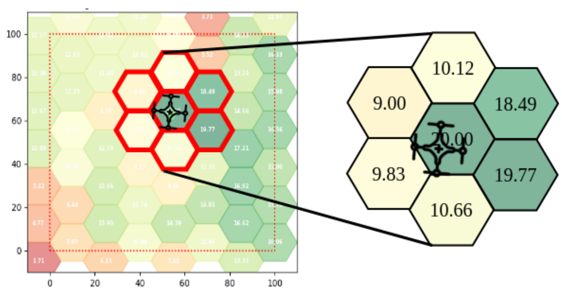
Off-the-shelf systems, such as UAVs, are typically designed in isolation to optimise single-agent behaviours. Our research question concerns how we could plan for and deploy autonomous solutions which bridge the gap between single and multi-agent behaviours, when individuals may possess differing objectives, constraints or beliefs about the state of the world. Importantly, how could the levels of de-centrality in the decision making and communication affect the way in which we design and deploy these autonomous solutions?



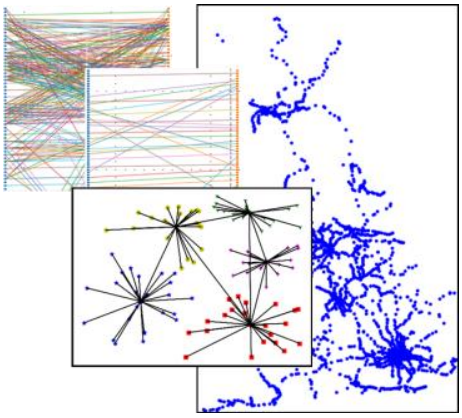
We developed several models for distributed learning in which individual agents, through local interactions, reach a consensus about the true state of the environment they inhabit [1,2]. In these models, agents learn more efficiently by communicating with their neighbours and sharing the information they gather. Furthermore, the process by which information is fused was shown to be more robust to noise than a system in which agents learn individually. The resulting simulations produced systems of agents which made better decisions because they based their decisions on more accurate information.

A particular focus has been the multi-agent persistent surveillance problem, in which we have shown that sensor noise could in fact be a desirable property [4]. As part of this work we have shown how seemingly reasonable designs of a standard state-policy-action-decision cycle could lead to highly undesirable emergent multi-agent behaviour.





Theme 4: Cascading Failure and Network Topology (Rayneau-Kirkhope, Thales)



Research led by a Thales researcher on Cascading Failure undertook to understand and develop techniques for predicting the loading of the UK Rail Transport Network under both failure and movement models based on current, future legacy and future train movement rules. Additionally, the research looked at the demand for resources (trains) against loading with changing constructs of operation. This built understanding around stress-point localisation, optimised loading capability and asset planning that may be used for future network planning and for on-line network re-planning in the event of disruptions and failure.

Benefits are predicted in the areas of network and fleet optimisation for service and the prediction of failure effects and propagation. This should benefit the rail passenger, rail operating companies and the rail infrastructure / track operations.

This work has led to the investigation of in-house proof-of-concept and technical demonstrators options at Thales.

New collaborations

During the past year we have extended our network within the University of Bristol and Thales with the aim to bring new directions and cross-disciplinary expertise into the T-B PHASE programme. At the University we have introduced additional supervisors into the co-investigative team, Dr Sabine Hauert and Dr Nikolai Bode, both from the Department of Engineering Mathematics. They bring expertise in swarm engineering and analysis of collective behaviour into the programme. Furthermore, we have appointed Jan Noyes as a professorial research fellow in Human Factors Psychology to oversee Theme 6 (Hybrid Autonomous Systems).

Within Thales, we have continued to work with the use case owners (technical specialists) identified at the start of the programme. This has been essential in ensuring the research is relevant to one or more of the various use cases. For example, recent interactions with the Thales Information, Surveillance and Reconnaissance (ISR) team enabled our researchers to identify how the algorithms they were developing could interface with current Thales simulators, such as those that are designed for autonomous sensor management.

Discussions with use case owners from Thales enabled novelty detection in real-world systems to be considered and was reported in the Neural Networks journal paper that was published by Pitonakova and Bullock under theme 1 [5].

Other useful interactions with Thales stakeholders included site visits to rail operative control rooms in Cardiff and London, and direct discussions with the Ground Transportation System (GTS) teams at Thales. These activities produced notable outputs under Theme 4 (see *Project Achievements* section) and will be further developed under Theme 6, which will focus primarily on human factor influences on hybrid autonomous systems.

Engagement of stakeholders beyond the UK is being explored, with the possibility of reaching Thales Germany and Canada through the human factors work on the GTS use case.

We recently hosted Professor Stephen Turnock (Professor of Maritime Fluid Dynamics at the University of Southampton), who presented his research on marine robotics to the T-B PHASE team.

Several potential linkages with T-B PHASE workstreams and Thales use cases were apparent, and further engagement (including possible collaboration with his research group) will be explored in the coming year.

Staff Highlights

Two team members moved onto new roles this year; Dr Lenka Pitonakova (University of Bristol Research Associate) moved to employment at A&K Robotics, Vancouver as a Robotic Systems Developer. Ben Rayneau-Kirkhope (Thales Researcher) was appointed as Computer Vision Scientist at Veridium UK.

Within T-B PHASE, we have appointed two new Research Associates: Dr Debora Zanatto (Theme 6, Hybrid Systems: Psychology and Autonomous Systems) and Dr Bugra Alkan (Theme 7, Systems Architecture). We welcomed a new researcher from Thales RTI, Vaishnavi Abhyankar, to continue the work started on Theme 4, Cascading Failure and Network Topology. In the supervisory team, Professor Eddie Wilson took over the Principle Investigator role from Professor Bullock, who will continue as a co-investigator for the remainder of the programme.

Team members have participated in numerous conferences this year, allowing current T-B PHASE research from themes 1-5 to reach international audiences within both academic and engineering/industrial communities.

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