Australian Government

Department of Defence
Science and Technology

PROGRAM TYCHE

STRATEGIC RESEARCH INITIATIVE IN TRUSTED AUTONOMOUS SYSTEMS

BIENNIAL REPORT 2015/16 & 2016/17

DST | Science and Technology for Safeguarding Australia

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Acknowledgments:
The conception, preparation and publication of this report have required a significant amount of assistance and goodwill from a large number of people.

Abbreviations:

ACFR	Australian Centre for Field Robotics
ADF	Australian Defence Force
ASC	Autonomy Strategic Challenge
BLOS	Beyond Line of Sight
CDS	Chief Defence Scientist
CERA	Competitive Evaluation Research Agreement
CLAND	Closed Loop Alternate Navigation Demonstration
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DST	Defence Science and Technology Group
Dstl	Defence Science and Technology Laboratory
HQJOC	Headquarters Joint Operations Command
ICT	Information and Communication Technology
IP	Intellectual Property
ISTAS	Invitational Symposium on Trusted Autonomous Systems
MoU	Memorandum of Understanding
RAN	Royal Australian Navy
NRL	Naval Research Laboratory
RAAF	Royal Australian Air Force
R&D	Research and Development
S&T	Science and Technology
STEM	Science, Technology, Engineering and Mathematics
TTCP	The Technical Cooperation Program

FOREWORD

Australia is a world leader in field robotics which has improved operating efficiency and safety in many sectors of our economy. Patricks "Autostrads" and monitoring and control systems developed by Australian Centre for Field Robotics, have allowed Port Botany container handling operations in Sydney to be automated. Similarly, Rio Tinto's *"Mine of the Future"* vision has started to be realised. All of these systems operate by removing humans from the operating area. When things go wrong, which does happen, the automated systems are shut down and human repair teams are sent in.

Defence has similarly succeeded in leveraging field robotics for operations including ScanEagle airborne drones flying 6,200 missions and 32,000 hours in Afghanistan, and RAAF Heron now used for training, as well as counter-IED robots. These systems operate in uncontested environments, or when operating conditions are manageable, and are remotely piloted by human operators.

In the future, Defence needs trusted autonomous systems that can operate under conditions which cannot be managed, facing determined adversaries, where the consequences of failure can be high.

The 2016 Defence White Paper identified Trusted Autonomous Systems as one of nine critical areas to receive support from the Next Generation Technologies Fund of $730M to develop "game changing" technologies over the next ten years. The new technologies developed through this initiative will help create a capability edge for the Australian Defence Force.

On behalf of Defence, DST manages the Next Generation Technologies Fund. Through this initiative Defence will establish a Defence-led Cooperative Research Centre for Trusted Autonomous Systems. The Tyche program will shift to this Cooperative Research Centre as a partnership between Defence, Industry and Academia.

The Tyche Program has been funded by DST since July 2015. The program has aimed to undertake collaborative R&D to support the development of autonomous systems capability and "get more machines into the fight". The projects reported here demonstrate that significant progress is being made in laying the foundations for future work in Trusted Autonomous Systems.

Dr Alex Zelinsky, AO
Chief Defence Scientist

CONTENTS

COMMAND AND CONTROL IN A FUTURE WITH AUTONOMOUS SYSTEMS

The Tyche themes provide a strong basis for exploring some of the important underlying principles when operating trusted autonomous systems in uncertain operating environments and when integrated with the human system.

Similarly, I would like to provide you four complementary themes or concepts from a military practitioner's perspective. Framed by the core military question "What will it mean to Command at the operational level of warfare when you have ubiquitous and pervasive Autonomous Systems operating in the battle space with various levels of automated control?"

This touches on the concept of the "5th Generation Headquarters" coined by my Chief of Joint Operations Vice Admiral David Johnston, AM, RAN and subject of a paper to be presented at the 21st International Command and Control Research and Technology Symposium: C2 in a Complex Connected Battle-space, later in the year.

Operational Risk. The appreciation of risk and its management as a commodity is a useful construct for dealing with uncertainty and coping with unpredicted environments. Risk can be considered both as a threat but also as an opportunity. Consequence can be considered both as a cost but also as a benefit. Risk management includes identification of ownership and appropriate command and control. It seeks to identify mitigation strategies for minimising negative consequence or maximising positive effects.

Mission Command. This is a military term which deals with providing command and control through intent rather than prescription. This process enables elements of the system to operate based on following high commander's guidance or intent. It enables agility and concurrent activity within the system. Unity of effort is achieved through synchronisation and clarity of the effect which is to be achieved. Mission Command also demands a level of trust between commanders at all levels.

Situational Awareness. In a military construct enables commanders at all levels to have a shared understanding of the battle space. The unity of effort and focus on the mission success is enhanced by a deep understanding of the operating environment. At the operational level the awareness of the battle space is enabled through situation updates and organisational battle rhythm driven at various natural organisational frequencies.

Campaigning View. This campaign view of the world is an intrinsic human characteristic which includes "Planning and Assessment". That is planning according to goals, striving to be self aware in performance and seeking to improve this performance assessed against metrics and way points;

I note the promise that Autonomous Systems are "just around the corner" and the observation that "they are not here yet!". It is my strong belief that it is only by getting the correct balance between "the human" and "the technology" the right blend of "the art" with "the science" that we will be able to set the correct conditions for fully realising "trusted autonomous systems" and importantly making operational capability "better" and "fit for purpose" when operating in complex or unpredicted future operating environments."

Major General Stuart Smith AO, DSC
Former Deputy Chief of Joint Operations

TRUSTED AUTONOMOUS SYSTEMS
RESEARCH LEADER'S REPORT

It seems that the promise of autonomous systems is perpetually "just around the corner".

Instead of autonomous systems, it seems we have a lot of automated decision and control systems with pre-programmed behaviours that are designed for efficiency. Automated systems often prove fragile when faced with the reality of unpredicted situations or when operated outside of expected operating conditions.

The Tyche program seeks to develop new technologies that enable machines to maintain fitness and act trustfully in an uncertain and open world. Tyche aims to achieve deployable autonomous systems with greater viability than automated systems that operate within user-agreed bounds even when subject to unpredicted environments.

So, returning to the question, why then haven't autonomous systems arrived? Maybe it is because:

- They aren't resilient enough?
- They aren't smart enough?
- People don't trust them?
- They don't have the right kind of intelligence?

The response to each question has a corresponding research theme, provided in the Overview, to follow.

Program Tyche 2015/16 Snapshot

- 58 Papers Published
- 17 International Visitors
- 8 Industry Briefings
- 130 ISTAS Conference Attendees

RESEARCH LEADER'S REPORT

We can't expect a different result if the research in this program is of the same type as the past. Hence, Tyche seeks breakthroughs in critical areas, as well as repurposing existing technologies in new ways.

A few of the many research achievements for this year include:

1. Prof Hussein Abbass of the University of NSW, in close partnership with myself and Dr Darryn Reid have completed editing of a new textbook entitled *"Foundations of Trusted Autonomy"* now in press with Springer publications. Considering the ultimate goals for Artificial Intelligence are to achieve autonomy and trustworthiness, this book establishes the foundations needed to bring these goals to life. Targeting scientists, researchers, technologists, practitioners, and students, this book brings contributions from like-minded authors to offer the basics, the challenges and the state-of-the-art on trusted autonomous systems in a single volume. The book is structured in three parts containing chapters written by eminent researchers and supplemented with short chapters from high calibre and outstanding practitioners and users of this field. The first part covers foundational artificial intelligence technologies. The second part covers philosophical, practical and technological perspectives on trust. The third part brings about advanced topics necessary to create future trusted autonomous systems. The book augments theory with real-world applications including Cyber Security, Defence and Space. It is expected to be available as an open-access publication later in 2017.
2. Developed and trialled advanced navigation technologies to allow unmanned aerial systems to navigate in GPS degraded and denied environments. The technologies fuse data from bio-inspired solutions (including sunlight polarisation, geo-registration and optical flow) to allow successful navigation over sparse terrain without external GPS data. Ultimately, this will improve the resilience and safety of flight of aircraft operating in GPS degraded situations.
3. Advanced an autonomous planning system with University of Sydney, for a cross-country undersea glider called "Deep Ray", which seeks to exploit oceanic currents for improved efficiency during months of operation. Based on "Fast Marching Trees" the algorithm provides guaranteed convergence rate bounds that will reduce power consumption for on-board computation.
4. Military subject matter experts (RAAF, USAF, RAF) trialled a US human-machine command and control system under development. The system allows a team oversight control of a large number of unmanned vehicles across multiple environmental domains. A five eyes demonstration with increased platform autonomy, autonomous cross-domain (air, sea and land) cueing and tasking is scheduled for 2018 in Jervis Bay.
5. Assessed the potential for autonomous fuel truck platoons to supply Defence remote air bases. This is an innovative solution to improve strategic air readiness, reduce exposure to risks, and offer significant savings in operating costs.

Dr Jason Scholz
Research Leader
Trusted Autonomous Systems

PROGRAM TYCHE

Overview

Program Tyche seeks to conduct research and development for game-changing trusted autonomous systems capabilities that will operate in contested and complex environments.

Themes

Human Machine Integration

- Human-autonomy team (HAT) effectiveness
- Legal decisions for autonomy
- Socialised autonomy
- Mobile robot control interaction

High-level Autonomy

- Human-autonomy team (HAT) learning
- Non-stationary planning
- Decentralised flow control
- Autonomous goal and resource management

Machine-Machine Interaction

- Survivable ad-hoc unmanned vehicle networks
- Coordinated delivery of effects
- Evolution of swarm behaviours

Embodied Autonomy

- Multi-modal Autonomous Systems for Urban Operations
- Long range navigation for UAVs
- Autonomous perception subject to uncertainty
- Adaptive Flight
- Deep Ray: Underwater Glider

HUMAN-MACHINE INTEGRATION

HUMAN AUTONOMY TEAMING

DST Lead: Michael Skinner

Objectives

- Develop methods to enhance the performance of teams comprised of human operators and autonomous systems that are working together in complex, dynamic, and uncertain environments.
- Focus on the context in which a single operator commands multiple assets possessing a high level of autonomous capability.

Related Research Agreements

- Optimising Human-Automation Interaction in UxV Command & Control, Shayne Loft, UWA;
- Influence of agent anthropomorphism and transparency on trust and performance, Chris Stanton, WSU;
- Providing automation with situational awareness of operator workload, Andrew Heathcote, UTAS;
- Fostering trust in human machine teams through emotion processing, Margaret Lech, RMIT;
- Cognitive Human-Machine Interface and Interaction for Future Aerospace Systems, Roberto Sabatini, RMIT

Approach

- Conduct basic research on factors affecting the performance of human-autonomy teams: agent transparency, trust, mental models, workload.
- Develop principles for design – and prototype – of HMI for controlling multiple autonomous assets
- Participate in coalition exercises demonstrating and evaluating emerging autonomous capabilities.

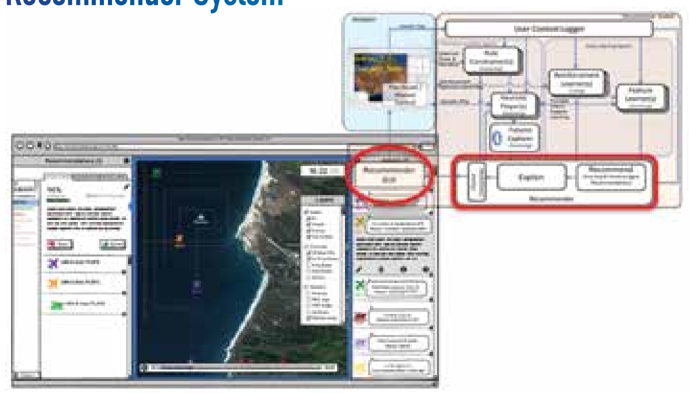
Key Achievements

• Developed HMI for Intelligent Watch Dog (with AOS Group)	11/2016
• Prototype HMI for Recommender Systems	10/2016
• Participation in Autonomy Strategic Challenge (design and IMPACT evaluation)	ongoing
• Development of simulation environments for evaluating issues in human-autonomy teaming	05/2017

Partners

AOS Group
RMIT University
Office of Naval Research Global (USA)
Western Sydney University
The University Of Western Australia
Air Force Office Of Scientific Research USA)

Human-Machine Interface (HMI) for Recommender System



Publications

Stolar M. N., Lech M, Bolia R. S., & Skinner M. J. (2017).

Towards autonomous machine reasoning: Multi-stage classification system with intermediate learning. International Conference on Signal Processing and Communication Systems (ICSPCS2017), Gold Coast, Australia, 13-15 December 2017.

Stolar M. N., Lech M, Bolia R. S., & Skinner M. J. (2017).

Applying image classification and deep learning to real-time speech emotion recognition. International Conference on Digital Image Computing: Techniques and Applications (DICTA2017), Sydney, Australia, 29 November – 1 December 2017..

Stolar M. N., Lech M, Bolia R. S., & Skinner M. J. (2017).

Real-time speech emotion recognition using RGB image classification and transfer learning. International Conference on Signal Processing and Communication Systems (ICSPCS2017), Gold Coast, Australia, 13-15 December 2017.

HUMAN-MACHINE INTEGRATION

COMMAND AND CONTROL IMPLICATIONS OF AUTONOMOUS SYSTEMS

DST Lead: Sharon Boswell

Objectives

- Development of C2 theories for next generation military HQs, where autonomous agents feature prominently
  - What impacts will autonomy have on military HQs?
  - **Where in the HQ should autonomy occur?**
  - How can human and autonomous agents for effective teams for decision making in risk environments?

Approach

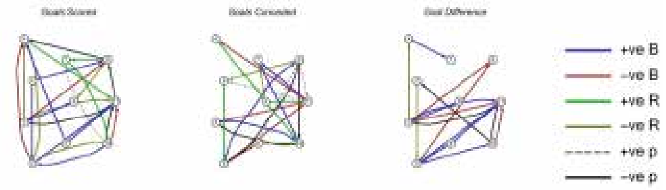
- Robocup agent communications – with USydney
- Design Principles for Hybrid Teams – RA with ANU

Key Achievements

- Presented 5th Gen HQ paper at 22ICCRTS
- ANU report – Design Principles for Hybrid Teams tasked with Risk-based Decision making in a Military Headquarters

Partners

USydney, ANU



Robocup agent communication for situation awareness and teaming

Publications (noting this is a new effort in 2017)

Yue, Y., Kalloniatis, A., Kohn, E., "A concept for 5th generation operational level military headquarters", 21st International Command and Control Research and Technology Symposium, London

Zuparic, M., Juaregui, V., Prokopenko, M., and Yue, Y., "Quantifying the impact of communication on performance in multi-agent teams" accepted by *Artificial life and Robotics.*

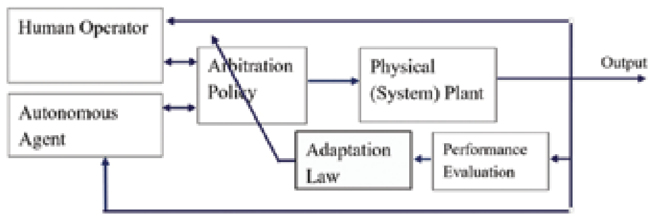
HUMAN-MACHINE INTEGRATION

BI-DIRECTIONAL HUMAN ROBOT COMMUNICATION AND SHARED CONTROL IN THE LAND DOMAIN

DST Lead: Michael Ling

Academic Lead: Denny Oemoto, University of Melbourne

Gesture communication with robot in real and synthetic environments



Schematic of the General Case Shared Control Framework

Objectives

- Explore and develop bi-directional communication modalities (emphasizing non-visual modes) between human operators and semi-autonomous robots for a range of complex land terrains
- Improve human-robot team effectiveness.
- Improve dynamic sharing of control between humans and robots with emphasis on decision context, transparency and trust.

Related Research Agreements

Human-Robot Teaming: Towards Shared Control between Human Operators and Autonomous Systems, Dr Denny Oemoto, University of Melbourne

Approach

- Literature review
- MYO™ band + Parrot™ drone + tactile feedback + CAVE + VR Engage for exploring interaction with robots in real and synthetic environments simultaneously.
- Development of fundamental framework of Shared Control which seeks the optimal balance between the authority of the Autonomous Systems and the Human Operator in collaborative interactions between the two entities.

Key Achievements

- Gesture control human trial plan in place, ethics approved.
- Conducted 2-day Human-Autonomy Teaming Workshop
- Established CERA collaboration on Shared Control

Partners

US Army Research Lab, University of Melbourne.

Publications (noting this is a new effort in 2017)

Bi-Directional Communications Literature Review, in preparation, due July'17

Human-Autonomy Teaming Workshop Report, in preparation, due July'17

Usability of Human Gesture Device for Robot Control Experiment Report, due July '17

HUMAN-MACHINE INTEGRATION

LEGAL & ETHICAL DECISION SUPPORT

DST Lead: Piers Duncan

Academic Lead: A/Prof Colin Wastell, Macquarie University

Objectives

- Identify the qualities needed for a fully or partly autonomous system to become sufficiently trusted by stakeholders to make or recommend life/death decisions.

Approach

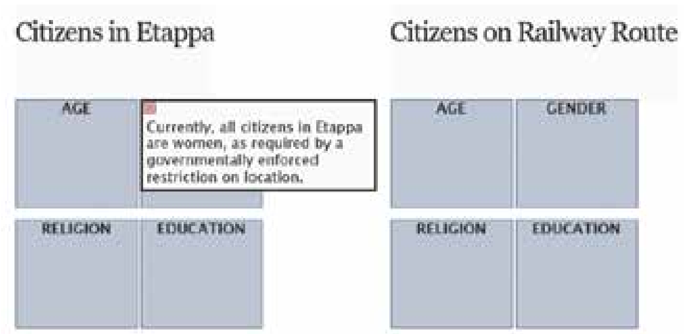
- Human psychological experiments.
- Identify and weight variables used by subjects to justify sacrificing some lives to save others.
- Separate utilitarian & deontological paradigms
- Develop understanding to guide developing algorithms for machine use.

Key Achievements

Experiments using de-militarised "trolley problem" to mirror proportionality in targeting, and four reports.

Partners

Macquarie University



Interface participants used to respond to experimental scenarios.

Results by Degree showing statistically even distribution of required lives saved for proposed lives lost.

Publications (noting this is a new effort in 2017)

Report 1 Experimental method and research questions 12/16

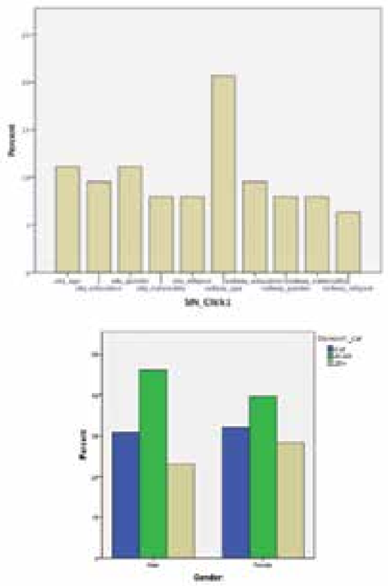
Report 2 Study of Gender effects on proportionality 4/17

Report 3 Study of Nationality effects on proportionality 5/17

Report 4 Integration of Reports 1-3 with recommendations:

Identifying complexity and absence of uniformity of reasoning elicited in experimental subjects re proportionality.

Recommendation: Design algorithm of variables that can be legally defended and test on military personnel for trust.



Distribution of features of civilians in both the city and along the railway route highlighting age as a concern.

HIGH-LEVEL AUTONOMY

DECENTRALISED FLOW CONTROL

DST Lead: Slava Shekh

Academic Lead: Michelle Blom,
University of Melbourne

Objectives

- Explore the use of decentralised decision making within autonomous logistics systems, which will form an integral part of future Defence logistics.
- Combine autonomous and human decision making to produce a human-on-the-loop logistics capability.

Related Research Agreements

- Human-on-the-loop Decentralised Defence Logistics
- Michelle Blom, University of Melbourne

Approach

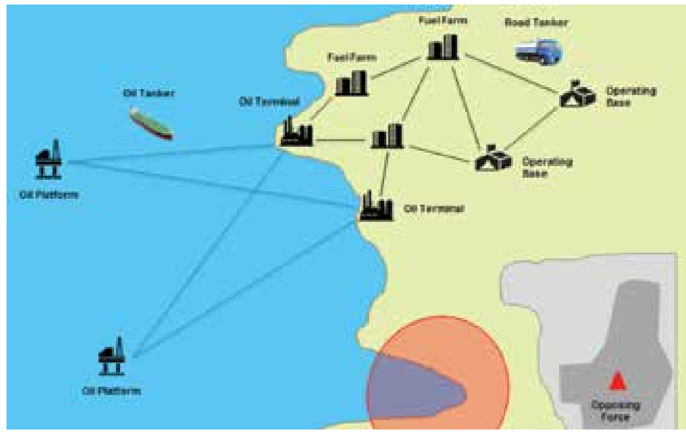
- Develop and evaluate decentralised control algorithms based on heuristics, mixed-integer programming, Monte Carlo tree search, Markov decision processes, and other techniques.
- Apply machine learning to find the best combination of techniques to use in a given situation and provide the ability to adapt behaviour over time as the situation changes.
- Visualise behaviour in a range of realistic logistics scenarios and provide the ability for a human operator to interact with the system by injecting real time data and performing role re-assignment.

Key Achievements

• Scenario development	2016
• Simulation framework development	2016
• Algorithm implementation	2016-2017
• Algorithm evaluation and analysis	2016-2017
• Visualisation and playback capability	2017

Partners

University of Melbourne



Publications

Blom, M., Shekh, S., Miller, T., Gossink, D., & Pearce, A. (2017).

Network Distribution Optimisation in Dynamic Environments. In Transportation Science. [under review]

Shekh, S., & Blom, M. (2017).

Decentralised Decision Making in Defence Logistic. In IJCAI-17 Workshop on Cognitive Partnerships. [under review]

HIGH-LEVEL AUTONOMY

NONSTATIONARY PLANNING

DST Lead: Darryn J Reid

Academic Lead: A/prof Tim Miller,
University of Melbourne

Objectives

- Develop logical planning frameworks and online algorithms suitable for implementation for machine planning under fundamental uncertainty.
- Extension of planning logics to allow for actions having consequences not known prior to their execution, for soft goal conditions and for the presence of terminal anti-goal conditions.
- Development of any-time online algorithms for computing solutions dynamically "in real-time" with the possibility of interruption.

Related Research Agreements

Safety for Autonomous Systems Under Uncertainty, ANU Human-Agent Planning for Survivability, University of Melbourne

Approach

1. Nondeterministic planning with antigoals model and anytime online algorithm development.
2. Evaluation with standard problems and in Defence-relevant surveillance scenarios.
3. Representing survivability as temporally extended soft goal conditions, extended strategy with hierarchical planning, and algorithm development.
4. Experimental evaluation and comparison of methods.

Key Achievements

• Literature reviews, evaluation and testing	06/06
• The nature of uncertainty	01/07
• Terminal states and online method	03/07
• First phase test and evaluation	05/07
• Hierachical planning & survivability goals	12/07
• Second phase experimental evaluation	05/08

Publications

Reid, D.J., An autonomy interrogative, in Abbass, H., Scholz, J.B. & Reid, D.J. (Eds.),

Foundations of Trusted Autonomy, (in Press), Chapter 21, Springer, 2017,

Jimenez, S., Miller, T., Pearce, A., Reid, D,

Cost-tolerance in non-deterministic planning with dead-end states, IJCAI-17, Melbourne, 2017.

HIGH-LEVEL AUTONOMY

HUMAN AUTONOMY TEAMING (HAT)

DST Lead: Luke Marsh

Objectives

- Develop a Recommender System to aid in the Command and Control of multiple autonomous vehicles
- Research advanced machine learning algorithms to recommend high-level tasks for autonomous vehicles in a mission
- Reduce cognitive load on operators controlling multiple vehicles
- Explain the utility of recommendations to operators.

Related Research Agreements

- Robust long-term navigation, Luke Marsh, University of Adelaide
- Visual Question Answering, Jason Scholz, University of Adelaide
- Zero-Shot Learning, Darren Williams, University of Adelaide
- Causal Explanation in TAS, Glennn Moy, University of Melbourne

Approach

Explore a number of machine learning, optimisation and heuristics techniques to recommend high-level tasks for autonomous vehicles:

- Deep Reinforcement Learning (Deep Q)
- Multi-play Multi-Armed Bayesian inference Bandits to learn likely red-force locations
- Evolutionary Algorithms, Simulated Annealing to learn optimal tasks given a static red force
- Recurrent Neural Networks and Evolution Strategies to learn adversarial strategies

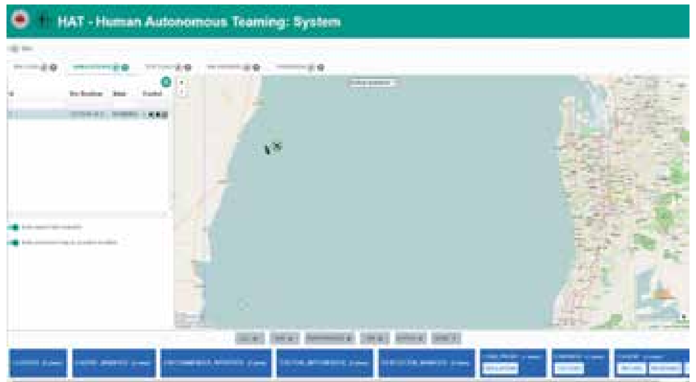
Key Achievements

Prototype Recommender System Developed	05/2016
Application of Deep Q Algorithm	08/2016
Best Paper award at ICCMS-17	02/2017
Application of Bayesian Technique	03/2017
Application of Simulated Annealing Technique	05/2017

Partners

Allied IMPACT (AIM) (AFRL Dayton OH, SPAWARSYSCEN San Diego) Teams

HAT Recommender System



Publications

AAAI-17 Spring Symposium:

"Machine Learning Approach for Task Generation in Uncertain Environments"

ICCMS-17:

"Simulation Framework for Machine Learning"

IJCAI-17:

"Human-Autonomy Teaming for C2 of Multiple Autonomous Vehicles"

ISTAS-16:

"Machine Learning and Recommender Systems for C2 of Autonomous Vehicles"

MODSIM-17:

"Machine Learning for high-level C2 using Modelling and Simulation" (Accepted - To be finalised)

HIGH-LEVEL AUTONOMY

MULTIMEDIA NARRATIVE WITH IMPACT

DST Lead: Dr. Steven Wark

Objectives

- Demonstrate multimedia narrative for the situation awareness of Humans-On-The-Loop using the Allied IMPACT (AIM) system to provide C2 for multiple autonomous platforms in the TTCP ASC Autonomous Warrior 2018 trial.
- Develop a generic narrative capability for effectively exploiting multimedia modalities that can be tuned to meet the human supervisor's changing information needs.
- Technologies include: Rhetorical Structure Theory (narrative generation and presentation); Pattern Recognition; Natural Language Generation; Knowledge Representation; Machine Learning; Virtual Humans.

Related Research Agreements

- Robust long-term navigation, University of Adelaide
- Visual Question Answering, University of Adelaide
- Zero-Shot Learning, University of Adelaide
- Causal Explanation in TAS, University of Melbourne

Approach

1. Exploit existing prototype multimedia presentation capability for content coordination and rendering.
2. Develop and refine narrative structures using Rhetorical Structure Theory for narrative generation and adaptation of 'Mission Briefing' and 'Status Report' use-cases.
3. Trial and evaluate in TTCP ASC trials at Dayton OH (July) and Cardigan Bay UK (Sept) in 2017. Review and identify technologies for further development.
4. Trial and evaluate refined capability in Autonomous Warrior 2018.

Key Achievements

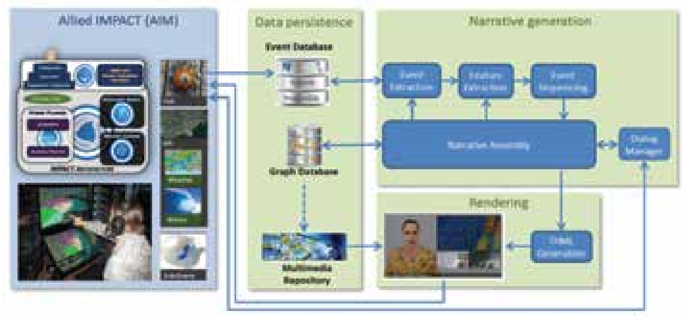
First end-to-end prototype	07/2016
Initial 'pathfinder' integration with IMPACT	10/2016
IMPACT provided to AS for AIM development	03/2017
Mission Report and Status Report use-cases	06/2017

Partners

US IMPACT (AFRL Dayton OH) team

Prof. Bruce Thomas, Uni SA, Narrative Visualisation

Architecture developed for Multimedia Narrative Generation



Publications

S. Wark & M. Nowina-Krowicki,:

"Generating Multimedia Narrative For Virtual Humans", Australasian Computer Science Week (ASCW) '16,, Canberra, Australia, Feb 2016.

S. Wark, M. Nowina-Krowicki, I. Dall, J. Chung, P. Argent & G. Bowering,

"Multimedia Narrative For Autonomous Systems", IJCAI'17 Workshop on Impedance Matching in Cognitive Partnerships, Melbourne, Australia, Aug 2017. (submitted)

AUTONOMOUS GOAL AND RESOURCE MANAGEMENT

DST Lead (acting): Martin Oxenham

Objectives

- Investigate and implement prototype machine cognition architectures in a synthetic environment.
- Develop theories that endow autonomous platforms with the means to be self-directing and manage competing intentions in an agile goal-driven fashion within platform and mission constraints.
- Investigate the application of these theories to the DST Deep Ray Glider.
- Demonstrate concepts at Autonomous Warrior 2018

Related Research Agreements

- Goal Analytics for Trusted Autonomous Underwater Vehicles, Griffith University, Nathan Campus, QLD
- Deep Ray Glider Robust Autonomy, UniSA, Mawson Lakes, SA (building on AMSI Internship)

Approach

Investigate, develop and apply goal-driven autonomy (GDA) technologies

1. Integrate the Metacognitive Integrated Dual-Cycle Architecture (MIDCA) for GDA with extant direct control technologies ie the Mission Oriented Operating Suite with IvP (MOOS-IvP).
2. Enhance MIDCA cognitive / metacognitive modules.
3. Collaborate with Unmanned Systems & Autonomy Group at DST Eveleigh for AW '18 demonstration.

Key Achievements

- AMSI Internship (UniSA) – GDA for the Deep Ray Glider 09/2016
  – Proof-of-Concept in a 'grid-world' environment
  – Inroads into the software integration of MOOS-IvP and MIDCA
- DST Goal-Driven Autonomy Workshop 04/2017
  – DST, WSRI, Griffith University, ANU participants
- Collaboration with Wright State Research Institute 04/2017
  – AFOSR Proposal - Goal-Driven Autonomy for Trusted Autonomous Reasoning Systems (GATARS)

Partners

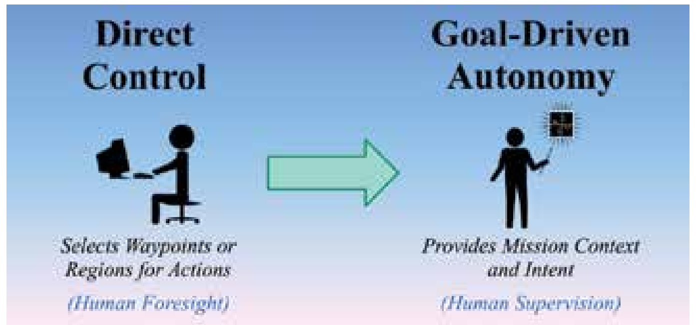
Australian Mathematical Sciences Institute

UniSA

Griffith University

Wright State Research Institute

US AFOSR



Integration of:

MOOS-IvP for Direct Control of Uninhabited Underwater Vehicles &

MIDCA for Goal-Driven Autonomy (GDA)

Publications

Oxenham, M.G., Green, R.S.,

From Direct Control to Goal-Driven Autonomy for Uninhabited Underwater Vehicles, IJCAI ' 17 Goal Reasoning Workshop, Melbourne, Victoria, Australia, 19-25 August 2017.

Dong, J.S., Dong, N., Hou Z., Mahony B., Oxenham, M.,

Goal Analytics via Model Checking for Autonomous Systems, IJCAI '17 Goal Reasoning Workshop, Melbourne, Victoria, Australia, 19-25 August 2017.

MULTI-MISSION AUTONOMOUS SYSTEMS FOR COMPLEX URBAN OPERATIONS: COMMS

DST Group Lead: Marek Kwiatkowski

Academic Leads: Prof. Hussein Abbass (UNSW), Dr Jan Barca (Monash)

Objectives

- Develop autonomous systems for ISR, communications, and other missions in cluttered and contested urban environments
- Overcome challenges presented by urban terrain and RF contested/denied environments

Related Research Agreements

- Multi-Objective Optimisation for Autonomous UAV Location Planning Over Dynamic Networks, UniSA
- Swarm Intelligence and Multi-Mission Coordination in Urban Areas, Adelaide University
- Autonomous UAV Communications Modelling Capability, Adelaide University
- Trust in Human-Machine Teaming Through Machine Education, UNSW@ADFA

Approach

Develop and demonstrate:

- cooperating autonomous platforms providing survivable tactical networks (contested RF)
- autonomous platforms providing data ferrying of mission critical information (highly contested/denied RF environment)

Key Achievements

- Developed and validated algorithms for cooperating autonomous platforms using simulations and emulations in lab environment (Dec/2016)
- Implemented core framework to support data ferrying (April/2017)
- Validated algorithms supporting swarming autonomous platforms using simulations and emulations in lab environment (May/2017)

Partners

Monash University

UniSA

University of Adelaide

UNSW@ADFA

Publications

Topology Control to Mitigate Sophisticated EMI Using a Fleet of UAVs, TTCP Technical Report, June 2016

On Simultaneously Increasing MANET Surviv-ability, Capacity, Power Efficiency and Security." International Journal of Information, Communica-tion Technology and Applications, 2016

Beyond Line-of-Sight Range Extension with OPAL using an Autonomous Unmanned Aerial Vehicle – submitted to MILCOM '17

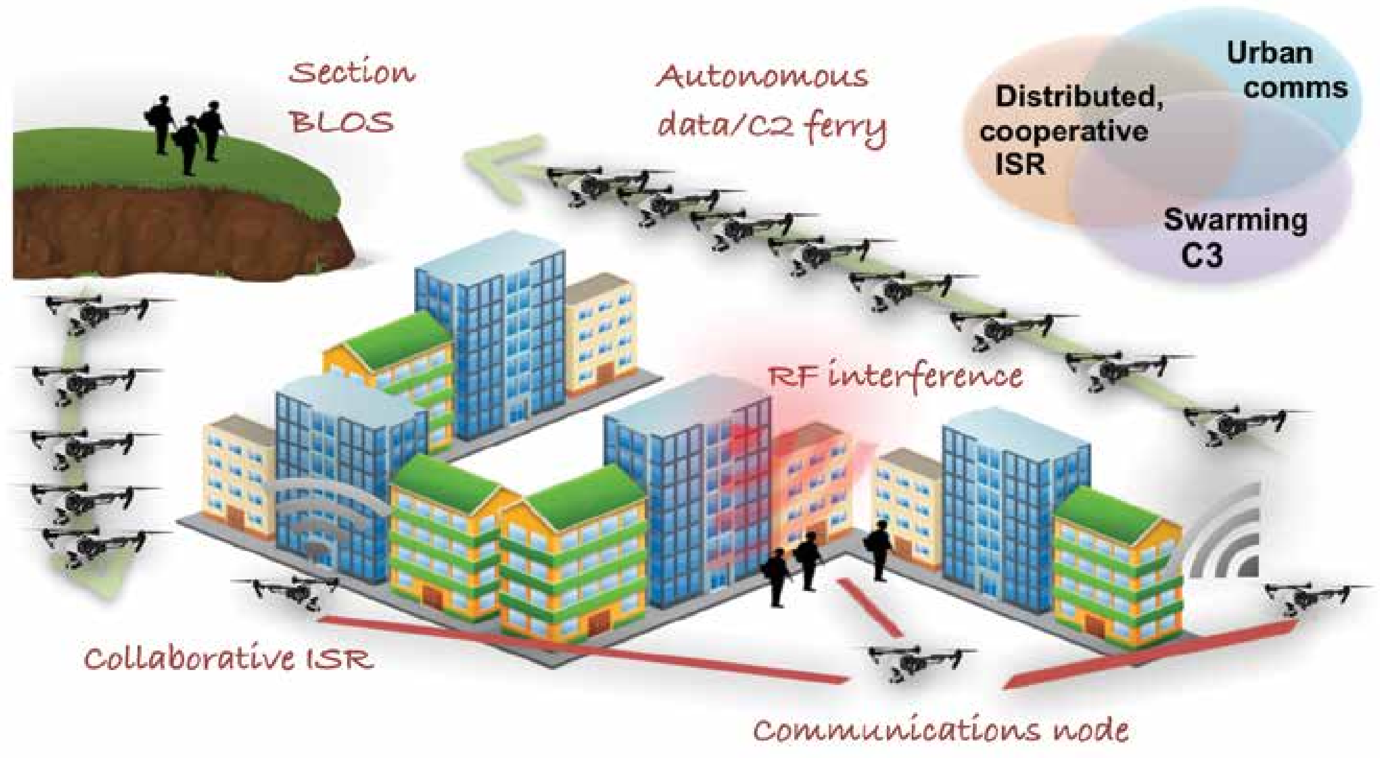
Swarming for Communications in Contested Urban Environment – Monash University report

Survivable Communications and Autonomous Delivery Service – submitted to MILCOM'17

Local State Scoring Relative to Global Goals for Self-organising Unmanned Systems in Contested RF Environments - ADFA report, 2017

Design Reflections – SCADS - Consunet Pty Ltd, design report of SCADS, May 2017

MULTI-MISSION AUTONOMOUS SYSTEMS FOR COMPLEX URBAN OPERATIONS: COMMS (CONT.)



Support to Land Forces in the Contested urban environment is hard problem that autonomous intelligent communications and networking can help to resolve.

EVOLUTION OF SWARM BEHAVIOURS

DST Group Lead: Robert Hunjet

Academic Leads: Dr Jan Barca, Monash University

Objectives

Establish:

- A credible Australian swarm robotics capability/program
- Real time swarm goal and behavioural evolution
- Heterogeneous, and agile, context aware swarms => Swarms that adapt to achieve goals

Related Research Agreements

- Swarm Intelligence and Multi-mission Coordination in Urban Areas, Adelaide
- Trust in Human Machine Teaming through Machine Education, UNSW
- Swarm Intelligence and Genetic Fuzzy Trees for Threat Avoidance and Target Selection, Adelaide
- Tactical Networks Autonomous UAV Communication, Adelaide

Approach

- Create swarm behaviour rules for data ferrying
- Simulate, emulate and implement swarming rules within physical platforms
- Create, evolve and select swarming rules for data transfer applications (Hyper heuristic and reinforcement learning approaches)
- Investigate the strengths and limitations of emergent behaviour within swarms.

Key Achievements

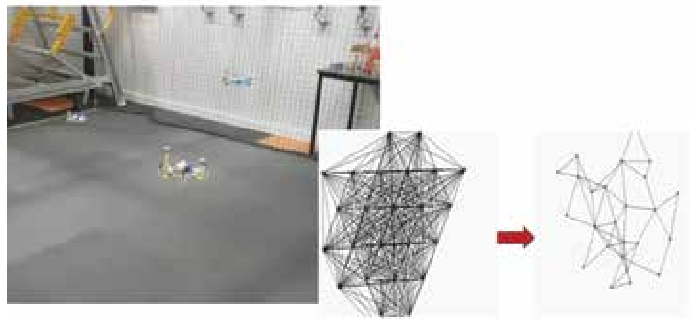
- Start PhD program in Swarm Intelligence and Emergence for Tactical Communications 7/2016
- Start PhD program in Hyper-heuristic (HH) swarm rule creation, evolution and selection 1/2017
- Scoped NPS Masters thesis in deployment of swarming data ferrying on fixed wing UAVS 5/2017
- Simulation, emulation and flight of data ferrying swarm rules using HH approach to swarm policy evolution (simulation) 5/2017

Partners

University of Adelaide

Monash University

US Naval Postgraduate School



CrazyFlie UAVS following data ferrying rules

Effect of degraded comms on emergence

Publications

ITNAC 2016:

Data Ferrying in Tactical Networks Using Swarm Intelligence and Stigmergic Coordination

WinterSim 2017:

Simulating the Effect of Degraded Communications on Emergent Behaviour (submitted)

International Journal of Parallel Emergent and Distributed Systems:

A Swarm Intelligence Approach to Data Ferrying in Sparse Disconnected Networks

MACHINE-MACHINE INTERACTION

COORDINATED DELIVERY OF EFFECTS

DST Leads: Jijoong Kim and Lloyd Damp,

Academic Leads: Dr Iman Shames (UoM), Prof Kutuyil Dogancay (UniSA), Prof CC Lim (UoA)

Objectives

- Autonomous coordination of teaming behaviour amongst multiple heterogeneous weapons systems to maximise combat effectiveness by distrupting the enemy's OODA loop.
- Multi agent control and weapon target allocation using intelligent systems techniques (optimisation techniques, reinforcement learning, genetic fuzzy system)

Related CERA

Swarm Intelligence and Genetic Fuzzy Trees for Threat Avoidance and Target Allocation, University of Adelaide

Approach

- Literature review and scoping Study
- Motion Control: predictive A*, fuzzy logic, Q learning, Model Predictive Control.
- Weapon Target Allocation: Decentralised algorithms (consensus based bundle & probabilistic greedy), Jonker Vulgernant, maximal graph matching, genetic fuzzy system

Key Achievements

3 x Reports and demo software (Deakin Uni)	06/2016
Technical note (DST Group)	12/2016
CRC Conference Paper UoM and DST (in review)	5/2016
Literature review and scope study (UoA)	4/2017
2 Reports and algorithms (UniSA)	5/2017

Partners

Deakin University (IISRI)

University of Melbourne (MIDAS)

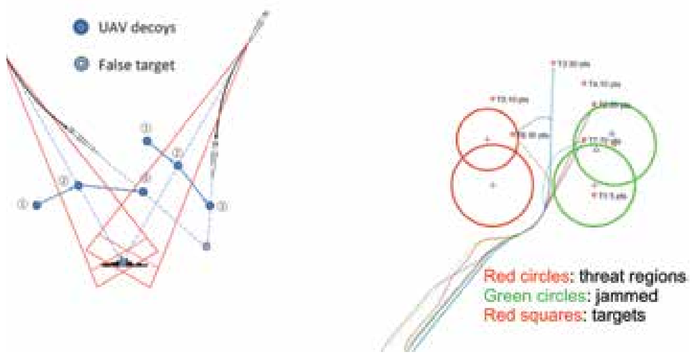
University of Adelaide (EEE)

BAE Systems

DefendTex

AMRDEC (US Army)

Teaming between missiles and jammers for penetration of the threat regions



Multiple decoys coordinating against networked threat missiles

Publications

Shamez I, Dostovalova A, Kim J, Hmam H.

"Task Allocation and Motion Control for Threat-Seduction Decoys" Proc. 56th IEEE Conf. on Decision and Control, Melbourne, Australia, 2017

Huang, H., Huynh A., Setyo, A., and Kim, J.,

Coordinated Strike with Multiple Networked Weapons, DSTG-TN-1574, Nov 2016

EMBODIED AUTONOMY

MULTI-MISSION AUTONOMOUS SYSTEMS FOR COMPLEX URBAN OPERATIONS

DST Group Lead: Jennifer Palmer

Academic Leads: Simon Watson, Andre van Shaik, Prof Peter Cork

Objectives

Develop autonomous systems for ISR, communications, and other missions in cluttered and contested urban environments

Overcome challenges presented by urban terrain

- highly variable lighting (from darkness to bright artificial lighting)
- large-scale turbulence
- GPS and comms denial
- dynamic features

Related CERA

- 24-GHz radar system for collision avoidance and mapping
- Co-operative simultaneous localisation and mapping

Approach

Develop and demonstrate

- multi-modal cognitive sensing with low-SWaP devices
- fault-tolerant flight control with disturbance rejection
- teamed mapping, chemical localisation, and comms
- dynamic collision avoidance and path planning

Key Achievements

Outdoor trials of collision avoidance and mapping	9/2016, 1-4/2017
Investigation of mapping with novel range sensors	7/2016, 5/2017
Establishment of Indoor Flight Lab	9/2016

Partners

RMIT

MARCS Institute

QUT

Publications

Ristic, B., D. Angley, B. Moran, and J.L. Palmer,

Autonomous multi-robot search for a hazardous source in a turbulent environment. Sens, 17(4), 2017.

Elbanhawi, M., A. Mohamed, R.A. Clothier, J.L. Palmer, M. Simic, and S. Watkins,

Enabling technologies for autonomous MAV operations. Prog Aerosp Sci, 2017.

Palmer, J.L., J. Kennedy, S. Kiss, C. Nagahawatte, and M. Clemente,

AD-2016-001 SK450 Flight Trial/Urban Operations Trial 1, Report DST-Group-TN-1626 (FOUO), 2017.

Newnham, T., A. Fisher, L. Fang, R.A. Clothier, and J.L. Palmer,

Improving the field of regard of a time-of-flight camera for UAV mapping and collision avoidance in cluttered environments in 17th Aus Int Aerosp Cong, 2017.

Fang, L., A. Fisher, S. Kiss, J. Kennedy, C. Nagahawatte, R.A. Clothier, and J.L. Palmer,

ToF sensors for mapping applications in Aus'asian Conf Rob Autom, 2016.

Lim, K.E.W., S. Watkins, R.A. Clothier, R. Ladani, A. Mohamed, and J.L. Palmer,

Full-scale meas-urement on a tall building with LIDAR. J Wind Eng Ind Aerodyn, 154: 69–75, 2016.

Fisher, A., M. Marino, R.A. Clothier, S. Watkins, L. Peters, and J.L. Palmer,

Emulating avian orographic soaring with a small autonomous glider. Bioins Biomim, 11(1), 2016. Highlights

Ristic, B., D. Angley, D. Selvaratnam, B. Moran, and J.L. Palmer,

A random finite set approach to occupancy-grid SLAM in 19th Int Conf Inf Fus, 2016.

EMBODIED AUTONOMY

ALTERNATE NAVIGATION

DST Lead: Kent Rosser

Academic Leads: Prof Javaan Chahl, University of South Australia

Objectives

To develop

- Closed-loop vision-aided navigation on an UAS in A2AD region
- Low space weight and power navigation sensors and behaviours for small unmanned aerial systems
- Extend visual and any-means navigation to operation over challenging visual environments

Approach

Project Arrangement with US

- Demonstration and development capability for closed-loop navigation on small UAS

Navigation Research

- Biological inspired sensing and embodied behaviour
- Development and experimentation in challenging environments (overwater and darkness)
- Foundation biological research on trusted fusion and direction sensing for robustness

Key Achievements

CLAND-1 US/AUS trial	04/2016
Overwater navigation proof of concept	04/2017
CLAND-2 US/AUS trial	08/2017

Partners

Lund University

UniSA

AFRL

AMRDEC

Publications

Rosser, K., and J. Chahl,

"Visual navigation without landmarks - Optical flow drift correction." (submitted) IEEE Transactions on Robotics (2017)

Chahl, J. S.

"Optical flow and motion detection for navigation and control of biological and technological systems." Journal of Modern Optics (2016)

Rosser, K., and J. Chahl,

Embodied motion and perception couple for optical flow based state estimation in 17th Australian International Aerospace Congress (2017)

DST Group TR.

"Activity Report: Closed-Loop Alternative Navigation Demonstration (C-LAND)" Rosser K., Card P. (submitted)

EMBODIED AUTONOMY

AUTONOMOUS PERCEPTION

DST Lead: Jason Scholz

Objectives

- Research and develop deployable autonomous machine perception
- Demonstrate high-resilient machine perception against uncertainty classes of: ontological (never seen before), epistemic (partially known) and semantic (different interpretations)
- Achieve symbolic, direct-explainable perceptions in terms of parts (features)
- Exceed state-of-art performance in zero-shot and few-shot training
- Improve perceptual recognition (ambiguous interpretations) by semantic priors / cognitive biasing.

Related CERA

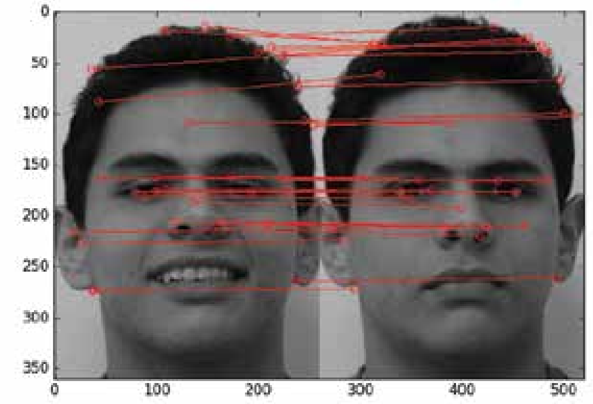
- Zero-shot Learning, University of Adelaide
- Explainable AI in Visual Question and Answering (VQA), University of Adelaide

Approach

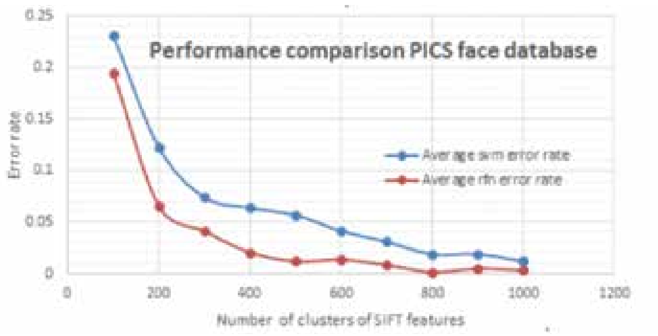
- Understand uncertainty in terms of classes of affect on perception
- Consider approaches to minimize high-consequence mistakes (user defined / e.g. anti-goals)
- Neurobiology-inspired approaches: evolved to be effective, efficient (simple) and robust
- Constrain study to symbolic ANN (Artificial Neural Networks) representations

Key Achievements

Linear neurobiology-inspired approach examined	6/2016
Developed machine learning technique that minimizes error consequences	11/2016
Non-negative matrix factorization discovery	5/2017
Demonstrated improvement over state of the art for one-shot and high uncertainty data	6/2017
Extend to ontological adaptation (never seen objects)	12/2017
Study semantic (context) constraint on perceptions	6/2018



The Neural Symbolic Layer explicitly identifies those features (overlaid on these images) that match between the one-shot trained example (right) and the test example (left).



Single shot performance beats state of the art Support Vector Machine (SVM) with SIFT feature extraction.

Publications (Noting new project in 2017)

Scholz, J.B., Ao, Z.

Autonomous Perception with Neural Symbolic Layers, Submitted to Frontiers in Robotics and AI I Sensor Fusion and Machine Perception Journal, June 2017.

Scholz, J.B.,

"Learning to Shape Errors with a Confusion Objective" to appear in "Foundations of Trusted Autonomy", in print, Springer, 2017

EMBODIED AUTONOMY

EVOLUTIONARY DESIGN FRAMEWORK

DST Lead: Jia Ming Kok

Academic Lead: Joshua Bongard, University of Vermont

Objectives

- Develop multi-mission novel flyer capable of surviving and thriving in uncertain environments
- Develop and apply evolutionary design framework for behaviour-morphology coupled design
- Co-evolution of morphological and controller parameters for a sub100gram Dragonfly-Inspired Micro Air Vehicle (DI-MAV)
- Targeted approach to allocating minimal resources to achieving complex system optimisation (not limited to a DI-MAV)

Related Research Agreements

AUSMURI proposal: Topic 5: Embodied Learning and Control ($5M)

Approach

Identify critical components in design framework (UVM)

- Optimisation algorithm
- Measure of simulation accuracy
- Self modelling
- Develop initial 4-wing prototype system (UniSA)
- Develop better aerodynamic models (Delft)

Key Achievements

• Implemented a novel optimisation algorithm	01/2017
• Transferability approach for measure of realism	02/2017
• Single wing, 10-12 grams lift	02/2017
• Developed prototype 4-wing test bench	04/2017
• Developed simulation models	04/2017

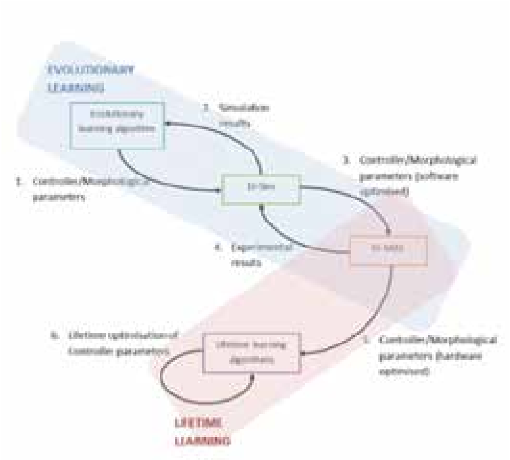
Partners

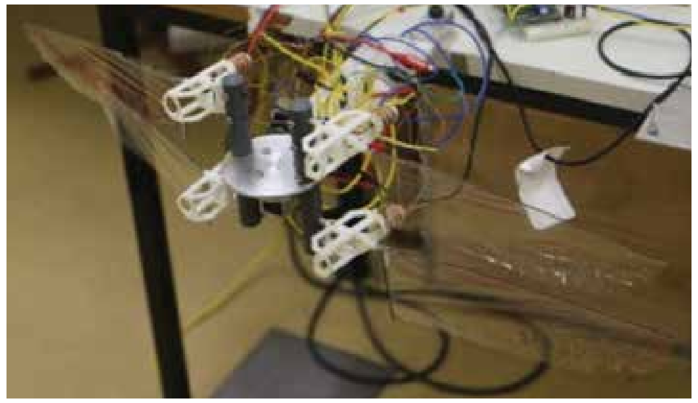
The University Of Vermont

University Of South Australia

Delft University Of Technology

Hardware-in-the-Loop Model Based Optimisation (HILMBO)





Dragonfly-Inspired MAV

Publications

Kok, J. M., Fatiaki, A., Rosser, K., Chahl, J. S., & Ogunwa, T. (2017).
Dragonfly inspired MAVs-adaptive and evolutionary approaches. In 17th Australian International Aerospace Congress: AIAC 2017 (p. 129). Engineers Australia, Royal Aeronautical Society

EMBODIED AUTONOMY

BIO-INSPIRED ADAPTIVE CONTROLLER DEVELOPMENT

DST Lead: Jia Ming Kok

Academic Lead: Matthew Garratt, UNSW

Objectives

- Develop an adaptive control system for a DI-MAV.
- The control system should be capable of responding to uncertain environments
- Characterisation of a mission envelope for a bio-inspired platform

Related CERA

Feasibility Testing for Adaptive Flight Control of a Dragonfly Inspired Micro Air Vehicle Assoc Prof Matt Garratt, UNSW

Approach

- Apply neural network and neuro-fuzzy approaches to adaptive control using existing flight simulators
- NTU have developed a system that has near rotorcraft hover efficiencies
- By analysing that system in forward flight, we can potentially demonstrate capability of a flyer that is able to perform both rotorcraft and fixed wing missions.

Key Achievements

• Inter-university exchange	10/2015
• Journal publication	03/2016
• International visits	11/2016
• Developed neural network controller	12/2016
• Developed neuro-fuzzy controller	12/2016
• Implemented and tested in simulation	04/2017

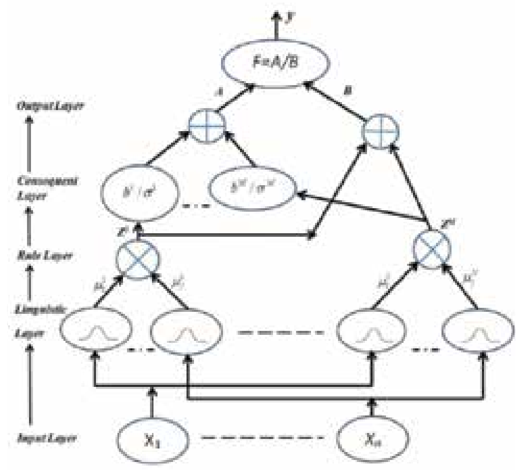
Partners

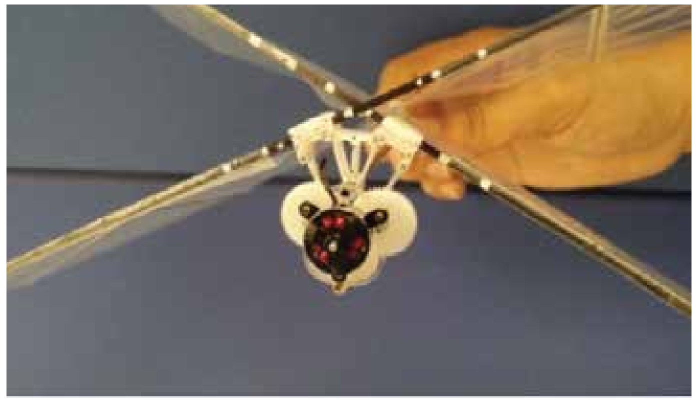
UNSW Canberra

Nanyang Technological University, Singapore

UniSA

Neuro-Fuzzy Adaptive Controller





NTU Flapper

Publications

Santosa et al. (2017),
Fuzzy Systems and Neural Networks for Modelling and Control of Quadcopter and Flapping Wing Micro Aerial Vehicles, DSTG Technical Report

J. M. Kok, G. K. Lau, and J. S. Chahl.
“On the Aerodynamic Efficiency of Insect-Inspired Micro Aircraft Employing Asymmetrical Flapping”, Journal of Aircraft, Vol. 53, No. 3 (2016), pp. 800-810.

EMBODIED AUTONOMY

DEEP RAY – UNDERSEA GLIDER

DST Lead: Stuart Anstee
Industry & Academic Leads: Ron Allum RADS
Robert Fitch UTS

Objectives

- Develop a capacity for persistent underwater acoustic surveillance based on an underwater glider fitted with an acoustic array
- Extend the blended-wing glider navigational envelope to sound channel depths to enhance signal detection and give the glider the ability to manoeuvre independently of ocean currents

Approach

- **Stage 1:** Sunray glider - de-risk design elements by testing drag, control mechanisms and sonar characteristics in a shallow-water configuration
- **Stage 2:** Deepray glider – monocoque hullform based on syntactic foam to achieve deep-water navigation capability and ease of manufacture.

Key Achievements

Proof of concept – buoyancy engine	May 2016
CFD drag and stability analysis	Aug 2016
Sunray demonstrator design finalised	Oct 2016
Assembly of vehicle	[Jun 2017]

Partners

Ron Allum Deepsea Services

AMC, ACFR, UTS, Curtin

Midspar

Publications

Australian Maritime College
"CFD study of lift and drag characteristics of underwater glider", Dec 2016

"Sunray" shallow-water prototype under construction – delivery exp. by end June

EMBODIED AUTONOMY

EXTENDED INTELLIGENT WATCH DOG

DST Lead: Simon Ng
Industry Lead: Andrew Lucas, AOS Group

Objectives

- Demonstrate a human-on-the-loop capability for perimeter security
- Exploit C-BDI™ to develop an agent-based solution
- Develop and evaluate a 'supervisory' interface
- Demonstrate end-to-end autonomous response using multiple systems

Approach

- Exploit existing collaboration in the are of bio-inspired sensing applied to sparse, denied environments
- Establish new program focussed on congested, denied environments and low-SWAP robotics
- Extend bio-inspired approaches to the design of robotic control systems and morphology
- Build key partnership

Key Achievements

2 demonstrations	Nov & Dec 2017
Intelligent Watch Dog (iWD) & Multi-Vehicle Tasking Station (MVTS) software	Nov 2017
Airshow Jericho Display	Feb 2017

Partners

Autonomous Decision-Making Software

Insitu Pacific

RMIT

Deakin University

Publications/Outputs

MVTS Software/source code

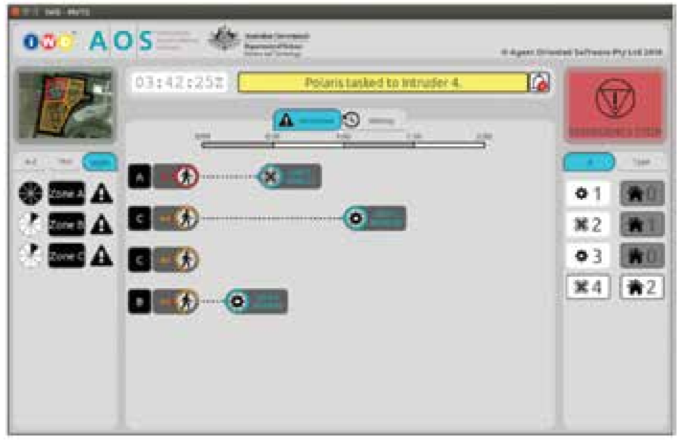
iWD™ software/source code

iWD™ UI Design Report

iWD™ Team Entity Architecture Report

IPL UAV

Multi-vehicle Tasking Station



ISTAS 2016

Invitational Symposium on Trusted Autonomous Systems

SURVIVING THE UNPREDICTED

Overview

Defence Science and Technology hosted the inaugural Invitational Symposium on Trusted Autonomous Systems (ISTAS) in the Barossa Valley from 9-11 May, 2016. The event signalled DST Group's intent to become a recognised international leader with its partners, in the emergent field of Trusted Autonomous Systems and brought together 120 minds from Defence, Industry and Academia, including a number of eminent researchers.

Following a welcome from Chief Defence Scientist, Dr Alex Zelinsky, ISTAS 2016 was officially opened by Major-General Stuart Smith AO, DSC who delivered a vision for command and control with autonomous systems in conflict and the unique partnership that Science and Technology leaders would play with Australian Defence Force leaders to maintain a technological and warfighting advantage.

• Day 1

Professor Josh Bongard provided a rich and entertaining keynote address on the novel research being undertaken at the University of Vermont on the role that morphology and evolution plays in embodied cognition. The Autonomy Resilience theme featured Dr Darryn Reid (DST Group), Dr Toby Murray (Data61), Associate Professor Adrian Pearce (University of Melbourne) and Dr Brandon Pincombe (DST Group) considering the implications for the operation of autonomous systems in unbounded and uncertain environments.

Major-General Stuart Smith AO

A/Professor Adrian Pearce

• Day 2

Dr David Aha (US Naval Research Laboratories) provided a highlight on the second day of the symposium with a presentation on "Goal Reasoning for Machine Cognition" along with Professor Bob Williamson (Chief Scientist at Data61) on "The Future of Machine Learning", and Professor Marcus Hutter on "Artificial General Intelligence" who collectively outlined challenges and opportunities that lay ahead in the Machine Cognition theme. The relationship and interactions of humans and machines was considered as part of the Trusted Human-Synthetic Partners theme led by Dr Glen Smith (DST Group) and featured Professor Janet Wiles (University of Queensland).

Dr David Aha

Dr David Battle

• Day 3

The final day was led by Dr Simon Ng (DST Group) and featured research on novel autonomous platforms and sensors as part of the theme Embodied Intelligence. Dr David Johnson (University of Sydney) showcased sensor integration research at the Australian Centre for Field Robotics while Dr Jan Barca (Monash University) provided an energetic and entertaining insight into advances being made at the Monash Swarm Robotics Laboratory. Day three concluded with a display of work being undertaken by DST Group in the area of embodied intelligence with presentations from Dr Kin-Ping Hui and Dr Robert Hunjet (DST Group) on their work in autonomous communications in complex environments and Dr David Battle's research on a multi-role autonomous underwater vehicle.

University competition

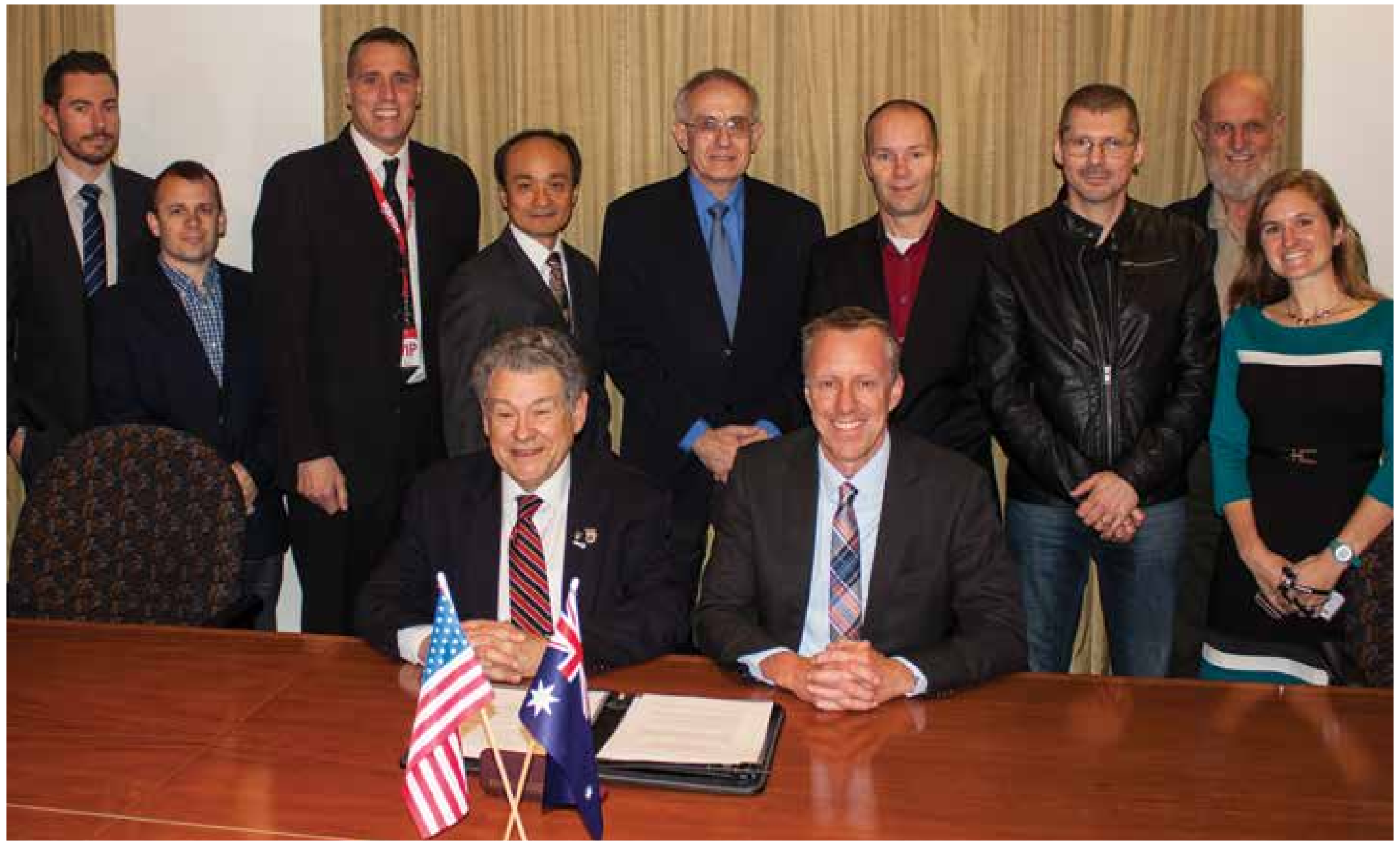
ISTAS 2016 also called on Australian University students to showcase their research through the Trusted Autonomous Systems - Student Research Competition. An expert judging panel identified ten worthy finalists, each of whom were offered the opportunity to present their research to symposium attendees. A ballot was cast to determine the most outstanding candidate which confirmed Ms Rudaba Khan of RMIT as the competition winner with her work on Fault Tolerant Flight Control System Design for UAVs."

Dr Robert Hunjet

RESEARCH AGREEMENTS

Agreement with United States Air Force Office of Scientific Research (AFOSR)

On the 27th of May 2016, Dr Tom Christian (Director, AFOSR) visited DST Group Edinburgh to sign an agreement to promote, develop and strengthen basic research in the field of autonomous systems and human-machine teaming. The agreement recognises the mutual interest shared between Australia and the United States of America in advancing the field and will enable greater collaboration between Australia and the US through exchange of information and co-funding research.



INTERNATIONAL VISITORS

Associate Professor Julie Shah
Massachusetts Institute of Technology

In November, 2015 Defence Science and Technology Group hosted Professor Julie Shah who leads the Interactive Robotics Group of the Computer Science and Artificial Intelligence Laboratories at the Massachusetts Institute of Technology. In 2014, Professor Shah received an NSF CAREER award for her work in "Human-aware Autonomy for Team-oriented Environments" and was recognised as one of the top innovators under the age of 35 in the MIT Technology Review TR35 list.

Professor Shah delivered an address in the Black Box Lecture Series on her work in developing interactive machines that emulate the qualities of effective human team members to improve efficiency of human-machine interaction.

Professor Josh Bongard
University of Vermont

Professor Josh Bongard visited Defence Science and Technology Group in May, 2016 and delivered the keynote address at the inaugural Invitational Symposium on Trusted Autonomous Systems. In 2007 Professor Bongard was recognised as one of the top innovators under the age of 35 in the MIT Technology Review TR35 list and was awarded a Presidential Early Career Award for Scientists and Engineers in 2010. He is the co-author of two highly regard books in the field of artificial intelligence, "How the Body Shapes the Way We Think: A New View of Intelligence" and "Designing Intelligence: Why Brains Aren't Enough".

In addition to attending ISTAS 2016, Professor Bongard participated in several workshops and provided valuable guidance to those working in the field of embodied intelligence over the course of several days.

Dr Thomas F. Christian
Director US Air Force Office of Scientific Research

Dr Thomas F. Christian manages the entire basic research investment for the US Air Force with a staff of 200 scientists, engineers and administrators in Arlington, Va., and foreign technology offices in London, Tokyo and Santiago, Chile. Each year, AFOSR selects, sponsors and manages revolutionary basic research that impacts the future Air Force. AFOSR interacts with leading scientists and engineers throughout the world to identify breakthrough opportunities; actively manages a $510 million investment portfolio encompassing the best of these opportunities; and transitions the resulting discoveries to other components of the Air Force Research Laboratory, to defense industries and to other federal agencies.

In May, 2016 Dr Christian visited DST Group Edinburgh to sign a Memorandum of Understanding to enable stronger collaboration with Australian based research agencies in partnership with DST Group.

Dr David Aha
US Naval Research Laboratory

David leads NRL's Adaptive Systems Section, whose current projects concern intelligent agents, deliberative autonomy, machine learning, explainable AI, case-based reasoning, proactive decision aids, and related topics. He has co-organized 35 events on these topics, hosted 13 post-docs, served on 20 dissertation committees, launched the UCI Repository for ML Databases, was a AAAI Councilor, received awards for 5 publications, and gave the Robert S. Engelmore Memorial Lecture at IAAI-17.

Dr. David W. Aha (US Naval Research Laboratory (NRL)) gave an invited presentation on *Goal Reasoning for Machine Cognition* at the 2016 Invitational Symposium on Trusted Autonomous Systems and visited the DSTG Edinburgh in May, 2016.

FUTURE DIRECTIONS

Aligned with Defence White Paper priorities, the Tyche program is expected in part to transition to a Defence-led Cooperative Research Centre (DCRC) in2017. This new program will deepen university engagement and establish industry-led projects, with a tight Defence focus.

The game-changing technologies developed in the DCRC have significant dual-use potential, because other government and commercial enterprises also operate in open uncontrollable environments. Possible partners are yet to be identified but might include climate change monitoring, agriculture, mining, nuclear waste handling, fisheries, border protection, police and emergency services, logistics and supply chains, humanitarian and disaster relief agencies.

The DCRC will pursue a range of “common good” activities with its partners, including education and advocacy in law and ethics, and certification of Trusted Autonomous Systems. The DCRC will support researcher education with a strong drive to ground new science with real-world experience. The education program will equip the scientific and engineering leadership workforce with augmented skills necessary to realise these technologies. The DCRC will support the education of university graduates, higher degree students and postgraduates in the science and technology of Trusted Autonomous Systems relevant to the Defence and partner sectors. The DCRC will support an active PhD Program, to be developed over the first few years of operation.

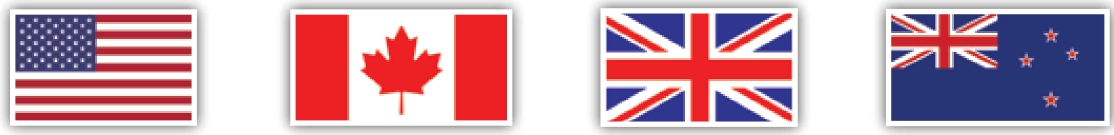
As a DCRC, Intellectual Property creation and management will be a focus. Commercialisation through Industry leadership and Industry-owned IP, for whom new technologies are part of their core business, is a critical step in successfully impacting Defence. The DCRC vision will offer industry the potential to realise new disruptive business models. Rather than develop very high-cost manned platforms, large enterprises may internally shift to providing (very low cost in comparison) unmanned platforms at large scale, where industry profit margin shifts from the initial procurement to a continuous capability evolution through life with ever improving machine intelligence. Systems Engineering would have a very different meaning for Defence if (for example) such capabilities are used operationally only once and then discarded or upgraded, to provide a transient capability edge. Through close partnering, we will help larger partners to exploit disruptive technologies through new business models that fit this dynamic technology area while also positioning smaller enterprises strongly within a global technology supply chain.

Throughout this change and ongoing into the future, the leadership of the Australian Government will persist. This should provide comfort for our allies, regional partnerships and established government to government relationships.

TTCP PARTNERS

AUTONOMY STRATEGIC CHALLENGE

The objectives of the Autonomy Strategic Challenge within the Technical Cooperation Program are to: determine the operational utility of autonomy technologies in a representative littoral environment; advance and demonstrate human-autonomy teaming concepts through simulation and live trials; improve interoperability of emerging autonomous systems; and stimulate, engage and spur industry development for military requirements.



Australian Government

Department of Defence
Science and Technology

PROGRAM TYCHE

BIENNIAL REPORT 2015/16 & 2016/17

FOR MORE INFORMATION ON PROGRAM TYCHE VISIT
www.dst.defence.gov.au/

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